COLORADO PARKS & WILDLIFE

Cyprinid Fish Larvae and Early Juveniles of the Upper Colorado River Basin

Morphological Descriptions, Comparisons, and Computer-Interactive Key

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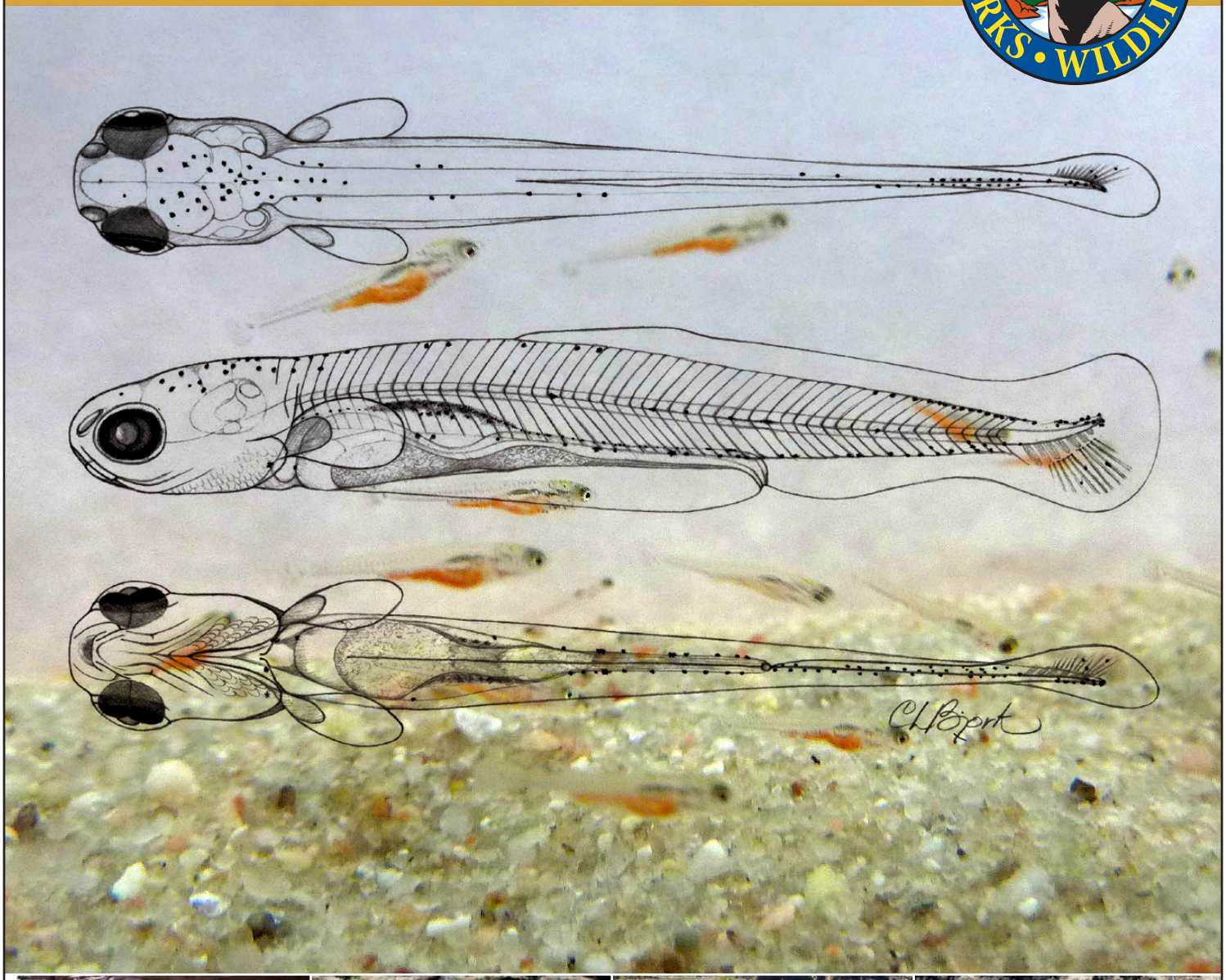

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COVER IMAGES

Front center: Three-view illustration of a Colorado pikeminnow larva (9.5 mm total length; adaptation of a drawing by C. L. Bjork) over a background of fathead minnow larvae (reared by Aquatic BioSystems, Inc.; photograph by D. E. Snyder)

Front bottom: Larval-seine, drift-net, juvenile-seine, and light-trap sampling (photographs by E. J. Wick, R. T. Muth, K. A. Zelasko, and E. J. Wick, respectively)

Back: View of Green River from Harper's Corner, Dinosaur National Monument (photograph by S. C. Seal)

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Morphological Descriptions, Comparisons, and Computer-Interactive Key

By

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PREFACE

Nearly 35 years ago the Larval Fish Laboratory (LFL, Colorado State University) published *Contributions to a Guide to the Cypriniform Fish Larvae of the Upper Colorado River System in Colorado* through the U.S. Bureau of Land Management (Snyder 1981). That document, which was based on descriptive information and illustrations from the literature and several developmental studies funded in part by the Colorado Division of Wildlife, was intended to serve as the foundation for a comprehensive UCRB guide. With publication of the guide to catostomid larvae by Snyder and Muth (1990) and the recent expansion and update thereof with a computer-interactive key (Snyder and Muth 2004), the catostomid portion of the guide was completed. The objectives of this project were to better describe and facilitate identification of the cyprinid larvae by similarly completing the remainder of the guide.

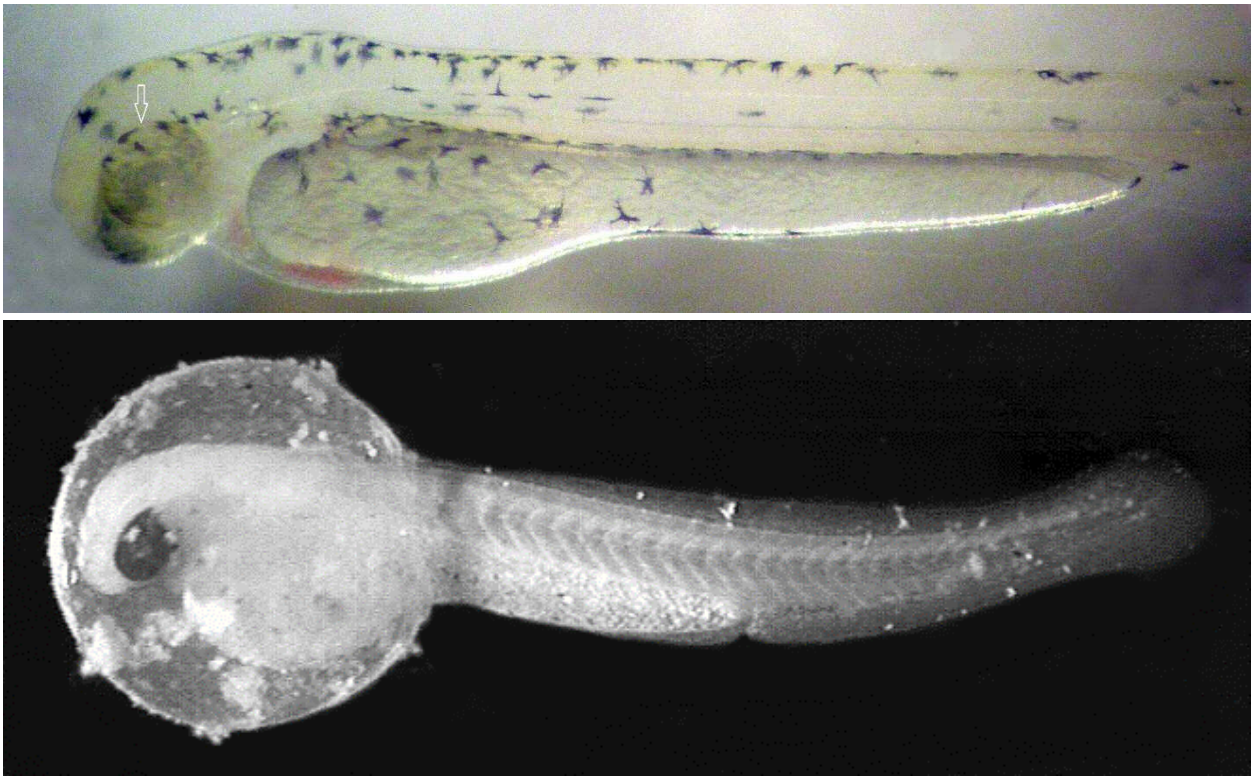
In his doctoral dissertation, Muth (1990) described the larvae and early juveniles of the endangered, nearly extirpated, bonytail, greatly expanded upon descriptions of roundtail chub *G. robusta* and the endangered humpback chub in Snyder (1981), and revealed criteria needed to distinguish these very similar appearing species. His detailed and well-illustrated species accounts and data for bonytail and roundtail chub were in turn consolidated and updated for inclusion in a guide for *Native Cypriniform Fish Larvae of the Gila River Basin* (Snyder et al. 2005). Species accounts for Colorado pikeminnow *Ptychocheilus lucius*, speckled dace *Rhinichthys osculus*, common carp *Cyprinus carpio*, red shiner *Cyprinella lutrensis*, and fathead minnow *Pimephales promelas* in that Gila River Basin guide were similarly adapted and updated from accounts and data prepared for Snyder (1981). The accounts and data for the seven UCRB cyprinids in Snyder et al. (2005), humpback chub in Muth (1990), the remaining six cyprinids in Snyder (1981), and golden shiner *Notemigonus crysoleucas* in Snyder et al. (1977) were in turn the foundation for this guide.

Building on this foundation, updates or completion of descriptive accounts for all 15 UCRB cyprinids covered herein, except roundtail chub and humpback chub, required new developmental series of study specimens, mensural and meristic data, and (or) three-view illustrations. All required new or supplemental data to document pigmentation and additional morphological characters. To complement study series and specimens available in the LFL Collection, full developmental series or at least recently hatched larvae had to be reared, collected, or borrowed for many species. Newly acquired or re-examined data from over 1,700 specimens were summarized for this guide. And 66 new three-view drawings were prepared to complete sets of 8 illustrations per species (120 total) to document typical body form and pigmentation at the beginning and middle of the protolarval, mesolarval, metalarval, and early juvenile phases of development.

For complex data sets, computer-interactive keys are much more user friendly and flexible than printed dichotomous or polychotomus keys. They are also much easier to prepare, correct, and update. Such keys have been prepared for the larvae and early juveniles of catostomids in the UCRB (Snyder 2003 onwards for Snyder and Muth 2004, replacing and supplementing a 60-page printed key in Snyder and Muth 1990) and for the larvae of native catostomids, native and selected non-native cyprinids, and families of fishes in the Gila River Basin (Snyder and Seal 2004a onwards, Snyder and Seal 2004b onwards, and Seal and Snyder 2004 onwards, respectively, for Snyder et al. 2005). The cyprinid key for the Gila River Basin was adapted and refined for species also found in the UCRB and

expanded to cover the remaining UCRB cyprinids. Also, in part for this project, Snyder and Seal (2008 onwards) prepared a family-level key for the larvae of most freshwater and anadromous fishes in the United States and Canada and defined a subset of that key specifically for families in the UCRB. For more ready and general reference, applicable portions of a pictorial guide to families by Wallus et al. (1990) were modified as an appendix to this guide.

Building on information, species accounts, and keys already assembled for Snyder (1981), Muth (1990), and Snyder et al. (2005), and other information and illustrations from the literature, this project of the Upper Colorado River Endangered Fish Recovery Program (and co-sponsors), begun in 2006, has met its objectives and resulted in a comprehensive guide to the cyprinid larvae and early juveniles of the UCRB (with the exception of several, mostly rare or incidental, species that are not likely to be encountered in Recovery Program investigations).



Frontispiece. Top – recently hatched brassy minnow *Hybognathus hankinsoni* larva (~4.0 mm total length) displaying pigmentation unique among described cyprinids—scattered melanophores on top of otherwise barely pigmented eyes (reared in 2008 at Colorado State University by Jeffrey Falke and Sean Seal; photographed alive by Sean Seal). Bottom – red shiner *Cyprinella lutrensis* larva (4.3 mm total length), preserved in the act of hatching with head and anterior body still in the egg chorion (reared in 2006 at Colorado State University by Michelle McGree; photographed by C. Lynn Bjork).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF KEY WORDS

Fish
Larvae
Juveniles
Cyprinidae
Upper Colorado River Basin
Arizona
Colorado
New Mexico
Utah
Wyoming
Descriptions
Ontogeny
Development
Morphology
Morphometrics
Meristics
Pigmentation
Species accounts
Taxonomic key
Computer-interactive key

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Most cyprinid specimens studied for Snyder (1981) were collected from Colorado's western slope as part of BLM (Denver) and CDOW surveys. Other cultured series or collected specimens were donated by or borrowed from Paul Holden (Bio-West Inc., Logan, UT), Lance Perry (Illinois Institute of Natural Resources, Urbana, IL), Karl Seethaler (formerly of Utah State University, Logan, UT), Royal Suttkus (Tulane University Museum of Natural History, Belle Chasse, LA), John Varley (Yellowstone National Park, WY), and the USFWS Willow Beach National Fish Hatchery (WBNFH, Boulder City, NV) via Roger Hamman.

Specimens studied by Muth (1990), upon which this guide is also built, included developmental series of bonytail *Gila elegans* and humpback chub *G. cypha* reared by Roger Hamman (WBNFH), humpback chub collected by Dennis Kubly (Arizona Game and Fish Department, Phoenix, AGFD), and roundtail chub *G. robusta* collected as part CDOW surveys. Edmund Wick (LFL) assisted with the capture of adult brood stock for LFL culture of roundtail chub.

Specimens for supplemental study by Snyder et al. (2005) of previously described Upper Colorado River Basin (UCRB) cyprinids also found in the Gila River Basin were selected mostly from reference or study series in the LFL Collection from the same sources acknowledged above. Michael Childs (AGFD Bubbling Ponds Hatchery) contributed reared series of speckled dace *Rhinichthys osculus*.

Many specimens newly examined for this study also have been maintained as part of the LFL Collection, but these holdings, mostly from the above sources and subsequent Colorado and UCRB surveys and monitoring programs, had to be supplemented with newly collected or reared developmental series. These included series of reared bonytail and Colorado pikeminnow *Ptychocheilus lucius* preserved and contributed by Catherine Sykes

and Manuel Ulibarri (USFWS Dexter National Fish Hatchery and Technology Center, Dexter, NM; now Southwest Native Aquatic Resource and Recovery Center) and collected golden shiner *Notemigonus crysoleucas* by Rene Reyes (BR, CA). Brood stock and (or) fertilized eggs for rearing other needed developmental study series were contributed by, or captured by or with the assistance of, Kevin Bestgen, Douglas Falconi, John Hawkins (and field crew), Angela Hill, Samantha Stiffler, Cameron Wilcox, and Koreen Zelasko (LFL); Jeffrey Falke and Michelle McGree (CSU graduate students); Robert Compton, D. Banks, A. Kern, M. Larocco, and M. Tauchen (Wyoming Game and Fish Department, WGFD); Justin Hart and assistants (Utah Department of Wildlife Resources, UDWR); Robert Mininger (Outlaw Bait and Tackle, Colorado Springs, CO); and Scott Kellman (Aquatic BioSystems, Inc., Fort Collins, CO). These fish were maintained or reared in our Department of Fish, Wildlife and Conservation Biology Aquatic Research Laboratory under annual protocol approvals by CSU's Institutional Animal Care and Use Committee. Others who planned, attempted, or facilitated capture of fish for us included Patrick Lionberger (BLM, Wyoming); Craig Amadio (WGFD); and Paul Birdsey, Alan Ward, and Krissy Wilson (UDWR). Fish were collected, transported, or imported under permits issued by CDOW (now Colorado Parks and Wildlife, CPW), UDWR, and WFGD.

Joseph R. Tomelleri provided and granted permission to use copies of his adult fish illustrations for all but one species account herein; New York State Department of Environmental Conservation similarly granted permission for use of an adult brassy minnow *Hybognathus hankinsoni* drawing by Ellen Edmonson and Hugh Chrisp. Likewise, permission was granted, and copies provided, for use of selected published illustrations of larval or juvenile fish by Daniel Faber (golden shiner; Sally Gadd, illustrator), Lee Fuiman (longnose dace *Rhinichthys cataractae*; photograph), Gerard Buynak and Harold Mohr (longnose dace and creek chub *Semotilus atromaculatus*, Gerard Buynak, illustrator; printed copies provided by Marion Hidlay, Ecology III), Vincent Kranz (creek chub; Susan Douglas, illustrator), and Karl Seethaler (Colorado pikeminnow; James Brogdon, illustrator). Selected larval fish drawings of Utah chub *Gila atraria* and redside shiner *Richardsonius balteatus* used herein were originally prepared by Gail Ridlon and Mark Jones, respectively, for Snyder (1981); Mark also prepared the final version of Figures 2 to 4 used herein from that earlier guide. Jana Mohrman (USFWS) arranged for David Smith and Don Meyer (Colorado River Conservation District) to prepare the UCRB map used in Figure 1. John Buffington and Joseph Mendoza (CSU Photographic Services) produced publication-quality digital scans of all original LFL larval and juvenile fish drawings included in this guide.

Many persons associated with the Recovery Program, federal and state agencies, and regional consulting firms and universities contributed data, reports, personal assessments, and edits of draft tables and maps for the summary of recent UCRB fish distributions and relative abundances in Table 1 and Colorado River Basin distributions in species-account maps. These included Brandon Albrecht (Bio-West, Inc.), Paul Badame (UDWR), Kevin Bestgen (LFL), George Blommer (UDWR), Howard Brandenburg (American Southwest Ichthyological Researchers, LLC; ASIR), Peter Cavalli (WGFD), Robert Clarkson (BR), Robert Compton (WGFD), Travis Francis (USFWS), Eliza Gilbert (New Mexico Department of Game and Fish), Kevin Guadalupe (Nevada Department of Wildlife, NDOW), Kevin Gelwicks (WGFD), Sarah Lindsey (UDWR), Lorraine McInness (Museum of Southwestern Biology), Paul Marsh (Marsh and Associates, LLC), Steven Meismer (Virgin River

Program), Antony Robinson (AGFD), Brandon Senger (NDOW), Andrew Treble (CPW), Sabra Tonn (AGFD Natural Heritage Program, Heritage Data Management System), Richard Valdez (Valdez and Associates), and Krissy Wilson (UDWR). Tyler Swarr (CSU graduate student) produced maps from a GIS shapefile provided by Sarah Lindsey (UDWR). Additional distribution information was extracted from several state agency or regional fishing websites as well as selected Recovery Program Biology Committee minutes and e-mail list communications.

We also thank the many other associates and contacts who contributed time and effort to this project and associated earlier investigations. Much of the earlier morphometric and meristic data which was re-examined and summarized along with newer data herein, was originally prepared for Snyder (1981) and Muth (1990) from hundreds of specimens by former LFL staff, student employees, and volunteers including James Barrowman, Mark Castagneri, Linda Deutsch, William Emerson, Lyndon Evans, Marty Hayden, Robert Hufziger, Carol Jefferson, Eric Leitzinger, Leo Lentsch, Robert Muth, Martin Ogle, Florence Richey, Gail Ridlon, Stephanie Salyer, Robert Upton, and Edmund Wick. Maryann Snyder assisted with the transcription of that older data from hand-written forms to spreadsheet files and the entry of combined and summarized data in species-account and summary tables as well as a DELTA database for the cyprinid key. Nolan Wolff also entered data in the DELTA database. Michael J. Dallwitz provided periodic guidance in the use of *Intkey* and other DELTA programs for the computer-interactive keys. Maryann Snyder and Matthew Haworth (LFL) reviewed the manuscript, as did Howard Brandenburg (ASIR), Bruce Haines (USFWS), and Brandon Albrecht (Bio-West, Inc.) as peer-review referees for the Recovery Program. We particularly thank Kevin Bestgen, LFL Director, for his support and patience, project administration, specific contributions (e.g., selected species-account summaries of adult description, reproduction, and young), and report and draft manuscript reviews.

CYPRINID FISH LARVAE AND EARLY JUVENILES OF THE UPPER COLORADO RIVER BASIN — Morphological Descriptions, Comparisons, and Computer-Interactive Key

Darrel E. Snyder, Sean C. Seal, Jennifer A. Charles, and C. Lynn Bjork (illustrator)

ABSTRACT

Use of collections of fish larvae and young-of-the-year juveniles to help document fish spawning sites and seasons or assess larval production, transport, distribution, nursery habitat, survival, and other aspects of early life history, requires diagnostic criteria to accurately distinguish target species from all similar appearing taxa in the waters sampled. For most fishes, morphological criteria for identification of their larvae change dramatically as they grow and develop from hatchlings to more adult-like juveniles, making diagnosis especially difficult and complicated.

During the past decade, 68 species of fish (14 families) have been found in the Upper Colorado River Basin (UCRB). Of these, only 13 species (4 families) are native and over a third (5 native plus 19 introduced) represent the family Cyprinidae. Of the native fishes, nearly a third are federally endangered and subject to recovery efforts by the Upper Colorado River Endangered Fish Recovery Program—one catostomid, razorback sucker *Xyrauchen texanus*, and three cyprinids, humpback chub *Gila cypha*, bonytail *G. elegans*, and Colorado pikeminnow *Ptychocheilus lucius*.

To better facilitate identification of larvae and early juveniles of most cyprinids in the UCRB, developmental series of reared and collected specimens were studied for differences in size relative to developmental state, morphology, meristics, and pigmentation. The development of each described species also was well-illustrated with a series of up to eight three-view drawings from recently hatched larvae through early juveniles. The results are presented in detailed descriptive species accounts, comparative summary tables, and an associated computer-interactive key. The 15 species covered by this guide include the three endangered cyprinids, two remaining native cyprinids—roundtail chub *G. robusta* and speckled dace *Rhinichthys osculus*), and ten non-native cyprinids—red shiner *Cyprinella lutrensis*, common carp *Cyprinus carpio*, Utah chub *G. atraria*, brassy minnow *Hybognathus hankinsoni*, golden shiner *Notemigonus crysoleucas*, sand shiner *Notropis stramineus*, fathead minnow *Pimephales promelas*, longnose dace *R. cataractae*, redside shiner *Richardsonius balteatus*, and creek chub *Semotilus atromaculatus*. Other non-native cyprinids in the UCRB were either not recognized as present when the guide was planned or considered unlikely to be encountered as larvae in Recovery Program investigations; however, descriptions for the larvae of all but two are referenced. This guide also includes an appended modification of a previously published pictorial guide and a second associated computer-interactive key for identification of all larvae in the basin at the family level, as well as references to guides or comparative descriptions covering all but a couple of the non-cyprinid species. Together with a similar previously published guide for UCRB catostomids (Snyder and Muth 2004, Colo. Div. Wildl. Tech. Publ. 42), this guide completes a long series of descriptive investigations begun over 35 years ago with publication of *Contributions to a Guide to the Cypriniform Fish Larvae of the Upper Colorado River System in Colorado* (Snyder 1981, U.S. Bur. Land Manag. Biol. Sci. Ser. 3, Denver).

INTRODUCTION

Importance of Early Life History Investigations and Identification

The collection and study of fish eggs, larvae, and early juveniles should be an integral part of holistic fish and aquatic ecology investigations. Densities and spatial and temporal distribution of these life stages are indicative of spawning grounds and seasons, larval production, nursery habitat, behavior, and potential year-class strength. A single specimen is proof of at least some reproductive success. Even in baseline surveys to determine presence and relative abundance of fishes, larval-fish collections can sometimes provide information on species that are difficult to collect or observe as adults because of gear selectivity, behavior, habitat, or low abundance.

Furthermore, for most fishes, larval and early (young-of-the-year) juvenile development includes at least a few life-history phases that are ecologically distinct from each other, as well as later juveniles and adults (Snyder 1990; such phases do not necessarily correspond with the morphologically based developmental intervals defined below). Accordingly, knowledge of fish early life history is often essential for better understanding aquatic ecosystems and communities and effective monitoring, protection, or management of fish populations and habitats. Such knowledge is particularly valuable in assessing environmental impacts and recovering endangered species.

Research or monitoring based on collections of fish larvae usually requires accurate identification of collected specimens. Inland fishery managers and researchers have often excluded potentially critical larval-fish investigations specifically because they haven't done it before or the taxonomic tools needed for the job—adequate descriptions of larvae, diagnostic criteria, and keys for identification—are not available.

Descriptive information and diagnostic criteria for larval fish identification must be well founded, sufficiently detailed, and documented in such a way that they are retrievable, usable, and verifiable by any interested researcher, now or in the future. Any such knowledge retained only in the minds of one or a few specialists cannot be effectively used, verified, or further developed by others. Taxonomic expertise must be shared and transferred to avoid risk of sudden loss and need for rediscovery and redevelopment. Although the inventory of such information is gradually increasing, much descriptive and taxonomic research on fish larvae (as well as embryos and early juveniles) remains piecemeal and uncoordinated.

Simon (1986) compiled a relatively comprehensive listing of 230 regional larval-fish guides, keys, and comparative descriptions available through the early 1980s, but only about 80 of these (35%) pertain to or include freshwater species. Kelso et al. (2013, updating Snyder 1983 and Kelso and Rutherford 1996) listed over two dozen regionally oriented larval-fish identification manuals for or including North American freshwater species (some for the same regions and nearly all incomplete in coverage at the species level). Overlooked or subsequently published guides to larvae in North American freshwaters include a series of four for the Sacramento-San Joaquin River Delta in California (Wang 2007, Wang and Reyes 2007, Wang and Reyes 2008, and Wang 2010—all updating corresponding portions of Wang 1986) and one each for Alaska (Sturm 2004—in part updating Sturm 1988), the St. Johns River in Florida (Scripter et al. 2009,

unpublished laboratory guide available upon request), and the Hudson River in New York (Arvidson and Alber 2013). A seventh volume of the Ohio River drainage series of guides (mostly by Wallus and Simon) is in preparation and will cover the cyprinids of that region.

More general freshwater fish guides sometimes include brief accounts of, or at least references to, early life history, descriptions, and (or) illustrations. For example, in *Fishes of the Great lakes Region* Hubbs et al. (2004) included an appendix of selected illustrations for some species, one each to depict diagnostic shapes and pigmentation, from Auer (1982—still one of the more comprehensive guides to freshwater fish larvae in North America).

Early life stage descriptions, keys, and guides are the foundation for field research, but we still have many gaps in that foundation (Snyder 1996). In a recent initial assessment of early life-stage descriptions in guides and selected comparative literature published through early 2010, Snyder et al. (2012) found that about 60% of 823 freshwater or anadromous fishes in the United States or Canada remain undescribed as larvae and considered only about 26% to be sufficiently well-described for identification purposes, just 11% more than estimated 35 years before (Snyder 1976a). Among the Cyprinidae (minnows, 245 species) in that recent survey, only 15% were assessed to have been well-described as larvae.

Objectives

Collections of the early life stages of fish are essential for much of the research on and monitoring of the federally endangered Colorado pikeminnow *Ptychocheilus lucius*, humpback chub *Gila cypha*, and bonytail *G. elegans*, as well as other fishes of the Upper Colorado River basin (UCRB, Figure 1 below). Identification of specimens in those collections requires knowledge of the morphological appearance of the target and all similar species in the waters sampled, as well as the diagnostic criteria for segregating them. Fortunately, most species in the basin have been moderately to well described. However, for many species, including the catostomids and cyprinids, morphological criteria for identification change dramatically as the fish grow and develop, making diagnosis especially difficult and complicated. This is well exemplified by the 60-page key in Snyder and Muth (1990) which covers the larvae and early juveniles of just six of seven species of catostomids in the UCRB.

The objectives of this guide, with its detailed and well-illustrated species accounts, comparative summary tables, and computer-interactive keys, are to more completely describe and better facilitate identification of the larvae and early juveniles of 15 cyprinids inhabiting the UCRB—the five native species (three endangered) and the ten non-native cyprinids most likely to be encountered in Upper Colorado River Endangered Fish Recovery Program (RP) monitoring and investigations (species denoted by asterisks in Table 1 below). Some non-native cyprinids not described herein were not recognized as present in the basin when this guide was planned. Descriptive information assembled herein should contribute to the conservation or recovery of the native cyprinids. Portions of this guide should also be of interest and use to biologists working in the Lower Colorado River Basin (LCRB) and wherever else the covered species are found.

Fishes of the Upper Colorado River Basin

The Colorado River Basin encompasses much of the southwestern interior of the United States west of the Continental Divide, extends from southwestern Wyoming to northwestern Mexico, and historically drained into the Gulf of California. Its rivers and streams have been highly altered by dams impounding reservoirs for hydro-electric power generation, water storage, flow regulation, and recreation, and by water diversions and withdrawals for agricultural irrigation, industry, and domestic uses. For water management purposes, the Colorado River Compact approved by Congress in 1928 politically divided the basin at Lee Ferry, Arizona (just below Glen Canyon Dam and Lake Powell), into upper and lower basins. As discussed above and mapped in Figure 1, the basin of primary concern for this guide is the Upper Colorado River Basin. The geography, waters, and importance of the UCRB, its fishes up to that time, and man's impacts upon it and its aquatic inhabitants were reviewed and well summarized by Joseph et al. (1977) and in a symposium proceedings on fishes of the basin edited by Miller et al. (1982).

Table 1 lists fishes recently recorded in the UCRB. Common and scientific names listed therein, and used herein, follow Page et al. (2013), except only proper nouns in common names are capitalized in accord with prior American Fisheries Society Committee on Names of Fishes publications (e.g., Nelson et al. 2004) and current RP policy regarding report format (www.coloradoriverrecovery.org /documents-publications/technical-reports/ reportformat/BCRepRevPro.pdf).

In the table, the presence and relative abundances of fishes in lotic and lentic habitats during the past decade (since 2003) are summarized for each of the basin's eight 4-digit HUC (U.S. Geological Survey hydrologic unit code) sub-basins, 1401–1408, as delineated in Figure 1. Based on these assessments, the UCRB is currently inhabited by 68 species of fish representing 14 families. However, only 13 (19%) of those species, representing four families, are native, and most of the fishes in the basin (31 of 68, 46%), as well as most of the native species (9 of 13, 69%), are cyprinids (carps and minnows) or catostomids (suckers), representing the order Cypriniformes. Also present in the basin are seven specifically recorded subspecies (1 cyprinid and 6 cutthroat trout) and 24 identified hybrids (4 cyprinid, 14 catostomid, 4 salmonid, 1 esocid, and 1 centrarchid).

As listed in Table 1, the current number of all species in the UCRB varies among its eight sub-basins from 42 (possibly 44) for HUCs 1403 (Upper Colorado-Delores) and 1407 (Upper Colorado-Dirty Devil) to 49 (possibly 50) for HUC 1401 (Colorado Headwaters). Of the native species, eight are currently present in all sub-basins, four in five to seven sub-basins, and one (Paiute sculpin) in just two sub-basins. Eight species are recorded as present only in lotic habitats and four only in lentic habitats.

Over three decades ago, Tyus et al. (1982) similarly assessed the relative abundance or presence of fishes in major rivers and reservoirs of the UCRB and mapped their distributions. Their listings were grouped within three major hydrologic subregions defined by Joseph et al. (1977), which for comparison are treated as sub-basin groupings in Table 1 and Figure 1. At that time they reported 52 species (plus 3 subspecies, and 10 hybrids) in the basin, including 12 native species (they designated 13 taxa as native, but one was a subspecies of another, the speckled dace). However, their list did not include two of the 46 species previously listed by Snyder (1981) for the Colorado portion of the basin (the native Paiute sculpin and non-native golden trout), and one of the non-native species they listed (leatherside chub *Gila copei*) is now recognized as two species (northern and southern leatherside chubs), both of which are present in the basin. Accordingly,

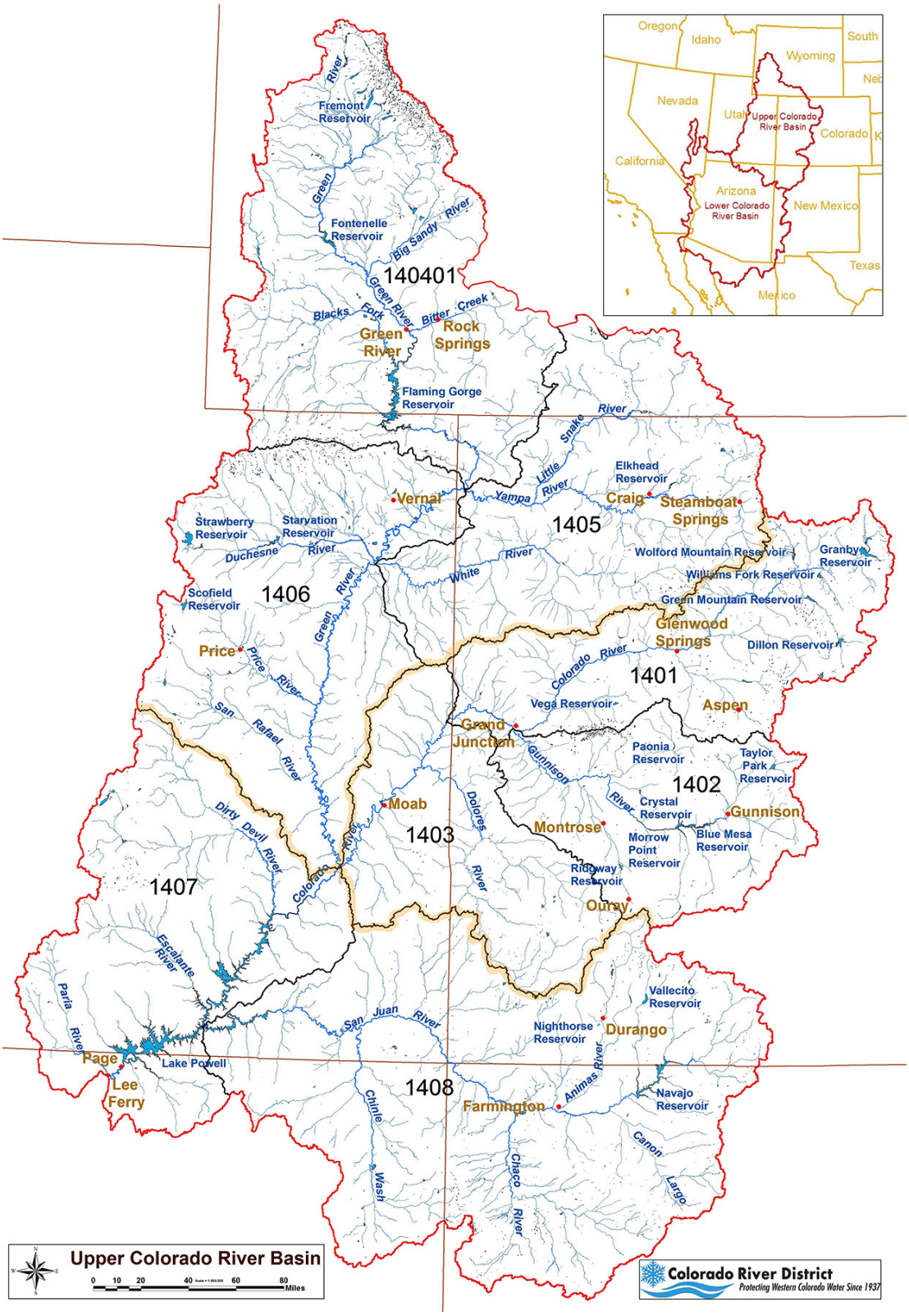

Figure 1. Upper Colorado River Basin and its 4-digit HUC (U.S. Geological Survey hydrologic unit code) sub-basins; boundaries separating Green, Upper Main Stem, and San Juan–Colorado sub-basin groups (major sub-basin regions defined by Iorns et al. 1965) are highlighted.

Table 1. Fishes of the Upper Colorado River Basin—distribution and relative abundance during the past decade (2004-2014) in lotic and lentic habitats by sub-basin. Native species are indicated by bold type and cyprinids described herein as larvae are preceded by an asterisk (*). Conservation status is designated as E (endangered), T (threatened) or SC (special concern, similar designation, or under conservation agreement) at federal or state levels. Relative abundance is assessed as C (commonly collected in appropriate habitats throughout much of the sub-basin), O (occasionally collected or generally less common in appropriate habitats), R (rarely collected, incidental, or very localized populations), X (present, but relative abundance not assessed), and "?" (presence uncertain). Sub-basins are as defined by U.S. Geological Survey 4-digit hydrologic unit codes (HUCs) and illustrated in Figure 1. Common and scientific names follow Page et al. (2013) except regarding capitalization of common names.

Sub-basin group:	Upper Main Stem			Green River			San Juan-Colorado	
HUC sub-basin:	1401	1402	1403	1404(01)	1405	1406	1407	1408
HUC name:	Colorado head-waters	Gunnison	Upper Colorado –Delores	Upper Green	White / Yampa	Lower Green	Upper Colorado–Dirty Devil	San Juan
Habitat:	lotic / lentic	lotic / lentic	lotic / lentic	lotic / lentic	lotic / lentic	lotic / lentic	lotic / lentic	lotic / lentic
Sources: [a]	1,2,9,12 / 2,12	1,2,12 / 2,12	2,9,10,12, 13 / 2,12, 13	1,2,3,12, 13 / 1,5, 12,13	1,2,3,11, 12,13 / 1, 2,12,13	1,2,10,12, 13 / 1,12, 13	6,12,13 / 4,12,13	2,7,12,13 / 2,4,8, 12,13
Species – Conservation status								
Clupeidae, herrings								
Dorosoma cepedianum, gizzard shad	O/O	O/-	O/-	R/-	R/-	O/R	O/C	?[b]/O
Dorosoma petenense, threadfin shad	-/-	-/-	-/-	-/-	-/-	-/-	-/O	-/O
Cyprinidae, carps and minnows								
Carassius auratus, goldfish	R/-	-/R	-/-	-/-	-/-	-/-	-/-	-/O
Couesius plumbeus, lake chub – E-CO	-/-	-/-	-/-	O/R	-/-	-/-	-/-	-/-
C. plumbeus x *Rhinichthys osculus*	-/-	-/-	-/-	R/-	-/-	-/-	-/-	-/-
Ctenopharyngodon idella, grass carp (triploid)	R/R	R/-	R/-	-/-	R/-	X/-	X/X	-/R
**Cyprinella lutrensis*, red shiner	O/R	O/O	O/O	O/R	O[c]/O	C/O	C/O	O/O
**Cyprinus carpio*, common carp	O/O	O/O	O/O	O/O	O/O	O/C	R/C	O/O
**Gila atraria*, Utah chub	-/-	-/-	-/-	O/O	-/-	R/O	R/R	-/-
***Gila cypha*, humpback chub** – E-US; T-CO; SC-AZ,UT	O/-	R/-	O/-	-/-	O/-	O/-	O/-	-/-
G. cypha x *elegans*	-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
G. cypha x *robusta*	-/-	-/-	R/-	-/-	R/-	R/-	-/-	-/-
***Gila elegans*, bonytail** – E-US,CO; SC-AZ,UT	O[d]/-	O[d]/O[d]	O[d]/-	R[d]/-	O[d]/-	O[d]/O[d]	R[d]/R[d]	-/-
Gila pandora, Rio Grande chub – SC-CO	-/-	R/O	-/-	-/-	-/-	-/-	-/-	R/-
***Gila robusta*, roundtail chub** – E-NM; SC-AZ,CO,UT,WY	C/O	O/R	O/R	O/O	O/-	O/-	O/-	O/R
**Hybognathus hankinsoni*, brassy minnow – T-CO, SC-WY	?[e]/-	-/-	?[e]/-	-/-	-/-	-/-	-/-	-/-
Lepidomeda aliciae, southern leatherside chub – SC-UT	-/-	-/-	-/-	-/-	-/-	-/-	X/-	-/-
Lepidomeda copei, northern leatherside chub – SC-UT,WY	-/-	-/-	-/-	O/-	-/-	-/-	-/-	-/-
**Notemigonus crysoleucas*, golden shiner	R/O	R/-	-/-	-/-	-/-	-/-	-/-	-/-
Notropis blennius, river shiner	-/-	R/-	R/-	-/-	-/-	-/-	-/-	R/-
Notropis dorsalis, bigmouth shiner	-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
Notropis hudsonius, spottail shiner	R/-	R/-	-/-	-/-	R/-	-/-	-/-	R/-
**Notropis stramineus*, sand shiner	O/R	R/R	O/-	O/-	O/O	C/O	O/-	-/-
**Pimephales promelas*, fathead minnow	O/O	O/O	C/O	C/O	C/O	O/O	C/O	O/O
***Ptychocheilus lucius*, Colorado pikeminnow** – E-US,NM; T-CO; SC-AZ,UT	O/R	O/-	O/-	R/-	O/-	O/O	O/R	O/R
**Rhinichthys cataractae*, longnose dace	R/-	O/R	-/-	O/-	O/R	R/-	-/-	-/-
***Rhinichthys osculus*, speckled dace** – SC-AZ	C/R	C/-	O/-	C/O	C/O	O/R	O/-	C/R
R. o. thermalis, Kendall Warm Springs dace – E-US; SC-WY	-/-	-/-	-/-	R[f]/-	-/-	-/-	-/-	-/-
R. osculus x *Richardsonius balteatus*	-/-	-/-	-/-	R/-	R/-	R/R	-/-	-/-
**Richardsonius balteatus*, redside shiner	R/-	O/R	R/-	O/O	O/R	O/O	R/R[g]	R/-
**Semotilus atromaculatus*, creek chub	O/R	-/-	-/-	R/-	O/O	R/-	-/-	O/-
Catostomidae, suckers								
Catostomus ardens, Utah sucker	-/-	-/-	-/-	R/R	-/-	R/R	X[h]/-	-/-
C. ardens x *commersonii*	-/-	-/-	-/-	R/O	-/-	-/-	-/-	-/-
C. ardens x *discobolus*	-/-	-/-	-/-	R/-	-/-	-/-	-/-	-/-
C. ardens x *latipinnis*	-/-	-/-	-/-	R/O	-/-	-/-	-/-	-/-

(continued)

Table 1. Continued.

Species – Conservation status	Sub-basin group: HUC sub-basin:	Upper Main Stem 1401	1402	1403	Green River 1404(01)	1405	1406	San Juan-Colorado 1407	1408
Catostomus catostomus, longnose sucker		O/C	O/C	O/O	R/O	O/O	-/-	-/-	-/-
C. catostomus x *discobolus*		R/-	R/-	-/-	R/-	-/-	-/-	-/-	-/-
C. catostomus x *latipinnis*		R/-	R/-	R/-	-/-	-/-	-/-	-/-	-/-
Catostomus commersonii, white sucker		C/C	C/C	O/O	O/O	O/O	O/O	O/-	O/O
C. commersonii x *catostomus*		R/-	R/-	-/-	-/-	-/-	-/-	-/-	-/-
C. commersonii x *discobolus*		O/R	O/R	-/O	O/-	O/-	O/-	-/-	O/R
C. commersonii x *discobolus* x *latipinnis*		-/-	-/-	-/-	R/-	R/-	R/-	-/-	-/-
C. commersonii x *latipinnis*		O/R	O/R	-/O	O/O	O/O	O/R	-/-	O/O
C. commersonii x *platyrhynchus*		-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
C. commersonii x *X. texanus*		-/-	-/-	-/-	R/-	-/-	R/R	-/-	-/-
***Catostomus discobolus*, bluehead sucker** – SC-AZ,CO,NM,UT,WY		O/R	O/R	O/O	O/R	O/-	O/O	O/R	O/O
C. discobolus x *latipinnis*		R/-	O/-	R/-	O/-	R/-	O/-	-/-	R/-
C. discobolus x *X. texanus*		-/-	-/-	R/-	-/-	-/-	-/-	-/-	-/-
***Catostomus latipinnis*, flannelmouth sucker** – SC-AZ,CO,NM,UT,WY		C/R	C/R	O/O	C/R	O/O	O/O	O/R	C/O
C. latipinnis x *X. texanus*		R/-	R/-	R/-	R/-	R/-	O/R	-/-	R/R
***Catostomus platyrhynchus*, mountain sucker** – SC-CO		R/O	O/-	O/-	O/O	O/O	R/-	-/-	-/-
***Xyrauchen texanus*, razorback sucker** – E-US,CO; SC-AZ,UT		O/R	O/R	O/-	R/-	O/?	O/O	O/R	O/O
Ictaluridae, North American catfishes									
Ameiurus melas, black bullhead		O/O	O/O	O/R	R/-	O/R	O/-	O/O	O/O
Ameiurus natalis, yellow bullhead		R/-	R/-	R/-	-/-	-/-	R/-	X/O	R/O
Ictalurus punctatus, channel catfish		O/O	O/O	O/R	O/O	O/O[i]	O/O	O/O	C/O
Salmonidae, trouts and salmons									
Oncorhynchus aquabonita, golden trout		-/R	-/O	-/-	-/R	-/-	-/-	-/-	-/-
***Oncorhynchus clarkii*, cutthroat trout**		O/C	O/C	O/O	O/O	O/O	O/O	-/-	O/O
O. c. behnkei, Snake River (fine-spotted) – SC-WY		R/O	O/O	O/O	R/O	R/O[i]	-/-	-/-	O/-
O. c. bouvieri, Yellowstone – SC-UT,WY		-/R	R/-	-/-	-/R	-/-	-/-	-/-	-/-
O. c. behnkei x *bouvieri*		-/-	-/-	-/-	-/O	-/-	-/-	-/-	-/-
***O. c. pleuriticus*, Colorado River** – SC-CO,UT,WY		O/C	O/C	O/O	O/R	O/O	R/R	-/-	O/O
O. c. stomias, greenback – T-US,CO		R/-	R/-	O/-	-/-	-/-	-/-	-/-	O/-
O. c. utah, Bonneville – SC-UT,WY		-/-	-/-	-/-	R/-	-/-	-/O	-/-	-/-
O. c. virginalis, Rio Grande – SC-CO		-/-	-/R	-/-	-/-	-/-	-/-	-/-	-/-
O. clarkii x *mykiss*		O/O	O/O	O/O	-/O	R/O	-/-	-/-	O/O
Oncorhynchus mykiss, rainbow trout		O/C	O/C	O/O	O/O	O/O[i]	O/O	-/R	O/O
Oncorhynchus nerka, sockeye salmon (kokanee)		R/C	O/C	R/O	R/O	-/X[j]	-/-	-/R	O/O
***Prosopium williamsoni*, mountain whitefish** [k] – SC-WY		O/R	-/R	-/-	O/O	O[j]/O[i]	O/-	-/-	-/-
Salmo trutta, brown trout		O/C	O/C	O/O	O/O	O[i]/O[i]	O/R	-/-	O/O
S. trutta x *Salvelinus fontinalis*, tiger trout		R/R	R/R	-/-	-/-	R[i]/X[j]	-/O	-/X	-/-
Salvelinus alpinus, Arctic char		R/O	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Salvelinus fontinalis, brook trout		O/C	O/C	O/O	O/O	O/O	O/O	O/O	O/O
S. fontinalis x *namaycush*, splake		R/R	-/O	-/-	-/X[i]	R/O[i]	-/O	?/X	-/-
Salvelinus namaycush, lake trout (mackinaw)		R/C	R/C	-/-	X[i]/O	-/O[i]	-/R	-/-	-/X
Thymallus arcticus, Arctic grayling		-/O	-/-	-/-	-/R	-/O[i]	-/R	-/-	-/-
Esocidae, pikes and mudminnows									
Esox lucius, northern pike		O/O	R/O	R/R	O/-	O/O	O/X	-/O	-/O
E. lucius x *masquinongy*, tiger muskie		-/-	-/-	-/-	-/-	-/R	-/R	-/O	-/O
Gadidae, cods									
Lota lota, Burbot – SC-WY		-/-	-/-	-/-	O/O	-/-	R/-	-/-	-/-
Fundulidae, topminnows									
Fundulus kansae, northern plains killifish – SC-WY		-/-	R[l]/-	R/-	R/-	O/-	R/-	-/-	O/R
Poeciliidae, livebearers									
Gambusia affinis, western mosquitofish		R/-	-/-	O/R	-/-	-/-	R/-	-/R	O/R
Gasterosteidae, sticklebacks									
Culaea inconstans, brook stickleback		R/-	R/-	-/-	R/-	O/R	O/O	-/-	-/-
Cottidae, sculpins									
***Cottus bairdii*, mottled sculpin**		O/R	O/-	O/-	O/R	O/R	O/-	R/-	O/O
***Cottus beldingii*, Paiute sculpin** [m]		O/-	-/-	O/-	-/-	-/-	-/-	-/-	-/-

(continued)

Table 1. Continued.

Species – Conservation status	Sub-basin group: HUC sub-basin:	Upper Main Stem 1401	1402	1403	Green River 1404(01)	1405	1406	San Juan-Colorado 1407	1408
Moronidae, temperate basses									
Morone chrysops, white bass		-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/O
Morone saxatilis, striped bass		R/-	-/-	X/-	-/-	-/-	-/-	R/C	R/O
Centrarchidae, sunfishes									
Lepomis cyanellus, green sunfish		O/C	O/O	O/O	O/O	O/O	O/O	O/O	O/O
L. cyanellus x *macrochirus*		-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
Lepomis gibbosus, pumpkinseed		-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
Lepomis macrochirus, bluegill		O/C	R/C	R/R	O/-	O/O	O/O	-/O	R/C
Micropterus dolomieu, smallmouth bass		O/O	O/O	O/O	O[i]/O	O/O[i]	O/O	R/O	O/O
Micropterus punctulatus, spotted bass		-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/X
Micropterus salmoides, largemouth bass		O/C	O/O	R/O	-/R	R/O	R/O	R/O	O/O
Pomoxis annularis, white crappie		-/-	-/-	-/-	-/-	R/-	-/-	-/O	-/O
Pomoxis nigromaculatus, black crappie		O/C	R/O	R/O	R/-	O/O	O/O	R/O	-/O
Percidae, perches and darters									
Etheostoma exile, Iowa darter – SC-CO,WY		-/-	-/-	-/-	R/-	O/R	O/O	-/-	-/-
Etheostoma nigrum, johnny darter		-/-	-/-	-/-	-/-	R/-	-/-	-/-	-/-
Perca flavescens, yellow perch		R/O	R/O	R/O	-/-	-/R	R/O	-/R	O/O
Sander vitreus, walleye		O/O	R/O	O/O	-/-	R/O[i]	O/O	O/C	R/O

[a] Sources (except as otherwise footnoted): 1 = for CO, WY, and UT, data from Colorado State University Larval Fish Laboratory Collection holdings, 2004-2014; 2 = for CO, data from Colorado Parks and Wildlife Aquatic Database (none for lentic habitats in 1404 and 1406) provided by Andrew Treble (PC, winter-summer 2014); 3 = for WY, Gelwicks et al. (2009) and supplemental data provided by Gelwicks (PC, winter-spring 2014); 4 = for UT, Blommer & Gustaveson (2010) and supplemental data provided by George Blommer (PC, spring 2014); 5 = for WY, Peter Cavalli (PC, spring 2014) and Robert Compton (PC and WGFD StreamLake database summary for Flaming Gorge and Fontanelle reservoirs, 11/12/14); 6 = for UT (Dirty Devil R.), Platania et al. (2012) and Howard Brandenburg (PC, 6/2014); 7 = for mostly UT & NM (San Juan River), Brandenburg (PC and data, 6/2014), Gilbert (2013, 2014), and Lorraine McInnes (PC and data from Museum of Southwestern Biology holdings post 2003, 10/29/14; 8 = for UT (San Juan Arm of L. Powell), Francis et al. (2013) and Brandenburg (PC, 6/2014), and for NM, various online websites (including New Mexico Game and Fish Department Fishing Rules and Information for 2014-15) for fish in New Mexico reservoirs and lakes in HUC 1408 (10/2/2014); 9 = for main-stem Colo. R. below RM 194, Osmundson and White (2014); 10 = for UT Colo. R. and Green R., young-of-the-year and small-bodied fishes in main-stem shorelines and backwaters, Harding et al. (2013) and Travis Francis (PC, 7/3/14: archived UCRB Recovery Program data for 2004-2013); 11 = for UT White R young-of-the-year and small-bodied fish in main-stem shorelines and backwaters, Francis (PC, 7/3/14: archived UCRB Recovery Program young-of-the-year ISMP data for 2008-2009); 12 = for CO, UT, and WY, Francis (PC, 7/3/14: UCRB Recovery Program pit-tag and stocking data for 2004-13), Francis (PC, 11/25/15: grass carp in L. Powell), selected Recovery Program e-mail list communications and Biology Committee meeting minutes in 2010-14, Martinez et al (2014 and associated invasive species summaries), and Battige (PC, 1/14/15, Researcher's Meeting presentation), with a few edits for Utah reaches by Paul Badame (PC, UDWR, 3/17/15); and 13 = for UT, Sarah Lindsey (PC, 9/15/14: sensitive cyprinid distribution maps, UDWR data since 2003), fish species lists from Utahfishinginfo.com (12/10/14) webpages for selected Utah lakes in UCRB, and UDWR website fish distribution maps (12/10/14, based mostly on pre-2004 data), all assessments of which were confirmed, revised, or refined by Paul Badame with recent UDWR abundance data (PC, 3/17/15).

[b] Mueller and Brooks (2004) and Webber and Jones (2013) report that gizzard shad were accidentally stocked in Morgan Lake, NM, and spread to the lower San Juan River by year 2000, but the species has not been reported in the river above the San Juan Arm of Lake Powell since 2003 (footnote a, source 7).

[c] Beginning in 2013, collected for first time in Wyoming in Little Snake River (Robert Compton, WGFD—PC 3/2/15).

[d] All presumed to be stocked fish—no definitive evidence yet of successful natural reproduction.

[e] In past decades, present and reproducing in Colorado River near De Beque and Grand Junction, CO, and Moab, UT, (and probably between), and collected downstream to Cataract Canyon; although no documented collections have been reported since 1999 (below Palisade, CO—Larval Fish Laboratory Collection), probably still present at least in CO.

[f] Present only in and near Kendall Warm Springs, WY (USFWS 2012).

[g] Present at least in Fish Lake of Fremont R. drainage (Mike Hadley via Erik Woodhouse, UDWR—PC, 10/5/15).

[h] Present, Fremont R.—3 juveniles collected in 2007 by UDWR in 2007 (Colorado State University Larval Fish Laboratory Collection).

[i] Absent in WY (WGFD 2011).

[j] Present in WY (WGFD 2011).

[k] Native only to Green River sub-basin, introduced elsewhere.

[l] Documented as present in the sub-basin from late 1960s to 1995, but not since until collection in 2014 in an isolated Gunnison R. side channel (but probably lotic in origin).

[m] These sculpin in headwater tributaries of the Colorado R. were originally described as *Cottus annae*, eagle sculpin, by Jordan and Starks (1896) and subsequently synonymized with *C. beldingii* by Bailey and Bond (1963) without explanation. Whether they are indeed of the latter species, variants of *C. bairdii*, or their own distinct species has yet to be determined (Snyder 1981, Woodling 1985, Bestgen and Zelasko 2004). The systematics of regional sculpins are currently under investigation (PC—Dennis Shiozawa, Brigham Young Univ., 4/27/15).

the total number of full species recognized as inhabiting the basin at that time was 55 (42 non-natives). The current list of 68 species (55 non-natives) therefore represents a net increase of 13 non-native species since 1982 (16 new species less 3 previously reported that are not in the current list—coho salmon *Oncorhynchus kisutch,* plains topminnow *Fundulus sciadicus*, and plains minnow *Hybognathus placitus*). Of the current 55 non-natives, 45 have been reported in the Colorado portion of the UCRB during the past decade and represent a net increase of 12 (13 new species less 1 no longer listed, plains topminnow) over the 33 non-natives listed therein by Snyder in 1981.

Systematics, Status, and Distribution of UCRB Cyprinids

Over a third of all fishes in the UCRB (24 of 68, 35%), as well as the native species (5 of 13, 38%), are cyprinids (Table 1). Cyprinidae is the largest and most diverse family of freshwater fishes in the world with over 2,500 species in Europe, Asia, Africa, and North America (NA). It is also the largest family in NA with at least 313 native species in 51 genera, plus 9 species introduced and established from other continents (Scharpf 2005). Two subfamilies are recognized, Cyprininae and Leuciscinae. All cyprinids native to NA belong to subfamily Leuciscinae and all but one to tribe Phoxini (Cavender 1991, Coburn and Cavender 1992). Golden shiner is the sole representative of the tribe Leuciscini in NA.

All cyprinids in the UCRB are native to NA except common carp, goldfish, and grass carp. All three belong to subfamily Cyprininae and are native to Eastern Europe or Asia, but have been widely introduced throughout NA and much of the world (Scharpf 2005). Common carp is perhaps the most widely distributed non-native cyprinid in the Colorado River Basin (CRB), whereas the other two species are limited mostly to private ponds or localized populations of escapees or unauthorized releases. All grass carp in the UCRB are assumed to be sterile triploids, thereby precluding the possibility of reproductively established populations and larvae.

Only five (21%) of the 24 cyprinids in the UCRB are native to the basin (Table 1), and of these all but speckled dace are endemic to the broader CRB. Three of the endemic species—Colorado pikeminnow, humpback chub, and bonytail—are federally endangered species respectively listed in 1967, 1967, and 1980 (USOFR 2015) with recovery plans initially approved in 1978, 1979, and 1984 (USFWS 1987a). In the UCRB, their recovery (along with that of another endangered endemic, the razorback sucker) has been the objective of intensive, multiple-agency, multiple-species efforts by the RP (USFWS 1987b—initiated by cooperative agreement in 1988; http://www.coloradoriverrecovery.org/) and the San Juan Basin Recovery Implementation Program (for Colorado pikeminnow and razorback sucker; http://www.fws.gov/southwest/sjrip/). Recovery efforts include flow protection and modification, habitat preservation and enhancement, removal or control of problematic non-native fishes, and the rearing and stocking of fish for reintroduction or population augmentation in selected reaches (USFWS 1987b, 1990a, 1990b, 1991, 2002a, 2002b, 2002c). The fourth endemic species, roundtail chub, is considered endangered by New Mexico and a species of special concern (or under conservation agreement) by other UCRB states (Bezzerides and Bestgen 2002; UDWR 2006).

The Colorado pikeminnow (formerly Colorado squawfish) is one of four living members of the western genus *Ptychocheilus*. It is the largest native minnow in NA with total

lengths (TL) commonly observed up to about 0.9 m, and older records up to twice that length. Historically, it was the top piscine predator in the middle to lower reaches of larger rivers throughout the CRB, but was functionally extirpated from the LCRB about a half a century ago, and remains so despite ongoing efforts to re-establish self-sustaining populations. Small reproducing populations remain in the Green and Colorado River sub-basins of the UCRB in Colorado and Utah and have been re-established in the San Juan River of Utah and New Mexico (http://www.coloradoriverrecovery.org/ general-information/general-publications/ briefingbook/ 2014HighlightsDig.pdf).

Among the *Gila* (western chubs) in the UCRB, the three native species—bonytail, humpback chub, and roundtail chub—belong to subgenus *Gila*. All roundtail chub in the UCRB are designated as subspecies *G. r. robusta*, Colorado roundtail chub, as are most populations in the LCRB (most other formerly recognized subspecies are now designated as distinct species). In the introduction to his doctoral dissertation, Muth (1990) reviewed in detail the systematics, taxonomy, status, and distribution of these endangered or special-concern species; references cited above provide additional and more recent information. Hybridization among these three natives has been well documented (Muth 1990, Bezzerides and Bestgen 2002, UDWR 2006) and complicates management, recovery, and specimen identification.

Bonytail has become the rarest and most endangered of the three species. Historically common in lower main-stem reaches throughout the CRB, wild self-sustaining populations have been functionally extirpated from the basin for at least a few decades (USFWS 1990a). The fish currently survives only through ongoing hatchery and pond culture and re-introduction efforts in the Green and Colorado rivers of Colorado and Utah and main-stem Colorado River reservoirs in the LCRB. Successful reproduction has been documented for bonytail stocked in isolated off-channel backwaters, coves, and ponds managed for grow-out or as native fish sanctuaries in the LCRB (Mueller 2007; Osborne and Turner 2014), but not yet for those stocked in CRB rivers or reservoirs themselves.

Historically, the humpback chub has been the most restricted of the three species in distribution and habitat, residing mostly in lower reach canyons of the Yampa, Green, and Colorado rivers in the UCRB and the uppermost portion of the LCRB at least through the Grand Canyon. Self-sustaining populations remain in the canyons of these reaches, but those in the UCRB are tenuous and declining, whereas the Grand Canyon population in the Colorado River and lower end of the Little Colorado River is currently the largest and, perhaps with some recovery assistance, the most stable with recent increases in population, distribution, and documented reproduction (Albrecht et al. 2014; Spurgeon et al. 2015; http://www.gcmrc.gov/ research_areas/humpback_chub/humpback_ chub_default.aspx).

Roundtail chub, perhaps historically the most wide-spread of the three native chubs, remain widely distributed throughout much of the UCRB. However, many of these populations have been declining (Bezzerides and Bestgen 2002) and in several tributaries of the San Juan River there are now state and tribal efforts to re-establish or augment populations. In the LCRB, populations remain only in relatively isolated reaches, mostly in the Salt River and Verde River basins.

Of the non-native *Gila* in the basin, Rio Grande chub also belongs to subgenus *Gila,* whereas the Utah chub belongs to subgenus *Siboma* (Scharpf 2005). The former, a native of the upper Rio Grande and Pecos River systems (CO, NM, TX), is restricted in the UCRB to localized populations in the Gunnison River and San Juan River sub-basins. The latter is a native of the upper Snake River

system (WY, ID) and Lake Bonneville Basin (ID, UT), but has been introduced into other nearby drainages. In the UCRB, the Utah chub is abundant in higher elevation reservoirs in Utah, Fontanelle Reservoir, and Flaming Gorge Reservoir, but rare in the Green River and lower tributaries below Flaming Gorge (Lentsch et al. 1996).

Unlike the other four native cyprinids in the UCRB, speckled dace are widely distributed in western North America with a multitude of variously recognized (and unrecognized) regional subspecies (Scharpf 2005, Minckley and Marsh 2009), many of which have been accorded federal or state protected or special concern status (Johnson 1987). Except for the federally endangered subspecies *R. o. thermalis* (USFWS 2012, USOFR 2015), which is restricted to Kendall Warm Springs and its outflow in the Green River headwaters of Wyoming, all speckled dace in the UCRB are recognized as *R. o. yarrowi*.

In contrast to speckled dace, its uncommon, non-native congeneric in the basin, the longnose dace, has very few recognized subspecies despite being considered the most widely distributed native cyprinid in North America (Scharpf 2005). It is a cool water fish of the more northern latitudes or higher elevations as far south as Georgia and northern Mexico. Most western and east-slope southern Rocky Mountain populations are either undesignated as to subspecies or provisionally recognized as *R. c. dulcis* (Page and Burr 1991), for which the type locality is in the headwaters of the North Platte River of Wyoming; most other populations east of the Continental Divide are recognized as *R. c. cataractae.*

The fathead minnow is native to most of northeastern and central NA including northeastern Mexico, but widely introduced and established elsewhere, including most of the CRB where it and red shiner are nearly as ubiquitous as common carp. Throughout its range, all but one isolated population are treated as subspecies *P. p. promelas* (Scharpf 2005).

Red shiner is native to the Mississippi River Basin and western Gulf coast drainages but widely introduced and established elsewhere, including most warmer waters of the CRB. It had been long included in the genus *Notropis* until Mayden (1989) raised subgenus *Cyprinella* to the generic level. All extant populations except one in Mexico are recognized as subspecies *C. l. lutrensis* (Scharpf 2005).

Although native only east of the Continental Divide, *Notropis* is the most speciose genus of North American cyprinids (over 90 species). Of the four species reported in the UCRB, only the sand shiner has become well established as a common non-native inhabitant of the lower to middle reaches of several rivers.

The sand shiner belongs to subgenus *Alburnops*, one of several subgenera or species groups, and is a wide-spread native of central and mid-western NA (Scharpf 2005), including most drainages in eastern Colorado and Wyoming (Woodling 1985 and Baxter and Stone 1995). Like populations of the Missouri and Arkansas river basins, the sand shiner in the UCRB is considered to be subspecies *N. s. missuriensis*, one of two or three subspecies designations across its range.

The remaining three species of *Notropis* recently reported in UCRB, the spottail, river and bigmouth shiners, were each reported only in a few Colorado localities. Their presence here is probably the result of bait-bucket releases, escape as forage fish from private ponds, or accidental stocking along with other fish. Whether any of the three species have become reproductively established and persist in those localities has not been documented. The spottail shiner and river shiner, like the sand shiner, are members of subgenus *Alburnops*, whereas the bigmouth shiner has not been assigned to a subgenus but rather, with

five other species, to its own "dorsalis" species group (Scharpf 2005).

The native range of the spottail shiner is expansive, including east-coast drainages as far south as Georgia, and more northern interior drainages from the upper Mississippi, Great Lakes, and St Lawrence basins to the Mackenzie system in northern Canada. Although not native to the Missouri River Basin, it had been introduced to and became established decades ago in certain eastern Colorado and Wyoming reservoirs as forage for game fishes (Woodling 1985, Baxter and Stone 1995).

The smaller native ranges of the river and bigmouth shiners are interior only, primarily in the Mississippi basin (Lee et al. 1980). The river shiner is a large river fish and its native range extends more broadly north to south from western Hudson Bay drainages to the mouth of the Mississippi River, but no further west than the eastern fringe of Colorado. In contrast, the native range of the bigmouth shiner extends more broadly east and west from Great Lakes drainages of Pennsylvania and New York to Platte River drainages in Colorado and Wyoming. Platte River populations of bigmouth shiner have been designated as subspecies *N. d. piptolepis,* whereas all others, except eastern-most populations, are considered *N. d. dorsalis* (Scharpf 2005).

The golden shiner is native throughout most eastern and mid-western portions of the continent (Scharpf 2005). However, as a commercially cultured and widely distributed bait minnow, non-native populations have become established in nearly every western state, including a couple UCRB localities in Colorado. Two subspecies are recognized with populations established in the UCRB and most of the west probably being *N. c. auratus* from the western Great Lakes and mid-western regions, rather than *N. c. crysoleucas* from the Atlantic and Gulf coast drainages (the description of golden shiner herein is based on representatives of both subspecies).

As a non-native in the UCRB, the redside shiner is commonly found in portions of the upper Green, Yampa, Duchesne, and Fremont river basins with sporadic populations elsewhere. Except for the Peace River Basin in Alberta and British Columbia, it is native only west of the Continental Divide in southwestern Canada, northwestern United States, and the Bonneville Basin of Idaho, Wyoming, Utah, and Nevada (Scharpf 2005). Two subspecies are recognized with those of the Bonneville Basin and non-native populations in the UCRB designated as *R. b. hydrophlox*.

The creek chub is native throughout most of southeastern and south central Canada and eastern and central United States, but has been widely introduced elsewhere (Scharpf 2005). In the UCRB, it is found mostly in the Yampa and Little Snake river drainages and in the Green River near its confluence with the Yampa; a few localized populations have also become established in Colorado portions of the Colorado and San Juan sub-basins.

The lake chub is the most northern cyprinid in NA. Its native range extends from Alaska, where it is the only native minnow, across most of Canada and the northern United States to the Great Lakes and New England. In the UCRB, non-native populations are common in some portions of the upper Green River sub-basin in Wyoming and probably represent the same subspecies as populations in the southern-most extent of its native range in the upper Missouri River drainage —the plains lake chub. That subspecies, one of three, was formerly designated as *C. p. dissimilis* but that name was determined to be unavailable and awaits resolution (Scharpf 2005).

The northern and southern leatherside chubs are small, western desert fishes with very restricted native ranges. The northern leather side chub is native to drainages of the upper Snake River and Bear River in Nevada, Idaho, Wyoming, and Utah, whereas the southern leatherside chub is native to drainages along the southeastern margin of the Bonneville

Basin in Utah, including those of Utah Lake and the Sevier River (Scharpf 2005; UDWR 2009, 2010). The fish are considered rare non-natives in just a few adjacent drainages of the UCRB—northern leatherside chub in the upper Green River drainage of Wyoming and presumably the southern leatherside chub in the Price, Fremont, and, formerly, Strawberry river drainages of Utah, although UDWR (2009, 2010) declared the form in the latter drainages unknown. These fish were treated as one species, the leatherside chub, either *Gila copei* (subgenus *Snyderichthys*) or *Snyderichthys copei*, until recognized by Johnson et al. (2004) as two separate species in the former tribe of spinedaces, Plagopterini (Hubbs 1955). Based on molecular data and cranial shape, and despite the lack of a dorsal-fin spine (spinous modification of the first two rays), they assigned the fish to genus *Lepidomeda.*

The native range of brassy minnow is widespread across the Great Lakes, south central Canada, and north central United States, and includes northeastern Colorado where it is considered a threatened species (Scheurer et al. 2003a). It is unknown in and west of the Rocky Mountains except for presumably native, disjunct populations in the Fraser River Basin of British Columbia (Scharpf 2005) and a couple small, non-native populations in the Colorado River near, and probably between, De Beque and Grand Junction, Colorado, and Moab, Utah. Captures were reported in the upper Dolores River drainage in 1973 (Cabin Creek—Andrew Treble, Colorado Parks and Wildlife Aquatic Database Manager, personal communication 3/6/15), as early as the late 1970s in the Colorado River near De Beque (Snyder 1981, Tyus et al. 1982), and somewhat later as far downstream as Cataract Canyon below the Green River confluence (Valdez and Williams 1993). Although no documented collections have been reported in the UCRB since 1999 (Larval Fish Laboratory Collection; near Grand Junction), the species seemed to have been moderately well established and is presumed to still be present, at least in Colorado. Despite some distinction between Great Lakes and Missouri River forms (those in the UCRB being presumably the latter), no subspecies are currently recognized (Scheurer et al. 2003a).

The plains minnow is a very similar congeneric of the brassy minnow with an overlapping but more southern Great Plains native range (Scheurer et al. 2003a). It had been reported a few decades ago in the San Juan River inflow to Lake Powell (Tyus et al. 1982, Lentsch et al. 1996), but no captures have been recorded in the UCRB since then and the species is assumed to be no longer present.

Contents of This Guide and Prior Descriptions

This guide is modeled after and complements a similar, previously published, guide to catostomid fish larvae and early juveniles of the UCRB by Snyder and Muth (2004, expanded update of Snyder and Muth 1990). Together, they culminate three and a half decades of descriptive work by the Larval Fish Laboratory (LFL) on early life stages of cypriniform fishes in the basin, completing work begun with publication of Snyder (1981). Some sections of text herein have been replicated or modified from the catostomid guide, and most descriptive accounts and the associated computer-interactive key have been progressively built upon prior descriptions by Snyder (1981), Muth (1990), and Snyder et al. (2005) and the keys associated with the catostomid guide and Snyder et al. (2005).

All species in the UCRB are covered herein at the family level in a computer-interactive key and an appended pictorial guide modified from Wallus et al. (1990). Descriptions of the

larvae of most non-cypriniform species are included in guides by Auer (1982), Wallus et al. (1990), Wallus and Simon (2004, 2006), Simon and Wallus (2006, 2008), Wang and Reyes (2008), or Wang (2010). Some are covered also in other guides referenced above. Exceptions are the cutthroat trout which was described by Martinez (1983, 1984), Iowa darter described by Simon and Faber (1987), mountain whitefish illustrated by Snyder and Bjork (2011), northern plains killifish described by Koster (1948), and Paiute sculpin for which the larvae remain undescribed (but which are expected to be very similar to mottled sculpin).

Identification of larval and early juvenile fishes, or any organism, is largely a process of elimination, and the list of possible species can be immediately reduced by knowledge of what species are present in vicinity of the waters sampled. Although not necessarily definitive and likely to change somewhat over time, recent distributions compiled in Table 1 below and illustrated later in generalized species-account maps should be helpful in this regard. Knowledge of spawning seasons and reproductive guilds or behaviors can also help narrow the list of candidate species; brief accounts of such reproductive information also are included in the species accounts herein.

Snyder (1981), using a combination of original and suitable previously published illustrations, provided relatively complete species accounts (summaries of size-relative-to-developmental-state, morphometric, and meristic data, and at least lateral-view illustrations for all or most of eight developmental stages) for common carp, red shiner (then *Notropis lutrensis*), humpback chub, and Colorado pikeminnow (then Colorado squawfish); partial accounts of descriptive data and illustrations for Utah chub, roundtail chub, sand shiner, speckled dace, and redside shiner; and only partial to complete sets of illustrations for brassy minnow, fathead minnow, longnose dace, and creek chub. No larval or juvenile data or illustrations were available for bonytail, but adult meristic data was included in a summary table and used in a preliminary dichotomous key to metalarvae of UCRB cypriniform fishes in Colorado. The key remains useful for most covered cyprinids. At that time, neither golden shiner, an additional species covered herein, nor six of nine other cyprinids listed in Table 1 were recognized as present in Colorado portions of the UCRB.

Muth (1990), in a very comprehensive, comparative dissertation, provided a detailed descriptive account of bonytail with four three-view illustrations and substantially expanded upon Snyder's (1981) humpback chub and roundtail chub accounts with re-evaluated old data, much new data, and additional illustrations. For comparative purposes, he separately summarized wild and cultured humpback and roundtail chub data by population. His diagnostic criteria and dichotomous keys remain useful for the larvae and early juveniles of this most difficult complex of species.

Several Gila River Basin cyprinids covered by Snyder et al. (2005) are found also in the UCRB. The accounts for bonytail and roundtail chub were adapted from Muth (1990); for roundtail chub, data from separately tabulated sources were combined and supplemented with selected data from Snyder (1981) not included in Muth's account. Both accounts were supplemented with a limited amount of new data and the roundtail chub account with a new illustration, completing the set of eight developmental stages. Snyder's (1981) accounts, and available original data on which they were based, were similarly adapted for Colorado pikeminnow, speckled dace, common carp, red shiner, and fathead minnow. Because the latter was originally an illustrations-only account, it was supplemented with limited data from the 1981 guide's comparative summary tables and adjusted morphometric and myomere-count data from

Snyder et al. (1977). All of these accounts were also supplemented with limited sets of new data, including several morphological and a multitude of pigmentation characters. Also, both the speckled dace and red shiner accounts were made more complete with a new original illustration, and the fathead minnow account with another previously published drawing. Most of the summarized data was incorporated in the first known application of a computer-interactive key for cyprinid larvae.

Few other authors have described the larvae of native species covered in this guide. Among these were Winn and Miller (1954) who published the earliest comparisons of and key to larvae for native cypriniform fishes in the American southwest. Their descriptions, illustrated with lateral- and dorsal-view photographs, and key for the LCRB below Lake Mead include roundtail chub and speckled dace, but are limited to mesolarval stages (developmental intervals defined in a later section). Their photographs of roundtail chub were attributed to subspecies *intermedia*, which is now recognized as a separate species, the Gila chub, but tabulated data for the onset of selected developmental events in roundtail chub were based on both subspecies *robusta* and *intermedia.* Although Colorado pikeminnow larvae were not described or illustrated, the species was noted as similar to roundtail chub in their discussion and key. The early development of reared Colorado pikeminnow was first described in detail and nicely illustrated in a thesis by Seethaler (1978); two of his three-view drawings are reprinted herein. Feeney and Swift (2008) described and illustrated the mesolarvae through recently transformed juveniles of the Santa Ana subspecies of speckled dace from coastal southern California.

In contrast to the native cyprinids (all endemic to the CRB except speckled dace, which is widely distributed in western NA), most non-native cyprinids covered herein are more widely distributed in the United States, and Canada (and in the case of common carp, world-wide). As might be expected, the larvae of many of these non-native species have been more frequently described, compared, and included in other guides.

Prior descriptions, comparisons, or guides for larvae of all cyprinids in the UCRB are listed in Appendix II. Despite very good and detailed prior descriptions of larvae and early juveniles for some species, differences in the specific characters examined and methods for assessing and summarizing them made it difficult to directly compare much of the data among those descriptions and incorporate it in our own species accounts, comparative summaries, and key. Consequently, for completeness and comparability, even for otherwise well-described species, it was necessary to do our own detailed analyses of mostly regionally collected and (or) reared developmental series, and to include only that data in our guide, except for separately tabulated juvenile and adult meristics from the literature and other specifically noted data. For comparable measurements, counts and developmental states, our data generally match well with that in prior descriptions, but there are some notable discrepancies, probably due to differences in the specific populations (in some cases subspecies) examined. For example, the early larvae of longnose dace previously described from eastern United States populations are notably larger relative to developmental state than those described herein from Colorado populations.

Also, despite many fine illustrations in prior descriptions and guides, it was usually necessary for comparative purposes to prepare original three-view drawings for most larval and juvenile illustrations in our species accounts. Previously published drawings or photographs of specific developmental stages illustrated herein were often not available, consisted of only lateral views, or lacked sufficient detail. Exceptions for non-native species accounts herein include selected

illustrations reprinted or modified from Bragensky (1960, via Jones et al. 1978—juvenile common carp), Fuiman and Loos (1977—metalarval longnose dace), Snyder et al. (1977—protolarval, mesolarval, and metalarval fathead minnow and golden shiner), Buynak and Mohr (1979a—mesolarval and juvenile longnose dace), Buynak and Mohr (1979b—metalarval creek chub), Kranz et al. (1979—mesolarval and metalarval creek chub), and Faber (2006 onwards—mesolarval golden shiner).

As noted above, the nine non-native cyprinids not further included in this guide are generally rare in the UCRB, very restricted in distribution (Table 1), and unlikely to be encountered in most RP investigations. Some may have been bait-bucket releases or incidentally stocked with other species and might not endure as reproducing populations (e.g., the river and bigmouth shiners); one, the grass carp, has been released into the basin presumably only as sterile triploids. Except for the leatherside chubs, all have been at least minimally described by others (Appendix II).

A Combined Developmental Interval Terminology[1]

It is often convenient and desirable to divide the ontogeny of fish into specifically defined intervals. If the intervals selected are used by many biologists as a frame of reference, such division can facilitate communication and comparison of independent results. The largest intervals, periods (e.g., embryonic, larval, juvenile, and adult), are often subdivided into phases and sometimes into steps (Balon 1975b and 1984); the word "stage," although commonly used as a synonym for period or phase (e.g., Kendall et al. 1984), should be reserved for instantaneous states of development.

The larval phase terminologies most commonly used in recent years, particularly for descriptive purposes, are those defined by Hardy et al. (1978—yolk-sac larva, larva, prejuvenile; modified from Mansueti and Hardy 1967), Ahlstrom et al. (1976—preflexion, flexion, postflexion; expanded upon by Kendall et al. 1984), and Snyder (1976b and 1981—protolarva, mesolarva, metalarva). Definitions for all three terminologies were presented in a chapter on “Fish Eggs and Larvae” by Snyder (1983) in the first edition of *Fisheries Techniques* (Neilson and Johnson 1983), as well as in expanded updates of that chapter by Kelso and Rutherford (1996) and Kelso et al. (2013); the individual terms are also defined in the glossary for this guide (Appendix I). During a workshop on standardization of such terminologies, held as part of the Seventh Annual Larval Fish Conference (Colorado State University, January 16-19, 1983), it became obvious that these are not competing terminologies, as they often are treated, but rather complementary options with subdivisions or phases defined for different purposes (Snyder and Holt 1984). As such, it is possible to utilize all three terminologies simultaneously to: (1) facilitate comparative descriptions and preparation of keys based on fish in similar states of development with respect to morphogenesis of finfold and fins; (2) segregate, for fishes with homocercal tails, morphometric data based on standard length measured to the end of the notochord prior to and during notochord flexion from those measured to the posterior margin of the hypural plates following notochord flexion; and (3)

[1] Reprinted with minor modifications from Snyder and Muth (2004) and Snyder et al. (2005), as previously modified from Snyder and Muth (1988, 1990).

Combined Developmental Interval Terminology

Larva: Period of fish development between hatching or birth and (1) acquisition of adult complement of fin spines and rays (principal and rudimentary) in all fins, and (2) loss beyond recognition of all finfold not retained by the adult.

Protolarva: Phase of larval development characterized by absence of dorsal-, anal-, and caudal-fin spines and rays. (Standard length measured to end of notochord.)

Mesolarva: Phase of larval development characterized by presence of at least one dorsal, anal, or caudal-fin spine or ray but either lacking the adult complement of principal soft rays in at least one median (dorsal, anal, or caudal) fin or lacking pelvic-fin buds or pelvic fins (if present in adult). (Standard length measured to end of notochord or, when sufficiently developed, axial skeleton.)

Preflexion Mesolarva: Among fishes with homocercal tails, subphase of mesolarval development characterized by absence of caudal-fin rays. (Posterior portion of notochord remains essentially straight and standard length measured to end of notochord. When first median-fin ray is a caudal ray, as in most fishes, larva progresses directly from protolarva to flexion mesolarva.)

Flexion Mesolarva: Among fishes with homocercal tails, subphase of mesolarval development characterized by an incomplete adult complement of principal caudal-fin rays. (Posterior portion of notochord flexes upward and standard length measured to end of notochord.)

Postflexion Mesolarva: Among fishes with homocercal tails, subphase of mesolarval development characterized by adult complement of principal caudal-fin rays. (Notochord flexion essentially complete and standard length measured to posterior-most margin of hypural elements or plates.)

Metalarva: Phase of larval development characterized by presence of (1) adult complement of principal soft rays in all median fins and (2) pelvic-fin buds or pelvic fins (if present in adult). (Standard length measured to posterior end of axial skeleton, hypural elements or plates in fishes with homocercal tails.)

Juvenile: Period of fish development from the larval period to the adult period which begins with the attainment of sexual maturity.

Yolk-sac, Yolk-bearing, With Yolk, Without Yolk: Examples of modifiers used with any of the above period or phase designations to indicate presence or absence of yolk material, including oil globules.

approximate transition from at least partially endogenous nutrition (utilization of yolk material) to fully exogenous nutrition (dependence on ingested food) based on presence or absence of yolk material.

The combined terminology presented above and utilized herein effectively integrates principal subdivisions and functions of the three component terminologies. In doing so, Ahlstrom's "preflexion-flexion-postflexion" terminology is treated, for fishes with homocercal tails, as a subset of Snyder's mesolarva phase. Because notochord flexion in the caudal region usually begins when the first caudal-fin rays appear and is essentially complete when all principal caudal-fin rays are well defined, and because presence of fin rays can be more precisely observed than the beginning or end of actual notochord flexion, fin rays are used as transition criteria. As a result, all protolarvae are preflexion larvae, and all metalarvae are postflexion larvae. Although most fish pass sequentially through at least the major phase subdivisions designated (as illustrated later in species accounts under Results and Discussion), some pass pertinent points of transition prior to hatching or birth and begin the larval period in a later phase or possibly skip the period entirely.

The definition for the end of the larval period is necessarily a compromise deleting all requirements (some taxon-specific, others difficult to determine precisely) except acquisition of the full complement of fin spines and rays in all fins and loss of all finfold (last remnants usually part of the preanal finfold). Provision for taxon-specific prejuvenile (or transitional) phases are also deleted. In some cases, finfold persists through the endpoint for such special intervals, which are then effectively included in the larval period.

Timing of complete yolk absorption varies from well before notochord flexion and initial fin ray formation, as in most fishes with pelagic larvae, to postflexion stages after all or most of the fin rays are formed, as in many salmonids. Accordingly, the interval during which fish larvae bear yolk should not be represented generally as a separate phase preceding phases based on fin formation as it has been treated by Kendall et al. (1984). The Hardy et al. terminology effectively distinguishes between larvae with and without yolk by modifying the period name with the adjective "yolk-sac" when yolk material is present. Any period or phase name of the combined terminology can be similarly modified to indicate presence or absence of yolk material (e.g., yolk-bearing larva, yolk-sac metalarva, postflexion mesolarva with yolk, protolarva without yolk).

The combined terminology is designed to be relatively simple but comprehensive, precise in its transition criteria, applicable to nearly all teleost fishes, and flexible. It can be utilized in part (essentially as one of its component terminologies) or its entirety depending on purposes of the user. For example, if it is necessary to acknowledge only that the fish is a larva and whether it bears yolk, the terms "yolk-sac larva" and "larva without yolk" are all that is needed. Biologists who formerly utilized one of its component terminologies should have no difficulty in adapting to the combined terminology because the essential features and terms of the original terminologies have been retained.

Characteristics Useful in Identification of Cypriniform Fish Larvae[2]

Fishes of the families Cyprinidae (minnows and carps) and Catostomidae (suckers), order Cypriniformes, are closely related and morphologically similar. As noted earlier, together the two families account for nearly half (46%) of the 68 species currently in the UCRB. Generalizations in the following discussion with respect to the order Cypriniformes refer specifically to North American species in these families. Figures 2 and 3 identify the more obvious morphological features and structures of cypriniform eggs and larvae; most are also defined in the glossary (Appendix I).

Identification of fish larvae is in part a process of elimination. Even before examination of a single specimen, the number of candidate species can be substantially reduced by a list of known or likely species based on adult captures in the study area or connected waters. However, there are cases in which the presence of certain species was first

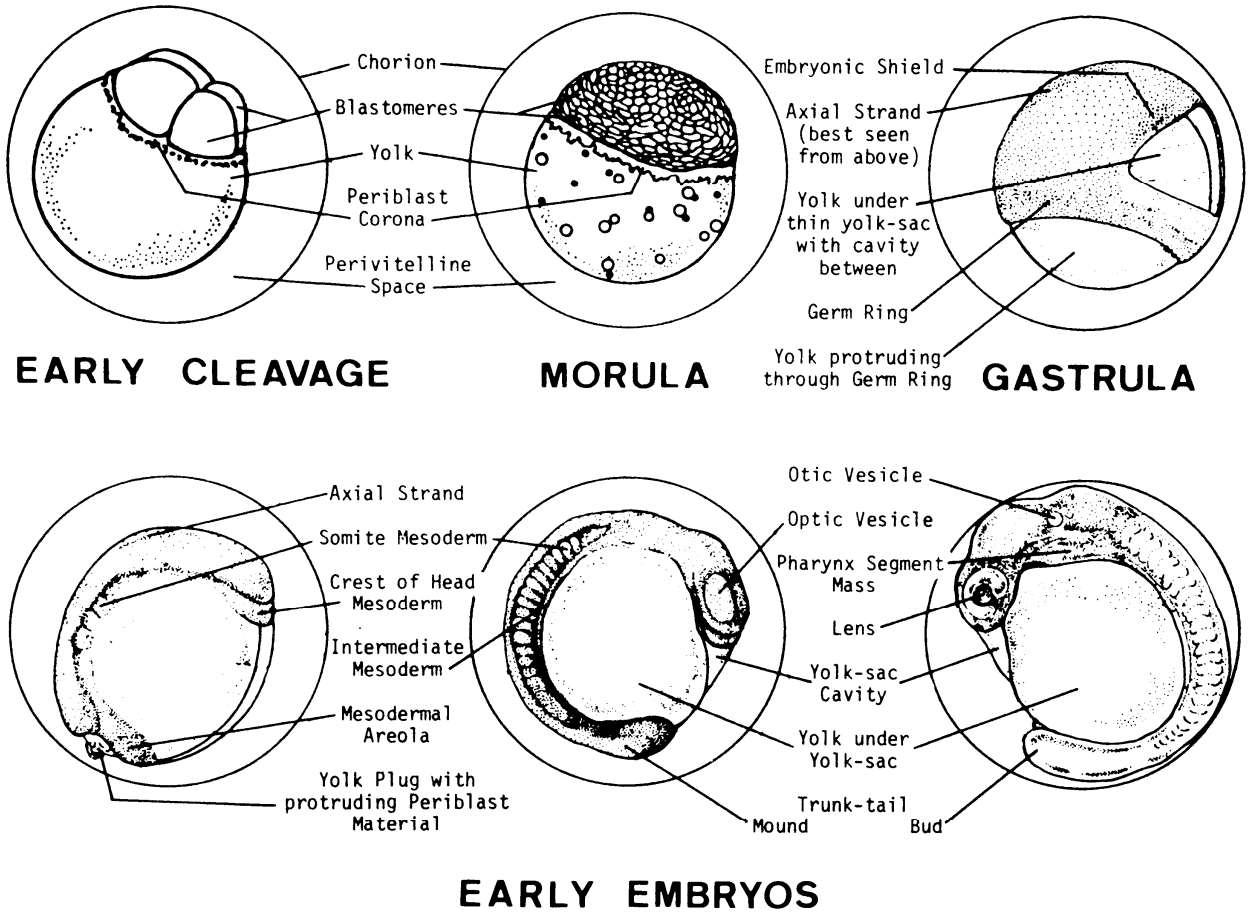

Figure 2. Selected anatomical features of cypriniform fish eggs and embryos (from Snyder 1981; based on drawings from Long and Ballard 1976).

[2] Progressively modified from Snyder (1981), Snyder and Muth (1988, 1990, and 2004), and Snyder et al. (2005).

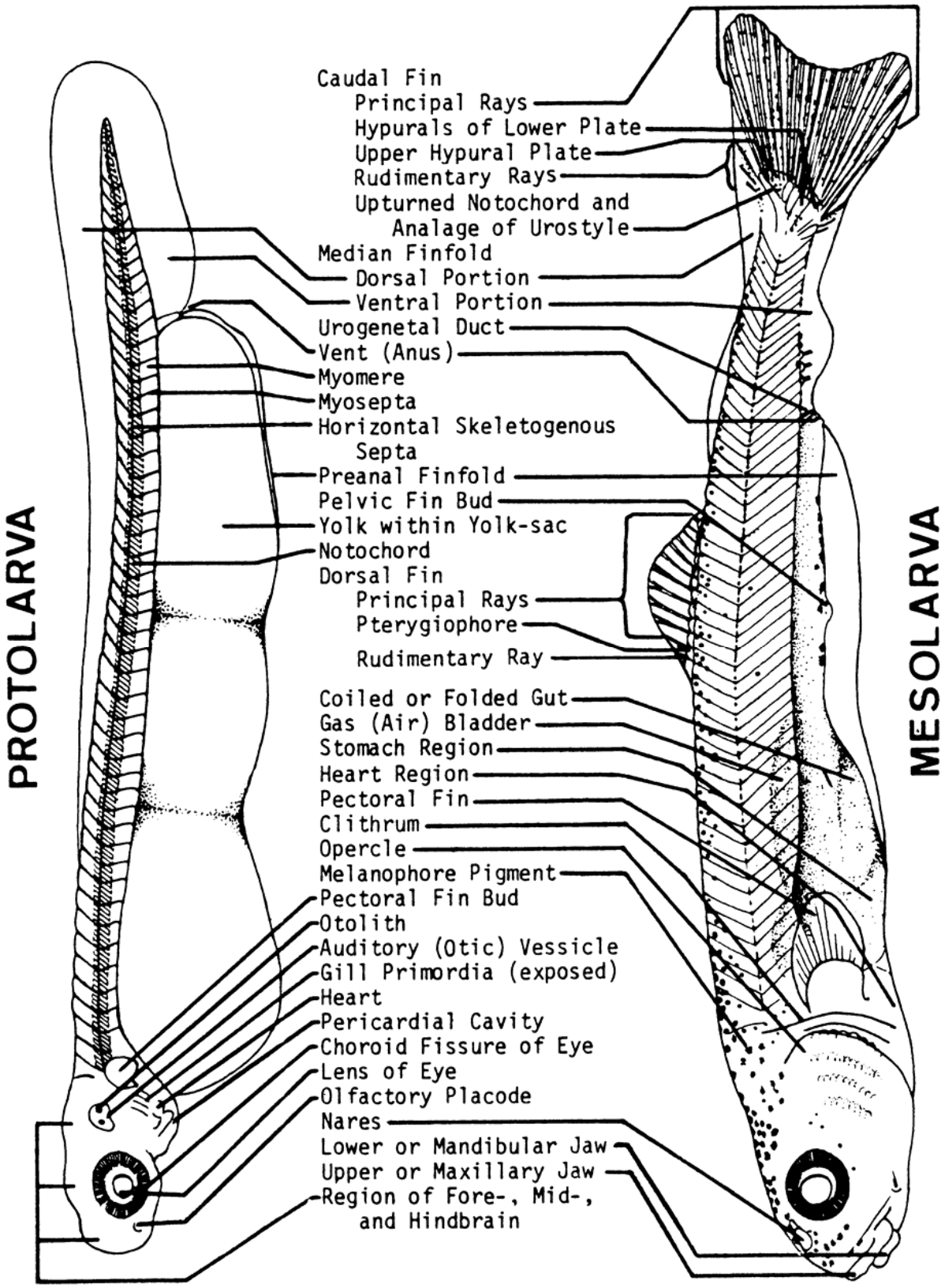

Figure 3. Selected anatomical features of cypriniform fish larvae (from Snyder 1981).

documented by collection and identification of larvae. Incidental transport of eggs or larvae from far upstream or distant tributaries also must be considered. Knowledge of spawning seasons, temperatures, habitats, and behavior coupled with information on egg deposition, larval nursery grounds, and larval behavior are also useful in limiting possibilities.

Berry and Richards (1973) noted that "although species of a genus may vary from one geographical area to another, generally the larval forms of closely related species look alike. At the same time, larvae of distantly related forms may be closely similar in gross appearance." Cypriniform larvae as a group are distinctive and generally easy to distinguish from larvae of other families. Beginning workers should become familiar with the general larval characteristics of each family likely to be encountered. The guides and keys listed by Kelso et al. (2013) and discussed earlier in this introduction are most useful in this respect. Auer (1982) is particularly recommended since the guide covers most families and many non-native species in the UCRB. Also recommended are discussions of taxonomic characters by Berry and Richards (1973) and Kendall et al. (1984) and the pictorial guides to families in Holland-Bartels et al. (1990) and Wallus et al. (1990; also subsequent guides in the Ohio River drainage series by Kay et al. 1994, Simon and Wallus 2004 and 2006, and Wallus and Simon 2006 and 2008). An adaptation of the latter pictorial guide to families is appended to this guide.

In the Upper Colorado River System, cypriniform larvae are readily distinguished as either cyprinids or catostomids. But elsewhere, if members of the cyprinid subfamily Cyprininae (carps) and the catostomid subfamily Ictiobinae (carpsuckers and buffalofishes) or tribe Erimyzontini (chubsuckers) are present, identification at the family level can be more difficult.

Within their respective families, and especially at the subfamily level, cypriniform larvae are very homogeneous in gross structure and appearance. Accordingly, they may be especially difficult to discriminate at genus or species levels. This is particularly true for catostomids and within genera of cyprinids (e.g., *Gila* and *Rhinichthys*) in the CRB. For the catostomids, specific identification of larvae relies on size at which certain developmental events occur, form of the gut, melanistic (brown or black) pigment patterns, osteological characters, and to a limited extent, morphometrics and meristics (especially dorsal-fin-ray counts for metalarvae and juveniles) (Snyder and Muth 2004, Snyder et al. 2005). Likewise for the cyprinids, but morphometrics and meristics are generally more useful and internal osteological characters less so for lack of comparative study.

There is often a noticeable amount of intra- as well as inter-regional variability in many of the characters to be discussed. This variability necessitates confirmation of identity based on as many diagnostic characters as possible.

Myomeres

Because they are obvious morphological features and relatively consistent in number and position, myomeres are one of the most useful characters available for identification of larvae above (and sometimes at) the species level, especially for protolarvae and mesolarvae. They begin as part of the embryonic somites and are usually formed in their full complement prior to hatching. Throughout the protolarval and much of the mesolarval phase, myomeres are chevron-shaped, but by the metalarval phase they evolve to their typical three-angled adult form. Fish (1932) and many subsequent authors observed that there is a nearly direct, one-to-one correlation between total myomeres and total vertebrae (including Weberian ossicles in cypriniforms). Fuiman (1982)

further documented this correspondence in teleosts with total myomere counts one greater than total vertebrae, but rather than defining all myomeres to be bounded anteriorly and posteriorly by myosepta (as treated herein), he considered the first myomere to precede the first myoseptum and the last, a urostylar segment corresponding the final or hypural vertebra centra, to follow the most posterior myoseptum. As noted by Fuiman, except for these first and last segments, the posterior half of one vertebra and the anterior half of the next develop within each myomere (with neural and hemal arches of the vertebrae forming in the myosepta between them), thereby accounting for one more myomere than vertebrae in his counts, and one less if segments before the first and after the last at least partial myosepta are not counted as myomeres. Snyder (1979) and Conner et al. (1980) summarized myomere and vertebral counts for many cypriniform fishes.

The most anterior and most posterior myosepta and therefore myomeres are frequently difficult to distinguish and probably account for at least some myomere count discrepancies in the literature. The most posterior myomere is defined herein, and by most authors, as lying anterior to the most posterior complete myoseptum. Siefert (1969) describes a "false (partial) myoseptum" posterior to the last complete myoseptum which adds to the difficulty of discerning the last myomere. The most anterior myomeres in cypriniform fishes are apparent only or mostly in the epaxial or dorsal half of the body, the first often being deltoid in shape and immediately behind the occiput. This first myomere, bounded anteriorly by what might be considered only a partial or epaxial myoseptum, might effectively correspond to the first myomere as defined by Fuiman (1982), and if so, would result in the same number of total myomeres as vertebrae (as most often recorded herein) rather than the expected one less. Early in the larval period, myomeres are most readily observed using transmitted light. Polarizing filters, depending on thickness and certain other qualities of the preserved tissues, can dramatically increase contrast between the muscle tissue of myomeres and the myosepta that separate them. Myomeres of some metalarvae and most juveniles are difficult to observe, even with polarizing filters; reflected light at a low angle from one side and higher magnification sometimes facilitates observation.

Typical counts used in taxonomic work include total, preanal, and postanal myomeres. Partial counts are frequently used to also reference the location of structures other than the vent or anus. The most generally accepted method of making partial counts was described by Siefert (1969) for distinguishing preanal and postanal myomeres: "postanal myomeres include all [entire] myomeres posterior to an imaginary vertical line drawn through the body at the posterior end of the anus . . . . Remaining myomeres, including those bisected by the line, are considered preanal." The technique is equally applicable with other structures or points of reference such as origins of fins or finfolds. The opposite approach was used by Snyder et al. (1977), Snyder and Douglas (1978), Loos and Fuiman (1977) and, according to the latter, Fish (1932)—only entire myomeres were included in counts anterior to points of reference. Siefert's method is recommended as standard procedure because resulting counts are expected to more nearly approximate the number of vertebrae to the referenced structures.

In the United States and Canada, the range of total myomere (and vertebral) counts for cyprinids, 28 to 52, is slightly larger and nearly includes that for catostomids, 32 to 53. Ranges for preanal and postanal myomere counts also overlap with 19 to 35 and 9 to 22, respectively, for cyprinids and 25 to 42 and 5 (possibly 3) to 14, respectively, for catostomids. For cypriniform fishes in the UCRB, the degree of overlap in total and preanal myomere counts is smaller and larvae with fewer than 42 total or

32 preanal myomeres can only be cyprinids. Despite the magnitude of overlap in these ranges, proportions of postanal to preanal and preanal to total myomeres will distinguish most cyprinids from catostomids (Snyder 1979). The postanal to preanal myomere proportion is at least 2/5 (often greater than 1/2) for cyprinids (exclusive of subfamily Cyprininae, the carps) and less (often less than 1/3) for catostomids. Also, the proportion of preanal to total myomeres is 5/7 or less (often less than 2/3) for cyprinids and greater (often greater than 3/4) for catostomids.

Fins and finfolds

Fin-ray meristics and fin positions are among the most useful characters for later mesolarvae and metalarvae, especially among the cyprinids. These data can be determined from older juveniles and adults or gleaned from published descriptions of adults. Also, the origin (anterior-most insertion) of finfolds, the sequence and timing of fin development (e.g., size at initial and final ray formation), fin lengths, and basal lengths of the dorsal and anal fins may be useful in the diagnosis of some larvae.

The median finfold, one of the most obvious structures in protolarvae and mesolarvae, is a thin, erect, medial fold of tissue that originates on the dorsal surface, usually well behind the head. It extends posteriorly to and around the end of the notochord, then anteriorly along the ventral surface to the posterior margin of the vent. During the mesolarval phase, the soft-rayed portions of the median fins (dorsal, anal, and caudal) differentiate from this finfold. As the median fins develop, the finfold diminishes and recedes before and between the fins until it is no longer apparent during or near the end of the metalarval phase.

The preanal finfold is a second median fold of tissue that extends forward from the vent. In cypriniform and most other fishes the preanal finfold is completely separated from the ventral portion of the median finfold by the vent. But in burbot *Lota lota*, and its marine relatives (Gadidae, codfishes), the preanal finfold is initially continuous with the median finfold and only later are the finfolds entirely separated by the vent (vent initially opens through right side of finfold). The preanal finfold may or may not be present upon hatching, depending upon size and shape of the yolk sac. In cypriniform fishes, it is typically absent or barely apparent upon hatching. As yolk is consumed and the yolk sac decreases in size prior to hatching or during the protolarval phase, a small preanal finfold appears just anterior to the vent. As more yolk is consumed and the larva grows, the preanal finfold enlarges and extends anteriorly. Ultimately, its origin lies anterior to that of the dorsal portion of the median finfold. The preanal finfold remains prominent throughout the mesolarval phase, then slowly diminishes and recedes in a posterior direction during the metalarval phase. It is typically the last finfold to be absorbed or lost.

The caudal fin is the first fin to differentiate from the median finfold in cypriniform and most other fishes with homocercal tails. The portion of the finfold involved first thickens along the ventral side of the posterior end of the notochord and begins to differentiate into the hypural elements of the caudal skeleton. Immediately thereafter, the first caudal-fin rays appear (beginning of flexion mesolarval phase) and the posterior portion of the notochord begins to bend or flex upward. Be careful not to confuse striations or folds in the finfold with developing fin rays. As the fin develops and the notochord continues to flex upward, the hypurals and developing caudal-fin rays, all ventral to the notochord, move to a posterior or terminal position. The first principal rays are medial and subsequent principal rays form progressively above and below. Principal caudal-fin rays

articulate with hypural bones of the caudal structure and ultimately include all branched rays plus two adjacent unbranched rays, one above and one below the branched rays. Branching and segmentation of rays can be observed as or shortly after the full complement of principal rays becomes evident and notochord flexion is completed (beginning of postflexion mesolarval phase).

The number of principal caudal-fin rays is typically very stable within major groupings of fish. Cyprinids generally have 19 principal rays (ten based on superior hypurals or hypural plate and nine on inferior hypurals or hypural plate), and catostomids usually have 18 principal rays (nine and nine respectively).

Dorsal and ventral rudimentary rays of the caudal fin (shorter unbranched rays anterior to the outermost principal rays which also remain unbranched in later stages) begin forming sequentially in an anterior direction immediately after all or nearly all principal caudal-fin rays are formed. Rudimentary caudal-fin rays are among the last groups of fin rays to form their full adult complement (others being the rays of the pectoral and pelvic fins, for which rudimentary rays, respectively, are not distinguished in counts or do not exist) and their full acquisition defines the end of the larva period for some species. Accordingly, counts of rudimentary caudal-fin rays are usually ignored in larval fish identification, but they may be of diagnostic value for juveniles and adults.

The dorsal and anal fins, which typically form either simultaneously (many cyprinids) or dorsal first (most catostomids), usually begin development prior to attainment of the full complement of principal caudal-fin rays. Tissue first thickens in vicinity of the future fin, after which pterygiophores, the skeletal supports of fin rays, gradually become evident. The latter structures, each ultimately supporting with a single principal ray, permit limited diagnostic use of dorsal and anal fin position and meristics about midway through the mesolarval phase before all the rays are formed. Anterior principal fin rays develop first and subsequent rays are added in a posterior direction. The first or most anterior principal ray in both fins remains unbranched while all other principal fin rays branch distally after ray segmentation becomes evident. However, the last or most posterior principal ray in the dorsal and anal fins of cypriniform fishes also branches at the base and consists of two elements that appear to be separate rays but are counted as one. Those branches actually form on the last pterygiophore as separate, but closely spaced, elements and later merge or fuse at their proximal, articulating ends. The anterior element forms first and, for purposes of defining transition to the metalarva phase, the full complement of rays in these fins is not considered complete until both elements of the last ray are evident. The first rudimentary ray (shorter unbranched rays anterior to the principal rays) in these fins frequently forms before the most posterior principal rays. If more than one, rudimentary fin rays are subsequently added in an anterior direction.

Principal dorsal- and anal-fin ray counts between and within certain genera often vary sufficiently to be of use in identification at the species level, especially anal-fin rays for cyprinids and dorsal-fin rays for catostomids. Positions of dorsal-fin origin (anterior end of attachment) and insertion (posterior end of attachment) relative to origin of pelvic fins or fin buds and the vent vary considerably among cyprinids and are useful in identification of genera or species. These fin-position characters are more consistent among catostomids (e.g., dorsal-fin origin is always well in advance of the pelvic fins), especially at subfamily level, and therefore, are of less value in identification for that family.

The pelvic fins begin as buds before or upon transition to the metalarval phase. In cypriniform fishes, they originate in an

abdominal position along each side of the preanal finfold. They may erupt shortly after dorsal and anal fin development begins or be delayed until just before or shortly after all principal rays are present in the median fins. Pelvic rays begin to form shortly after the buds appear and the adult complement of rays quickly ensues. Among cypriniform fishes, pelvic-ray counts are seldom used diagnostically. However, position of the pelvic fins or fin buds, relative to other structures (e.g., the dorsal fin as discussed above), and their formation in the sequence of developmental events can be useful in identification, especially among cyprinids.

The pectoral fins typically begin as buds immediately behind the head in the late embryo. However, pectoral buds are not evident in some cypriniform fishes until shortly after hatching. Though strongly striated and occasionally with membranous folds and breaks, they typically remain rayless in cypriniforms until late in the mesolarval phase after most of the principal median-fin rays are present. The pectoral fins, pelvic fins, or rudimentary portions of the caudal fin are often the last fins (or portions thereof) to form their full complement of rays, marking the end of the larval period for some species. For this reason and because the number of pectoral rays is usually relatively large and difficult to count without excision (especially the smaller ventral rays), pectoral-fin-ray counts are generally of little value in larval fish identification.

Other countable structures

Other structures that may be treated meristically (and in some cases morphologically) include branchiostegals, gill rakers, pharyngeal teeth, and scales. Branchiostegals form early in larval development, but counts are usually constant within major taxon groups. Within the order Cypriniformes, all members of superfamily Cyprinoidea, which includes Cyprinidae and Catostomidae, have three branchiostegals (McAllister 1968). Due to later development, small size or internal location, the other characters are seldom used to diagnose fish larvae. Gill rakers form gradually in postflexion mesolarvae or metalarvae with numbers increasing throughout much of the early portion of the juvenile period. The adult complement of gill rakers on the first gill arch is not achieved in many Catostominae until they reach about 70 mm standard length (Smith 1966). Although he didn't mention a minimum size, Muth (1990) found gill raker counts essentially complete and diagnostically useful for distinguishing young-of-the-year juvenile bonytail from humpback chub and roundtail chub. Pharyngeal teeth form relatively early but may not be sufficiently well developed to be readily removed and observed until late in the larval period or early in the juvenile period. Detailed study of gill rakers and pharyngeal teeth might reveal some useful diagnostic qualities, including size, shape, and number. However, most specimens are more easily identified using external characters. Scales typically become apparent late in the larval period or early in the juvenile period. First scales on cypriniforms typically appear midlaterally on the posterior half of the body and from there spread anteriorly, dorsally, and ventrally toward adult coverage. Scales of large-scaled species are sometimes sufficiently obvious by late in the metalarval phase to distinguish certain species or genera.

Morphology

The shape or form of larvae and specific anatomical structures (e.g., gut, air bladder, yolk sac, and mouth) changes as fish grow and provides some of the most obvious characters for identification, particularly at family and subfamily levels. Within genera, morphological differences among species are usually much more subtle, but may still be of

diagnostic value. Much shape or form-related information can be quantified via proportional measurements or morphometrics.

Morphometric data emphasize the relative position and relative size of various body components and dimensions and may be critical to species identification. Such measurements may be allometric, changing in proportion as the fish grow; thus morphometric data should be related to size, at least for protolarvae and mesolarvae. Referencing Bookstein et al. (1985), Fuiman and Corazza (1979), Humphries et al. (1981), and Strauss and Bookstein (1982), among others, Muth (1990) briefly reviewed and discussed the problem of allometry and alternatives for presenting and analyzing morphometric and shape-related data. Some morphometric data, particularly body depths and widths, may be directly affected by the condition of individual specimens and volume and form of food items in their digestive tracts. The source of specimens and the preservative in which they are stored also may affect morphometric data. Some measures in wild fish may differ from those of laboratory-reared specimens (e.g., fin lengths). Shrinkage and deformation are notably greater for fish preserved in alcohol than in formalin solutions (see Kelso et al. 2013 for the latest recommendations regarding fixation and preservation of fish larvae).

Morphometric data in this guide are reported as percentages of standard length (% SL). Use of standard length (SL) avoids the allometric influence of caudal fin growth included in percentages based on total length (TL). As explained later (Methods), if TL is included as % SL, other individual specimen and mean data recorded as % SL (but generally not summarized ranges) can be easily converted to % TL, and vice versa, for comparison with other works. Prior to hypural plate formation and completion of notochord flexion (protolarvae and flexion mesolarvae), SL is the length from snout to posterior end of the notochord (notochord length). Thereafter, SL is measured from the anterior margin of the snout to the most posterior margin of the hypural plates (usually the superior plate or hypurals). Use of notochord length for protolarvae and early mesolarvae gives the appearance of greater allometric growth differences than may really exist, at least in comparison with subsequent measures based on the posterior margin of the hypural plates. This undesirable effect is a result of upward bending or flexing of the notochord and the switch from use of end of the notochord to posterior margin of the hypurals as the basis for length measurement. These factors must be taken into account when reviewing morphometric data herein.

In contrast to procedures recommended by Hubbs and Lagler (1958) for larger juveniles and adults, measurements of body length and various parts thereof for fish larvae are generally taken along lines parallel to the horizontal axis of the fish. Exceptions are fin lengths which, in studies conducted for this manual, were measured from origin of the fin base to most distal margin of the fin rays. Typical measures include total, standard, head, snout, eye, and fin lengths, as well as snout-to-vent and snout-to-origin-of-fin (dorsal, anal, and pelvic) lengths.

Snout-to-vent length is measured to the posterior margin of the vent or anus. It is a primary diagnostic character for many species, especially at the family and sometimes subfamily level. In the Upper Colorado River System, most cyprinid larvae are readily differentiated from catostomid larvae by snout-to-vent lengths less than 72% SL. Exceptions are most larvae of common carp and occasionally mesolarvae of Colorado pikeminnow. The term "preanal length" is often applied to this measure but might be misinterpreted as length to origin of the anal fin. For many fishes, including cypriniforms, the latter measure is approximately the same as

snout-to-vent length because the anal fin begins at or near the posterior margin of the vent.

Head length is typically measured to the posterior margin of the operculum in juveniles and adults, but the operculum may be absent or incomplete throughout much of the larval period. Accordingly, many biologists have redefined head length for larvae to be measured to the posterior end of the auditory vesicle or the anterior or posterior margin of the cleithrum, one of the first bones to ossify in fish larvae (Berry and Richards 1973). Unfortunately, the auditory vesicle and cleithrum are not always easy to discern, especially in postflexion mesolarvae and metalarvae. Also, resultant measures to the auditory vesicle are considerably anterior to the eventual posterior margin of the operculum. Snyder et al. (1977) and Snyder and Douglas (1978) measured larval head length to origin (anterior attachment) of the pectoral fin. This measure has distinct advantages over the alternatives: the base of the pectoral fin is readily observed throughout the larval period (except in the few species that hatch prior to pectoral bud formation), it approximates the position of the cleithrum (part of its supporting structure), and it more closely approximates the posterior margin of the operculum than does the posterior margin of the auditory vesicle. Accordingly, we recommend this definition of head length and have used it in all our descriptive work. For purposes of consistency, we apply it to juveniles as well as larvae. The measure is most precisely determined while examining the specimen from above or below and, if necessary, while holding the fin away from the body.

Body depths and widths are measured in planes perpendicular to the horizontal axis of the fish. Many biologists report these as maximum or minimum measures (e.g., greatest-head depth, greatest-body depth, and least-caudal-peduncle depth). However, for comparative purposes, it seems more logical to specify standard reference points for such measures as was done by Moser and Ahlstrom (1970), Fuiman (1979), and Snyder and Douglas (1978). Five specific locations, four corresponding to specific length measurements, are used herein: (1) immediately posterior to eyes, (2) origin of pectoral fin, (3) origin of dorsal fin, (4) immediately posterior to vent, and (5) at anterior margin of most posterior myomere (along the horizontal myosepta). If desired, a reference point in larvae prior to formation of the referenced structure (e.g., origin of dorsal fin for protolarvae and flexion mesolarvae herein) can be approximated to its position in later stages. Neither fins nor finfolds are included in depth measurements herein. As mentioned earlier, care must be used in evaluation of depth and width measures affected by body condition and gut contents (e.g., measures at the origin of the dorsal fin).

Other morphological characters such as position, size, and form of the mouth and gut, and related changes, can be among the more useful characters for identification at the species level. Size of the mouth, as well as its position, its angle of inclination, and the form of specific mouth structures are diagnostic for some cypriniforms, especially in metalarvae. Timing of mouth migration from terminal to inferior position can be especially useful for catostomid metalarvae. Gut-loop length, timing of loop formation, and eventual degree and form of gut loops, folds, or coils can be diagnostic for the larvae of many fishes. Such gut characters are useful in identifying postflexion mesolarvae, metalarvae, and early juveniles of catostomids and certain cyprinids that have long, coiled or well-folded guts as later juveniles and adults, and especially in distinguishing these from most other cyprinids which develop shorter guts that are folded back or looped just once in a flattened S-shape (gut phase 3, Figure 5 below in Methods).

Pigmentation

Basic patterns of chromatophore distribution, and changes in these patterns as fish grow are often characteristic at the species level. Used with caution, preferably in combination with other characters, and with an awareness of both intra- and inter-regional variation, chromatophore distribution and patterns for many fishes are among the most useful characters available for identification. However, in some instances, differences are so subtle or variation so great that use of pigmentation is impractical and may be misleading.

In cypriniform and most other fishes, chromatophores other than melanophores have not been sufficiently studied for identification purposes. Such chromatophores are typically neither as numerous nor as obvious as melanophores and their pigments are difficult to preserve. In contrast, melanin, the amino acid breakdown product responsible for the dark, typically black, appearance of melanophores (Lagler et al. 1962), remains relatively stable in preserved specimens. However, melanin is subject to fading and bleaching if specimens are stored or studied extensively in bright light for long periods of time, stored in alkaline preservatives, or subjected to changing concentrations of preservative fluids. To minimize the latter effects, as well as shrinkage and deformation, dilute formalin solutions (3–5%, unbuffered or buffered to near neutral) are strongly recommended over alcohol solutions as storage media for specimens fixed in formalin (5% to, preferably, 10%). Most of the following discussion refers to chromatophores in general, but in this manual and others for freshwater species in North America, pigmentation typically refers to that of melanophores.

According to Orton (1953), pigment cells originate in the neural crest region (dorsal portion of body and tail) and migrate in amoeboid fashion in waves to their eventual position. The first wave of chromatophores occurs late in the embryonic period or early in the larval period and establishes a relatively fixed basic or primary pattern of chromatophore distribution. In a few species (mostly marine), such cells acquire pigment prior to chromatophore migration and the actual migration can be observed and documented. But in cypriniform and most other freshwater fishes, pigment is not typically present in chromatophores until after the cells reach their ultimate destination.

For a specific species and developmental stage, pigmental variation in general or specific areas is largely a function of the number of chromatophores exhibiting pigment rather than differences in chromatophore distribution. Chromatophores without pigment cannot contribute to the visible pigmentation pattern. In addition, pigment in chromatophores can be variously displayed from tight, contracted spots, resulting in a relatively light appearance, to widely expanded, reticular networks, resulting in a dark or more strongly pigmented appearance. Differences in environmental conditions and food can significantly affect the presence and displayed form of pigmentation. Accordingly, researchers must be aware that pigmentation of cultured specimens can appear quite different from that of field-collected material.

Pigmentation often changes considerably as larvae and early juveniles grow. Most of the change is due to increased numbers and distribution of chromatophores. Observable pigmentation might also be lost from certain areas through loss of pigment in chromatophores, loss of chromatophores themselves, or, in the case of subsurface or internal chromatophores, by growth and increased opacity of overlying tissues. Peritoneal melanophore pigmentation is an obvious character for later stages of some larvae, but in late metalarvae and especially juveniles, dark peritoneal pigmentation can be obscured by overlying muscle or membranes

with silvery iridophores (this silvery pigment often dissipates over time in formalin preservative, but is usually retained in alcohol). If internal melanophore pigmentation is obscured by overlying tissues, it can be observed by selective dissection or careful clearing of specimens.

Osteology

When externally visible characters fail to segregate species conclusively, osteological characters may come to the rescue. Although whole-specimen clearing and cartilage- and bone-staining techniques are relatively simple (see Methods in Snyder and Muth 1988, 1990, or 2004), they require much time (a few days, mostly waiting) and a fair amount of attention (monitoring progress and changing fluids). Soft (longwave) X-ray techniques (Tucker and Laroche 1984) may be faster and easier, especially when examining many specimens, but they require appropriate X-ray equipment and a darkroom.

Dunn (1983, 1984) reviewed use of skeletal structures and the utility of developmental osteology in taxonomic studies. Among the first bones to ossify are those associated with feeding, respiration, and orientation (e.g., jaws, bones of the branchial region, cleithrum, and otoliths). The axial skeleton follows with formation of vertebrae and associated bones. Once the axial skeleton is sufficiently established, median- and pelvic-fin supports form, and fins develop. Presence, number, position, and shape of certain bones can have diagnostic value, even among some closely related species. Although use of osteological characters for identification of fish larvae has received little attention, it has great potential value, particularly for confirmation of questionable identities and distinguishing species for which external characters are diagnostically inadequate. For example, Muth and Snyder (1990 and 2004) found selected osteological characters useful in the identification of late larval and early juvenile catostomids in the UCRB. However, aside from externally visible structures and in some cases, vertebra and fin ray counts based on cleared and stained specimens, skeletal characters were not included in developmental studies of UCRB cyprinids for this guide.

METHODS

Specimens Examined

Using both prior (usually re-examined) and new descriptive data and illustrations, the larval and juvenile descriptions herein for all but one species are based on both positively identified wild (field-collected) and cultured specimens (at least protolarvae). The exception is the description of bonytail which is based only on reared specimens.

Most of the specimens studied and illustrated for Snyder (1981) were collected in Colorado during 1976 through 1979 from the Yampa River west of Milner to the Lily Park area below Cross Mountain Canyon, White River between Rio Blanco Lake and Spring Creek, Colorado River between Palisade and the Utah border, and Gunnison River between Whitewater and Redlands Dam (Carlson et al. 1979, Prewitt et al. 1978, Wick et al. 1979, and Wick et al. 1981). Unrecognized larval specimens were originally segregated into like groups. Continua were then established with identifiable juveniles. Once distinguishing characters were determined for the various species, most larvae and early juveniles were assembled into developmental study series based on size. Series of a few cyprinid species were reared from larvae collected in the above rivers during the summer of 1977. In addition to specimens collected in 1979 from the Colorado River reach noted above, Colorado pikeminnow used in this study included developmental series reared by Willow Beach National Fish Hatchery (WBNFH, Boulder City, NV) in 1975 (borrowed from Karl Seethaler, Utah State University) and 1979 with parental stock from the Yampa River, CO (Toney 1974), juveniles collected in 1977 from the Green River (preserved in 40% isopropanol, borrowed from Paul Holden, cat. no. 77-275), and metalarvae and juveniles collected in 1962 from the Green River (borrowed from Royal Suttkus, Tulane University Museum of Natural History cat. no. 108940). Humpback chub were described and illustrated exclusively from a developmental series reared and provided by WBNFH in 1980 with parental stock from the Black Rocks reach of the Colorado River east of the Utah border. Similarly, Utah chub were partially described and illustrated exclusively using specimens reared by John Varley in 1969 (alcohol preserved) and 1971 with parental stock from Flaming Gorge Reservoir for a UDWR investigation (Varley and Livesay 1976).

Specimens studied by Muth (1990) included the reared series of humpback chub used for description by Snyder (1981), humpback chub and bonytail reared by WBNFH in 1981 with parental stock from the Little Colorado River and Lake Mohave, respectively (Hamman 1982a, 1982b), and roundtail chub Muth reared at LFL in 1983 with parental stock from the Roundbottom–Juniper Hot Springs reach of the Yampa River. He also analyzed late larval and juvenile humpback chub collected in 1989 from the Little Colorado River by Dennis Kubly (Arizona Game and Fish Department, AGFD) and series of roundtail chub collected by LFL for CDOW studies in 1979 from the White River between Rio Blanco Lake and Spring Creek and in 1982 from the Yampa River from Government Bridge to Juniper Hot Springs.

Specimens for supplemental study by Snyder et al. (2005) of previously described UCRB cyprinids also found in the Gila River Basin were selected mostly from reference or study series in the LFL Collection including some from the same sources specified above for prior studies. Additionally, a few early larvae were analyzed from a series of speckled dace reared in 1998 by Michael Childs (AGFD

Bubbling Ponds Hatchery) with parental stock collected locally in Arizona.

Many specimens newly examined for this guide also have been maintained as part of the LFL Collection, but these holdings, mostly from the above sources and subsequent fish surveys, research, and monitoring programs in Colorado and the UCRB, had to be supplemented with newly collected or reared developmental series, particularly for recently hatched stages of many species and more complete series for rarely collected species. Some new study specimens were contributed by outside sources and others were collected locally, but most were reared in 2006 through 2009 in our Department of Fish, Wildlife and Conservation Biology's on-campus Aquatic Research Laboratory. The sources of these newly acquired study specimens were:

Bonytail—developmental series reared and provided in 2006 by Dexter National Fish Hatchery and Technology Center (NM; now Southwest Native Aquatic Resource and Recovery Center); parental stock from Lake Mead.

Brassy minnow—series of embryos and recently hatched larvae and several early juveniles reared in 2008 by graduate student Jeffrey Falke from eggs artificially fertilized in lab; parental stock from a local CDOW experimental pond population originally from the South Platte River, Tamarack Ranch State Wildlife Area, Logan Co., CO (most progeny required for Falke's research). Additional larvae and early juveniles were collected in summer 2008 and 2009 from the same pond.

Colorado pikeminnow—developmental series reared and provided in 2006 by Dexter National Fish Hatchery and Technology Center (NM); mixed parental stock from the Colorado River, Mesa Co., CO, and the Green River, UT.

Common carp—reared (in-house) in 2007 from naturally fertilized eggs collected locally at River Bend Ponds, Fort Collins, CO.

Creek chub—reared through early larval stages in 2007 from eggs artificially fertilized in lab; parental stock from Spring Creek, Fort Collins. Also reared (complete series) in 2008 from eggs artificially fertilized on site, Spring Creek, Fort Collins, and from naturally spawned eggs collected in the same creek.

Fathead minnow—reared through early larvae in 2006 from fertilized eggs provided by Aquatic BioSystems, Inc., Fort Collins.

Golden shiner—reared successfully only through yolk absorption in 2007, 2008, and 2009 from tank-spawned eggs; parental stock provided by a commercial bait dealer, Outlaw Bait and Tackle of Colorado Springs, CO. Collections in or near Fort Collins, CO, in 2008 and 2009 yielded only several 50–60 mm TL juveniles, but Rene Reyes (U.S. Bureau of Reclamation, CA) collected and contributed series of 5–15 mm TL larvae in 2010 from backwaters near the Tracy Fish Collection Facility, Sacramento-San Joaquin River Delta, Byron, CA.

Longnose dace—reared in 2007 and 2008 from trough-spawned eggs; parental stock from Cache la Poudre River, Fort Collins.

Red shiner—reared successfully only through yolk absorption in 2006 by graduate student Michelle McGree and in 2007 and 2008 by LFL staff from aquarium-spawned late embryos and hatchlings; parental stock from Cache la Poudre River east of Fort Collins.

Redside shiner—reared in 2007 to early 2008 from tank-spawned eggs; parental stock collected from Scofield Reservoir, UT, by Justin Hart and crew, UDWR.

Sand shiner—reared in 2008 to early 2009 from trough-spawned eggs; parental stock from Spring Creek and Cache la Poudre River, Fort Collins.

Speckled dace—reared in 2007 from eggs artificially fertilized on site, McKinney Creek, WY, by Robert Compton and Koreen Zelasko.

Utah chub—reared in 2007 from eggs artificially fertilized on site by LFL staff with parental stock collected from Joe's Valley Reservoir, UT, by Justin Hart and crew, UDWR.

Most specimens selected for illustration and analysis were killed and fixed in 10% formalin, then stored in 3% formalin buffered with marble chips or phosphate to avoid confounding data with the greater shrinkage and deformation effects typical of alcohol-preserved specimens. However, some morphometric data are based on specimens preserved in 70% ethanol or 40–50% isopropanol—14 Colorado pikeminnow (mostly borrowed juveniles), 14 Utah chub, and nine golden shiner. Also, some meristic data (e.g., vertebrae and fin ray counts) from Muth (1990) are based on specimens cleared and stained for skeletal features and stored in 100% glycerol—13 bonytail, 38 humpback chub, and 34 roundtail chub.

Over 1,700 specimens were specifically analyzed, including drawing specimens, for the descriptions herein, and many more were at least cursorily examined. Most had been or are now maintained as part of the LFL Collection (Appendix III lists the total number of specimens analyzed for each species and the associated LFL Collection catalog numbers for those individually comprising or removed from previously cataloged lots). Unfortunately, many specimens originally analyzed or illustrated for Snyder (1981) were inadequately segregated (and cannot be recovered) from other specimens in their original lots, inadequately labeled (e.g., only external vial labels which lost adhesion), or otherwise displaced or lost. However, the individual data (e.g., counts and measures) for those specimens remain available and were re-examined and summarized with new data for descriptions herein. Data for those and more recently analyzed specimens, including drawing specimens, are available in computer spreadsheet files maintained by LFL and, for at least more recent analyses, can be linked with individually maintained and available specimens. Most newly analyzed specimens (and previously analyzed specimens that had been found), as well as most other specimens recently reared or collected for this study, have yet to be cataloged as part of study series in the LFL Collection.

Specimen Data, Observations, and Illustrations

Both previously and most newly examined specimens were analyzed, when applicable, for differences in up to 32 morphometric and 18 meristic characters (37 and 25 respectively for Muth 1990), whereas newly examined specimens (and illustrations) for Snyder et al. (2005) and herein were also (or only) analyzed, when applicable, for up to 29 of 49 pigmentation characters and 11 additional morphological characters. When available, individual data for specimens analyzed for prior descriptions were re-examined, with questionable data verified or corrected if possible, and combined with new data herein. Meristic data (except myomere counts) were supplemented with observations from adult specimens and occasionally juveniles cleared and stained for skeletal characters.

Figure 4 illustrates the various measurements, fin-ray counts, and myomere counts that were made on at least two specimens, if available, in each 1-mm-TL interval throughout the larval period of each species. Thereafter, to a length of about 50 mm

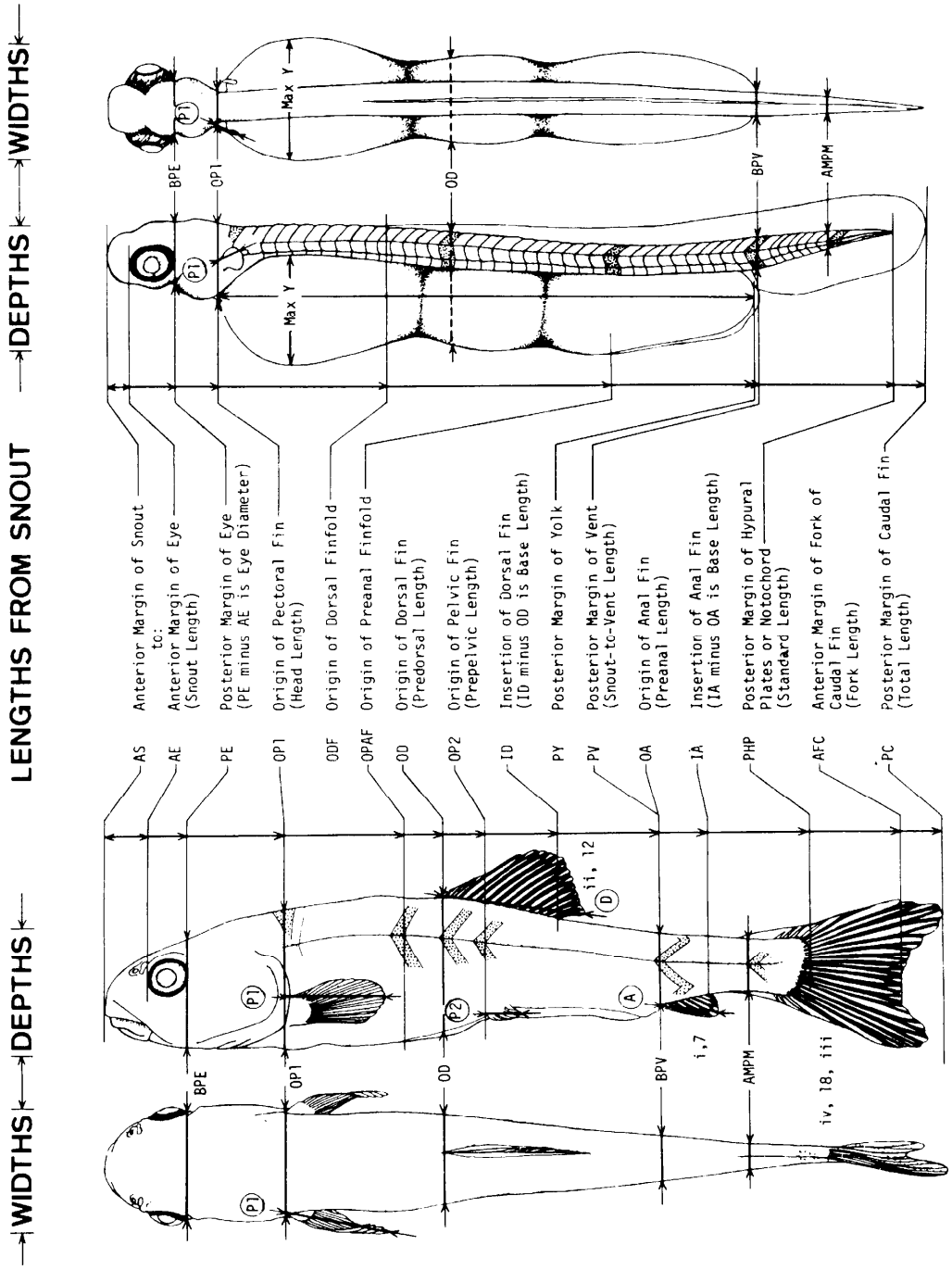

Figure 4. Measures and counts for larval and early juvenile fishes. Yolk sac and pterygiophores are included in width and depth measures but fins and finfolds are not. "B" in BPE and BPV means immediately behind. AMPM is anterior margin of most posterior myomere. Location of width and depth measures at OD prior to D formation is approximated to that of later larvae. PHP is measured to end of notochord until adult complement of principal caudal-fin rays are observed (beginning of postflexion mesolarval phase). Fin lengths (D, A, P1, and P2, encircled) are measured along plane of fin from origin to most distal margin. When reported together, rudimentary median-fin rays (outlined above) are given in lower case Roman numerals, while principal median-fin rays (darkened above) are given in Arabic numerals; rudimentary rays are not distinguished in paired fins. Most anterior, most posterior, and last myomeres in counts to specific points of reference are shaded above. (From Snyder 1981.)

TL, two or more specimens were similarly processed for each 5-mm interval, if available. Specimens were studied under low-power stereo-zoom microscopes with measuring eyepiece reticles and various combinations of reflected, transmitted, and polarized light. For Snyder (1981) and Muth (1990), morphometric analyses were conducted by adjusting microscope magnification before each series of measurements to calibrate the scale in the eyepiece against a stage micrometer for direct measurement. Measurements were made to the nearest 0.1 mm and occasionally to half that unit. Remeasurement of selected specimens by a second observer indicated that most measurements are repeatable to within 0.1 mm. For more recent morphometric analyses, most measurements were made using multiple digital images of the specimens captured through the microscope and a computer image-analysis and measurement program. Most measurements are summarized herein by developmental phase as % SL, but the means can be readily converted to percent TL (% TL) by dividing 100 times the % SL value for the length of interest by the % SL value for TL (AS to PC).

Other assessed characters included developmental phase for all specimens and gut form (loops or folds), eye shape, mouth position, relative fin positions, presence of special structures (e.g., mouth barbels), and chub; five each for fathead minnow, longnose dace, and creek chub; four for bonytail; three each for Colorado pikeminnow, golden shiner, and redside shiner; and one for speckled dace. These drawings, together with 37 similarly prepared drawings from prior LFL guides and 17 illustrations adapted from other publications (120 total), document typical body form and pigmentation at the beginning and middle of the protolarval, mesolarval, metalarval, and early (young-of-the-year) juvenile phases of development. All but two of the illustrations (both lateral-view drawings reprinted from specifically defined pigment distribution or patterns for specimens newly analyzed for Snyder et al. (2005) and this guide. Gut form was categorized as one of five sequential phases (Figure 5), but for most cyprinids, the final form of the gut is a relatively short and simple S-shape (gut folded back on itself in a single loop) and only the first three phases are applicable. Pigmentation was categorized in 49 specifically defined characters (up to 29 applicable per developmental phase), each with 2 to 8 alternative states (see summary Table 71 and the key for other pigment characters at the end of summary Table 74).

Size at apparent onset of selected developmental events and transition to developmental and gut phases was assessed by examination of associated data for analyzed and cursorily examined specimens. Selected events were hatching, attainment of eye pigment, formation of pectoral- and pelvic-fin buds, loss of yolk and preanal finfold, formation of first and last principal fin rays in each of the median and paired fins, formation of first and last rudimentary rays of the caudal fin, and initial and complete formation of lateral scales on the body.

Sixty-six (66) new three-view, continuous-tone graphite and black-ink drawings of larvae or early juveniles were prepared for this guide: eight each for brassy minnow, red shiner, sand shiner; seven for common carp; six for Utah other publications) consist of dorsal, lateral, and ventral views.

For all LFL original drawings, black ink was used only for surface or near-surface pigmentation to distinguish it from deeper pigmentation, anatomical structures, and shading. Enlarged photographs or digital prints of primary drawing specimens were traced to assure accurate body proportions. Various structures were checked and detail added while drawing specimens were examined under a microscope. If necessary, drawings were idealized (e.g., closed or frayed

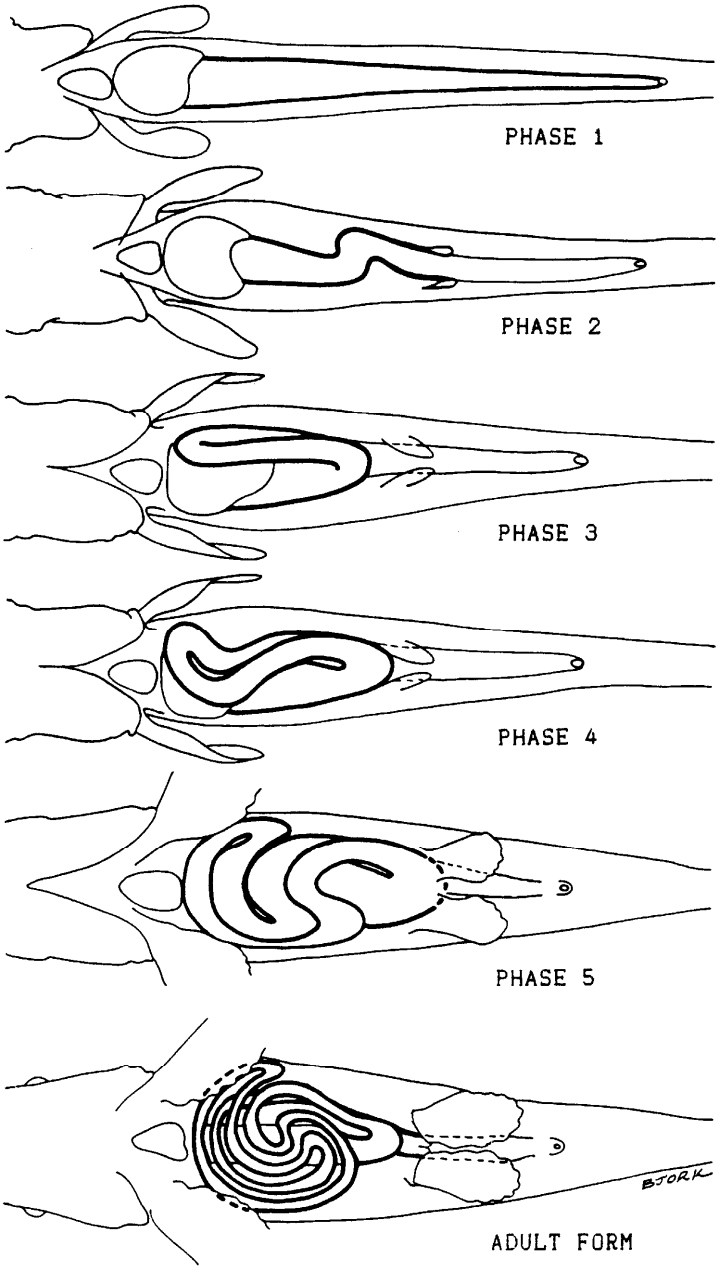

Figure 5. Phases of gut coil development in cypriniform fish larvae and early juveniles based on typical pattern in catostomid fishes and adult form in *Catostomus commersonii* (latter modified from Stewart 1927). Phase 1—essentially straight gut. Phase 2—initial loop formation (usually on left side), begins with 90° bend. Phase 3—full loop, begins with straight loop extending to near anterior end of visceral cavity (to or under liver). Phase 4—partial fold and crossover, begins with folding of first limb of loop over ventral midline; in some fish (e.g., *Pimephales promelas*), tip of main loop itself crosses midline toward opposite side (usually left to right) at anterior end of visceral cavity (behind heart). Phase 5—full fold and crossover to adult form, begins with both limbs of loop extending fully across ventral midline to opposite (usually right) side, usually resulting in four segments of gut crossing nearly perpendicular to body axis; however, in some fish (e.g., *P. promelas*), phase begins with tip of main loop completely crossing ventral midline at anterior end of visceral cavity with only two gut segments initially perpendicular to body axis (tip of loop then grows posteriorly along opposite side and secondary folds later crossover somewhat as illustrated). Later in Phase 5 and in adult form, outer portions of gut folds or coils often extend well up both sides of visceral cavity.

fins opened and smoothed and curved bodies straightened), and melanophore distribution and other structures were modified to represent a more typical pattern or condition based on secondary or tertiary drawing specimens.

All morphometric, meristic, and size at onset of selected developmental event data are summarized in species accounts with associated illustrations, maps of recent (last decade) CRB distribution, and brief descriptions of the adult, reproduction, and early life history (young). The more diagnostically useful of those data are also compared among species in sets of summary tables, along with all pigmentation and special character data not in the species accounts. All data, except those in terms of TL, are used also by, and accessible in, the computer-interactive key.

Computer-Interactive Key

For complex sets of organisms, computer-interactive keys are easier to prepare, update, and expand than traditional printed keys, and much more flexible for the user. Most computer-interactive keys are data sets designed to be used with specific commercial, public-domain, or proprietary host programs (Dallwitz et al. 2000 onwards). The features and flexibility of several alternative computer-interactive key programs were compared (in part via Dallwitz 2000 onwards) during preparation of early versions of the key included in Snyder and Muth (2004). Based on this comparison, our prior experience with the DELTA (DEscriptive Language for TAxonomy) suite of programs for taxon description and keys (Dallwitz 1974, 1980, 1993; Dallwitz and Paine 1986), including *Intkey* (Dallwitz et al. 1993 onwards, 1995 onwards), and successful production of keys for Snyder and Muth (2004) and Snyder et al. (2005), we decided to continue developing our keys for use by the *Intkey* program. The latest versions of *Intkey*, *DELTA Editor* (Dallwitz et al. 1999 onwards), and associated programs and files can be freely downloaded from the Internet (http://delta-intkey.com/).

DELTA Editor was used to update character data for the seven species herein previously covered in a cyprinid database prepared for Snyder et al. (2005) and add corresponding data for the remaining eight UCRB species. Characters were encoded using the DELTA format, a powerful, flexible, and widely accepted method for recording descriptive taxonomic data for computer processing. Because developmental state changes dramatically as fish grow, and to better facilitate use of character dependencies in the key (e.g., if yolk is absent, characters such as length of yolk are removed from consideration), it was necessary to treat each developmental phase and size interval for a species as a separate taxon (e.g., *Ptychocheilus lucius* metalarva, 15 mm SL). Output from *DELTA Editor* to the derived files required by *Intkey* was then limited to just UCRB cyprinids. Rich-text files providing an introduction to the key, beginning user instructions, and related background information were prepared or modified for access and display when using *Intkey*. Character lists and natural-language taxon descriptions were also generated as rich-text files for reference when using the key.

A similar set of data and derived and associated files was preliminarily prepared for family-level identification of the larvae of most freshwater and anadromous fishes in the United States and Canada. Subsets of families were predefined to limit the key to just families present in selected drainage basins, including one for the UCRB and another to replace the family-level key for the Gila River Basin

previously prepared for Snyder et al. (2005). All characters in the key (data set) are based on external or externally visible morphology and melanophore pigmentation. Most characters are specific to larvae either with or without yolk and were derived mostly from characters used in family keys or pictorial guides by Drewry (1979), Auer (1982), Holland-Bartels, et al. (1990), and Wallus et al. (1990) for the Great Lakes, upper Mississippi River, and Ohio River. Mostly to illustrate representative larvae for use with the key, but also as an alternative to it, a pictorial guide to the families of UCRB fish larvae was modified (like one for Gila River Basin larvae in Snyder et al. 2005) from pertinent portions of the pictorial guide to families of Ohio River drainage larvae by Wallus et al. (1990) and included herein as Appendix IV.

Although *Intkey* can make extensive use of taxon and character-state-selection images, preparation and inclusion of such were neither critical for operation of the program nor logistically and budgetarily feasible for the keys prepared for this guide (if there is enough interest and support, they could be prepared and incorporated in future versions of the keys). Also, such images can require a considerable amount of storage memory and at times a mostly text key may be preferable, especially for the experienced user or when using a slower computer with limited memory. Instead, the user is expected to extensively reference the illustrations and descriptive information provided in the species accounts. However, as examples of how character-state-selection images function, such illustrations were prepared and included in the cyprinid key for designating developmental intervals and phases of gut development. Images used by *Intkey* were created or modified from scanned files using computer drawing and presentation programs. Based on reviews and user feedback, future refinements of the keys, possibly including more images, will likely be implemented and made available for download over the Internet.

RESULTS AND DISCUSSION

Results are divided into three complementary sections—Species Accounts, Comparative Summary Tables, and Computer-Interactive Keys. For identification purposes, users should become familiar with and use all three taxonomic tools. Although all descriptive data in the species accounts and comparative summary tables (except those replicated in terms of total length in the species accounts) comprise the data sets for the cyprinid key, results of the key can be confirmed using the well-illustrated species accounts and comparative summary tables. Diagnostic differences among these species may be found by scrutinizing the comparative summary tables or systematically querying the cyprinid computer-interactive key.

Whenever possible, specimen identification should be based on multiple characters. More than 1,700 specimens were analyzed in detail for morphometrics, meristics, and morphological developmental state relative to size, and several hundred of these and additional specimens for pigmentation and special morphological characters. Still, there are undoubtedly rare specimens with character extremes beyond the ranges recorded herein.

For the most part, the characters examined for this guide were the same as those used for cyprinids in the Gila River basin guide (Snyder et al. 2005), but the states considered for some characters were refined, or in some cases expanded upon, based on new observations. For example, with respect to eye pigmentation in protolarvae (Tables 71-73), such new state observations included sparsely scattered melanophores over the dorsal and dorso-lateral surfaces of otherwise unpigmented to moderately pigmented eyes (and head) in recently hatched brassy minnow (not previously observed in cypriniform fishes, but characteristic of some recently hatched pike and pickerel, Esocidae) and diagonal bands of more intense pigment across otherwise lightly to moderately pigmented eyes in recently hatched speckled dace, longnose dace, and occasionally, but less prominently, sand shiner.

Because of the similarity among some UCRB cyprinids during certain intervals of larval development, the specific identity of some larvae will remain inconclusive or questionable after application of the key and diagnostic criteria provided herein. The identity of such specimens must be considered tentative and should be designated as such by appending a question mark ("?") to the most probable taxon name (e.g., "*Gila robusta* ?", preferably with a footnote on other possibilities), or by leaving the identity at family level (e.g., "unidentified Cyprinidae"), or genus (i.e., *Gila* sp.) if other genera can be eliminated. Some inconclusive specimens may be hybrids.

Hybridization has been documented among some Colorado River System cyprinids and might be particularly prevalent among the native *Gila* (e.g., Sigler and Miller 1963, Kaeding et al. 1990, DeMarais et al. 1992). Based on the key or diagnostic criteria summarized herein, some hybrid metalarvae and early juveniles may be at least tentatively identified as such by more experienced users, but with fewer available characters hybrid protolarvae and mesolarvae will likely be identified as the parental species they most closely resemble or remain questionable.

Although prepared for use by UCRB biologists, the species accounts, comparative summary tables, and keys that follow, as well as introductory information at the beginning of this guide, may also be useful to early life history investigators working elsewhere. Allowing for potential population differences in developmental morphology, these descriptions and the keys can be used for

identification of covered species wherever they may occur. For example, roundtail chub, speckled dace, red shiner, fathead minnow, and common carp are also found in other reaches of the CRB, and the latter four species in many other North American river systems. Where two or more species covered herein occur together and any other closely related sympatric species can be eliminated otherwise as possibilities, the computer-interactive key has the flexibility of being limited to just those species of concern, effectively becoming a key for that region, site, or circumstance. Similarly, the key to families of freshwater-spawning fishes in the United States and Canada prepared in part for this guide can be limited to just those families of concern or found in a specific body of water.

Species Accounts

The following accounts serve as concise, detailed, and well-illustrated descriptions of the larvae and early juveniles of the subject species. Together with the comparative summary tables, they are the source of the data set for the associated computer-interactive key, provide the taxon illustrations referenced in that cyprinid key, and intended to facilitate specimen identification with or without the key.

All species accounts herein, except that for golden shiner, are reformatted and completed versions of descriptive accounts initially prepared for Snyder (1981); combined, reformatted, and supplemented versions of accounts by Muth (1990), or completed or supplemented and updated accounts from Snyder et al. (2005). Each 6-page account begins with an illustration of the adult fish; map of its distribution in the CRB; brief summaries of adult descriptions, reproduction (including reproductive guilds as defined by Balon 1975a and 1981, and Simon 1998), and the young (early life history); and a table of adult meristics. Much of this information was extracted from literature cited at the bottom of the first page. Each account continues with description of the larvae and early juveniles. Page one concludes with a table of size at apparent onset of selected developmental events. Page two consists of a table of size at developmental-interval and gut-phase transitions and a table of morphometrics and meristics summarized by developmental phase. The next four pages illustrate eight stages of development from just hatched protolarvae through early juveniles up to about 40 mm SL

Species Account – *Cyprinella lutrensis*, red shiner

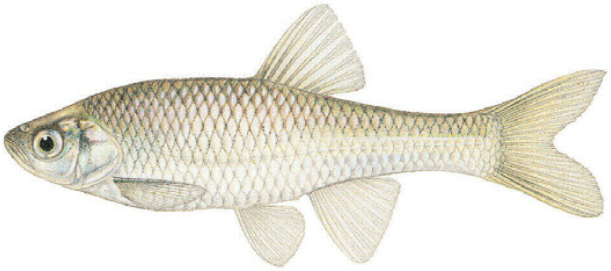

Figure 6. *Cyprinella lutrensis* adult (© Joseph R. Tomelleri).

Adult description: Small, 4–9, rarely 10 cm TL. Deep-bodied and laterally compressed. Mouth small, oblique, and terminal to superior. Head relatively short with blunt snout. Dorsal fin origin behind pelvic fin origin. Scales large and diamond-shaped; lateral line decurved. Usually olivaceous above, silvery laterally, and white below. Breeding males often metallic blue dorsally and laterally, white below, and red over head and in paired, anal, and caudal fins; have small tubercles concentrated on the head, snout, and ventral surface. (Also, Table 2.)

Reproduction: Non-guarding, brood-hiding, speleophil (crevice spawner). Mature at age 1; fractional spawner. Spawn early spring through late summer when water reaches day-time highs of ≥16°C, usually in low-velocity areas such as backwaters or pools over or in crevices of rocks, woody debris, or aquatic vegetation. Males are territorial. Water-hardened eggs are demersal, adhesive, and 1.0–1.4 (mean 1.2–1.3) mm in diameter.

Young: Hatch in 2.5 d @ 29°C to 5 d @ 21°C. Larvae occupy near-shore, low-velocity channel margins, backwaters, eddies, and pools. Consume early instars of chironomids and other small invertebrates, algae and detritus; larger individuals may prey on fish larvae.

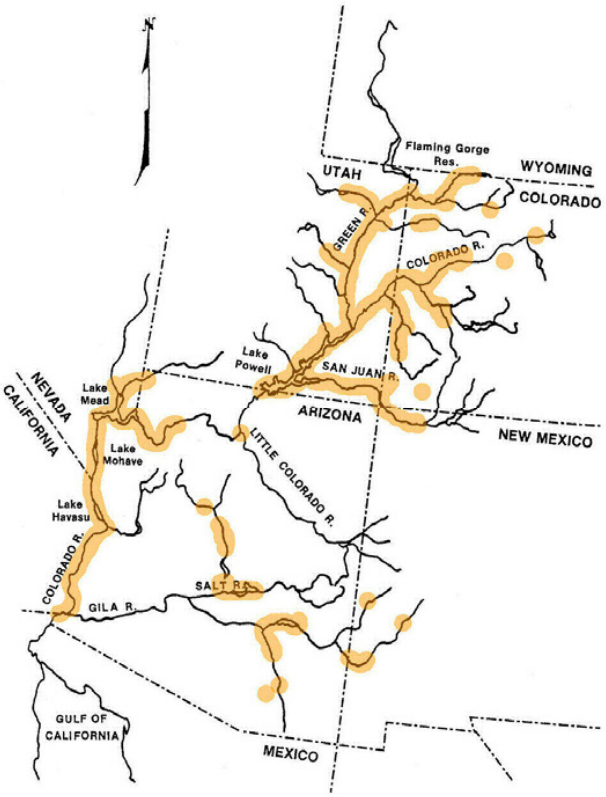

Figure 7. Recent distribution of *Cyprinella lutrensis* in the Colorado River Basin.

Table 2. Selected juvenile and adult meristics for *Cyprinella lutrensis*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	(7)8(9)	(6-)8(9)	Dorsal-fin rays - R	1-2-3(4)	–
Anal-fin rays - P	8-9-10	(7)8-9-10(-13)	Anal-fin rays - R	(1)2-3	–
Caudal-fin rays - P	(18)19	(18)19	Caudal-fin rays - RD	(5-)9-10-11(-13)	–
Pectoral-fin rays	(8-)12-14-15(16)	(9-)13-14-15(16)	Caudal-fin rays - RV	(6-)8-9-10(11)	–
Pelvic-fin rays	(6)7-8-9	8-9(10)	Lateral scales	(34-)36-38	30-32-37-40
Vertebrae	35-36	32-35-36	Pharyngeal teeth	–	0-1,4(5)/4,0-1

* Includes re-examined data originally prepared for Snyder (1981) and Snyder et al. (2005) and supplements and updates those accounts.

Table 3. Size at onset of selected developmental events for *Cyprinella lutrensis*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data as per footnote for Table 2.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	3-4	(3)4	Dorsal - P	6	7	7(8)	8(9)
Eyes pigmented	*	*	Anal - P	7	8	7-8	(8)9
Yolk assimilated	(4)5	5	Caudal - P	5	(5)6	6	7
Finfold absorbed	10(-12)	(12)13(-15)	Caudal - R	7	8	10(11)	12(13)
Pectoral-fin buds	*	*	Pectoral	7(8)	8-9	(8-)10(11)	(9-)12-13
Pelvic-fin buds	7(8)	8-9	Pelvic	8-9	(9)10(11)	(9)10(11)	11-12(13)
* before hatching			Scales	(12)13	(15)16-17	14-15	18-19

References: Becker 1983; Beckman 1952; Clay 1975; Coburn 1986; Eddy and Underhill 1974; Etnier and Starnes 1993; Gale 1986; Lentsch et al. 1996; Minckley 1973; Muth and Snyder 1995; Page and Burr 1991; Perry 1979; Perry and Menzel 1979; Pflieger 1997; Ruppert et al. 1993; Saksena 1962; Simon 1998; Snyder 1981; Snyder et al. 2005; Sublette et al. 1990; Tyus et al. 1982; Wang 1986; Wang and Reyes 2007; Woodling 1985. ***Other larval descriptions***: Feeney and Swift 2008; Fuiman et al. 1983; Holland-Bartels et al 1990; Loos and Fuiman 1978; Perry 1979; Perry and Menzel 1979; Saksena 1962; Snyder1981; Snyder et al. 2005; Taber 1969; Wang 1986; Wang and Reyes 2007.

Table 4. Size at developmental interval (left) and gut phase (right) transitions for *Cyprinella lutrensis*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	5	(5)6	2 - 90° bend	8-9	10-11(12)
Postflexion mesolarva	6	7	3 - Full loop	12-13	15-16
Metalarva	(7)8	9	4 - Partial crossover	not applicable	
Juvenile	10(-12)	(12)13(-15)	5 - Full	not applicable	

Table 5. Summary of morphometrics and myomere counts by developmental phase for *Cyprinella lutrensis*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts, in part with data extracted from selected Taber 1969 and Perry and Menzel 1979 illustrations used therein.)

	Protolarvae (N=10)			Flexion mesolarvae (N=9)			Postflexion mesolarvae (N=11)			Metalarvae (N=20)			Juveniles (N=55)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	4	1	3 - 5	6	0	5 - 6	7	0	6 - 8	9	1	7 - 12	21	9	10 - 41
TL, mm	5	1	3 - 5	6	0	6 - 7	8	0	7 - 9	11	1	9 - 15	26	11	13 - 50
Lengths %SL															
AS to AE	3	1	2 - 4	3	1	2 - 5	4	1[h]	3 - 5[a]	5	1	4 - 7	6	1	4 - 8
PE	10	1	8 - 12	10	1	9 - 13	12	1	11 - 13	13	1	12 - 15	13	1	11 - 15
OP1	20	1	17 - 22	21	1	19 - 23	23	1	21 - 24	25	2[j]	22 - 28	25	2	22 - 28
OP2							48	[i]	48 - 48	49	1	47 - 51	48	1[p]	46 - 51[a]
PY	62	4[b]	57 - 66												
OPAF	43	11[c]	30 - 61	37	2	34 - 41	37	3	29 - 40	47	8	37 - 58			
ODF	41	5	33 - 49	45	4	38 - 49	48	2[c]	45 - 51	50	1[g]	49 - 51			
OD							50	1[c]	49 - 52	52	1	49 - 53[a]	50	1[p]	47 - 52
ID							63	0[b]	63 - 64	65	1	63 - 67	63	2	60 - 67
PV	64	3[c]	61 - 70	64	2	61 - 67	66	1	65 - 67	65	2	61 - 68	62	1	60 - 64
OA							66	1[f]	65 - 66	64	1[c]	62 - 66	63	1[c]	61 - 64
IA										76	1	74 - 78	76	1	73 - 78
AFC							109	3	102 - 112	112	2[j]	109 - 118	114	2	111 - 118
PC	105	1	104 - 108	107	2	104 - 111	112	2	108 - 116	120	3	115 - 126	125	2	120 - 129
Y	23	25[c]	0 - 57[a]												
P1	11	4	6 - 17	13	2	10 - 15	14	2[h]	11 - 16	14	2[k]	11 - 18	19	2	15 - 23
P2							0	1	0 - 3	8	3	3 - 13	14	1[p]	11 - 17
D							14	1[b]	13 - 15	19	2	16 - 22	22	1	20 - 24
A										16	2	13 - 21	20	1	17 - 23
Depths %SL															
at BPE	14	4[c]	11 - 23	13	1	11 - 13	13	1	12 - 14	15	1	12 - 18	16	1	14 - 18
OP1	16	6[c]	10 - 28	13	1	11 - 14	15	1	14 - 16	17	2	14 - 21	20	2	17 - 24
OD	12	2[d]	10 - 14	12	2[f]	10 - 15	13	1[c]	12 - 15	16	1	14 - 19	20	2	17 - 25
BPV	8	0[c]	7 - 8	9	2	8 - 13	10	1	9 - 12	13	1	11 - 15	17	2	13 - 20
AMPM	4	0[c]	3 - 5	4	1	3 - 5	6	1	5 - 8	8	1	7 - 10	10	1	8 - 12
Max. yolk	6	9[c]	0 - 22												
Widths %SL															
at BPE	12	1[c]	11 - 14	13	1[e]	12 - 14	13	1[h]	12 - 15	15	1[k]	12 - 16	14	1	12 - 16
OP1	13	5[c]	9 - 22	10	1[e]	9 - 13	10	0[h]	10 - 11	12	1[k]	11 - 14	14	1	11 - 16
OD	6	2[d]	5 - 9	6	2[g]	5 - 8	7	1[e]	6 - 8	9	1[k]	8 - 11	12	2	9 - 17
BPV	5	1[c]	4 - 6	5	1[e]	4 - 8	6	1[h]	5 - 7	8	1[k]	6 - 9	10	1	8 - 14
AMPM	3	1[c]	2 - 4	3	1[e]	2 - 4	3	1[h]	2 - 4	4	1[k]	2 - 5	4	1	3 - 7
Max. yolk	9	9[e]	0 - 23[a]												
Myomeres															
to PY	20	1[b]	19 - 22												
OPAF	12	4[e]	9 - 17	9	1[e]	7 - 11[a]	8	2	5 - 11	12	4[m]	7 - 19			
OP2							12	[i]	12 - 12	14	1[n]	12 - 15[a]	14	1[q]	12 - 15[a]
ODF	10	2[e]	6 - 11	12	1	10 - 14	13	1[h]	11 - 15	15	2[g]	13 - 16			
OD							15	1[c]	14 - 16	15	1[n]	13 - 17[a]	15	1[q]	13 - 16[a]
PV	21	1[e]	20 - 22	22	1	20 - 24	23	1	21 - 24	22	1[o]	19 - 24	21	1[r]	19 - 22[a]
Total	35	2[e]	31 - 36	35	1	34 - 36	35	1	34 - 37	35	1[o]	34 - 37	35	1[r]	34 - 36
After PV	14	1[e]	11 - 15	13	1	12 - 15	13	1	12 - 15	14	1[o]	12 - 15[a]	14	1[r]	12 - 15[a]

[a] Range 1 or 2 units less than reported by Snyder (1981) and/or Snyder et al. (2005) because highly questionable values were excluded from this summary. [b] N=5. [c] N = 9. [d] N = 6. [e] N = 8. [f] N = 4. [g] N = 3. [h] N = 10. [i] N = 1. [j] N= 19. [k] N = 18. [l] N = 16. [m] N = 13. [n] N = 15. [o] N = 17. [p] N = 54. [q] N = 39. [r] N = 40.

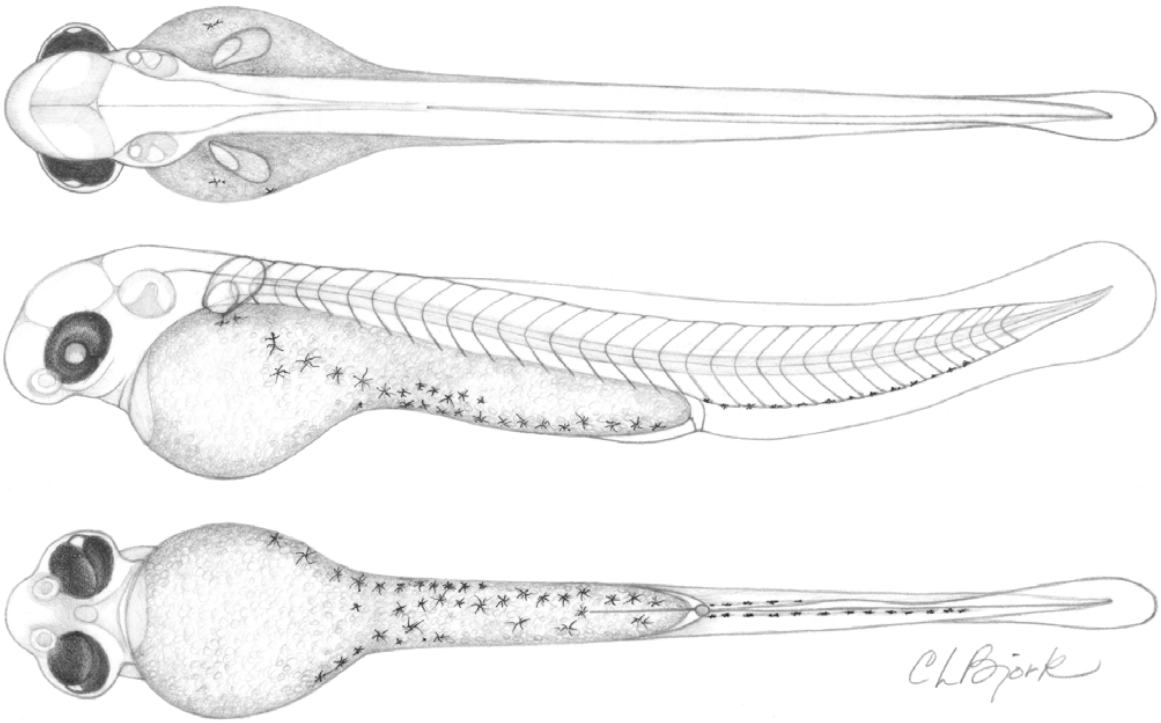

Figure 8. *Cyprinella lutrensis* protolarva, recently hatched, 4.1 mm SL, 4.3 mm TL. (Cultured in 2006 by Michelle McGree at Colorado State University with stock from Poudre River east of Fort Collins, Colorado. Some hatch without body pigmentation or with less over yolk.)

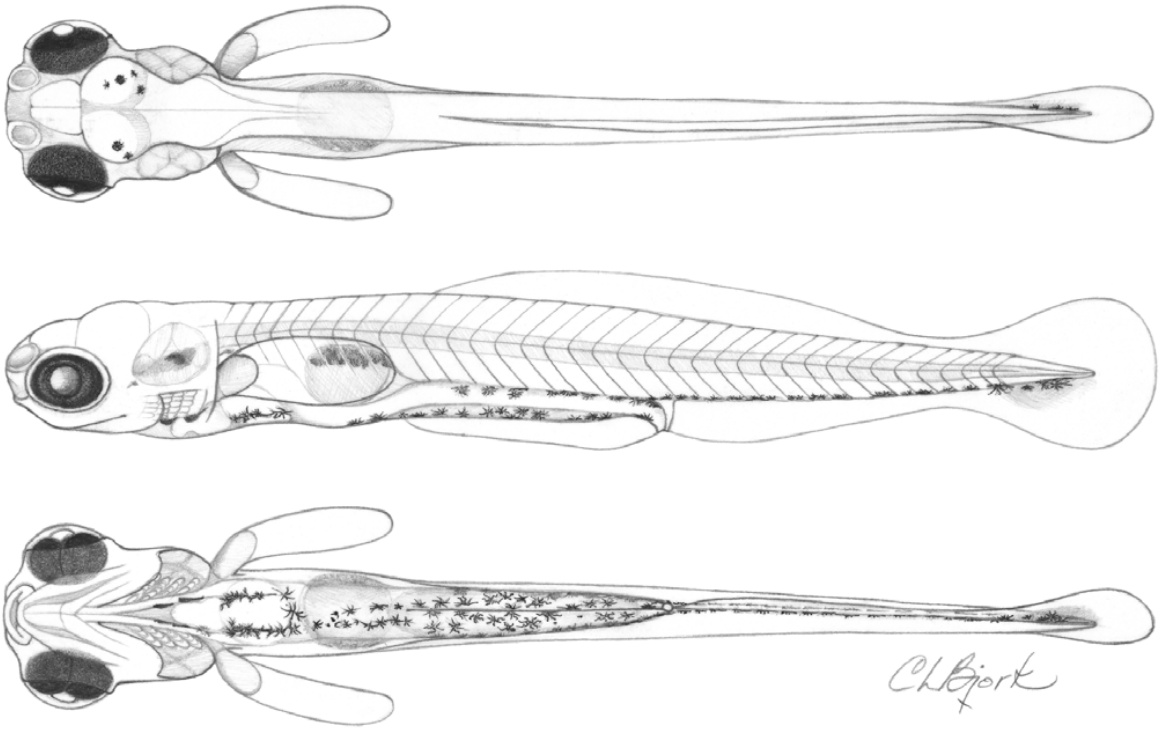

Figure 9. *Cyprinella lutrensis* protolarva, 4.6 mm SL, 4.9 mm TL. (Cultured in 2006 by Michelle McGree at Colorado State University with stock from Poudre River east of Fort Collins, Colorado. Pigmentation under gut often much less to nearly absent in wild specimens.)

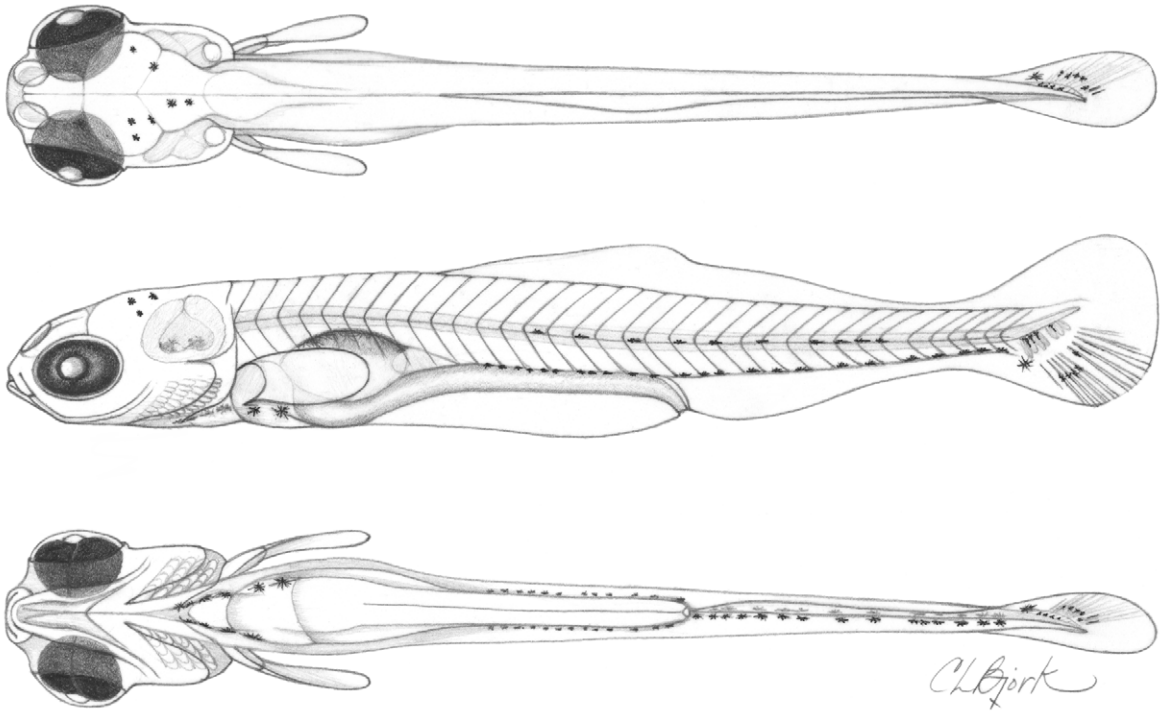

Figure 10. *Cyprinella lutrensis* flexion mesolarva, 5.5 mm SL, 5.9 mm TL. (Collected in 1987 from Yampa River in Echo Park, Dinosaur National Monument, Colorado; from LFL #48862.)

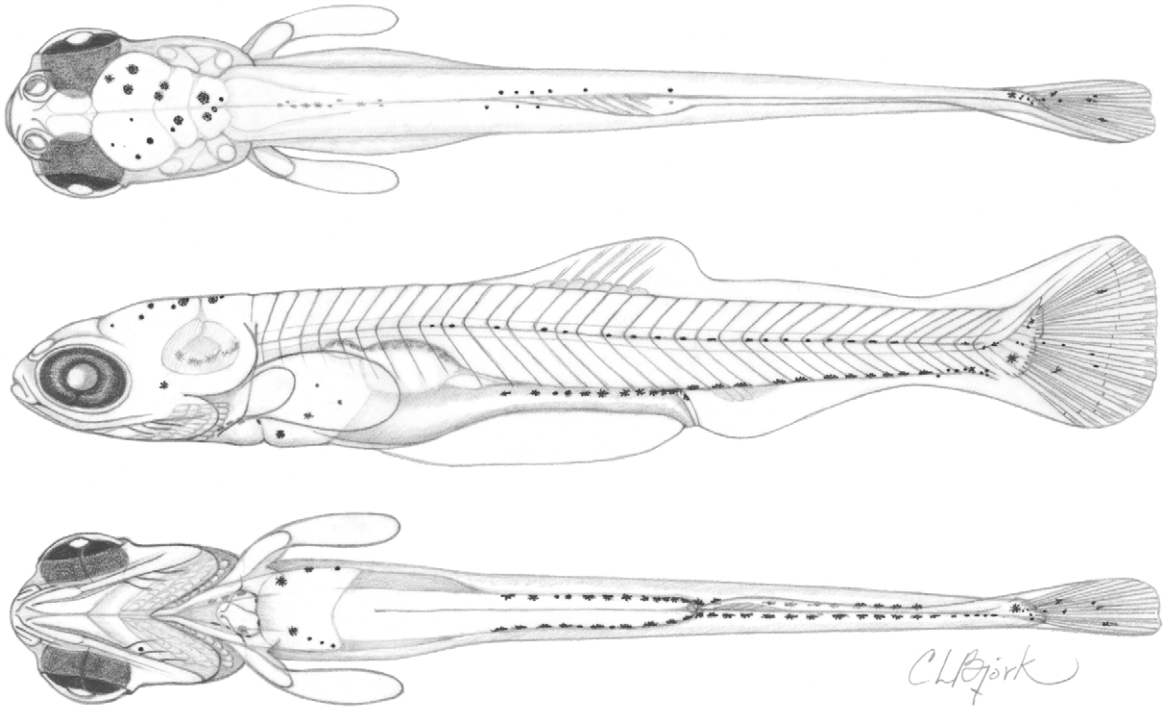

Figure 11. *Cyprinella lutrensis* postflexion mesolarva, 7.0 mm SL, 7.7 mm TL. (Collected in 2005 from Green River in Whirlpool Canyon, Dinosaur National Monument, Colorado; from LFL #97898.)

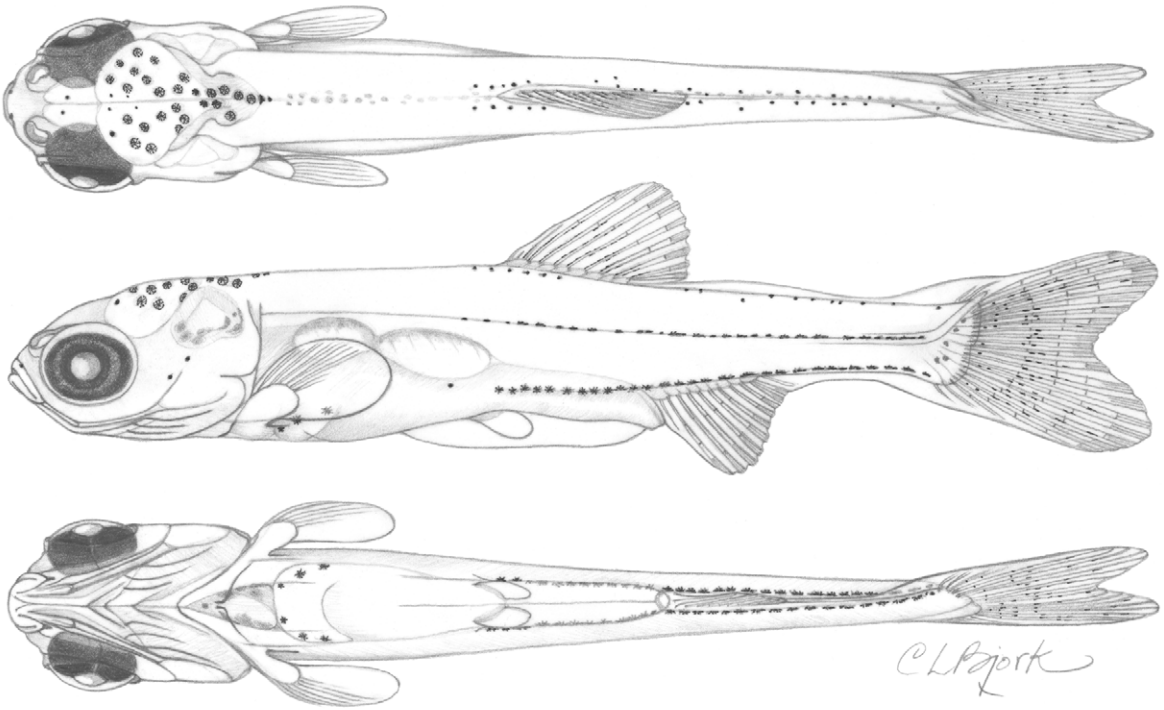

Figure 12. *Cyprinella lutrensis* metalarva, recently transformed, 8.3 mm SL, 9.9 mm TL. (Collected in 2005 from Green River in Whirlpool Canyon, Dinosaur National Monument, Colorado; from LFL #97898.)

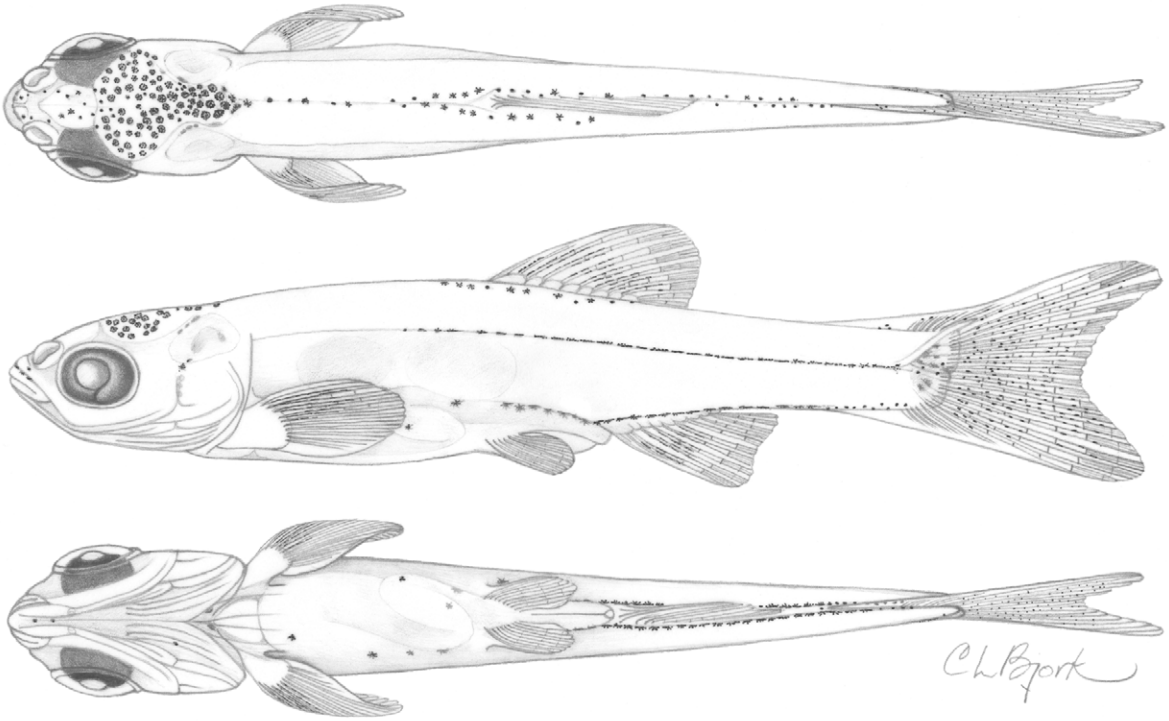

Figure 13. *Cyprinella lutrensis* metalarva, 9.7 mm SL, 11.9 mm TL. (Collected in 1979 from Gunnison River near Grand Junction, Colorado; from LFL #72828.)

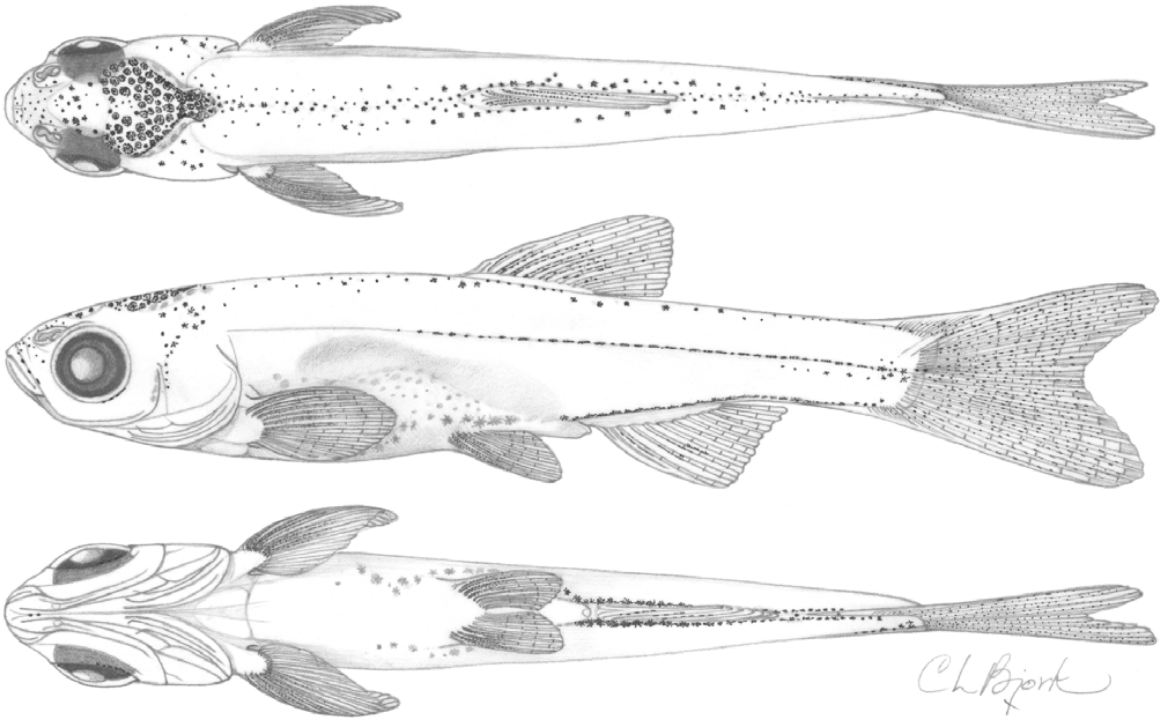

Figure 14. *Cyprinella lutrensis* juvenile, recently transformed, 11.5 mm SL, 14.5 mm TL. (Collected in 1977 from Colorado or Gunnison River near Grand Junction, Colorado; from LFL #72788.)

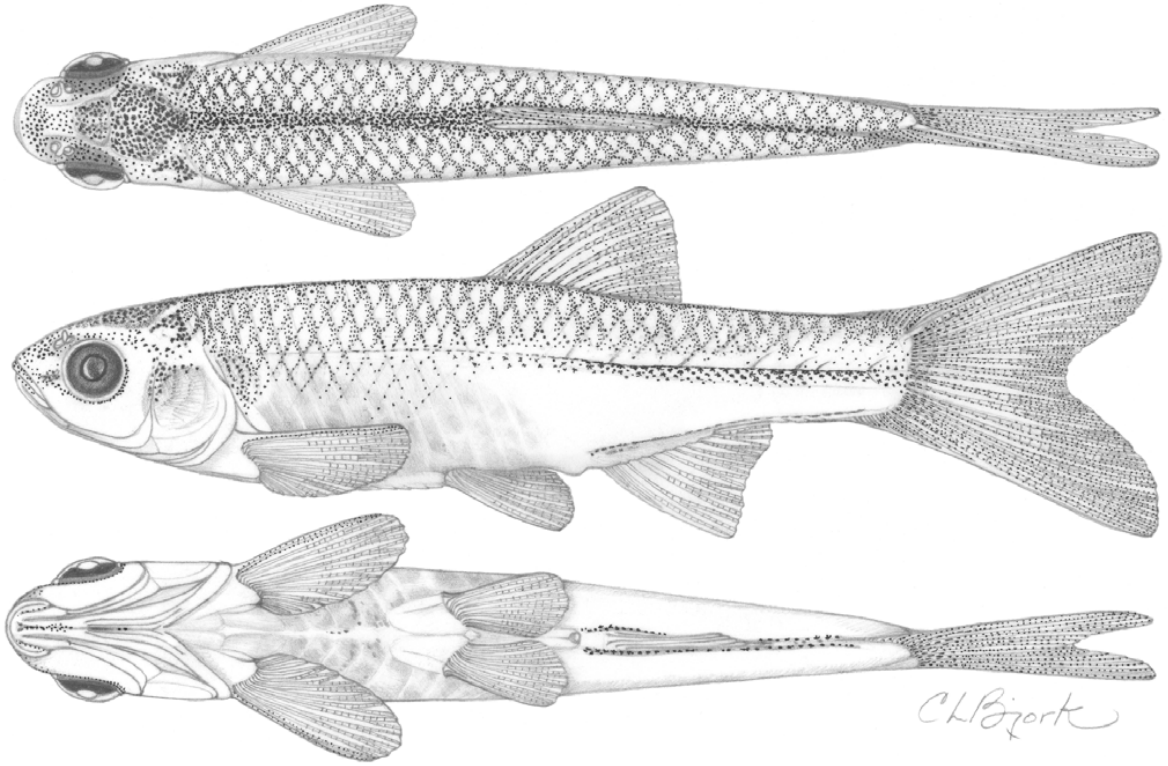

Figure 15. *Cyprinella lutrensis* juvenile, 30.7 mm SL, 38.0 mm TL. (Collected in 2005 from Green River in Whirlpool Canyon, Dinosaur National Monument, Colorado; from LFL #97881.)

Species Account – *Cyprinus carpio*, common carp

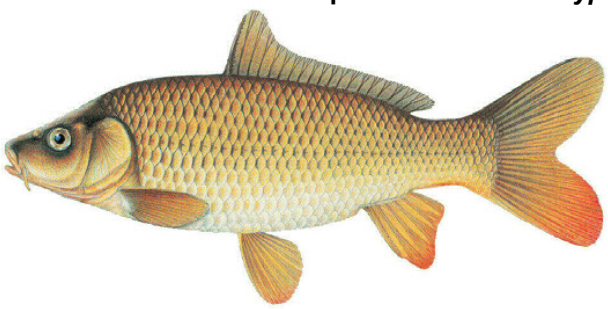

Figure 16. *Cyprinus carpio* adult (© Joseph R. Tomelleri).

Adult description: Large, 30–120 cm TL. Deep-bodied, laterally compressed, dorsally arched and often ventrally flat. Head relatively large, triangular with long snout. Mouth at least somewhat oblique, terminal to subterminal, moderate in size, ending well before highly positioned eyes, with two pair of maxillary barbels (large at corners of mouth, small well forward above upper lips). Gut long and folded; peritoneum gray or speckled. Dorsal fin very long; first principal ray of dorsal and anal fins spine-like and serrated on posterior margin. Scales large (variants with none or enlarged, sparsely scattered scales). Usually dark to olivaceous above, golden-yellow laterally and light ventrally; orange-tinged lower fins in breeding males. (Also, Table 6.)

Reproduction: Non-guarding, open-substrate phytolithophil. Spawn from early March to August, when water reaches day-time highs of at least 15°C, scattering demersal, adhesive eggs, often in clusters, usually over flooded terrestrial or submerged aquatic vegetation in low-velocity areas such as backwaters, pools, flooded tributary mouths, or flood plains. Water-hardened eggs 1.3–2.1 mm diameter.

Young: Hatch in 3–5 d at 21–15 °C, 1.5–4.6 d at 32–20 °C. Larvae initially adhere to or lie in vegetation, remain in shallow, near-shore or other low-velocity habitats until ~12 mm TL, then move to deeper waters. Consume plankton, small invertebrates, algae, and detritus.

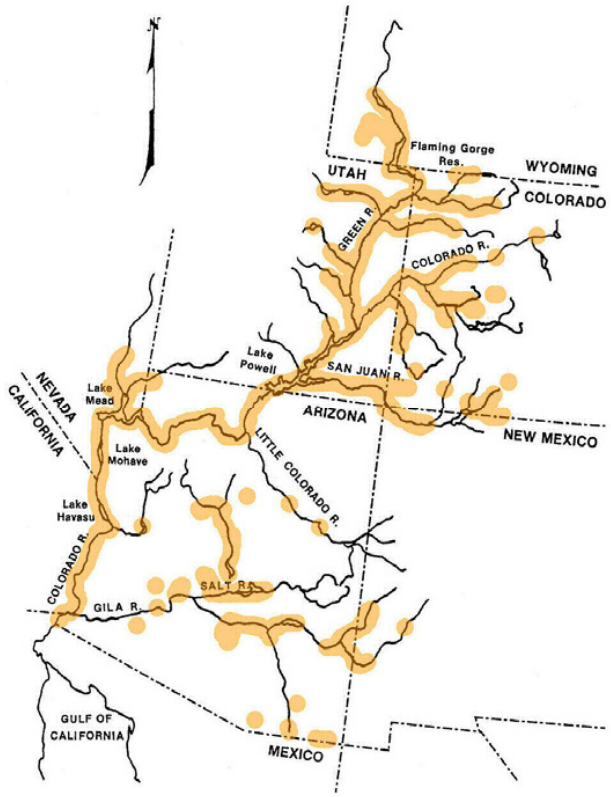

Figure 17. Recent distribution of *Cyprinus carpio* in the Colorado River Basin.

Table 6. Selected juvenile and adult meristics for *Cyprinus carpio*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	(17)18-19-20-21**	(15-)18-22(-24)**	Dorsal-fin rays - R	(1)2-3	1-4
Anal-fin rays - P	5-6-7**	(4)5-6-7(8)**	Anal-fin rays - R	(1)2	1-3
Caudal-fin rays - P	(18)19	(18)19(20)	Caudal-fin rays - RD	(5)6-7-8-9(10)	3-7
Pectoral-fin rays	(12-)14-16-17(18)	14-15-16-18	Caudal-fin rays - RV	(5)6-7-8(9)	5-7
Pelvic-fin rays	(6)7-8-9	(5-)8-9	Lateral scales	34-40	32-35-38-41
Vertebrae	37-38	(32-)35-36(-39)	Pharyngeal teeth	–	1,1(2),3/3,1(2),1

*Includes re-examined data originally prepared for Snyder (1981) and Snyder et al. (2005) and supplements and updates those accounts.
**First principal ray is spine-like (thickened and hardened) and serrated on posterior margin; rudimentary rays before it are also spine-like.

Table 7. Size at onset of selected developmental events for *Cyprinus carpio*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	(4)5	5	Dorsal - P	9-10(11)	10-12	12-13	15-16
Eyes pigmented	*	*	Anal - P	11(12)	12-13(14)	(11)12(13)	(13)14-15(16)
Yolk assimilated	6-7	(6)7	Caudal - P	7-8	8	(8)9(10)	(9)10(11)
Finfold absorbed	(17)18-19	(21)21-23	Caudal - R	9-10(11)	10-12(13)	(13)14-16(17)	(16)17-19(20)
Pectoral-fin buds	*	*	Pectoral	(10)11-12	(12)13-15	(13)14-16(17)	(16)17-19(20)
Pelvic-fin buds	(10)11	12(13)	Pelvic	(11)12	14-15	(12)13-16(17)	(15)16-19(20)
* before hatching			Scales	14-15	17-19	(15-)17-18	(19)21-22

References: Balon 1975a; Becker 1983; Beckman 1952; Carlander 1969; Gerlach 1983; Heufelder and Fuiman 1982; Jones et al. 1978; Korwin-Kossakowski 2008; La Rivers 1962; Lentsch et al. 1996; Minckley 1973; Moyle 1976; Page and Burr 1991; Scott and Crossman 1973; Simon 1998; Snyder 1981; Snyder et al. 2005; Sublette et al. 1990; Swee and McCrimmon 1966; Tyus et al. 1982; Woodling 1985.
Other larval descriptions: See end of account.

Table 8. Size at developmental interval (left) and gut phase (right) transitions for *Cyprinus carpio*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	7-8	8	2 - 90° bend	11-12	(12)13-15
Postflexion mesolarva	(8)9(10)	(9)10(11)	3 - Full loop	12-15	15-19
Metalarva	12-13	15-16	4 - Partial crossover	19-27	23-32
Juvenile	(17)18-19	(21)22-23	5 - Full	27-31(32)	32-39

Table 9. Summary of morphometrics and myomere counts by developmental phase for *Cyprinus carpio*. (See Figure 4 for abbreviations and methods of measurement and counting. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts, in part with data extracted from selected Fish 1932, Bragensky 1960, Nakamura 1969, Taber 1969, and Wang and Kernehan 1979 illustrations used therein.)

	Protolarvae (N=14)			Flexion mesolarvae (N=8)			Postflexion mesolarvae (N=18)			Metalarvae (N=19)			Juveniles (N=21)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	6	1	5 - 8	8	1	7 - 10	11	1	8 - 13	15	2	12 - 18	29	7	19 - 42
TL, mm	6	1	5 - 8	9	1	8 - 11	13	2	10 - 16	19	2	15 - 22	35	9	23 - 50
Lengths %SL															
AS to AE	4	1	3 - 6	5	1	4 - 7	6	1	5 - 7	7	1	6 - 9	9	1[r]	7 - 11
PE	11	1	9 - 13	13	1	11 - 15	15	1[g]	13 - 17	16	1	13 - 18	17	1[r]	14 - 19
OP1	20	2	16 - 23	24	1	22 - 26	29	2	26 - 33	32	2	29 - 35	31	2[r]	29 - 34
OP2							52	2[h]	49 - 55	52	1	50 - 55	53	2	48 - 56
PY	68	3[a]	63 - 71												
OPAF	42	7	34 - 59	37	4	31 - 45	43	6[i]	35 - 57	56	7[p]	44 - 64			
ODF	42	3	37 - 47	46	2	44 - 49	48	2[f]	46 - 51	47	[m]	47 - 47			
OD							49	1[j]	48 - 52	49	1	47 - 52	49	2	46 - 51
ID										81	1[p]	79 - 83	82	1	80 - 86
PV	72	1	70 - 75	74	2	70 - 75	76	1	74 - 78	75	1	72 - 77	75	1	72 - 77
OA							76	1[k]	74 - 77	74	1[q]	74 - 75	74	2[a]	72 - 77
IA							82	0[l]	82 - 82	83	1	80 - 84	83	2	80 - 86
AFC							111	2	108 - 113	112	2[g]	109 - 115	112	2	109 - 116
PC	106	1	104 - 110	108	1	106 - 110	118	4	109 - 125	122	3	118 - 127	123	2	117 - 127
Y	42	19[b]	0 - 59												
P1	11	3	4 - 14	14	1	12 - 15	13	2	10 - 18	14	2[p]	12 - 17	16	2[r]	12 - 19
P2							4	3	0 - 9	10	1	8 - 13	14	2	11 - 17
D										34	1	31 - 36	38	2	35 - 41
A							13	[m]	13 - 13	14	1[p]	10 - 16	17	2	14 - 19
Depths %SL															
at BPE	15	1	13 - 18	16	1[f]	15 - 18	20	2	12 - 23	22	1	20 - 24	23	1	21 - 25
OP1	17	4[b]	13 - 29	18	1	16 - 20	23	2	19 - 27	27	1	24 - 30	31	2	28 - 35
OD	13	1	11 - 16	12	2	11 - 16	20	4	13 - 25	27	2	23 - 30	33	2	30 - 37
BPV	7	1	6 - 8	7	1	6 - 8	11	3	7 - 15	15	1	13 - 17	20	2	17 - 23
AMPM	4	1	2 - 5	5	1	4 - 7	8	1	7 - 10	10	1	8 - 12	12	1	11- 13
Max. yolk	11	8[c]	0 - 23												
Widths %SL															
at BPE	14	1[d]	12 - 16	15	1	13 - 16	18	1	15 - 20	20	1[g]	19 - 20	19	1[s]	18 - 21
OP1	11	6[e]	6 - 28	11	1	10 - 13	15	2	11 - 17	18	2[g]	16 - 21	21	2[s]	18 - 24
OD	7	1[d]	5 - 10	7	1	5 - 8	11	2[g]	7 - 15	15	2[g]	11 - 17	19	2[s]	16 - 22
BPV	5	1[d]	3 - 5	5	1	4 - 7	8	1	6 - 11	9	1[g]	8 - 12	12	3[p]	8 - 17
AMPM	2	1[e]	1 - 4	3	1	2 - 5	4	1	2 - 6	5	1[g]	3 - 6	6	2[s]	3 - 9
Max. yolk	11	8[f]	0 - 25												
Myomeres															
to PY	23	1[e]	22 - 26												
OPAF	10	2	7 - 15	7	1[f]	5 - 9	9	2[d]	7 - 12	15	3[n]	10 - 20			
OP2							14	1[n]	13 - 15	13	1[b]	11 - 14	12	1[f]	11 - 14
ODF	10	1	9 - 12	11	1	10 - 13	12	1[o]	10 - 12						
OD							12	1[q]	11 - 13	11	1[b]	10 - 13	10	1[f]	9 - 11
PV	26	1	23 - 27	27	1	25 - 28	27	1[h]	26 - 28	26	1[b]	25 - 28	25	1[f]	24 - 27
Total	37	1	35 - 38	38	1	36 - 39	37	1[h]	36 - 38	37	1[b]	36 - 39	37	0[f]	36 - 37
After PV	11	1	10 - 12	11	1	10 - 11	11	1[h]	10 - 12	11	1[b]	10 - 12	12	1[f]	10 - 13

[a]N = 9. [b]N = 13. [c]N = 10. [d]N = 12. [e]N = 11. [f]N = 7. [g]N = 17. [h]N = 14. [i]N = 16. [j]N = 15. [k]N = 4. [l]N = 2. [m]N = 1. [n]N = 8. [o]N = 6. [p]N = 18. [q]N = 10. [r]N = 20. [s]N = 19.

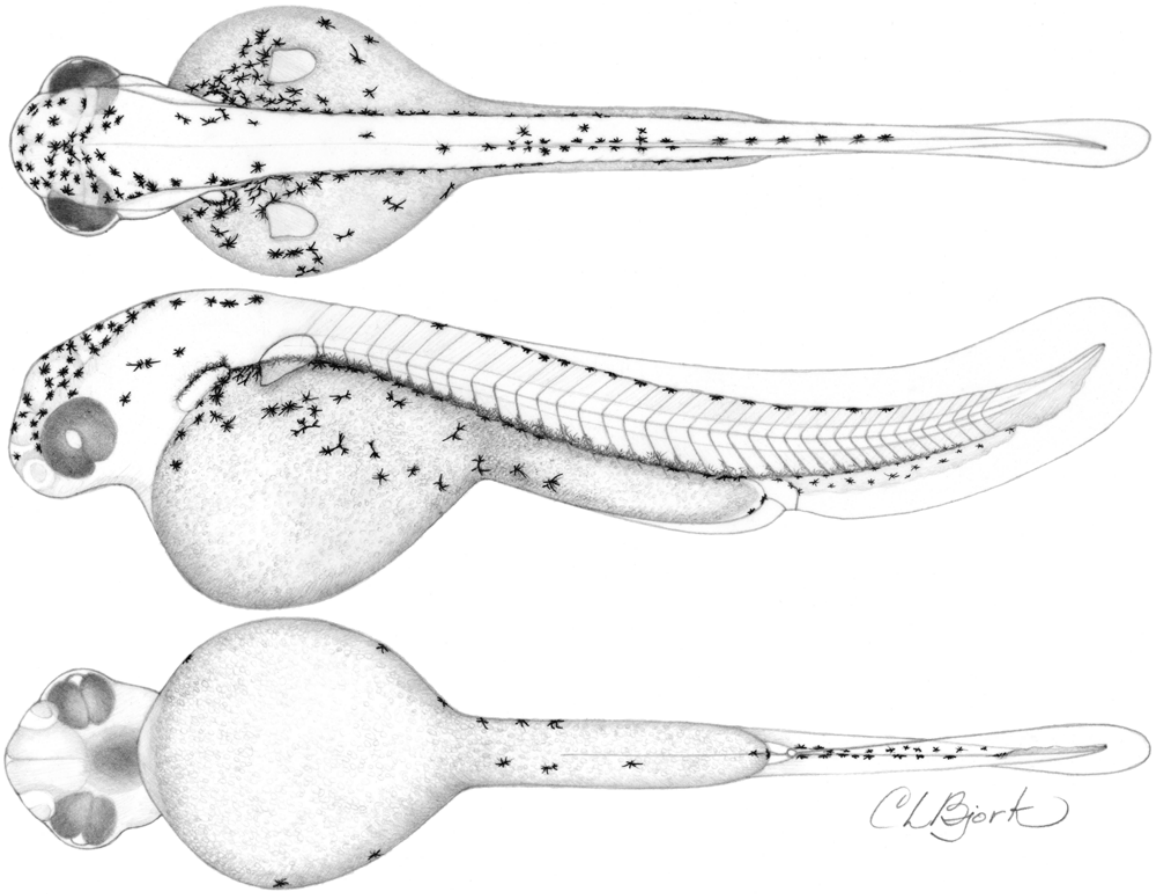

Figure 18. *Cyprinus carpio* protolarva, recently hatched, 4.8 mm SL, 5.0 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University from eggs collected at River Bend Ponds, Fort Collins, Larimer County, Colorado.)

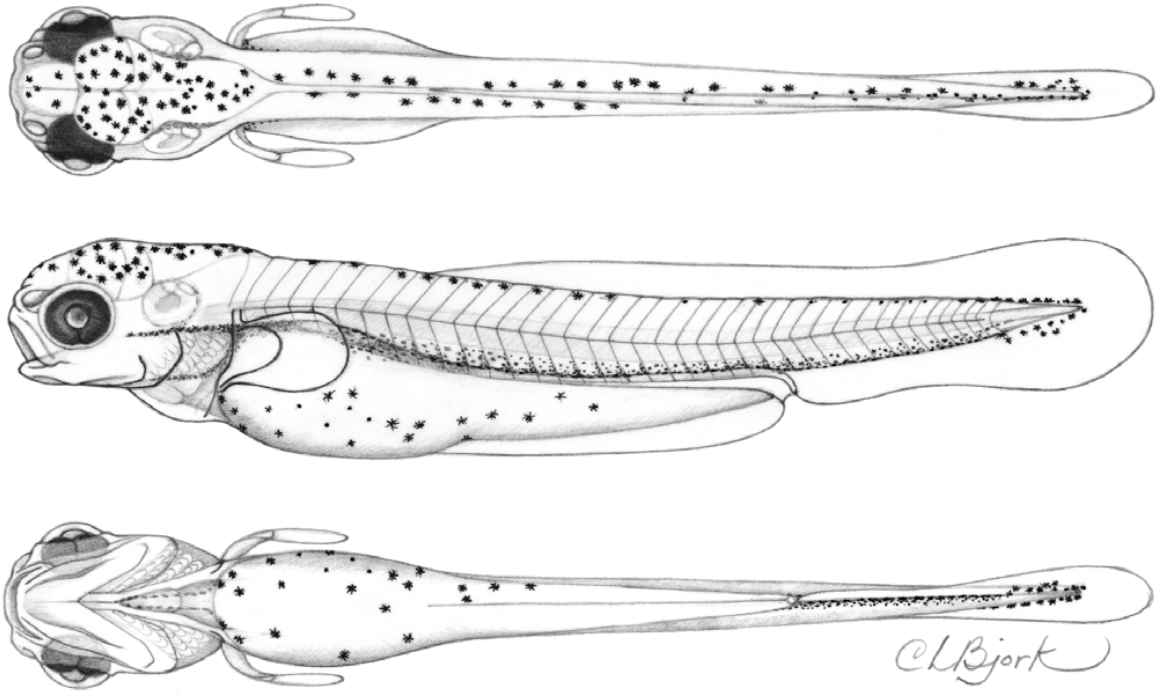

Figure 19. *Cyprinus carpio* protolarva, 5.7 mm SL, 6.1 mm TL. (Collected in 1976 or 1977 from the Yampa River between Dinosaur National Monument, Moffat County, and Hayden, Routt County, Colorado; from LFL #73048.)

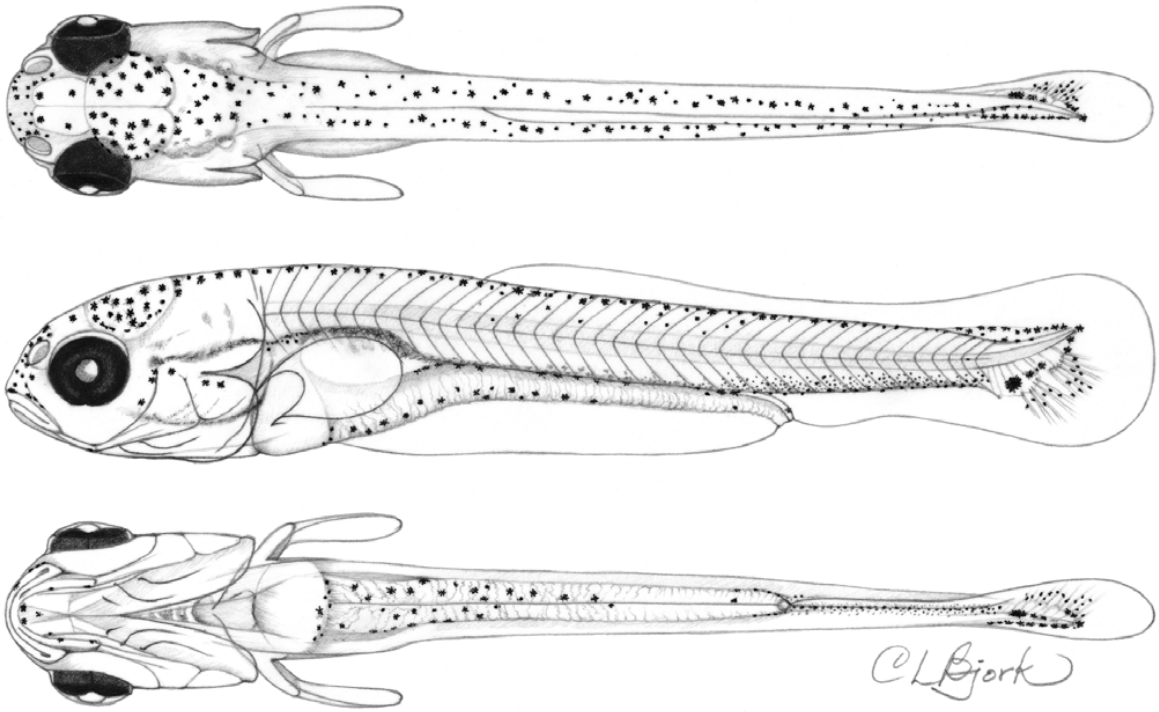

Figure 20. *Cyprinus carpio* flexion mesolarva, recently transformed, 8.2 mm SL, 8.8 mm TL. (Collected in 1996 from the Gunnison River near Grand Junction, Colorado; from LFL #31315.)

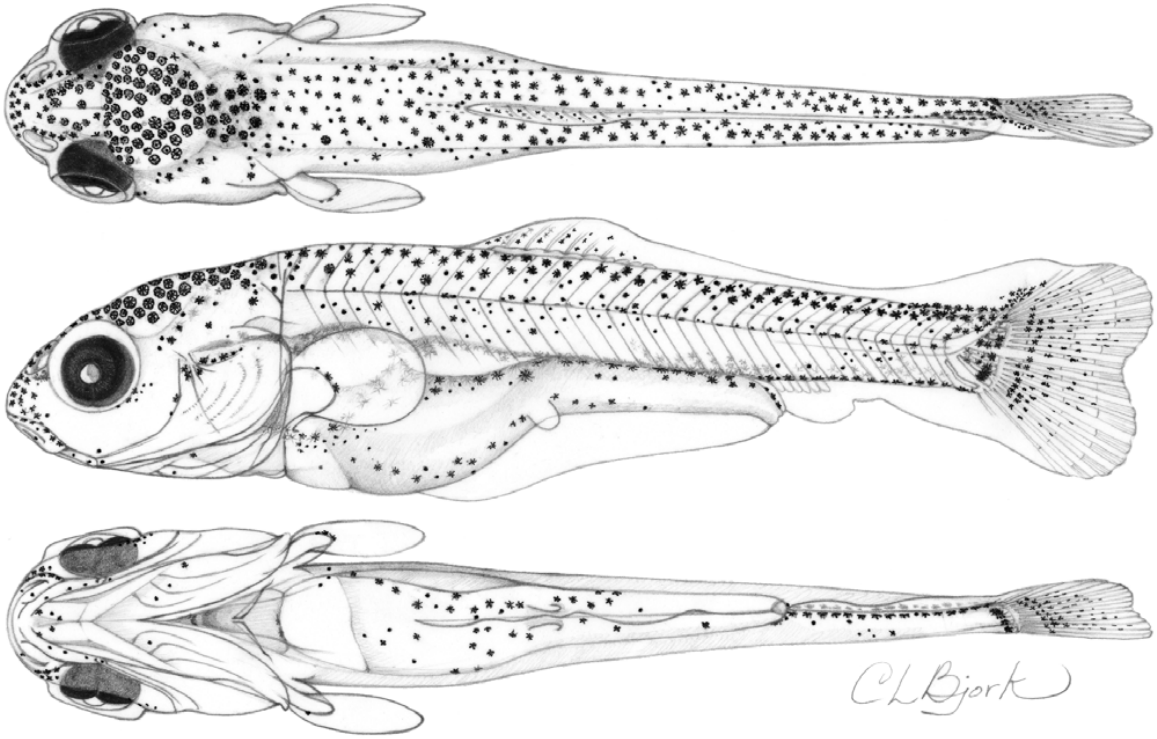

Figure 21. *Cyprinus carpio* postflexion mesolarva, 10.5 mm SL, 12.1 mm TL. (Collected in 2002 from the Gunnison River near Escalante, Colorado; from LFL #82354.)

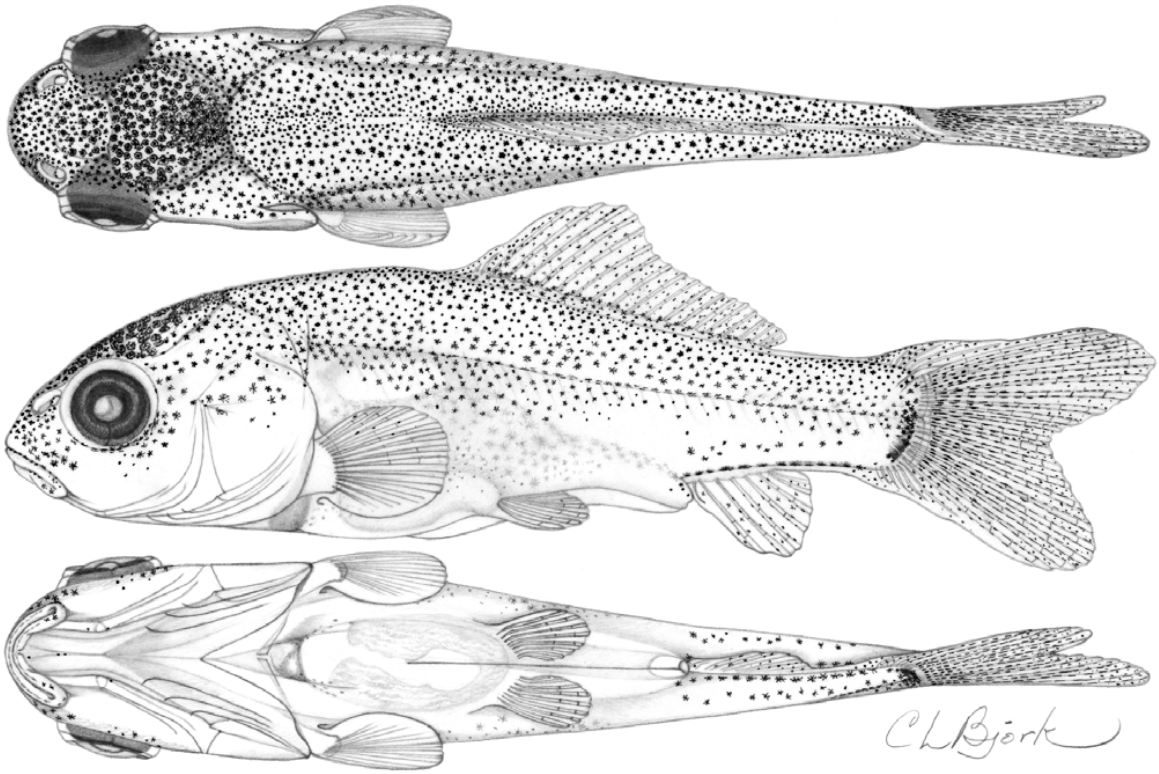

Figure 22. *Cyprinus carpio* metalarva, recently transformed, 13.1 mm SL, 16.4 mm TL. (Collected in 1989 from the Gunnison River near Grand Junction, Colorado; from LFL #8515.)

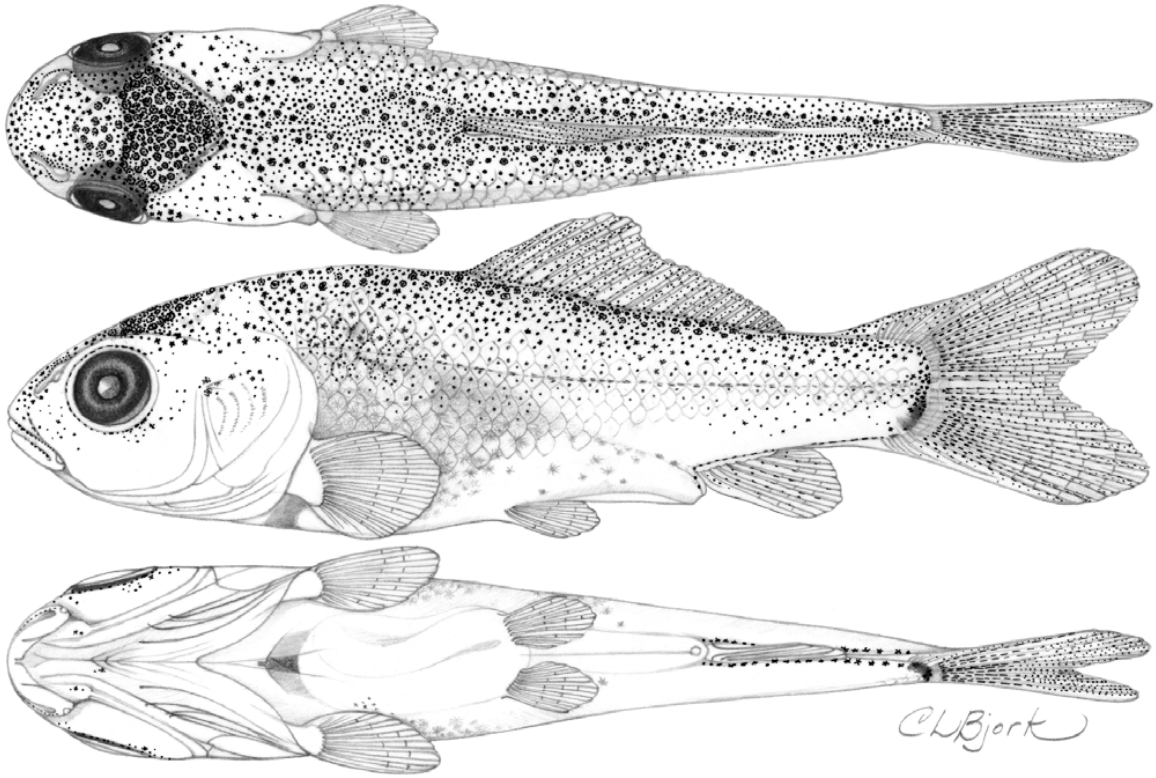

Figure 23. *Cyprinus carpio* metalarva, 17.3 mm SL, 21.2 mm TL. (Collected in 2003 from the Green River, Dinosaur National Monument, Moffat County, Colorado; from LFL #87799.)

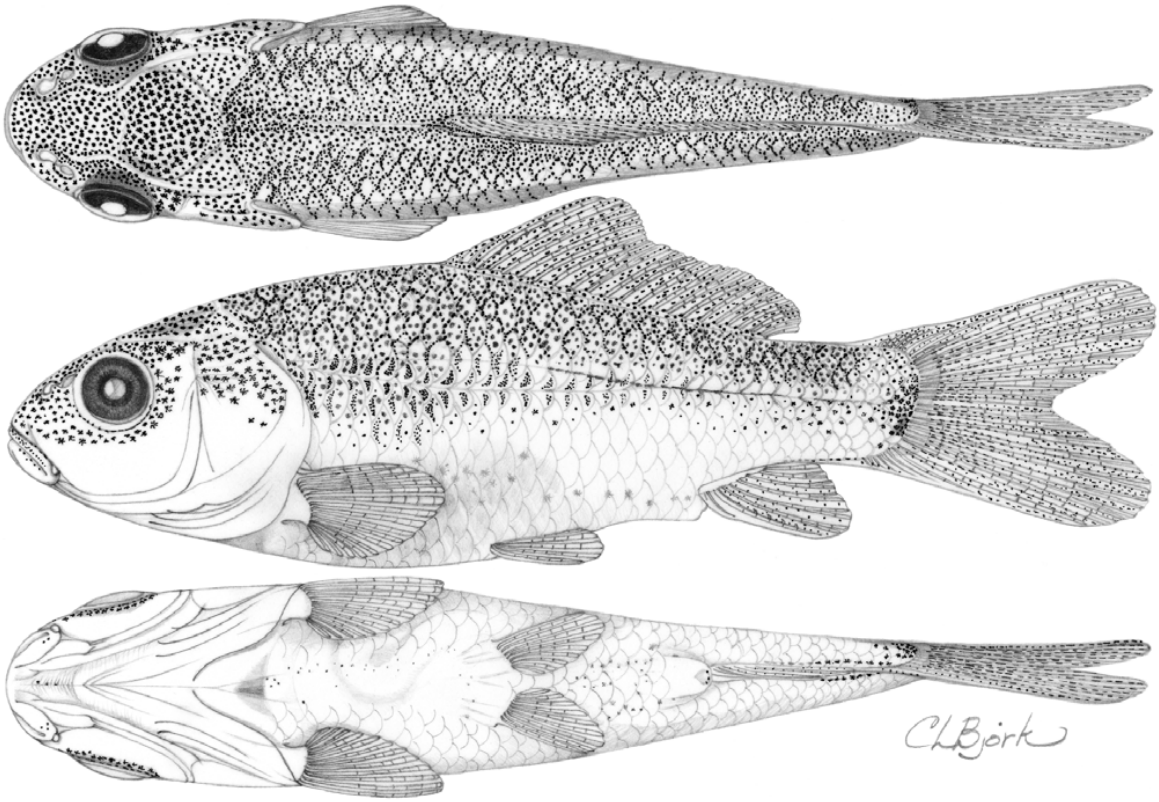

Figure 24. *Cyprinus carpio* juvenile, recently transformed, 22.4 mm SL, 27.5 mm TL. (Collected in 2004 from the Green River, Dinosaur National Monument, Moffat County, Colorado; from LFL #88897.)

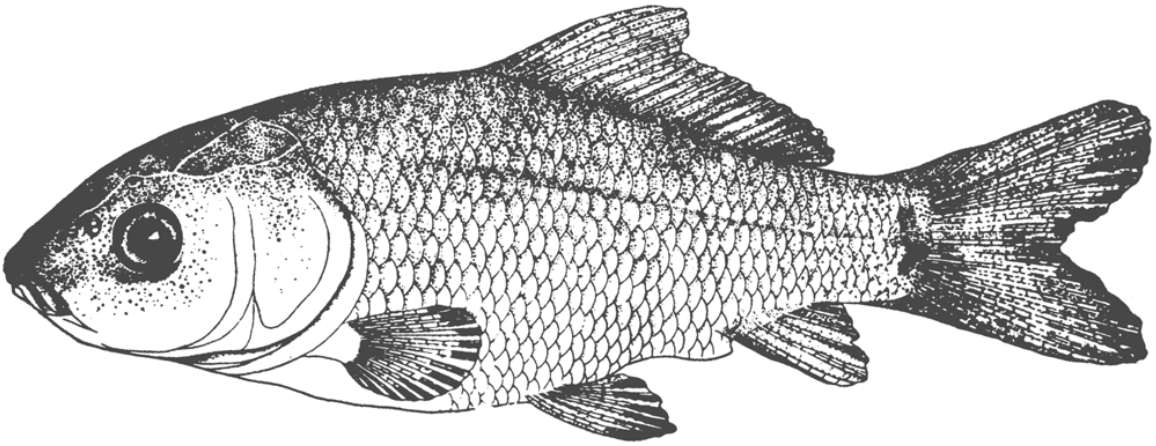

Figure 25. *Cyprinus carpio* juvenile, 24.2 mm SL, 30.0 mm TL. (From Bragensky 1960, Figure 9.)

Other larval descriptions: Arvidson and Alber 2013; Balon 1958; Bragensky 1960; Conner et al. 1980; Ehrenbaum 1909; Faber 2006 onwards; Fish 1932; Fuiman et al. 1983; Gerlach 1983; Heufelder and Fuiman 1982; Hikita 1956; Hoda and Tsukahara 1971; Hogue et al. 1976; Holland-Bartels et al. 1990; Itazawa 1963; Jones et al. 1978; Jude et al. 1979; Korwin-Kossakowski 2008; Lippson and Moran 1974; Loos et al. 1979; Mansueti and Hardy 1967; May and Gasaway 1967; McCrimmon and Swee 1967; McGowan 1988; Nakamura 1969; Nakatani et al. 2001; Nordqvist 1914; Okada 1960; Penaz et al. 1983; Pinder 2001; Scheidegger 1990; Smallwood and Derrickson 1933; Smallwood and Smallwood 1931; Snyder 1981; Snyder et al. 2005; Taber 1969; Verma 1970; Wang 1986; Wang and Kernehan 1979; Wang and Reyes 2007; others cited by these.

Species Account – *Gila atraria*, Utah chub

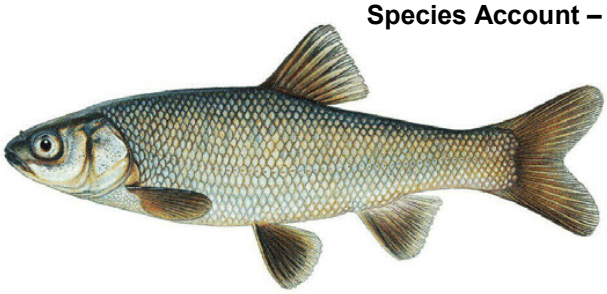

Figure 26. *Gila atraria* adult (© Joseph R. Tomelleri).

Adult description: Usually 13–30 cm TL, up to 41, very rarely to58 cm. Body stout with moderately short head and deep caudal peduncle. Mouth terminal, with lower jaw sometimes projecting beyond upper, oblique, and usually extending to below anterior margin of eye. Gut short, usually s-shaped. Dorsal fin origin over or slightly before or after pelvic origin. Scales moderate. Olivaceous to brownish black dorsally and on fins, brassy, golden, or silvery laterally, and yellowish, silvery, or white, sometimes dark, below. Breeding males yellow-orange along ventral and ventrolateral surfaces with traces of orange in axil of pectoral fins, corner of mouth and on preopercle; sometimes golden streak on upper sides; no tubercles. (Also, Table 10.)

Reproduction: Non-guarding, open-substrate phytolithophil. Mature at ages 2-5, mostly 3(♂) or 4(♀). Spawn April through August when water ranges 11–20°C , mostly June to mid-July when water surface approaches 20–21°C, in shallow (<0.6 m) littoral shoals, sloughs, or shorelines, usually over vegetation, but silt, mud, or sand substrate if absent. Eggs initially very adhesive, demersal, and 1.6–1.9 mm in diameter (range 0.8–2.6 mm), but mostly 1.9–2.3 mm with a range of 1.8–2.5 (orig.) after water hardening.

Young: Hatch in 3–9 d at 22–17°C, respectively. Young grow to ~10 mm TL in 1.5 month. and generally remain in spawning habitat for at least the next couple months, schooling along mostly vegetated, shallow (~4–12 cm) shorelines.

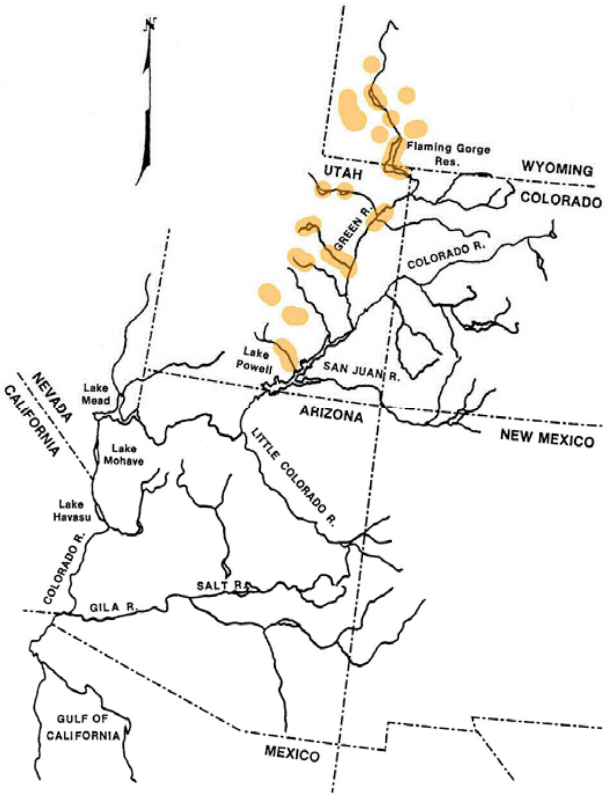

Figure 27. Recent distribution of *Gila atraria* in the Colorado River Basin.

Table 10. Selected juvenile and adult meristics for *Gila atraria*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	(8)9(10)	8-9-10	Dorsal-fin rays - R	2-3	–
Anal-fin rays - P	(7)8(9)	7-8-9	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	(18)19(20)	–	Caudal-fin rays - RD	8-9-10	–
Pectoral-fin rays	(12)13-14(-16)	–	Caudal-fin rays - RV	(7)8-9	–
Pelvic-fin rays	(7)8(9)	–	Lateral scales	(52)53-56(57)	(45-)50-63(-65)
Vertebrae	39	–	Pharyngeal teeth	–	2,5/4,2

* Includes re-examined data originally prepared for Snyder (1981) and supplements and updates that account.

Table 11. Size at apparent onset of selected developmental events for *Gila atraria*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	4-5	(4)5	Dorsal - P	8	(8)9	9-10	10-11
Eyes pigmented	*4-5	*(4)5	Anal - P	8(9)	9-10	9-10	(10)11-12
Yolk assimilated	6-7	7	Caudal - P	7	7(8)	8	(8)9
Finfold absorbed	15-16	(18)19	Caudal - R	8(9)	9(10)	(13)14-16	(16)17-19
Pectoral-fin buds	*4(5)	*(4)5	Pectoral	10	11-12	12-13	15
Pelvic-fin buds	(8)9	10	Pelvic	10	12	12-13	15-16
* before hatching			Scales	19-20	23-25	(22)23-25	27-30(31)

References: Balon 1975a; Baxter and Simon 1970; Baxter and Stone 1995; Carlander 1969; La Rivers 1962; Lentsch et al. 1996; Minckley 1973; Moore 1968; Page and Burr 1991; Sigler and Miller 1963; Sigler and Sigler 1996; Simpson and Wallace 1978; Snyder 1981; Tyus et al. 1982; Vanicek et al. 1970; Varley and Livesay 1976.

Other larval descriptions: Fuiman et al. 1983; Snyder 1981; Valdes-Gonzales 1982.

Table 12. Size at developmental interval (left) and gut phase (right) transitions for *Gila atraria*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	7	7(8)	2 - 90° bend	10-11(12)	12-13(14)
Postflexion mesolarva	8	(8)9	3 - Full loop	15(16)	19
Metalarva	(9)10	(10)11-12	4 - Partial crossover	(not applicable)	
Juvenile	(15)16	(18)19-20	5 - Full	(not applicable)	

Table 13. Summary of morphometrics and myomere counts by developmental phase for *Gila atraria*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981, except morphometric data based on alcohol-preserved specimens, and supplements and updates that account.)

	Protolarvae (N=21)			Flexion mesolarvae (N= 11)			Postflexion mesolarvae (N=15)			Metalarvae (N=29)			Juveniles (N=13)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	6	1	4 - 7	7	0	7 - 8	9	1	8 - 10	12	2	9 - 16	23	7	16 - 38
TL, mm	6	1	5 - 7	8	1	7 - 9	10	1	9 - 12	15	2	11 - 19	29	9	20 - 46
Lengths %SL															
AS to AE	3	1[a]	2 - 4	3	0[g]	3 - 3	3	1[i]	3 - 5	4	1[n]	3 - 6	5	1	4 - 6
PE	10	1[a]	8 - 11	10	1[g]	9 - 11	12	1[i]	11 - 13	13	1[n]	12 - 15	13	1	12 - 14
OP1	19	1[a]	17 - 22	21	1[g]	20 - 22	24	1[i]	22 - 26	27	1[n]	24 - 30	26	1	25 - 28
OP2							50	1[k]	49 - 51	52	2[n]	49 - 55	52	2	49 - 54
PY	63	5[b]	58 - 71												
OPAF	39	11[a]	26 - 60	30	4[g]	24 - 33	36	2[i]	33 - 38	48	9[o]	36 - 64			
ODF	39	4[c]	30 - 44	42	2[g]	39 - 44	46	2[i]	43 - 50	49	1[p]	48- 50			
OD							51	1[j]	49 - 52	51	1[n]	49 - 54	51	1	48 - 53
ID							60	2[j]	58 - 63	62	2[n]	59 - 66	63	1	60 - 65
PV	68	2[a]	66 - 72	68	1[g]	67 - 68	70	2[i]	67 - 72	68	1[n]	66 - 72	68	1	65 - 70
OA							70	1[g]	68- 71	69	1[n]	66 - 71	69	1	65 - 70
IA							77	1[g]	75- 78	77	1[n]	76 - 79	78	2	75 - 81
AFC							109	1[i]	108 - 110	112	1[q]	109 - 115	113	2	110 - 115
PC	105	1[a]	103 - 107	106	1[g]	104 - 107	112	2[i]	108 - 116	121	2[n]	115 - 125	122	2	119 - 125
Y	36	21[d]	0 - 61												
P1	9	3[a]	3 - 12	12	1[g]	11 - 13	13	1[i]	12 - 14	15	2[n]	12 - 18	16	2	13 - 18
P2							1	2[i]	0 - 5	9	3[n]	4 - 13	13	1	12 - 15
D							13	1[k]	11- 15	18	2[n]	15 - 23	21	1	19 - 24
A							10	1[h]	9 - 11	13	1[n]	11 - 17	16	1	13 - 18
Depths %SL															
at BPE	13	1[a]	10 - 16	12	1[g]	11 - 13	15	1[i]	13 - 18	18	1[n]	16 - 20	19	1	17 - 21
OP1	15	4[a]	11 - 24	13	1[g]	12 - 15	17	1[i]	15 - 19	20	1[n]	18 - 22	23	1	22 - 24
OD	11	2[e]	9 - 15	10	1[h]	9 - 11	13	2[i]	10 - 16	19	3[n]	14 - 23	24	2	21 - 26
BPV	6	1[a]	5 - 8	7	1[g]	6 - 7	9	1[i]	7 - 11	13	1[n]	10 - 15	17	1	14 - 18
AMPM	4	1[a]	3 - 5	4	1[g]	3 - 5	6	1[i]	4 - 8	8	1[n]	7 - 10	10	1	9 - 12
Max. yolk	7	7[d]	0 - 18												
Widths %SL															
at BPE	12	2[a]	9 - 16	13	2[g]	11 - 15	16	1[i]	14 - 18	17	1[n]	15 - 20	17	1	15 - 20
OP1	11	3[a]	7 - 19	9	1[g]	8 - 11	13	2[i]	10 - 18	16	1[n]	13 - 18	17	2	14 - 19
OD	6	1[e]	5 - 9	5	1[h]	5 - 6	7	1[i]	6 - 10	12	2[n]	8 - 16	16	2	12 - 20
BPV	5	1[a]	3 - 5	4	1[g]	4 - 5	6	1[i]	5 - 7	8	1[n]	7 - 10	11	1	9 - 13
AMPM	2	1[a]	1 - 3	2	1[g]	2 - 3	4	0[i]	3 - 4	5	0[n]	4 - 5	5	1	4 - 7
Max. yolk	8	7[d]	0 - 21												
Myomeres															
to PY	25	2[d]	22 - 28												
OPAF	12	5	6 - 22	6	2	4 - 9	8	1	5 - 10	15	5[q]	7 - 23			
OP2							15	1[l]	13 - 17	17	1	15 - 19	16	1[r]	15 - 18
ODF	12	2[f]	7 - 16	12	1	10 - 14	14	1	11 - 16	14	1[h]	13- 16			
OD							16	1[m]	13 - 18	16	1	14 - 18	16	1[r]	15 - 17
PV	27	1	26 - 28	26	1	25 - 28	27	1	25 - 28	27	1	24 - 28	27	1[r]	25 - 28
Total	40	1	38 - 41	39	1	38 - 41	40	1	39 - 40	40	1	37 - 41	40	1[r]	39 - 41
After PV	12	1	10 - 14	13	1	12 - 14	13	1	12 - 14	13	1	12 - 14	13	1[i]	12 - 14

[a]N = 18. [b]N = 13. [c]N = 17. [d]N = 16. [e]N = 12. [f]N = 20. [g]N = 6. [h]N = 4. [i]N = 11. [j]N = 10. [k]N = 5. [l]N = 7. [m]N = 14. [n]N = 27. [o]N = 24. [p]N = 3. [q]N = 26. [r]N = 9.

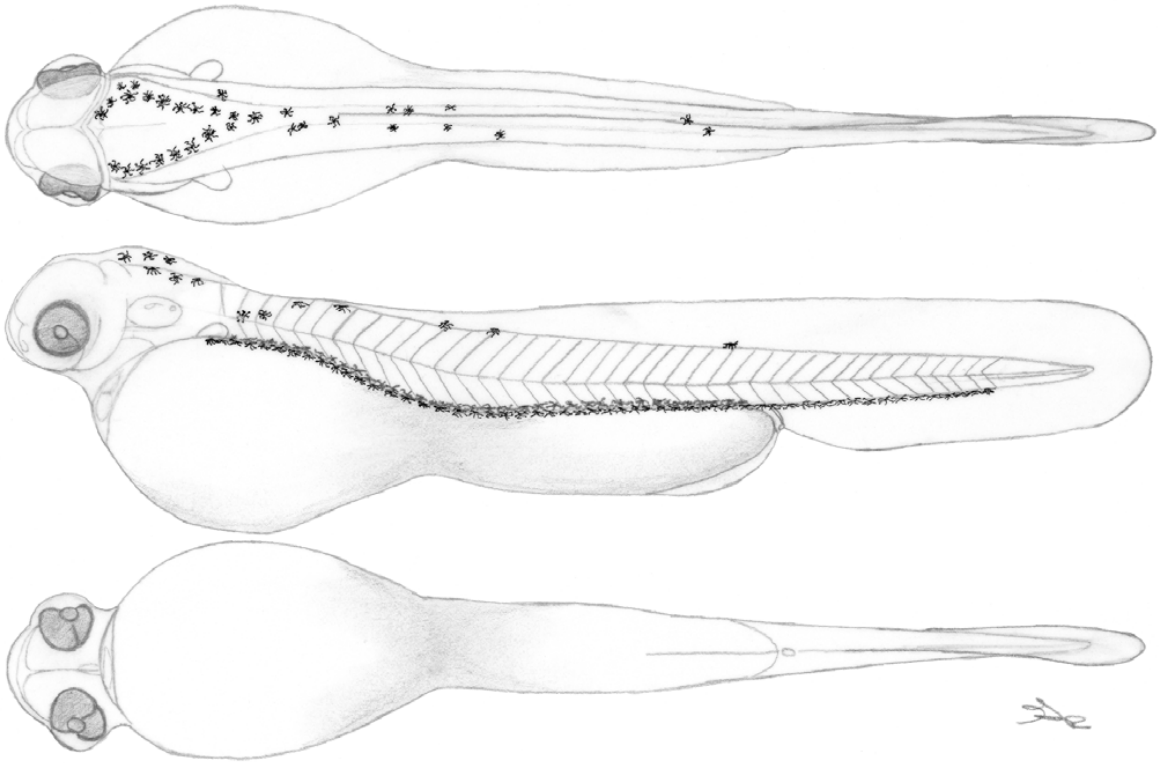

Figure 28. *Gila atraria* protolarva with yolk, recently hatched, 4.4 mm SL, 4.7 mm TL. (Cultured in 1971 by John D. Varley, Utah Division of Wildlife, with stock from Flaming Gorge Reservoir. From Snyder1981, page 23.)

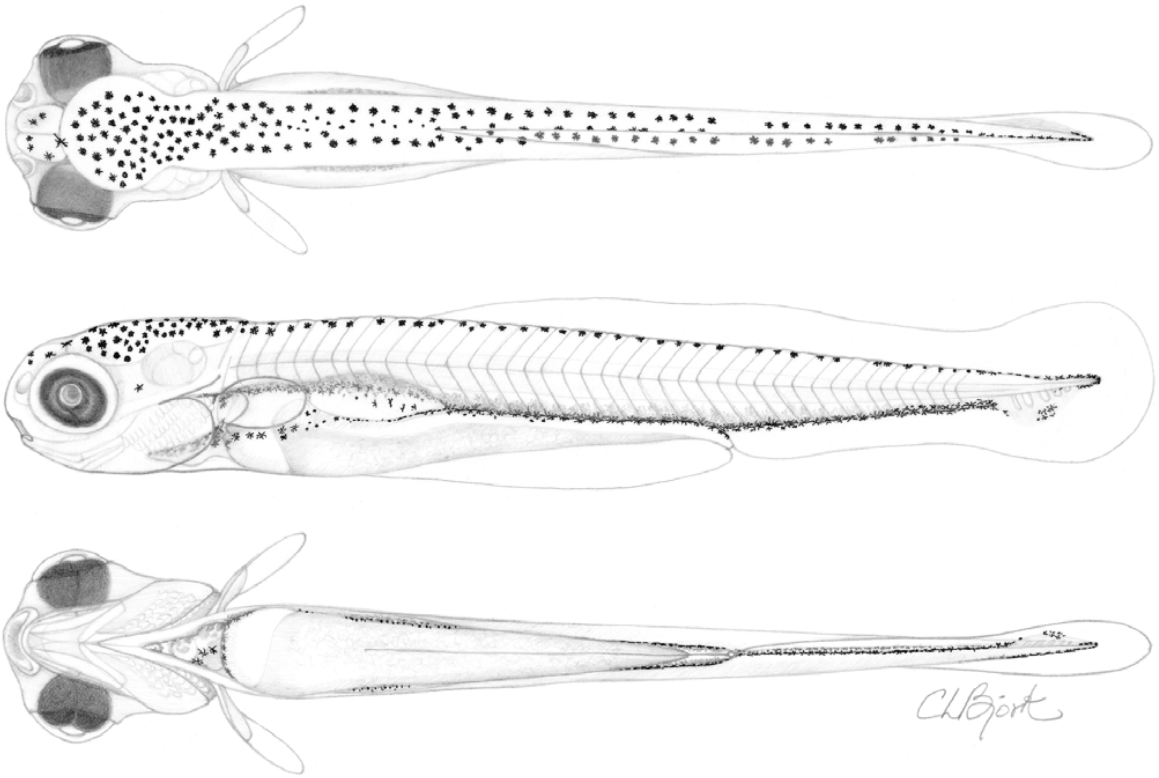

Figure 29. *Gila atraria* protolarva with yolk ,6 d posthatch, 6.6 mm SL, 6.9 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock from Joe's Valley Reservoir, Emery County, Utah.)

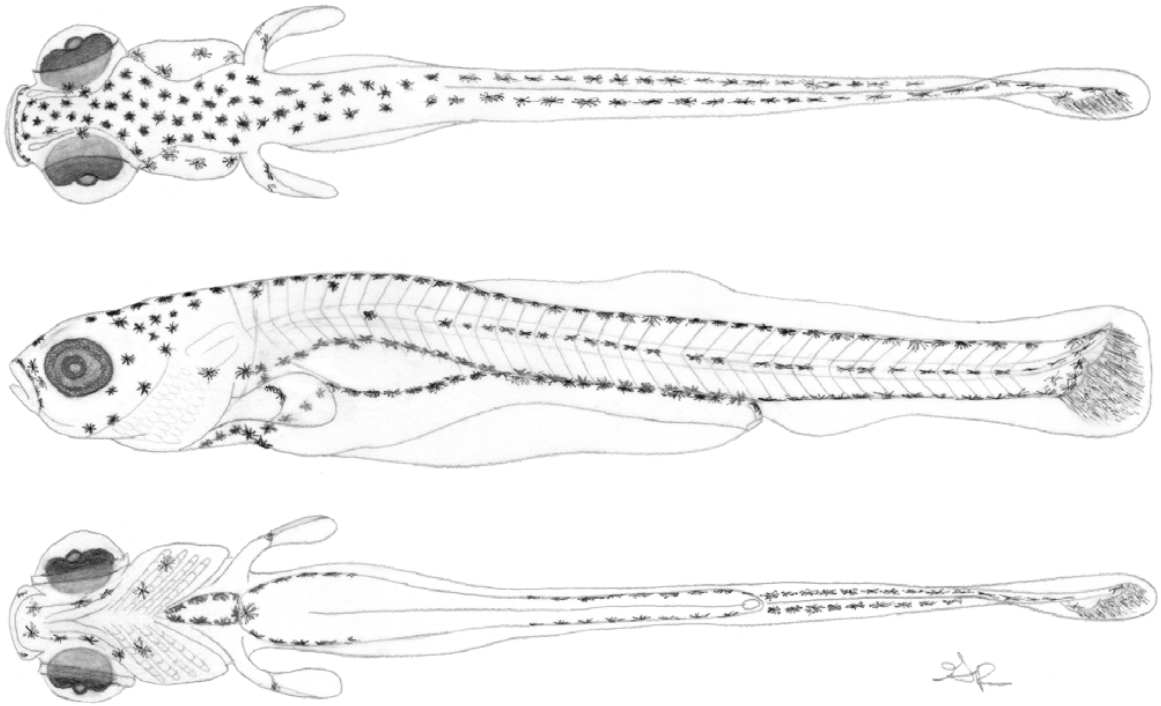

Figure 30. *Gila atraria* flexion mesolarva, recently transformed, 7.1 mm SL, 7.4 mm TL. (Cultured in 1971 by John D. Varley, Utah Division of Wildlife, with stock from Flaming Gorge Reservoir. From Snyder 1981, page 23.)

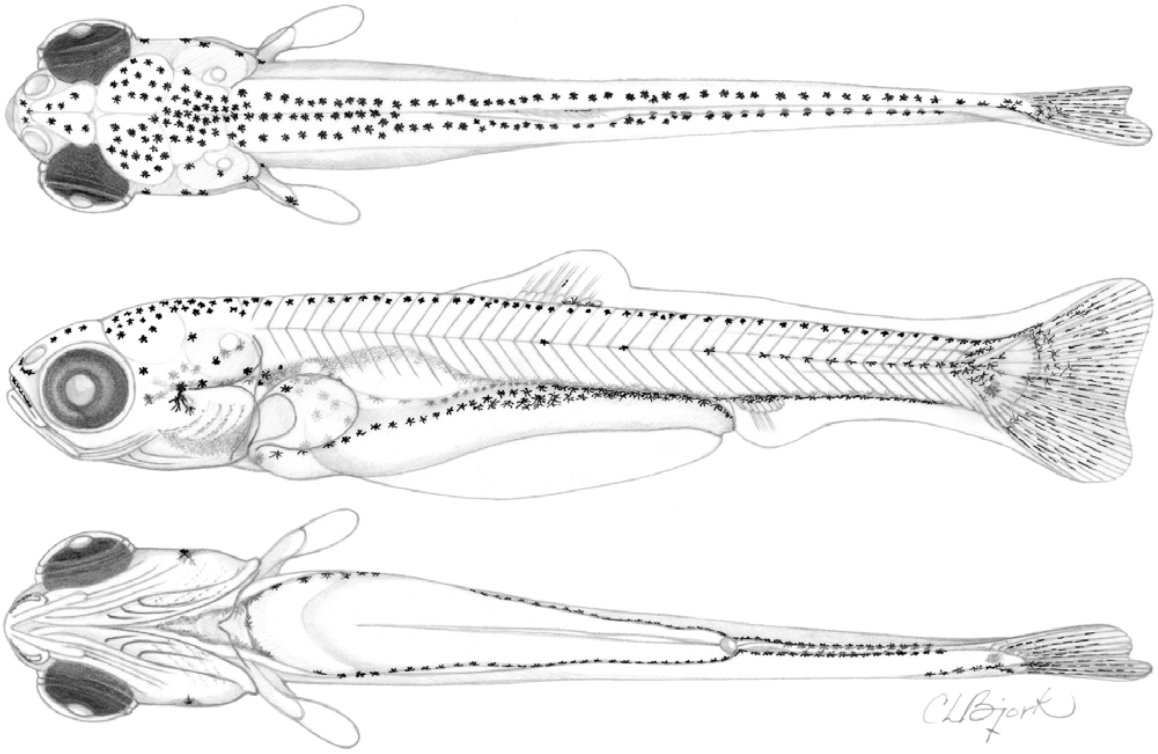

Figure 31. *Gila atraria* postflexion mesolarva, 9.0 mm SL, 10.0 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock from Joe's Valley Reservoir, Emery County, Utah.)

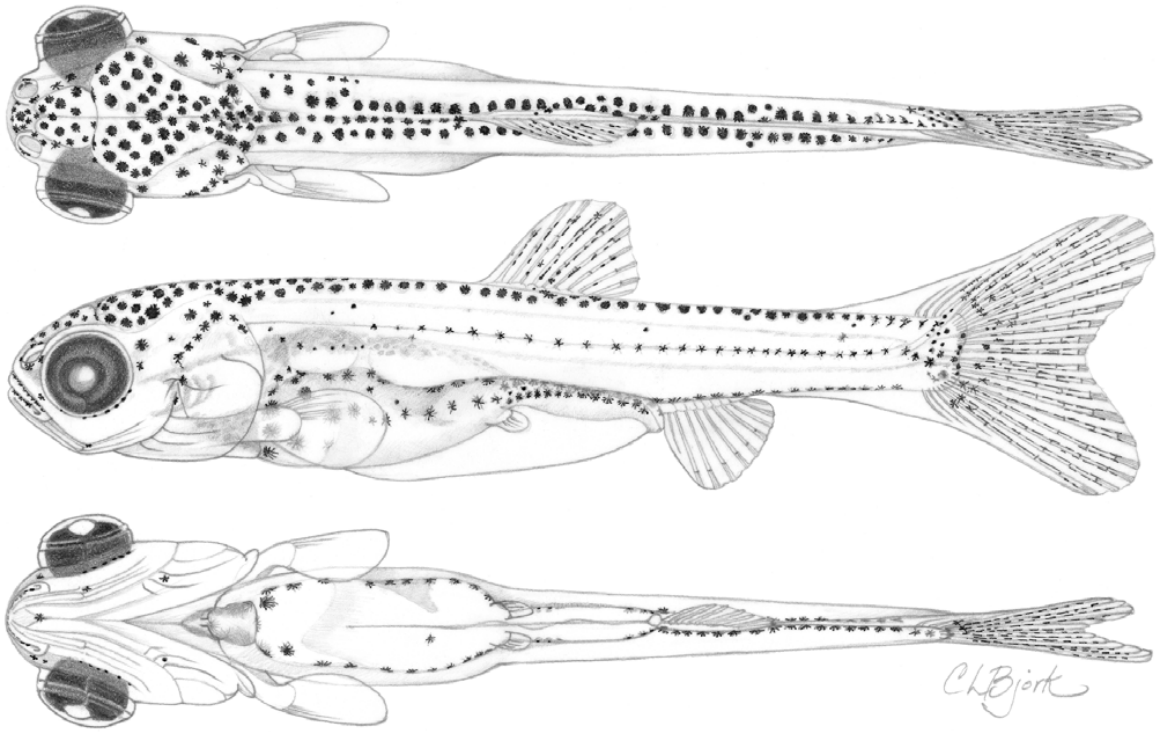

Figure 32. *Gila atraria* metalarva, recently transformed, 9.9 mm SL, 11.8 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock from Joe's Valley Reservoir, Emery County, Utah.)

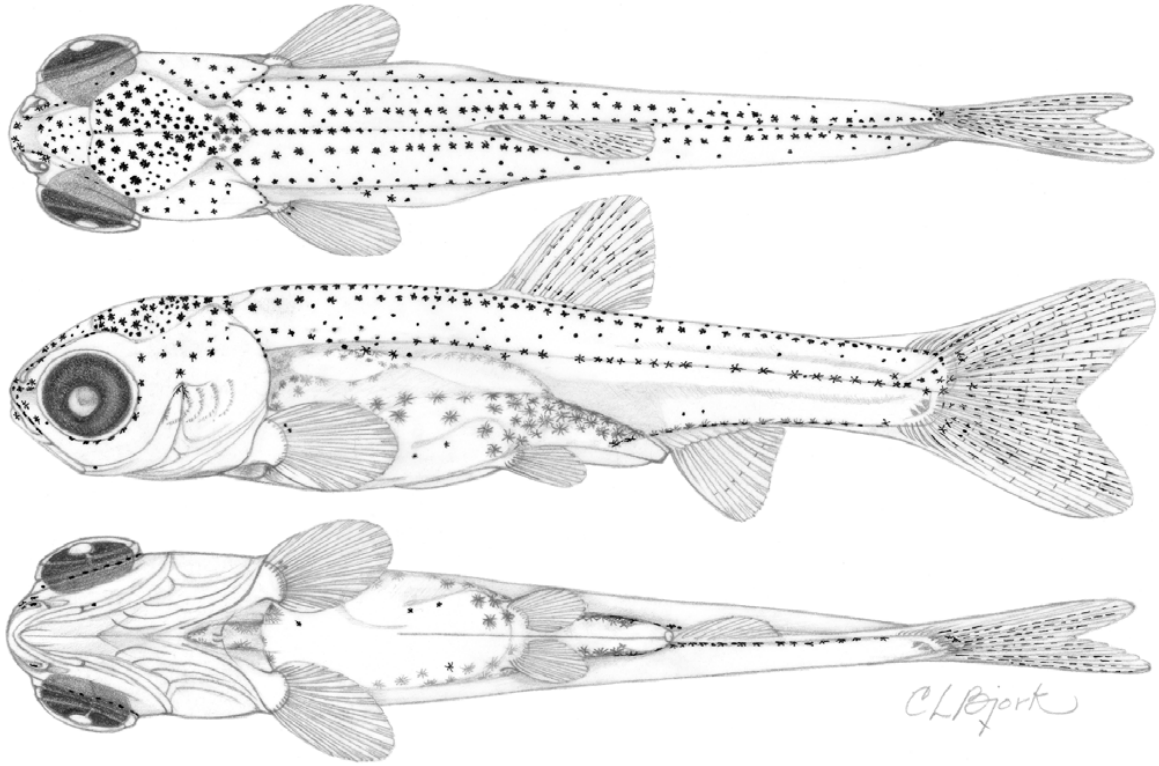

Figure 33. *Gila atraria* metalarva, 12.2 mm SL, 14.7 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock from Joe's Valley Reservoir, Emery County, Utah.)

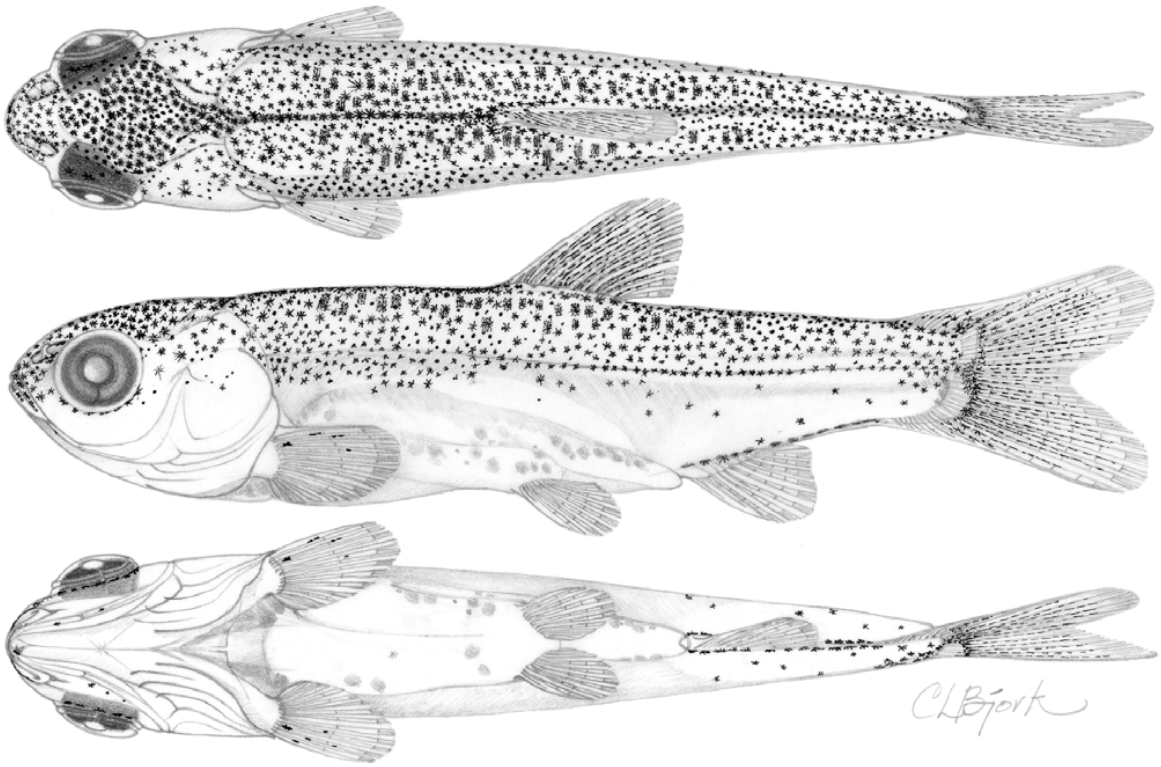

Figure 34. *Gila atraria* juvenile, recently transformed, 18.4 mm SL, 21.8 mm TL. (Collected in 1998 from Strawberry Reservoir, Wasatch County, Utah; from LFL #68738.)

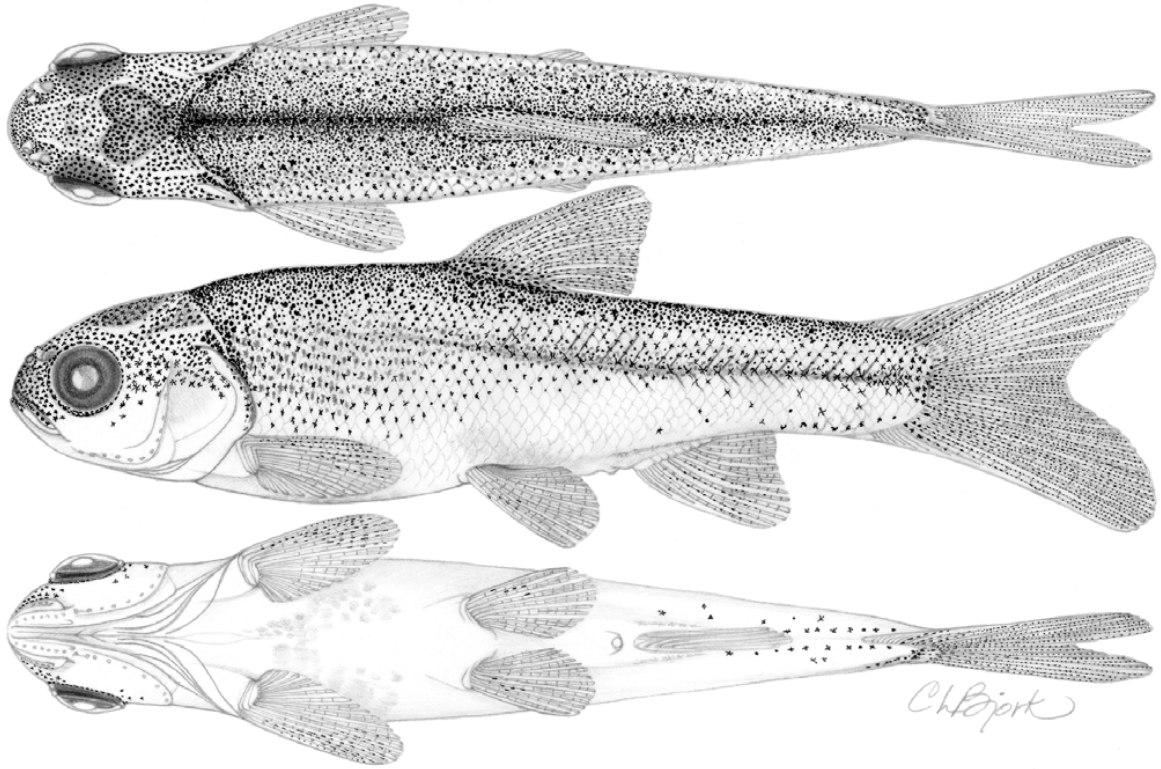

Figure 35. *Gila atraria* juvenile, 31.5 mm SL, 39.2 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock from Joe's Valley Reservoir, Emery County, Utah.)

Species Account – *Gila cypha*, humpback chub

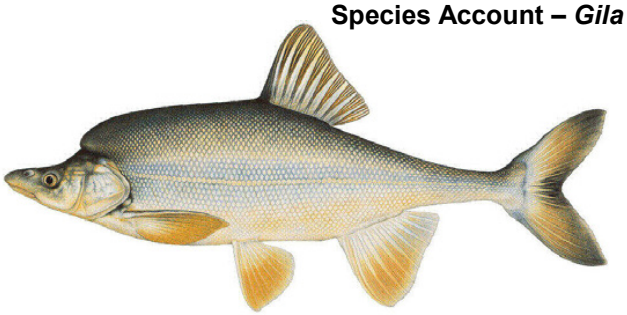

Figure 36. *Gila cypha* adult (© Joseph R. Tomelleri).

Adult description: Up to 35–48 cm TL. Body streamlined, compressed, with typically prominent anterodorsal nuchal hump, abrupt and truncate over occiput. Head dorsally flattened or concave with very small eyes (as little as 8% HL) and long, fleshy snout overhanging subterminal to inferior, nearly horizontal, mouth. Caudal peduncle slender (least depth ~21% HL). Fins expansive, falcate; caudal-fin lobes moderately long and pointed; dorsal origin well behind pelvic origin. Angle of line from along base of anal fin extends along upper margin of caudal fin to middle of upper lobe. Scales nearly lacking or well embedded over nuchal hump and sometimes elsewhere except laterally. Gray or olivaceous dorsally, silvery or white ventrolaterally. Breeding males orange-red along ventrolateral surfaces with small tubercles on anterior body. (Also, Table 14.)

Reproduction: Non-guarding, open-substrate lithophil. Mature at age 3–5. Spawn shortly after peak spring flows during late April to early July at 12–22°C, typically 16–19°C, probably in near-shore areas of moderate velocity and depth over sand, gravel or cobble. Water-hardened eggs demersal, adhesive, and (2.3–)2.6–3.1(–3.3) mm in diameter (means 2.7 & 2.9 (orig.) mm).

Young: Hatch in 3–7 d and swim up 3–4 d later at 19–20°C. Young diurnally active; in near-shore, low-velocity habitats, especially at night; some move to eddies or larger-substrate habitats during day.

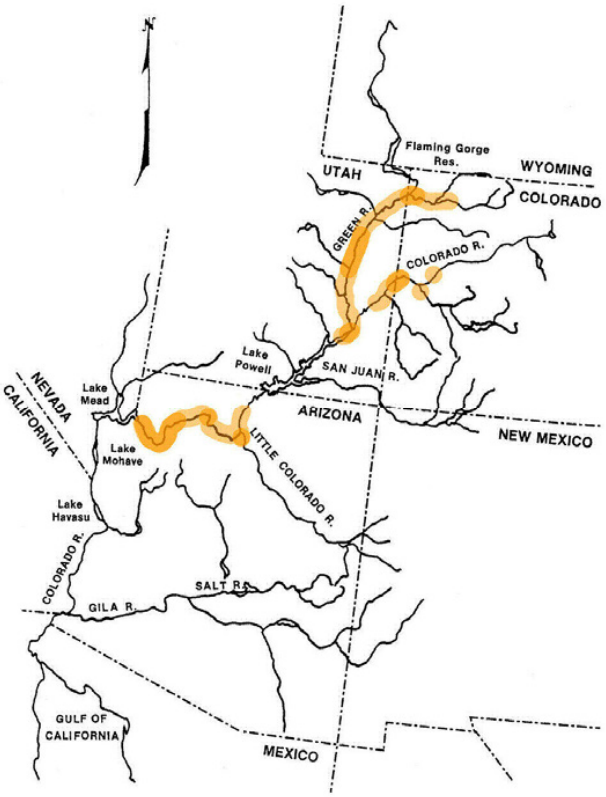

Figure 37. Recent distribution of *Gila cypha* in the Colorado River Basin (residing mostly in canyon reaches–darker zones).

Table 14. Selected juvenile and adult meristics for *Gila cypha*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	9-10	(8)9-10	Dorsal-fin rays - R	2-3(4)	3
Anal-fin rays - P	(8)9-10(11)	9-10-11	Anal-fin rays - R	2-3	3
Caudal-fin rays - P	(18)19(20)	(18)19(20)	Caudal-fin rays - RD	8-10(11)	–
Pectoral-fin rays	(14)15-16-17	(15)16-17-18(19)	Caudal-fin rays - RV	(7)8-10(11)	–
Pelvic-fin rays	9(10)	(8)9-10	Lateral scales	–	(73-)76-80-82-87(-90)
Vertebrae	44-46-47-48(49)	45-46-47-48(49)	Pharyngeal teeth	–	(1)2,5/4(5),(1)2

* Includes re-examined data originally prepared for Snyder 1981 or Muth 1990 and supplements and updates those accounts.

Table 15. Size at apparent onset of selected developmental events for *Gila cypha*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data as per footnote for Table 14.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	6-7	6-7	Dorsal - P	9-10(11)	(10)11	(10)11-12	(12)13-14
Eyes pigmented	*-6(7)	*-7(8)	Anal - P	10(11)	11-12	(12)13	(14)15-16
Yolk assimilated	9-10(11)	(9)10-11	Caudal - P	9	9-10	9-10(11)	10-11
Finfold absorbed	(18-)20	(23-)25	Caudal - R	(9)10(11)	(10)11-12	15-16(17)	20-21
Pectoral-fin buds	*	*	Pectoral	11(12)	12-13(14)	(15)16-19(20)	(20)21-24(25)
Pelvic-fin buds	10-11	(11)12	Pelvic	12-13	14-16	(14)15-16(17)	(17)18-20(21)
* before hatching			Scales	(24-)26-29	(31-)34-36	(36-)40->44	(45-)51->57

References: Balon 1975a; Behnke and Benson 1983; Behnke et al. 1982; Bulkley et al. 1982; Carlson and Muth 1989; Gaufin et al. 1960; Hamman 1982b; Holden 1968; Holden and Stalnaker 1970, 1975; Johnson 1987; Joseph et al. 1977; Kaeding and Zimmerman 1983; Lee et al. 1980; Marsh 1985; Miller 1946; Miller and Lowe 1964; Minckley 1973; Minckley and Marsh 2009; Moore 1968; Muth 1990; Page and Burr 1991; Sigler and Miller 1963; Smith et al. 1979; Snyder 1981; Stanford and Ward 1986; Stone and Gorman 2006; Suttkus and Clemmer 1977; Tyus and Karp 1989; Tyus et al. 1982, 1987; USFWS 1990b, 2002c; Valdez 1987, 1988; Valdez and Clemmer 1982.
Other larval descriptions: Muth 1990; Snyder 1981.

Table 16. Size at developmental interval (left) and gut phase (right) transitions for *Gila cypha*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 or Muth 1990, and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	9	9-10	2 - 90° bend	(11)12-13	(13)14-16
Postflexion mesolarva	9-10(11)	10-11	3 - Full loop	(17)18-19(20)	(21-)23-25
Metalarva	(12)13	(14)15-16	4 - Partial crossover	(not applicable)	
Juvenile	(18-)20	(23-)25	5 - Full	(not applicable)	

Table 17. Summary of morphometrics and myomere counts by developmental phase for *Gila cypha*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 or Muth 1990[a], and supplements and updates those accounts.)

	Protolarvae (N=66)			Flexion mesolarvae (N=37)			Postflexion mesolarvae (N=40)			Metalarvae (N=35)			Juveniles (N=94)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	8	1	6 - 9	10	1	9 - 11	10	1	9 - 13	16	2	13 - 20	30	6	18 - 45
TL, mm	9	1	6 - 10	10	1	9 - 11	11	2	10 - 15	20	3[q]	16 - 25	38	8[t]	23 - 58
Lengths %SL															
AS to AE	3	1	2 - 5	3	1	2 - 5	4	1	2 - 5	5	1	5 - 7	6	1	4 - 8
PE	9	1	8 - 11	10	1	8 - 11	11	1	9 - 12	13	1	11 - 14	13	1	11 - 14
OP1	18	1	14 - 20	20	1	18 - 22	22	1	19 - 25	26	1	24 - 28	25	1[u]	22 - 28
OP2							45	2[h]	41 - 48	47	1	45 - 50	46	1[u]	43 - 49
PY	63	3	52 - 71	53	9[d]	36 - 65	46	9[i]	34 - 63						
OPAF	42	7[b]	28 - 62	32	3	26 - 39	30	2	26 - 35	43	8	31 - 61			
ODF	40	4	34 - 50	40	2	36 - 44	42	2	37 - 50	48	1[n]	47 - 48			
OD							50	2[j]	47 - 53	51	2	48 - 54	50	1	46 - 53
ID							62	2[h]	59 - 66	65	2	61 - 68	64	1	60 - 68
PV	66	2[b]	61 - 71	65	1	61 - 68	67	1	64 - 70	66	1	63 - 69	63	1[t]	59 - 67
OA							67	1[k]	65 - 69	65	2	62 - 69	64	1[v]	60 - 67
IA							76	1[l]	74 - 77	76	1	72 - 79	76	1[u]	73 - 78
AFC							109	1	106 - 112	113	2	110 - 116	113	1[t]	108 - 115
PC	105	1	103 - 107	107	1	104 - 109	112	3	108 - 119	126	3[q]	118 - 130	127	2[t]	121 - 132
Y	47	6	33 - 63	31	12[e]	0 - 44	4	8	0 - 26						
P1	8	3	3 - 13	12	1	7 - 14	14	1[m]	12 - 16	16	2	13 - 20	18	2[t]	15 - 22
P2							1	2	0 - 7	12	3	5 - 16	16	1[t]	13 - 18
D							18	0[n]	18 - 18	22	2	17 - 25	24	1	21 - 28
A							11	2[n]	10 - 12	18	2	12 - 21	20	1	17 - 23
Depths %SL															
at BPE	13	2	10 - 20	13	1	11 - 15	14	1	12 - 17	17	1	15 - 18	16	1[t]	14 - 19
OP1	17	5	12 - 31	14	1	12 - 17	15	2	12 - 19	22	1[r]	19 - 25	23	1[w]	19 - 26
OD	15	2	10 - 23	12	1	10 - 14	12	2	9 - 19	21	3[r]	16 - 27	25	2[x]	20 - 31
BPV	8	1[b]	6 - 9	8	1	7 - 9	8	1	7 - 12	14	2[r]	11 - 18	17	1[w]	14 - 20
AMPM	4	1	2 - 5	4	1	3 - 5	5	1	3 - 8	8	1	6 - 9	7	0	6 - 8
Max. yolk	14	5	5 - 28	7	3[e]	0 - 16	1	1	0 - 6						
Widths %SL															
at BPE	12	1	10 - 16	14	1	12 - 16	15	1	12 - 18	18	2[d]	15 - 21	17	2[u]	13 - 21
OP1	12	5	7 - 27	11	1	9 - 14	12	2	8 - 17	19	2[s]	15 - 22	20	2[y]	15 - 23
OD	7	2	5 - 14	6	1	5 - 7	6	1	5 - 11	15	3[s]	10 - 19	19	2[z]	11 - 24
BPV	5	1[b]	4 - 10	5	1[e]	4 - 6	5	1	4 - 7	11	1[s]	8 - 13	13	1[z]	8 - 16
AMPM	2	0	2 - 3	2	0	2 - 3	3	1	2 - 4	4	1[d]	3 - 5	4	1[aa]	3 - 5
Max. yolk	15	5	7 - 30	8	3[e]	0 - 13	1	2	0 - 8						
Myomeres, Vertebrae for Some Juveniles															
to PY	28	2[c]	24 - 32	22	6[f]	11 - 30	17	6[o]	10 - 28						
OPAF	14	3[d]	8 - 22	9	2[g]	4 - 12	7	1[p]	5 - 10	15	5[p]	8 - 24			
OP2							16	1[h]	14 - 17	16	1[q]	15 - 17	16	1[ab]	14 - 18
ODF	13	2[c]	10 - 18	14	1[g]	11 - 16	14	1[p]	11 - 17	16	1[n]	15 - 16			
OD							19	1[k]	17 - 20	19	1[q]	17 - 20	18	1[ab]	16 - 20
PV	29	1	28 - 32	29	1	28 - 30	29	1	27 - 31	29	1[q]	27 - 30	27	1[ab]	25 - 29
Total	46	1	45 - 49	47	1	45 - 48	46	1	45 - 48	46	1[q]	44 - 48	47	1[ab]	44 - 49
After PV	17	1	15 - 19	18	1	17 - 19	17	1	16 - 19	17	1[q]	16 - 19	19	1[ab]	18 - 22

[a] Developmental phase of some specimens reassigned; highly questionable data for missing specimens excluded from this summary. [b] N = 65. [c] N = 35. [d] N = 34. [e] N = 36. [f] N = 23. [g] N = 25. [h] N = 9. [i] N = 8. [j] N = 18. [k] N = 11. [l] N = 3. [m] N = 39. [n] N = 2. [o] N = 7. [p] N = 30. [q] N = 33. [r] N = 28. [s] N = 27. [t] N = 93. [u] N = 92. [v] N = 88. [w] N = 75. [x] N = 73. [y] N = 70. [z] N = 71. [aa] N = 91. [ab] N = 43, includes vertebral counts with Weberian and urostylar units from data for 33 of 37 cleared and stained specimens in Muth (1990), 20 of which are additional to N for other data in this table.

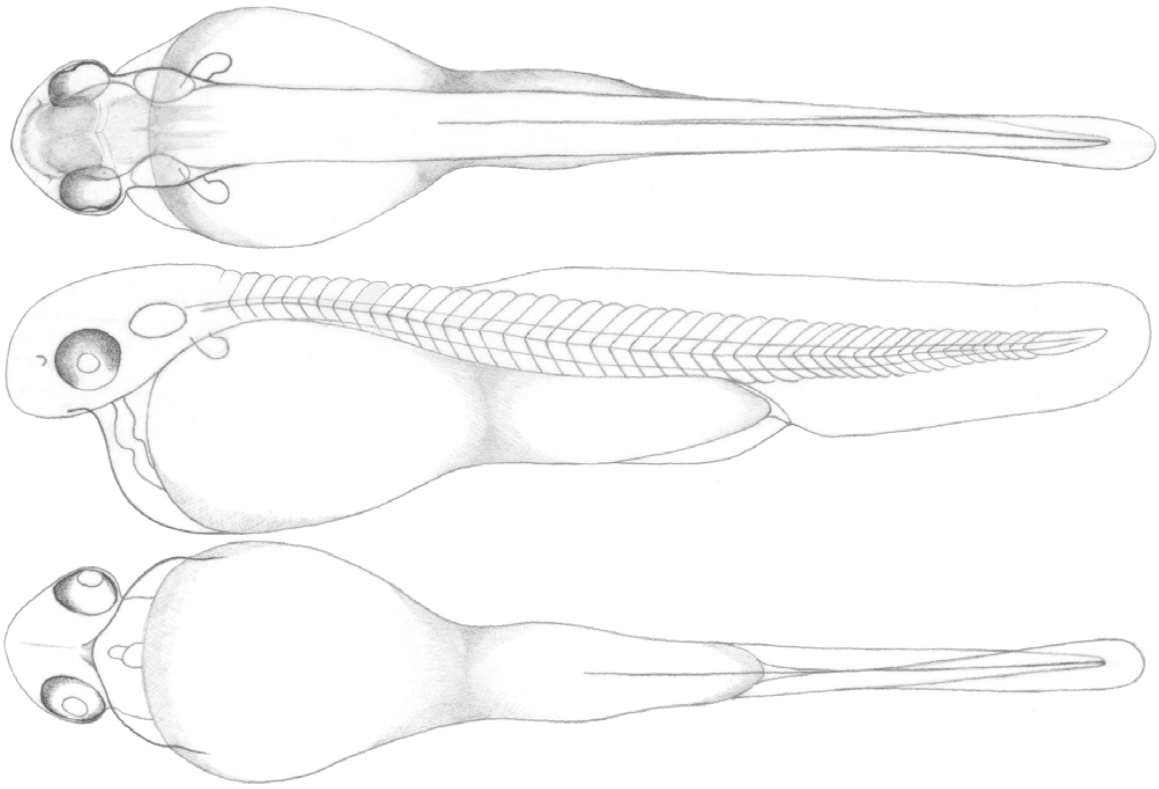

Figure 38. *Gila cypha* protolarva with yolk, recently hatched, 6.3 mm SL, 6.6 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, Arizona, with stock from the Colorado River, Colorado. From Snyder 1981 and Muth 1990.)

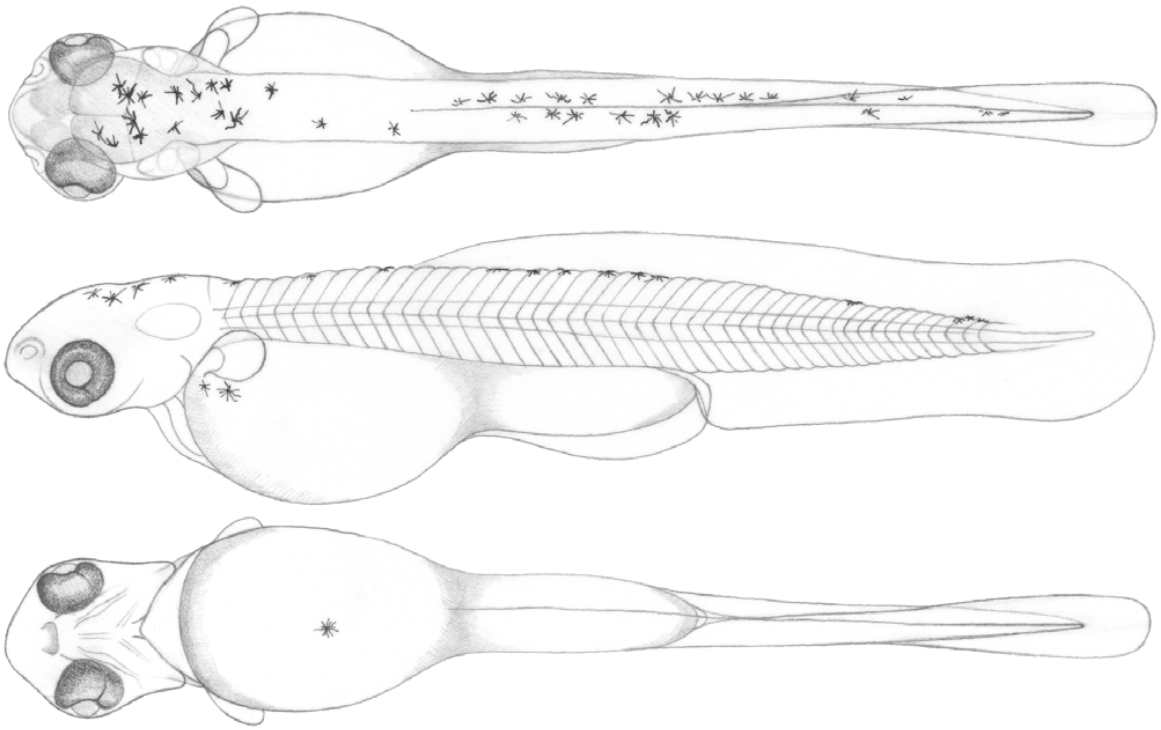

Figure 39. *Gila cypha* protolarva with yolk, 8.3 mm SL, 8.7 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, AZ, with stock from Colorado River, Black Rocks area, CO, near UT border. From Snyder 1981 and Muth 1990.)

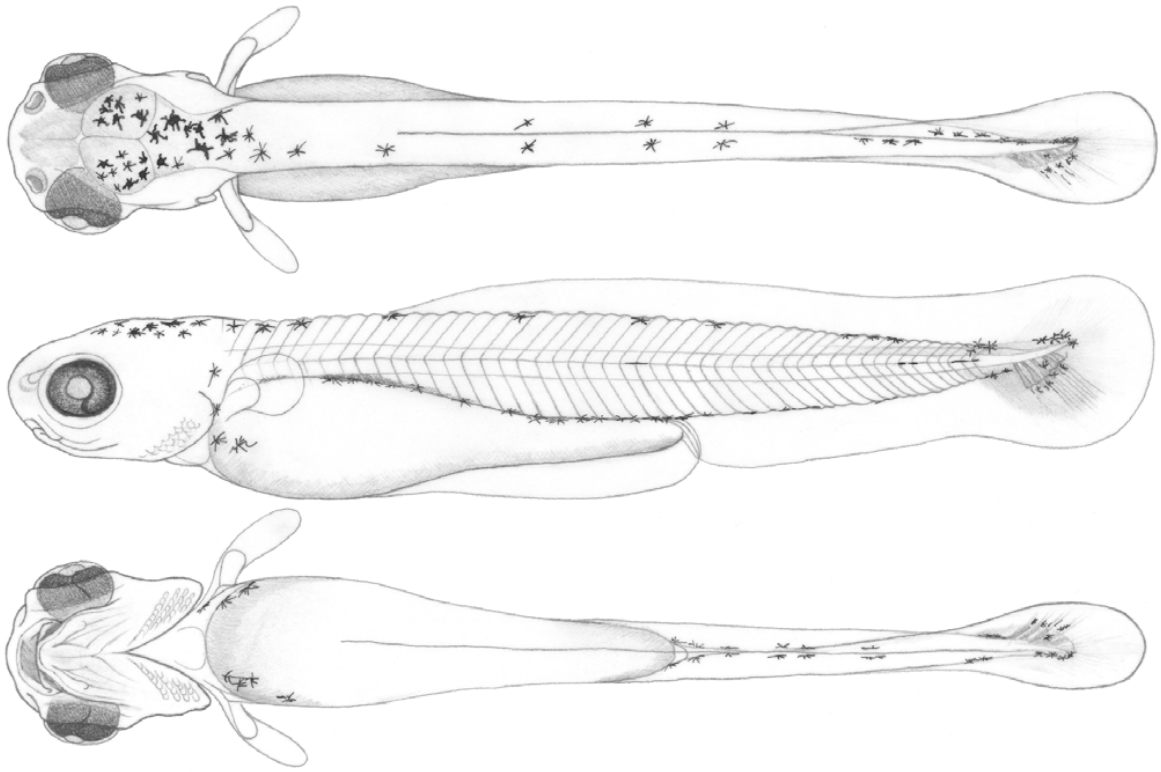

Figure 40. *Gila cypha* flexion mesolarva with yolk, recently transformed, 8.6 mm SL, 9.3 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, AZ; stock from Colo. R., Black Rocks area, CO. From Snyder 1981 and Muth 1990.)

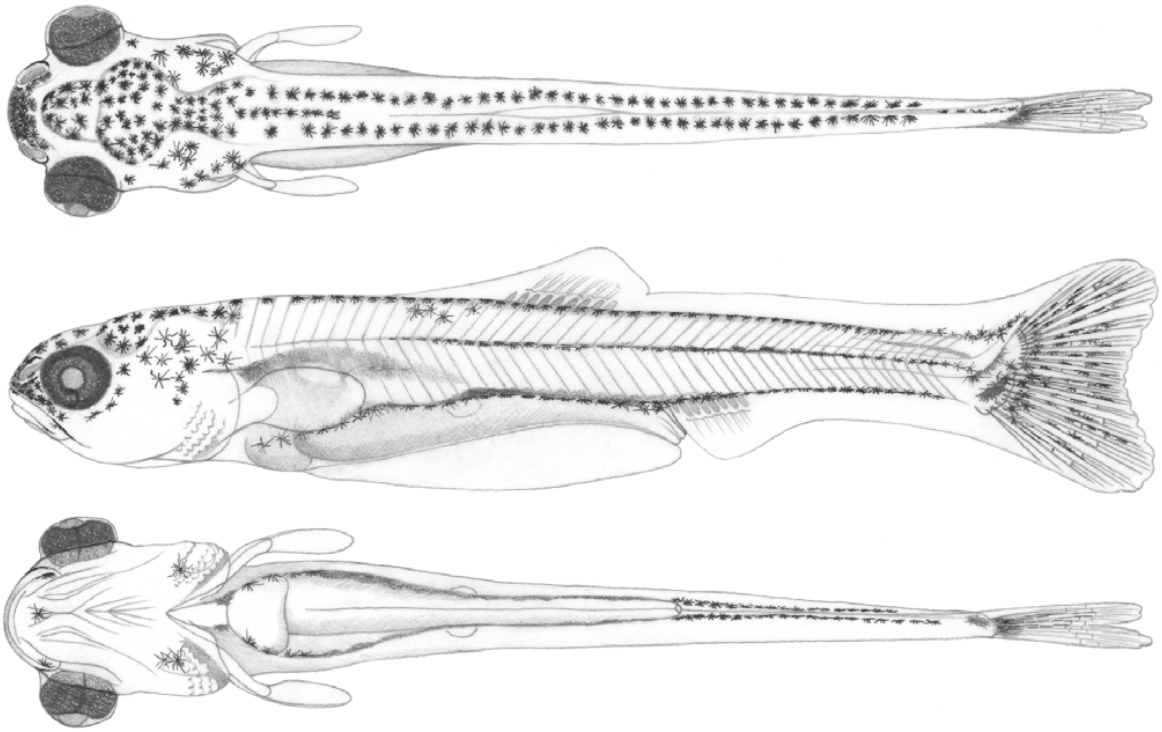

Figure 41. *Gila cypha* postflexion mesolarva, 10.4 mm SL, 11.7 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, AZ, with stock from Colorado River, Black Rocks area, CO, near UT border. From Snyder 1981 and Muth 1990.)

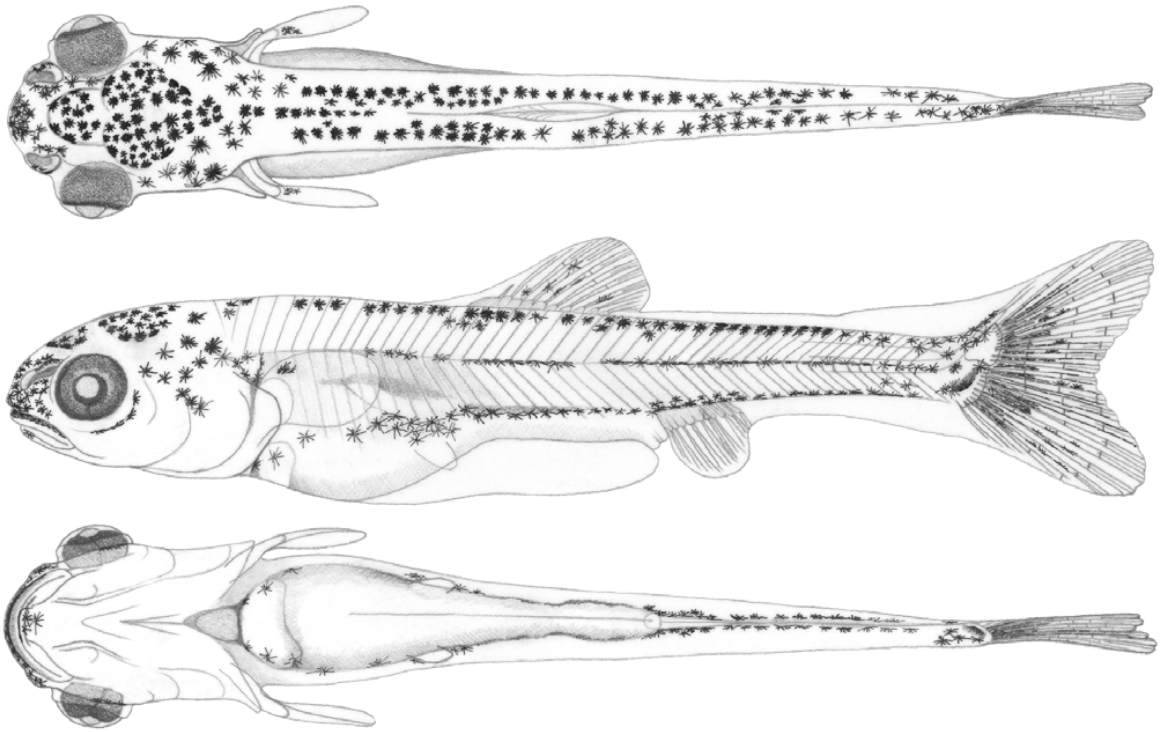

Figure 42. *Gila cypha* postflexion mesolarva near transition to metalarva (lacks second elements of last dorsal and anal fin rays), 12.2 mm SL, 14.0 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, Arizona, with stock from Colorado River, Black Rocks area, Colorado, near Utah border. From Muth 1990, modified from Snyder 1981.)

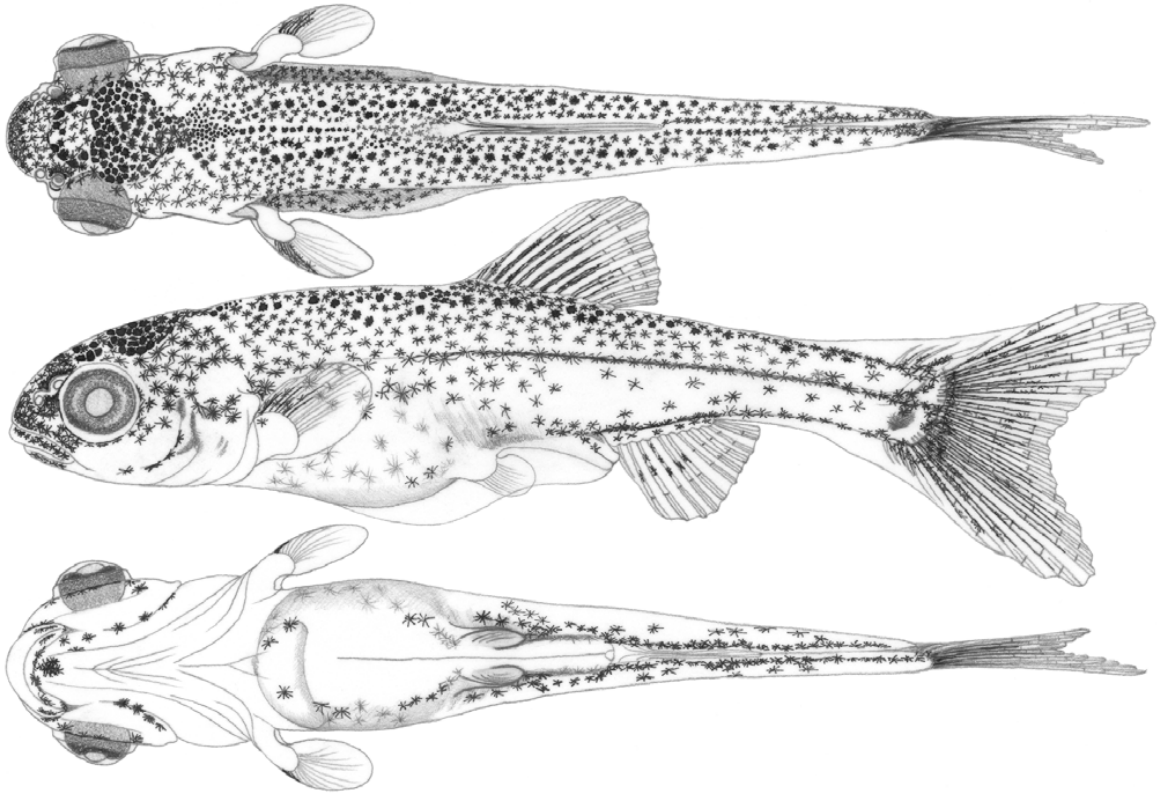

Figure 43. *Gila cypha* metalarva, 15.0 mm SL, 18.4 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, AZ, with stock from Colorado River, Black Rocks area, Colorado, near Utah border. From Snyder 1981 and Muth 1990.)

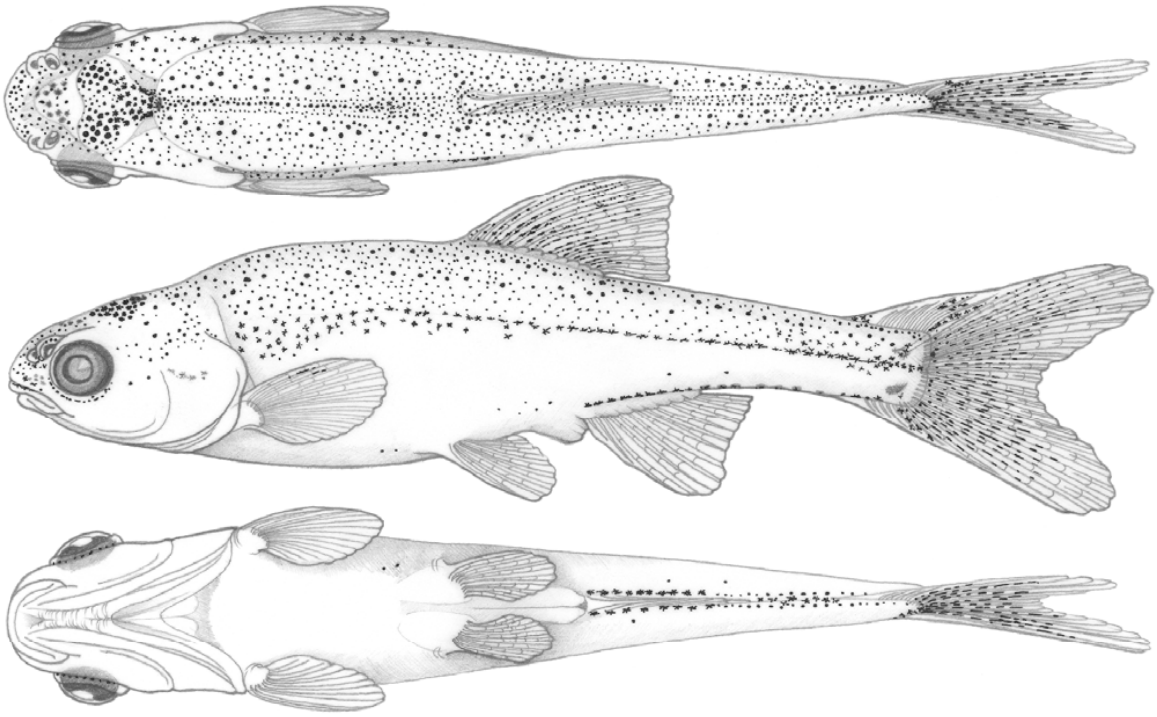

Figure 44. *Gila cypha* juvenile, recently transformed, 20.1 mm SL, 25.0 mm TL. (Cultured in 1980 or 1981 by Willow Beach National Fish Hatchery, Arizona, with stock from Colorado River, Black Rocks area, Colorado. From Muth 1990.)

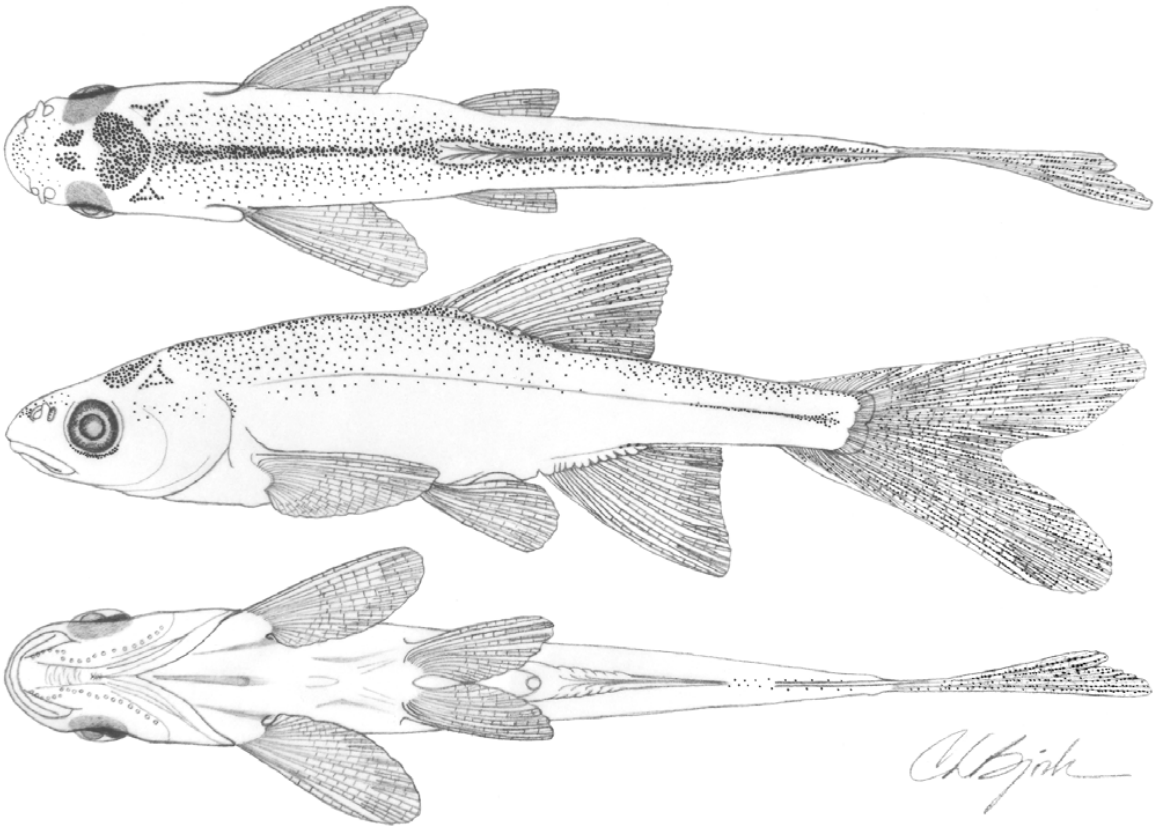

Figure 45. *Gila cypha* juvenile, 33.6 mm SL, 44.2 mm TL. (Cultured in 1980 by Willow Beach National Fish Hatchery, AZ, with stock from Colorado River, Black Rocks area, Colorado, near Utah border. From Snyder 1981 and Muth 1990.)

Species Account – *Gila elegans*, bonytail

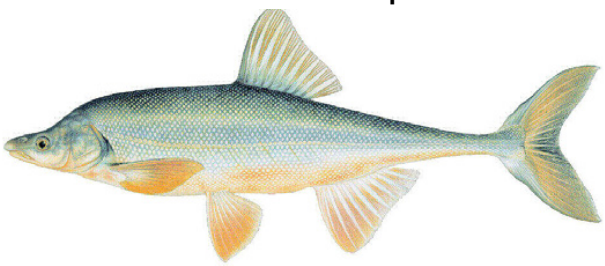

Figure 46. *Gila elegans* adult (© Joseph R. Tomelleri).

Adult description: Up to 50 cm TL. Head small, strongly depressed anteriorly, concave over and behind eyes, and arching posteriorly, in larger specimens to a moderately high nuchal hump. Body very streamlined, elongate, and somewhat compressed, narrowing to an extremely slender and long caudal peduncle with least depth 15–20% of head length (HL). Mouth terminal to subterminal, slightly oblique. Eyes small, about 14% of HL. Fins large; dorsal origin well behind pelvics; caudal deeply forked. Angle of line from along base of anal fin extends well above posterior caudal peduncle and often upper margin of caudal fin. Scales small, coverage often incomplete or deeply embedded dorsally, ventrally and on caudal peduncle. Gray to olivaceous on dorsal surface, silver laterally, white ventrally. Breeding males orange-red ventrolaterally with small tubercles on anterior body; less pronounced in females. (Also, Table 18.)

Reproduction: Non-guarding, open-substrate lithophils. Spawn May to early July at water temperatures of 17–21° in eddies or pools over gravel shelf, cobble, or boulders and sometimes tumbleweeds. Water-hardened eggs demersal, adhesive, and 2.0–2.4 mm in diameter.

Young: At 20–21°C, hatch in 4–7 d and swim up 2–3 d later. Young mostly found in near-shore, low-velocity habitats (e.g., backwaters) over silt, sand, or gravel. In laboratory, preferred 24°C.

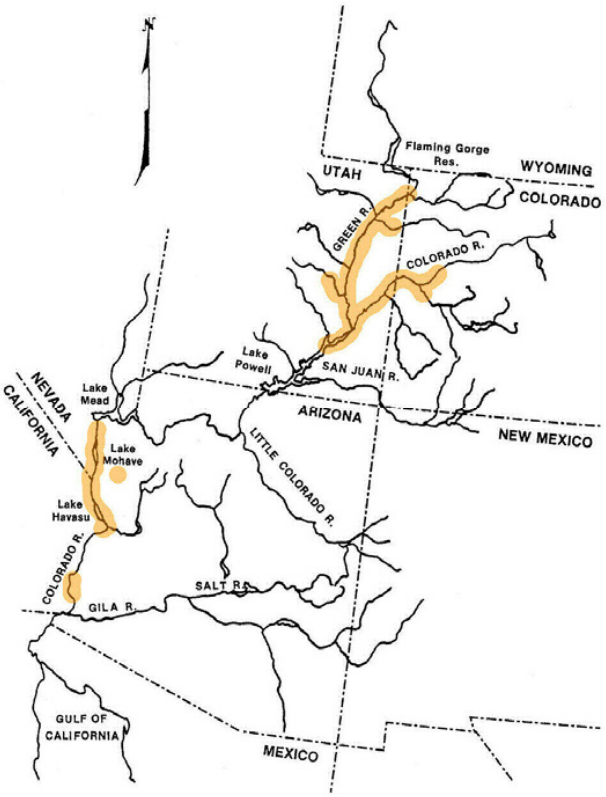

Figure 47. Recent distribution of *Gila elegans* in the Colorado River Basin (includes stocked reaches).

Table 18. Selected juvenile and adult meristics for *Gila elegans*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed	Literature
Dorsal-fin rays - P	10(11)	(9)10-11	Dorsal-fin rays - R	2-3(4)	2
Anal-fin rays - P	10-11	(9)10-11	Anal-fin rays - R	2-3	2
Caudal-fin rays - P	(18)19(20)	(18)19	Caudal-fin rays - RD	(8-)10-11(12)	9
Pectoral-fin rays	14-16-17	16	Caudal-fin rays - RV	(8-)10-11(12)	10
Pelvic-fin rays	(8)9(10)	9-10	Lateral scales	82 [n=1]	75-88-99-~110
Vertebrae	49-50-51	(46-)48-49-51	Pharyngeal teeth	–	2,5/4,2

* Includes re-examined data originally prepared for Muth (1990) or Snyder et al. (2005) and supplements and updates those accounts.

Table 19. Size at onset of selected developmental events for *Gila elegans*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data as per footnote for Table 18.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	5-6	5-6	Dorsal - P	9	9-10	11	12-13
Eyes pigmented	*-6	*-6	Anal - P	9	10(11)	11-12	13(14)
Yolk assimilated	8	(8)9	Caudal - P	(7)8	8	(8)9	9
Finfold absorbed	22	27-28	Caudal - R	9	9(10)	17-19	21-24
Pectoral-fin buds	*	*	Pectoral	11-12	13-14	13-14	16(17)
Pelvic-fin buds	10	11-12	Pelvic	(11)12	(13)14-15	13-14	16(17)
* before hatching			Scales	(22)23	28(29)	34-37(-40)	43-46(-50)

References: AGFD 2002; Baird and Girard 1853a, 1853b; Balon 1981; Baxter and Simon 1970; Beckman 1952; Behnke and Benson 1983; Bozek et al. 1984; Hammon 1982a, 1985; Holden 1968; Holden and Stalnaker 1970; La Rivers 1962; Marsh 1985; Miller 1946; Minckley 1973; Minckley and DeMarais 2000; Minckley and Marsh 2009; Moore 1968; Moyle 1976; Muth 1990; Page and Burr 1991; Rinne 1976; Sigler and Miller 1963; Smith et al. 1979; USFWS 1990a, 2002a; Valdez and Clemmer 1982; Vanicek and Kramer 1969.

Other larval descriptions: Muth 1990; Snyder 1981 (in metalarval key and meristic summary table only); Snyder et al. 2005.

Table 20. Size at developmental interval (left) and gut phase (right) transitions for *Gila elegans*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Muth 1990 or Snyder et al. 2005 and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	(7)8	8	2 - 90° bend	11-12	13-14
Postflexion mesolarva	(8)9	9	3 - Full loop	(20-)22	(25-)27(28)
Metalarva	11-12	13(14)	4 - Partial crossover	not applicable	
Juvenile	22	27-28	5 - Full	not applicable	

Table 21. Summary of morphometrics and myomere counts by developmental phase for *Gila elegans*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Muth 1990[a] or Snyder et al. 2005, and supplements and updates those accounts.)

	Protolarvae (N=33)			Flexion mesolarvae (N=14)			Postflexion mesolarvae (N=18)			Metalarvae (N=35)			Juveniles (N=55)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	7	0	6 - 8	8	0	8 - 9	9	1	8 - 12	15	3	11 - 22	31	6	22 - 44
TL, mm	8	0	6 - 8	9	0	8 - 9	10	1	9 - 13	19	4	13 - 28	38	8	27 - 54
Lengths %SL															
AS to AE	3	0	2 - 5	3	0	2 - 4	3	1[h]	2 - 3	5	1	3 - 6	5	0	4 - 6
PE	9	1	7 - 10	9	1	8 - 10	10	1[h]	8 - 11	12	1	10 - 14	12	1	10 - 13
OP1	18	1	14 - 21	20	1	19 - 21	22	1	20 - 24	25	1	23 - 28	24	1	22 - 26
OP2							44	0[i]	44 - 44	47	1	44 - 49	45	1	44 - 47
PY	63	2[b]	59 - 68	45	8[d]	33 - 52									
OPAF	36	9[b]	25 - 51	26	2[e]	24 - 30	29	2[j]	27 - 32	41	9[f]	32 - 55			
ODF	37	8[b]	15 - 41	38	6[e]	25 - 41	42	2[j]	40 - 46	43	1[n]	42 - 45			
OD							51	1[k]	50 - 52	52	1	49 - 54	51	1	47 - 53
ID							63	1[l]	62 - 63	65	1[o]	63 - 67	64	1	61 - 66
PV	65	2	62 - 69	64	1	62 - 67	67	1	66 - 70	65	2[o]	62 - 69	63	1	60 - 65
OA							67	1[e]	65 - 69	65	1[o]	63 - 68	64	1	61 - 66
IA							76	0[i]	76 - 76	77	1[o]	74 - 78	76	1	73 - 78
AFC							108	1[m]	106 - 111	111	1	108 - 112	112	1	108 - 114
PC	105	1	102 - 107	106	1	105 - 110	111	3	107 - 116	122	2	116 - 126	125	1	121 - 128
Y	44	5[b]	37 - 52	7	11[f]	0 - 29									
P1	9	2	4 - 12	12	1	12 - 13	12	1	11 - 14	14	1	11 - 16	17	1	15 - 20
P2							0	1	0 - 3	9	4	3 - 15	16	1	14 - 18
D							13	2[d]	12 - 16	19	2	15 - 23	22	1	20 - 24
A							11	1[d]	10 - 11	16	2	10 - 19	20	1	18 - 22
Depths %SL															
at BPE	12	1	10 - 16	12	0	11 - 12	14	1	12 - 16	16	1[o]	14 - 18	15	1	14 - 17
OP1	13	2	11 - 19	12	1	11 - 13	15	1	13 - 16	20	2	16 - 23	22	1	20 - 23
OD	12	1	10 - 16	10	1	8 - 11	11	1	10 - 14	19	3[o]	15 - 24	23	1	20 - 26
BPV	8	1	7 - 9	7	1	6 - 8	8	1	7 - 10	14	2	9 - 18	18	1	15 - 20
AMPM	4	1	3 - 4	4	1	3 - 5	4	1	3 - 6	7	0	6 - 7	6	0	5 - 7
Max. yolk	9	4[c]	4 - 18	1	2[f]	0 - 6									
Widths %SL															
at BPE	11	1	9 - 14	11	1	10 - 12	13	1	11 - 16	15	1	14 - 17	15	1	14 - 17
OP1	9	1	8 - 13	9	1	7 - 10	11	2	9 - 14	16	1	13 - 18	18	1	16 - 20
OD	6	1	5 - 7	5	1	4 - 6	6	1	4 - 8	12	3	7 - 18	17	2	15 - 21
BPV	4	1	4 - 6	4	1	4 - 5	5	1	4 - 7	10	2	6 - 13	13	1	10 - 14
AMPM	3	0	1 - 3	2	1	1 - 4	2	0	1 - 3	3	0	3 - 5	4	0	3 - 5
Max. yolk	11	4[c]	6 - 19	2	3[g]	0 - 7									
Myomeres															
to PY	30	1[b]	28 - 31	18	5[d]	11 - 22									
OPAF	12	5[b]	6 - 19	6	1[e]	5 - 6	6	1[j]	4 - 7	15	7[g]	7 - 25			
OP2							17	1[i]	16 - 17	17	0[o]	16 - 18	17	1[c,p]	16 - 18
ODF	13	4[b]	1 - 17	14	5[e]	5 - 17	15	1[j]	14 - 15	16	1[n]	15 - 17			
OD							20	0[k]	20 - 21	20	1[o]	19 - 22	20	1[c,p]	19 - 21
PV	30	1	29 - 32	30	1	29 - 32	31	1	30 - 32	30	1[o]	29 - 32	29	0[c,p]	29 - 30
Total	51	1	49 - 51	50	1	47 - 51	51	1	48 - 52	50	1[o]	47 - 52	50	1[c,p]	48 - 51
After PV	20	1	18 - 21	20	1	17 - 21	20	1	17 - 21	20	1[o]	16 - 21	21	1[c,p]	19 - 22

[a] Developmental phase of some specimens reassigned, especially protolarvae and mesolarvae; highly questionable data for missing specimens excluded from this summary. [b] N = 10. [c] N = 9. [d] N = 4. [e] N = 6. [f] N = 12. [g] N = 11. [h] N = 17. [i] N = 2. [j] N = 7. [k] N = 8. [l] N = 5. [m] N = 15. [n] N = 3. [o] N = 34. [p] Includes vertebral counts for 5 cleared and stained specimens in data prepared for Muth 1990, but some counts to OD and PV are 1 more than ranges reported by Muth (1990) for 16 cleared and stained juveniles, the individual data for which all or most are missing.

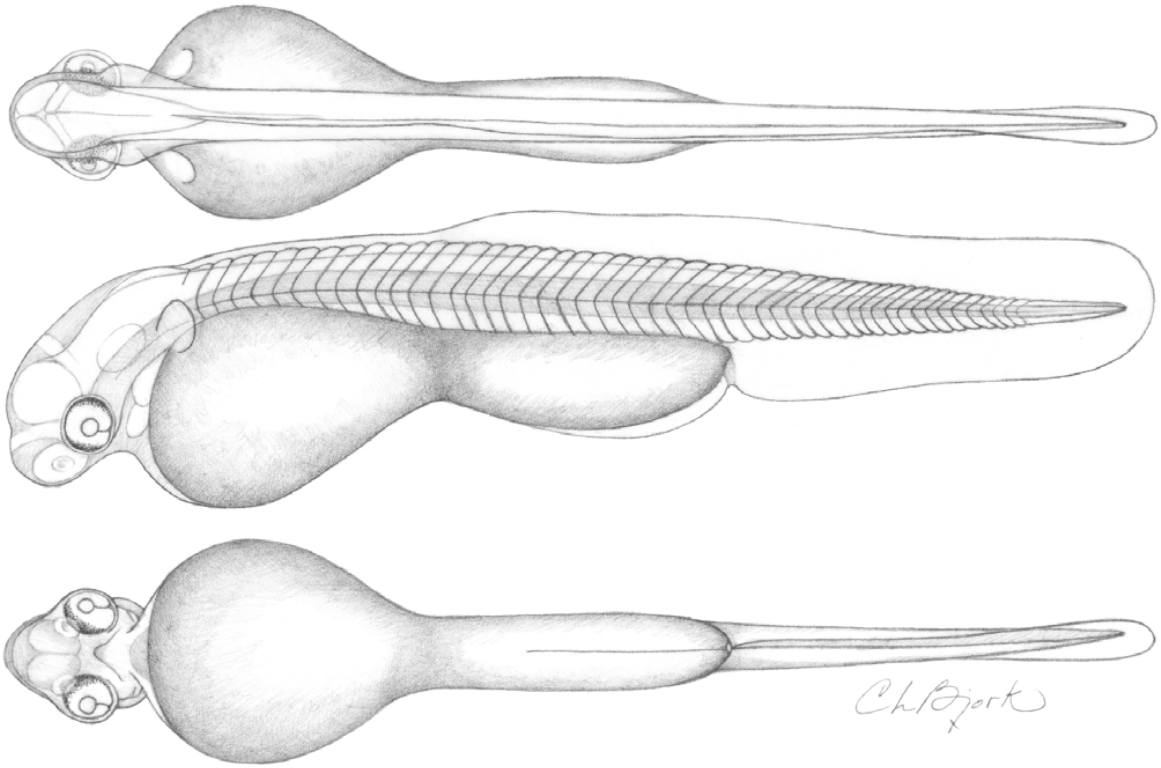

Figure 48. *Gila elegans* protolarva with yolk, recently hatched, 6.2 mm SL, 6.3 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave.)

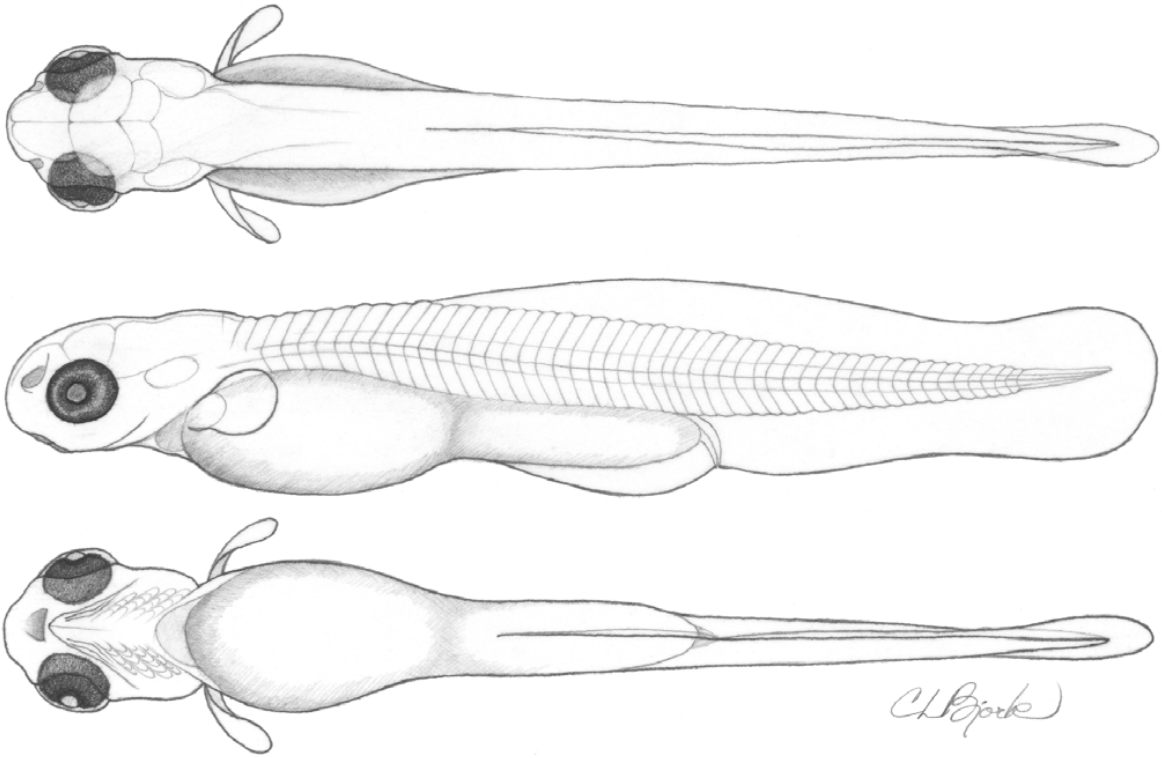

Figure 49. *Gila elegans* protolarva with yolk, 7.2 mm SL, 7.5 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave. From Muth 1990.)

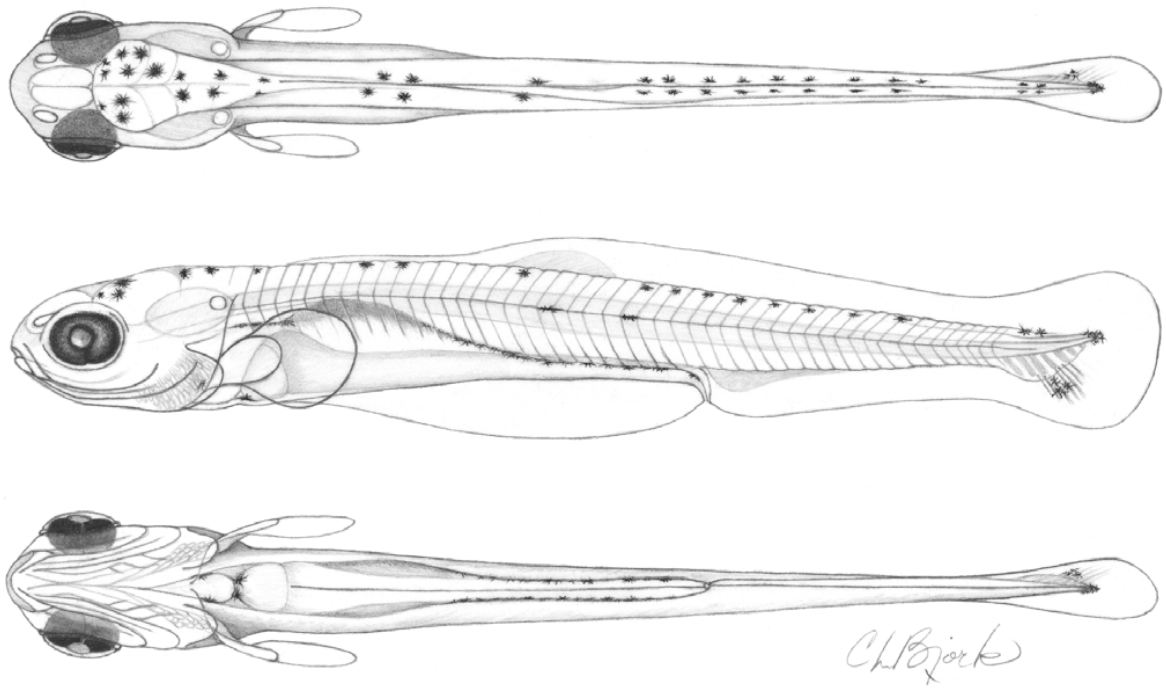

Figure 50. *Gila elegans* flexion mesolarva, 8.3 mm SL, 8.7 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave.)

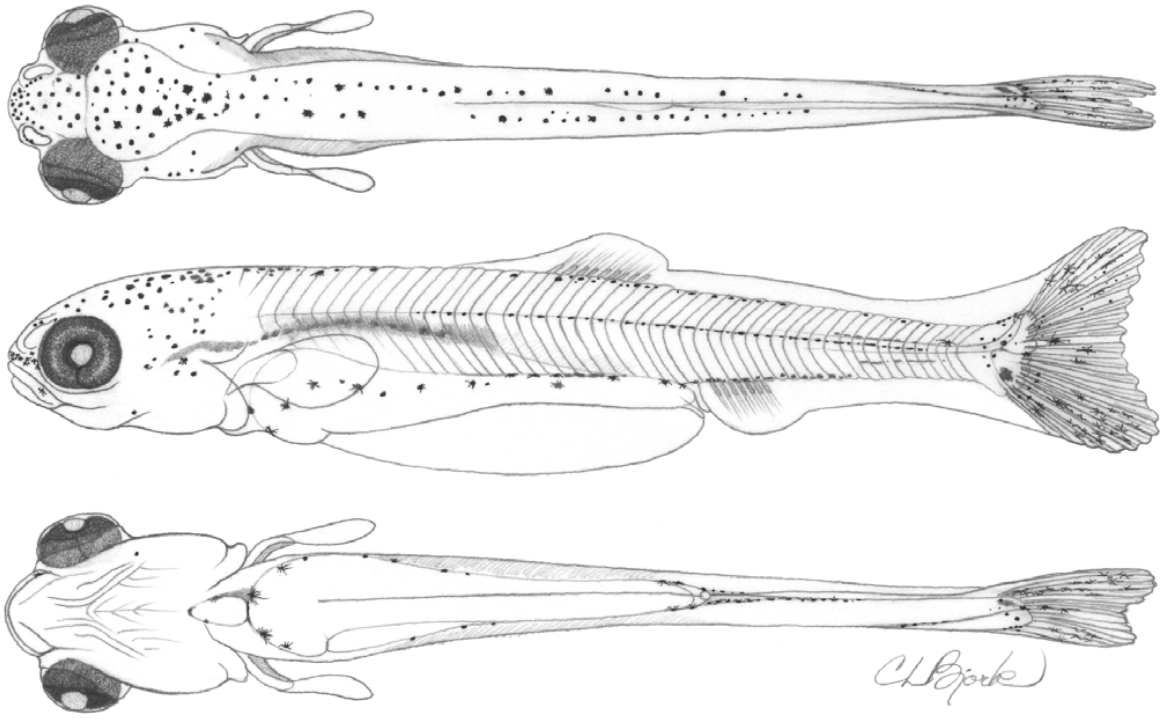

Figure 51. *Gila elegans* postflexion mesolarva, 9.6 mm SL, 10.7 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave. From Muth 1990.)

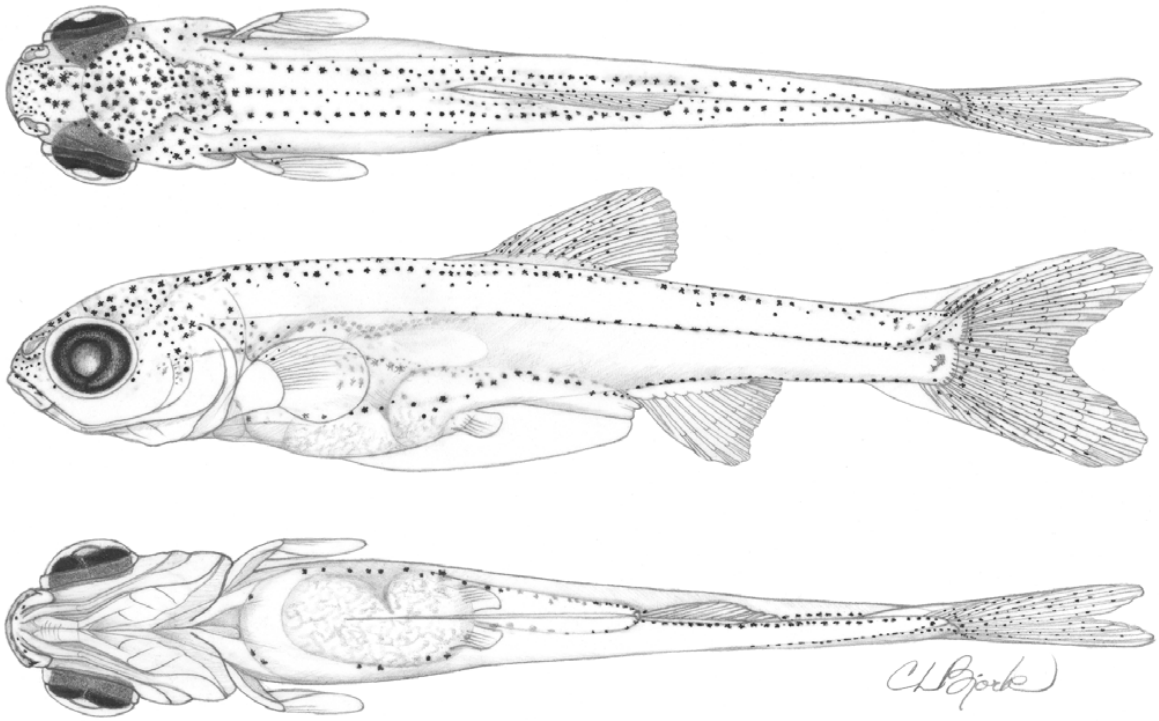

Figure 52. *Gila elegans* metalarva, recently transformed, 12.5 mm SL, 14.9 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave.)

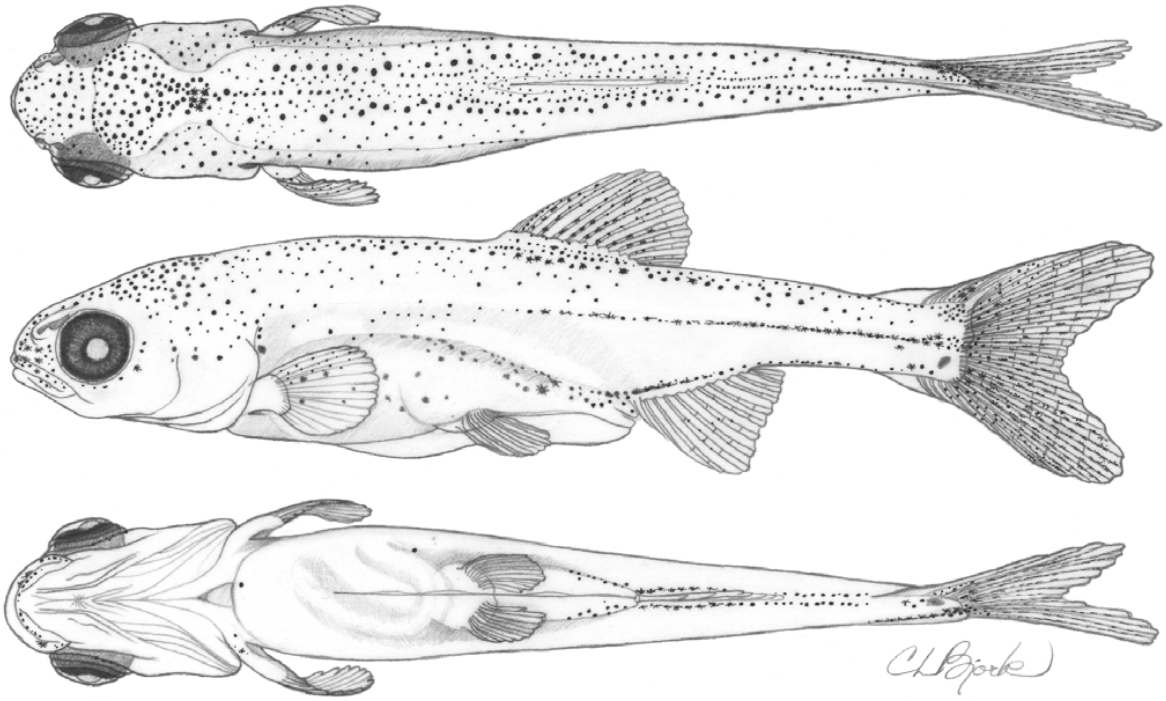

Figure 53. *Gila elegans* metalarva, 15.3 mm SL, 18.2 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave. From Muth 1990.)

Figure 54. *Gila elegans* juvenile, recently transformed, 22.3 mm SL, 27.0 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave.)

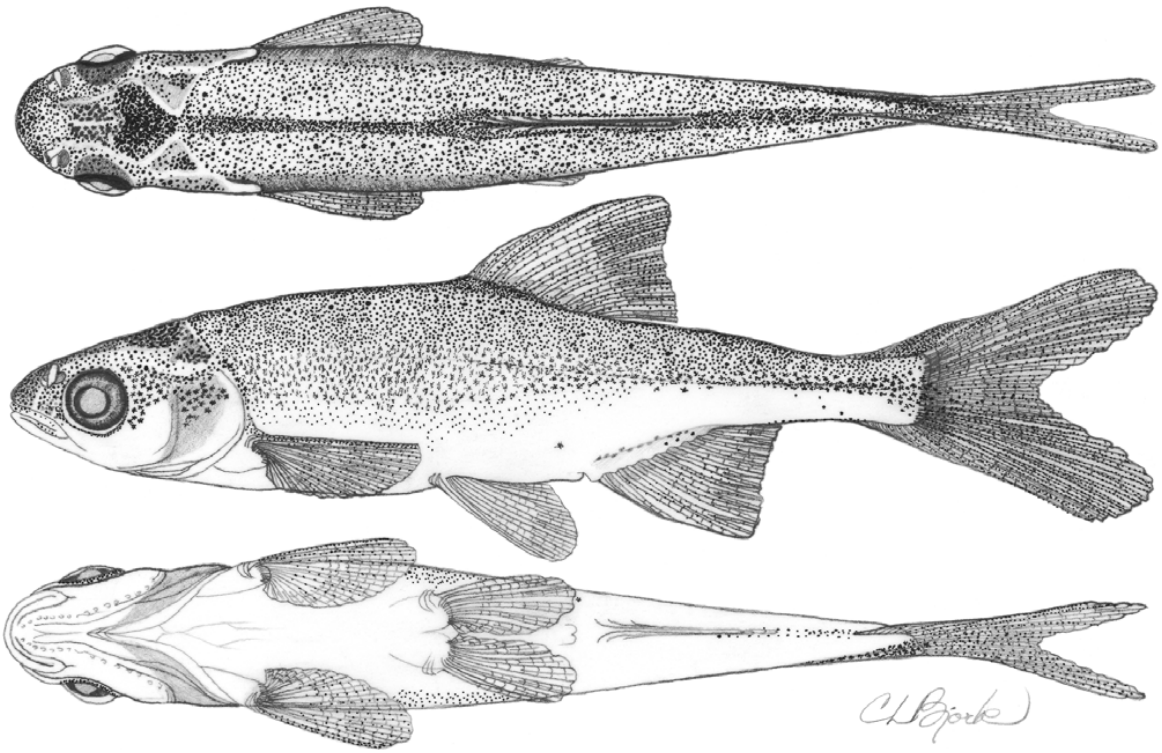

Figure 55. *Gila elegans* juvenile, 34.2 mm SL, 42.7 mm TL. (Cultured in 1981 at Willow Beach National Fish Hatchery, Arizona, with stock from Lake Mohave. From Muth 1990.)

Species Account – *Gila robusta*, roundtail chub

Figure 56. *Gila robusta* adult (© Joseph R. Tomelleri).

Adult description: Usually <26 cm, but up to 43, possibly 50 cm TL. Body moderately streamlined, elongate, sometimes slightly arched behind head. Dorsal surface of head slightly depressed, flat or rounded. Mouth terminal, slightly oblique, not extending beyond anterior margin of small eyes. Caudal peduncle relatively short and moderately deep, usually 23–33% of HL. Dorsal and anal fins small to moderately large, rounded to slightly falcate; dorsal fin origin usually well behind pelvic origin. Angle of line from along base of anal fin extends through middle of caudal fin to middle of upper lobe. Scales small. Generally gray or olivaceous dorsally, sometimes with dark dorsolateral blotches in certain subspecies or populations; silver to white ventrolaterally. Breeding males orange-red along ventrolateral surfaces with small tubercles over much of body, at least anteriorly, both less pronounced in females. (Also, Table 22.)

Reproduction: Non-guarding, open-substrate lithophil. Usually mature in 4–5 yr. Spawn late May to late July at 16–20 °C, typically ≥18 °C, in shallow pools or eddies over gravel or cobble. Water-hardened eggs demersal, adhesive, and ~2.8 (2.5–3.1) mm diameter.

Young: Hatch in 5–6 d and swim up 3–5 d later at 19–20 °C. Larvae subject to capture in downstream drift. Young found mostly in near-shore, low-velocity habitats (e.g., eddies, backwaters, embayments) over silt, sand, gravel, or boulders.

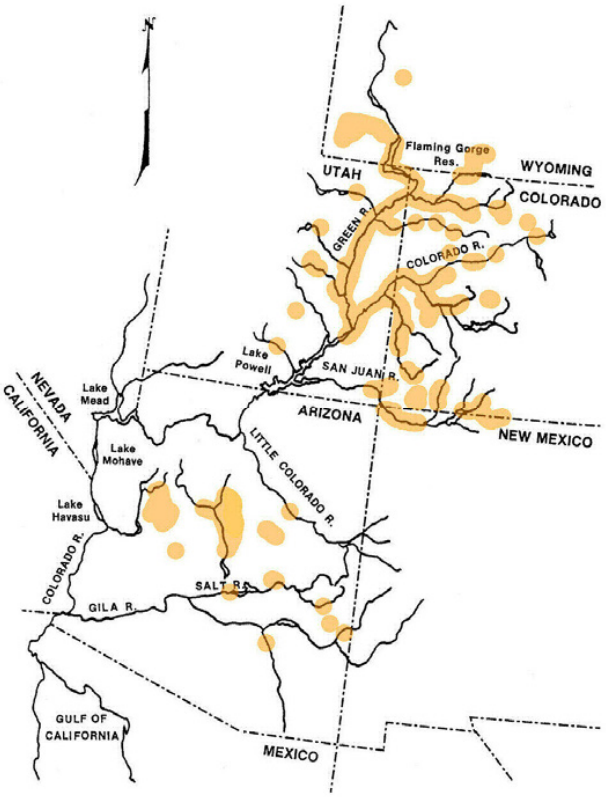

Figure 57. Recent distribution of *Gila robusta* in the Colorado River Basin.

Table 22. Selected juvenile and adult meristics for *Gila robusta*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	9	8-9(10)	Dorsal-fin rays - R	1-2-3	–
Anal-fin rays - P	(8)9-10	(7)8-9-10	Anal-fin rays - R	1-2-3(4)	–
Caudal-fin rays - P	(18)19(20)	19(20)	Caudal-fin rays - RD	(6-)9-10-11	8
Pectoral-fin rays	(12-)14-15-16(17)	(12-)14-17-19	Caudal-fin rays - RV	(7-)9-10-11	7
Pelvic-fin rays	(7)8-9	(7)8-9(10)	Lateral scales	80-87	(69-)71-77-91-97(-99)
Vertebrae	(44)45-46-47	(42)43-44-46-48(49)	Pharyngeal teeth	–	(1)2(3),(4)5/4(5),(1)2(3)

* Includes re-examined data originally prepared for Snyder (1981), Muth (1990), or Snyder et al. (2005); supplements and updates those accounts.

Table 23. Size at apparent onset of selected developmental events for *Gila robusta*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data as per footnote for Table 14.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	7-8	7-8	Dorsal - P	10-11	11-12	(10)11-12	(11)12-13(14)
Eyes pigmented	*	*	Anal - P	11-12	12-13(14)	12-13(14)	14-15(16)
Yolk assimilated	(9)10-11	10-11(12)	Caudal - P	9(10)	10	(9)10-11	(10)11(12)
Finfold absorbed	(18)19-20(-22)	(22-)24-25(-27)	Caudal - R	10-11(12)	11-12(13)	(14-)16-18(19)	(18-)20-22(23)
Pectoral-fin buds	*	*	Pectoral	(11)12-13	(12-)14-15	14-15(16)	(16)17-18(-20)
Pelvic-fin buds	11-12	12-13	Pelvic	(12)13-14(15)	(14)15-16(-18)	(14)15(16)	(16-)18(19)
* before hatching			Scales	(25-)27-28(-30)	(30-)33-34(-37)	34-38	43-48

References: AGFD 2002; Baird and Girard 1853a, 1853b; Balon 1981; Baxter and Simon 1970; Beckman 1952; Behnke and Benson 1983; Behnke et al. 1982; Bestgen 1985; Bestgen et al. 1987; Carlson et al. 1979; DeMarais 1986; Gaufin et al. 1960; Holden 1968; Holden and Stalnaker 1970; Jordan and Evermann 1896; Joseph et al. 1977; Koster 1957; La Rivers 1962; Miller 1946; Minckley 1973; Minckley and DeMarais 2000; Minckley and Marsh 2009; Moore 1968; Muth 1990; Muth et al. 1985; Page and Burr 1991; Rinne 1976; Sigler and Miller 1963; Smith et al. 1979; Snyder 1981; Sublette et al. 1990; Uyeno 1961; Vanicek and Kramer 1969; Winn and Miller 1954.
Other larval descriptions: Muth 1990; Snyder 1981; Snyder et al. 2005; Winn and Miller 1954.

Table 24. Size at developmental interval (left) and gut phase (right) transitions for *Gila robusta*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981, Muth 1990, or Snyder et al. 2005, and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	9(10)	10	2 - 90° bend	12(13)	14(15)
Postflexion mesolarva	(9)10-11	(10)11(12)	3 - Full loop	(25-)29-34(-36)	(31-)36-43(-47)
Metalarva	12-13(14)	14-15(16)	4 - Partial crossover	(not applicable)	
Juvenile	(18)19-20(-22)	(22-)24-25(-27)	5 - Full	(not applicable)	

Table 25. Summary of morphometrics and myomere counts by developmental phase for *Gila robusta*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981, Muth 1990[a], or Snyder et al. 2005, and supplements and updates those accounts.)

	Protolarvae (N=24)			Flexion mesolarvae (N=20)			Postflexion mesolarvae (N=42)			Metalarvae (N=85)			Juveniles (N=82)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	8	1	7 - 10	10	0	9 - 11	11	1	10 - 12	15	2	12 - 20	28	8	19 - 50
TL, mm	9	1	7 - 10	10	0	10 - 11	13	1	11 - 14	19	3	14 - 25	35	10	24 - 62
Lengths %SL															
AS to AE	3	0	2 - 4	4	1	3 - 5	4	1	3 - 6	6	1	4 - 8	6	1	5 - 8
PE	9	1	8 - 11	10	1	9 - 12	12	1	10 - 13	13	1	11 - 15	14	1	12 - 15
OP1	18	1	17 - 20	21	1[e]	19 - 22	24	1	21 - 26	27	1[z]	23 - 29	27	1	23 - 29
OP2							48	1[j]	47 - 50	51	2	47 - 54	50	2	46 - 53
PY	67	2[b]	65 - 70	52	12[f]	29 - 64	34	30[d]	0 - 53						
OPAF	42	7[b]	37 - 51	32	2[g]	29 - 36	33	3[k]	25 - 39	47	9[aa]	34 - 60			
ODF	39	3[b]	37 - 43	43	2[g]	40 - 47	46	2[k]	42 - 50	49	2[ab]	45 - 51			
OD							53	1[l]	51 - 55	54	1	51 - 58	53	2[af]	49 - 57
ID							64	1[m]	62 - 65	66	1	63 - 69	65	2[af]	62 - 69
PV	69	1	67 - 72	67	1	64 - 70	69	1[n]	66 - 71	67	2	63 - 71	65	2[af]	61 - 68
OA							69	1[o]	67 - 70	67	2[ac]	62 - 71	66	1[ac]	64 - 69
IA							77	1[p]	75 - 78	77	1	74 - 81	76	1[af]	74 - 80
AFC							109	2[q]	106 - 113	111	2	107 - 115	112	2	108 - 116
PC	104	1	102 - 106	106	1	104 - 110	113	3	108 - 118	122	3	116 - 128	125	2	120 - 129
Y	52	7[b]	48 - 62	25	16	0 - 45	1	5	0 - 32						
P1	6	2	3 - 10	11	1[h]	10 - 13	13	1	11 - 15	15	1	12 - 17	16	1[af]	14 - 18
P2							1	2[r]	0 - 5	7	3	3 - 13	12	2	9 - 17
D							15	2[s]	13 - 17	18	2	14 - 22	20	1	18 - 23
A							11	1[d]	9 - 12	15	2	10 - 19	18	1	15 - 21
Depths %SL															
at BPE	11	1	10 - 16	12	1	11 - 13	14	1[t]	12 - 16	16	1	14 - 18	16	1	14 - 19
OP1	18	4	13 - 25	14	1	12 - 15	16	1[t]	12 - 19	20	1	17 - 22	21	1	19 - 23
OD	15	1	13 - 17	12	1	10 - 13	12	1[t]	10 - 16	17	2	13 - 21	20	1[af]	18 - 22
BPV	7	1	6 - 9	8	1	8 - 10	9	1[t]	8 - 11	13	1	10 - 15	15	1[af]	13 - 18
AMPM	4	1	2 - 5	4	0	4 - 5	6	0[t]	5 - 7	7	1	6 - 9	8	1	7 - 10
Max. yolk	12	4[b]	9 - 18	4	3	0 - 10	0	0	0 - 2						
Widths %SL															
at BPE	10	2	8 - 13	12	1	10 - 14	14	1[t]	13 - 16	16	1	15 - 18	16	1	13 - 18
OP1	15	6	9 - 22	11	1	9 - 13	13	1[t]	11 - 15	16	2	12 - 19	16	2	13 - 19
OD	9	1[c]	7 - 9	6	1	5 - 8	7	1[t]	5 - 9	10	2	8 - 16	13	2	10 - 17
BPV	5	1	4 - 6	5	1	4 - 6	6	1[t]	4 - 7	8	1	6 - 11	11	1	8 - 14
AMPM	3	1	2 - 4	2	1	2 - 3	3	0[t]	2 - 4	4	1	2 - 5	4	1	2 - 5
Max. yolk	15	6[b]	11 - 24	6	3	0 - 11	0	1	0 - 9						
Myomeres															
to PY	30	1[d]	29 - 30	21	8[f]	6 - 30	22	2[u]	20 - 23						
OPAF	14	3[b]	10 - 18	8	1[i]	6 - 11	8	4[v]	4 - 19	15	6[ad]	7 - 26			
OP2							17	1[w]	15 - 18	17	1[ae]	15 - 20	17	1[k]	14 - 19
ODF	13	3[b]	10 - 16	15	1[i]	14 - 16	16	2[v]	14 - 20	16	1[ab]	14 - 18			
OD							20	1[x]	18 - 21	19	1[z]	17 - 21	19	1[ag]	17 - 21
PV	29	1	28 - 31	29	1	26 - 31	29	1[y]	27 - 32	28	1[z]	25 - 30	27	1[ah]	25 - 29[ai]
Total	46	1	45 - 48	46	1	43 - 47	46	1[y]	44 - 48	46	1[z]	42 - 48	45	1[ag]	43 - 47[ai]
After PV	17	1	14 - 19	17	1	15 - 18	17	1[y]	14 - 19	17	1[z]	15 - 19	17	1[ag]	15 - 19[ai]

[a] Developmental phase of some specimens reassigned; highly questionable data for missing specimens excluded from this summary. [b] N = 4. [c] N = 23. [d] N = 3. [e] N = 17. [f] N = 18. [g] N = 13. [h] N = 19. [i] N = 12. [j] N = 22. [k] N = 25. [l] N = 24. [m] N = 16. [n] N = 43. [o] N = 9. [p] N = 7. [q] N = 35. [r] N = 38. [s] N = 5. [t] N = 41. [u] N = 2. [v] N = 15. [w] N = 20. [x] N = 21. [y] N = 44. [z] N = 84. [aa] N = 57. [ab] N = 8. [ac] N = 55. [ad] N = 36. [ae] N = 80. [af] N = 81. [ag] N = 27. [ah] N = 28. [ai] Corresponding vertebra count ranges for 21 cleared and stained specimens: to PV 25–28, Total 44–47, After PV 18–20.

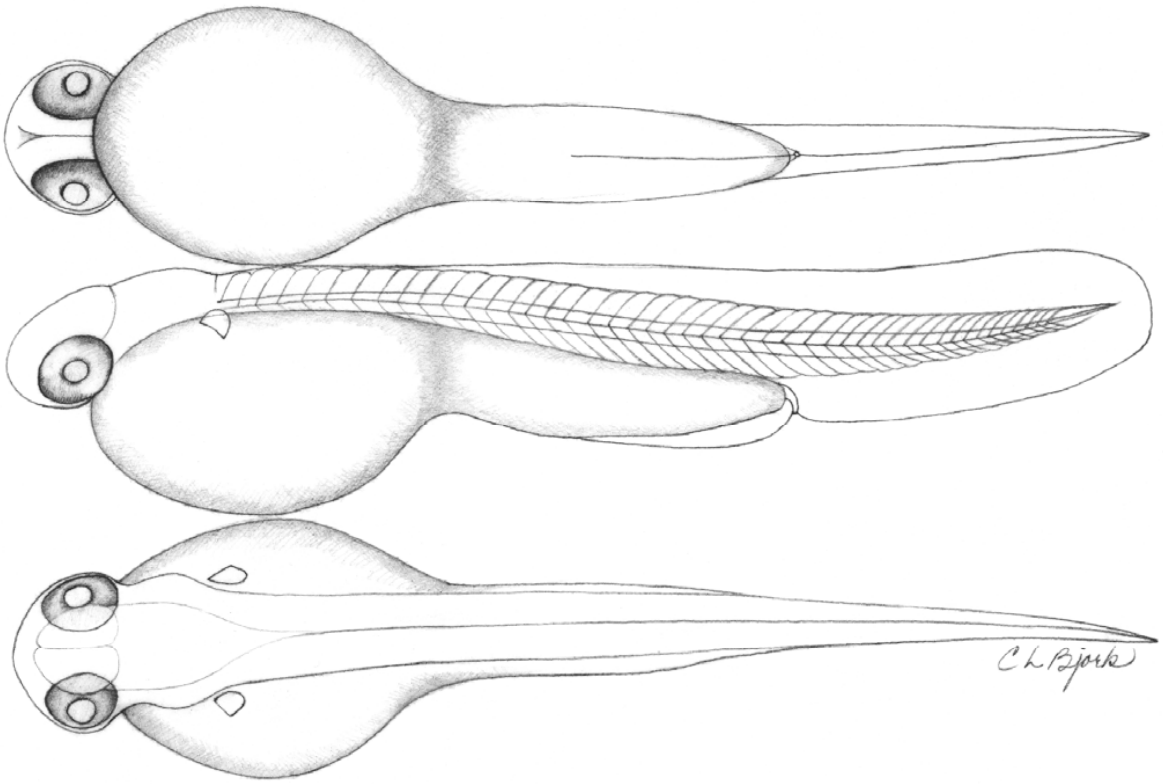

Figure 58. *Gila robusta* protolarva, recently hatched, 7.4 mm SL, 7.6 mm TL. (Cultured in 1983 by Larval Fish Laboratory at Colorado State University with stock from the Yampa River southwest of Craig, Colorado. From Muth 1990.)

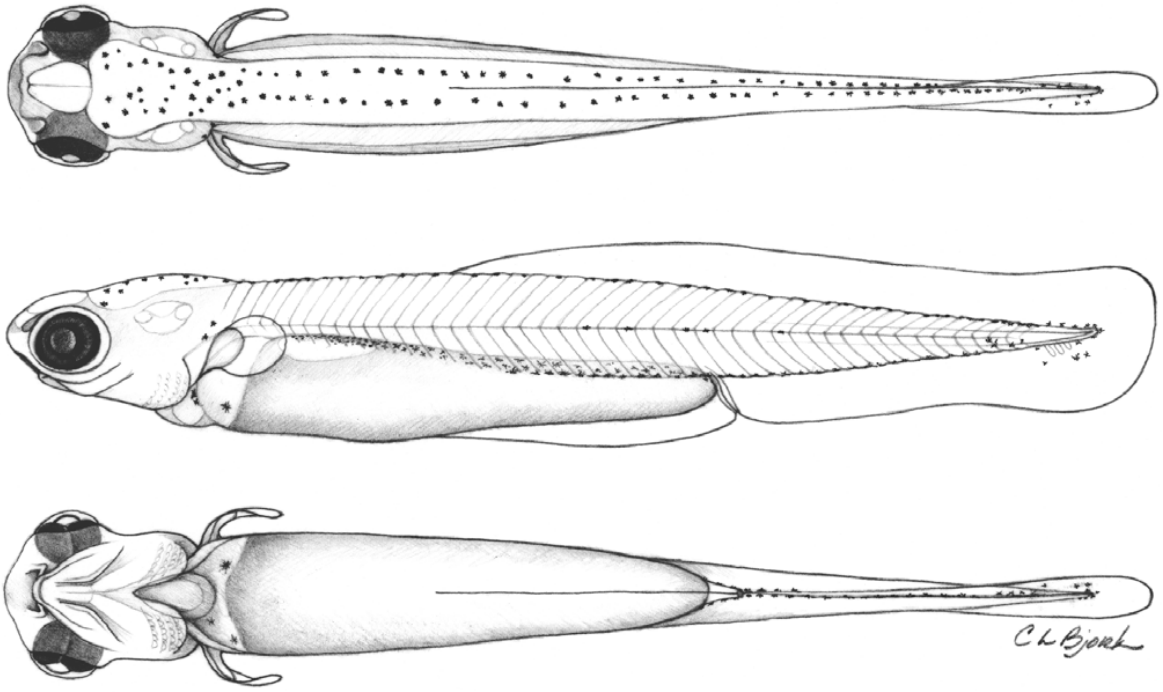

Figure 59. *Gila robusta* protolarva, 9.0 mm SL, 9.4 mm TL. (Cultured in 1983 by Larval Fish Laboratory at Colorado State University with stock from the Yampa River southwest of Craig, Colorado. From Snyder et al. 2005.)

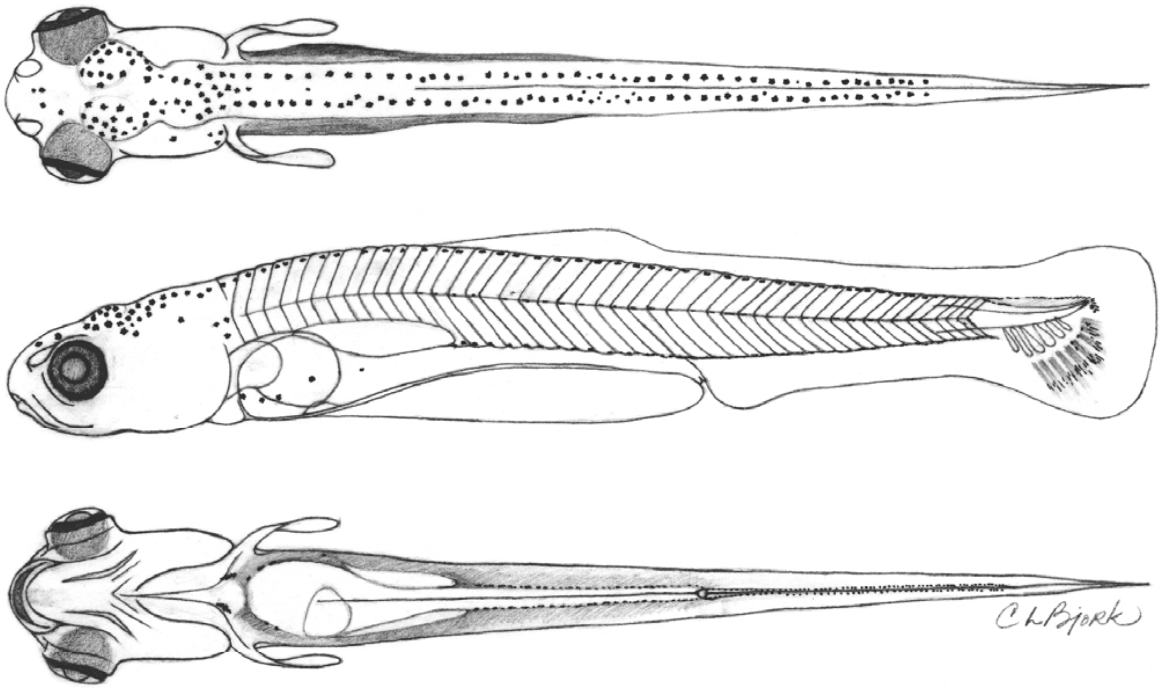

Figure 60. *Gila robusta* flexion mesolarva, recently transformed, 9.2 mm SL, 9.8 mm TL. (Collected in late 1970s from the Yampa River, Colorado. From Snyder 1981.)

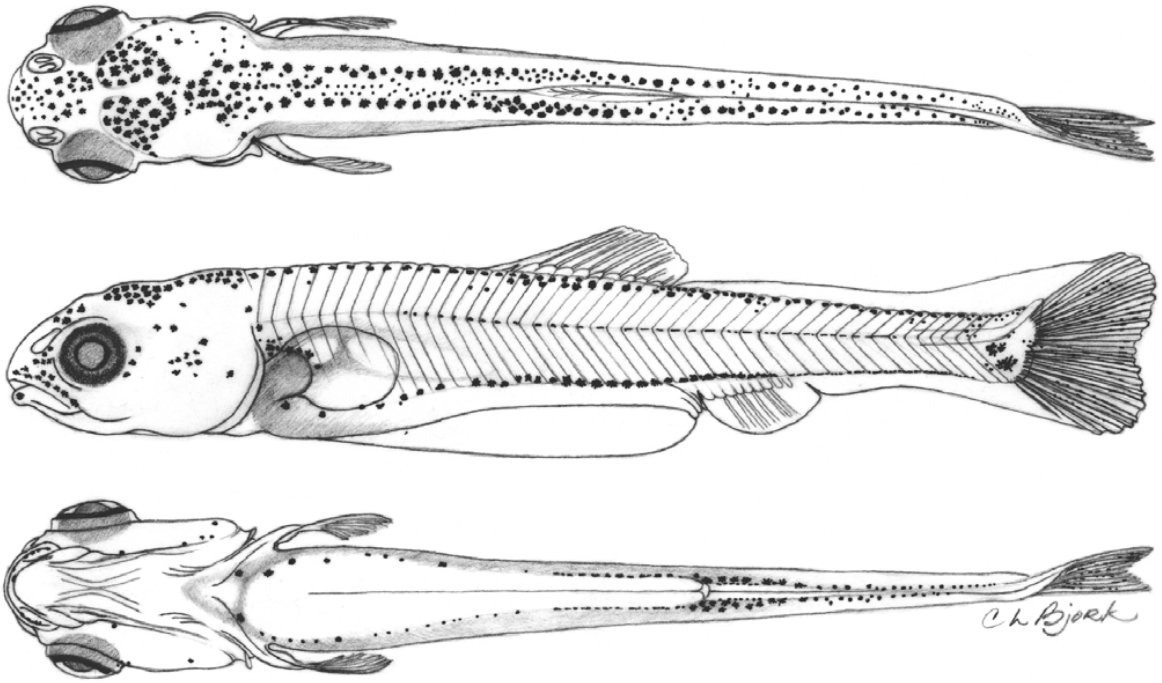

Figure 61. *Gila robusta* postflexion mesolarva, 10.8 mm SL, 12.0 mm TL. (Collected in late 1970s from the Yampa River, Colorado. From Snyder 1981.)

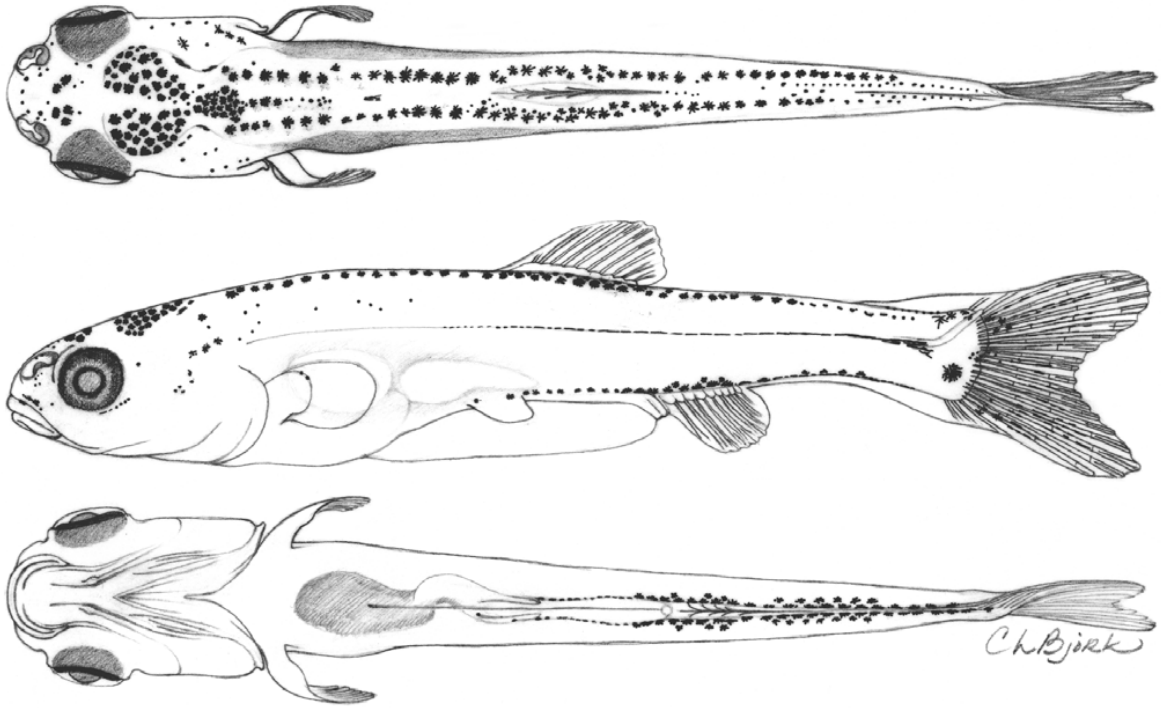

Figure 62. *Gila robusta* metalarva, recently transformed, 12.0 mm SL, 14.0 mm TL. (Collected in late 1970s from the White River, Colorado. From Snyder 1981.)

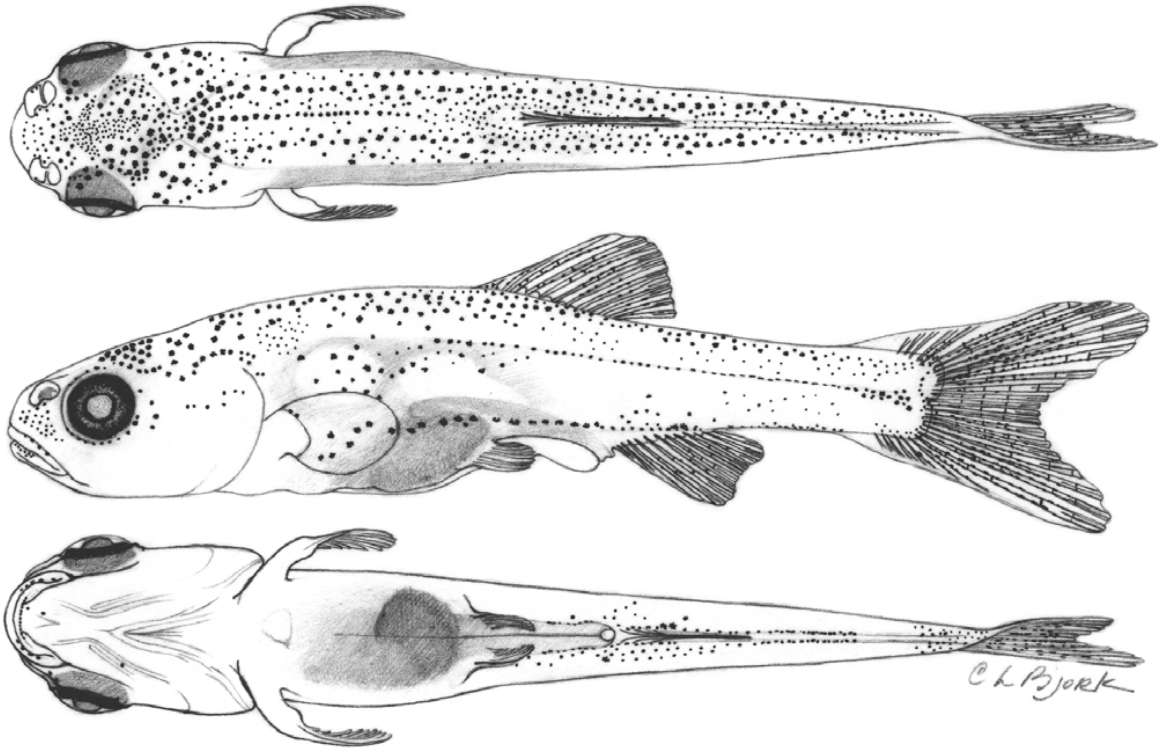

Figure 63. *Gila robusta* metalarva, 14.8 mm SL, 18.0 mm TL. (Collected in late 1970s from the White River, Colorado. From Snyder 1981.)

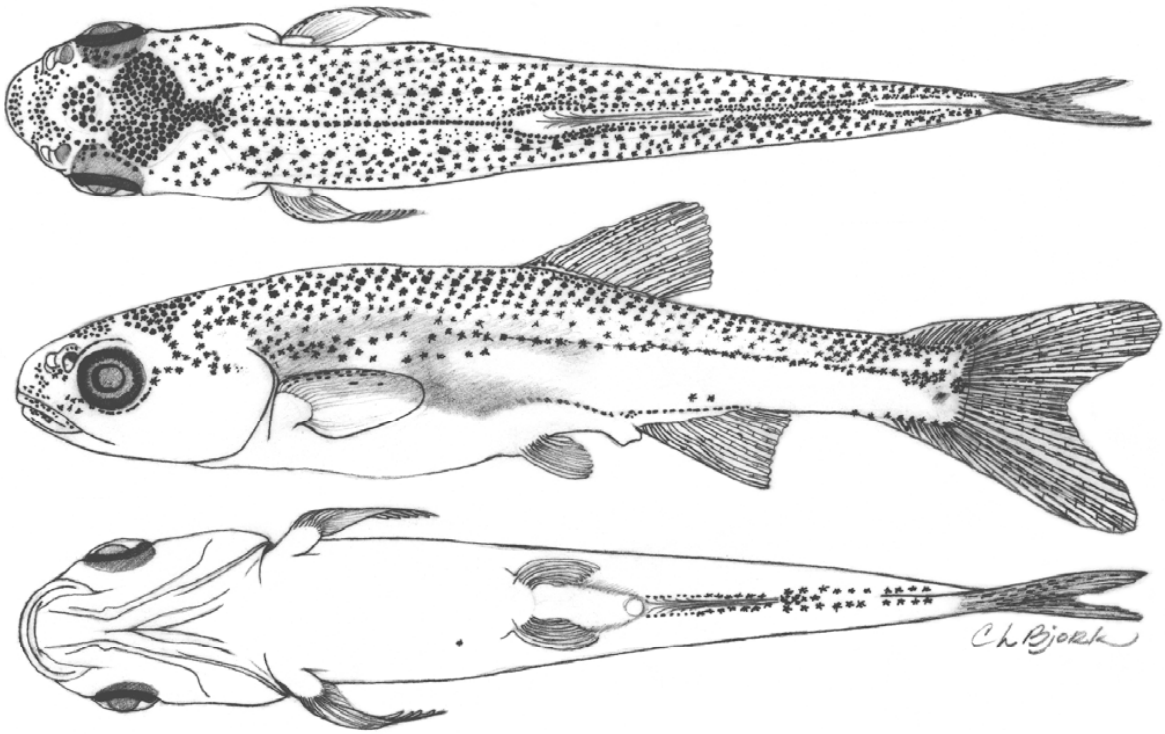

Figure 64. *Gila robusta* juvenile, recently transformed, 20.1 mm SL, 24.1 mm TL. (Collected in late 1970s from the Yampa River, Colorado. From Snyder 1981.)

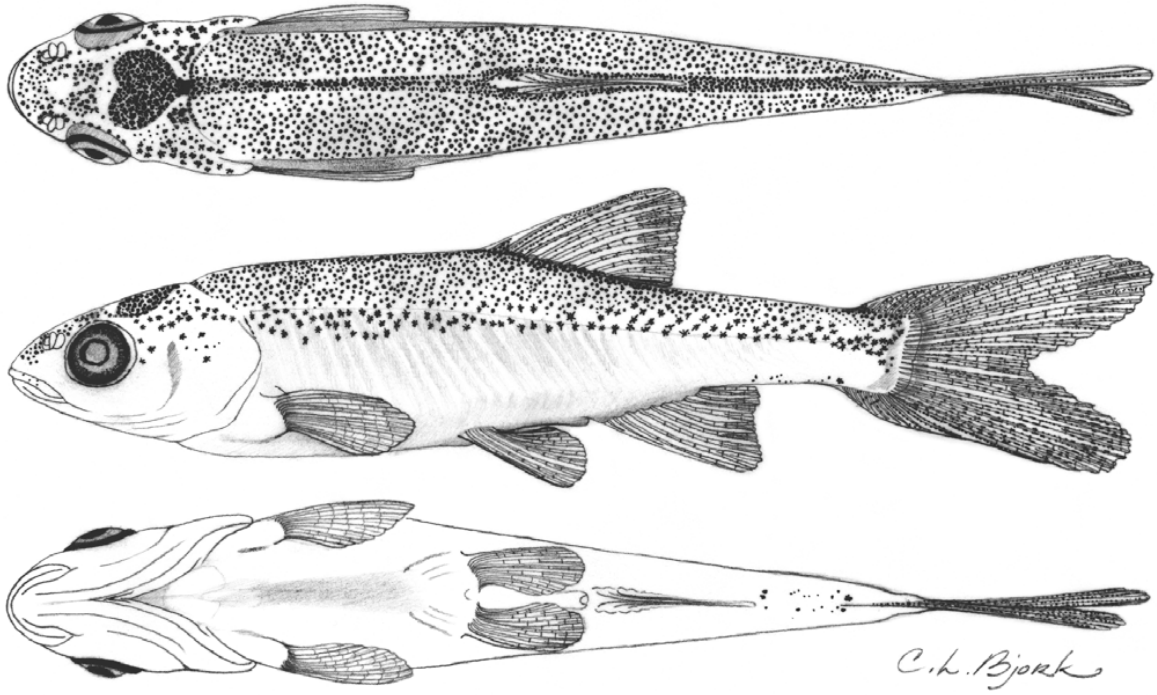

Figure 65. *Gila robusta* juvenile, 29.5 mm SL, 37.0 mm TL. (Collected in late 1970s from the White River, Colorado. From Snyder 1981.)

Species Account – *Hybognathus hankinsoni*, brassy minnow

Figure 66. *Hybognathus hankinsoni* adult (© New York State Department of Environmental Conservation).

Adult description: Usually 5–8, up to 10 cm TL. Body somewhat laterally compressed. Mouth small, slightly oblique, terminal or subterminal and slightly overhung by a blunt snout. Moderately large eye, center approximately level with tip of snout. Dorsal fin rounded at tip with first principal ray shorter than the second and third, not falcate, origin anterior to pelvic fin. Scales large, number of often incomplete radii increase with size, usually 15 to >20 for fish >5 cm TL. Long coiled gut with dark peritoneum. Color usually green to brassy on dorsal to dorso-lateral surfaces, yellow laterally, and white below, with a dark mid-dorsal stripe and dusky lateral band, posteriorly darker; breeding males are more brassy or golden. (Also, Table 26.)

Reproduction: Non-guarding, open-substrate phytolithophil (non-obligatory plant spawner). Mature at age 1 or 2 and usually spawn in mid to late spring at water temperatures of 16–27 °C (at least 10–13 °C) in shallow, calm, backwater areas, scattering eggs over vegetation when available. Eggs are demersal, adhesive, and usually 1.2–1.5 mm in diameter.

Young: Hatch in 3 days at 20–21 °C. Recently hatched larvae are usually found in vegetated floodplain and backwater habitats. Recent juveniles shift to in-stream pools and channel margins where they may be subject to downstream dispersal.

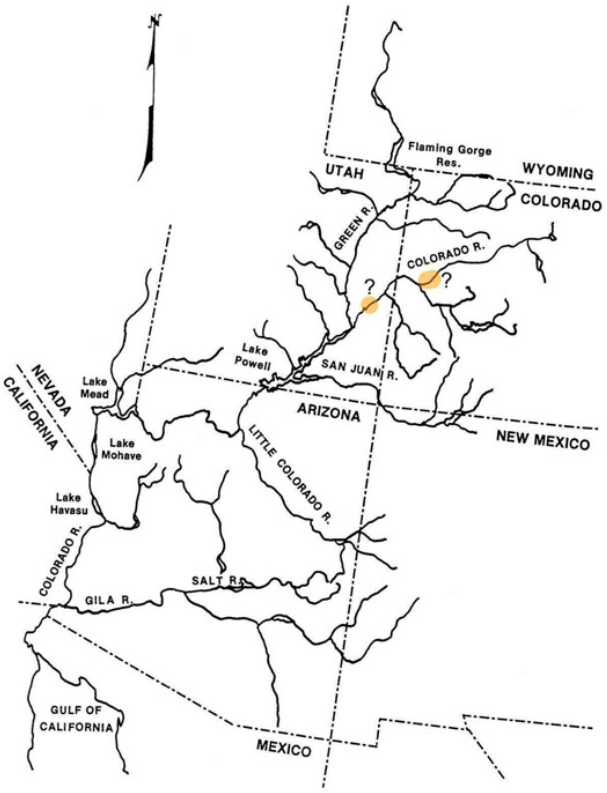

Figure 67. (Suspected) recent distribution of *Hybognathus hankinsoni* in the Colorado River Basin (see Table 1).

Table 26. Selected juvenile and adult meristics for *Hybognathus hankinsoni*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed	Literature	Character	Observed	Literature
Dorsal-fin rays - P	8	(7)8	Dorsal-fin rays - R	2(3)	–
Anal-fin rays - P	(7)8	(6)7-8(9)	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	19(20)	19	Caudal-fin rays - RD	8-10-11(12)	–
Pectoral-fin rays	12-13(14)	13-15	Caudal-fin rays - RV	(7)8-9-10	–
Pelvic-fin rays	8	8	Lateral scales	(35)36-37-38(39)	(32-)35-39(-41)
Vertebrae	-	35-37	Pharyngeal teeth	–	0,4-4,0

Table 27. Size at apparent onset of selected developmental events for *Hybognathus hankinsoni*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	3(4)	3-4	Dorsal - P	8	8-9	(9)10	11(12)
Eyes pigmented	*-3(4)	*-(3)4	Anal - P	(8)9	9	(9)10-11	11-12(13)
Yolk assimilated	5	5	Caudal - P	6	6(7)	8(9)	(8)9
Finfold absorbed	(13)14-16(17)	(15-)17-19(-21)	Caudal - R	9-10	10-11	14-15	17-18
Pectoral-fin buds	*-3(4)	*-(3)4	Pectoral	(9)10	11	(14)15	18(19)
Pelvic-fin buds	(7)8	8	Pelvic	(9)10-11	11-12(13)	(14)15-16	18-19
* before hatching			Scales	(14)15	(17)18	16(17)	19-20(21)

References: Balon 1981; Baxter and Stone 1995; Becker 1983; Beckman 1952; Copes 1975; Dobie et al. 1956; Eddy and Underhill 1974; Falke 2009; Heufelder and Fuiman 1982; Lentsch et al. 1996; Moore 1968; Page and Burr 1991; Pflieger 1997; Scheurer et al. 2003a, 2003b; Scott and Crossman 1973; Simon 1998; Smith 1979; Tyus et al. 1982; Woodling 1985.

Other larval descriptions: Fuiman et al. 1983; Heufelder and Fuiman 1982; Perry 1979; Perry and Menzel 1979; Snyder 1981.

Table 28. Size at developmental interval (left) and gut phase (right) transitions for *Hybognathus hankinsoni*. (See Figure 5 for phases of gut folding. Rare values in parentheses.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	6	6(7)	2 - 90° bend	(9)10-12	11-14
Postflexion mesolarva	8(9)	(8)9	3 - Full loop	13-14	16
Metalarva	(9)10-11	11-12(13)	4 - Partial crossover	(14)15-16	18-19
Juvenile	(14)15-16(17)	(17)18-19(-21)	5 - Full	16-17	20

Table 29. Summary of morphometrics and myomere counts by developmental phase for *Hybognathus hankinsoni*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5.)

	Protolarvae (N=10)			Flexion mesolarvae (N=9)			Postflexion mesolarvae (N=11)			Metalarvae (N=20)			Juveniles (N=33)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	5	1	3 - 6	7	1	6 - 9	9	1	8 - 11	13	2	9 - 17	23	7	14 - 40
TL, mm	5	1	4 - 6	8	1	6 - 9	10	1	9 - 13	16	2[g]	11 - 21	29	9[h]	18 - 50
Lengths %SL															
AS to AE	2	1	2 - 4	3	1	2 - 4	4	1	3 - 5	5	1	4 - 6	6	1	5 - 7
PE	10	1	8 - 11	11	1	10 - 12	12	1	9 - 13	13	1	11 - 14	14	1	12 - 16
OP1	20	1	18 - 21	22	1	20 - 22	23	1	21 - 25	26	1	23 - 28	27	1	25 - 29
OP2				47	0[b]	47 - 47	49	2[d]	46 - 52	51	2	47 - 54	54	1	51 - 56
PY	65	5[a]	58 - 71												
OPAF	37	8	28 - 53	31	1	30 - 32	33	1	30 - 35	44	8[g]	35 - 59			
ODF	39	3	35 - 44	41	2	39 - 44	46	2[d]	42 - 50	46	[c]	46 -			
OD				48	[c]	48 -	50	1	48 - 52	50	1	46 - 51	51	1	48 - 53
ID				59	[c]	59 -	59	2[d]	58 - 63	61	1	58 - 63	62	1	58 - 67
PV	70	2	67 - 73	70	1	67 - 71	71	1	70 - 74	70	1	67 - 72	70	1	68 - 73
OA							70	1[d]	68 - 72	69	1	67 - 72	69	2	67 - 71
IA							78	1[d]	77 - 81	79	1	77 - 82	79	1	77 - 81
AFC							110	1	109 - 112	113	1[g]	111 - 115	115	1	113 - 116
PC	106	1	105 - 107	106	1	105 - 108	111	2	109 - 115	119	2[g]	115 - 121	123	1[h]	121 - 126
Y	34	26	0 - 62												
P1	8	4	2 - 12	13	1	11 - 15	13	1	10 - 13	15	1	13 - 17	17	1	15 - 19
P2				1	1	0 - 4	4	1	0 - 5	9	2	5 - 12	13	1	11 - 15
D							14	1[e]	13 - 14	17	2	13 - 21	21	1	19 - 22
A							12	1[f]	11 - 12	15	2	12 - 17	16	1	15 - 18
Depths %SL															
at BPE	14	1	11 - 17	14	1	12 - 15	16	1	14 - 18	17	1	15 - 19	17	1	16 - 19
OP1	15	3	11 - 21	15	1	13 - 16	17	1	15 - 20	20	1	16 - 22	22	1	19 - 23
OD	10	2	7 - 13	11	1	9 - 12	14	2	12 - 17	19	2	15 - 21	22	1	20 - 24
BPV	6	1	5 - 7	7	1	6 - 8	10	1	8 - 11	13	1	10 - 15	15	1	12 - 17
AMPM	4	0	3 - 5	5	0	4 - 6	7	1	6 - 8	9	1	7 - 10	10	1	8 - 12
Max. yolk	6	6	0 - 16												
Widths %SL															
at BPE	12	1	11 - 13	13	1	12 - 15	14	1	13 - 16	16	1	15 - 17	15	1	14 - 18
OP1	9	4	6 - 18	10	1	9 - 11	12	1	10 - 15	15	1	12 - 16	17	1	13 - 18
OD	5	1	4 - 7	6	1	5 - 7	8	1	7 - 10	12	2	9 - 14	16	2	10 - 19
BPV	4	1	3 - 5	5	1	4 - 6	6	1	5 - 7	8	1	6 - 10	10	1	7 - 13
AMPM	2	0	2 - 3	3	0	2 - 4	4	1	3 - 4	5	1	4 - 6	5	1	3 - 6
Max. yolk	7	7	0 - 18												
Myomeres															
to PY	23	2[a]	20 - 26												
OPAF	10	3	7 - 14	7	0	7 - 8	7	1	6 - 8	12	4[g]	8 - 21			
OP2				15	0[b]	15 - 15	16	1	14- 17	16	1	15 - 18	16	1[i]	15 - 17
ODF	11	1	10 - 12	12	1	11 - 13	14	1[d]	12 - 15	15	[c]	15 -			
OD							16	1	15 - 17	16	1	14 - 17	15	1[i]	14 - 16
PV	26	1	25 - 28	27	0	26 - 27	27	1	26 - 28	26	1	25 - 27	26	1[i]	24 - 27
Total	37	1	36 - 38	38	1	37 - 39	38	1	36 - 39	37	1	36 - 39	37	1[i]	36 - 38
After PV	11	0	10 - 12	11	1	11 - 12	11	1	10 - 12	11	0	11 - 12	11	1[i]	11 - 12

[a]N = 7. [b]N = 2. [c]N = 1. [d]N = 10. [e]N = 5. [f]N = 3. [g]N = 19. [h]N = 32. [i]N = 17.

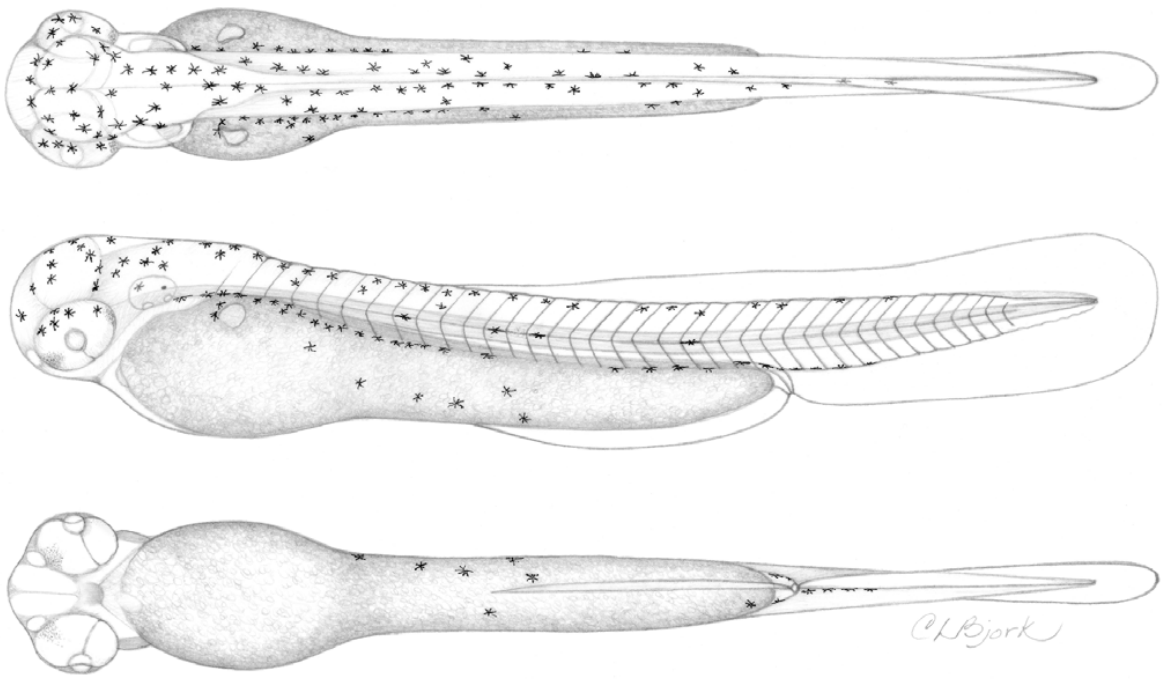

Figure 68. *Hybognathus hankinsoni* protolarva, 1 d posthatch, 3.8 mm SL, 4.0 mm TL. (Cultured in 2008 at Colorado State University (CSU) Larval Fish Laboratory by Jeffrey Falke and Sean Seal with Colorado Division of Wildlife stock maintained at CSU foothills ponds, originally from S. Platte R.,Tamarack Ranch State Wildlife Area, Logan Co., CO.)

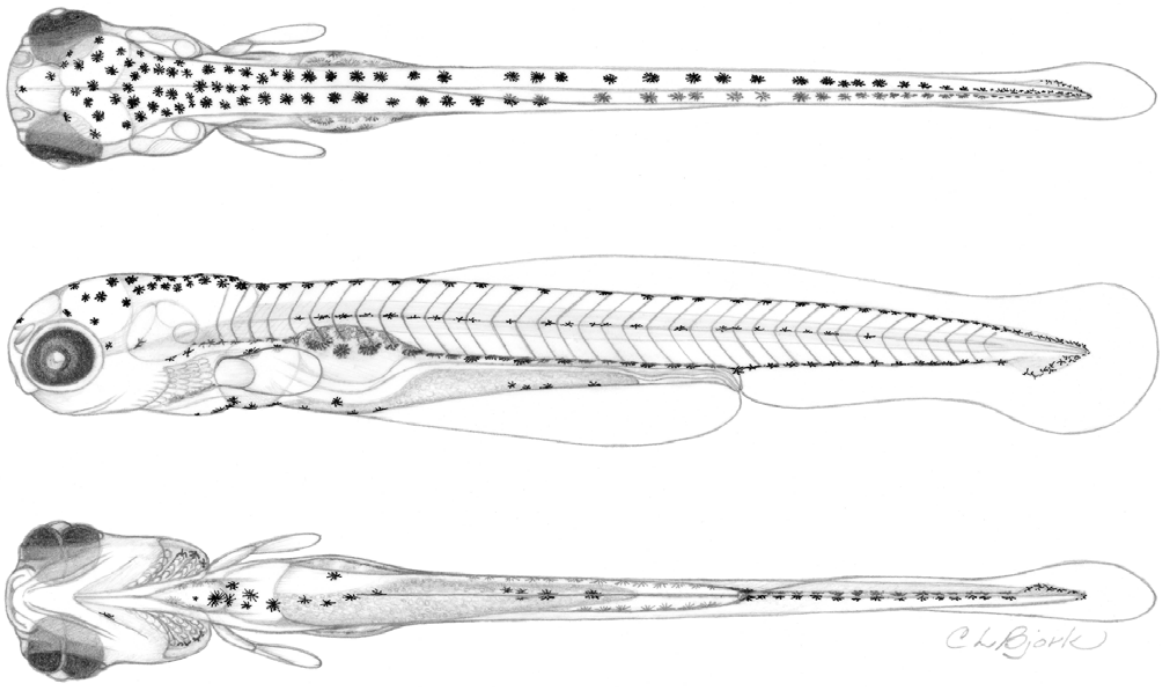

Figure 69. *Hybognathus hankinsoni* protolarva, 4 d posthatch, 4.9 mm SL, 5.2 mm TL. (Cultured in 2008 at Colorado State University (CSU) by Jeffrey Falke and Sean Seal with Colorado Division of Wildlife stock maintained at CSU foothills ponds, originally from S. Platte R.,Tamarack Ranch State Wildlife Area, Logan County, Colorado.)

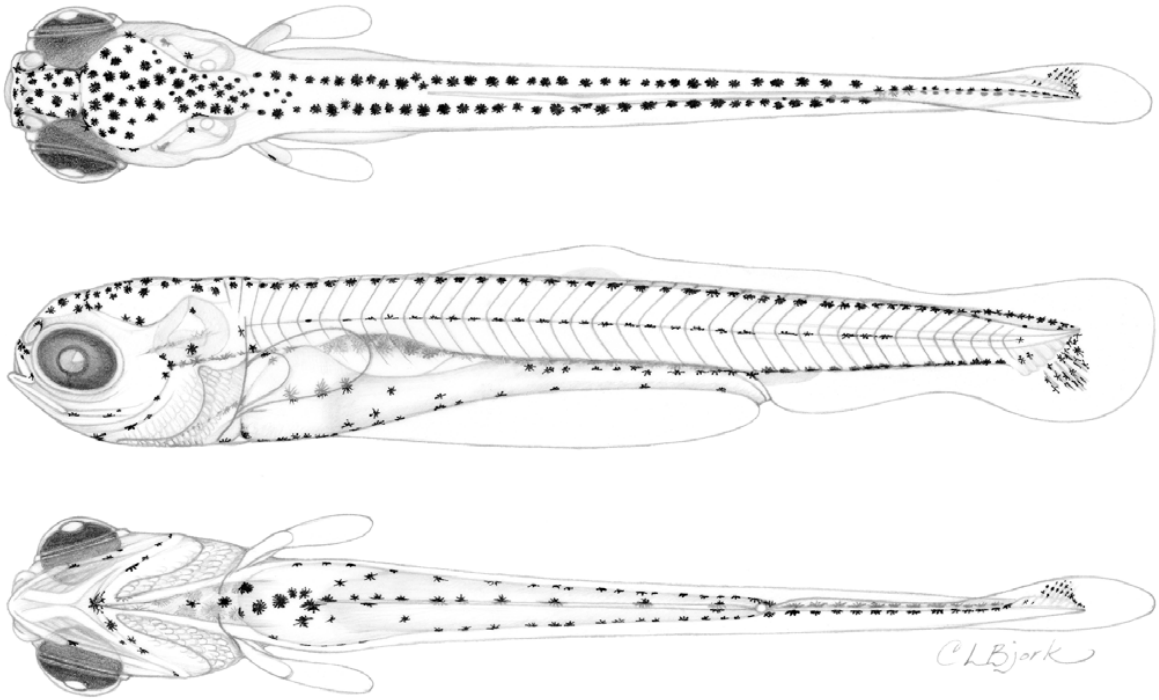

Figure 70. *Hybognathus hankinsoni* flexion mesolarva, recently transformed, 6.6 mm SL, 7.0 mm TL. (Pond cultured–collected in 2009 from Colorado Division of Wildlife stock maintained at Colorado State University foothills ponds, originally from South Platte River,Tamarack Ranch State Wildlife Area, Logan County, Colorado.)

Figure 71. *Hybognathus hankinsoni* postflexion mesolarva, 8.5 mm SL, 9.3 mm TL. (Pond cultured–collected in 2009 from Colorado Division of Wildlife stock maintained at Colorado State University foothills ponds, originally from South Platte River, Tamarack Ranch State Wildlife Area, Logan County, Colorado.)

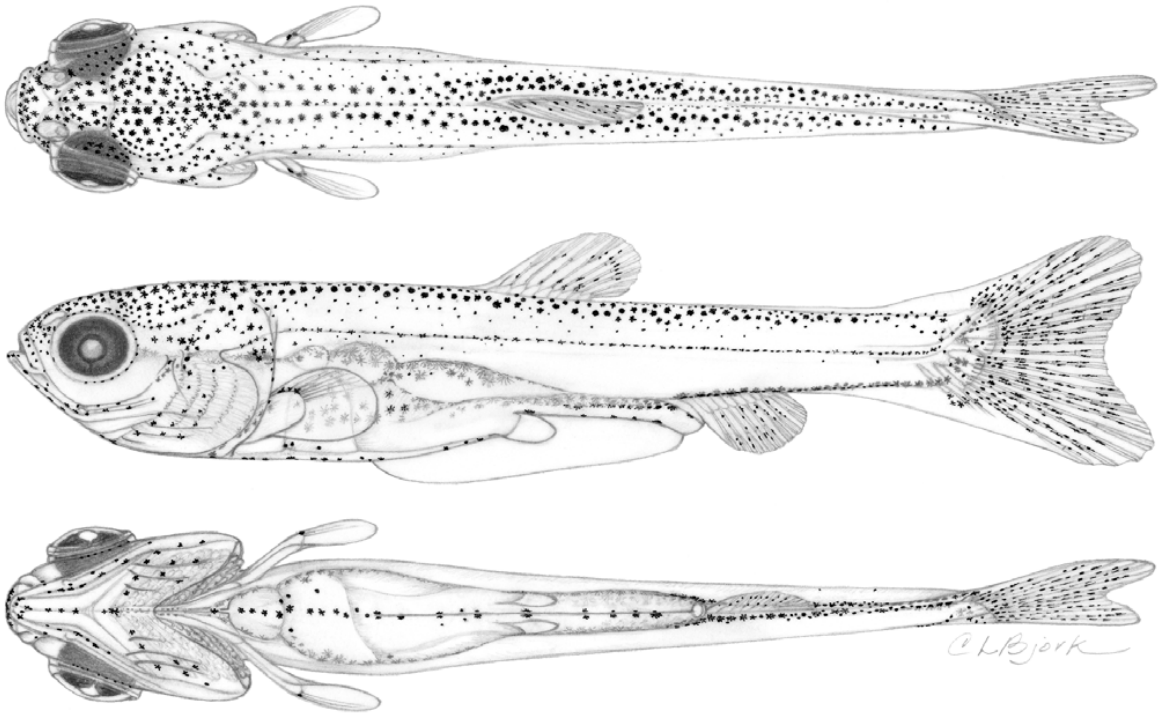

Figure 72. *Hybognathus hankinsoni* metalarva, recently transformed, 10.8 mm SL, 12.5 mm TL. (Collected in 2001 from Arikaree River, Yuma County, Colorado; from LFL #98634.)

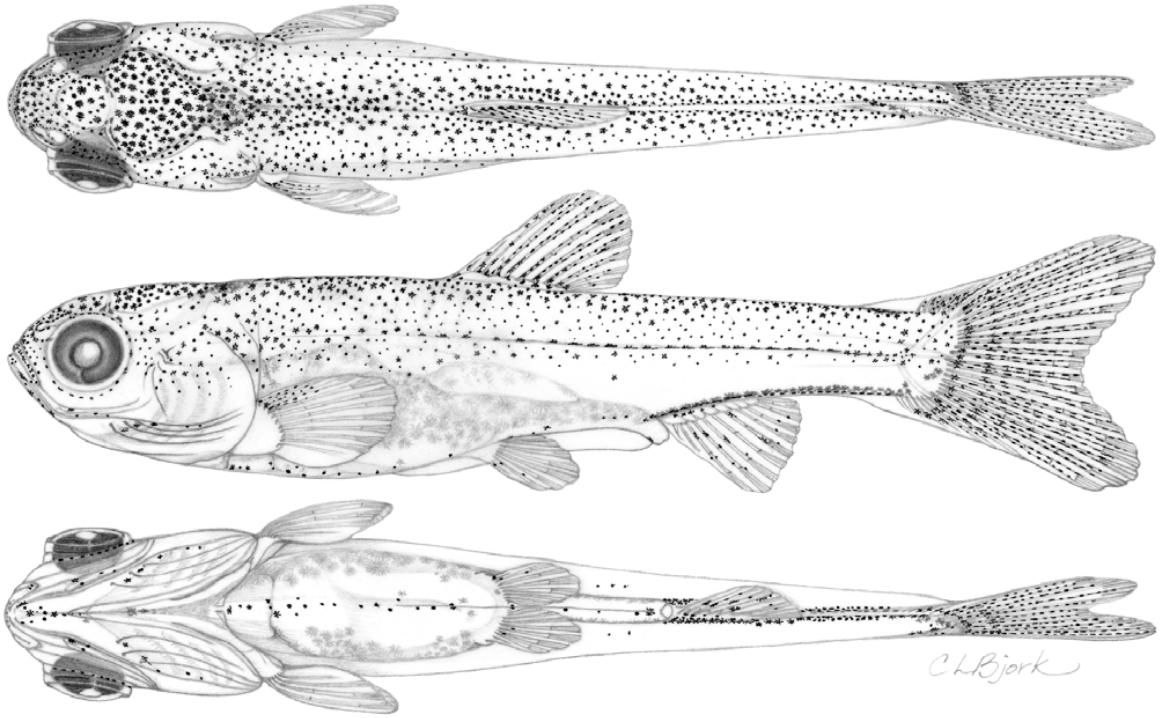

Figure 73. *Hybognathus hankinsoni* metalarva, 13.6 mm SL, 16.4 mm TL. (Collected in 2001 from Arikaree River, Yuma County, Colorado; from LFL #98634.)

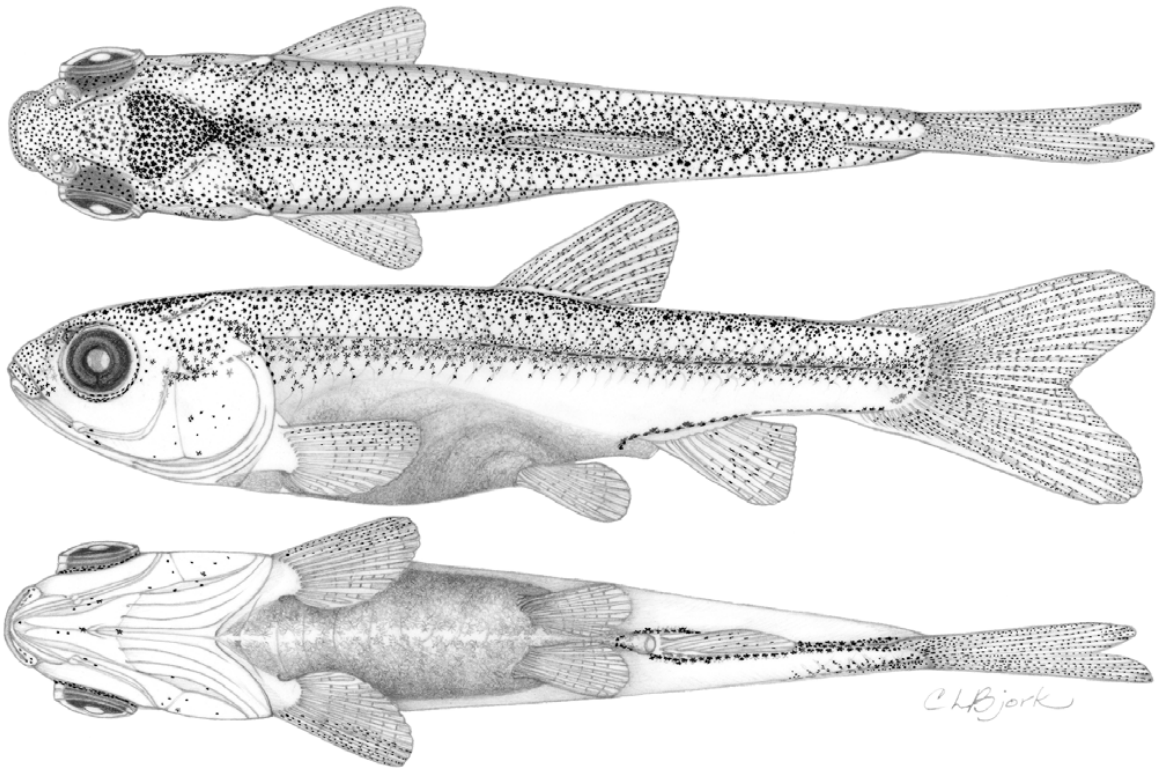

Figure 74. *Hybognathus hankinsoni* juvenile, recently transformed, 18.9 mm SL, 23.5 mm TL. (Collected in 2001 from Arikaree River, Yuma County, Colorado; from LFL #98648.)

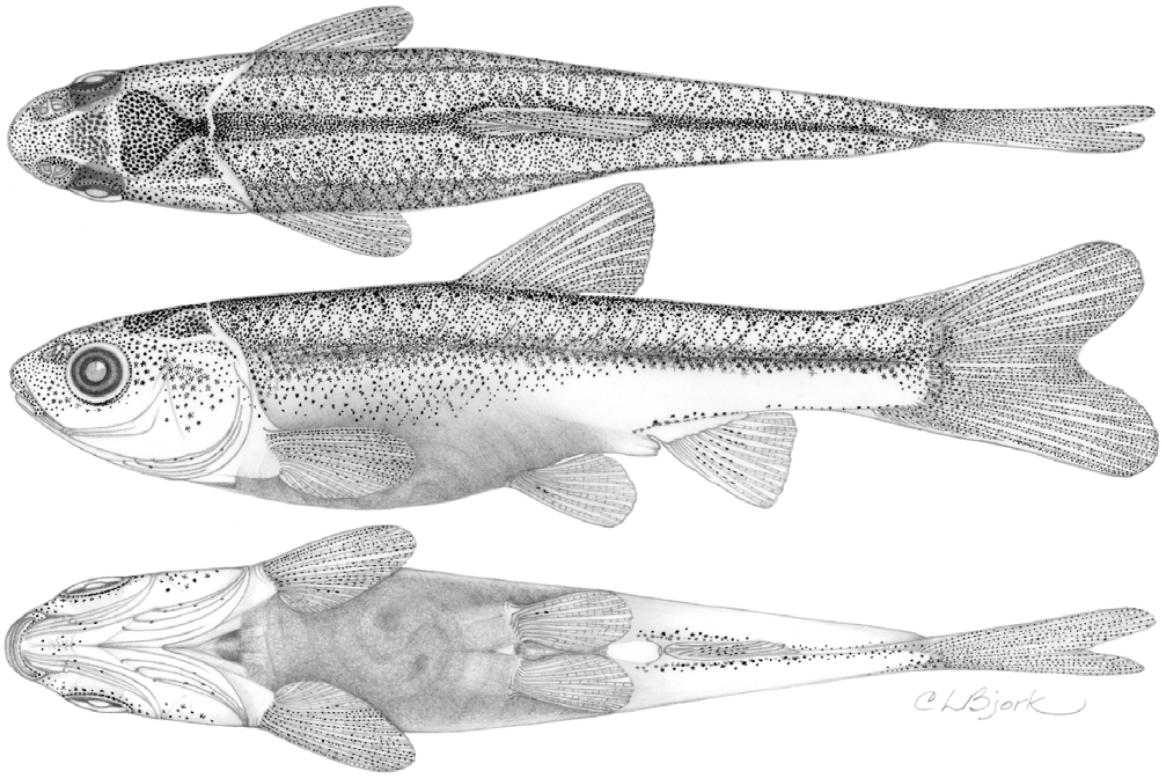

Figure 75. *Hybognathus hankinsoni* juvenile, 32.0 mm SL, 39.5 mm TL. (Collected in 1990 from Colorado River near De Beque, Colorado; from LFL #69367.)

Species Account – *Notemigonus crysoleucas*, golden shiner

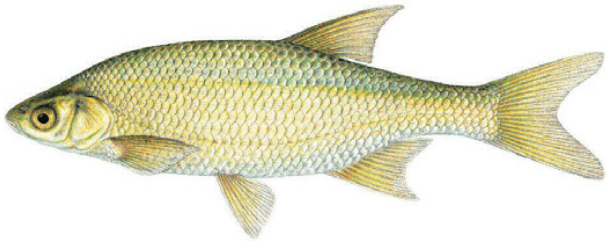

Figure 76. *Notemigonus crysoleucas* adult (© Joseph R. Tomelleri).

Adult description: 5–30 cm, usually 7–20 cm TL. Very deep, laterally compressed body with distinctly decurved lateral line and fleshy (scaleless edged) mid-ventral keel between pelvic fins and vent. Short triangular head with pointed snout, oblique terminal to somewhat superior mouth ending before eyes, lower jaw often projecting slightly beyond upper. Dorsal fin acute, posterior margin straight to slightly falcate, origin well behind pelvic fins. Anal fin long and falcate; pectorals pointed, short to long, sometimes extending to pelvics. Gut short, s-shaped; peritoneum dusky to dark. Usually olivaceous back, brassy to golden sides, yellowish to silvery below; breeding males brilliant gold sometimes with reddish ventral fins. (Also, Table 30.)

Reproduction: Non-guarding, open-substrate phytolithophil. Usually mature by age 1–2 and spawn late spring to mid-summer (some places as early as March or late as October) at 20–27 °C in quiet waters of ponds, lakes, or streams over filamentous algae, vegetation, debris, gravel, or sometimes centrarchid nests. Water-hardened eggs are demersal (semi-buoyant?), adhesive, 1.0 or 1.2–1.4 mm in diameter.

Young: Hatch in 2–4 d at 24–17 °C and attach to plants via cephalic adhesive glands or lie on bottom. Later larvae and early juveniles school loosely at surface to mid-depths in or near vegetation, feed on algae and zooplankton; occasionally taken in drift collections. Later young silvery with dark to dusky lateral band, school offshore.

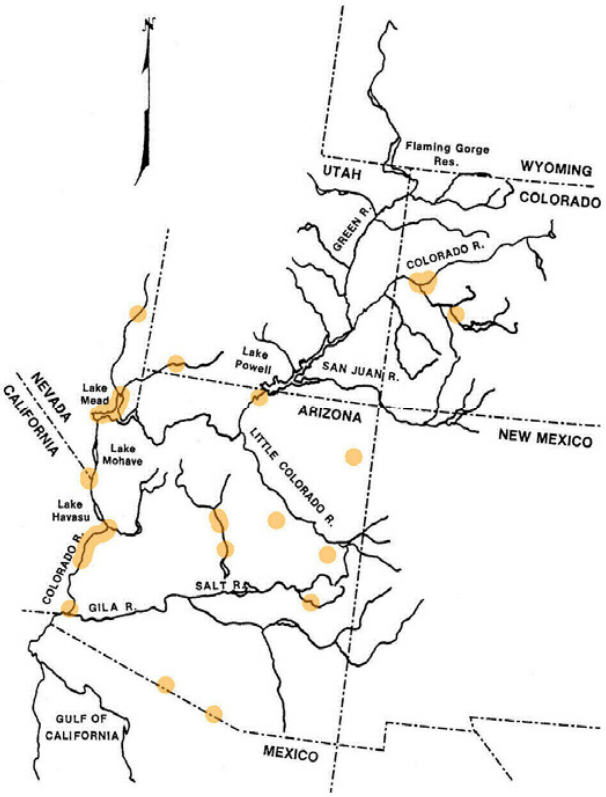

Figure 77. Recent distribution of *Notemigonus crysoleucas* in the Colorado River Basin .

Table 30. Selected juvenile and adult meristics for *Notemigonus crysoleucas*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed	Literature	Character	Observed	Literature
Dorsal-fin rays - P	8	7-8-9	Dorsal-fin rays - R	1-2	–
Anal-fin rays - P	13-14-16	(8-)11-12-14-15(-19)	Anal-fin rays - R	2	–
Caudal-fin rays - P	19	19	Caudal-fin rays - RD	4-9	–
Pectoral-fin rays	15-16	15-16-17-18	Caudal-fin rays - RV	6-8	–
Pelvic-fin rays	8-10	8-9	Lateral scales	49-53	(40-)44-54(-57)
Vertebrae		(36)37-39	Pharyngeal teeth	–	0,(4)5(6)/(4)5,0(1)

Table 31. Size at apparent onset of selected developmental events for *Notemigonus crysoleucas*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	3-4	(3)4	Dorsal - P	(7-)9	(8-)10	10	(11)12
Eyes pigmented	*3(4)	*4	Anal - P	(7-)9	(8-)10	10-11	(11)12-13
Yolk assimilated	5	5(6)	Caudal - P	6(7)	6-7	(7)8	8-9
Finfold absorbed	16	20-21	Caudal - R	(7-)9-10	(8-)10-11(12)	13-16	15-20(21)
Pectoral-fin buds	*4	*4	Pectoral	9-10	10-12	16	20-21
Pelvic-fin buds	9-10	10-12	Pelvic	11(12)	13(14)	13-16	15-21
* before hatching			Scales	13-16	15-20	17-22	21-28

References: Balon 1975a; Baxter & Simon 1970; Becker 1983; Beckman 1952; Carlander 1969; Eddy & Underhill 1974; Faber 1980; Faber 2006 onwards; Harlan & Speaker 1969; Jones et al. 1978; La Rivers 1962; Lippson & Moran 1974; Minckley 1973; Moore 1968; Moyle 1976; Page & Burr 1991; Pflieger 1997; Scott & Crossman 1973; Sigler & Miller 1963; Simon 1998; Snyder et al. 1977; Sublette et al. 1990; Wang & Reyes 2007; Woodling 1985. ***Other larval descriptions***: Arvidson & Alber 2013, Buynak & Mohr 1980; Conrow & Zale 1985; Faber 1980, Faber 2006 onwards; Fish 1932 (wrong illustration); Fowler 1945; Fuiman et al. 1983; Heufelder & Fuiman 1982; Hogue et al. (1976); Holland-Bartels et al. 1990; Lippson & Moran 1974; Loos et al. 1979; Jones et al. 1978; Mansueti & Hardy 1967; McGowan 1984, 1988; Scheidegger 1990; Scripter 2009 (wrong embryo illustration?); Snyder et al. 1977; Wang 1986; Wang & Kernehan 1979; Wang & Reyes 2007.

Table 32. Size at developmental interval (left) and gut phase (right) transitions for *Notemigonus crysoleucas*. (See Figure 5 for phases of gut folding. Rare values in parentheses.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	6(7)	6-7	2 - 90° bend	12(13)	14-15
Postflexion mesolarva	(7)8	8-9	3 - Full loop	16(17)	20-21
Metalarva	10-11	(11)12-13	4 - Partial crossover	(not applicable)	
Juvenile	16	20-21	5 - Full	(not applicable)	

Table 33. Summary of morphometrics and myomere counts by developmental phase for *Notemigonus crysoleucas*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5 Includes data extracted from illustrations in Snyder et al. 1977 (based on specimens preserved in isopropanol) and Faber 2006 onwards.)

	Protolarvae (N=11)			Flexion mesolarvae (N=7)			Postflexion mesolarvae (N=9)			Metalarvae (N=8)			Juveniles (N=4)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	5	1	3 - 6	8	1	6 - 8	9	1	7 - 11	12	2	10 - 16	30	13	16 - 43
TL, mm	5	1	4 - 6	8	1	7 - 9	10	2	8 - 13	15	3	12 - 21	38	16	20 - 55
Lengths %SL															
AS to AE	4	1	3 - 5	4	1	3 - 4	4	1	2 - 5	5	0	4 - 6	5	1	4 - 6
PE	11	1	8 - 12	11	1	9 - 12	11	1	9 - 13	13	0	12 - 13	13	2	11 - 15
OP1	19	1[b]	17 - 20	21	1	19 - 22	22	2	19 - 24	25	2	23 - 27	24	2	22 - 25
OP2							48	0[e]	47 - 48	47	1	46 - 49	46	1	44 - 47
PY	62	6[c]	54 - 69												
OPAF	36	10	27 - 56	30	1	29 - 31	31	2	28 - 35	35	8	30 - 55			
ODF	42	4	37 - 50	47	4	41 - 54	50	4	40 - 55	53	1[f]	52 - 55			
OD							56	1[f]	54 - 57	56	2	53 - 58	54	1	52 - 55
ID							66	2[f]	64 - 67	67	1	65 - 69	66	2	64 - 68
PV	66	2	64 - 71	67	2	64 - 69	67	1	66 - 68	67	2	64 - 68	64	1	62 - 65
OA							67	1[f]	65 - 68	66	2	63 - 68	64	1	63 - 65
IA										82	2	80 - 85	80	2	79 - 82
AFC							110	2	108 - 112	112	1	110 - 114	114	3	112 - 118
PC	106	1	105 - 109	108	2	105 - 110	112	4	108 - 117	119	4	115 - 126	126	1	125 - 128
Y	25	25	0 - 56												
P1	7	5	0 - 13	12	1	10 - 14	12	1	11 - 14	13	2	11 - 19	19	1	18 - 20
P2							5	0[e]	5 - 5	7	3	4 - 13	16	1	15 - 17
D							14	0[e]	13 - 14	17	3	13 - 22	24	2	21 - 27
A							16	2[e]	14 - 19	19	3	16 - 24	23	1	22 - 25
Depths %SL															
at BPE	14	3	11 - 22	13	1[c]	11 - 14	14	1	12 - 15	15	1	14 - 17	16	1	15 - 16
OP1	15	4	11 - 23	13	0[c]	13 - 14	14	1	13 - 16	16	2	15 - 19	20	1	19 - 21
OD	10	2	8 - 13	10	0[c]	10 - 11	12	1	10 - 14	15	2	14 - 20	22	1	20 - 23
BPV	7	1	6 - 8	8	0[c]	8 - 9	9	1	8 - 11	12	2	9 - 16	17	1	16 - 18
AMPM	4	0	3 - 5	5	0[c]	4 - 5	6	1	5 - 7	8	1	7 - 10	10	0	9 - 10
Max. yolk	6	8	0 - 19												
Widths %SL															
at BPE	12	0	12 - 13	12	0[c]	12 - 12	13	1	11 - 13	13	1[c]	12 - 14	13	1	13 - 15
OP1	11	4	7 - 19	10	1[c]	9 - 11	10	1	9 - 11	12	1[c]	11 - 14	13	2	12 - 16
OD	5	1	4 - 7	7	0[c]	6 - 7	7	1	6 - 9	8	1[c]	8 - 9	11	0	11 - 12
BPV	5	1	3 - 5	6	0[c]	5 - 6	6	1	5 - 7	7	1[c]	6 - 8	9	1	7 - 10
AMPM	3	0	2 - 3	3	0[c]	3 - 4	4	1	3 - 5	4	1[c]	3 - 5	4	1	4 - 6
Max. yolk	7	8	0 - 19												
Myomeres[a]															
to PY	22	2[c]	18 - 23												
OPAF	9	4	6 - 16	7	1[c]	6 - 7	7	1	6 - 8	8	5	6 - 20			
OP2							14	1[e]	14 - 15	15	1	13 - 17	15	1[g]	14 - 15
ODF	12	1	11 - 14	14	2[c]	11 - 16	16	1	15 - 19	18	1[f]	17 - 19			
OD							19	1[f]	18 - 20	19	1	18 - 20	19	0[g]	19 - 19
PV	25	1	24 - 26	25	1[c]	23 - 27	25	1	24 - 26	25	1	24 - 26	26	1[g]	25 - 26
Total	37	1[d]	36 - 39	38	1[c]	36 - 39	38	1	37 - 39	38	1	36 - 39	38	0[g]	38 - 38
After PV	12	1[d]	11 - 13	13	1[c]	12 - 13	13	1	12 - 14	13	1	11 - 13	13	1[g]	12 - 13

[a]Note that myomere counts to selected landmarks (e.g., ODF, OD, PV) reported by Snyder et al. (1977) and some other descriptions include only entire myomeres to those landmarks and are therefore 1–3 myomeres fewer than reported here, and the reverse for those posterior to the vent . [b]N = 9. [c]N = 6. [d]N = 10. [e]N = 3. [f]N = 4 [g]N = 2.

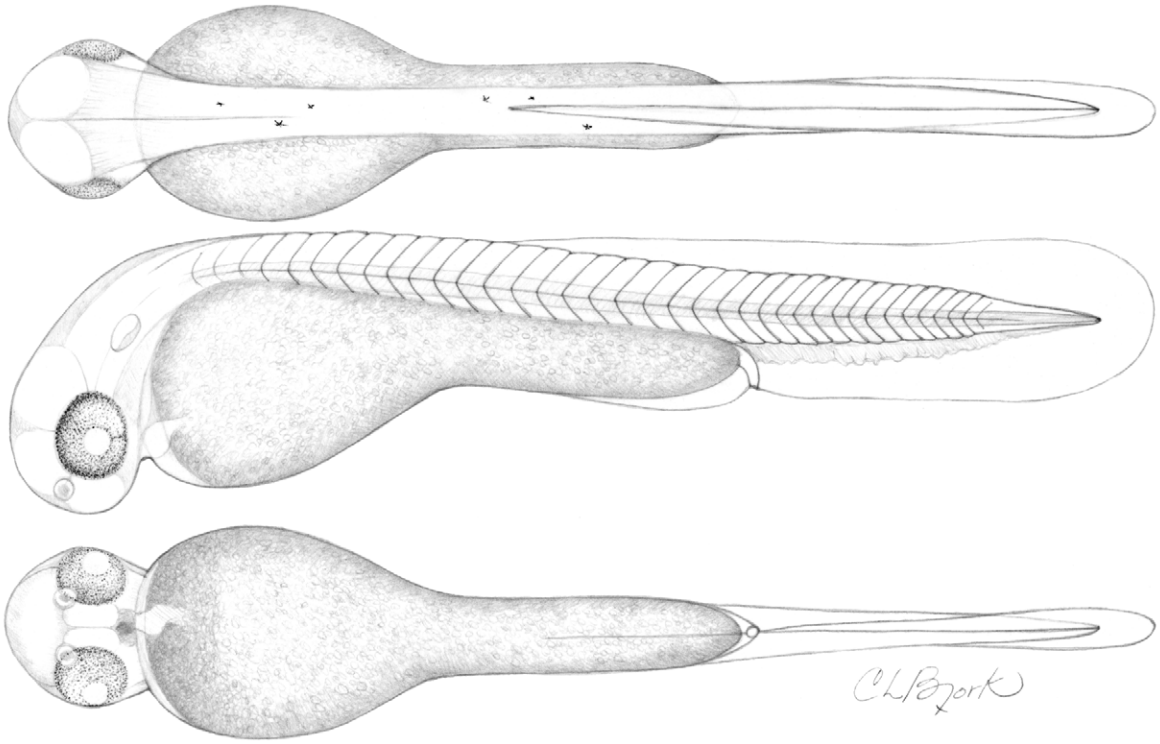

Figure 78. *Notemigonus crysoleucas* protolarva, recently hatched, 3.4 mm SL, 3.6 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with commercial stock contributed by Outlaw Bait and Tackle, Colorado Springs, Colorado.)

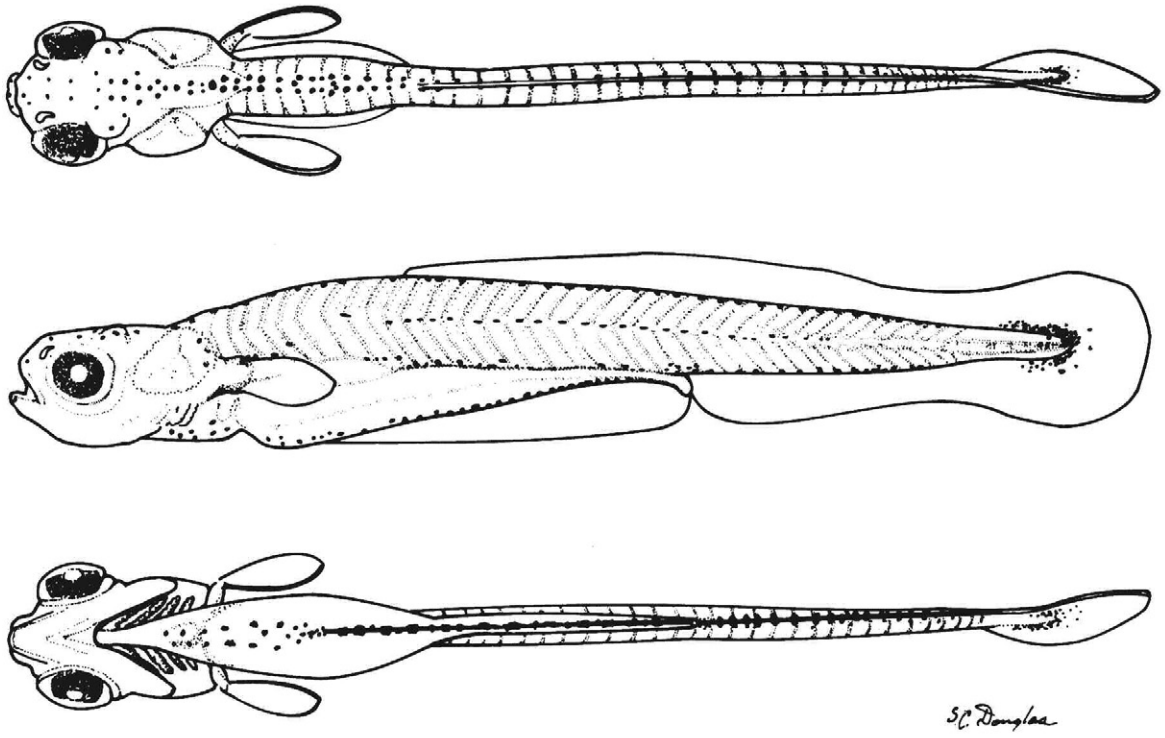

Figure 79. *Notemigonus crysoleucas* protolarva with yolk, 4.3 mm SL, 4.6 mm TL (in 40% isopropanol). (Cultured in 1970 by D. E. Snyder at Conowingo-Muddy Run Laboratory, Ichthyological Associates Inc., Drumore, Pennsylvania, with stock collected locally from Conowingo Reservoir, Susquehanna River. Modified from Snyder et al. 1977, Figure 3.)

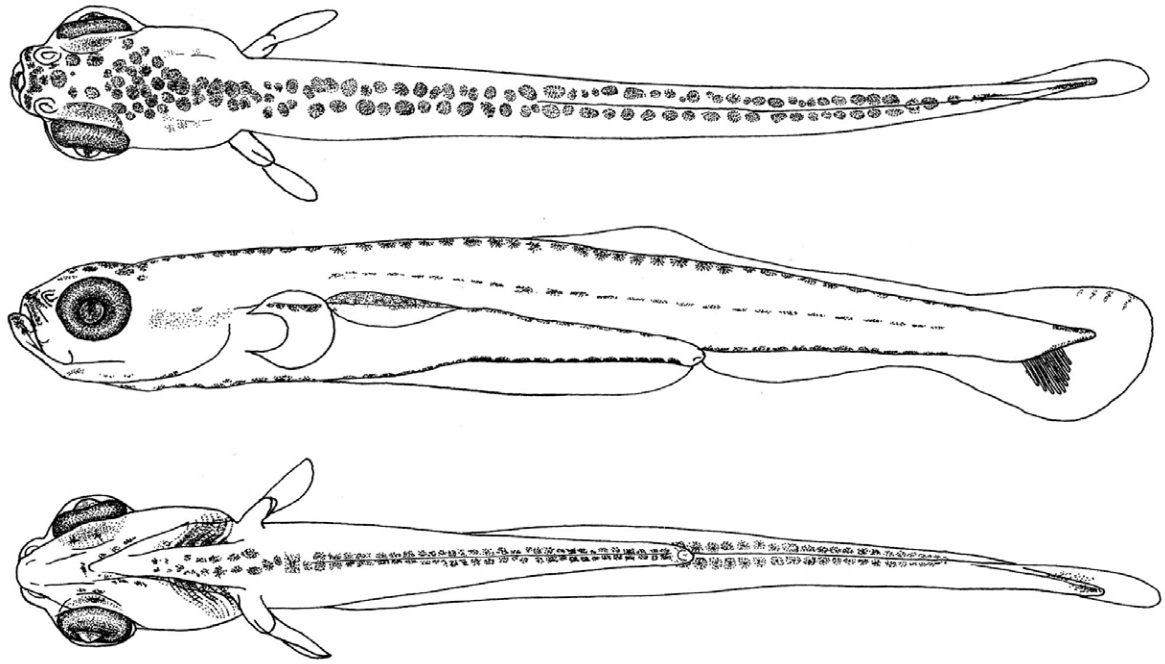

Figure 80. *Notemigonus crysoleucas* flexion mesolarva, recently transformed, 7.8 mm SL, 8.2 mm TL. (Collected in 1979 by D. J. Faber from Lac Heney, Quebec, Canada. From Faber 2006 onwards (http://fishbabies.ca/freshwaterspecies/notcrys.html), with author permission; illustrated by Sally Gadd, © 2000 Canadian Museum of Nature, Ottawa, Ontario.)

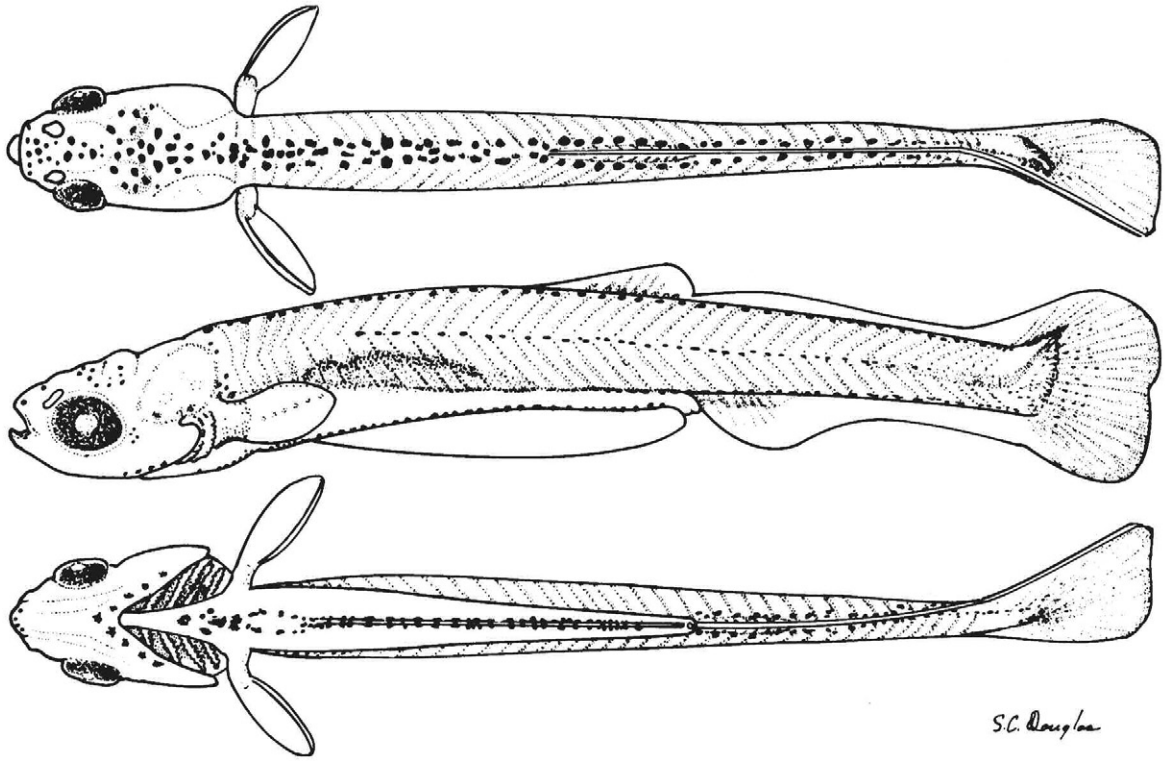

Figure 81. *Notemigonus crysoleucas* postflexion mesolarva, 7.2 mm SL, 7.9 mm TL (in 40% isopropanol). (Collected in 1968 by Ichthyological Associates Inc., Drumore, Pennsylvania, locally from Conowingo Reservoir or tributaries, Susquehanna River. Modified from Snyder et al. 1977, Figure 7.)

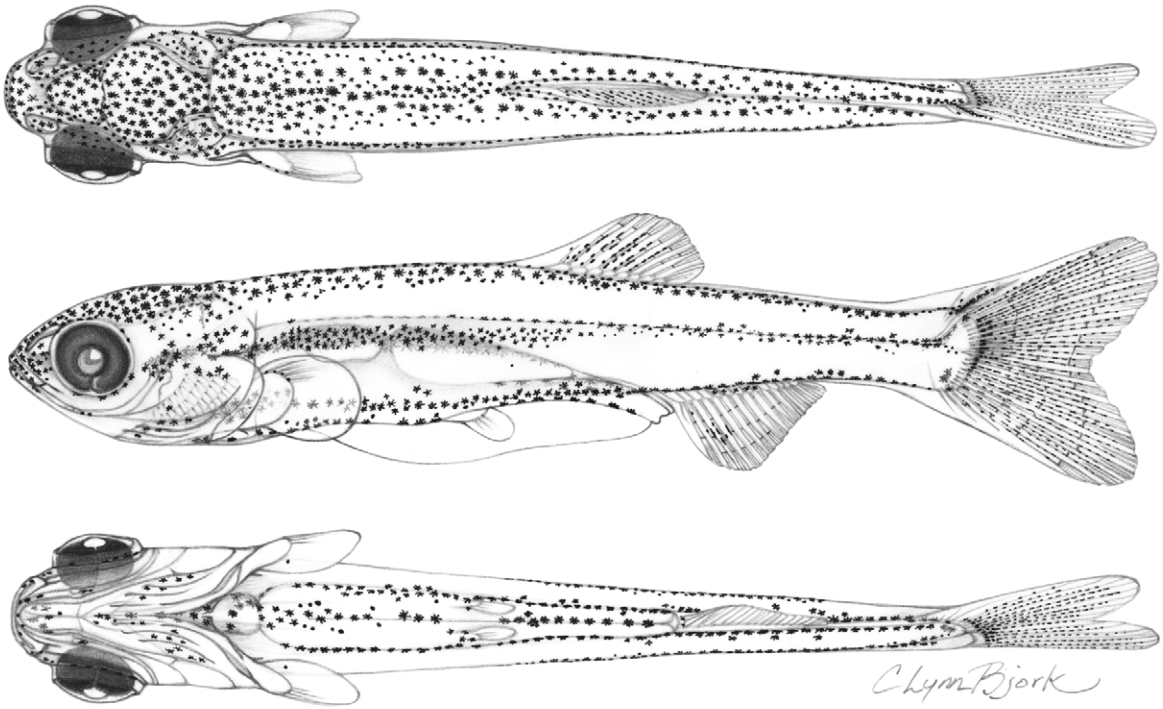

Figure 82. *Notemigonus crysoleucas* metalarva, recently transformed, 11.4 SL, 13.5 mm TL. (Collected and contributed in 2010 by Renee Reyes, U. S. Bureau of Reclamation, Byron California from a Tracy Fish Collection Facility backwater, Sacramento-San Joaquin Delta, Tracy, California.) (Note extreme posterior extent of air bladder.)

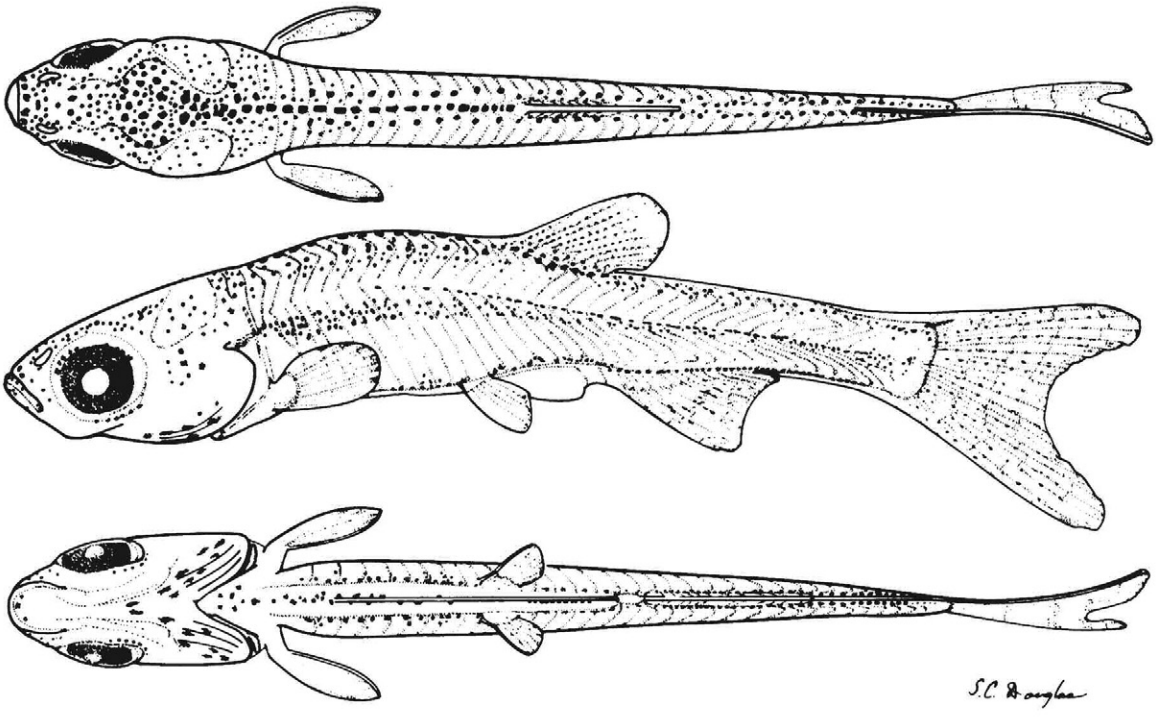

Figure 83. *Notemigonus crysoleucas* metalarva, 12.2 mm SL, 14.8 mm TL (in 40% isopropanol). (Collected in 1968 by Ichthyological Associates Inc., Drumore, Pennsylvania, locally from Conowingo Reservoir or tributaries, Susquehanna River. Modified from Snyder et al. 1977, Figure 11.)

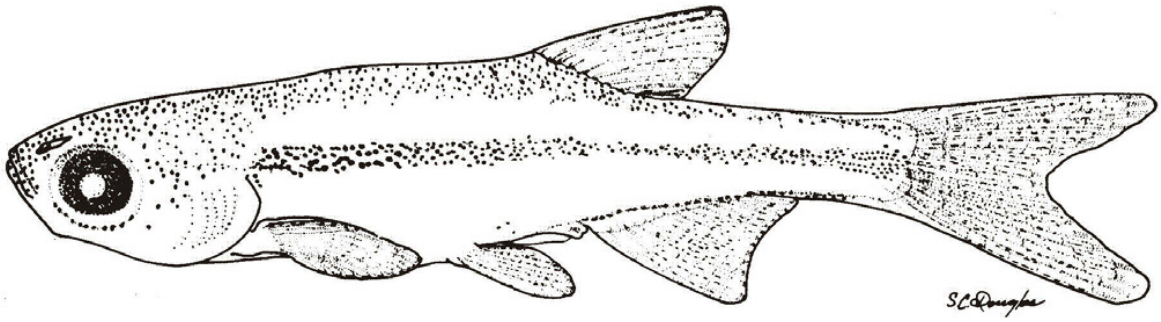

Figure 84. *Notemigonus crysoleucas* metalarva near transition to juvenile period (some preanal finfold remains), 16.4 mm SL, 20.7 mm TL (in 40% isopropanol). (Collected in 1968 by Ichthyological Associates Inc., Drumore, Pennsylvania, locally from Conowingo Reservoir or tributaries, Susquehanna River. Modified from Snyder et al. 1977, Figure 14.)

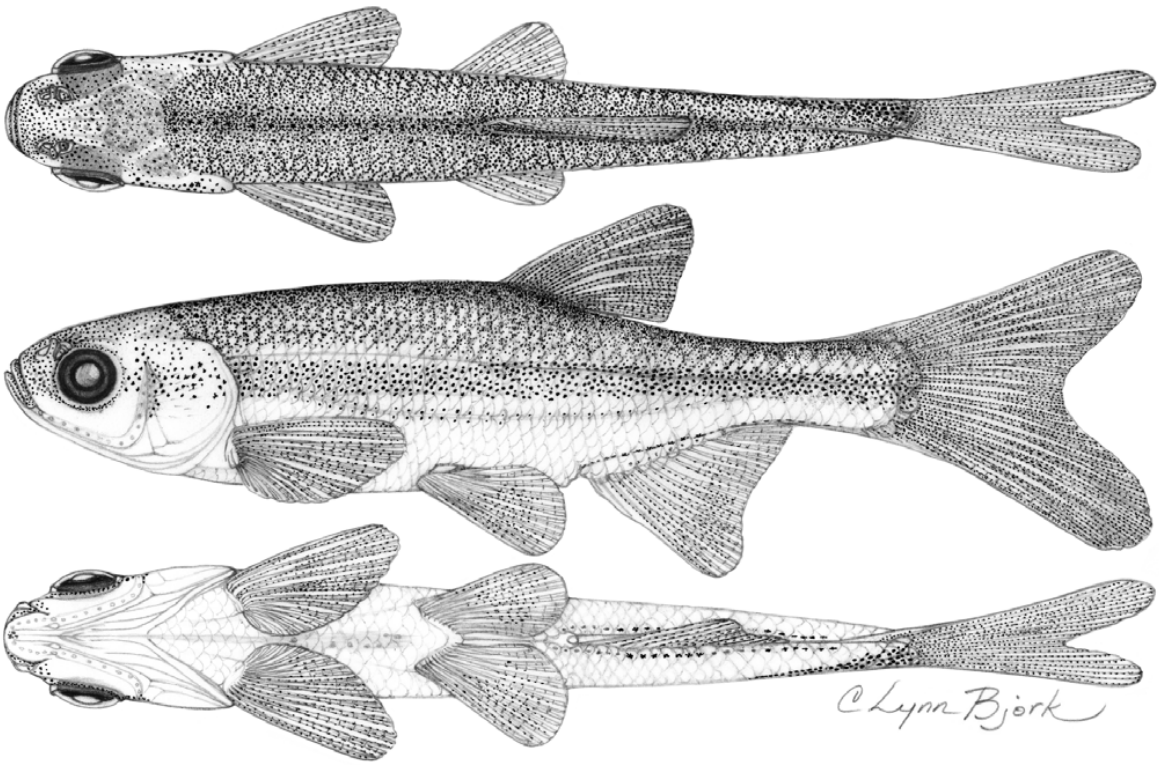

Figure 85. *Notemigonus crysoleucas* juvenile, 37.5 mm SL, 48.0 mm TL. (Collected in 1974 by NUS Corporation, Ecological Sciences Division, Pittsburgh, Pennsylvania, from Ohio River, Beaver Valley, Pennsylvania.)

Species Account – *Notropis stramineus*, sand shiner

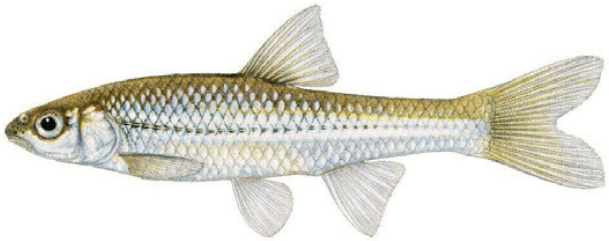

Figure 86. *Notropis stramineus* adult (© Joseph R. Tomelleri).

Adult description: Small, usually 4–7, rarely 8–10 cm TL. Body moderately slender to stout, little to moderately compressed, back slightly arched to dorsal fin. Snout blunt, about equal to moderately large eyes. Mouth low terminal to slightly subterminal, slightly oblique to nearly horizontal, ending at or before eyes . Dorsal fin origin usually over or slightly behind pelvic origin. Pectoral fins short, broad. Scales large, present on nape, dorsally outlined with pigment. At least anterior lateral line pores accentuated above and below with dark pigment. Gut short, s-shaped; peritoneum silvery, lightly speckled. Olivaceous to straw-colored on upper body, silvery to white on sides and venter. If evident, lateral band dusky, sometimes dark posteriorly. Narrow mid-dorsal stripe widening just before and continuing, less obviously, shortly after dorsal fin; base of fin posteriorly accentuated with dash of dark pigment. (Also, Table 34.)

Reproduction: Non-guarding, open-substrate lithophil. Mature at age 1–2. Spawn late spring-early fall, peaking in July-August during low flows and high temperatures, in shallows over sand or gravel riffles (in lab, preferred gravel to sand (lit., 27°C) or cobble to gravel or sand (orig., 18–19°C)). Minute nuptial tubercles form on head and pectoral-fin rays of males and colors may intensify. Water-hardened eggs are demersal, adhesive, and 1.1–1.3 (orig.) –1.6 mm in diameter.

Young: Hatch in at least 4 d at 18–19°C (orig.). Young feed mostly on bottom ooze and diatoms.

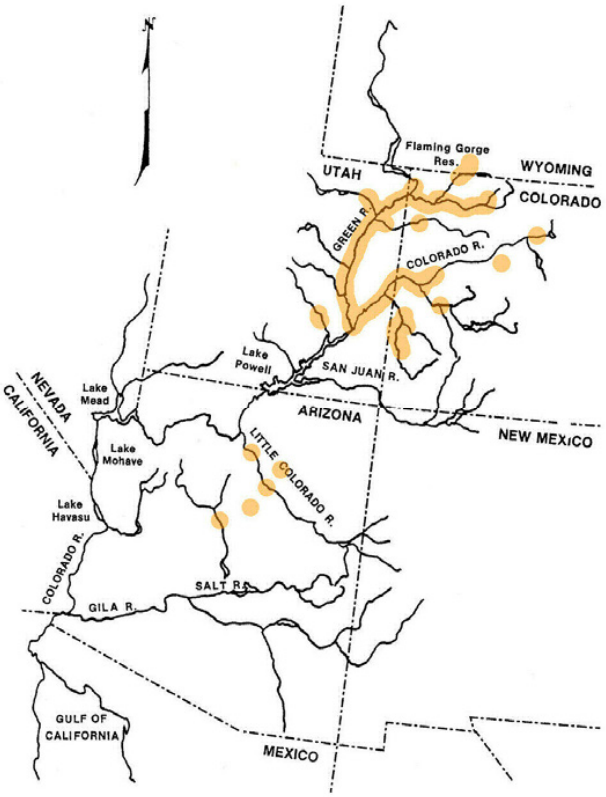

Figure 87. Recent distribution of *Notropis stramineus* in the Colorado River Basin.

Table 34. Selected juvenile and adult meristics for *Notropis stramineus*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	(7)8(9)	(7)8(9)	Dorsal-fin rays - R	(1)2(3)	–
Anal-fin rays - P	7(8)	(6)7(8)	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	(18)19(20)	(18)19(20)	Caudal-fin rays - RD	(8)9-10-11(12)	–
Pectoral-fin rays	(11)12-14(-16)	12-13-14-16(-18)	Caudal-fin rays - RV	8-9-10(11)	–
Pelvic-fin rays	7-8	(7)8	Lateral scales	(34)35-37(38)	(31)32-34-35-38(39)
Vertebrae	35-36	33-35-36	Pharyngeal teeth	–	0,4(5)/4(5),0

*Includes re-examined data originally prepared for Snyder (1981) and supplements and updates that account.

Table 35. Size at apparent onset of selected developmental events for *Notropis stramineus*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	3-4	(3)4	Dorsal - P	6(7)	6-7(8)	7-8	8-9
Eyes pigmented	*	*	Anal - P	(6)7-8	7-8(9)	(7)8(9)	8-9(10)
Yolk assimilated	(4)5	(4)5	Caudal - P	(5)6	6	7	8
Finfold absorbed	12(13)	15(16)	Caudal - R	8	9-10	(12)13	(15)16
Pectoral-fin buds	*	*	Pectoral	7-9	8-10	10-11(12)	12-13(-15)
Pelvic-fin buds	7-8	8-9	Pelvic	8-9	10(11)	(12)13	(15)16
* before hatching			Scales	13-14	16-17	14-15(16)	(17)18-19(20)

References: Balon 1975a; Baxter & Stone 1995; Becker 1983; Beckman 1952; Breder & Rosen 1966; Carlander 1969; Clay 1975; Coburn 1986; Eddy & Underhill 1974; Heufelder & Fuiman 1982; Jordan & Evermann 1896; Koster 1957; Lentsch et al. 1996; Minckley 1973; Moore 1968; Page & Burr 1991; Pflieger 1997; Platania & Altenbach 1998; Scott & Crossman 1973; Simon 1998; Smith 1979; Snyder 1981; Sublette et al. 1990; Summerfelt & Minckley 1969; Trautman 1981; Tyus et al. 1982; Woodling 1985. ***Other larval descriptions***: Fish 1932; Fuiman et al. 1983; Heufelder & Fuiman 1982; Holland-Bartels et al. 1990; Loos & Fuiman 1978; Perry 1979; Perry & Menzel 1979; Snyder 1981.

Table 36. Size at developmental interval (left) and gut phase (right) transitions for *Notropis stramineus*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	(5)6	6	2 - 90° bend	9	10-11
Postflexion mesolarva	7	8	3 - Full loop	(13-)15	(16)19
Metalarva	8(9)	9(10)	4 - Partial crossover	(not applicable)	
Juvenile	(12)13	(15)16	5 - Full	(not applicable)	

Table 37. Summary of morphometrics and myomere counts by developmental phase for *Notropis stramineus*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

	Protolarvae (N=12)			Flexion mesolarvae (N=9)			Postflexion mesolarvae (N=5)			Metalarvae (N=24)			Juveniles (N=62)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	5	1[a]	3 - 6	6	1[c]	5 - 7	8	1[b]	7 - 9	10	2[i]	8 - 13	22	8[p]	13 - 38
TL, mm	5	1[a]	4 - 6	7	1[c]	6 - 8	8	1[b]	8 - 10	12	2[i]	9 - 16	28	11[p]	16 - 48
Lengths %SL															
AS to AE	3	1	1 - 5	3	1	2 - 5	4	1	3 - 4	5	1	3 - 6	6	1[q]	4 - 7
PE	11	1	9 - 13	11	1	10 - 12	12	1	11 - 13	13	1	11 - 14	13	1[q]	11 - 16
OP1	19	1	16 - 21	22	1	20 - 23	23	2	21 - 27	26	1	23 - 28	26	1	23 - 29
OP2							47	[f]	47 -	49	1	47 - 51	49	1[q]	46 - 52
PY	60	1[b]	58 - 62												
OPAF	41	9	31 - 56	37	3	32 - 42	37	5	34 - 45	45	7[j]	35 - 57			
ODF	39	4	33 - 46	42	5	37 - 49	45	3	43 - 51	46	0[g]	46 - 47			
OD							48	2	47 - 51	49	1[k]	47 - 50	49	1[r]	47 - 52
ID							61	2[g]	59 - 63	62	1	59 - 64	61	1[s]	58 - 63
PV	63	1	59 - 65	64	1	62 - 66	66	1	64 - 68	66	1	63 - 68	63	1	62 - 66
OA							64	[f]	64 -	65	1[e]	64 - 66	64	1[t]	62 - 66
IA							75	3[h]	73 - 77	75	1	73 - 77	74	1	72 - 77
AFC							110	1	109 - 112	114	2[l]	110 - 116	116	2	113 - 122
PC	105	2[a]	102 - 109	109	2[c]	105 - 111	111	2[b]	109 - 113	120	4[i]	113 - 125	126	2[p]	121 - 132
Y	21	22[a]	0 - 49												
P1	11	4	4 - 16	13	1	12 - 14	14	1	12 - 15	16	1	13 - 19	18	1	16 - 21
P2							4	[f]	4 -	8	2[l]	4 - 12	15	2	11 - 17
D							17	[f]	17 -	21	1[l]	18 - 23	23	1	20 - 26
A							12	[f]	12 -	14	2	10 - 17	18	1	16 - 20
Depths %SL															
at BPE	13	2	10 - 16	12	1[b]	11 - 13	13	0	13 - 14	15	1	13 - 17	16	1	14 - 18
OP1	14	3	11 - 20	13	1[b]	12 - 14	15	1	15 - 16	17	1	14 - 19	20	1	18 - 23
OD	11	2	9 - 14	12	1	10 - 14	14	1	13 - 15	17	2	13 - 21	21	2	18 - 25
BPV	8	1	6 - 9	8	1	7 - 10	9	0	9 - 10	12	2	9 - 15	16	1	13 - 19
AMPM	4	1	2 - 6	5	1	3 - 6	6	1	5 - 7	8	1	6 - 10	10	1	8 - 12
Max. yolk	5	6[a]	0 - 15												
Widths %SL															
at BPE	13	1	10 - 15	13	1[b]	12 - 14	15	1	13 - 15	16	1	14 - 18	15	1	13 - 17
OP1	10	4	6 - 16	10	1[b]	8 - 11	11	1	10 - 12	13	2	10 - 17	16	1	13 - 18
OD	6	1	4 - 8	6	1	5 - 7	7	0	6 - 8	11	2	7 - 15	15	1	12 - 18
BPV	5	1	4 - 6	5	1	4 - 6	6	0	5 - 6	8	1	5 - 10	11	2	9 - 15
AMPM	3	1	1 - 4	2	1	2 - 3	3	0	3 - 3	3	1	2 - 5	5	1	3 - 7
Max. yolk	6	7[a]	0 - 17												
Myomeres															
to PY	21	1[b]	19 - 22												
OPAF	12	4[a]	8 - 19	9	1[d]	8 - 11	9	1[b]	7 - 11	11	3[j]	7 - 17			
OP2							15	1[h]	14 - 15	13	1	11 - 15	13	1[u]	12 - 15
ODF	10	1[a]	9 - 11	11	1[d]	10 - 12	12	1[b]	10 - 13	12	1[m]	11 - 13			
OD				13	1[e]	12 - 14	14	1[b]	12 - 15	13	1[n]	12 - 15	13	1[u]	12 - 15
PV	22	1[a]	21 - 23	22	2[d]	20 - 24	23	1[b]	22 - 24	21	1[o]	20 - 23	21	1[u]	19 - 22
Total	35	1[a]	33 - 36	35	1[d]	34 - 36	35	1[b]	33 - 36	35	1[o]	33 - 36	34	1[v]	33 - 36
After PV	13	1[a]	11 - 15	13	1[c]	11 - 15	12	1[b]	10 - 14	13	1[o]	12 - 15	14	1[v]	12 - 15

[a]N = 13. [b]N = 7. [c]N = 12. [d]N = 10. [e]N = 4. [f]N = 1. [g]N = 3. [h]N = 2. [i]N = 26. [j]N = 20. [k]N = 21. [l]N = 23. [m]N = 6. [n]N = 22. [o]N = 25. [p]N = 67. [q]N = 61. [r]N = 58. [s]N = 60. [t]N = 9. [u]N = 49. [v]N = 48.

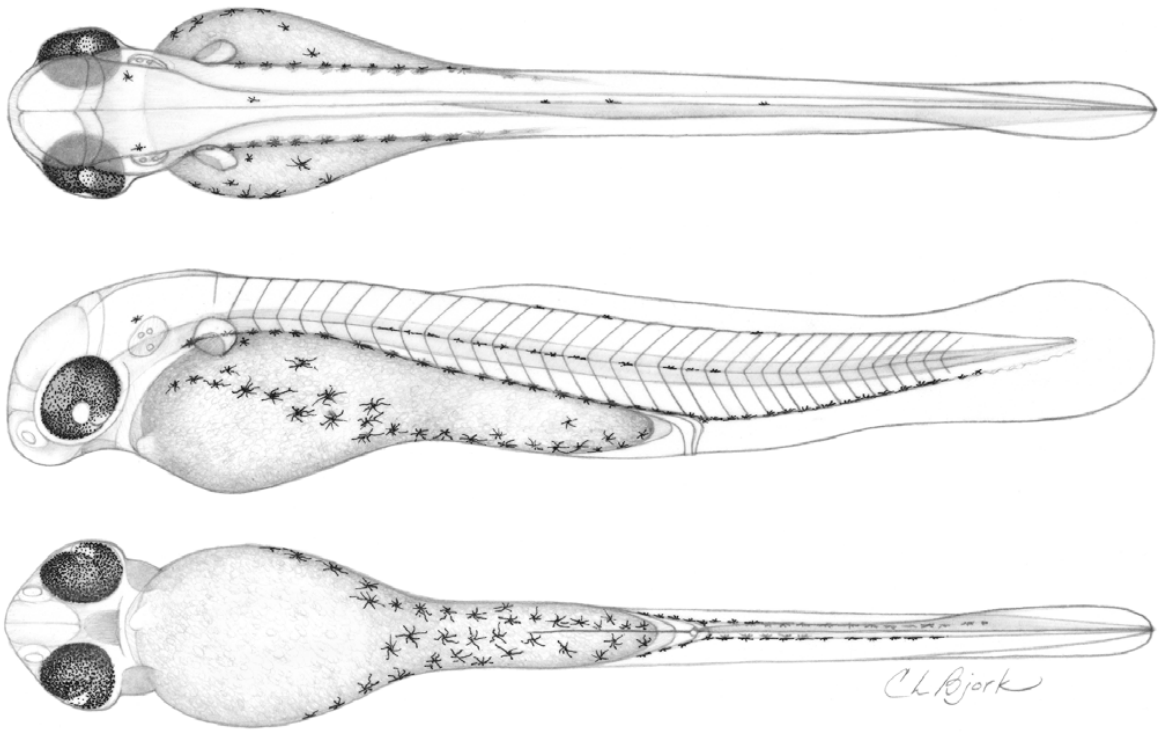

Figure 88. *Notropis stramineus* protolarva, recently hatched, 3.4 mm SL, 3.7 mm TL. (Cultured in 2008 by Larval Fish Laboratory, Colorado State University, with stock from Spring Creek, Fort Collins, and South Platte River, southeast of Greeley, Colorado.)

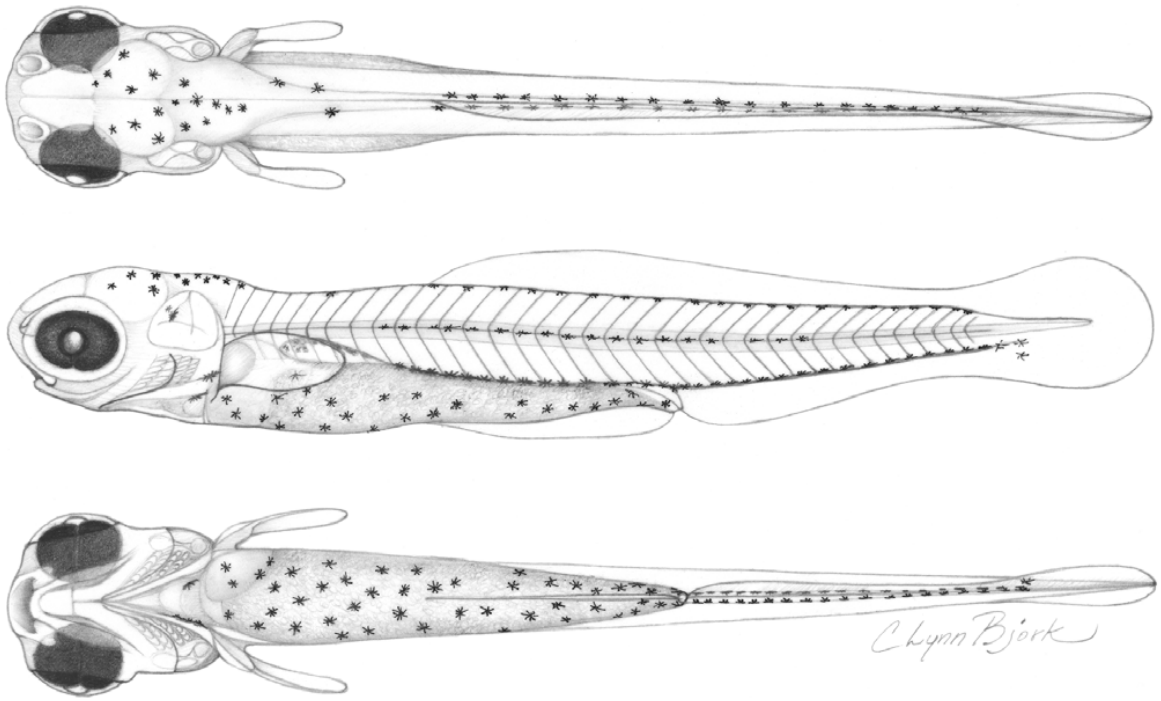

Figure 89. *Notropis stramineus* protolarva, ~3 d posthatch (?), 4.6 mm SL, 4.9 mm TL. (Cultured in 2008 by Larval Fish Laboratory, Colorado State University, with stock from Spring Creek, Fort Collins, and South Platte River, southeast of Greeley, Colorado.)

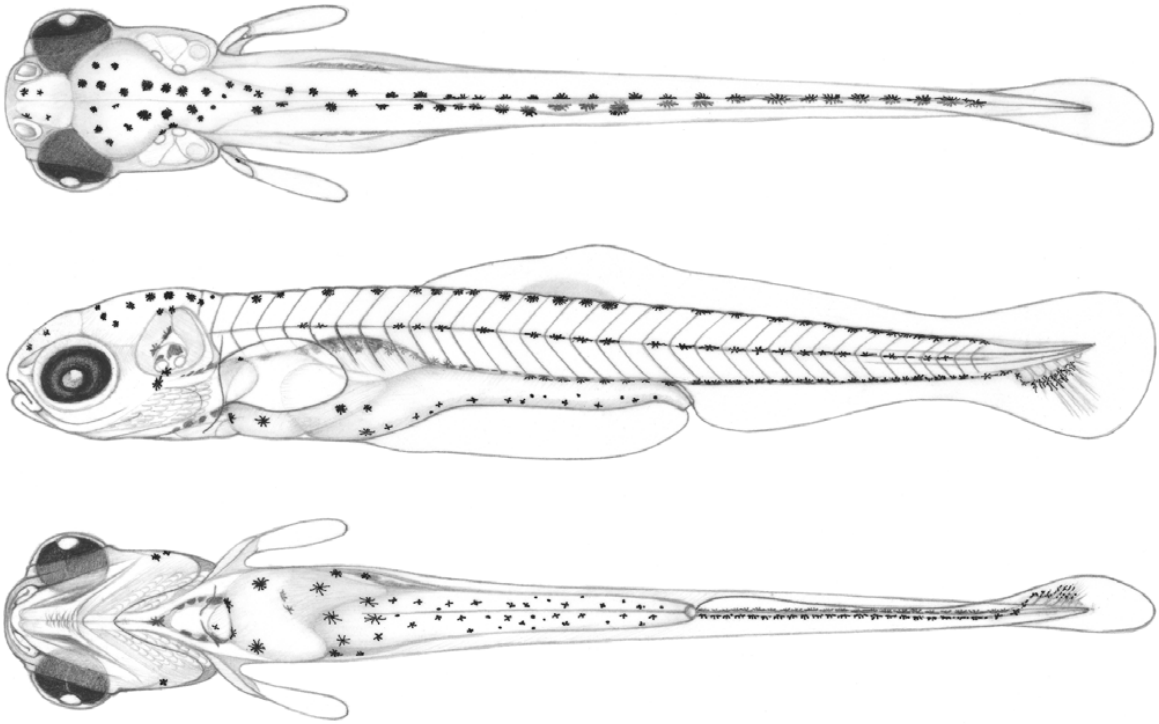

Figure 90. *Notropis stramineus* flexion mesolarva, recently transformed, 12 d posthatch, 6.1 mm SL, 6.5 mm TL. (Cultured in 2008 by Larval Fish Laboratory, Colorado State University, with stock from Spring Creek, Fort Collins, and South Platte River, southeast of Greeley, Colorado.)

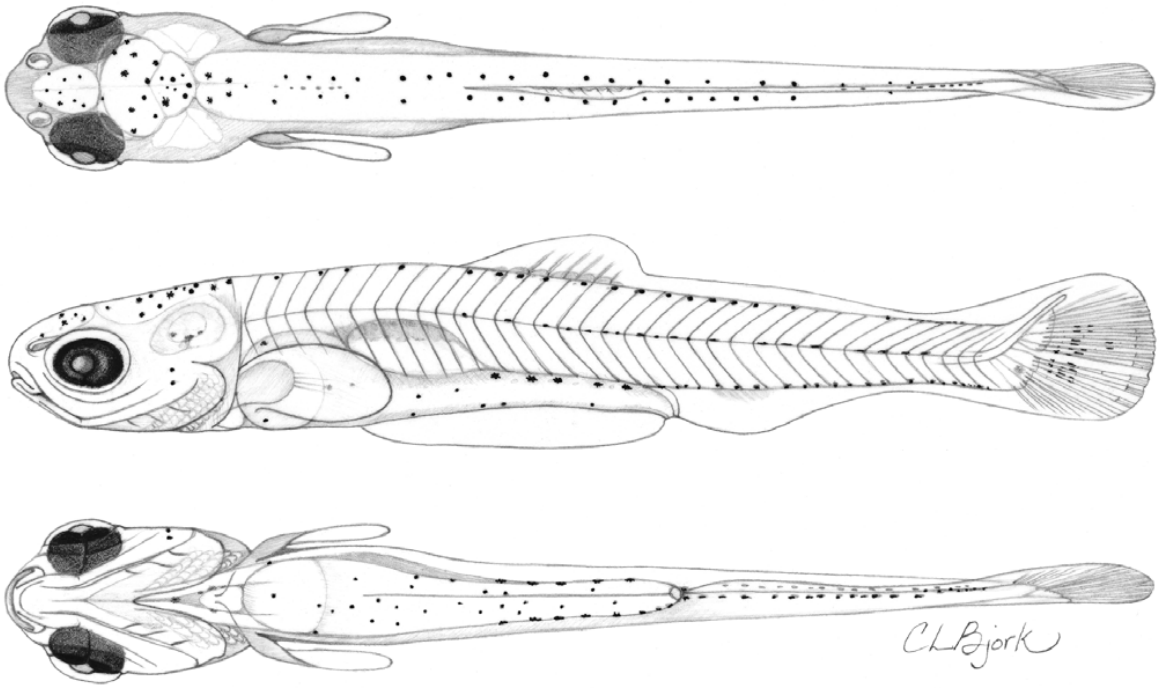

Figure 91. *Notropis stramineus* postflexion mesolarva, 7.0 mm SL, 7.6 mm TL. (Collected in 1977 from Colorado or Gunnison River near Grand Junction, Colorado; from LFL #72688.)

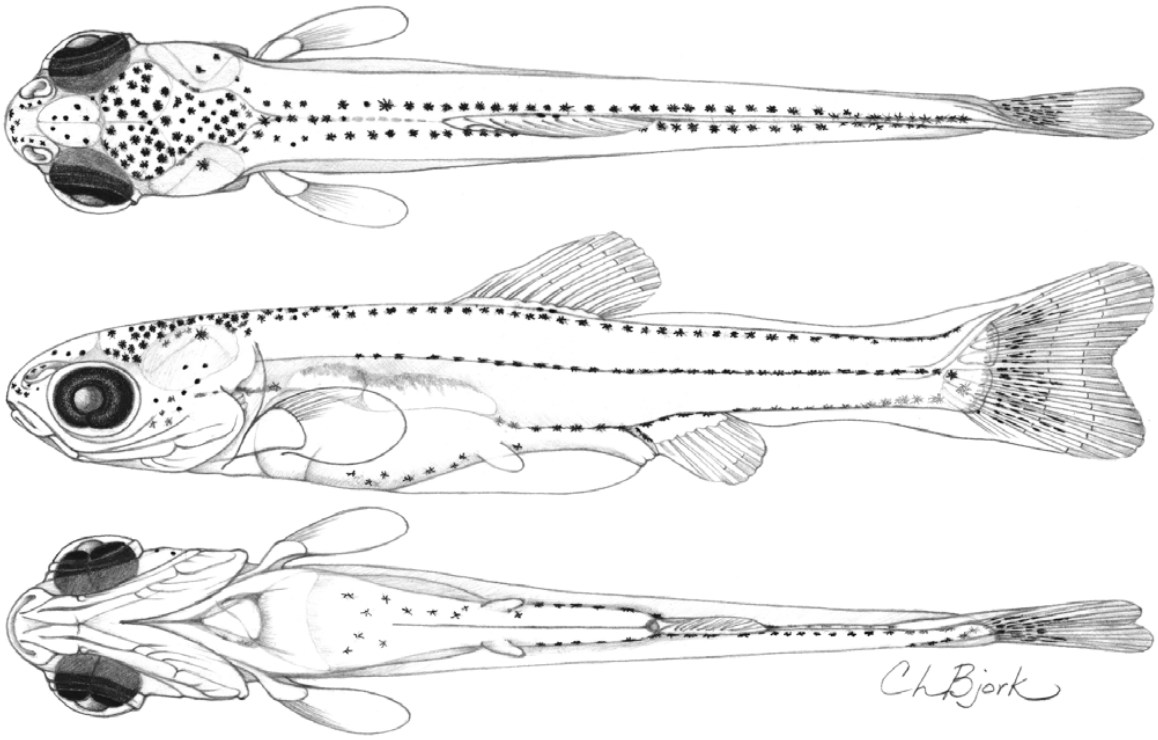

Figure 92. *Notropis stramineus* metalarva, recently transformed, 8.2 mm SL, 9.5 mm TL. (Collected in 1979 from Yampa River, Moffat or Routt County, Colorado; from LFL #72769.)

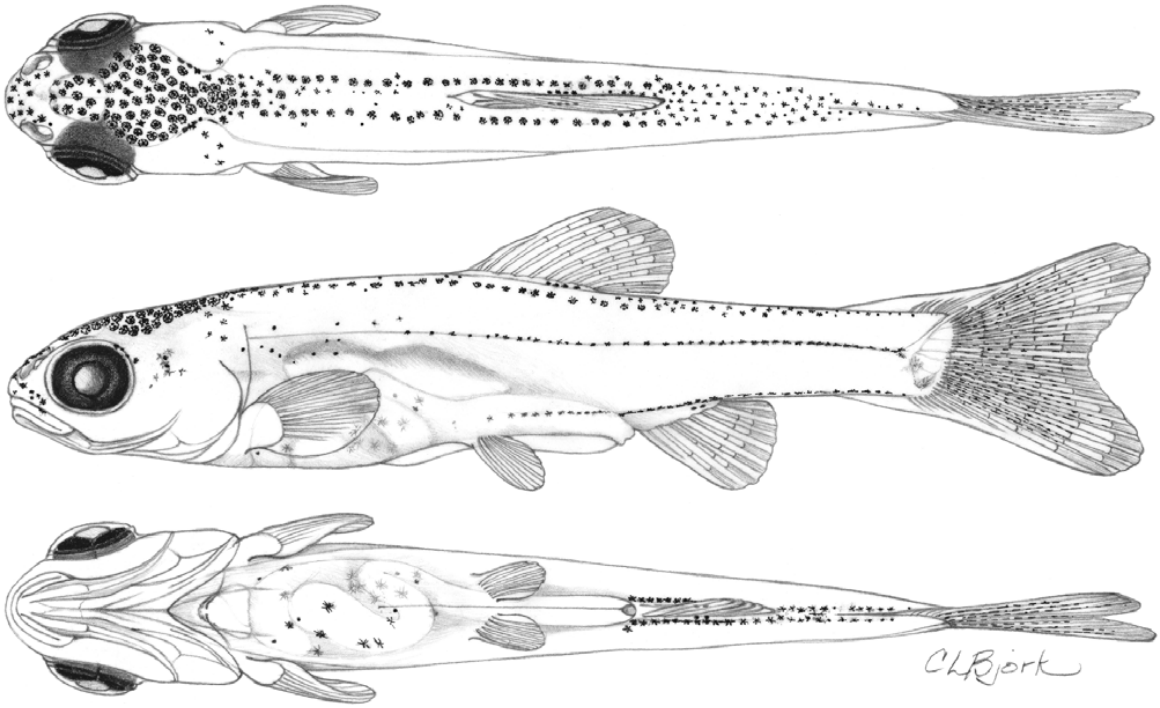

Figure 93. *Notropis stramineus* metalarva, 10.9 mm SL, 13.2 mm TL. (Collected in 1979 from Colorado River near Grand Junction, Colorado; from LFL #72727.)

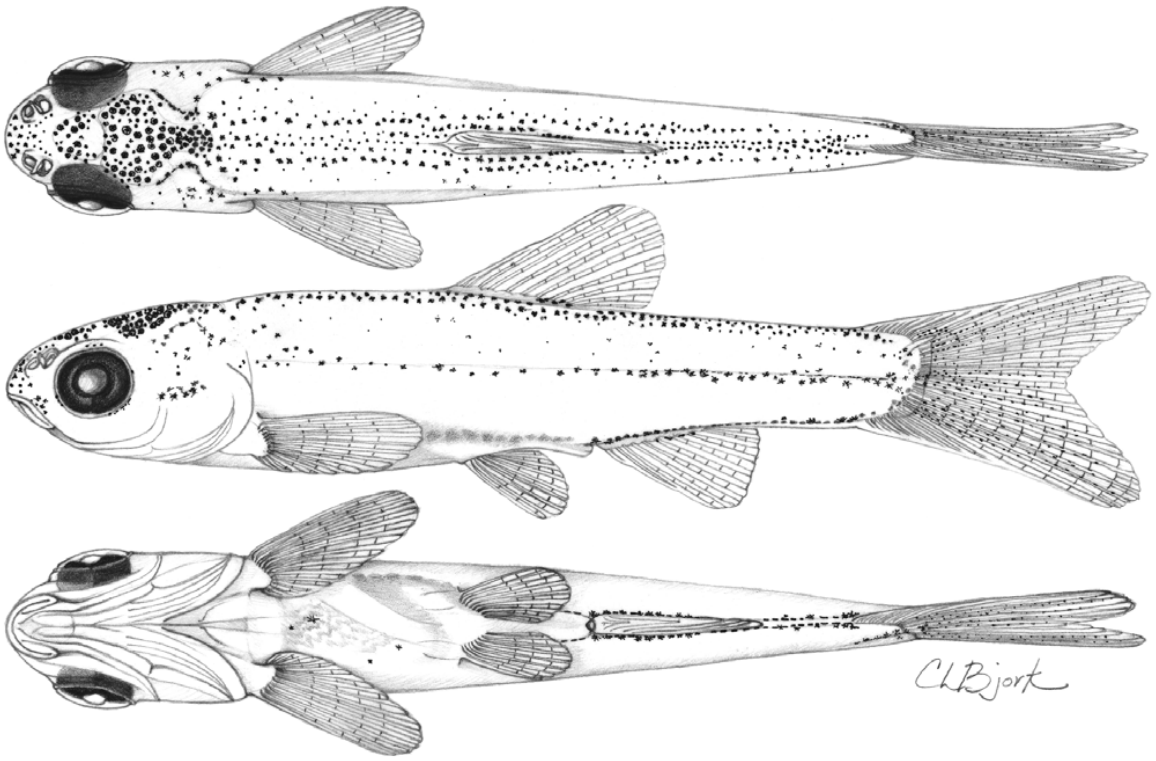

Figure 94. *Notropis stramineus* juvenile, recently transformed, 13.2 mm SL,16.0 mm TL. (Collected in 1979 from Colorado River near Grand Junction, Colorado; from LFL #72730.)

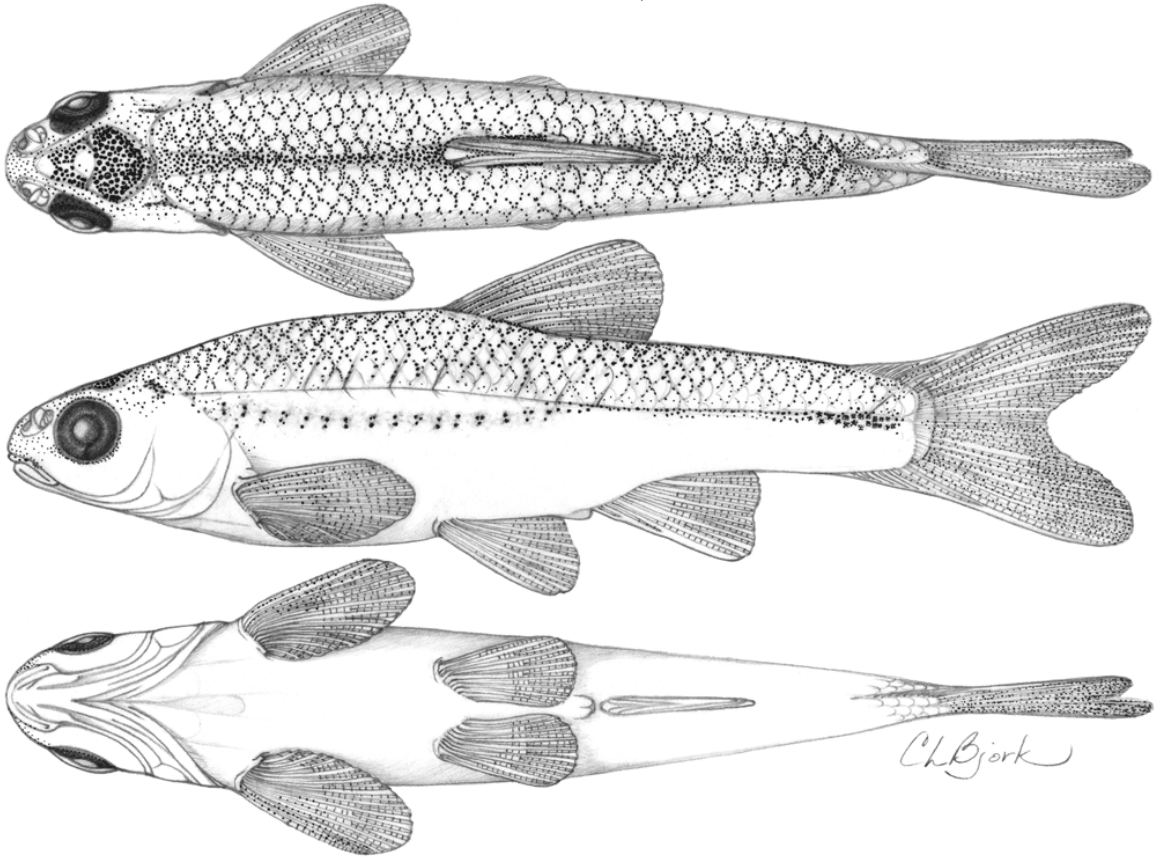

Figure 95. *Notropis stramineus* juvenile, 31.7 mm SL, 40.0 mm TL. (Collected in 1977 from Colorado or Gunnison River near Grand Junction, Colorado; from LFL #72701.)

Species Account – *Pimephales promelas*, fathead minnow

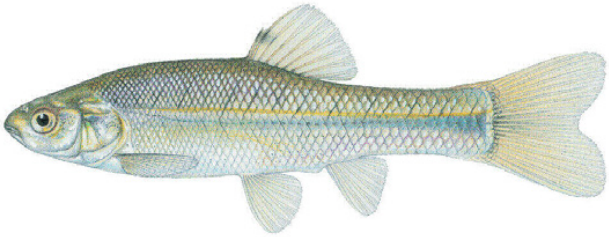

Figure 96. *Pimephales promelas* adult (©Joseph R. Tomelleri).

Adult description: Small, 4–8, rarely 9 cm TL. Heavy-bodied, round to oval in cross section. Head short; fat and rounded in males. Mouth small, terminal to slightly subterminal, somewhat oblique. Gut long and coiled; peritoneum dark. Dorsal fin rounded, last rudimentary ray often thickened, origin usually over pelvic origin. Scales outlined, moderately large posteriorly, but smaller and crowded dorsally before dorsal fin. Generally olivaceous above, silvery-grey laterally and white below, usually with a dusky lateral band and anterior spot in dorsal fin. Breeding males very dark, often with broad, light, vertical bands behind head and between dorsal and pelvic fins; dorsal pad behind head; stout tubercles on very rounded snout. (Also, Table 38.)

Reproduction: Guarding nest-spawning speleophil. Usually mature at age 1 and spawn mid-spring through summer when day-time waters are >15–17 but <30°C, typically in shallow, low-velocity areas such as backwaters, pools, or shorelines. Territorial males mate with several females, one at a time. Females are fractional spawners and deposit clutches of adhesive eggs on the exposed undersides of solid surfaces (e.g., rocks, vegetation) cleared by males, who then guard and care for the eggs. Eggs are 1.1–1.6, usually 1.3–1.5, mm in dia.

Young: Hatch in 4–6 d at 30–23°C, respectively. Larvae occupy near-shore, low-velocity channel margins, backwaters, eddies, and pools. Young school in shallows; consume early instar chironomids and other small invertebrates, as well as algae and detritus.

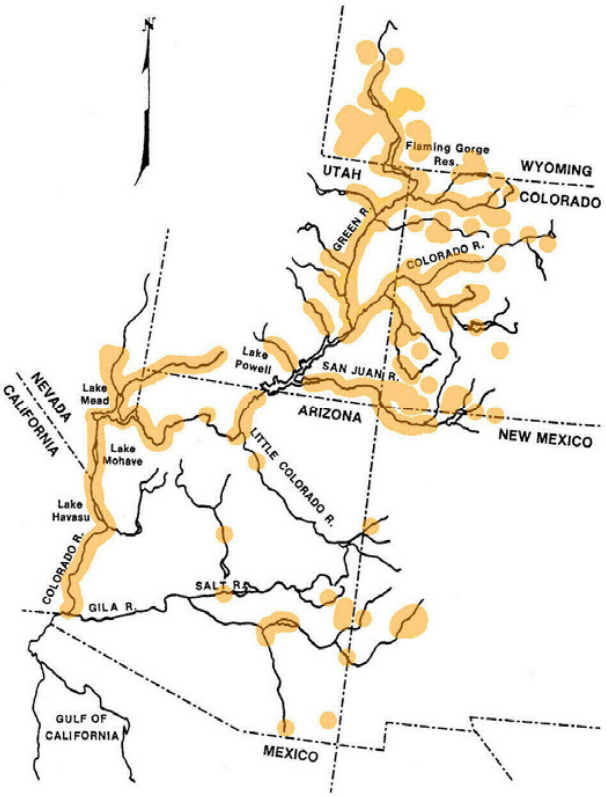

Figure 97. Recent distribution of *Pimephales promelas* in the Colorado River Basin.

Table 38. Selected juvenile and adult meristics for *Pimephales promelas*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed	Literature	Character	Observed	Literature
Dorsal-fin rays - P	(7)8(9)	(7)8(9)	Dorsal-fin rays - R	2(3)	1
Anal-fin rays - P	7	7	Anal-fin rays - R	2(3)	–
Caudal-fin rays - P	19(20)	19	Caudal-fin rays - RD	11-12	–
Pectoral-fin rays	14-15(16)	14-15-16-18	Caudal-fin rays - RV	(9)10-11	–
Pelvic-fin rays	7-8-9	8-9	Lateral scales	43-48-51	40-44-48-54(-60)
Vertebrae	–	35-37-38	Pharyngeal teeth	–	0,4/4,0

Table 39. Size at onset of selected developmental events for *Pimephales promelas*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Updates accounts in Snyder 1981 and Snyder et al. 2005 .)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	4(5)	4-5	Dorsal - P	7-8	8-9	8-9	9-10
Eyes pigmented	*	*	Anal - P	8	9	8-10(11)	9-12
Yolk assimilated	5(6)	5-6	Caudal - P	6-7	(6)7	7-8	8-9
Finfold absorbed	14	16-17	Caudal - R	7-8	8-9	14-15	(16)17-18
Pectoral-fin buds	*	*	Pectoral	8-10(11)	10-12	14-15	(16)17-18
Pelvic-fin buds	8(9)	9-10	Pelvic	11-12	13-14	12-13	14-15(16)
* before hatching			Scales	(14)15	(17)18	(15)16	(18)19(20)

References: Andrews & Flickinger 1974; Balon 1975a; Baxter & Simon 1970; Becker 1983; Beckman 1952; Carlander 1969; Eddy & Underhill 1974; Gale & Buynak 1982; Heufelder & Fuiman 1982; Hubbs & Lagler 1958; Lentsch et al. 1996; Markus 1934; Minckley 1973; Moore 1968; Moyle 1976; Muth & Snyder 1995; Page & Burr 1991; Pfleiger 1997; Scott & Crossman 1973; Simon 1998; Snyder et al. 1977, 2005; Sublette et al. 1990; Tyus et al. 1982; Woodling 1985; Wynne-Edwards 1932. ***Other larval descriptions***: Andrews 1970; Buynak & Mohr 1979c; Feeney & Swift 2008; Fish 1932; Fuiman et al. 1983; Heufelder & Fuiman 1982; Hogue et al. 1976; Holland-Bartels et al. 1990; Perry 1979; Perry & Menzel 1979; Remple & Markle 2005; Snyder 1981; Snyder et al. 1977, 2005; Wang 1986; Wang & Reyes 2007.

Table 40. Size at developmental interval (left) and gut phase (right) transitions for *Pimephales promelas*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Updates accounts in Snyder 1981 and Snyder et al. 2005.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	6-7	(6)7	2 - 90° bend	9-10	(10)11
Postflexion mesolarva	7-8	8-9	3 - Full loop	11-14	14-16
Metalarva	8-10(11)	9-12	4 - Partial crossover	(15)16	(18)19
Juvenile	14-15	(16)17-18	5 - Full	16	19-20

Table 41. Summary of morphometrics and myomere counts by developmental phase for *Pimephales promelas*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes data extracted from selected Snyder et al. 1977 and Perry and Menzel 1979 illustrations used herein or in Snyder 1981 and Snyder et al. 2005. Updates accounts in Snyder 1981 and Snyder et al. 2005 which were based on broad extrapolations from %TL morphometric ranges and methodological adjustments to myomere counts reported by Snyder et al. 1977.)

	Protolarvae (N=9)			Flexion mesolarvae (N=5)			Postflexion mesolarvae (N=5)			Metalarvae (N=9)			Juveniles (N=14)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	5	1	4 - 6	7	1	6 - 8	9	1	7 - 10	11	2	8 - 14	23	7	15 - 34
TL, mm	5	1	4 - 6	7	1	7 - 9	10	2	8 - 12	13	3	9 - 16	29	9[f]	18 - 42
Lengths %SL															
AS to AE	3	1	1 - 4	3	1	2 - 4	4	1	3 - 5	5	0	4 - 5	5	1	4 - 7
PE	10	1	8 - 12	11	1	10 - 12	12	1	10 - 13	13	1	11 - 15	13	1	11 - 15
OP1	19	1	18 - 21	20	0[e]	20 - 21	23	1	21 - 24	26	1	25 - 28	25	1	23 - 27
OP2							49	1[d]	48 - 49	51	1	49 - 53	52	2	49 - 55
PY	63	2[a]	61 - 66												
OPAF	39	10	31 - 57	32	2[c]	30 - 34	36	1	35 - 39	43	8[b]	38 - 56			
ODF	41	2	38 - 45	43	1[c]	41 - 44	48	3	43 - 49	51	3[d]	49 - 55			
OD							51	2	49 - 54	52	2	51 - 56	51	2	49 - 54
ID							62	1	61 - 64	65	2	63 - 69	64	1	63 - 66
PV	65	3	60 - 68	65	1	64 - 66	70	2	68 - 72	69	1	67 - 71	67	1	65 - 69
OA							68	1[c]	67 - 70	68	1	66 - 70	66	1	65 - 69
IA							77	1[d]	76 - 77	76	1	74 - 78	75	1	73 - 78
AFC							110	1	108 - 111	111	2	108 - 113	114	2[f]	110 - 117
PC	105	1	104 - 107	106	1	104 - 108	112	3	108 - 114	118	3	114 - 122	122	2[f]	118 - 126
Y	28	27	0 - 54												
P1	10	4	4 - 15	12	1[c]	11 - 12	12	2	11 - 14	13	1	11 - 15	16	2[f]	13 - 20
P2							3	3	0 - 6	7	2	4 - 12	13	2	9 - 17
D							16	1[d]	16 - 18	19	2	14 - 21	21	2	18 - 24
A							10	0[d]	10 - 11	13	1	11 - 15	15	1	13 - 18
Depths %SL															
at BPE	14	1	11 - 16	13	1[c]	11 - 14	14	1	13 - 15	16	1	14 - 18	17	1	16 - 19
OP1	17	5	12 - 25	13	1[c]	12 - 15	17	2	15 - 19	20	2	17 - 22	22	1	19 - 24
OD	11	1	10 - 12	11	1[c]	9 - 13	15	3	11 - 17	17	3	13 - 22	21	2	18 - 25
BPV	7	1	6 - 8	8	1[c]	7 - 8	9	1	8 - 11	12	2	9 - 14	14	2	12 - 17
AMPM	4	1	3 - 4	4	0[c]	4 - 5	7	1	6 - 8	9	1	7 - 10	10	1	9 - 12
Max. yolk	8	8	0 - 20												
Widths %SL															
at BPE	12	1[b]	11 - 14	12	0[c]	12 - 13	14	1	13 - 15	16	1[b]	15 - 19	15	1[f]	14 - 16
OP1	11	3[b]	9 - 16	9	1[c]	8 - 10	12	1	10 - 13	15	2[b]	11 - 18	16	1[f]	14 - 19
OD	6	0[b]	5 - 7	6	1[c]	5 - 8	8	2	6 - 10	11	2[b]	9 - 13	14	2[f]	11 - 18
BPV	5	0[b]	4 - 5	5	1[c]	4 - 6	6	1	5 - 7	8	1[b]	6 - 9	10	2[f]	7 - 12
AMPM	2	0[b]	2 - 3	3	0[c]	2 - 3	4	0	3 - 4	5	1[b]	4 - 6	5	1[f]	4 - 6
Max. yolk	8	8[b]	0 - 18												
Myomeres															
to PY	22	1[a]	20 - 23												
OPAF	11	4	6 - 18	8	2[c]	6 - 10	9	2	6 - 10	12	4[b]	8 - 19			
OP2							15	0[d]	15 - 15	15	1	14 - 17	16	1[g]	15 - 17
ODF	12	1	10 - 15	14	1[c]	13 - 14	14	1	12 - 15	14	1[e]	13 - 14			
OD							16	1	15 - 16	15	1	15 - 16	16	1[g]	15 - 16
PV	23	1	21 - 25	24	1[c]	23 - 25	25	2	23 - 27	25	1	24 - 25	24	1[g]	23 - 25
Total	36	1	36 - 37	37	1[c]	35 - 37	36	1	35 - 38	36	1	34 - 37	37	1[g]	36 - 38
After PV	13	1	11 - 15	13	1[c]	11 - 14	11	1	10 - 13	11	1	10 - 13	13	1[b]	11 - 14

[a]N=5. [b]N = 8. [c]N = 4. [d]N = 3. [e]N = 2. [f]N = 13. [g]N = 7.

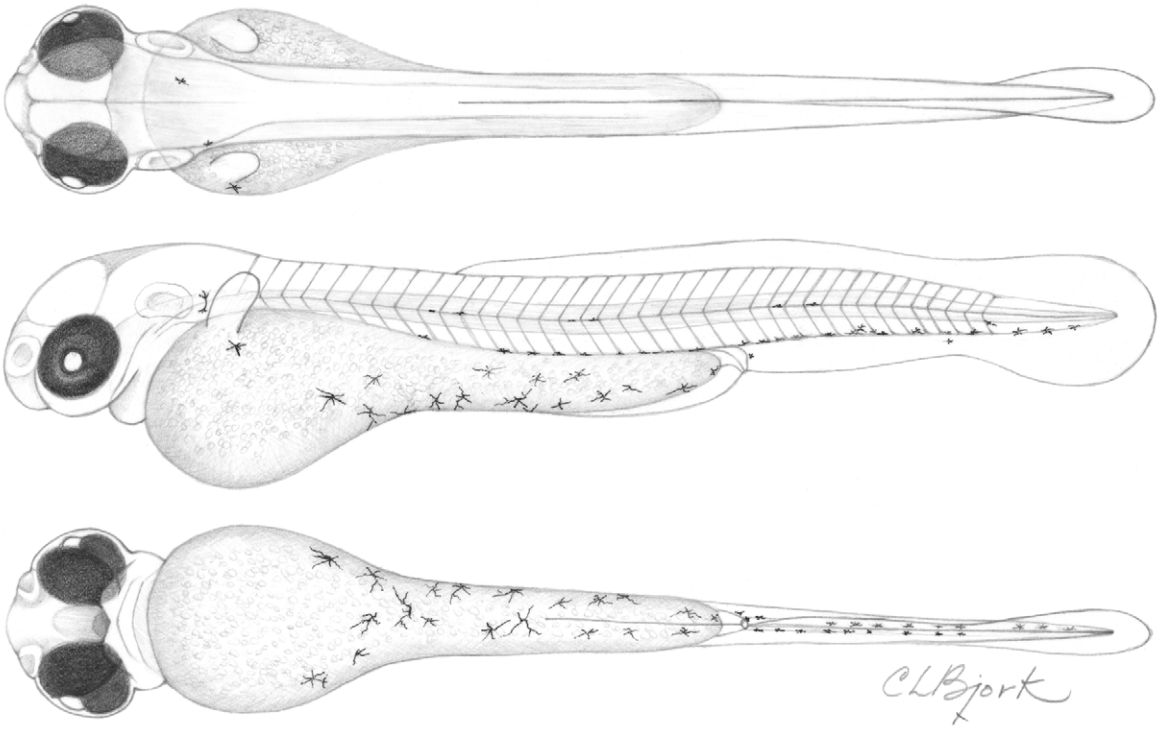

Figure 98. *Pimephales promelas* protolarva, recently hatched, 4.0 mm SL, 4.1 mm TL. (Cultured in 2006 by Larval Fish Laboratory at Colorado State University with embryos from Aquatic BioSystems, Inc., Fort Collins, Colorado.)

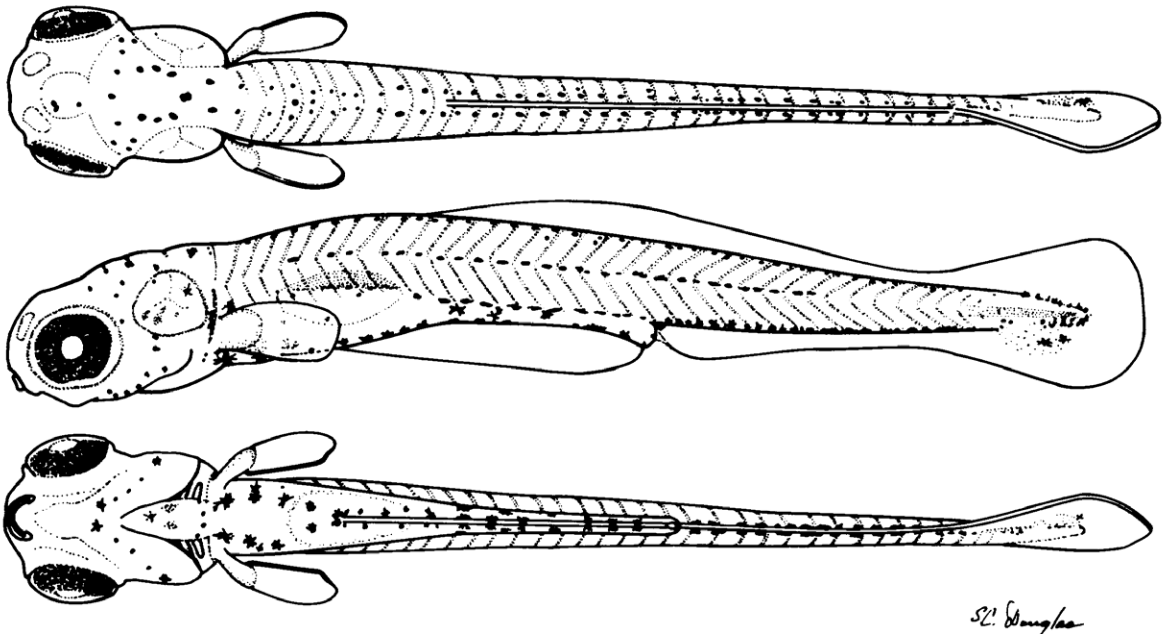

Figure 99. *Pimephales promelas* protolarva, 5.3 mm SL, 5.6 mm TL. (Cultured in 1974 by William Stone at NUS Corporation, Ecological Sciences Division, Pittsburgh, Pennsylvania, with stock from commercial bait ponds in Ohio. Modified from Snyder et al. 1977, Figure 5.)

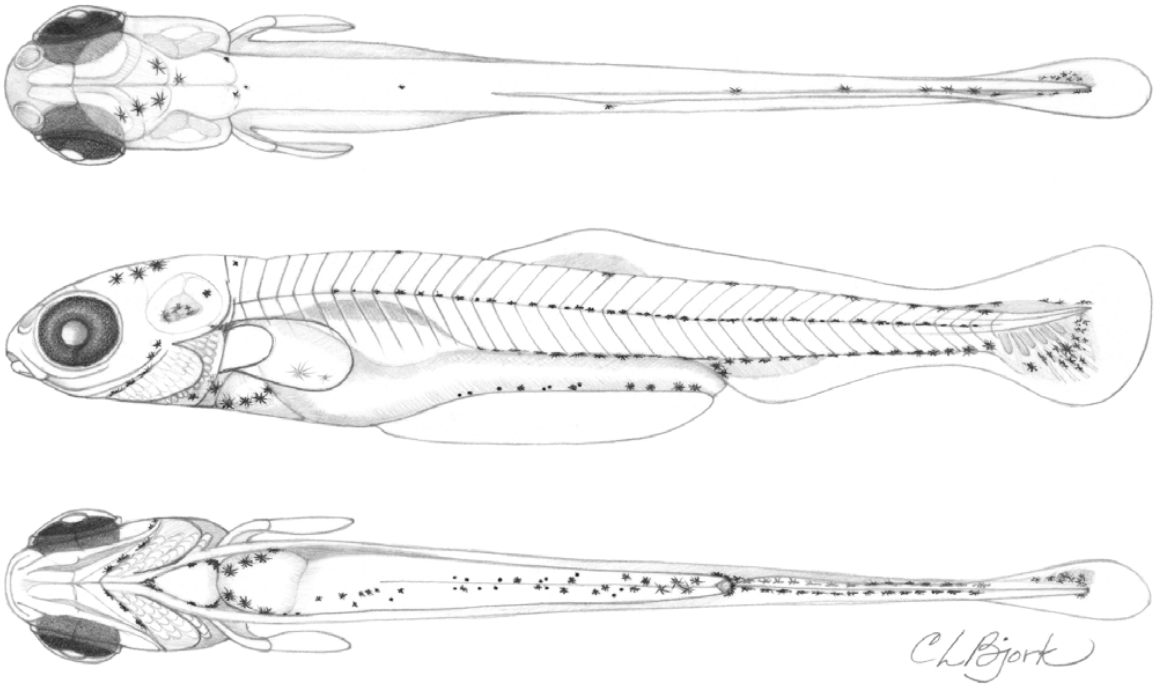

Figure 100. *Pimephales promelas* flexion mesolarva, recently transformed, 6.4 mm SL, 6.7 mm TL. (Cultured in 2006 by Larval Fish Laboratory at Colorado State University with embryos from Aquatic BioSystems, Inc., Fort Collins, Colorado.)

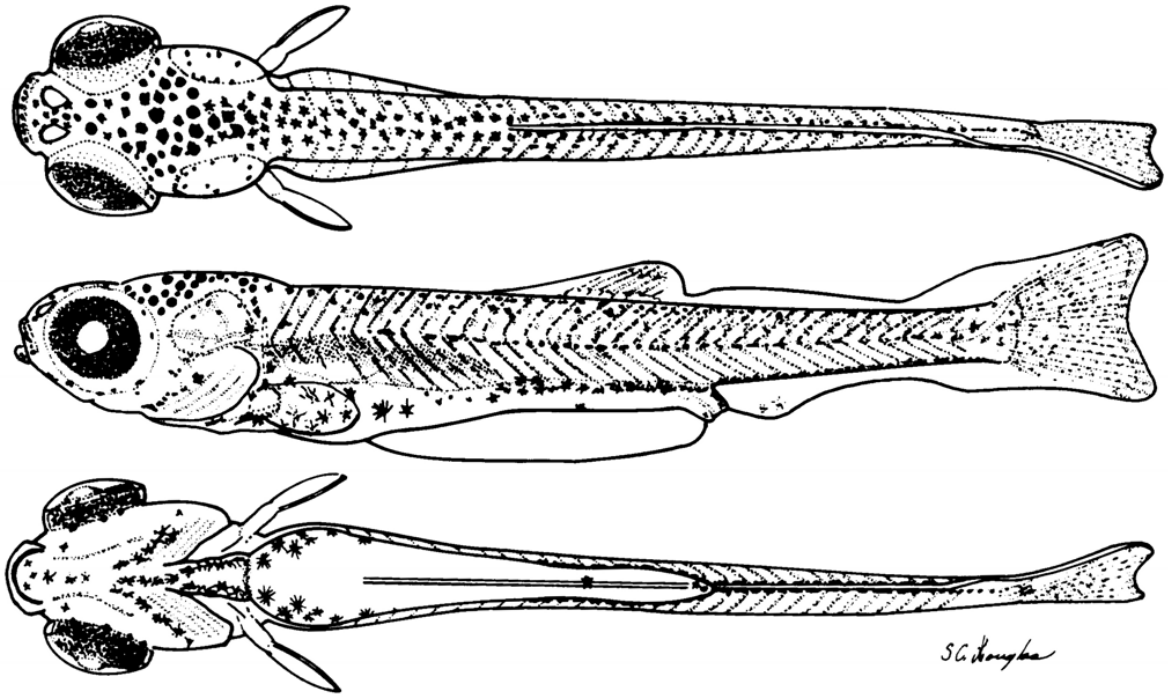

Figure101. *Pimephales promelas* postflexion mesolarva, 7.0 mm SL, 7.9 mm TL. (Cultured in 1974 by Paul Blatt and Darrel Snyder at NUS Corporation Ecological Sciences Division, Pittsburgh, Pennsylvania, with stock from commercial bait ponds in Ohio. Modified from Snyder et al. 1977, Figure 9.)

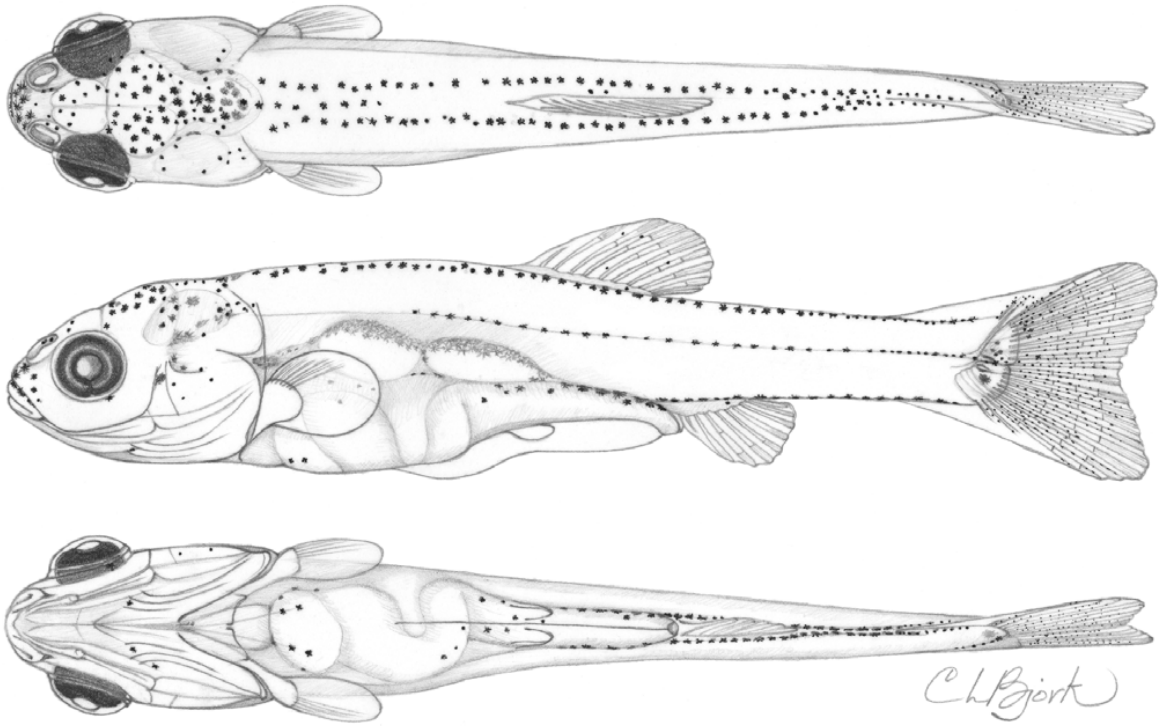

Figure 102. *Pimephales promelas* metalarva, recently transformed, 9.9 mm SL, 11.3 mm TL. (Collected in 2002 from Gunnison River, northwest of Escalante, Delta County, Colorado; from LFL #82227.)

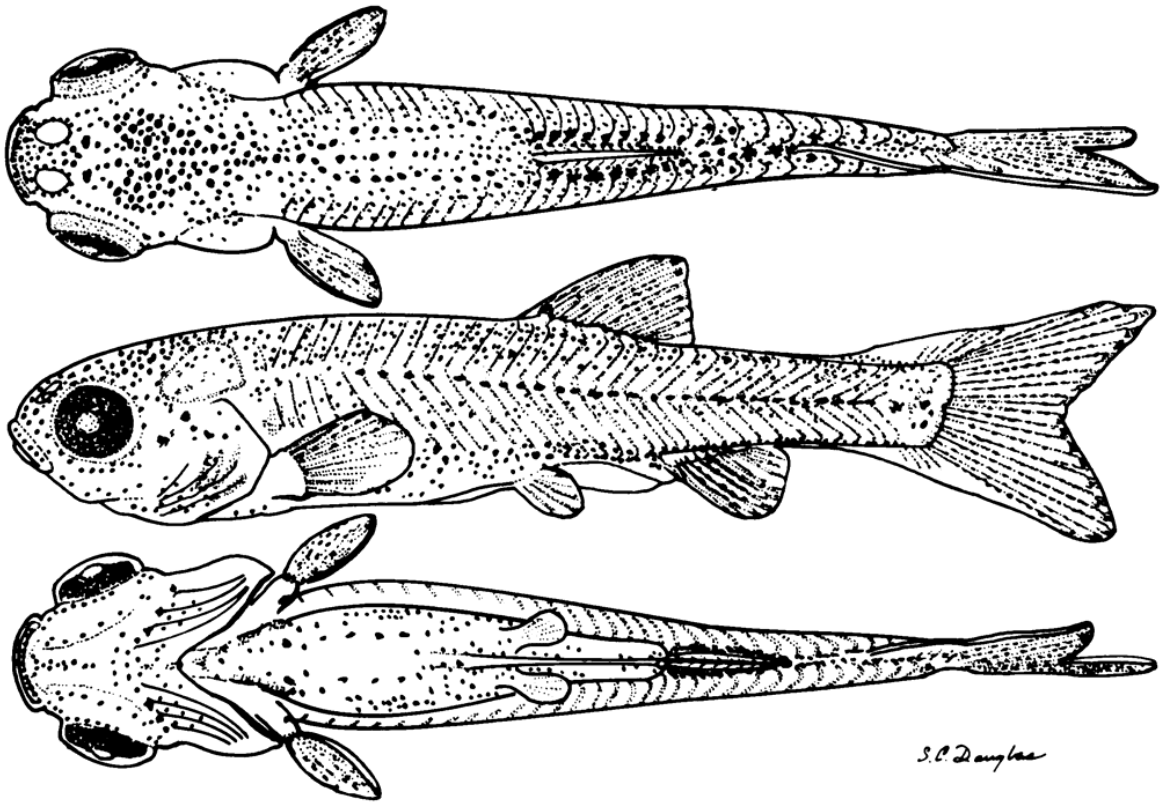

Figure 103. *Pimephales promelas* metalarva, 11.7 mm SL, 14.3 mm TL. (Collected in 1971 by Ichthyological Associates, Inc., Pottstown, Pennsylvania, locally from East Branch Perkiomen Creek. Modified from Snyder et al.1977, Figure 13.)

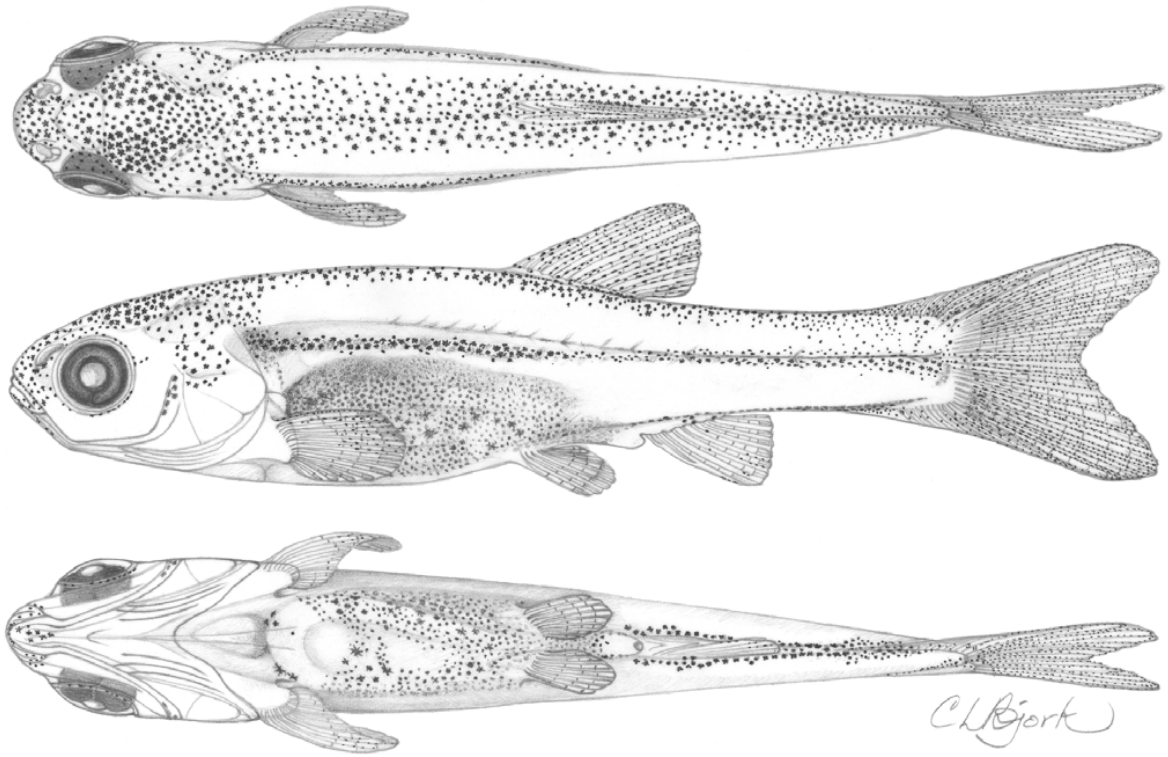

Figure 104. *Pimephales promelas* juvenile, recently transformed, 15.9 mm SL, 18.8 mm TL. (Collected in 1976 or 1977 from Yampa River between Dinosaur National Monument, Moffat Co., and Hayden, Routt Co., Colorado; from LFL #72877.)

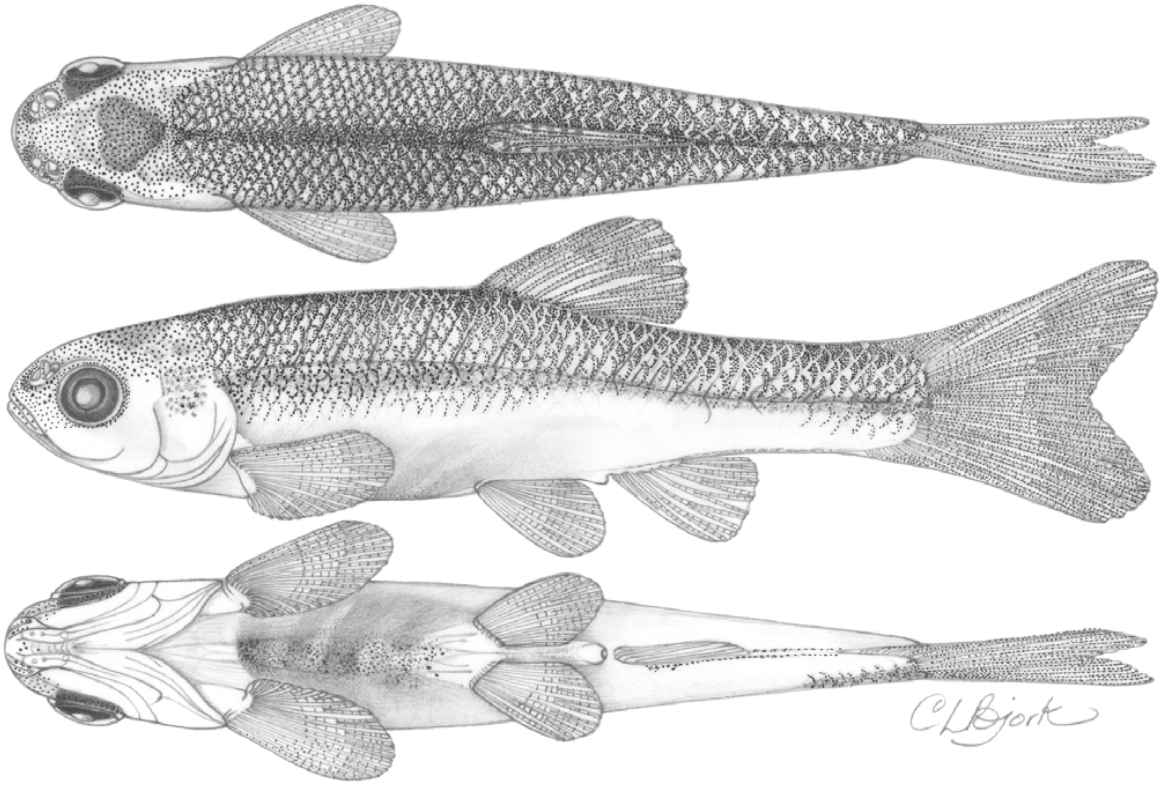

Figure 105. *Pimephales promelas* juvenile, 33.2 mm SL, 41.6 mm TL. (Collected in 1976 or 1977 from White River, Rio Blanco County, Colorado; from LFL #72860.)

Species Account – *Ptychocheilus lucius*, Colorado pikeminnow

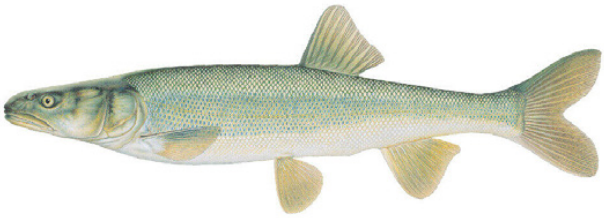

Figure 106. *Ptychocheilus lucius* adult (©Joseph R. Tomelleri).

Adult description: Large, 45–180 cm TL. Fusiform body. Head large, ~25% of SL, and somewhat dorso-ventrally flattened with long snout and small eyes, ~10% of head length. Mouth large, terminal, and horizontal with thick lips; maxillary extending to at least middle of eye. Dorsal fin well back on body behind pelvic fins; caudal fin expansive. Scales moderately small. Typically green to tan above, silvery laterally, and white below. Breeding males yellowish on lower sides; tuberculate over head, paired fins, and ventral surface onto caudal peduncle and fin; females less so. (Also, Table 42.)

Reproduction: Non-guarding, open-substrate lithophil. In Upper Colorado River Basin, spawn when water reaches day-time highs of 16–25°C (usually 18–21°) in early June to early August (usually late June to late July) over gravel-cobble riffles. Water-hardened eggs are adhesive, demersal, and 1.9–2.2 mm in diameter and develop in the interstices of the substrate.

Young: Hatch in 6 d at 18°C and as little as 3 d at 30°C. Emerge 4–7 d later from spawning substrate as late protolarvae and mesolarvae (7–10 mm TL) and are transported in considerable numbers downstream. Larvae occupy near-shore, low-velocity channel margins, backwaters, eddies, and pools. Growth rate is directly related to water temperature. Larvae consume early instars of chironomids and other small invertebrates, larger juveniles add fish to their diet.

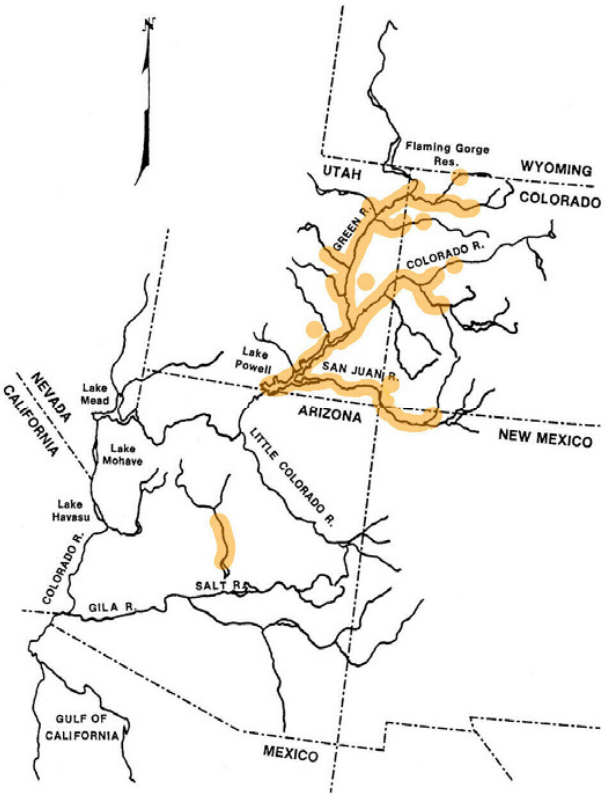

Figure 107. Recent distribution of *Ptychocheilus lucius* in the Colorado River Basin.

Table 42. Selected juvenile and adult meristics for *Ptychocheilus lucius*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	9(10)	9(10)	Dorsal-fin rays - R	1-2-3	–
Anal-fin rays - P	(8)9(10)	(8)9(10)	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	19	19	Caudal-fin rays - RD	(8)9-10(11)	–
Pectoral-fin rays	12-14-17(18)	14-16-17-18	Caudal-fin rays - RV	9-10(11)	–
Pelvic-fin rays	8-9(10)	8-9-10	Lateral scales	(79-)83-88-95	(76-)80-84-93-95(-98)
Vertebrae	48-49	47-48-49	Pharyngeal teeth	–	2,5/4,2

*From Snyder (1981), supplemented with original data.

Table 43. Size at onset of selected developmental events for *Ptychocheilus lucius*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. From Snyder 1981 and Snyder et al. 2005, supplemented with original data.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	(5)6-7	(5)6-7	Dorsal - P	8(9)	9(10)	10-11	12-13
Eyes pigmented	*	*	Anal - P	9(10)	10	(10)11	(12)13
Yolk assimilated	(7)8-9	8-9(10)	Caudal - P	(7)8(9)	8-9	(7)8-9	8-9(10)
Finfold absorbed	19-20(21)	(24)25(-27)	Caudal - R	(7)8-9(10)	8-9(10)	17	21(22)
Pectoral-fin buds	*-6	*-6	Pectoral	(9-)11	(10-)13	(11)12-15	(13)14-18
Pelvic-fin buds	(10)11	(12)13	Pelvic	12	14-15	15	18-19
* before hatching			Scales	(27-)31-34	(35-)41-44	34-38	44-50

References: AGFD 2002; Balon 1975a; Behnke and Benson 1982; Bestgen unpublished data; Bestgen 1996;Bestgen and Bundy 1998; Bestgen and Williams 1994; Bestgen et al. 1998; Girard 1856; Haynes et al. 1984; La Rivers 1962; Marsh 1985; Minckley 1973; Minckley and Marsh 2009; Moore 1968; Muth and Snyder 1995; Nesler et al. 1988; Page and Burr 1991; Seethaler 1978; Sigler and Miller 1963; Snyder 1981; Sublette et al. 1990; Toney 1974; USFWS 1991, 2002b; Vanicek 1967.

Other larval descriptions: Seethaler 1978; Snyder 1981; Snyder et al. 2005; Winn and Miller 1954 (mentioned as similar to *Gila robusta*).

Table 44. Size at developmental interval (left) and gut phase (right) transitions for *Ptychocheilus lucius*. (See Figure 5 for phases of gut folding. Rare values in parentheses. From Snyder 1981 and Snyder et al. 2005, supplemented with original data.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	(7)8(9)	8-9	2 - 90° bend	12-14	14-18
Postflexion mesolarva	(7)8-9	8-9(10)	3 - Full loop	>57, <111	>73. <138
Metalarva	(10)11	(12)13	4 - Partial crossover	not applicable	
Juvenile	19-20(21)	(24)25(-27)	5 - Full	not applicable	

Table 45. Summary of morphometrics and myomere counts by developmental phase for *Ptychocheilus lucius*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

	Protolarvae (N=14)			Flexion mesolarvae (N=5)			Postflexion mesolarvae (N=17)			Metalarvae (N=14)			Juveniles (N=32)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	7	1	6 - 8	8	1	8 - 9	9	1	7 - 11	16	2	12 - 19	28	6	19 - 42
TL, mm	8	1	7 - 9	9	1	8 - 10	10	1	8 - 13	19	3	14 - 24	36	8[n]	25 - 54
Lengths %SL															
AS to AE	3	1	1 - 4	3	0	3 - 3	4	1	3 - 5	6	1	5 - 9	6	1	5 - 8
PE	9	1	8 - 11	10	1	9 - 10	11	1	9 - 13	14	2	12 - 18	14	1	12 - 16
OP1	18	2	15 - 20	20	0	20 - 20	22	1	20 - 25	26	1	24 - 29	26	2	24 - 30
OP2							50	[f]	50	52	1[k]	49 - 54	52	1	49 - 54
PY	66	3[a]	60 - 72	57	11[d]	36 - 66									
OPAF	43	10	33 - 65	27	2	25 - 29	29	2	27 - 34	40	7[a]	32 - 56			
ODF	43	4	32 - 47	44	1	43 - 45	46	1[g]	44 - 49	52	1[m]	51 - 53			
OD							55	1[h]	53 - 57	55	2	51 - 57	54	1	53 - 56
ID							65	1[e]	63 - 67	66	2	63 - 68	66	2[o]	63 - 68
PV	69	2[b]	67 - 73	67	0	67 - 68	70	2	67 - 74	68	2	65 - 72	67	1	64 - 69
OA										70	1[i]	67 - 73	68	1[p]	66 - 69
IA							80	0[i]	80 - 80	79	2	75 - 82	79	2	76 - 82
AFC							107	2	104 - 111	111	1	108 - 113	113	2	110 - 116
PC	105	1[a]	102 - 106	106	1[b]	104 - 109	112	3	106 - 118	124	3[a]	120 - 130	128	2[q]	123 - 133
Y	51	6[a]	42 - 66	27	19[b]	0 - 48									
P1	7	2	2 - 10	12	0	11 - 12	13	1	11 - 15	15	2	11 - 17	16	1[r]	13 - 19
P2							0	1[j]	0 - 4	9	3[k]	4 - 14	15	1	11 - 18
D							13	[f]	13	19	3	15 - 24	22	1	18 - 25
A										16	1	13 - 18	18	1	14 - 21
Depths %SL															
at BPE	13	4	9 - 26	13	1	11 - 13	14	1	12 - 16	15	1[b]	14 - 17	15	1	13 - 16
OP1	16	4	12 - 28	13	1	13 - 14	15	1	13 - 17	17	1	15 - 20	18	1	17 - 20
OD	13	2[c]	11 - 16	11	0	11 - 11	11	1	10 - 14	16	2	14 - 19	19	1	17 - 21
BPV	8	1	6 - 9	8	0	8 - 9	8	1	7 - 12	13	1	11 - 15	15	1	13 - 17
AMPM	3	1	3 - 4	4	1	4 - 5	5	1	4 - 7	8	1	7 - 9	9	0	8 - 9
Max. yolk	14	4[a]	8 - 23	4	3[b]	0 - 10									
Widths %SL															
at BPE	11	2	8 - 13	12	0	12 - 13	13	1	12 - 15	15	1	13 - 16	14	1	13 - 16
OP1	11	3	8 - 20	10	0	9 - 10	10	1	9 - 12	13	1	11 - 15	15	1	12 - 17
OD	8	2[c]	5 - 11	6	0	6 - 6	6	1	5 - 8	10	1	8 - 12	13	1	10 - 16
BPV	5	1	3 - 7	5	0	4 - 5	5	1	4 - 7	8	1	6 - 11	11	2	8 - 14
AMPM	3	1	2 - 4	2	0	2 - 3	3	1	2 - 5	4	0	3 - 5	4	1	2 - 5
Max. yolk	14	4[a]	9 - 22	7	4[b]	0 - 11									
Myomeres															
to PY	32	1	29 - 34	24	9	12 - 33									
OPAF	15	4[b]	10 - 21	6	1	5 - 6	6	1[k]	5 - 8	12	5[h]	5 - 23			
OP2							20	[f]	20	20	1[a]	18 - 22	20	1[n]	19 - 21
ODF	17	2[c]	10 - 18	17	1	16 - 18	18	1[b]	15 - 19	20	[f]	20			
OD							22	1[l]	21 - 24	23	1[b]	21 - 24	22	1[n]	21 - 23
PV	33	1	32 - 35	34	1[e]	33 - 35	34	1[k]	31 - 35	33	1[b]	31 - 34	32	1[n]	30 - 34
Total	50	1	48 - 51	50	1[e]	48 - 51	49	1[k]	48 - 51	49	1[b]	48 - 51	49	1[n]	48 - 50
After PV	16	1	14 - 17	16	1[e]	15 - 17	15	1[k]	14 - 17	16	1[b]	15 - 18	18	1[n]	16 - 19

[a]N = 15. [b]N = 13. [c]N = 9. [d]N = 7. [e]N =6. [f]N = 1. [g]N = 14. [h]N = 12. [i]N = 3. [j]N = 19. [k]N = 16. [l]N = 5. [m]N = 2. [n]N = 26. [o]N = 31. [p]N = 4. [q]N = 25. [r]N = 30.

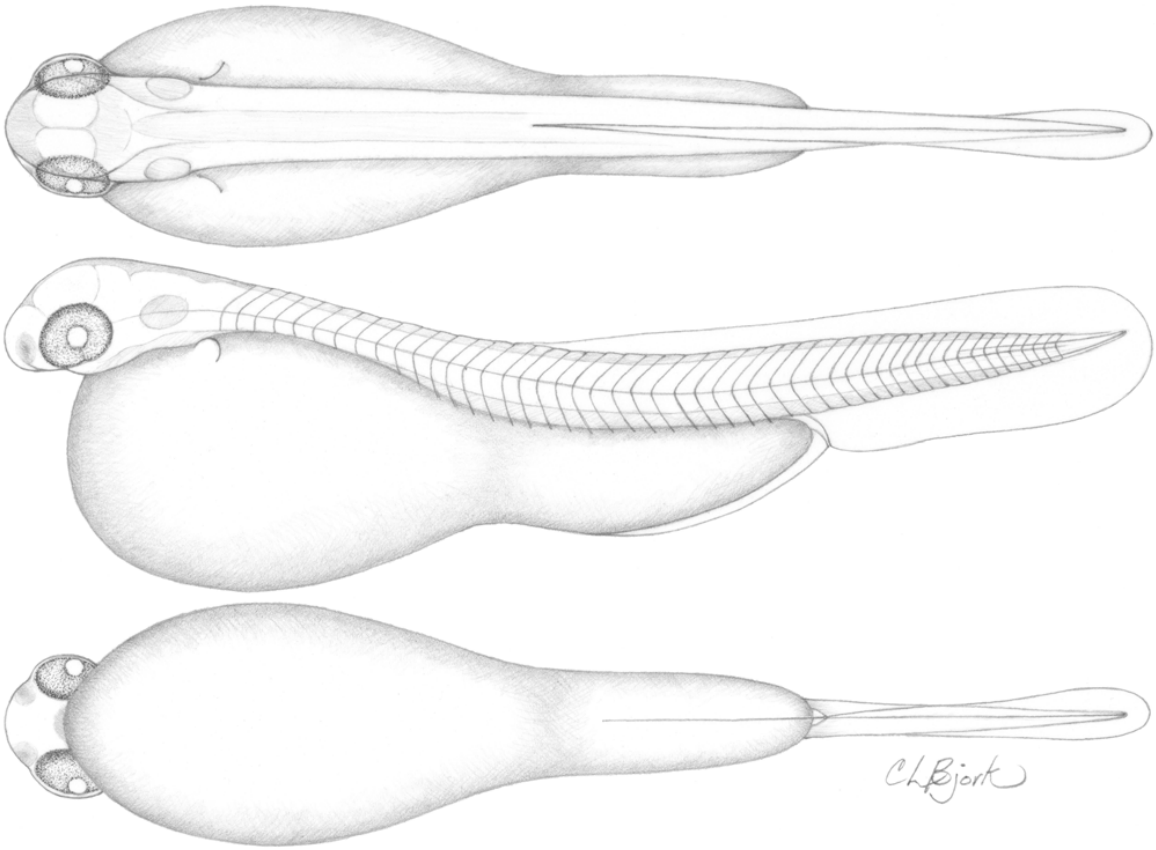

Figure 108. *Ptychocheilus lucius* protolarva with yolk, recently hatched, 6.5 mm SL, 6.6 mm TL. (Cultured in 1989 by Larval Fish Laboratory at Colorado State University with embryos provided by Dexter National Fish Hatchery, New Mexico.)

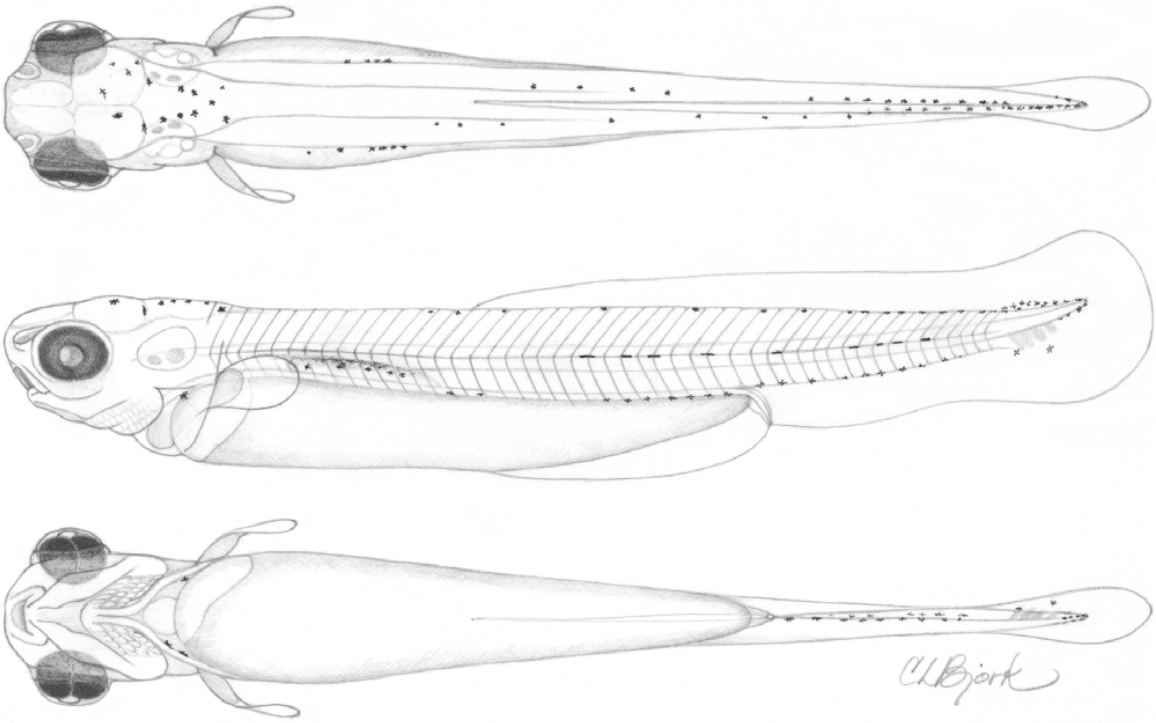

Figure 109. *Ptychocheilus lucius* protolarva with yolk, 8.2 mm SL, 8.7 mm TL. (Cultured in 1991 by Larval Fish Laboratory at Colorado State University with embryos provided by Dexter National Fish Hatchery, New Mexico.)

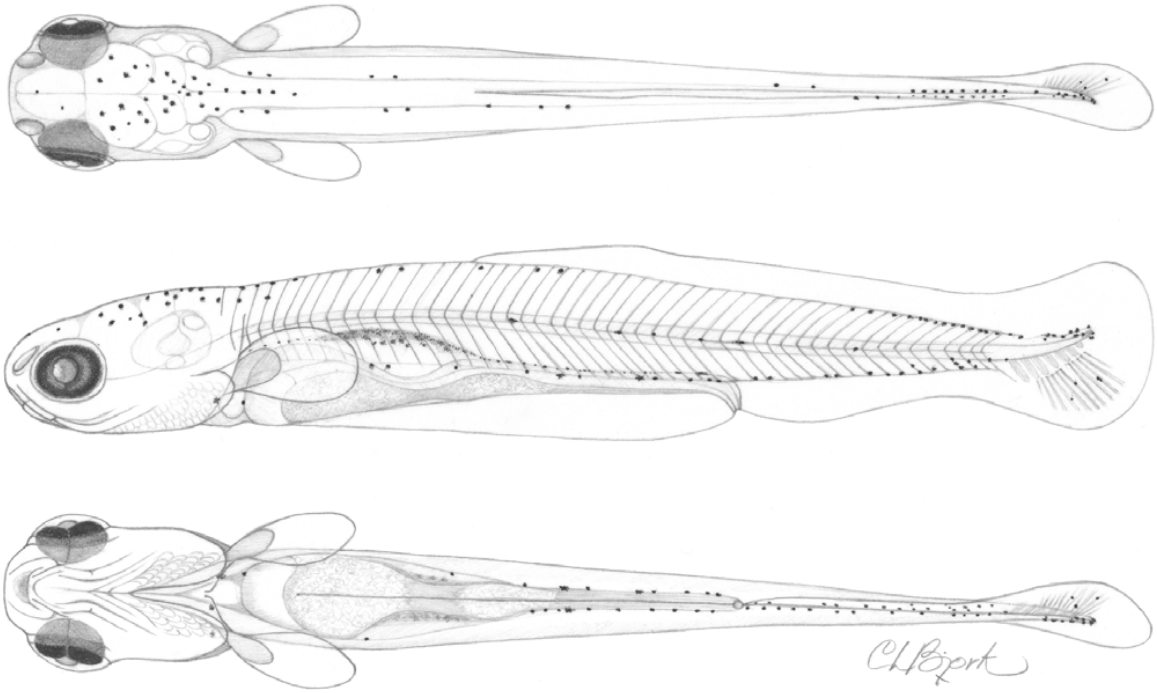

Figure 110. *Ptychocheilus lucius* flexion mesolarva with yolk, recently transformed, 9.0 mm SL, 9.5 mm TL. (Collected in 1993 from Colorado River near Loma, Colorado; LFL 41741.)

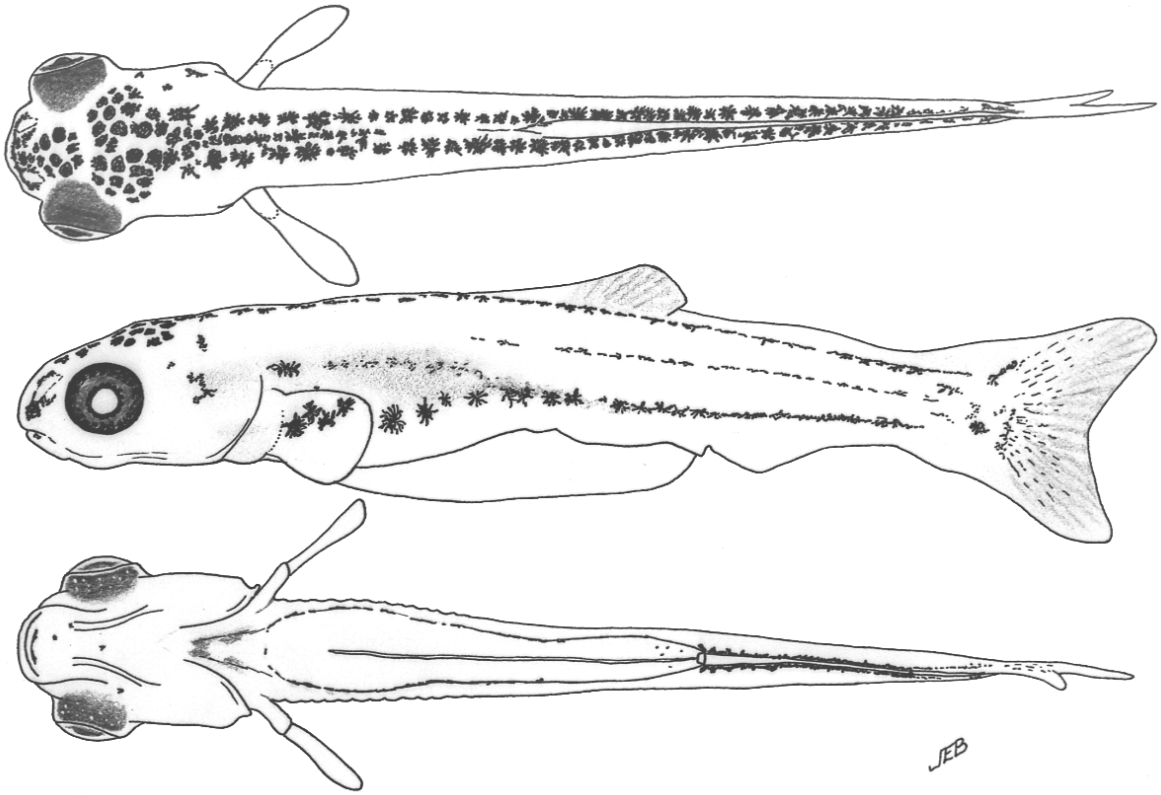

Figure 111. *Ptychocheilus lucius* postflexion mesolarva, 8.7 mm SL, 10.0 mm TL. (Cultured in 1975 by Willow Beach National Fish Hatchery, Arizona, with stock from the lower Yampa River, Colorado. From Seethaler 1978.)

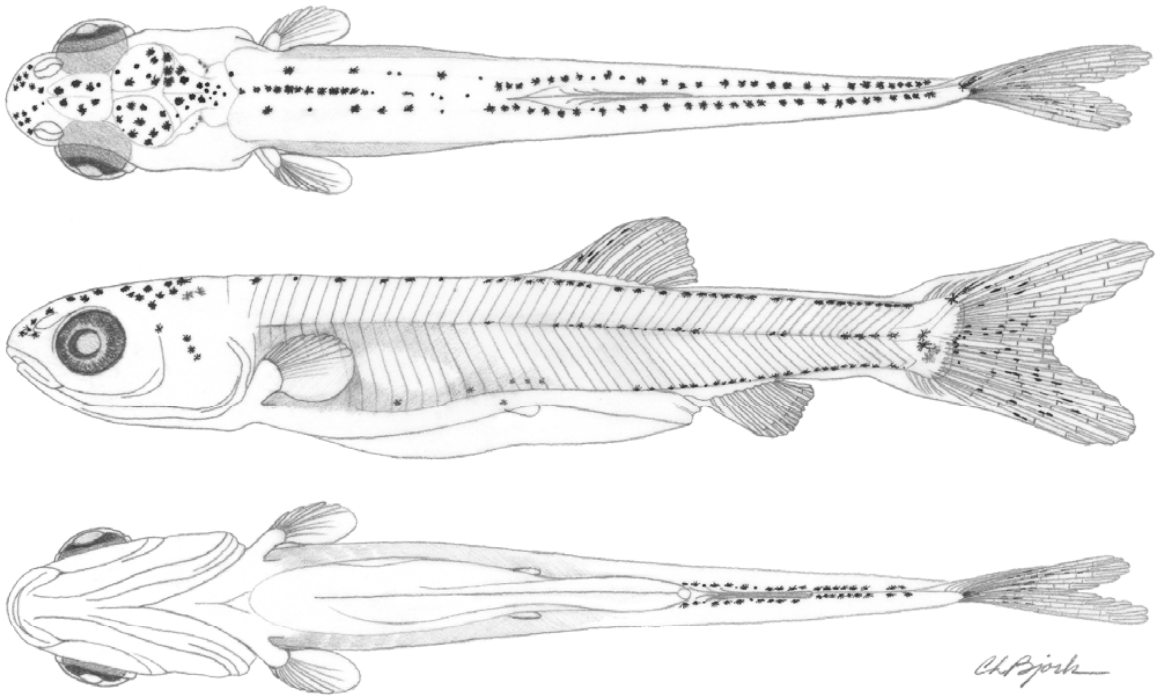

Figure 112. *Ptychocheilus lucius* metalarva, recently transformed, 11.7 mm SL, 14.0 mm TL. (Collected in 1979 from the Colorado River west of Grand Junction, Colorado; probably LFL 56243. From Snyder 1981.)

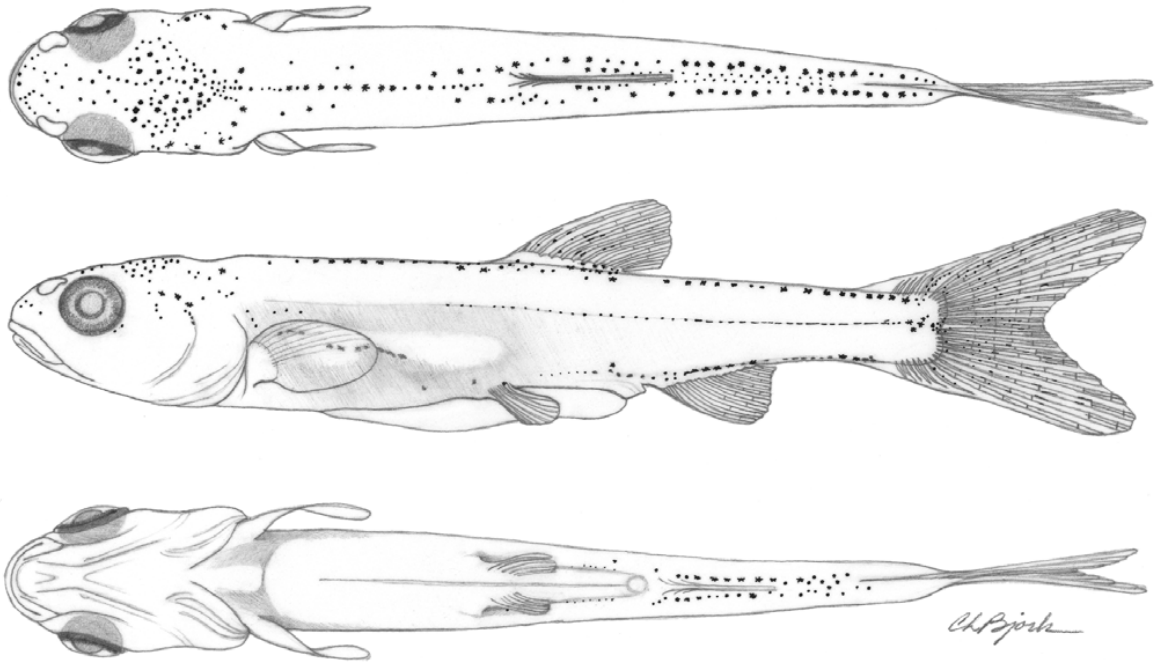

Figure 113. *Ptychocheilus lucius* metalarva, 14.2 mm SL, 17.2 mm TL. (Collected in 1979 from the Colorado River west of Grand Junction, Colorado; probably LFL 56243. From Snyder 1981.)

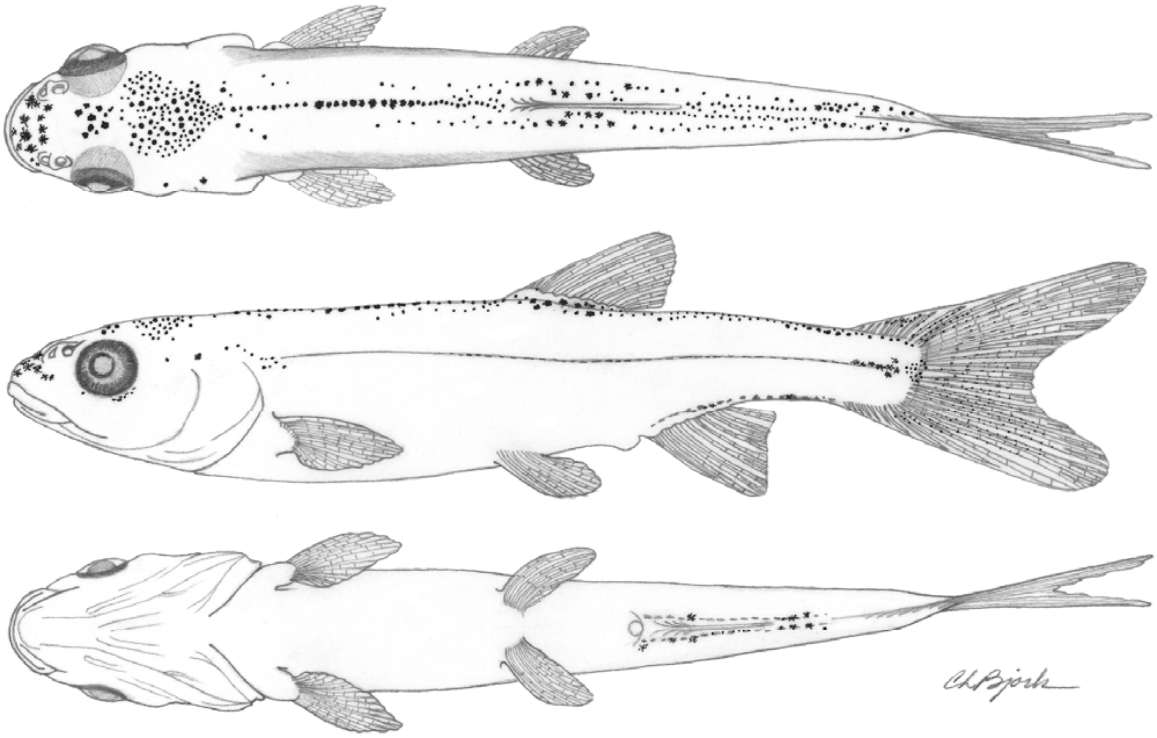

Figure 114. *Ptychocheilus lucius* juvenile, recently transformed, 20.4 mm SL, 25.2 mm TL. (Collected in 1979 from the Colorado River in Black Rocks area, Colorado near Utah border; probably LFL 56242. From Snyder 1981.)

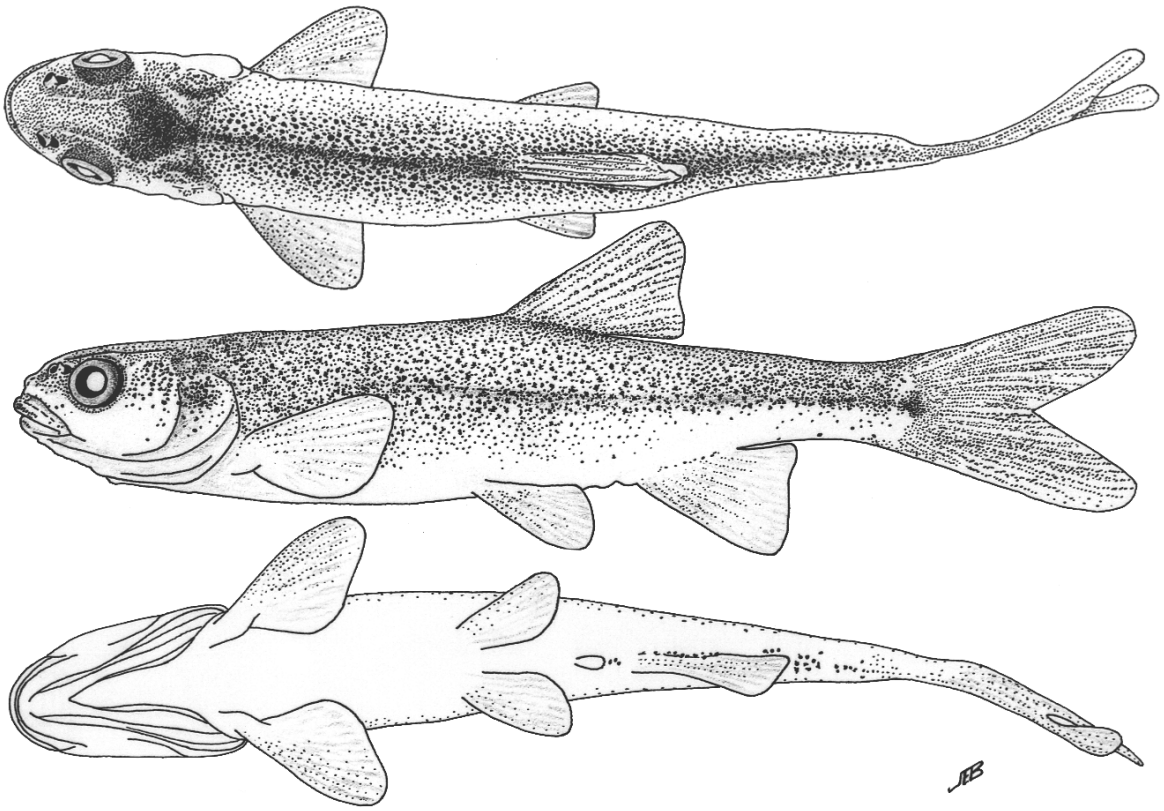

Figure 115. *Ptychocheilus lucius* juvenile, 41.4 mm SL, 51.4 mm TL. (Cultured in 1975 by Willow Beach National Fish Hatchery, Arizona, with stock from the lower Yampa River, Colorado. From Seethaler 1978.)

Species Account – *Rhinichthys cataractae*, longnose dace

Figure 116. *Rhinichthys cataractae* adult (© Joseph R. Tomelleri).

Adult description: Usually 7.5–9 cm, but up to 15 cm TL. Body moderately streamlined, elongate. Head conical or triangular; long, bulbous snout overhanging frenum and nearly horizontal, subterminal to inferior mouth. Mouth ends with small, often concealed barbels before small, highly positioned eyes. Dorsal fin base with dash of dark pigment and origin well behind that of pelvics. Gut s-shaped; peritoneum speckled. Scales small. Brown to olive dorsally and laterally, often mottled or speckled, with a dark caudal spot; silver to white below; dusky lateral band on snout and body of smaller fish. (Also, Table 46.)

Reproduction: Non-guarding, open substrate lithophils or lithopelagophils. Usually mature at age 2 and spawn mid spring to early summer at 11–19°C in swift currents over riffles or wave-swept shorelines, rarely in nests of other cyprinids. Breeding males tuberculated on top of head and orange-red at corners of mouth, sides of head, and bases of anal and paired fins (faint or absent in western subspecies). Males may guard spawning area. Water-hardened eggs demersal, adhesive, and 2.0–2.1 (orig.) or 2.1–2.7 mm in diameter.

Young: Hatch in 3–10 d at 24–15°C, respectively; absorb yolk in ~7 d. Found mostly in near-shore, low-velocity habitats (e.g., backwaters, embayments) in mid-water column; remain pelagic for several weeks to 4 months before moving to benthic habitats in swifter water.

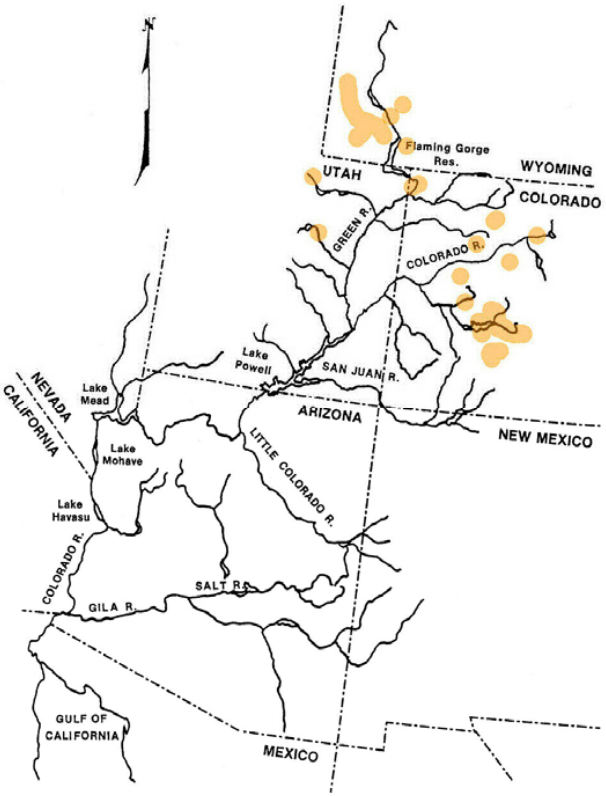

Figure 117. Recent distribution of *Rhinichthys cataractae* in the Colorado River Basin.

Table 46. Selected juvenile and adult meristics for *Rhinichthys cataractae*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed	Literature	Character	Observed	Literature
Dorsal-fin rays - P	8	7-8-9	Dorsal-fin rays - R	2-3	–
Anal-fin rays - P	7	(6)7(-9)	Anal-fin rays - R	(1)2-3	–
Caudal-fin rays - P	(18)19(20)	19	Caudal-fin rays - RD	7-8(-10)	–
Pectoral-fin rays	12-13-14	12-13-14-15	Caudal-fin rays - RV	7-8(9)	–
Pelvic-fin rays	8(9)	7-8(9)	Lateral scales	62-64-69	58-61-72(-76)
Vertebrae	–	37-38-40-42	Pharyngeal teeth	–	(1)2,4/4,2(-0)

Table 47. Size at apparent onset of selected developmental events for *Rhinichthys cataractae*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Bracketed data from other descriptions for eastern US populations where larvae were notably larger.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	(4)5[-6]	(4)5[-6]	Dorsal - P	8	9	10	11-12
Eyes pigmented	*4(5)[*-6]	*4(5)[*-6(7)]	Anal - P	9	9-10	10(11)	12(13)
Yolk assimilated	7[-9]	7-8 [9(10)]	Caudal - P	7[-9]	7-8[9]	8(9)	9
Finfold absorbed	(14)15(16)	18-19	Caudal - R	9-10	10-11(12)	14	17-18
Pectoral-fin buds	*	*	Pectoral	9(10)	10(11)	(12)13-14	(14)15-16(17)
Pelvic-fin buds	8(9)[-11]	9[-11-12]	Pelvic	10	12	14-15	18
* before hatching			Scales	17-19	21-23	(18-)20-22(-25)	(22-)25-27(-30)

References: Balon 1975a; Baxter and Simon 1970; Baxter and Stone 1995; Becker 1983; Beckman 1952; Coburn 1986; Eddy and Underhill 1974; Heufelder and Fuiman 1982; Lentsch et al. 1996; Moore 1968; Page and Burr 1991; Scott and Crossman 1973; Sigler and Miller 1963; Sigler and Sigler 1996; Simon 1998; Simpson and Wallace 1978; Sublette et al. 1990; Tyus et al. 1982; Werner 2004; Woodling 1985.

Other larval descriptions: Bartnik 1970; Buynak and Mohr 1979a; Cooper 1978, 1980; Fish 1932 (possibly *R. atratulus*); Fuiman and Loos 1977; Fuiman et al. 1983; Heufelder and Fuiman 1982; Loos et al. 1979; Snyder 1981.

Table 48. Size at developmental interval (left) and gut phase (right) transitions for *Rhinichthys cataractae*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Bracketed data from other descriptions for eastern US populations where larvae were notably larger.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	7[-9]	7-8[-9]	2 - 90° bend	11	13
Postflexion mesolarva	8(9)	9	3 - Full loop	(21-)25(26)	(27-)30-32
Metalarva	10(11)	12(13)	4 - Partial crossover	(not applicable)	
Juvenile	(14)15(16)	18-19	5 - Full	(not applicable)	

Table 49. Summary of morphometrics and myomere counts by developmental phase for *Rhinichthys cataractae*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes data extracted from Buynak and Mohr 1979a and Fuiman and Loos 1977 illustrations used herein.)

	Protolarvae (N=11)			Flexion mesolarvae (N=7)			Postflexion mesolarvae (N=12)			Metalarvae (N=12)			Juveniles (N=17)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	6	1	5 - 7	8	0	7 - 8	9	1	8 - 10	13	2	10 - 16	24	8[g]	14 - 40
TL, mm	6	1	5 - 7	8	0	8 - 9	10	1	9 - 12	15	2	12 - 19	30	9[g]	18 - 48
Lengths %SL															
AS to AE	3	0	3 - 4	4	1	3 - 5	4	1	3 - 5	5	1	4 - 8	8	1	6 - 10
PE	11	1	10 - 12	12	1	11 - 14	12	1	10 - 13	13	1	11 - 16	14	1	13 - 16
OP1	19	1	18 - 21	21	1	20 - 23	23	1	20 - 25	25	1	23 - 28	26	1	23 - 27
OP2							46	1[b]	45 - 48	50	1	48 - 51	50	2[h]	46 - 54
PY	62	6	51 - 68												
OPAF	45	9	34 - 56	34	1	32 - 36	34	3	31 - 41	46	6	39 - 54			
ODF	44	2	39 - 48	44	2	40 - 46	45	3	42 - 53	49	1[d]	48 - 50			
OD							52	1[c]	50 - 55	52	1	50 - 53	53	1	51 - 55
ID							62	2[d]	59 - 63	63	1[f]	62 - 64	64	1	62 - 65
PV	67	2	64 - 69	65	2	64 - 69	67	2	63 - 70	67	1	66 - 69	65	1	63 - 67
OA							67	1[c]	65 - 69	66	1	65 - 68	65	1	62 - 67
IA							75	1[d]	74 - 76	75	1	74 - 77	75	2	72 - 77
AFC							109	1	108 - 111	114	1[f]	111 - 115	115	1	114 - 118
PC	105	1	103 - 107	107	2	105 - 110	110	2	108 - 116	120	2	116 - 123	123	2[g]	121 - 127
Y	46	10	29 - 57												
P1	7	3	4 - 11	14	0	13 - 14	14	1	11 - 16	16	1	14 - 17	19	1	17 - 23
P2							4	1[b]	2 - 6	9	3[f]	6 - 13	14	1	13 - 16
D							14	1[e]	12 - 15	18	1	16 - 20	21	1	19 - 24
A							11	2[e]	9 - 12	15	2	12 - 19	19	2	15 - 21
Depths %SL															
at BPE	14	1	13 - 17	15	1	14 - 15	15	1	14 - 16	16	1	15 - 18	16	2	14 - 18
OP1	19	4	15 - 26	15	1	15 - 17	17	1	16 - 18	19	1	18 - 22	20	1	17 - 23
OD	14	2	11 - 18	12	0	11 - 12	13	1	11 - 14	17	2	13 - 20	20	2	18 - 26
BPV	8	1	7 - 9	8	0	8 - 9	9	1	8 - 11	13	1	9 - 14	15	1	14 - 19
AMPM	5	1	4 - 6	5	0	5 - 6	6	1	5 - 8	9	1	7 - 11	11	1	9 - 13
Max. yolk	13	7	4 - 21												
Widths %SL															
at BPE	13	1	11 - 15	14	1	13 - 16	15	1	14 - 16	16	0[f]	16 - 17	16	1	14 - 18
OP1	14	5	10 - 22	12	1	11 - 13	13	1	11 - 14	16	1[f]	13 - 18	19	1	17 - 22
OD	8	1	6 - 10	6	1	5 - 7	7	1	6 - 8	10	2[f]	7 - 13	15	2	11 - 21
BPV	6	0	5 - 6	5	0	5 - 5	6	0	5 - 6	8	1[f]	5 - 9	11	1	8 - 14
AMPM	3	0	3 - 4	3	1	3 - 4	4	0	3 - 4	4	0[f]	4 - 5	5	1	5 - 7
Max. yolk	15	7	7 - 24												
Myomeres															
to PY	22	3[a]	17 - 25												
OPAF	13	4[a]	9 - 19	9	1	8 - 11	9	1	8 - 11	13	3[f]	9 - 18			
OP2							16	1[b]	15 - 17	16	1[f]	14 - 17	16	1[i]	14 - 17
ODF	13	1[a]	12 - 15	14	1	13 - 16	15	1	14 - 16	16	1[d]	15 - 18			
OD							18	1[c]	17 - 19	17	1[f]	15 - 19	17	1[j]	15 - 18
PV	25	1[a]	24 - 26	26	1	25 - 27	27	1	26 - 27	25	1[f]	24 - 27	25	1[j]	23 - 26
Total	38	1[a]	36 - 40	39	1	38 - 40	39	1	38 - 40	39	1[f]	37 - 40	38	1[j]	37 - 39
After PV	13	1	12 - 15	13	1	12 - 14	13	1	11 - 14	13	1[f]	12 - 15	13	1[j]	12 - 14

[a]N = 10. [b]N = 9. [c]N = 10. [d]N = 4. [e]N = 3. [f]N = 11. [g]N = 23. [h]N = 16. [i]N = 7. [j]N = 8.

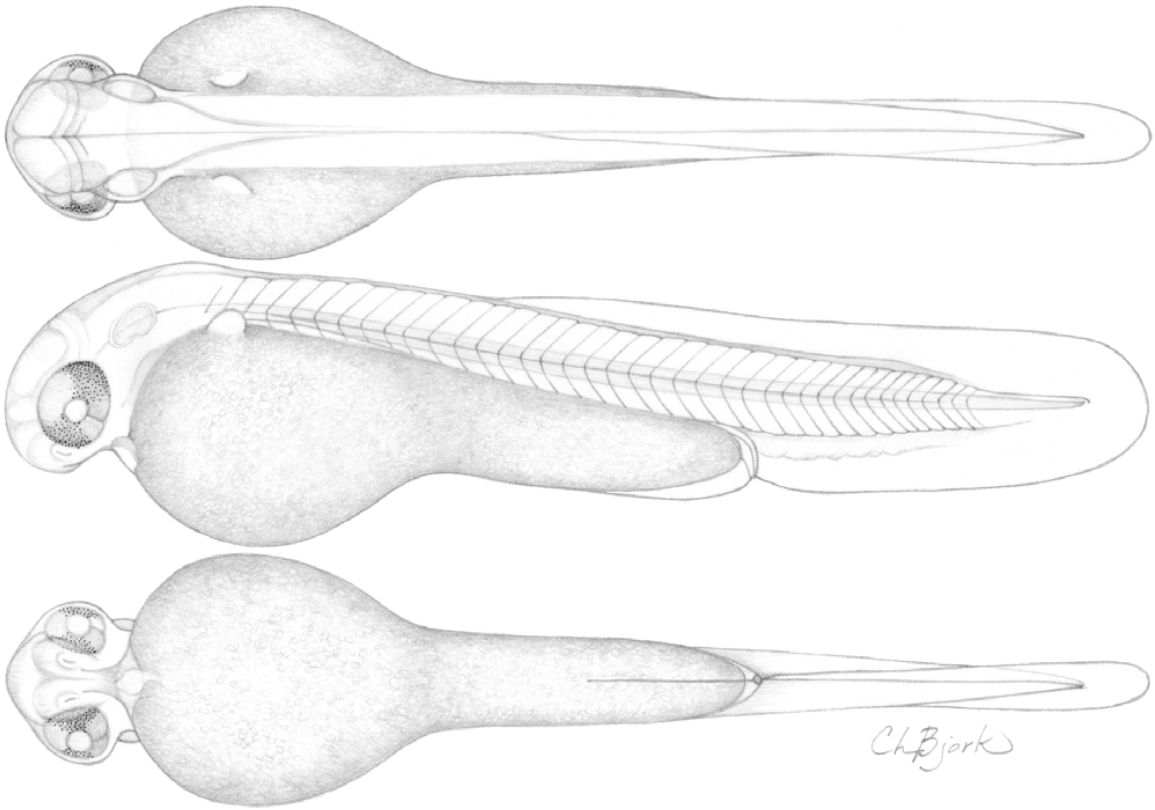

Figure 118. *Rhinichthys cataractae* protolarva, recently hatched, 4.8 mm SL, 5.1 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock collected from Cache la Poudre R.,in or near Fort Collins, Colorado.)

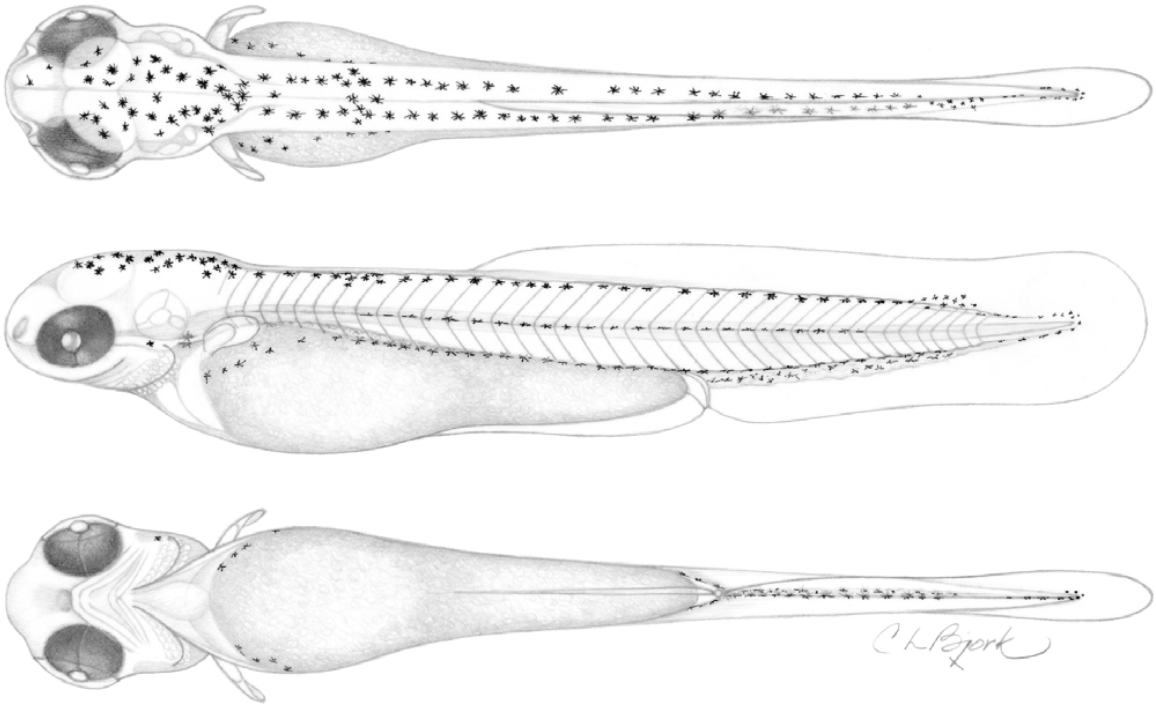

Figure 119. *Rhinichthys cataractae* protolarva, 3 d posthatch, 6.0 mm SL, 6.4 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock collected from Cache la Poudre River in or near Fort Collins, Colorado.)

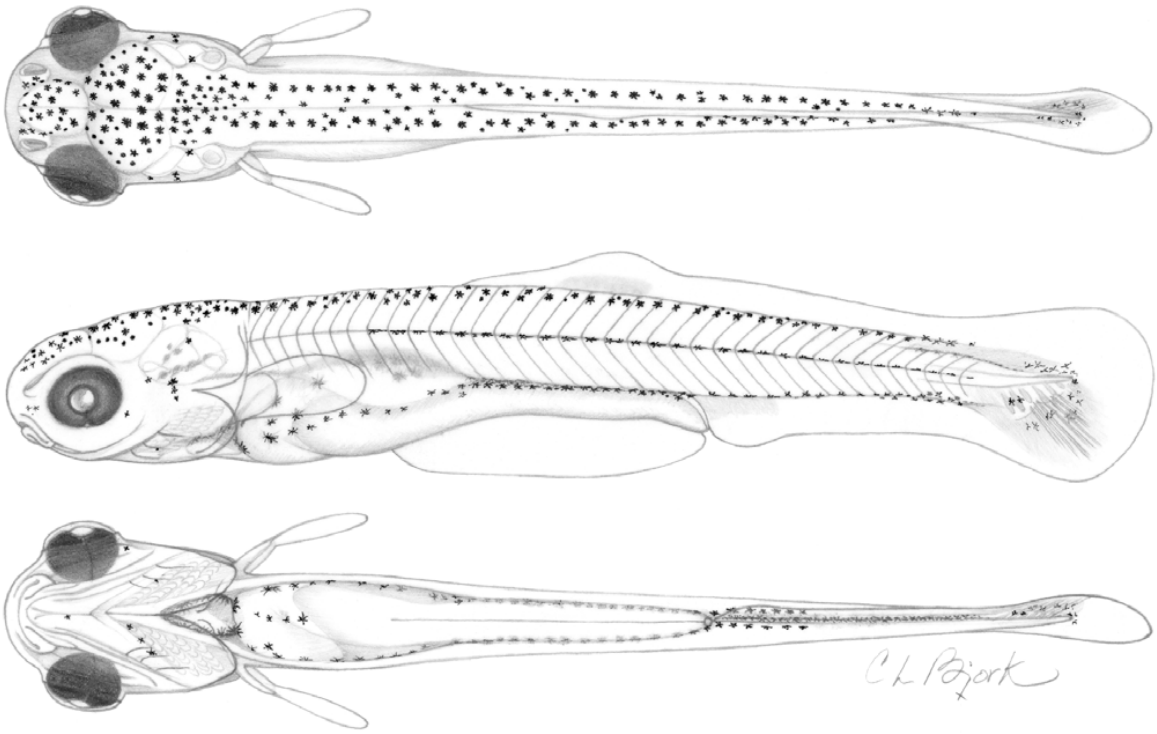

Figure 120. *Rhinichthys cataractae* flexion mesolarva, recently transformed, 9 d posthatch, 7.7 mm SL, 8.3 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with stock collected from Cache la Poudre River in or near Fort Collins, Colorado.)

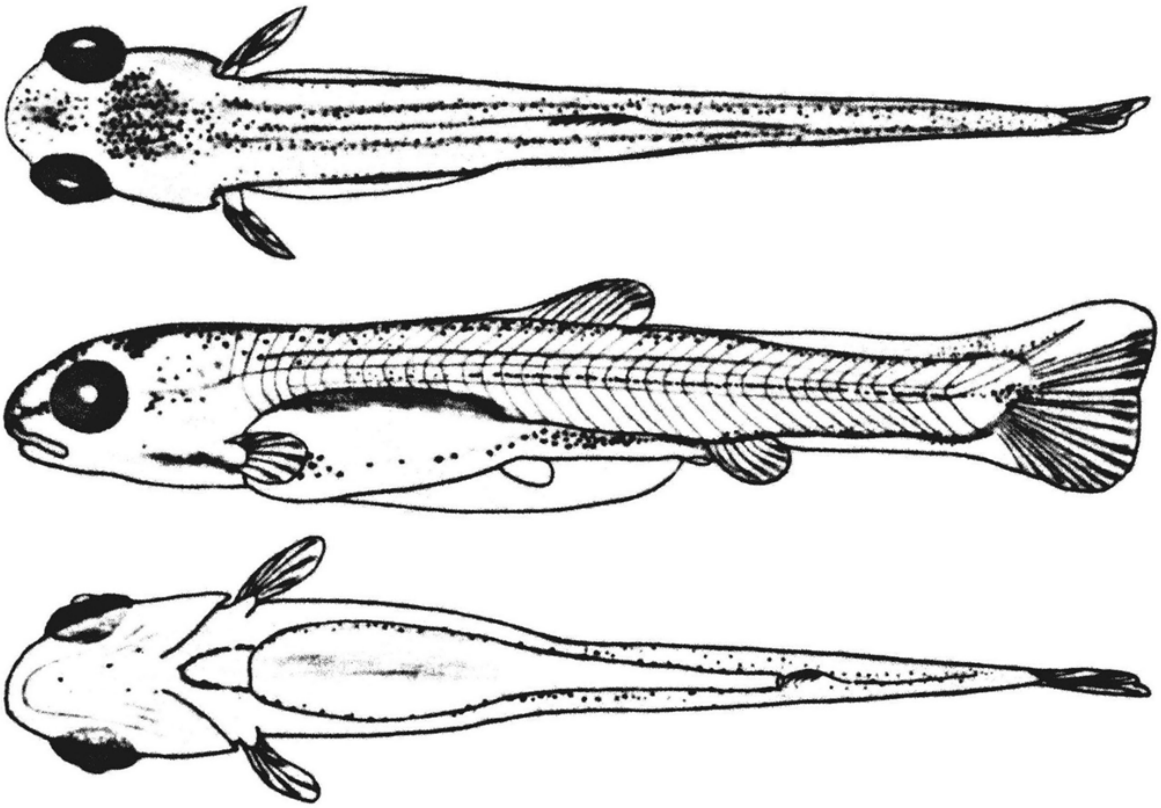

Figure 121. *Rhinichthys cataractae* postflexion mesolarva, 10.4 mm SL, 11.6 mm TL. (Cultured in 1977by Ichthyological Associates, Inc., Berwick, PA, with stock collected from nearby Briar Creek. Modified from Buynak and Mohr 1979a, Figure 2e, with author permission; fin ray counts not accurate.)

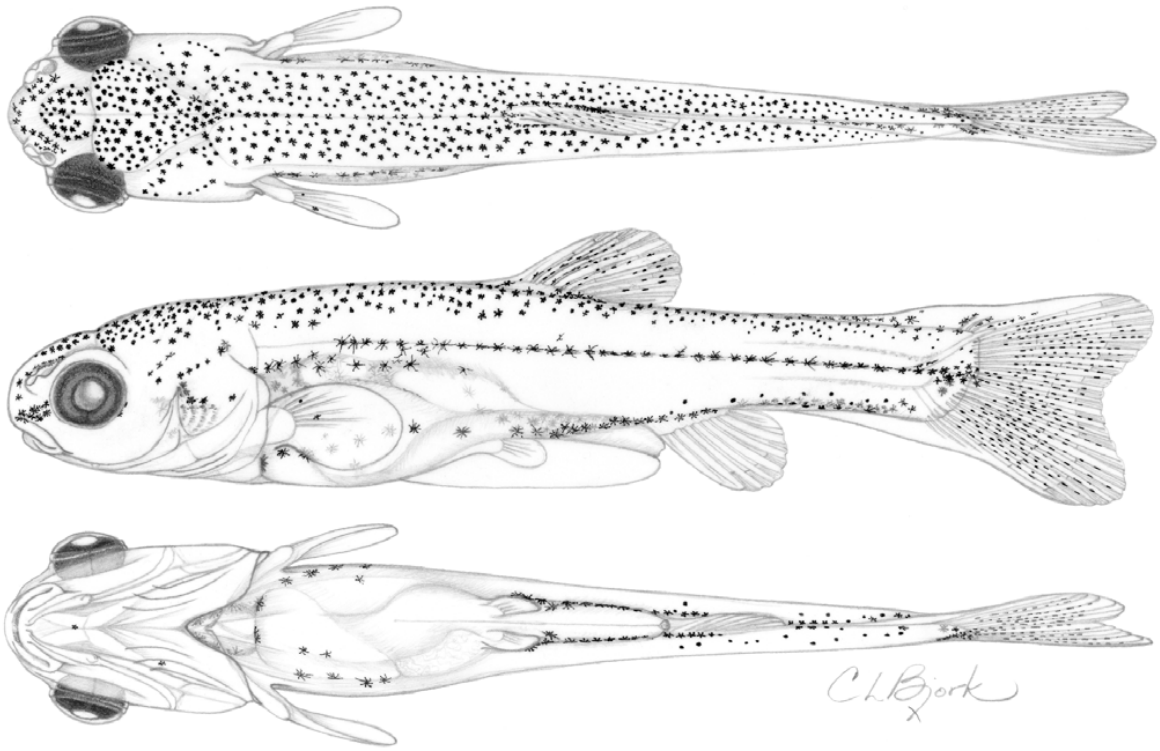

Figure 122. *Rhinichthys cataractae* metalarva, recently transformed, 11.4 mm SL, 13.5 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State Univ. with stock collected from Cache la Poudre R. in or near Fort Collins, CO.)

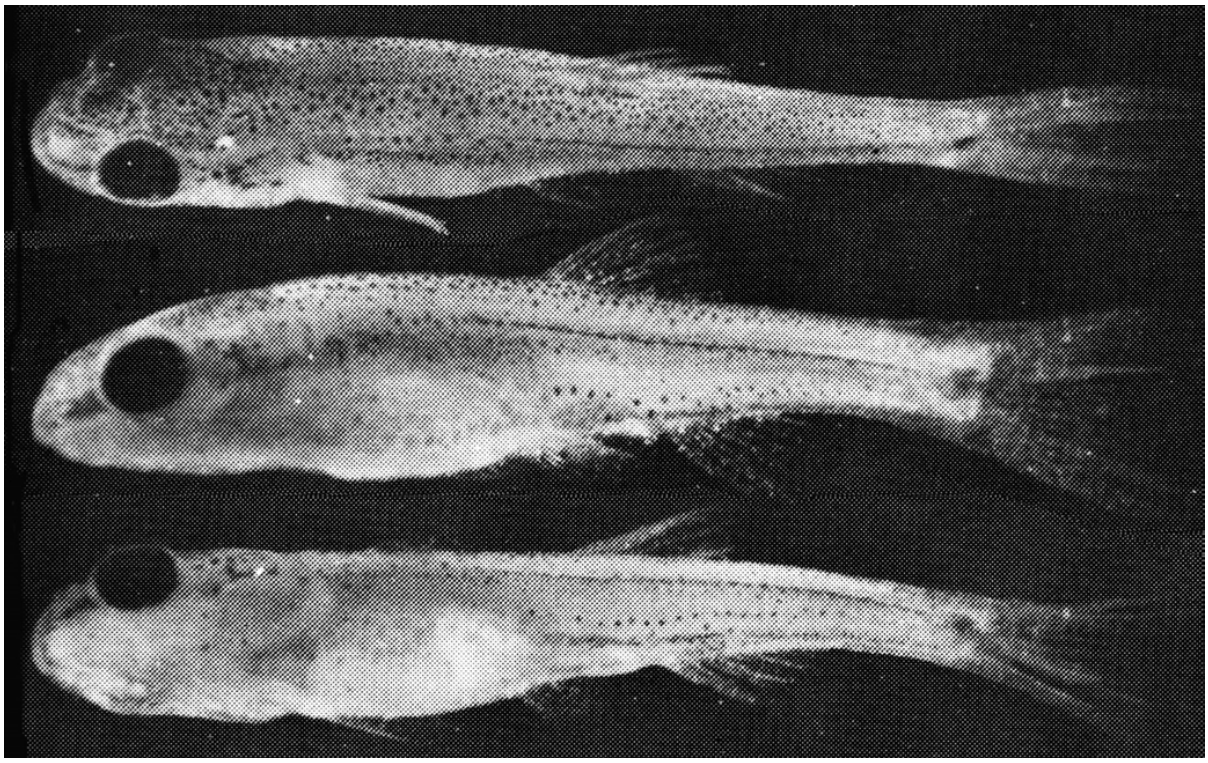

Figure 123. *Rhinichthys cataractae* metalarva, 13.1 mm SL, 15.9 mm TL. (Cultured in 1973 or 1975 at the Academy of Natural Sciences of Philadelphia with eggs collected from Lackawaxen River, Honesdale, Pennsylvania; from ANSP #131939. Modified from Fuiman and Loos 1977, Figure 3a-c, with author permission.)

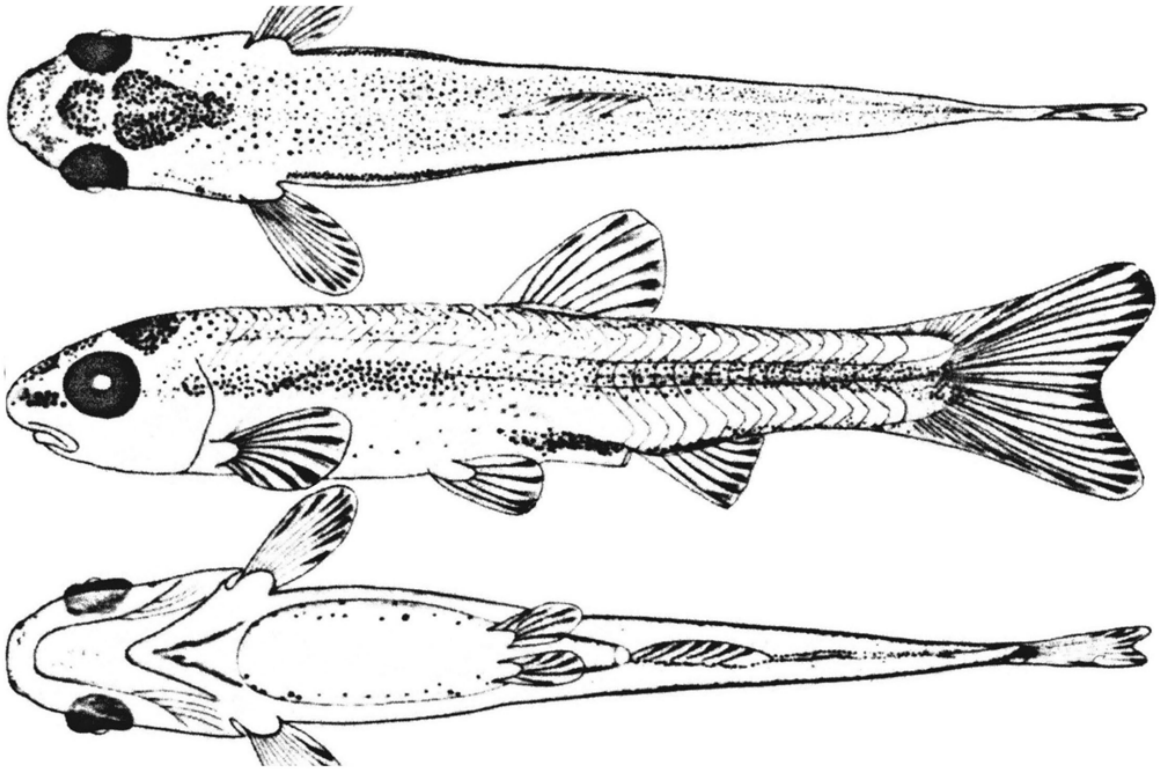

Figure 124. *Rhinichthys cataractae* juvenile, recently transformed, 14.7 mm SL, 17.8 mm TL. (Cultured in 1977by Ichthyological Associates, Inc., Berwick, PA, with stock collected from nearby Briar Creek. Modified from Buynak and Mohr 1979a, Figure 2h, with author permission; fin ray counts not accurate.)

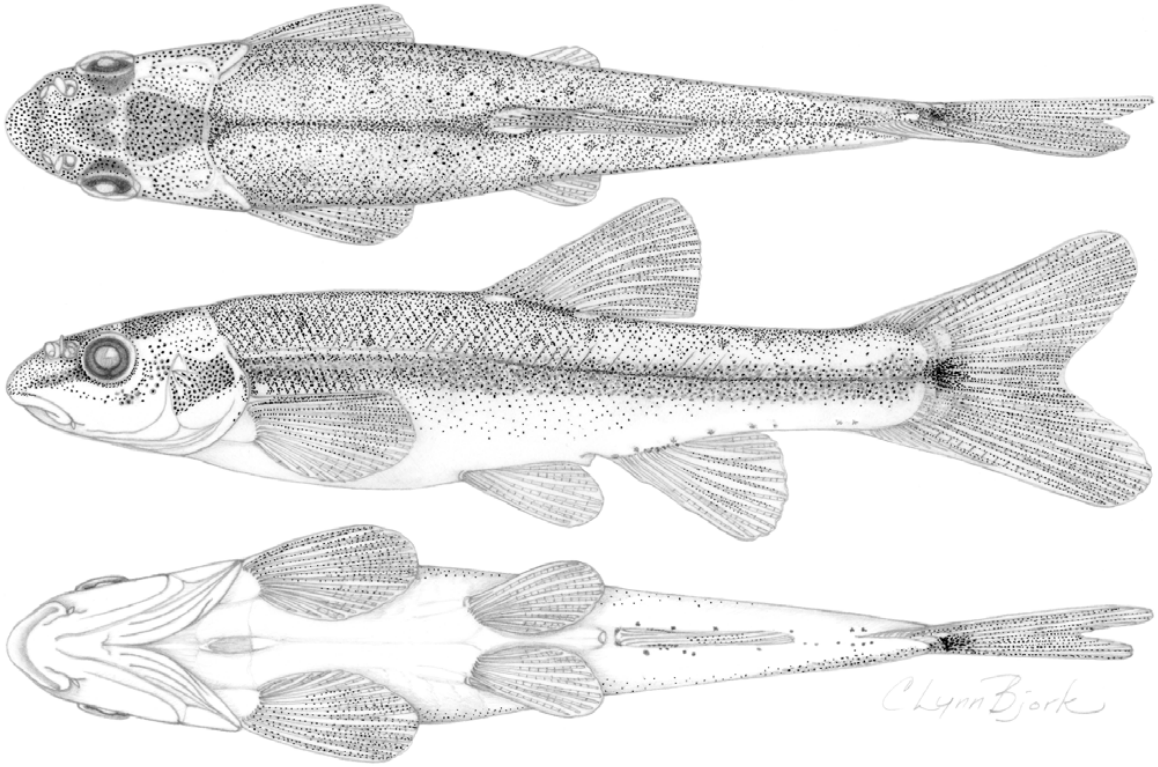

Figure 125. *Rhinichthys cataractae* juvenile, 29.6 mm SL, 36.5 mm TL. (Collected in 2001 by Colorado State University Larval Fish Laboratory from Conejos River, Conejos County, Colorado; from LFL #80239.)

Species Account – *Rhinichthys osculus*, speckled dace

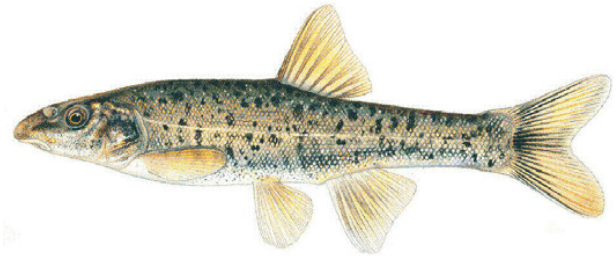

Figure 126. *Rhinichthys osculus* adult (© Joseph R. Tomelleri).

Adult description: Up to 10 cm TL. Heavy, spindle-shaped body, round in cross section. Larger, more streamlined specimens with falcate dorsal and pectoral fins occur in larger rivers. Head somewhat dorso-ventrally flattened; mouth small and sub-terminal with small barbel in each corner and usually lacking an upper-lip frenum. Scales moderately small. Color, mottling, and speckling pattern on body highly variable; young usually have a broad lateral band often extending onto operculum and snout and fading away with age. Breeding males red ventrally, particularly on lips and paired fin bases, and tuberculate over head, paired fins, and ventral surface to caudal fin; females less tuberculate. (Also, Table 50.)

Reproduction: Non-guarding open-substrate or nest-guarding lithophil. Spawn when water reaches day-time highs of 15–25°C (usually 18°) in early March to late August, sometimes in response to high flows or streambed disturbance. In pairs or large groups, spawn in shallow gravel-cobble riffles or runs, depositing adhesive eggs in interstices or under rocks, or the male constructs and defends a nest. Water-hardened eggs 1.6–2.2 mm in diameter.

Young: Hatch in 6 d at 18–19°C (4–5 d at higher temperatures) and remain in gravel for several days; then drift downstream as 6–9 mm TL larvae to nursery grounds. Larvae occupy near-shore, low-velocity, channel margins, backwaters, eddies, and pools; consume early instars of chironomids and other small invertebrates.

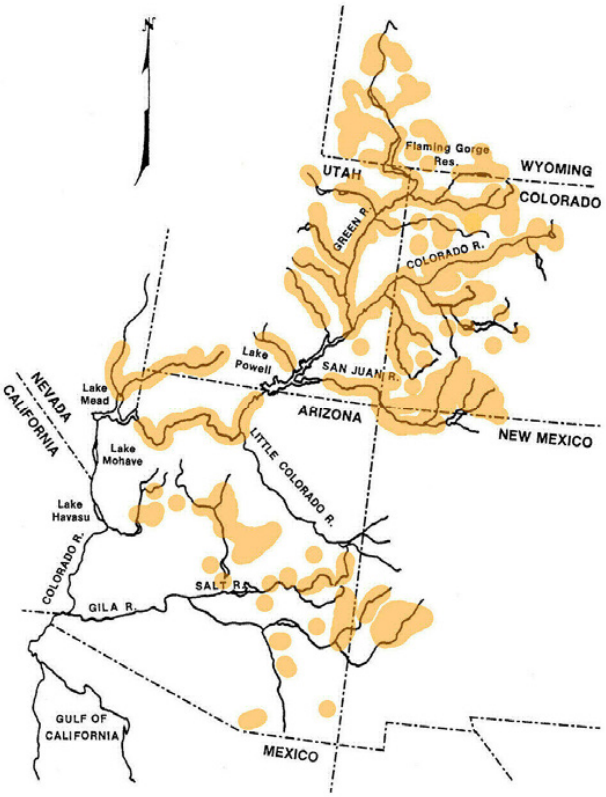

Figure 127. Recent distribution of *Rhinichthys osculus* in the Colorado River Basin.

Table 50. Selected juvenile and adult meristics for *Rhinichthys osculus*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	7-8	(6)7-8-9	Dorsal-fin rays - R	1-2-3	–
Anal-fin rays - P	(6)7-8	6-7-8	Anal-fin rays - R	1-2-3	–
Caudal-fin rays - P	(18)19	(18)19(20)	Caudal-fin rays - RD	7-9-10	–
Pectoral-fin rays	12-13-14-15	(10-)13-14(15)	Caudal-fin rays - RV	7-8-9-10	–
Pelvic-fin rays	(6)7-8-9	7-8-9	Lateral scales	65-71-81	(47-)55-80(->90)
Vertebrae	38-40	37-38	Pharyngeal teeth	–	(0)1-2,4/4,1-2(0)

* Includes re-examined data originally prepared for Snyder (1981) and Snyder et al. (2005) and supplements and updates those accounts.

Table 51. Size at onset of selected developmental events for *Rhinichthys osculus*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	5	5(6)	Dorsal - P	8(9)	8-9(10)	9-11	10-12(13)
Eyes pigmented	*(5)	*(5)	Anal - P	8(9)	9(10)	9-11	10-12(13)
Yolk assimilated	6-8(9)	(6)7-8(-10)	Caudal - P	(6)7	7(8)	8-9	9-10
Finfold absorbed	(14-)16(17)	(17-)19(20)	Caudal - R	9-10	10-11	14-15	(16)17-18(19)
Pectoral-fin buds	*	*	Pectoral	11	(12)13	(13)14-15(16)	(15)16-18(-20)
Pelvic-fin buds	9	10(11)	Pelvic	11-12	13-14	(12)13-14(-16)	(14)15-17(-20)
* before hatching			Scales	17(18)	(19)20-21	24-28	30-34(35)

References: AGFD 2002; Baxter & Simon 1970; Beckman 1952; Bestgen unpublished data; Bestgen et al. 1998; Childs 1998; Girard 1856; John 1963; Kaya 1991; La Rivers 1962; Minckley 1973; Minckley & Marsh 2009; Moore 1968; Moyle 1976; Mueller 1984; Muth & Snyder 1995; Page & Burr 1991; Scott & Crossman 1973; Sigler & Miller 1963; Simpson & Wallace 1978; Snyder 1981; Snyder et al, 2005; Sublette et al. 1990; Tyus et al. 1982; Woodling 1985.

Other larval descriptions: Feeney & Swift 2008 (Santa Ana subspecies); Snyder 1981; Snyder et al. 2005; Winn & Miller 1954.

Table 52. Size at developmental interval (left) and gut phase (right) transitions for *Rhinichthys osculus*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	(6)7	7(8)	2 - 90° bend	(10)11	(11)12(13)
Postflexion mesolarva	8-9	9-10	3 - Full loop	24-28	(29)30-34(35)
Metalarva	9-11	(10)11-12(13)	4 - Partial crossover	(not applicable)	
Juvenile	(15)16(17)	(18)19(20)	5 - Full	(not applicable)	

Table 53. Summary of morphometrics and myomere counts by developmental phase for *Rhinichthys osculus*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 and Snyder et al. 2005 and supplements and updates those accounts.)

	Protolarvae (N=7)			Flexion mesolarvae (N=18)			Postflexion mesolarvae (N=11)			Metalarvae (N=43)			Juveniles (N=56)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	6	1	5 - 7	8	1	6 - 9	9	1	8 - 10	12	2	9 - 16	25	8	15 - 42
TL, mm	7	1	5 - 8	8	1	7 - 10	10	1	9 - 12	15	2	11 - 20	30	10	18 - 50
Lengths %SL															
AS to AE	2	1	2 - 3	3	1[d]	3 - 4	5	1	3 - 6	5	1	4 - 6	6	1	4 - 9
PE	11	1[a]	10 - 12	11	1[d]	11 - 13	13	1	11 - 15	13	1[n]	12 - 15	13	1	10 - 15
OP1	18	2	16 - 21	22	1[d]	20 - 24	24	1	22 - 27	25	1[n]	23 - 28	25	1[v]	21 - 28
OP2							48	1[j]	48 - 49	50	2	48 - 54	50	2[w]	47 - 53
PY	66	3[a]	61 - 69	58	3[e]	56 - 61									
OPAF	42	14[a]	29 - 58	35	5[d]	30 - 44	38	7	30 - 48	49	7[n]	36 - 58			
ODF	45	4	41 - 49	47	3[f]	43 - 54	46	3[k]	43 - 49						
OD							53	2	51 - 56	55	2[n]	51 - 58	54	2[x]	50 - 57
ID							65	1[a]	64 - 66	67	1[o]	65 - 69	65	2[y]	62 - 69
PV	68	3	63 - 70	65	1[g]	63 - 67	68	2[i]	65 - 70	66	1	63 - 69	63	2[z]	59 - 65
OA							66	2[j]	65 - 67	65	1[j]	64 - 65	63	0[k]	63 - 64
IA										74	1[p]	72 - 77	73	2[y]	70 - 77
AFC							109	2[e]	106 - 111	112	2[q]	106 - 114	112	1[aa]	109 - 115
PC	105	1	103 - 107	106	1[h]	105 - 108	114	4	109 - 122	119	2	114 - 124	121	2	117 - 125
Y	43	22[a]	0 - 57	7	13	0 - 35									
P1	8	3	4 - 12	12	1[d]	11 - 13	13	1	11 - 15	14	2	11 - 18	17	2	13 - 23
P2							0	1	0 - 3	7	3[q]	2 - 13	13	1[ab]	10 - 16
D							–	[l]	15	18	2[q]	13 - 22	21	1[ab]	16 - 24
A										15	2[q]	10 - 20	19	2[ab]	15 - 22
Depths %SL															
at BPE	14	2	11 - 18	13	1[b]	12 - 14	15	1[a]	13 - 15	17	1[r]	15 - 18	16	1[ac]	13 - 18
OP1	18	5[a]	12 - 23	14	1[d]	12 - 15	17	2	15 - 21	20	1	17 - 23	21	1	18 - 24
OD	13	2[a]	10 - 16	11	1[i]	10 - 13	13	1[m]	12 - 14	17	2[q]	13 - 21	20	1[ab]	18 - 23
BPV	8	1	7 - 10	9	1[d]	8 - 11	10	1	9 - 12	13	2	10 - 16	16	1	13 - 19
AMPM	4	1	3 - 5	5	1[d]	4 - 6	6	1	5 - 7	8	1	6 - 10	10	1	9 - 12
Max. yolk	12	8[a]	0 - 19	1	1	0 - 5									
Widths %SL															
at BPE	13	1	11 - 14	14	1[b]	13 - 15	15	1[a]	14 - 16	17	1[r]	15 - 19	15	2[ac]	12 - 18
OP1	13	4	8 - 18	9	1[f]	8 - 11	12	2[i]	10 - 16	14	2	12 - 18	16	2	13 - 21
OD	7	1[a]	5 - 8	6	1[i]	6 - 8	7	1[m]	6 - 9	10	1[q]	7 - 13	14	2[aa]	11 - 18
BPV	5	1	3 - 6	6	1[d]	4 - 8	6	1	5 - 8	9	1	6 - 11	11	1[v]	9 - 15
AMPM	3	1	2 - 3	3	1[d]	1 - 5	3	1	2 - 6	4	1	2 - 5	6	1	3 - 7
Max. yolk	14	9[a]	0 - 22	1	2	0 - 7									
Myomeres															
to PY	24	1[b]	22 - 26	21	2[e]	20 - 23									
OPAF	13	5[a]	8 - 19	7	1[d]	6 - 10	8	1[m]	5 - 9	15	4[s]	8 - 20			
OP2							17	0[j]	17 - 17	16	1[t]	14 - 17	16	1[ad]	14 - 17
ODF	14	1[c]	13 - 15	15	1[d]	13 - 16	14	1[k]	14 - 15						
OD							18	1[a]	17 - 19	19	1[t]	18 - 20	18	1[ae]	17 - 20
PV	26	1[c]	25 - 27	25	1[d]	23 - 26	26	1[m]	24 - 27	24	1[p]	23 - 27	24	1[ad]	22 - 25
Total	38	2[c]	35 - 40	38	1[h]	37 - 39	38	1	37 - 40	38	1[u]	36 - 40	38	1[y]	36 - 40
After PV	12	2[c]	10 - 14	13	1[d]	11 - 14	13	1[m]	12 - 14	14	1[p]	11 - 16	15	1[ac]	12 - 17

[a]N = 6. [b]N = 8. [c]N = 9. [d]N = 13. [e]N = 4. [f]N = 12. [g]N = 15. [h]N = 16. [I]N = 10. [j]N = 2. [k]N = 3. [l]N = 1. [m]N = 7. [n]N = 42. [o]N = 31. [p]N = 30. [q]N = 32. [r]N = 28. [s]N = 24. [t]N = 29. [u]N = 41. [v]N = 55. [w]N = 54. [x]N = 52. [y]N = 47. [z]N = 53. [aa]N = 49. [ab]N = 50. [ac]N = 46. [ad]N = 45. [ae]N = 44.

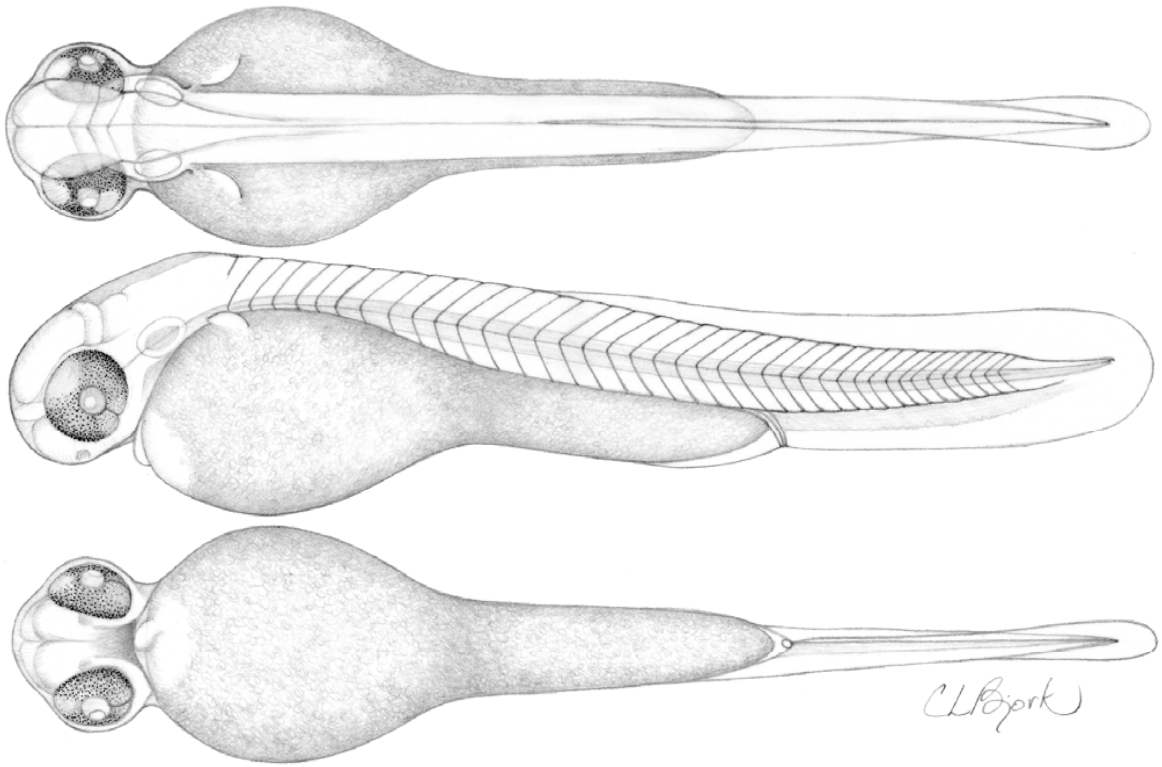

Figure 128. *Rhinichthys osculus* protolarva, recently hatched, 5.2 mm SL, 5.4 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University with embryos from stock in McKinney Creek, Carbon County, Wyoming.)

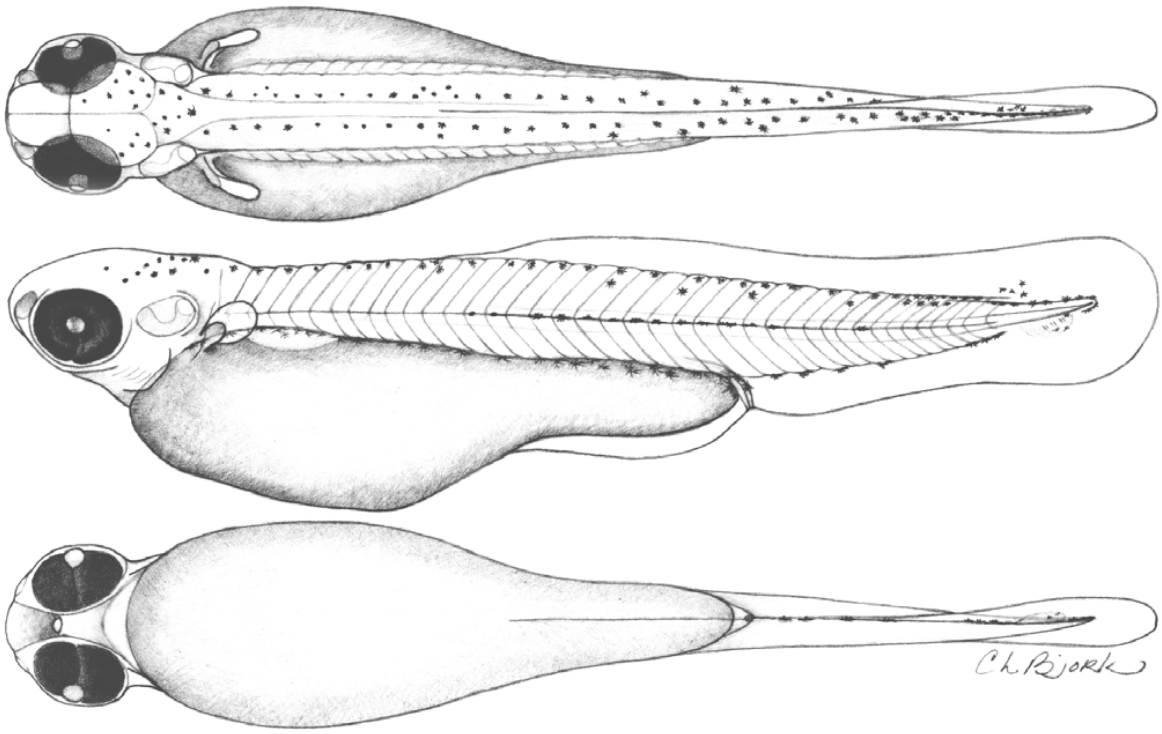

Figure 129. *Rhinichthys osculus* protolarva, 6.6 mm SL, 7.0 mm TL. (Collected in 1994 from the Gunnison River near Grand Junction, Mesa County, Colorado; from LFL #23403. From Snyder et al. 2005, Figure 89.)

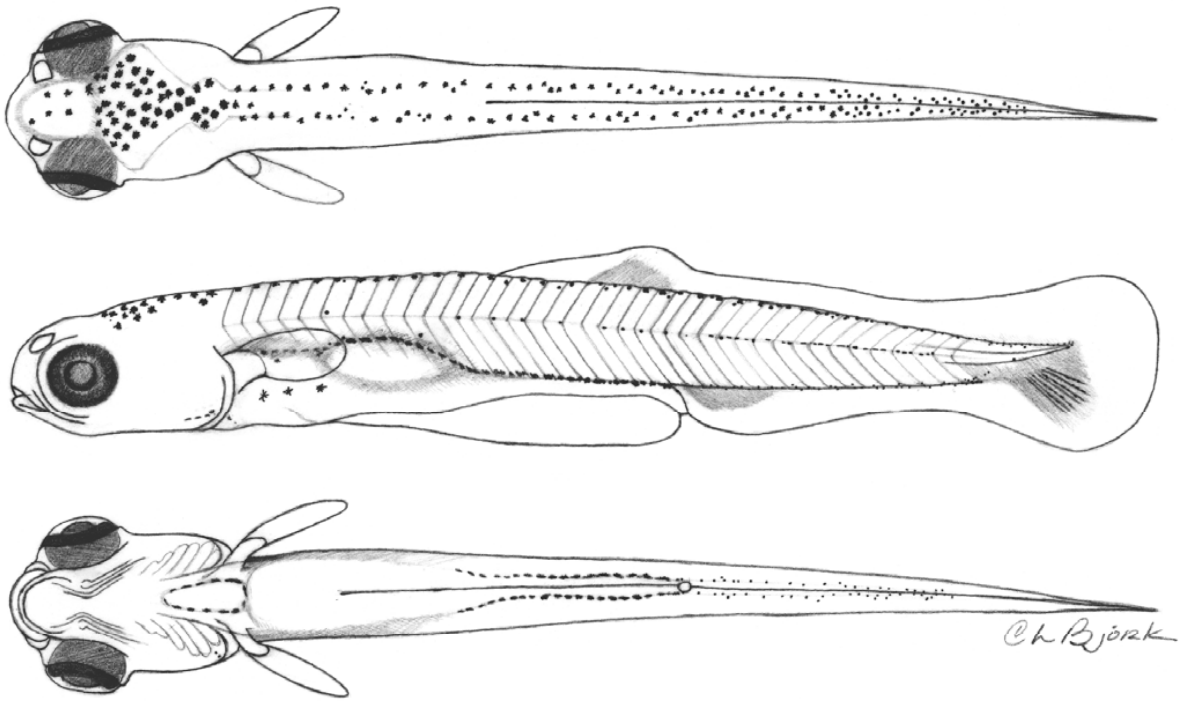

Figure 130. *Rhinichthys osculus* flexion mesolarva, 6.5 mm SL, 7.0 mm TL. (Collected in late 1970's from Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 52.)

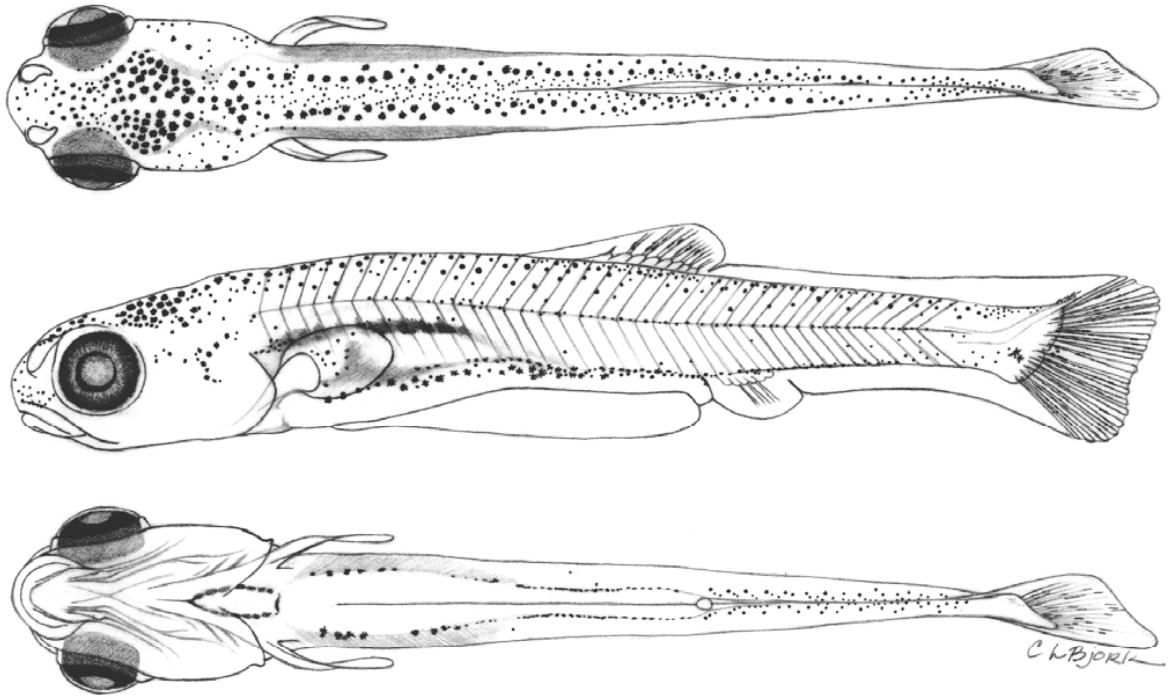

Figure 131. *Rhinichthys osculus* postflexion mesolarva, 9.0 mm SL, 9.8 mm TL. (Collected in late 1970's from the Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 52.)

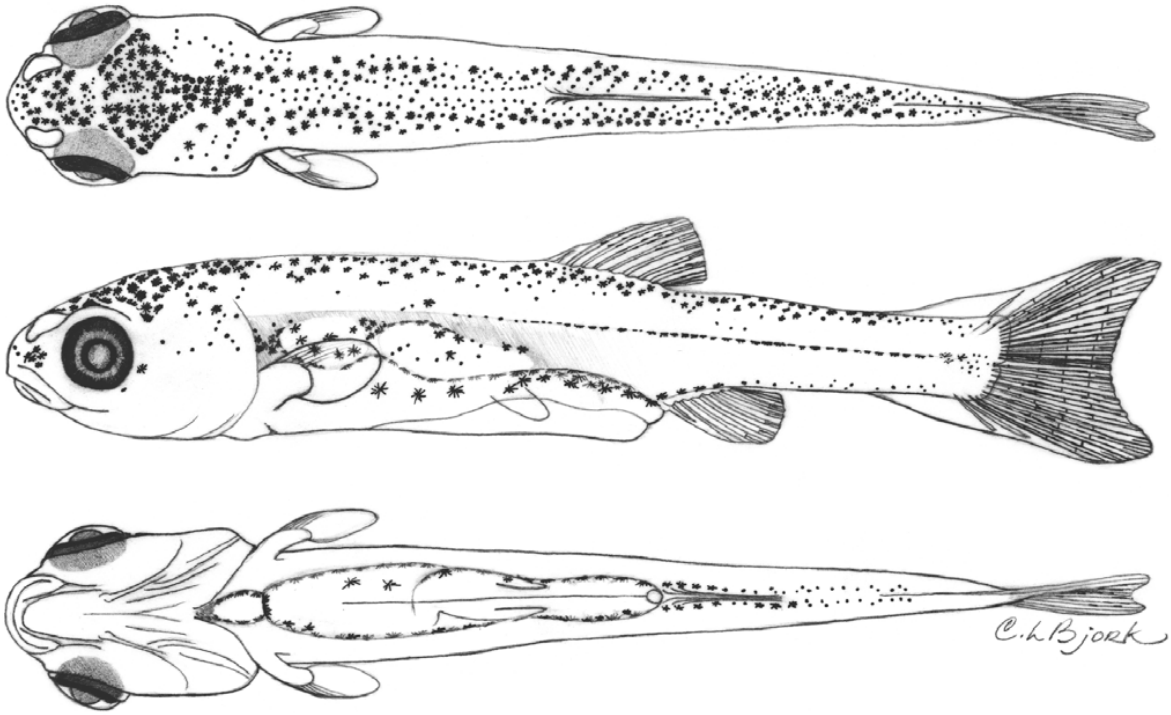

Figure 132. *Rhinichthys osculus* metalarva, recently transformed, 10.8 mm SL, 12.4 mm TL. (Collected in late 1970's from Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 53.)

Figure 133. *Rhinichthys osculus* metalarva, 13.9 mm SL, 16.4 mm TL. (Collected in late 1970's from Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 53.)

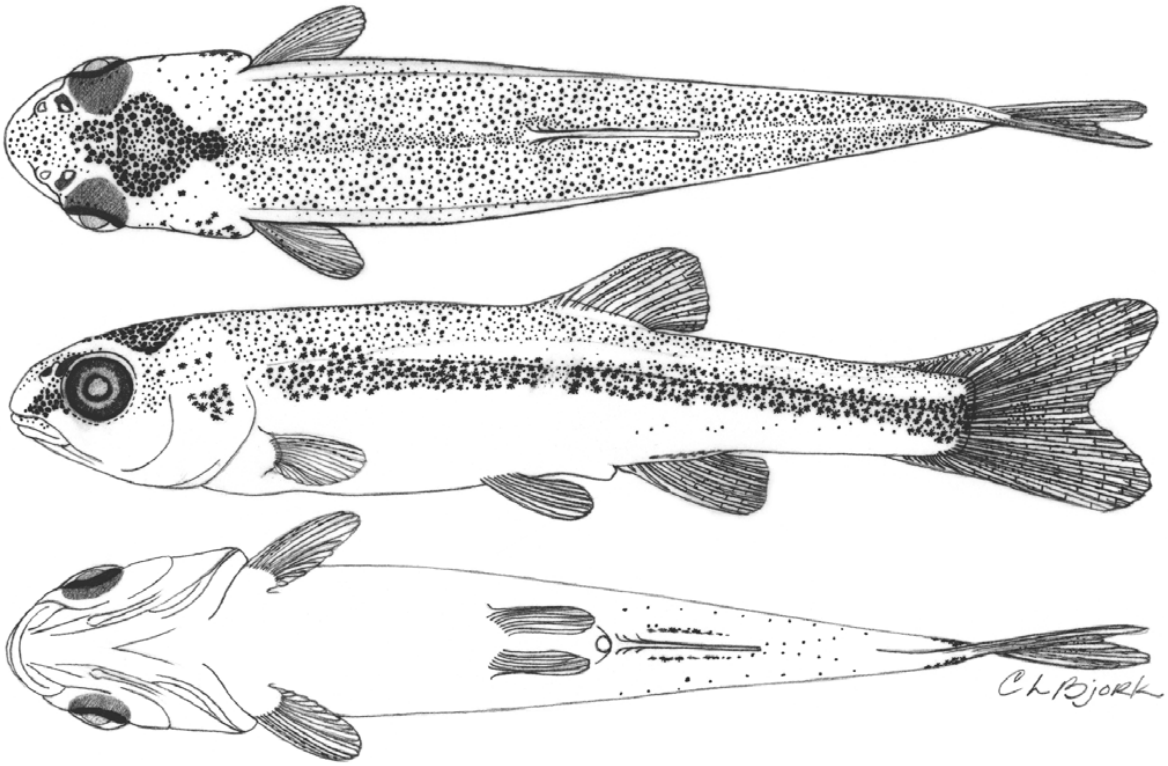

Figure 134. *Rhinichthys osculus* juvenile, recently transformed, 17.7 mm SL, 21.0 mm TL. (Collected in late 1970's from Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 53.)

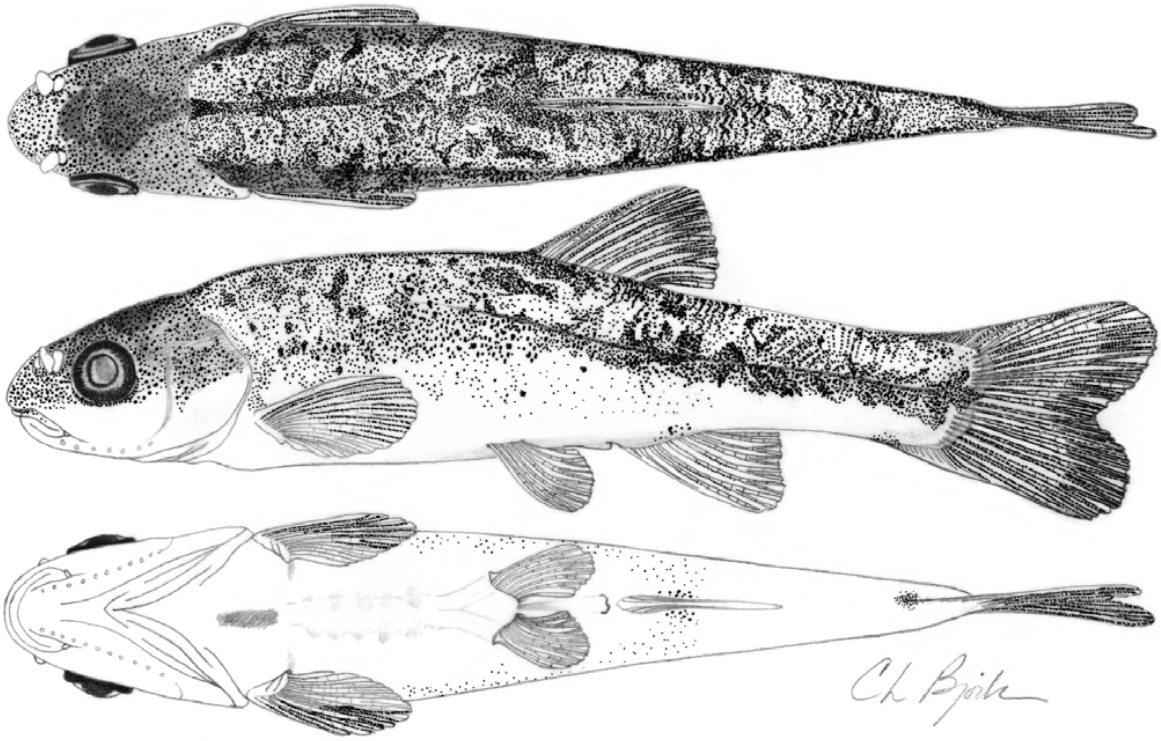

Figure 135. *Rhinichthys osculus* juvenile, 32.2 mm SL, 38.0 mm TL. (Collected in late 1970's from Yampa River, Moffat or Routt County, Colorado. From Snyder 1981, page 53.)

Species Account – *Richardsonius balteatus*, redside shiner

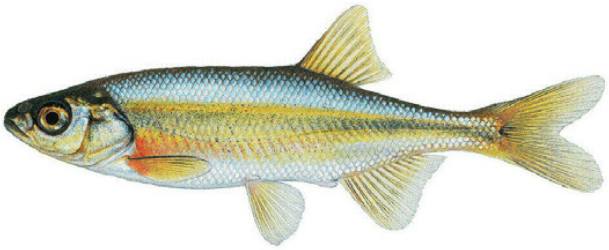

Figure 136. *Richardsonius balteatus* adult (© Joseph R. Tomelleri).

Adult description: Usually <7–12 cm, but up to 18 cm TL. Body moderately deep and laterally compressed with relatively narrow caudal peduncle. Eyes large, about equal to length of bluntly pointed snout. Mouth terminal, moderately large and oblique, ending near anterior margin of large eyes. Origin of dorsal fin well behind pelvic fin origin. Anal large and falcate; caudal fin deeply forked. S-shaped gut with silvery, lightly speckled peritoneum. Blue or olivaceous to black dorsally and white ventrally with a dark, anteriorly broad, lateral band bordered anteriorly above by a thin light or golden stripe. Breeding fish have a distinct red to pink or golden band anteriorly below the lateral band and an intense red patch at and above the base of the pectoral fins. (Also, Table 54.)

Reproduction: Non-guarding, open-substrate phytolithophil. Mature at age 2 or 3. Broadcast spawn in small groups, usually in late spring to mid summer at >10°C, in shallows of streams or lakes, over rocky riffles, fine gravel, upwellings, or inshore vegetation. Eggs are spawned in small batches per act, demersal, adhesive, and 1.7–2.0 (orig.) or 1.9–2.2 mm in diameter.

Young: Hatch in 11–15 d at 15–12°C, respectively, 5-10 d at 18–17°C, 4–5 d at 20°C (orig.), or 3–7 d at 23–21°C. Larvae are initially photophobic, demersal, and reclusive, but after several days begin feeding, swim actively, and become subject to downstream drift.

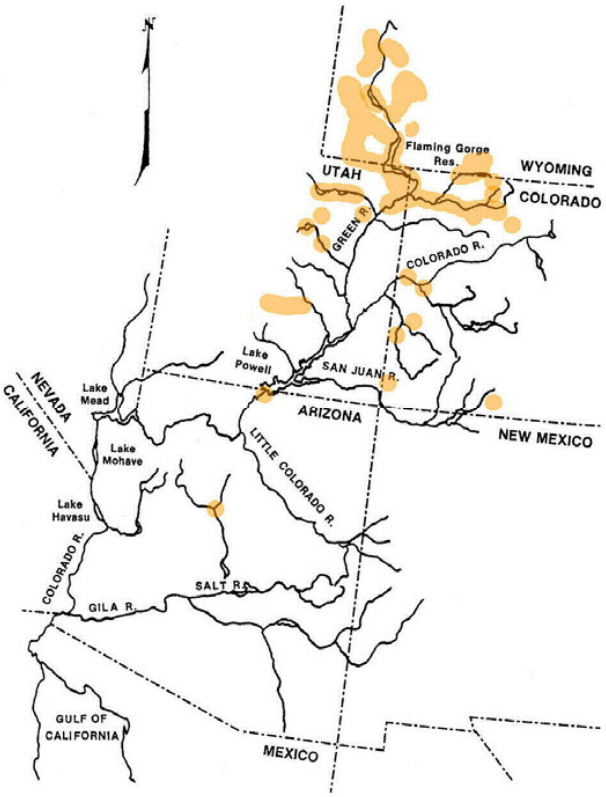

Figure 137. Recent distribution of *Richardsonius balteatus* in the Colorado River Basin.

Table 54. Selected juvenile and adult meristics for *Richardsonius balteatus*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed*	Literature	Character	Observed*	Literature
Dorsal-fin rays - P	8-9(10)	8-9-10(11)**	Dorsal-fin rays - R	1-2-3	–
Anal-fin rays - P	(9)10-11-12(13)	(9)10-12-13(-16)**	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	(18)19(-21)	–	Caudal-fin rays - RD	8-9-10(11)	7
Pectoral-fin rays	11-12-15(16)	13-16(17)	Caudal-fin rays - RV	(7)8-9	7
Pelvic-fin rays	(7)8-9	8-9	Lateral scales	50-58-64	49-55-63-67
Vertebrae	39-40	38-43	Pharyngeal teeth	–	2,5/4(5),2

*Includes re-examined data originally prepared for Snyder (1981) and supplements and updates that account. ** Subspecies *R. b. hydrophlox*, described herein; *R. b. balteatus* reported to have up to 12 dorsal- and 24 anal-fin rays with typical counts of 10 and 15 or 16 respectively.

Table 55. Size at apparent onset of selected developmental events for *Richardsonius balteatus*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	4-5	4-5	Dorsal - P	8(9)	9	(8)9-10	10-11
Eyes pigmented	*-4	*-4	Anal - P	8(9)	9	(8)9-10	10-11
Yolk assimilated	(6)7	(6)7(8)	Caudal - P	(6)7(8)	(6)7-8	8-9	9-10
Finfold absorbed	19-20	(23)24-25	Caudal - R	8-9	9-10	(15)16(-18)	19-20(-22)
Pectoral-fin buds	*-4-5	*-(4)5	Pectoral	(9)10(11)	(10)11-12	(11)12-13	(12-)14-16
Pelvic-fin buds	9-10	11	Pelvic	(11)12	(13)14	14(15)	17-18
* before hatching			Scales	(18)19	23	20-22	25-27

References: Balon 1975a; Baxter and Simon 1970; Baxter and Stone 1995; Breder and Rosen 1966; Carlander 1969; Jordan and Evermann 1896; La Rivers 1962; Lentsch et al. 1996; Minckley 1973; Moore 1968; Page and Burr 1991; Scott and Crossman 1973; Sigler and Miller 1963; Sigler and Sigler 1996; Simpson and Wallace 1978; Snyder 1981; Tyus et al. 1982; Woodling 1985; Wydosky and Whitney 1979.

Other larval descriptions: Lindsey and Northcote 1963; Snyder 1981; Weisel and Newman 1951.

Table 56. Size at developmental interval (left) and gut phase (right) transitions for *Richardsonius balteatus*. (See Figure 5 for phases of gut folding. Rare values in parentheses. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	(6)7(8)	(6)7-8	2 - 90° bend	(11)12	(13)14
Postflexion mesolarva	8-9	9-10	3 - Full loop	18-20(-22)	22-25(-27)
Metalarva	(9)10	11	4 - Partial crossover	(not applicable)	
Juvenile	19-20	(23)24-25	5 - Full	(not applicable)	

Table 57. Summary of morphometrics and myomere counts by developmental phase for *Richardsonius balteatus*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes re-examined data originally prepared for Snyder 1981 and supplements and updates that account.)

	Protolarvae (N=20)			Flexion mesolarvae (N=19)			Postflexion mesolarvae (N=15)			Metalarvae (N=57)			Juveniles (N=57)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	6	1	4 - 8	8	1	6 - 9	9	1	8 - 10	14	3	9 - 20	28	6	19 - 41
TL, mm	6	1	4 - 8	8	1	6 - 10	10	1	9 - 11	17	4	11 - 25	34	7	23 - 50
Lengths %SL															
AS to AE	3	0	2 - 4	3	1	2 - 4	4	1	3 - 5	5	1	3 - 7	6	1	5 - 7
PE	10	1	9 - 11	10	1	9 - 12	11	1	11 - 13	14	1[k]	11 - 16	13	1	12 - 16
OP1	18	1[a]	16 - 19	20	1	19 - 23	23	2	21 - 26	25	1	22 - 28	23	1	21 - 26
OP2							44	0[c]	44 - 44	49	2	44 - 52	48	1	45 - 51
PY	63	4[b]	53 - 70												
OPAF	42	11	26 - 65	28	3	25 - 35	31	4	26 - 38	46	9[l]	32 - 62			
ODF	46	2	42 - 52	47	4	42 - 57	49	3[d]	45 - 53						
OD							54	2[e]	52 - 58	55	2	52 - 58	54	1	53 - 56
ID							67	1[f]	66 - 69	66	2	62 - 70	66	1	63 - 68
PV	66	3	62 - 72	65	2	62 - 69	66	1	65 - 69	65	1	62 - 68	63	1	61 - 66
OA							66	2[g]	63 - 69	65	2[m]	61 - 67	64	2[p]	61 - 67
IA							78	2[f]	76 - 80	79	1[n]	75 - 81	78	1	75 - 81
AFC							111	2	107 - 114	113	2	109 - 117	112	1	109 - 117
PC	105	1	103 - 107	107	2	104 - 112	112	3	108 - 119	121	3	114 - 125	123	2	119 - 127
Y	45	14	0 - 62												
P1	6	4	0 - 12	12	1	10 - 13	13	1	11 - 14	14	2[l]	11 - 19	17	2	13 - 20
P2							0	1	0 - 4	9	3	2 - 14	13	1	10 - 15
D							14	1[h]	12 - 15	18	2	13 - 21	20	1	18 - 21
A							13	1[f]	13 - 15	17	3	12 - 21	20	1	18 - 22
Depths %SL															
at BPE	13	2	11 - 18	13	1	11 - 15	15	1	13 - 17	17	1	14 - 18	17	1	15 - 18
OP1	17	5	12 - 26	13	1	11 - 15	16	1	14 - 17	19	1	16 - 22	21	1	19 - 23
OD	13	2	9 - 16	10	1	9 - 13	12	1	11 - 14	17	2	12 - 21	20	1	16 - 23
BPV	7	1	5 - 9	8	1	7 - 9	9	1	8 - 11	14	2	9 - 18	17	1	15 - 21
AMPM	4	1	3 - 5	5	1	3 - 6	6	0	5 - 7	8	1	6 - 9	9	1	7 - 10
Max. yolk	12	7	0 - 26												
Widths %SL															
at BPE	12	1	11 - 13	12	1	10 - 13	13	1	12 - 15	14	1	13 - 16	14	1	13 - 15
OP1	13	6	9 - 26	9	2	6 - 11	11	1	9 - 13	13	1	10 - 15	14	1	12 - 16
OD	8	2	5 - 10	5	1	4 - 6	7	1	6 - 7	10	2	6 - 13	12	1	10 - 15
BPV	5	0	5 - 6	4	0	4 - 5	5	0	5 - 6	8	1	5 - 10	10	1	8 - 13
AMPM	3	0	2 - 4	2	1	1 - 4	3	0	2 - 4	4	1	3 - 6	5	1	4 - 6
Max. yolk	14	7	0 - 28												
Myomeres															
to PY	24	1[b]	21 - 25												
OPAF	12	3	8 - 20	6	2	3 - 10	7	1[e]	6 - 8	12	5[o]	6 - 21			
OP2							16	1[c]	15 - 16	15	1[l]	13 - 17	15	1[o]	13 - 16
ODF	15	1	12 - 17	16	1	14 - 19	16	1[i]	15 - 19						
OD							19	1[j]	17 - 20	18	1[l]	17 - 20	19	1[o]	17 - 21
PV	25	1	24 - 26	25	1	24 - 27	26	1[e]	24 - 27	24	1[l]	23 - 27	24	1[o]	23 - 26
Total	39	1[b]	38 - 40	39	1	37 - 41	39	1[e]	37 - 40	38	1[l]	36 - 41	37	1[o]	36 - 40
After PV	13	1[b]	12 - 15	14	1	13 - 16	13	0[e]	13 - 14	14	1[l]	12 - 15	13	1[o]	12 - 15

[a]N = 18. [b]N = 19. [c]N = 2. [d]N = 11. [e]N = 13. [f]N = 3. [g]N = 9. [h]N = 4. [I]N = 10. [j]N = 12. [k]N = 56. [l]N = 55. [m]N = 23. [n]N = 53. [o]N = 38. [p]N = 16.

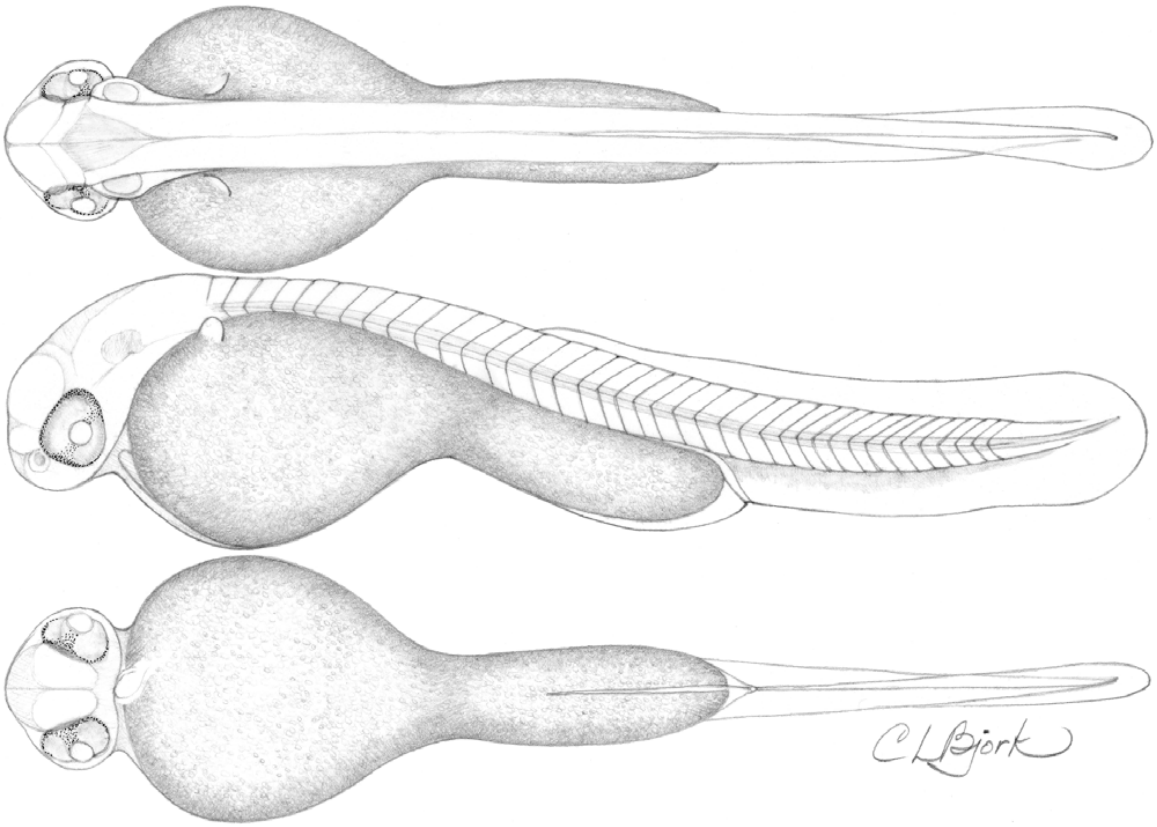

Figure 138. *Richardsonius balteatus* protolarva, recently hatched, 4.7 mm SL, 4.8 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University, with stock from Scofield Reservoir, Carbon County, Utah.)

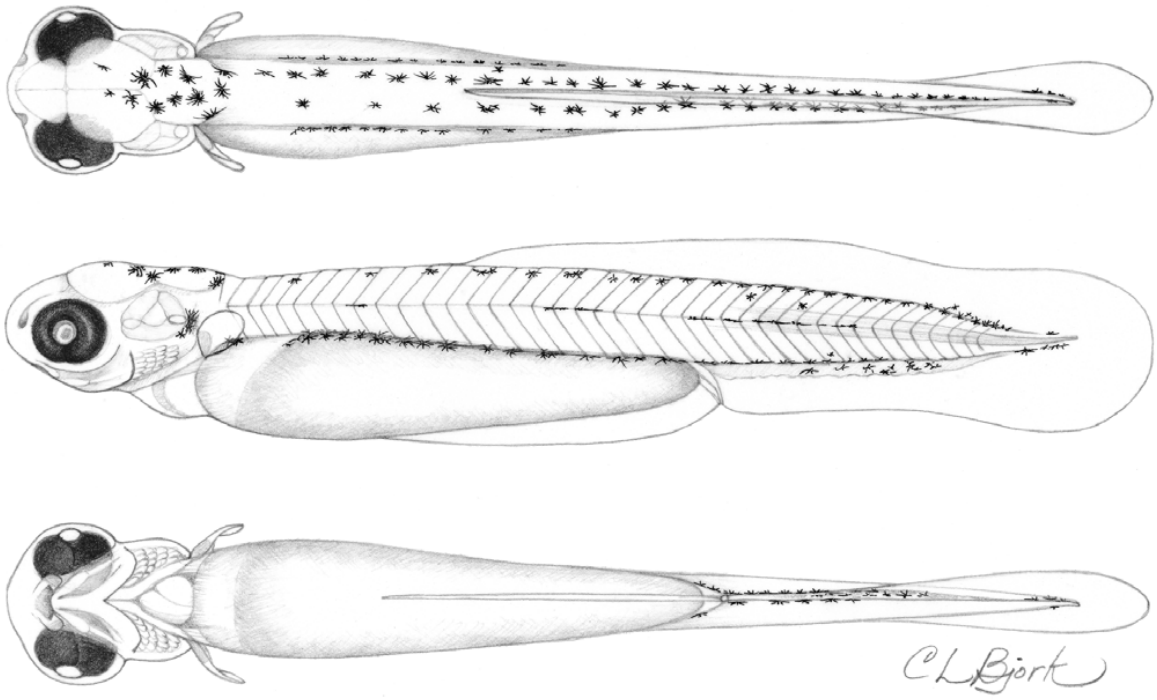

Figure 139. *Richardsonius balteatus* protolarva, 3-4 d posthatch, 5.7 mm SL, 6.1 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University, with stock from Scofield Reservoir, Carbon County, Utah.)

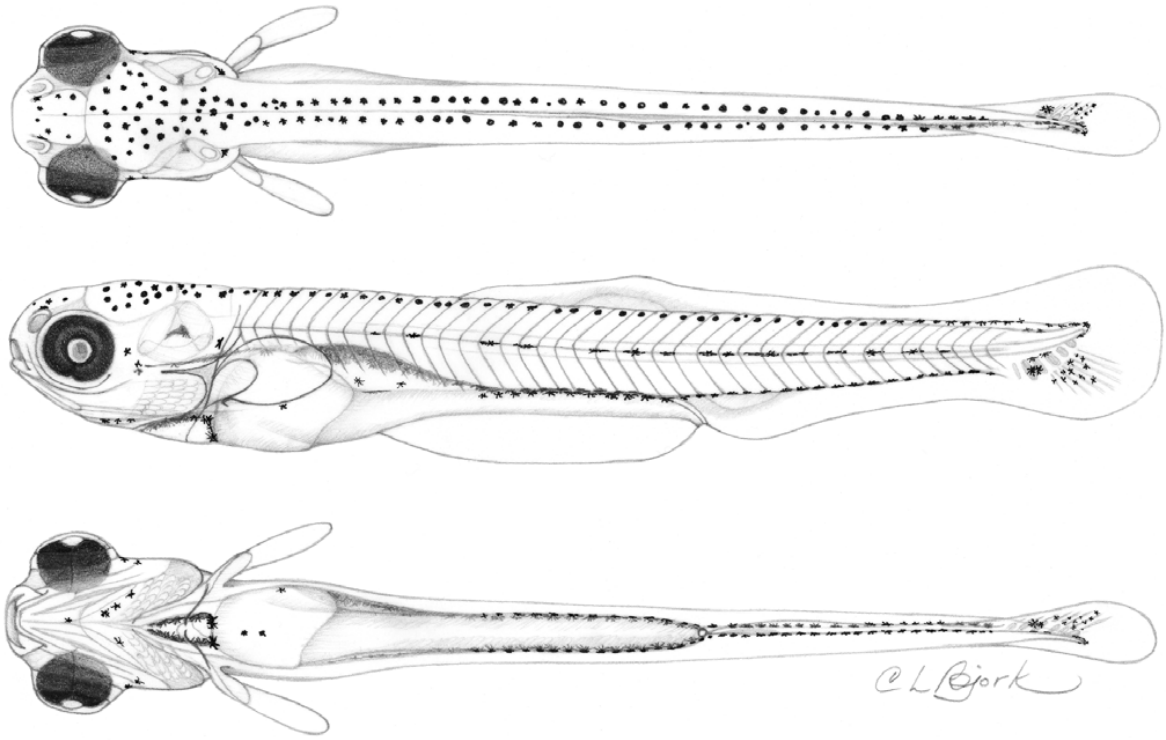

Figure 140. *Richardsonius balteatus* flexion mesolarva, recently transformed, 15-16 d posthatch, 7.8 mm SL, 8.3 mm TL. (Cultured in 2007 by Larval Fish Laboratory at Colorado State University, with stock from Scofield Reservoir, Carbon County, Utah.)

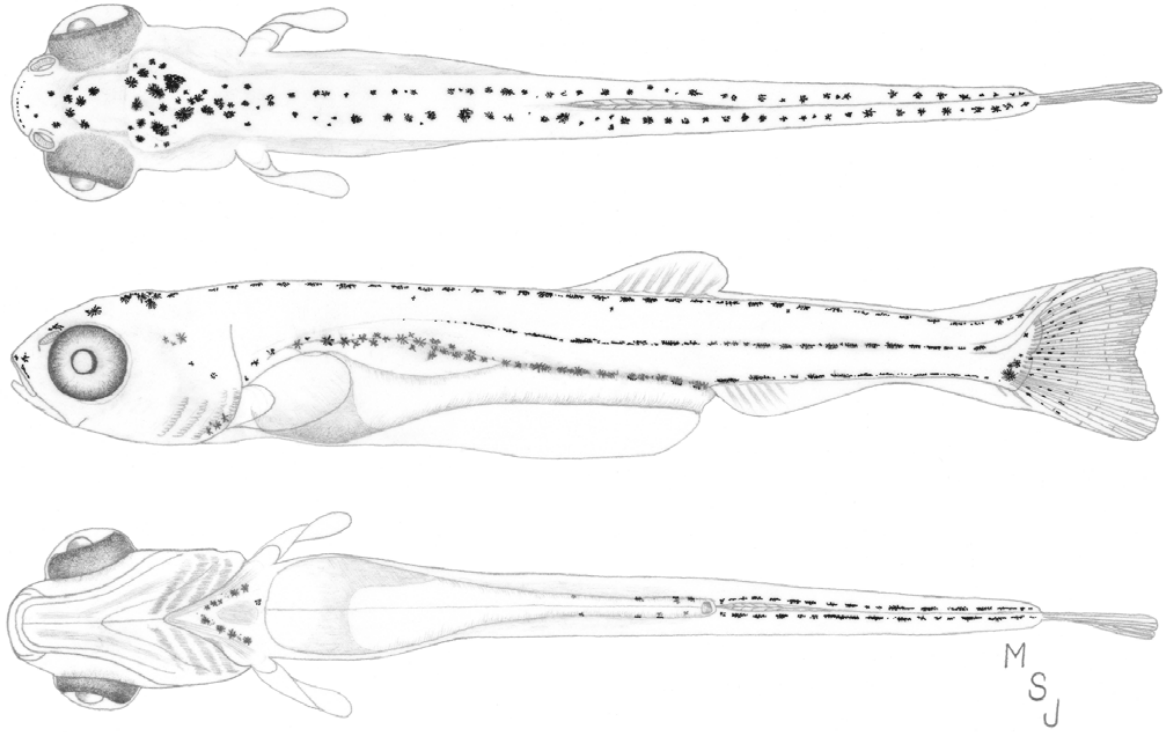

Figure 141. *Richardsonius balteatus* postflexion mesolarva, 8.2 mm SL, 9.1 mm TL (well-separated lower lip lobes not illustrated in ventral view). (Collected in late 1970s from Yampa River, Colorado. From Snyder 1981, page 56.)

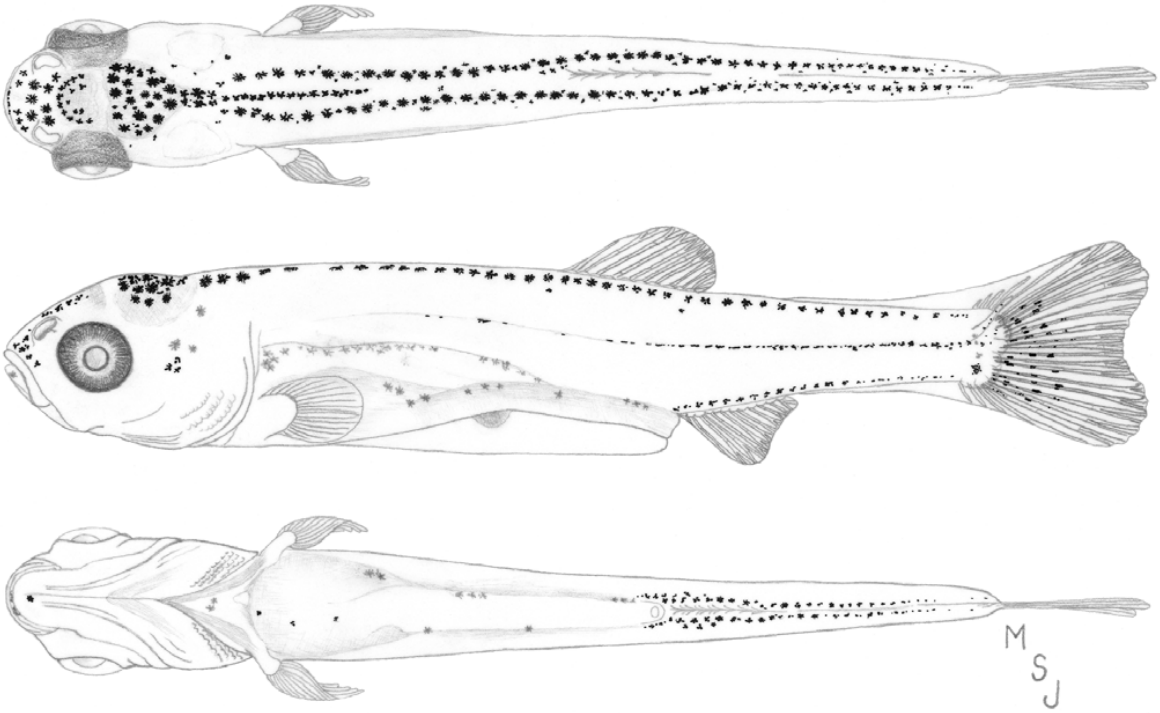

Figure 142. *Richardsonius balteatus* metalarva, recently transformed, 10.6 mm SL, 12.0 mm TL (well-separated lower lip lobes, preanal finfold, and pelvic fin buds not illustrated in ventral view). (Collected in late 1970s from Yampa River, Colorado. From Snyder 1981, page 57.)

Figure 143. *Richardsonius balteatus* metalarva, 15.0 mm SL, 17.6 mm TL (well-separated lower lip lobes not illustrated in ventral view). (Collected in late 1970s from Yampa River, Colorado. From Snyder 1981, page 57.)

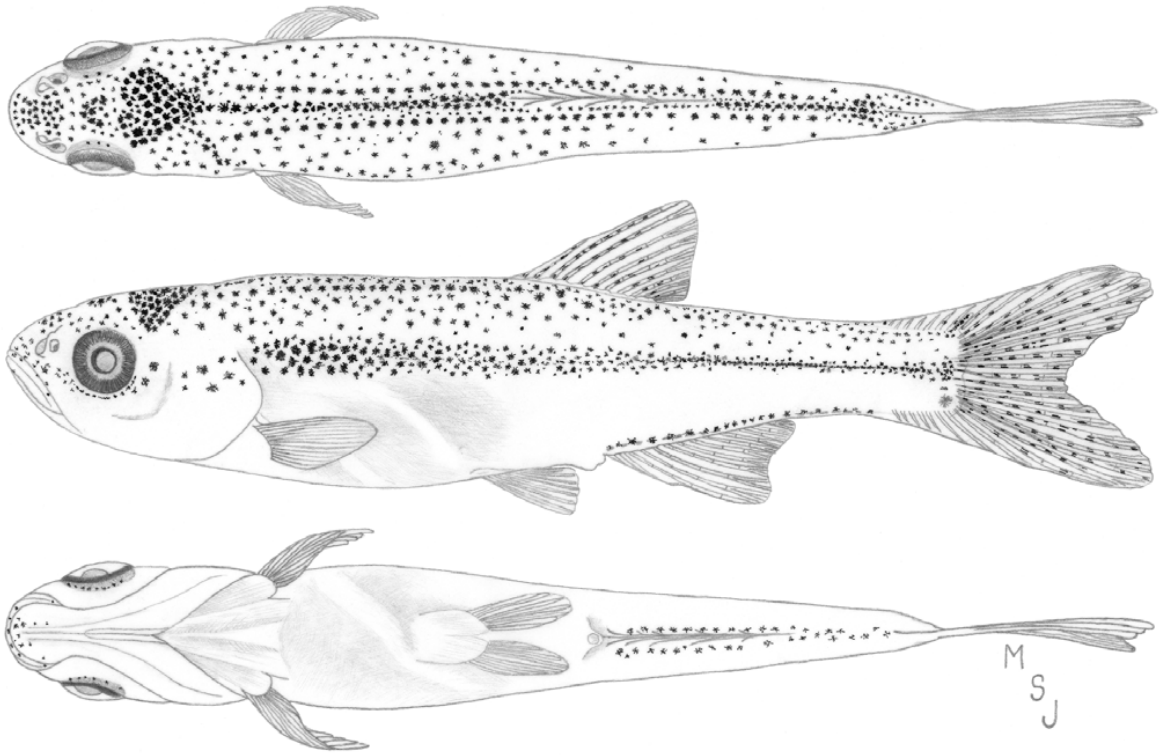

Figure 144. *Richardsonius balteatus* juvenile, recently transformed, 20.2 mm SL, 24.0 mm TL (well-separated lower lip lobes not illustrated in ventral view). (Collected in late 1970s from Yampa River, Colorado. From Snyder 1981, page 57.)

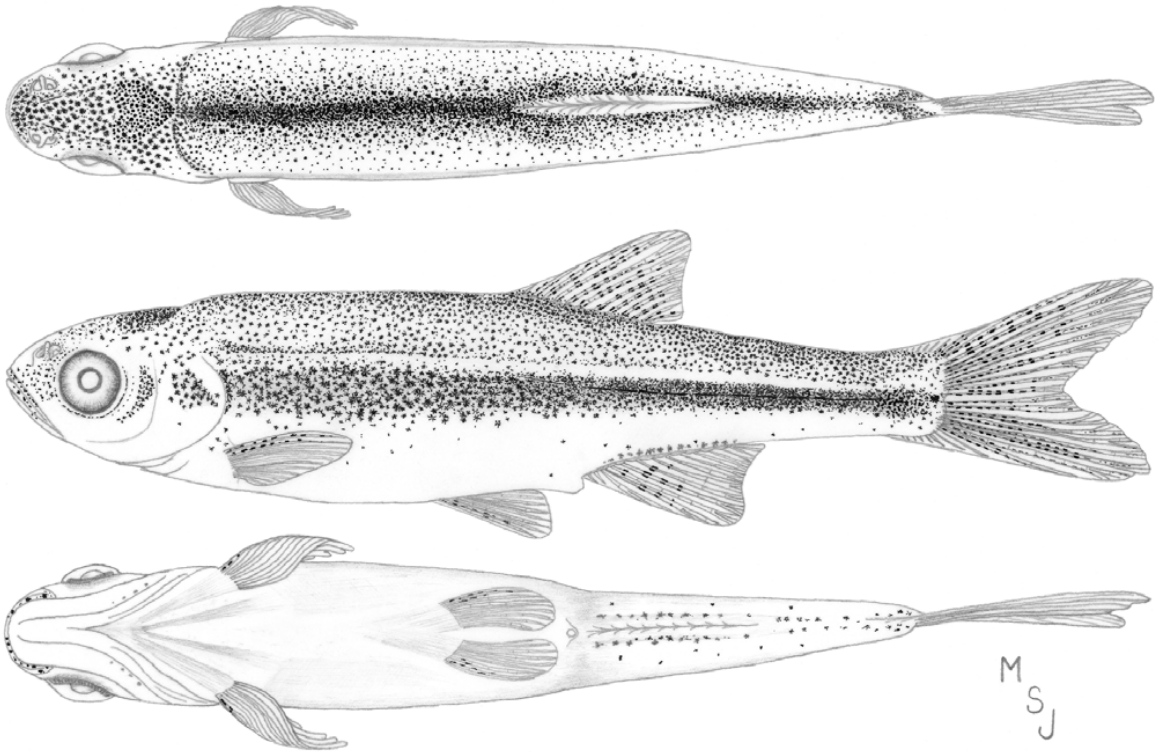

Figure 145. *Richardsonius balteatus* juvenile, 32.6 mm SL, 39.5 mm TL (well-separated lower lip lobes not illustrated in ventral view). (Collected in late 1970s from Yampa River, Colorado. From Snyder 1981, page 57.)

Species Account – *Semotilus atromaculatus*, creek chub

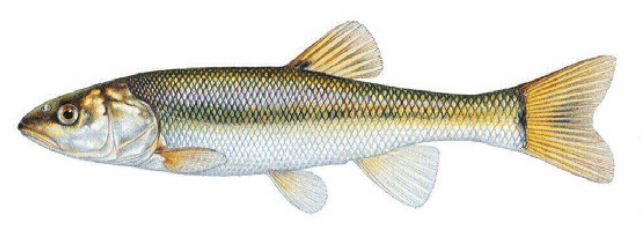

Figure 146. *Semotilus atromaculatus* adult (© Joseph R. Tomelleri).

Adult description: Body elongate, robust, moderately large, usually 8–20 cm TL, rarely to 26 or 33 cm in males. Relatively large head, small eyes. Large terminal, slightly oblique mouth extending beyond front of eyes. Usually have a small, flap-like barbel in groove above upper lip before corner of mouth. Dorsal fin has distinctive black spot at anterior base and origin slightly behind pelvic origin. Dark dorsally and silver to white on lower body with lateral band from tip of upper lip and snout to base of caudal fin, ending in a distinct spot; band fades away in larger adults. Breeding males are rosy tinted ventrally, and have large tubercles on dorsum of head and pectoral fins. (Also, Table 58.)

Reproduction: Non-guarding, brood-hiding lithophil. Males usually mature at age 2–3, females at age 1. Spawn in spring to early summer at ≥13 or 15°C in gravel-bottom runs of small streams or littoral zones of lakes. Male defends nest site as he progressively excavates pit downstream, moves gravel to its upstream end, and thereby buries successive batches of eggs ~5-8 (up to 15) cm deep under gravel mounds 20–36 cm wide by 30–80 (up to 550) cm long. Eggs are demersal, nonadhesive, and 2.0–2.2 or 1.9–2.3 mm (orig.) in diameter.

Young: Hatch in 10 d at 13°C, 6 d at 18°C, 4–5 d at 20°C, or 3 d at 21.5°C. Young favor shallows and feed mostly on chironomid larvae, other dipterans, and ephemeropteran naiads.

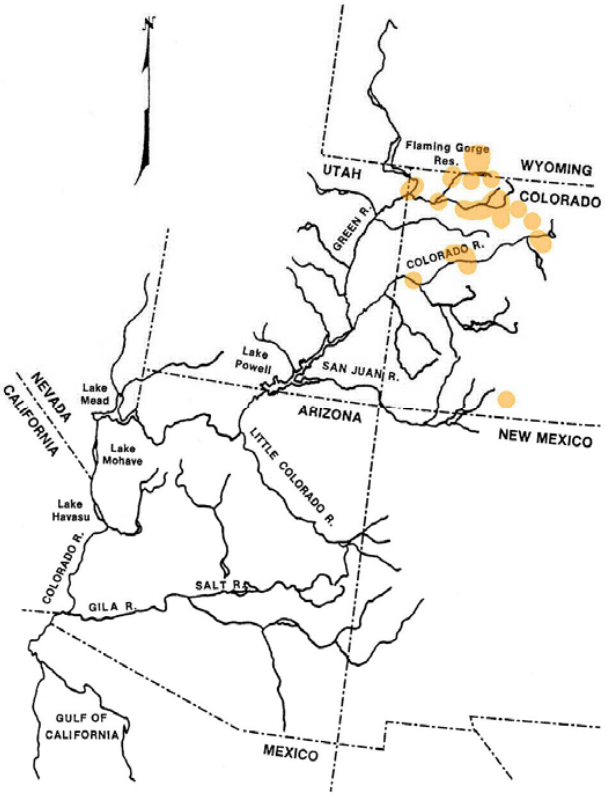

Figure 147. Recent distribution of *Semotilus atromaculatus* in the Colorado River Basin.

Table 58. Selected juvenile and adult meristics for *Semotilus atromaculatus*. (P = principal rays; R = rudimentary rays; D = dorsal; V = ventral. Scales are lateral series or line when complete. Four added to vertebral count for Weberian complex. Pharyngeal teeth given as left outer row, inner row/right inner row, outer row. Mean or modal values underlined if known and noteworthy; rare values in parentheses.)

Character	Observed	Literature	Character	Observed	Literature
Dorsal-fin rays - P	8	7-8(9)	Dorsal-fin rays - R	2-3	–
Anal-fin rays - P	8(9)	(7)8(9)	Anal-fin rays - R	2-3	–
Caudal-fin rays - P	19(20)	19	Caudal-fin rays - RD	(8)-9-11-12	–
Pectoral-fin rays	13-14-15	13-15-17(18)	Caudal-fin rays - RV	10-11(12)	–
Pelvic-fin rays	8	8	Lateral scales	(52)53-60-65(-67)	(49)50-55-62-66(-70)
Vertebrae	–	(39-)41-42-43-44	Pharyngeal teeth	–	2,(4)5/4(5),2

Table 59. Size at apparent onset of selected developmental events for *Semotilus atromaculatus*. (As apparent under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare values in parentheses.)

Event or structure	Onset or formation mm SL	mm TL	Fin rays or scales	First formed mm SL	mm TL	Last formed mm SL	mm TL
Hatched	5-6	5-6	Dorsal - P	(8)9-10	(9)10-11	10-11	12(13)
Eyes pigmented	5-6	5-6	Anal - P	(8)9-10	(9)10-11	11	12-13
Yolk assimilated	8-9	9	Caudal - P	8(9)	8-9(10)	8-9	9-10
Finfold absorbed	17-19	20-23	Caudal - R	9-10	(10)11	17-19	20-23
Pectoral-fin buds	6-7	6-7	Pectoral	(8)9(-11)	(9)10(-13)	(14-)17(-19)	(16-)19-20(-23)
Pelvic-fin buds	(9)10(11)	(10)11(-13)	Pelvic	12-13	(14)15	(16-)19	(19-)23
			Scales	17-19	20-23	19(20)	23(24)

References: Balon 1981; Baxter and Simon 1970; Becker 1983; Beckman 1952; Breder and Rosen 1966; Carlander 1969; Clay 1975; Copes 1978; Eddy and Underhill 1974; Everhart and Seaman 1971; Heufelder and Fuiman 1982; Lentsch et al. 1996; Moore 1968; Pflieger 1997; Reighard 1910; Scarola 1973; Scott and Crossman 1973; Simon 1998; Sublette et al. 1990; Tyus et al. 1982; Woodling 1985.

Other larval descriptions: Buynak and Mohr 1979b; Embody 1914; Fish 1932; Fuiman et al. 1983; Heufelder and Fuiman 1982; Kranz et al. 1979; Loos et al. 1979; Perry 1979; Perry and Menzel 1979; Snyder 1981.

Table 60. Size at developmental interval (left) and gut phase (right) transitions for *Semotilus atromaculatus*. (See Figure 5 for phases of gut folding. Rare values in parentheses.)

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion mesolarva	8(9)	8-9(10)	2 - 90° bend	11-12	13(14)
Postflexion mesolarva	8-9	9-10	3 - Full loop	19(20)	23-24
Metalarva	11	(12)13	4 - Partial crossover	(not applicable)	
Juvenile	(17-)19	(20-)23	5 - Full	(not applicable)	

Table 61. Summary of morphometrics and myomere counts by developmental phase for *Semotilus atromaculatus*. (See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded. Standard deviation (SD) of 0 represents a value <0.5. Includes data extracted from selected Buynak and Mohr 1979b and Kranz et al. 1979 illustrations used in Snyder 1981 and herein.)

	Protolarvae (N=10)			Flexion mesolarvae (N=11)			Postflexion mesolarvae (N=17)			Metalarvae (N=16)			Juveniles (N=13)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm	7	1	6 - 9	8	0	8 - 9	10	1	8 - 11	14	2	11 - 19	26	7	19 - 40
TL, mm	7	1	6 - 10	9	0	8 - 10	11	1	9 - 13	16	3	13 - 23	31	8	23 - 48
Lengths %SL															
AS to AE	3	0	2 - 3	3	0	2 - 3	3	1	3 - 5	5	1	2 - 6	6	0	5 - 7
PE	10	1	8 - 11	11	1	9 - 11	12	1	11 - 13	13	1	11 - 15	13	1	12 - 14
OP1	17	1[a]	16 - 20	20	1	19 - 21	23	1	21 - 24	25	1	22 - 26	26	1	24 - 28
OP2							49	1[a]	47 - 50	50	1	47 - 52	50	2	46 - 54
PY	66	12	33 - 72	63	2[b]	60 - 64									
OPAF	54	14	28 - 69	28	1	26 - 31	30	1	27 - 32	36	4[g]	31 - 44			
ODF	47	2	43 - 50	47	1	45 - 48	50	2	48 - 54	50	1[h]	49 - 52			
OD							53	1[d]	51 - 56	54	2	51 - 56	54	1	52 - 57
ID							62	2[e]	59 - 64	65	2	62 - 68	66	1	64 - 68
PV	71	2	66 - 74	68	1	67 - 69	70	1	68 - 71	69	2	66 - 72	66	2	64 - 69
OA							70	1[a]	69 - 71	69	1	66 - 71	67	2	65 - 70
IA							78	0[b]	78 - 79	78	1	76 - 79	76	2	74 - 79
AFC							110	1	107 - 112	112	1	110 - 113	114	1	112 - 115
PC	104	1	102 - 105	107	1	106 - 108	112	2	109 - 115	117	2	113 - 119	121	1	119 - 123
Y	51	17	6 - 64	16	19	0 - 40									
P1	4	3	0 - 9	12	1	9 - 14	14	1	12 - 15	14	1	13 - 16	15	1	13 - 17
P2							1	1	0 - 3	6	2	3 - 10	12	1	10 - 14
D							12	1[f]	11 - 13	16	2	13 - 19	20	1	17 - 23
A							10	1[b]	9 - 11	13	2	10 - 16	17	1	16 - 18
Depths %SL															
at BPE	12	2	11 - 15	12	0	12 - 13	14	1	13 - 16	16	1	14 - 18	16	0	15 - 17
OP1	15	4	12 - 23	13	0	12 - 14	16	1	14 - 17	19	2	17 - 22	21	1	20 - 22
OD	13	0	12 - 14	10	1	10 - 11	12	1	10 - 14	16	2	12 - 21	20	1	18 - 21
BPV	6	1	5 - 8	8	0	7 - 8	9	1	7 - 10	12	1	10 - 16	15	1	14 - 16
AMPM	4	1	3 - 5	5	0	4 - 5	6	1	5 - 7	8	1	7 - 9	10	1	9 - 11
Max. yolk	11	5	1 - 19	1	2	0 - 7									
Widths %SL															
at BPE	11	1	9 - 13	13	1[c]	12 - 15	14	1	13 - 15	17	1[d]	14 - 18	17	1	16 - 18
OP1	11	5	8 - 21	10	0[c]	9 - 11	13	1	10 - 14	16	1[d]	14 - 17	18	1	17 - 19
OD	8	1	6 - 9	6	0[c]	5 - 7	7	1	6 - 8	10	1[d]	7 - 12	15	1	13 - 16
BPV	5	0	4 - 5	5	0[c]	4 - 5	5	0	5 - 6	8	1[d]	6 - 9	11	1	9 - 14
AMPM	3	0	2 - 3	3	0[c]	2 - 3	3	0	3 - 4	4	1[d]	4 - 5	5	0	4 - 5
Max. yolk	13	6	1 - 22	2	3	0 - 8									
Myomeres															
to PY	27	5	12 - 30	27	2[b]	24 - 28									
OPAF	20	6	9 - 27	7	1	5 - 9	6	1	5 - 7	9	2[c]	7 - 14			
OP2							17	0[a]	16 - 17	17	1[c]	14 - 18	16	1[h]	15 - 16
ODF	17	1	16 - 19	18	1	17 - 19	18	1	16 - 19	18	1[h]	18 - 19			
OD							19	1[g]	18 - 20	19	1[c]	17 - 20	18	1[h]	17 - 18
PV	30	1	29 - 32	30	1	29 - 31	30	1	28 - 31	29	1[c]	28 - 30	27	0[h]	27 - 27
Total	42	1	40 - 44	42	1	41 - 44	42	1	41 - 43	42	1[c]	40 - 43	41	1[h]	40 - 41
After PV	12	1	11 - 13	12	1	11 - 14	13	1	12 - 14	13	1[i]	11 - 14	14	1[h]	13 - 14

[a]N = 8. [b]N = 5. [c]N = 10. [d]N = 14. [e]N = 13. [f]N = 7. [g]N = 15. [h]N = 4. [I]N = 12.

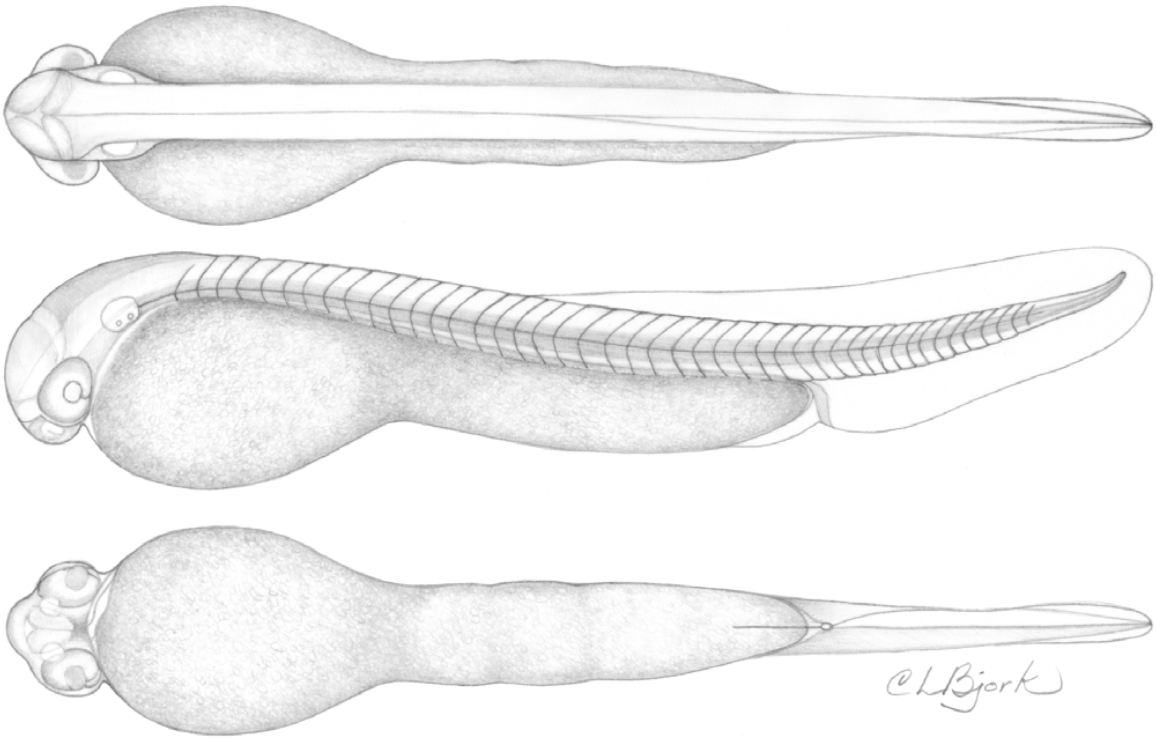

Figure 148. *Semotilus atromaculatus* protolarva, recently hatched, 6.0 mm SL, 6.1 mm TL. (Collected in 2008 from Spring Creek, Fort Collins, Colorado.)

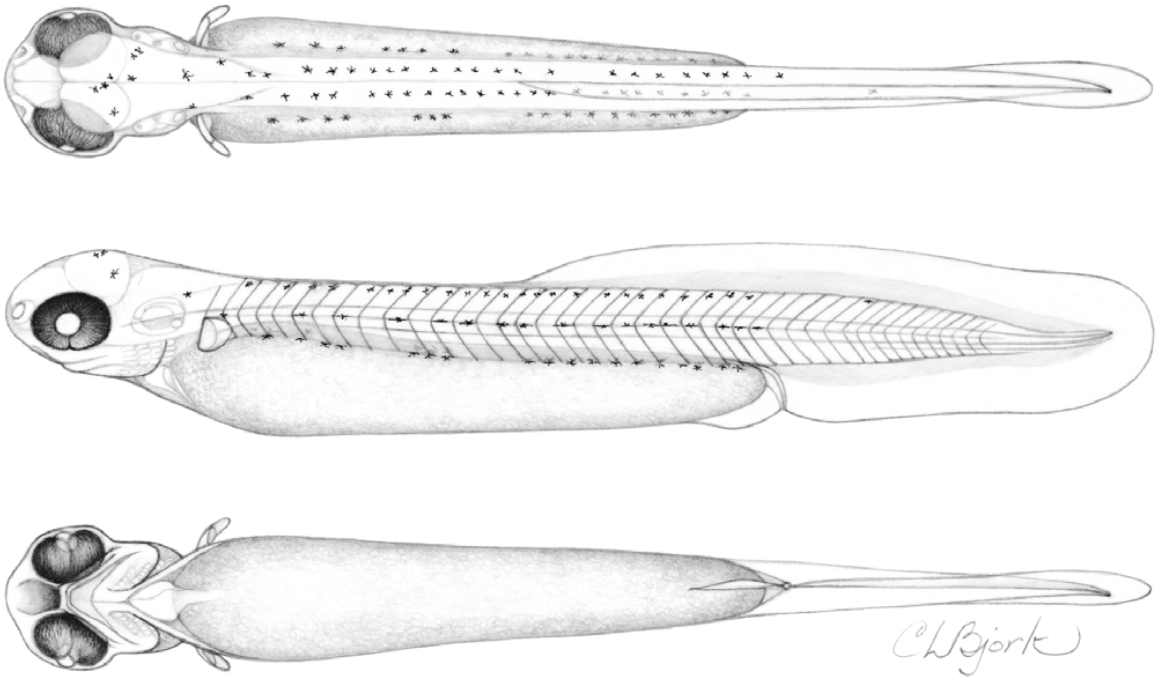

Figure 149. *Semotilus atromaculatus* protolarva, 7.2 mm SL, 7.5 mm TL. (Cultured in 2008 by Larval Fish Laboratory, Colorado State University, with stock from Spring Creek, Fort Collins, Colorado.)

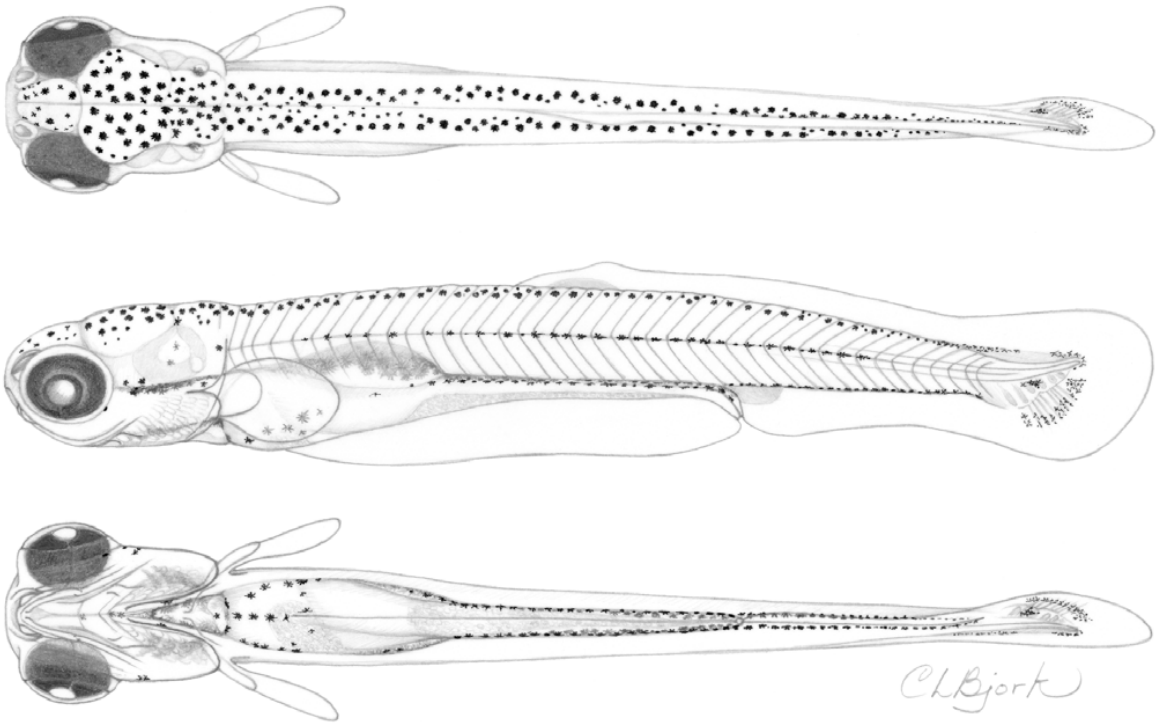

Figure 150. *Semotilus atromaculatus* flexion mesolarva, recently transformed, 8.1 mm SL, 8.7 mm TL. (Cultured in 2008 by Larval Fish Laboratory, Colorado State University, with stock from Spring Creek, Fort Collins, Colorado.)

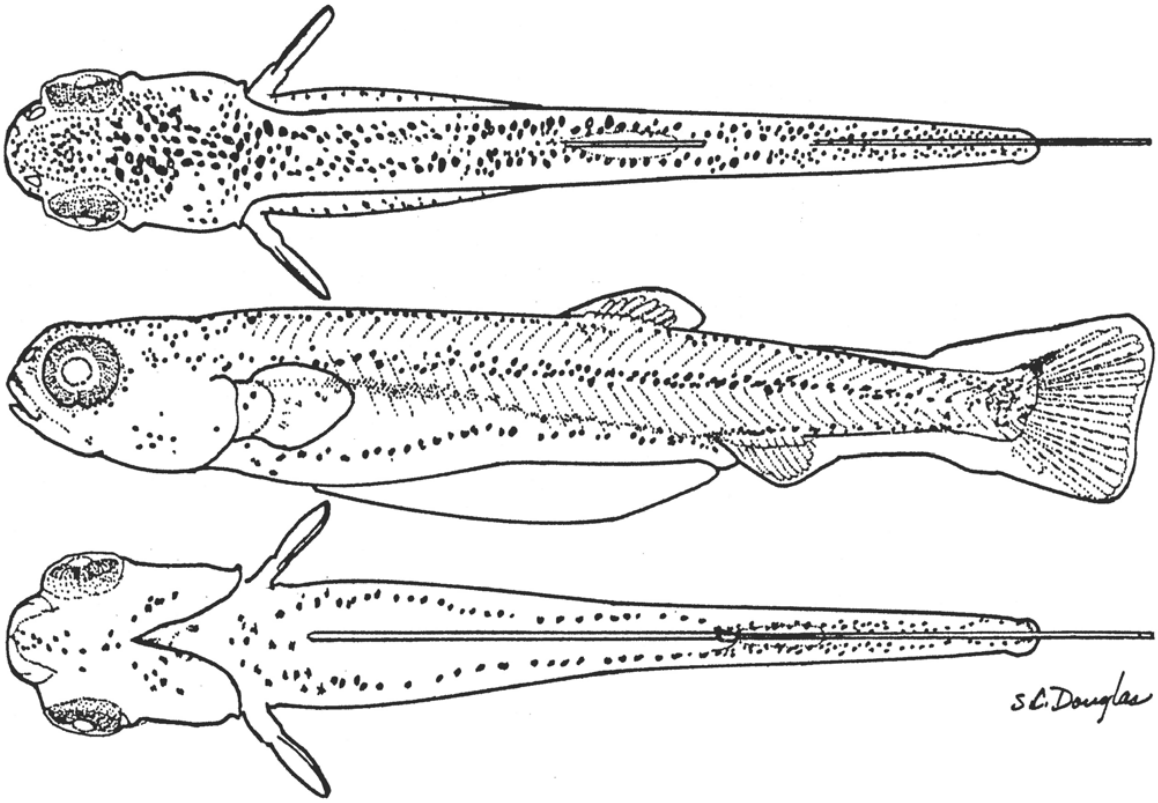

Figure 151. *Semotilus atromaculatus* postflexion mesolarva, 11.3 mm SL, 12.6 mm TL. (Collected in 1970s by NUS Corp., Pittsburgh, Pennsylvania from Duscham Creek or Chippewa River, Dunn County, Wisconsin. Modified from Kranz et al. 1979, Figure 3, with author permission.)

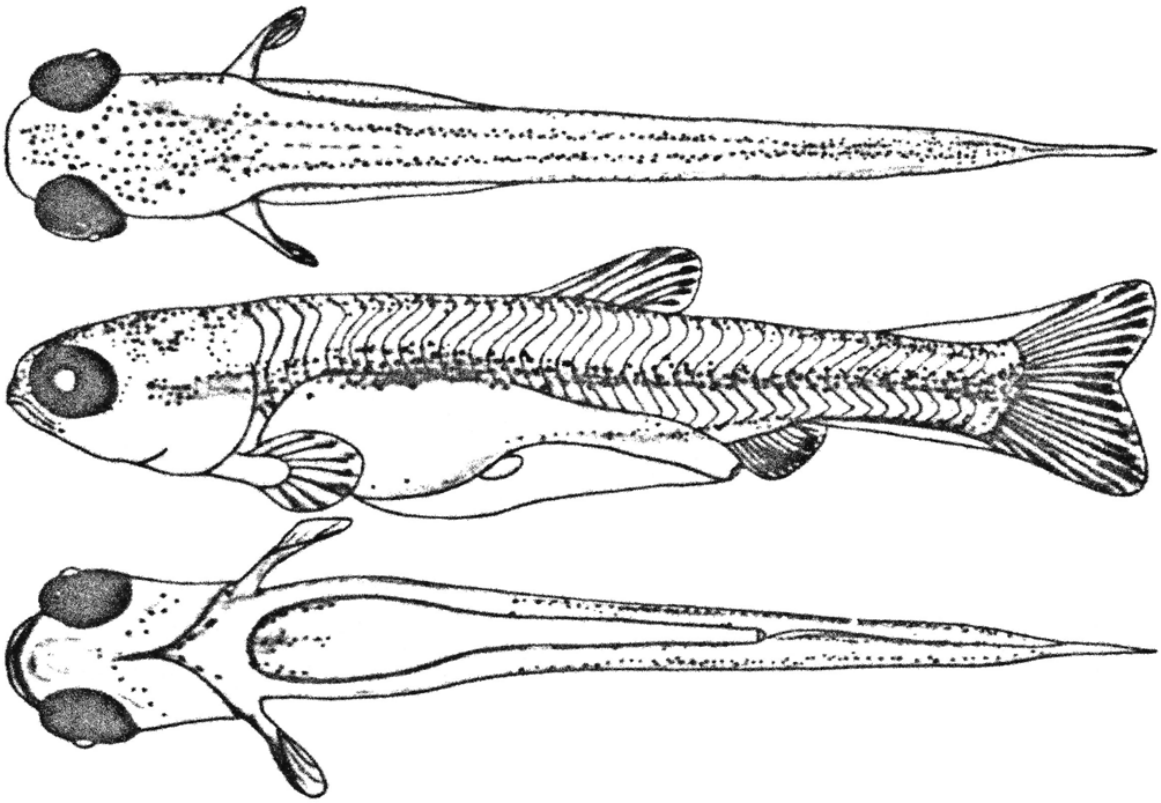

Figure 152. *Semotilus atromaculatus* metalarva, recently transformed, 12.4 mm SL, 14.0 mm TL. (Cultured in 1977 by Gerald Buynak and Harold Mohr, Ichthyological Associates, Inc., Berwick, Pennsylvania, with stock from nearby Briar Creek. Modified from Buynak and Mohr 1979b, Fig 1f, with author permission.)

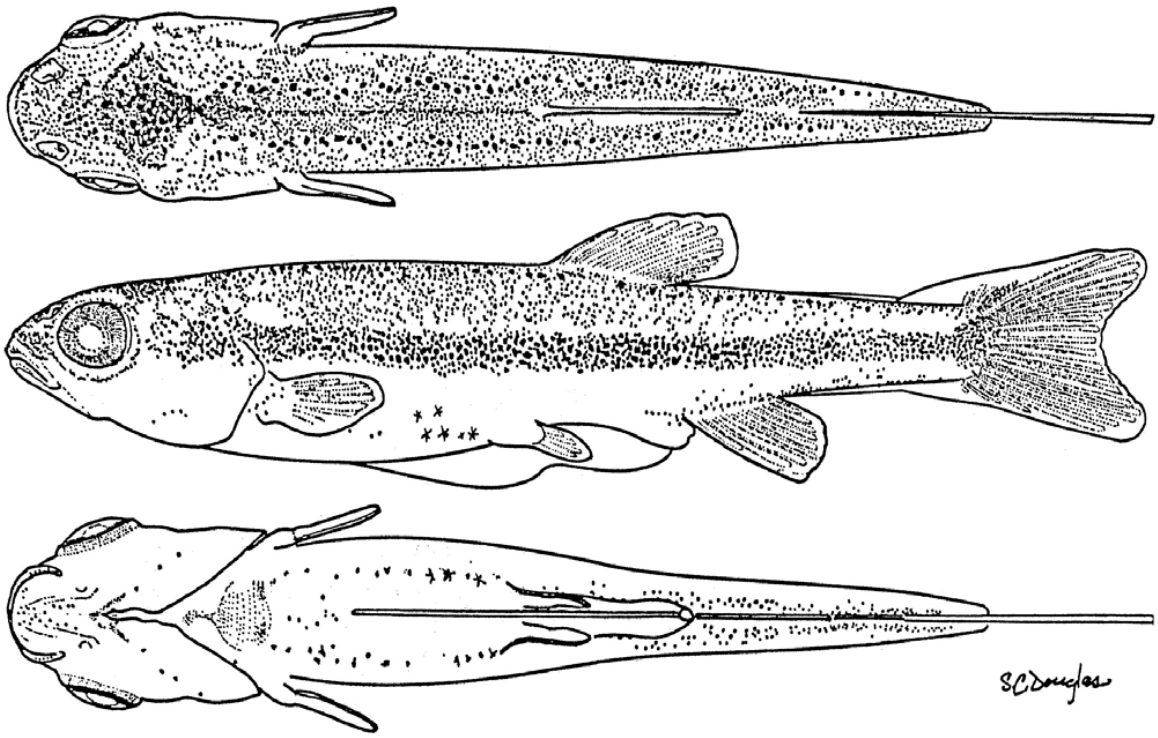

Figure 153. *Semotilus atromaculatus* metalarva, 16.5 mm SL, 19.2 mm TL. (Collected in 1970s by NUS Corp., Pittsburgh, Pennsylvania, from Duscham Creek or Chippewa River, Dunn County, Wisconsin. Modified from Kranz et al. 1979, Figure 5, with author permission.)

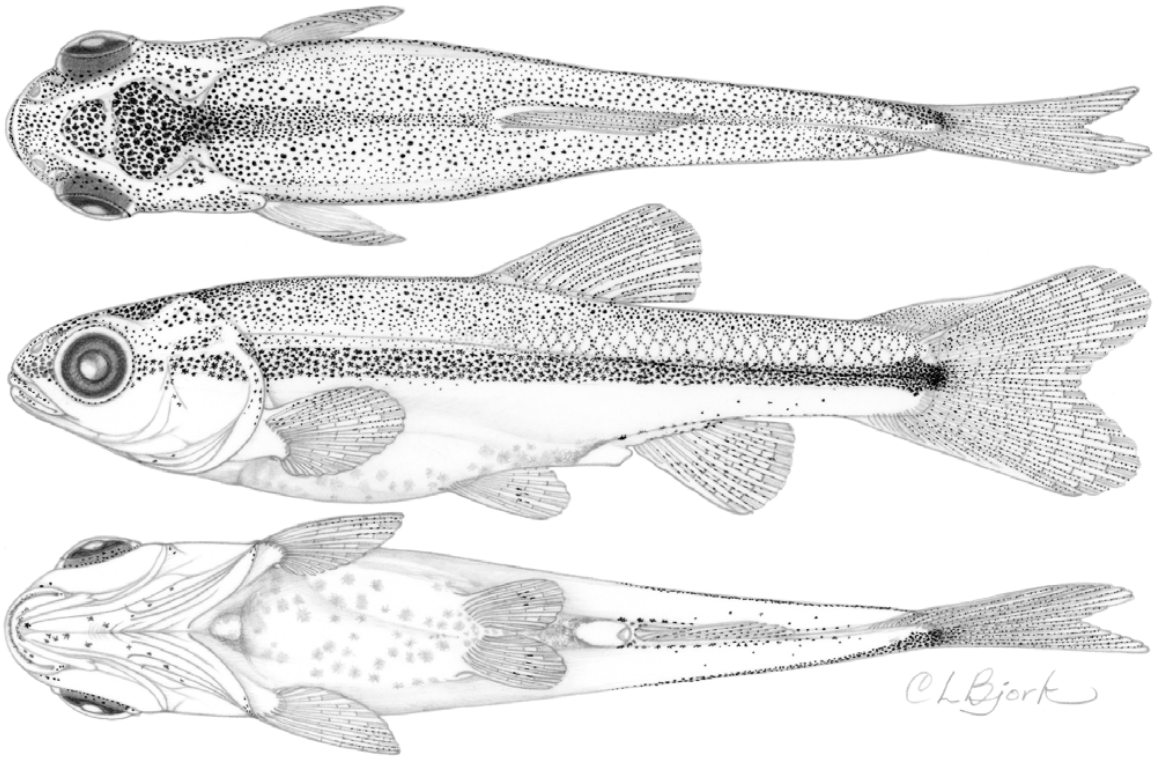

Figure 154. *Semotilus atromaculatus* juvenile, recently transformed, 19.6 mm SL, 24.0 mm TL. (Collected in 2004 from South Fork Republican River, Yuma County, Colorado; from LFL #96160.)

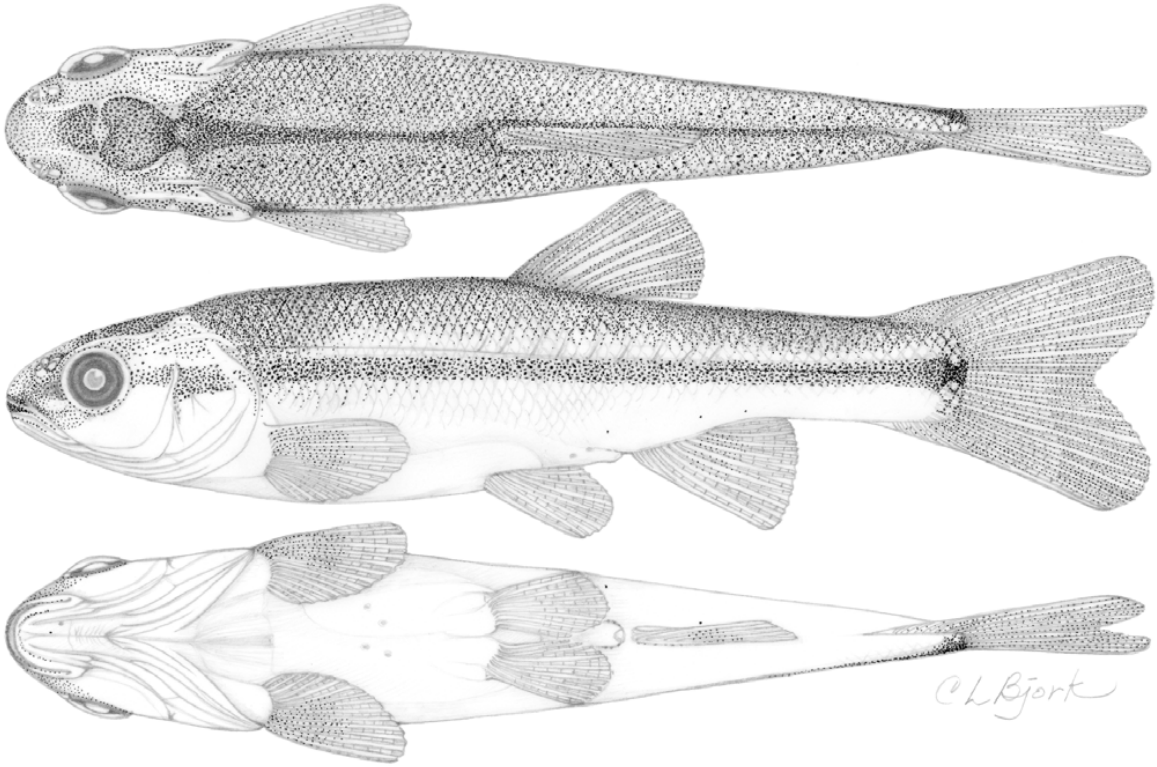

Figure 155. *Semotilus atromaculatus* juvenile, 32.0 mm SL, 38.5 mm TL. (Collected in 1985 from Green River, Uintah County, Utah; from LFL #18409.)

Comparative Summary Tables

The following tables summarize the more diagnostically useful data in the species accounts in a convenient comparative format and supplement the species accounts with comparative information on pigmentation and special characters. They are organized in sets of three for native cyprinids, more common non-native cyprinids, and less common non-native cyprinids. These sets of tables compare: size at the onset of selected developmental events (Tables 62–64), selected meristics (Tables 65–67), the more diagnostically useful morphometrics (Tables 68–70), size relative to pigmentation of the eyes and body in protolarvae and peritoneal pigmentation in metalarvae and early juveniles (Tables 71–73), selected melanophore pigmentation patterns coded by developmental phase (Tables 74–76), and diagnostic eye, mouth, and fin position characters (Tables 77–79).

Size relative to developmental state

Table 62. Comparison of size of water-hardened eggs (mm diameter) and larvae or early juveniles (mm SL) at onset of or transition to developmental intervals, gut phases, and other developmental events for the native cyprinids of the Upper Colorado River Basin. (Rare values in parentheses. NA = not applicable.)

Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Egg diameter	(2.3-)2.6-3.1(-3.3)	2.0-2.4	2.7-3.0(3.1)	1.9-2.2	1.6-2.2
Phase/period transitions					
Embryo to larva	6-7	5-6	7-8	(5)6-7	5
Protolarva to mesolarva	9	(7)8	9(10)	(7)8(9)	(6)7
Flexion to postflexion mesolarva	9-10(11)	(8)9	(9)10-11	(7)8-9	8-9
Mesolarva to metalarva	(12)13	11-12	12-13(14)	(10)11	9-11
Larva to juvenile	(18-)20	22	(18)19-20(-22)	19-20(21)	(15)16(17)
Gut phase transitions					
1 to 2 (90° bend)	(11)12-13	11-12	12(13)	12-14	(10)11
2 to 3 (full loop)	(17)18-19(20)	(20-)22	(25-)29-34(-36)	>57,<111	24-28
3 to 4 (partial crossover)	NA	NA	NA	NA	NA
4 to 5 (full crossover)	NA	NA	NA	NA	NA
Onset of selected events					
Eyes pigmented	6(7) [b]	5-6 [b]	[b]	[b]	(5) [b]
Yolk assimilated	9-10(11)	8	(9)10-11	(7)8-9	6-8(9)
Finfold absorbed	(18-)20	22	(18)19-20(-22)	19-20(21)	(14-)16(17)
Pectoral-fin buds	[b]	[b]	[b]	(5)6 [b]	[b]
Pelvic-fin buds	10-11	10	11-12	(10)11	9
Dorsal spine formation [a]	NA	NA	NA	NA	NA
Maxillary barbels	NA	NA	NA	NA	(17)18
Fin rays first observed					
Dorsal, principal	9-10(11)	9	10-11	8(9)	8(9)
Anal, principal	10(11)	9	11-12	9(10)	8(9)
Caudal, principal	9	(7)8	9(10)	(7)8(9)	(6)7
Caudal, rudimentary	(9)10(11)	9	10-11(12)	(7)8-9(10)	9-10
Pectoral	11(12)	11-12	(11)12-13	(9-)11	11
Pelvic	12-13	(11)12	(12)13-14(15)	12	11-12
Full fin-ray counts first observed					
Dorsal, principal	(10)11-12	11	(10)11-12	10-11	9-11
Anal, principal	(12)13	11-12	12-13(14)	(10)11	9-11
Caudal, principal	9-10(11)	(8)9	(9)10-11	(7)8-9	8-9
Caudal, rudimentary	15-16(17)	17-19	(14-)16-18(19)	17	14-15
Pectoral	(15)16-19(20)	13-14	14-15(16)	(11)12-15	(13)14-15(16)
Pelvic	(14)15-16(17)	13-14	(14)15(16)	15	(12)13-14(-16)
Scales, lateral series					
First observed	(24-)26-29	(22)23	(25-)27-28(-30)	(27-)31-34	17(18)
Full series first observed	(36-)40->44	34-37(-40)	34-38	34-38	24-28

[a] Transformation of first principal dorsal-fin ray (thickening with serrations forming along posterior margin) to a distinctive spine or spine-like structure.
[b] (Or) before hatching.

Table 63. Comparison of size of water-hardened eggs (mm diameter) and larvae or early juveniles (mm SL) at onset of or transition to developmental intervals, gut phases, and other developmental events for the more common non-native cyprinids of the Upper Colorado River Basin. (Rare values in parentheses. NA = not applicable.)

Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Egg diameter	1.3-2.1	(1.0)1.2-1.3(1.4)	1.1-1.6	(1.1-)1.3-1.5(1.6)	1.7-2.2
Phase/period transitions					
Embryo to larva	(4)5	3-4	3-4	4(5)	4-5
Protolarva to mesolarva	7-8	5	(5)6	6-7	(6)7(8)
Flexion to postflexion mesolarva	(8)9(10)	6	7	7-8	8-9
Mesolarva to metalarva	12-13	(7)8	8(9)	8-10(11)	(9)10
Larva to juvenile	(17)18-19	10(-12)	(12)13	14-15	19-20
Gut phase transitions					
1 to 2 (90° bend)	11-12	8-9	9	9-10	(11)12
2 to 3 (full loop)	12-15	12-13	(13-)15	11-14	18-20(-22)
3 to 4 (partial crossover)	19-27	NA	NA	(15)16	NA
4 to 5 (full crossover)	27-31(32)	NA	NA	16	NA
Onset of selected events					
Eyes pigmented	[b]	[b]	[b]	[b]	4[b]
Yolk assimilated	6-7	(4)5	(4)5	5(6)	(6)7
Finfold absorbed	(17)18-19	10(-12)	12(13)	14	19-20
Pectoral-fin buds	[b]	[b]	[b]	[b]	4-5[b]
Pelvic-fin buds	(10)11	7(8)	7-8	8(9)	9-10
Dorsal spine formation[a]	20-21 (serrated)	NA	NA	NA	NA
Maxillary barbels	14-15(-20) (corner pair) 25-28(-39) (anterior pair)	NA	NA	NA	NA
Fin rays first observed					
Dorsal, principal	9-10(11)	6	6(7)	7-8	8(9)
Anal, principal	11(12)	7	(6)7-8	8	8(9)
Caudal, principal	7-8	5	(5)6	6-7	(6)7(8)
Caudal, rudimentary	9-10(11)	7	8	7-8	8-9
Pectoral	(10)11-12	7(8)	7-9	8-10(11)	(9)10(11)
Pelvic	(11)12	8-9	8-9	11-12	(11)12
Full fin-ray counts first observed					
Dorsal, principal	12-13	7(8)	7-8	8-9	(8)9-10
Anal, principal	(11)12(13)	7-8	(7)8(9)	8-10(11)	(8)9-10
Caudal, principal	(8)9(10)	6	7	7-8	8-9
Caudal, rudimentary	(13)14-16(17)	10(11)	(12)13	14-15	(15)16(-18)
Pectoral	(13)14-16(17)	(8-)10(11)	10-11(12)	14-15	(11)12-13
Pelvic	(12)13-16(17)	(9)10(11)	(12)13	12-13	14(15)
Scales, lateral series					
First observed	14-15	(12)13	13-14	(14)15	(18)19
Full series first observed	(15-)17-18	14-15	14-15(16)	(15)16	20-22

[a] Transformation of first principal dorsal-fin ray (thickening with serrations forming along posterior margin) to a distinctive spine or spine-like structure.
[b] (Or) before hatching.

Table 64. Comparison of size of water-hardened eggs (mm diameter) and larvae or early juveniles (mm SL) at onset of or transition to developmental intervals, gut phases, and other developmental events for the less common non-native cyprinids of the Upper Colorado River Basin. (Rare values in parentheses. NA = not applicable.)

Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae* [d]	*Semotilus atromaculatus*
Egg diameter	1.6-2.3(-2.6) [c]	1.2-1.5	1.0-1.4	2.0-2.7	1.9-2.3
Phase/period transitions					
Embryo to larva	4-5	3(4)	3-4	(4)5[-6]	5-6
Protolarva to mesolarva	7	6	6(7)	7[-9]	8(9)
Flexion to postflexion mesolarva	8	8(9)	(7)8	8(9)	8-9
Mesolarva to metalarva	(9)10	(9)10-11	10-11	10(11)	11
Larva to juvenile	(15)16	(14)15-16(17)	16	(14)15(16)	(17-)19
Gut phase transitions					
1 to 2 (90° bend)	10-11(12)	(9)10-12	12(13)	11	11-12
2 to 3 (full loop)	15(16)	13-14	16(17)	(21-)25(26)	19(20)
3 to 4 (partial crossover)	NA	(14)15-16	NA	NA	NA
4 to 5 (full crossover)	NA	16-17	NA	NA	NA
Onset of selected events					
Eyes pigmented	4-5[b]	3(4)[b]	3(4)[b]	4(5)[b] [4-6[b]]	5-6
Yolk assimilated	6-7	5	5	7[-9]	8-9
Finfold absorbed	15-16	(13)14-16(17)	16	(14)15(16)	17-19
Pectoral-fin buds	4(5)[b]	3(4)[b]	4[b]	[b]	6-7
Pelvic-fin buds	(8)9	(7)8	9-10	8(9)[-11]	(9)10(11)
Dorsal spine formation [a]	NA	NA	NA	NA	NA
Maxillary barbels	NA	NA	NA	17(18)	>40
Fin rays first observed					
Dorsal, principal	8	8	(7-)9	8	(8)9-10
Anal, principal	8(9)	(8)9	(7-)9	9	(8)9-10
Caudal, principal	7	6	6(7)	7[-9]	8(9)
Caudal, rudimentary	(8)9	9-10	(7-)9-10	9-10	9-10
Pectoral	10	(9)10	9-10	9(10)	(8)9(-11)
Pelvic	10	(9)10-11	11(12)	10	12-13
Full fin-ray counts first observed					
Dorsal, principal	9-10	(9)10	10	10	10-11
Anal, principal	9-10	(9)10-11	10-11	10(11)	11
Caudal, principal	8	8(9)	(7)8	8(9)	8-9
Caudal, rudimentary	(13)14-16	14-15	13-16	14	17-19
Pectoral	12-13	(14)15	16	(12)13-14	(14-)17(-19)
Pelvic	12-13	(14)15-16	13-16	14-15	(16-)19
Scales, lateral series					
First observed	19-20	(14)15	13-16	17-19	17-19
Full series first observed	(22)23-25	16(17)	17-22	(18-)20-22(-25)	19(20)

[a] Transformation of first principal dorsal-fin ray (thickening with serrations forming along posterior margin) to a distinctive spine or spine-like structure.
[b] (Or) before hatching.
[c] Reported extreme low for range of egg diameter is 0.8 mm, but not likely for mature and water-hardened eggs.
[d] Bracketed data from descriptions for eastern US populations where larvae were notably larger relative to respective developmental events.

Selected meristics

Table 65. Comparison of selected meristics for larvae and early juveniles of the native cyprinids of the Upper Colorado River Basin. (Character range is followed by the mean, mode, or more typical range. See Figure 4 for methods of counting myomeres and fin rays. ODF = origin of dorsal finfold, OD = origin of dorsal fin, OP2 = origin of pelvic buds or fins, and PV = posterior margin of the vent. Vertebra counts include four for the Weberian complex; dorsal- and anal-fin-ray counts are of principal rays; scale counts are of the lateral line or series. Data previously published by other authors are given in parentheses; sources are listed in corresponding species accounts.)

Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Myomeres to ODF					
Protolarvae	10-18, 13	1-17, 13	10-16, 13	10-18, 17	13-15, 14
Flexion mesolarvae	11-16, 14	5-17, 14	14-16, 15	16-18, 17	13-16, 15
Postflexion mesolarvae	11-17, 14	14-15, 15	14-20, 16	15-19, 18	14-15, 14
Myomeres to OD					
Postflexion mesolarvae	17-20, 19	20-21, 20	18-21, 20	21-24, 22	17-19, 18
Metalarvae	17-20, 19	19-22, 20	17-21, 19	21-24, 23	18-20, 19
Myomeres to OP2					
Postflexion mesolarvae	14-17, 16	16-17 [a]	15-18, 17	20 [b]	17-17 [a]
Metalarvae	15-17, 16	16-18, 17	15-20, 17	18-22, 20	14-17, 16
Myomeres to PV					
Proto- & mesolarvae	27-32, 29	29-32, 30-31	26-32, 29	31-35, 33-34	23-27, 25-26
Metalarvae	27-30, 29	29-32, 30	25-30, 28	31-34, 33	23-27, 24
All larvae	27-32, 29	29-32, 30-31	25-32, 28-29	31-35, 33-34	23-27, 24-26
Myomeres after PV					
Proto- & mesolarvae	15-19, 17-18	17-21, 20	14-19, 17	14-17, 15-16	10-14, 12-13
Metalarvae	16-19, 17	16-21, 20	15-19, 17	15-18, 16	11-16, 14
All larvae	15-19, 17-18	16-21, 20	14-19, 17	14-18, 15-16	10-16, 12-14
Myomeres, total					
Proto- & mesolarvae	45-49, 46-47	47-52, 50-51	43-48, 46	48-51, 49-50	35-40, 38
Metalarvae	44-48, 46	47-52, 50	42-48, 46	48-51, 49	36-40, 38
All larvae	44-49, 46-47	47-52, 50-51	43-48, 46	48-51, 49-50	35-40, 38
Vertebrae	44-49, 46-47 (45-49, 46-47)	49-51, 50 (46-51, 49)	44-47, 46 (42-49, 44-46)	48-49, 48-49 (47-49, 48-49)	38-40 (37-38)
Dorsal-fin rays	9-10, 9 (8-10, 9)	10-11, 10 (9-11, 10)	9 (8-10, 9)	9-10, 9 (9-10, 9)	7-8, 8 (6-9, 8)
Anal-fin rays	8-11, 10 (9-11, 10)	10-11, 10 (9-11, 10)	8-10, 9 (7-10, 9)	8-10, 9 (8-10, 9)	6-8, 7 (6-8, 7)
Lateral-line scales	– (73-90, 80-82)	82 [b] (75-110, 88-99)	80-87 (69-99, 77-91)	79-95, 88 (76-98, 84-93)	65-81, 71 (47-90, 55-80)

[a] N = 2.
[b] N = 1.

Table 66. Comparison of selected meristics for larvae and early juveniles of the more common non-native cyprinids of the Upper Colorado River Basin. (Character range is followed by the mean, mode, or more typical range. See Figure 4 for methods of counting myomeres and fin rays. ODF = origin of dorsal finfold, OD = origin of dorsal fin, OP2 = origin of pelvic buds or fins, and PV = posterior margin of the vent. Vertebra counts include four for the Weberian complex; dorsal- and anal-fin-ray counts are of principal rays; scale counts are of the lateral line or series. Data previously published by other authors are given in parentheses; sources are listed in corresponding species accounts.)

Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Myomeres to ODF					
Protolarvae	9-12, 10	6-11, 10	9-11, 10	10-15, 12	12-17, 15
Flexion mesolarvae	10-13, 11	10-14, 12	10-12, 11	13-14, 14	14-19, 16
Postflexion mesolarvae	10-12, 12	11-15, 13	10-13, 12	12-15, 14	15-19, 16
Myomeres to OD					
Postflexion mesolarvae	11-13, 12	14-16, 15	12-15, 14	15-16, 16	17-20, 19
Metalarvae	10-13, 11	13-17, 15	12-15, 13	15-16, 15	17-20, 18
Myomeres to OP2					
Postflexion mesolarvae	13-15, 14	12 [b]	14-15, 15 [c]	15-15, 15	15-16, 16 [c]
Metalarvae	11-14, 13	12-15, 14	11-15, 13	14-17, 15	13-17, 15
Myomeres to PV					
Proto- & mesolarvae	23-28, 26-27	20-24, 21-23	20-24, 22-23	21-27, 23-25	24-27, 25-26
Metalarvae	25-28, 26	19-24, 22	20-23, 21	24-25, 25	23-27, 24
All larvae	23-28, 26-27	19-24, 21-23	20-24, 21-23	21-27, 23-25	23-27, 24-26
Myomeres after PV					
Proto- & mesolarvae	10-12, 11	11-15, 13-14	10-15, 12-13	10-15, 11-13	12-16, 13-14
Metalarvae	10-12, 11	12-15, 14	12-15, 13	10-13, 11	12-15, 14
All larvae	10-12, 11	11-15, 13-14	10-15, 12-13	10-15, 11-13	12-16, 13-14
Myomeres, total					
Proto- & mesolarvae	35-39, 37-38	31-37, 35	33-36, 35	35-38, 36-37	37-41, 39
Metalarvae	36-39, 37	34-37, 35	33-36, 35	34-37, 36	36-41, 38
All larvae	35-39, 37-38	31-37, 35	33-36, 35	34-38, 36-37	36-41, 38-39
Vertebrae	37-38 (32-39, 35-36)	35-36 (32-36, 35)	35-36 (33-36, 35)	– (35-38, 37)	39-40 (38-43)
Dorsal-fin rays	17-21, 19-20 [a] (15-24, 18-22)	7-9, 8 (6-9, 8)	7-9, 8 (7-9, 8)	7-9, 8 (7-9, 8)	8-10, 9 (8-11, 9)
Anal-fin rays	5-7, 6 [a] (4-8, 6)	8-10, 9 (7-13, 9)	7-8, 7 (6-8, 7)	7 (7)	9-13, 11 (9-16, 10-12)
Lateral-line scales	34-40 (32-41, 35-38)	34-38, 36-38 (30-40, 32-37)	34-38, 35-37 (31-39, 34-35)	43-51, 48 (40-60, 44-48)	50-64, 58 (49-67, 55-63)

[a] The serrated spine at the beginning of juvenile and adult *Cyprinus carpio* dorsal and anal fins are hardened lepidotrichia (first principal rays) rather than true spines and, as such, are not separated in counts by use of Roman numerals (as in spinous-rayed fishes).
[b] N = 1.
[c] N = 2.

Table 67. Comparison of selected meristics for larvae and early juveniles of the less common non-native cyprinids of the Upper Colorado River Basin. (Character range is followed by the mean, mode, or more typical range. See Figure 4 for methods of counting myomeres and fin rays. ODF = origin of dorsal finfold, OD = origin of dorsal fin, OP2 = origin of pelvic buds or fins, and PV = posterior margin of the vent. Vertebra counts include four for the Weberian complex; dorsal- and anal-fin-ray counts are of principal rays; scale counts are of the lateral line or series. Data previously published by other authors are given in parentheses; sources are listed in corresponding species accounts.)

Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
Myomeres to ODF					
Protolarvae	7-16, 12	10-12, 11	11-14, 12	12-15, 13	16-19, 17
Flexion mesolarvae	10-14, 12	11-13, 12	11-16, 14	13-16, 14	17-19, 18
Postflexion mesolarvae	11-16, 14	12-15, 14	15-19, 16	14-16, 15	16-19, 18
Myomeres to OD					
Postflexion mesolarvae	13-18, 16	15-17, 16	18-20, 19	17-19, 18	18-20, 19
Metalarvae	14-18, 16	14-17, 16	18-20, 19	15-19, 17	17-20, 19
Myomeres to OP2					
Postflexion mesolarvae	13-17, 15	14-17, 16	14-15, 14	15-17, 16	16-17, 17
Metalarvae	15-19, 17	15-18, 16	13-17, 15	14-17, 16	14-18, 17
Myomeres to PV					
Proto- & mesolarvae	25-28, 26-27	25-28, 26-27	23-27, 25	24-27, 25-27	28-32, 30
Metalarvae	24-28, 27	25-27, 26	24-26, 25	24-27, 25	28-30, 29
All larvae	24-28, 26-27	25-28, 26-27	23-27, 25	24-27, 25-27	28-32, 29-30
Myomeres after PV					
Proto- & mesolarvae	10-14, 12-13	10-12, 11	11-14, 12-13	11-15, 13	11-14, 12-13
Metalarvae	12-14, 13	11-12, 11	11-13, 13	12-15, 13	11-14, 13
All larvae	10-14, 12-13	10-12, 11	11-14, 12-13	11-15, 13	11-14, 12-13
Myomeres, total					
Proto- & mesolarvae	38-41, 39-40	36-39, 37-38	36-39, 37-38	36-40, 38-39	40-44, 42
Metalarvae	37-41, 40	36-39, 37	36-39, 38	37-40, 39	40-43, 42
All larvae	37-41, 39-40	36-39, 37-38	36-39, 37-38	36-40, 38-39	40-44, 42
Vertebrae	39 (–)	– (35-37)	– (36-39, 37-39)	– (37-42, 38-40)	– (39-44, 42-43)
Dorsal-fin rays	8-10, 9 (8-10, 9)	8 (7-8, 8)	8 (7-9, 8)	8 (7-9, 8)	8 (7-9, 8)
Anal-fin rays	7-9, 8 (7-9, 8)	7-8, 8 (6-9, 8)	13-16, 14 (8-19, 12-14)	7 (6-9, 7)	8-9, 8 (7-9, 8)
Lateral-line scales	52-57, 53-56 (45-65, 50-63)	35-39, 37 (32-41, 35-39)	49-53 (40-57, 44-54)	62-69, 64 (58-76, 61-72)	52-67, 60 (49-70, 50-66)

Selected morphometrics

Table 68. Comparison of the more diagnostic differences in morphometrics for larvae and juveniles (≤40 mm SL) of the native cyprinids of the Upper Colorado River Basin. (Except as indicated, all data are percentages of standard length, % SL, presented as ranges followed by means. HL = head length measured to the origin of the pectoral fin, AS to OP1; see Figure 4 for other abbreviations and methods of measurement.)

Developmental Phase Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Protolarvae					
Eye diameter [a]	5-7, 6	5-7, 6	5-7, 7	5-8, 6	7-9, 8
AS-to-PE length	8-11, 9	7-10, 9	8-11, 9	8-11, 9	10-12, 11
AS-to-ODF length	34-50, 40	15-41, 37	37-43, 39	32-47, 43	41-49, 45
AS-to-PV length	61-71, 66	62-69, 65	67-72, 69	67-73, 69	63-70, 68
Yolk length [b]	33-63, 47	37-52, 44	48-62, 52	42-66, 51	0-57, 43
Pectoral-fin length [c]	3-13, 8	4-12, 9	3-10, 6	2-10, 7	4-12, 8
Depth at OD [b]	10-23, 15	10-16, 12	13-17, 15	11-16, 13	10-16, 13
Width at OD [b]	5-14, 7	5-7, 6	7-9, 9	5-11, 8	5-8, 7
Max. yolk depth [b]	5-28, 14	4-18, 9	9-18, 12	8-23, 14	0-19, 12
Max. yolk width [b]	7-30, 15	6-19, 11	11-24, 15	9-22, 14	0-22, 14
Flexion mesolarvae					
Eye diameter, % HL [a]	28-37, 33	27-38, 33	28-42, 33	31-37, 34	36-40, 38
AS-to-AE length	2-5, 3	2-4, 3	3-5, 4	3-3, 3	3-4, 3
AS-to-PE length	8-11, 10	8-10, 9	9-12, 10	9-10, 10	11-13, 11
AS-to-OP1 length	18-22, 20	19-21, 20	19-22, 21	20-20, 20	20-24, 22
AS-to-OPAF length	26-39, 32	24-30, 26	29-36, 32	25-29, 27	30-44, 35
AS-to-ODF length	36-44, 40	25-41, 38	40-47, 43	43-45, 44	43-54, 47
AS-to-PV length	61-68, 65	62-67, 64	64-70, 67	67-68, 67	63-67, 65
Yolk length	0-44, 31	0-29, 7	0-45, 25	0-48, 27	0-35, 7
Pectoral-fin length	7-14, 12	12-13, 12	10-13, 11	11-12, 12	11-13, 12
Depth at OP1	12-17, 14	11-13, 12	12-15, 14	13-14, 13	12-15, 14
Depth at OD [d]	10-14, 12	8-11, 10	10-13, 12	11-11, 11	10-13, 11
Depth at BPV	7-9, 8	6-8, 7	8-10, 8	8-9, 8	8-11, 9
Width at BPE	12-16, 14	10-12, 11	10-14, 12	12-13, 12	13-15, 14
Width at OP1	9-14, 11	7-10, 9	9-13, 11	9-10, 10	8-11, 9
Width at OD [d]	5-7, 6	4-6, 5	5-8, 6	6-6, 6	6-8, 6
Max. yolk depth	0-16, 7	0-6, 1	0-10, 4	0-10, 4	0-5, 1
Max. yolk width	0-13, 8	0-7, 2	0-11, 6	0-11, 7	0-7, 1
Postflexion mesolarvae					
Eye diameter, % HL [a]	26-37, 32	28-39, 33	25-36, 30	31-37, 34	31-38, 34
AS-to-AE length	2-5, 4	2-3, 3	3-6, 4	3-5, 4	3-6, 5
AS-to-PE length	9-12, 11	8-11, 10	10-13, 12	9-13, 11	11-15, 13
AS-to-OP1 length	19-25, 22	20-24, 22	21-26, 24	20-25, 22	22-27, 24
AS-to-OP2 length	41-48, 45	44-44, 44 [h]	47-50, 48	50 [i]	48-49, 48 [h]
AS-to-OPAF length	26-35, 30	27-32, 29	25-39, 33	27-34, 29	30-48, 38
AS-to-PV length	64-70, 67	66-70, 67	66-71, 69	67-74, 70	65-70, 68
Yolk length	0-26, 4	0	0-32, 1	0	0
Pectoral-fin length	12-16, 14	11-14, 12	11-15, 13	11-15, 13	11-15, 13
Dorsal-fin-base length [e,f]	11-13, 12	11-12, 11	9-13, 11	10-11, 10	8-13, 11
Depth at OP1	12-19, 15	13-16, 15	12-19, 16	13-17, 15	15-21, 17
Depth at OD	9-19, 12	10-14, 11	10-16, 12	10-14, 11	12-14, 13
Depth at BPV	7-12, 8	7-10, 8	8-11, 9	7-12, 8	9-12, 10
Width at BPE	12-18, 15	11-16, 13	13-16, 14	12-15, 13	14-16, 15
Width at OP1	12-17, 12	9-14, 11	11-15, 13	9-12, 10	10-16, 12
Width at OD	5-11, 6	4-8, 6	5-9, 7	5-8, 6	6-9, 7
Max. yolk depth	0-6, 1	0	0-2, 0	0	0
Max. yolk width	0-8, 1	0	0-9, 0	0	0
Metalarvae					
Eye diameter, % HL [a]	25-32, 28	26-35, 30	22-34, 28	25-32, 29	26-38, 32
AS-to-AE length	5-7, 5	3-6, 5	4-8, 6	5-9, 6	4-6, 5
AS-to-PE length	11-14, 13	10-14, 12	11-15, 13	12-18, 14	12-15, 13
AS-to-OP1 length	24-28, 26	23-28, 25	23-29, 27	24-29, 26	23-28, 25
AS-to-OP2 length	45-50, 47	44-49, 47	47-54, 51	49-54, 52	48-54, 50

(continued)

Table 68. Continued.

Developmental Phase Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
AS-to-OD length	48-54, 51	49-54, 52	51-58, 54	51-57, 55	51-58, 55
AS-to-ID length	61-68, 65	63-67, 65	63-69, 66	63-68, 66	65-69, 67
AS-to-PV length	63-69, 66	62-69, 65	63-71, 67	65-72, 68	63-69, 66
AS-to-IA length	72-79, 76	74-78, 77	74-81, 77	75-82, 79	72-77, 74
Caudal-fin length [g]	18-30, 26	16-26, 22	16-28, 22	20-30, 24	14-24, 19
Pectoral-fin length	13-20, 16	11-16, 14	12-17, 15	11-17, 15	11-18, 14
Pelvic-fin length	5-16, 12	3-15, 9	3-13, 7	4-14, 9	2-13, 7
Dorsal-fin-base length [f]	12-15, 14	11-15, 13	9-14, 12	10-13, 11	9-13, 11
Depth at BPE	15-18, 17	14-18, 16	14-18, 16	14-17, 15	15-18, 17
Depth at OP1	19-25, 22	16-23, 20	17-22, 20	15-20, 17	17-23, 20
Depth at OD	16-27, 21	15-24, 19	13-21, 17	14-19, 16	13-21, 17
Depth at BPV	11-18, 14	9-18, 14	10-15, 13	11-15, 13	10-16, 13
Depth at AMPM	6-9, 8	6-7, 7	6-9, 7	7-9, 8	6-10, 8
Width at BPE	15-21, 18	14-17, 15	15-18, 16	13-16, 15	15-19, 17
Width at OP1	15-22, 19	13-18, 16	12-19, 16	11-15, 13	12-18, 14
Width at OD	10-19, 15	7-18, 12	8-16, 10	8-12, 10	7-13, 10
Width at BPV	8-13, 11	6-13, 10	6-11, 8	6-11, 8	6-11, 9
Width at AMPM	3-5, 4	3-5, 3	2-5, 4	3-5, 4	2-5, 4
Juveniles ≤40 mm SL					
Eye diameter, % HL [a]	20-31, 25	23-34, 27	23-35, 27	23-31, 27	23-35, 28
AS-to-AE length	4-8, 6	4-6, 5	5-8, 6	5-8, 6	4-9, 6
AS-to-PE length	11-14, 13	10-13, 12	12-15, 14	12-16, 14	10-15, 13
AS-to-OP1 length	22-28, 25	22-26, 24	23-29, 27	24-30, 26	21-28, 25
AS-to-OP2 length	43-49, 46	44-47, 45	46-53, 50	49-54, 52	47-53, 50
AS-to-OD length	46-53, 50	47-53, 51	49-57, 53	53-56, 54	50-57, 54
AS-to-ID length	60-68, 64	61-66, 64	62-69, 65	63-68, 66	62-69, 65
AS-to-PV length	59-67, 63	60-65, 63	61-68, 65	64-69, 67	59-65, 63
AS-to-IA length	73-78, 76	73-78, 76	74-80, 76	76-82, 79	70-77, 73
AS-to-AFC length	108-115, 113	108-114, 112	108-116, 112	110-116, 113	109-115, 112
Caudal-fin length [g]	21-32, 27	21-28, 25	20-29, 25	23-33, 28	17-25, 21
Pectoral-fin length	15-22, 18	15-20, 17	14-18, 16	13-19, 16	13-23, 17
Pelvic-fin length	13-18, 16	14-18, 16	9-17, 12	11-18, 15	10-16, 13
Dorsal-fin length	21-28, 24	20-24, 22	18-23, 20	18-25, 22	16-24, 21
Anal-fin length	17-23, 20	18-22, 20	15-21, 18	14-21, 18	15-22, 19
Dorsal-fin-base length [f]	12-16, 14	12-15, 14	10-15, 12	10-14, 11	10-15, 12
Depth at BPE	14-19, 16	14-17, 15	14-19, 16	13-16, 15	13-18, 16
Depth at OP1	19-26, 23	20-23, 22	19-23, 21	17-20, 18	18-24, 21
Depth at OD	20-31, 25	20-26, 23	18-22, 20	17-21, 19	18-23, 20
Depth at BPV	14-20, 17	15-20, 18	13-18, 15	13-17, 15	13-19, 16
Depth at AMPM	6-8, 7	5-7, 6	7-10, 8	8-9, 9	9-12, 10
Width at BPE	13-21, 17	14-17, 15	13-18, 16	13-16, 14	12-18, 15
Width at OP1	15-23, 20	16-20, 18	13-19, 16	12-17, 15	13-21, 16
Width at OD	11-24, 19	15-21, 17	10-17, 13	10-16, 13	11-18, 14
Width at BPV	8-16, 13	10-14, 13	8-14, 11	8-14, 11	9-15, 11
Width at AMPM	3-5, 4	3-5, 4	2-5, 4	2-5, 4	3-7, 6

[a] Eye diameter = (AS to PE)-(AS to AE).
[b] Ignore differences in maximum values because they may be affected by developmental state at hatching.
[c] Ignore differences in minimum values because they may be affected by developmental state at hatching.
[d] OD for protolarvae and early flexion mesolarvae is approximated at one-half of standard length (AS to PHP).
[e] Applicable only to specimens with a full complement of dorsal-fin pterygiophores or principal rays.
[f] Dorsal-fin base = (AS to ID)-(AS to OD).
[g] Caudal-fin length = (AS to PC)-(AS to PHP), total length minus standard length.
[h] N = 2.
[i] N = 1.

Table 69. Comparison of the more diagnostic differences in morphometrics for larvae and juveniles (≤40 mm SL) of the more common non-native cyprinids of the Upper Colorado River Basin. (Except as indicated, all data are percentages of standard length, % SL, presented as ranges followed by means. HL = head length measured to the origin of the pectoral fin, AS to OP1. See Figure 4 for other abbreviations and methods of measurement.)

Developmental Phase Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Protolarvae					
Eye diameter [a]	6-8, 7	6-8, 7	6-9, 8	7-8, 7	6-8, 7
AS-to-PE length	9-13, 11	8-12, 10	9-13, 11	8-12, 10	9-11, 10
AS-to-ODF length	37-47, 42	33-49, 41	33-46, 39	38-45, 41	42-52, 46
AS-to-PV length	70-75, 72	61-70, 64	59-65, 63	60-68, 65	62-72, 66
Yolk length [b]	0-59, 42	0-57, 23	0-49, 21	0-54, 28	0-62, 45
Pectoral-fin length [c]	4-14, 11	6-17, 11	4-16, 11	4-15, 10	0-12, 6
Depth at OD[b]	11-16, 13	10-14, 12	9-14, 11	10-12, 11	9-16, 13
Width at OD [b]	5-10, 7	5-9, 6	4-8, 6	5-7, 6	5-10, 8
Max. yolk depth [b]	0-23, 11	0-22, 6	0-15, 5	0-20, 8	0-26, 12
Max. yolk width [b]	0-25, 11	0-23, 9	0-17, 6	0-18, 8	0-28, 14
Flexion mesolarvae					
Eye diameter, % HL [a]	29-33, 31	32-43, 36	31-42, 36	31-41, 36	31-42, 36
AS-to-AE length	4-7, 5	2-5, 3	2-5, 3	2-4, 3	2-4, 3
AS-to-PE length	11-15, 13	9-13, 10	10-12, 11	10-12, 11	9-12, 10
AS-to-OP1 length	22-26, 24	19-23, 21	20-23, 22	20-21, 20	19-23, 20
AS-to-OPAF length	31-45, 37	34-41, 37	32-42, 37	30-34, 32	25-35, 28
AS-to-ODF length	44-49, 46	38-49, 45	37-49, 42	41-44, 43	42-57, 47
AS-to-PV length	70-75, 74	61-67, 64	62-66, 64	64-66, 65	62-69, 65
Yolk length	0	0	0	0	0
Pectoral-fin length	12-15, 14	10-15, 13	12-14, 13	11-12, 12	10-13, 12
Depth at OP1	16-20, 18	11-14, 13	12-14, 13	12-15, 13	11-15, 13
Depth at OD[d]	11-16, 12	10-15, 12	10-14, 12	9-13, 11	9-13, 10
Depth at BPV	6-8, 7	8-13, 9	7-10, 8	7-8, 8	7-9, 8
Width at BPE	13-16, 15	12-14, 13	12-14, 13	12-13, 12	10-13, 12
Width at OP1	10-13, 11	9-13, 10	8-11, 10	8-10, 9	6-11, 9
Width at OD[d]	5-8, 7	5-8, 6	5-7, 6	5-8, 6	4-6, 5
Max. yolk depth	0	0	0	0	0
Max. yolk width	0	0	0	0	0
Postflexion mesolarvae					
Eye diameter, % HL [a]	25-33, 29	29-38, 34	28-39, 34	31-39, 34	32-40, 35
AS-to-AE length	5-7, 6	3-5, 4	3-4, 4	3-5, 4	3-5, 4
AS-to-PE length	13-17, 15	11-13, 12	11-13, 12	10-13, 12	11-13, 11
AS-to-OP1 length	26-33, 29	21-24, 23	21-27, 23	21-24, 23	21-26, 23
AS-to-OP2 length	49-55, 52	48 [h]	47 [h]	48-49, 49	44-44, 44 [i]
AS-to-OPAF length	35-57, 43	29-40, 37	34-45, 37	35-39, 36	26-38, 31
AS-to-PV length	74-78, 76	65-67, 66	64-68, 66	68-72, 70	65-69, 66
Yolk length	0	0	0	0	0
Pectoral-fin length	10-18, 13	11-16, 14	12-15, 14	11-14, 12	11-14, 13
Dorsal-fin-base length [e,f]	–	11-14, 12	11-13, 12	10-13, 12	12-13, 13
Depth at OP1	19-27, 23	14-16, 15	15-16, 15	15-19, 17	14-17, 16
Depth at OD	13-25, 20	12-15, 13	13-15, 14	11-17, 15	11-14, 12
Depth at BPV	7-15, 11	9-12, 10	9-10, 9	8-11, 9	8-11, 9
Width at BPE	15-20, 18	12-15, 13	13-15, 15	13-15, 14	12-15, 13
Width at OP1	11-17, 15	10-11, 10	10-12, 11	10-13, 12	9-13, 11
Width at OD	7-15, 11	6-8, 7	6-8, 7	6-10, 8	6-7, 7
Max. yolk depth	0	0	0	0	0
Max. yolk width	0	0	0	0	0
Metalarvae					
Eye diameter, % HL [a]	24-32, 27	30-40, 33	28-40, 33	27-37, 31	29-39, 34
AS-to-AE length	6-9, 7	4-7, 5	3-6, 5	4-5, 5	3-7, 5
AS-to-PE length	13-18, 16	12-15, 13	11-14, 13	11-15, 13	11-16, 14
AS-to-OP1 length	29-35, 32	22-28, 25	23-28, 26	25-28, 26	22-28, 25
AS-to-OP2 length	50-55, 52	47-51, 49	47-51, 49	49-53, 51	44-52, 49
AS-to-OD length	47-52, 49	49-53, 52	47-50, 49	51-56, 52	52-58, 55

(continued)

Table 69. Continued.

Developmental Phase Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
AS-to-ID length	79-83, 81	63-67, 65	59-64, 62	63-69, 65	62-70, 66
AS-to-PV length	72-77, 75	61-68, 65	63-68, 66	67-71, 69	62-68, 65
AS-to-IA length	80-84, 83	74-78, 76	73-77, 75	74-78, 76	75-81, 79
Caudal-fin length [g]	18-27, 22	15-26, 20	13-25, 20	14-22, 18	14-25, 21
Pectoral-fin length	12-17, 14	11-18, 14	13-19, 16	11-15, 13	11-19, 14
Pelvic-fin length	8-13, 10	3-13, 8	4-12, 8	4-12, 7	2-14, 9
Dorsal-fin-base length [f]	30-36, 32	11-17, 13	10-14, 13	12-14, 13	9-16, 12
Depth at BPE	20-24, 22	12-18, 15	13-17, 15	14-18, 16	14-18, 17
Depth at OP1	24-30, 27	14-21, 17	14-19, 17	17-22, 20	16-22, 19
Depth at OD	23-30, 27	14-19, 16	13-21, 17	13-22, 17	12-21, 17
Depth at BPV	13-17, 15	11-15, 13	9-15, 12	9-14, 12	9-18, 14
Depth at AMPM	8-12, 10	7-10, 8	6-10, 8	7-10, 9	6-9, 8
Width at BPE	19-20, 20	12-16, 15	14-18, 16	15-19, 16	13-16, 14
Width at OP1	16-21, 18	11-14, 12	10-17, 13	11-18, 15	10-15, 13
Width at OD	11-17, 15	8-11, 9	7-15, 11	9-13, 11	6-13, 10
Width at BPV	8-12, 9	6-9, 8	5-10, 8	6-9, 8	5-10, 8
Width at AMPM	3-6, 5	2-5, 4	2-5, 3	4-6, 5	3-6, 4
Juveniles ≤40 mm SL					
Eye diameter, % HL [a]	22-31, 26	21-38, 31	24-36, 30	25-34, 29	26-40, 34
AS-to-AE length	7-11, 9	4-8, 6	4-7, 6	4-7, 5	5-7, 6
AS-to-PE length	14-19, 17	11-15, 13	11-16, 13	11-15, 13	12-16, 13
AS-to-OP1 length	29-34, 31	22-28, 25	23-29, 26	23-27, 25	21-26, 23
AS-to-OP2 length	48-56, 53	46-51, 48	46-52, 49	49-55, 52	45-51, 48
AS-to-OD length	46-51, 49	47-52, 50	47-52, 49	49-54, 51	53-56, 54
AS-to-ID length	80-86, 82	60-67, 63	58-63, 61	63-66, 64	63-68, 66
AS-to-PV length	72-77, 75	60-64, 62	62-66, 63	65-69, 67	61-66, 63
AS-to-IA length	80-86, 83	73-78, 76	72-77, 74	73-78, 75	75-81, 78
AS-to-AFC length	109-116, 112	111-118, 114	113-122, 116	110-117, 114	109-117, 112
Caudal-fin length [g]	17-27, 23	20-29, 25	21-32, 26	18-26, 22	19-27, 23
Pectoral-fin length	12-19, 16	15-23, 19	16-21, 18	13-20, 16	13-20, 17
Pelvic-fin length	11-17, 14	11-17, 14	11-17, 15	9-17, 13	10-15, 13
Dorsal-fin length	35-41, 38	20-24, 22	20-26, 23	18-24, 21	18-21, 20
Anal-fin length	14-19, 17	17-23, 20	16-20, 18	13-18, 15	18-22, 20
Dorsal-fin-base length [f]	31-37, 34	10-16, 12	10-14, 12	11-14, 13	9-14, 11
Depth at BPE	21-25, 23	14-18, 16	14-18, 16	16-19, 17	15-18, 17
Depth at OP1	28-35, 31	17-24, 20	18-23, 20	19-24, 22	19-23, 21
Depth at OD	30-37, 33	17-25, 20	18-25, 21	18-25, 21	16-23, 20
Depth at BPV	17-23, 20	13-20, 17	13-19, 16	12-17, 14	15-21, 17
Depth at AMPM	11-13, 12	8-12, 10	8-12, 10	9-12, 10	7-10, 9
Width at BPE	18-21, 19	12-16, 14	13-17, 15	14-16, 15	13-15, 14
Width at OP1	18-24, 21	11-16, 14	13-18, 16	14-19, 16	12-16, 14
Width at OD	16-22, 19	9-17, 12	12-18, 15	11-18, 14	10-15, 12
Width at BPV	8-17, 12	8-14, 10	9-15, 11	7-12, 10	8-13, 10
Width at AMPM	3-9, 6	3-7, 4	3-7, 5	4-6, 5	4-6, 5

[a] Eye diameter = (AS to PE)-(AS to AE).
[b] Ignore differences in maximum values because they may be affected by developmental state at hatching.
[c] Ignore differences in minimum values because they may be affected by developmental state at hatching.
[d] OD for protolarvae and early flexion mesolarvae is approximated at one-half of standard length (AS to PHP).
[e] Applicable only to specimens with a full complement of dorsal-fin pterygiophores or principal rays.
[f] Dorsal-fin base = (AS to ID)-(AS to OD).
[g] Caudal-fin length = (AS to PC)-(AS to PHP), total length minus standard length.
[h] N = 1.
[i] N = 2.

Table 70. Comparison of the more diagnostic differences in morphometrics for larvae and juveniles (≤40 mm SL) of the less common non-native cyprinids of the Upper Colorado River Basin. (Except as indicated, all data are percentages of standard length, % SL, presented as ranges followed by means. HL = head length measured to the origin of the pectoral fin, AS to OP1. See Figure 4 for other abbreviations and methods of measurement.)

Developmental Phase Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
Protolarvae					
Eye diameter [a]	5-8, 7	7-9, 8	5-8, 7	7-9, 8	5-8, 7
AS-to-PE length	8-11, 10	8-11, 10	8-12, 9	10-12, 11	8-11, 10
AS-to-ODF length	30-44, 39	35-44, 39	37-50, 42	39-48, 44	43-50, 47
AS-to-PV length	66-72, 68	67-73, 70	64-71, 66	64-69, 67	66-74, 71
Yolk length [b]	0-61, 36	0-62, 34	0-56, 25	29-57, 46	6-64, 51
Pectoral-fin length [c]	3-12, 9	2-12, 8	0-13, 7	4-11, 7	0-9, 4
Depth at OD[b]	9-15, 11	7-13, 10	8-13, 10	11-18, 14	12-14, 13
Width at OD [b]	5-9, 6	4-7, 5	4-7, 5	6-10, 8	6-9, 8
Max. yolk depth [b]	0-18, 7	0-16, 6	0-19, 6	4-21, 13	1-19, 11
Max. yolk width [b]	0-21, 8	0-18, 7	0-19, 7	7-24, 15	1-22, 13
Flexion mesolarvae					
Eye diameter, % HL [a]	31-36, 33	35-41, 38	30-36, 34	33-40, 37	37-44, 41
AS-to-AE length	3-3, 3	2-4, 3	3-4, 4	3-5, 4	2-3, 3
AS-to-PE length	9-11, 10	10-12, 11	9-12, 11	11-14, 12	9-11, 11
AS-to-OP1 length	20-22, 21	20-22, 22	19-22, 21	20-23, 21	19-21, 20
AS-to-OPAF length	24-33, 30	30-32, 31	29-31, 30	32-36, 34	26-31, 28
AS-to-ODF length	39-44, 42	39-44, 41	41-54, 47	40-46, 44	45-48, 47
AS-to-PV length	67-68, 68	67-71, 70	64-69, 67	64-69, 65	67-69, 68
Yolk length	0	0	0	0	0-40, 16
Pectoral-fin length	11-13, 12	11-15, 13	10-14, 12	13-14, 14	9-14, 12
Depth at OP1	12-15, 13	13-16, 15	11-14, 13	15-17, 15	12-14, 13
Depth at OD[d]	9-11, 10	9-12, 11	10-11, 10	11-12, 12	10-11, 10
Depth at BPV	6-7, 7	6-8, 7	8-9, 8	8-9, 8	7-8, 8
Width at BPE	11-15, 13	12-15, 13	12-12, 12	13-16, 14	12-15, 13
Width at OP1	8-11, 9	9-11, 10	9-11, 10	11-13, 12	9-11, 10
Width at OD[d]	5-6, 5	5-7, 6	6-7, 7	5-7, 6	5-7, 6
Max. yolk depth	0	0	0	0	0-7, 1
Max. yolk width	0	0	0	0	0-8, 2
Postflexion mesolarvae					
Eye diameter, % HL [a]	34-39, 36	29-37, 33	33-38, 35	30-37, 34	33-41, 37
AS-to-AE length	3-5, 3	3-5, 4	2-5, 4	3-5, 4	3-5, 3
AS-to-PE length	11-13,12	9-13, 12	9-13, 11	10-13, 12	11-13, 12
AS-to-OP1 length	22-26, 24	21-25, 23	19-24, 22	20-25, 23	21-24, 23
AS-to-OP2 length	49-51, 50	46-52, 49	47-48, 48	45-48, 46	47-50, 49
AS-to-OPAF length	33-38, 36	30-35, 33	28-35, 31	31-41, 34	27-32, 30
AS-to-PV length	67-72, 70	70-74, 71	66-68, 67	63-70, 67	68-71, 70
Yolk length	0	0	0	0	0
Pectoral-fin length	12-14, 13	10-13, 13	11-14, 12	11-16, 14	12-15, 14
Dorsal-fin-base length [e,f]	8-11, 10	8-12, 10	10-11, 10	8-11, 9	8-11, 9
Depth at OP1	15-19, 17	15-20, 17	13-16, 14	16-18, 17	14-17, 16
Depth at OD	10-16, 13	12-17, 14	10-14, 12	11-14, 13	10-14, 12
Depth at BPV	7-11, 9	8-11, 10	8-11, 9	8-11, 9	7-10, 9
Width at BPE	14-18, 16	13-16, 14	11-13, 13	14-16, 15	13-15, 14
Width at OP1	10-18, 13	10-15, 12	9-11, 10	11-14, 13	10-14, 13
Width at OD	6-10, 7	7-10, 8	6-9, 7	6-8, 7	6-8, 7
Max. yolk depth	0	0	0	0	0
Max. yolk width	0	0	0	0	0
Metalarvae					
Eye diameter, % HL [a]	26-40, 34	27-33, 30	28-35, 32	28-32, 31	28-39, 34
AS-to-AE length	3-6, 4	4-6, 5	4-6, 5	4-8, 5	2-6, 5
AS-to-PE length	12-15, 13	11-14, 13	12-13, 13	11-16, 13	11-15, 13
AS-to-OP1 length	24-30, 27	23-28, 26	23-27, 25	23-28, 25	22-26, 25
AS-to-OP2 length	49-55, 52	47-54, 51	46-49, 47	48-51, 50	47-52, 50
AS-to-OD length	49-54, 51	46-51, 50	53-58, 56	50-53, 52	51-56, 54

(continued)

Table 70. Continued.

Developmental Phase Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
AS-to-ID length	59-66, 62	58-63, 61	65-69, 67	62-64, 63	62-68, 65
AS-to-PV length	66-72, 68	67-72, 70	64-68, 67	66-69, 67	66-72, 69
AS-to-IA length	76-79, 77	77-82, 79	80-85, 82	74-77, 75	76-79, 78
Caudal-fin length [g]	15-25, 21	15-21, 19	15-26, 19	16-23, 20	13-19, 17
Pectoral-fin length	12-18, 15	13-17, 15	11-19, 13	14-17, 16	13-16, 14
Pelvic-fin length	4-13, 9	5-12, 9	4-13, 7	6-13, 9	3-10, 6
Dorsal-fin-base length [f]	9-13, 11	10-13, 11	10-14, 11	9-12, 11	9-14, 11
Depth at BPE	16-20, 18	15-19, 17	14-17, 15	15-18, 16	14-18, 16
Depth at OP1	18-22, 20	16-22, 20	15-19, 16	18-22, 19	17-22, 19
Depth at OD	14-23, 19	15-21, 19	14-20, 15	13-20, 17	12-21, 16
Depth at BPV	10-15, 13	10-15, 13	9-16, 12	9-14, 13	10-16, 12
Depth at AMPM	7-10, 8	7-10, 9	7-10, 8	7-11, 9	7-9, 8
Width at BPE	15-20, 17	15-17, 16	12-14, 13	16-17, 16	14-18, 17
Width at OP1	13-18, 16	12-16, 15	11-14, 12	13-18, 16	14-17, 16
Width at OD	8-16, 12	9-14, 12	8-9, 8	7-13, 10	7-12, 10
Width at BPV	7-10, 8	6-10, 8	6-8, 7	5-9, 8	6-9, 8
Width at AMPM	4-5, 5	4-6, 5	3-5, 4	4-5, 4	4-5, 4
Juveniles ≤40 mm SL					
Eye diameter, % HL [a]	26-40, 32	21-32, 28	26-31, 28	19-34, 25	21-32, 27
AS-to-AE length	4-6, 5	5-7, 6	5-6, 5	6-10, 8	5-7, 6
AS-to-PE length	12-14, 13	12-16, 14	11-15, 13	13-16, 14	12-14, 13
AS-to-OP1 length	25-28, 26	25-29, 27	22-25, 24	23-27, 26	24-28, 26
AS-to-OP2 length	49-54, 52	51-56, 54	44-47, 46	46-54, 50	46-54, 50
AS-to-OD length	48-53, 51	48-53, 51	52-55, 54	51-55, 53	52-57, 54
AS-to-ID length	60-65, 63	58-67, 62	64-68, 66	62-65, 64	64-68, 66
AS-to-PV length	65-70, 68	68-73, 70	62-65, 64	63-67, 65	64-69, 66
AS-to-IA length	75-81, 78	77-81, 79	79-82, 80	72-77, 75	74-79, 76
AS-to-AFC length	110-115, 113	113-116, 115	112-118, 114	114-118, 115	112-115, 114
Caudal-fin length [g]	19-25, 22	21-26, 23	25-28, 26	21-27, 23	19-23, 21
Pectoral-fin length	13-18, 16	15-19, 17	18-20, 19	17-23, 19	13-17, 15
Pelvic-fin length	12-15, 13	11-15, 13	15-17, 16	13-16, 14	10-14, 12
Dorsal-fin length	19-24, 21	19-22, 21	21-27, 24	19-24, 21	17-23, 20
Anal-fin length	13-18, 16	15-18, 16	22-25, 23	15-21, 19	16-18, 17
Dorsal-fin-base length [f]	10-14, 11	9-14, 11	10-11, 11	9-13, 11	10-15, 12
Depth at BPE	17-21, 19	16-19, 17	15-16, 16	14-18, 16	15-17, 16
Depth at OP1	22-24, 23	19-23, 22	19-21, 20	17-23, 20	20-22, 21
Depth at OD	21-26, 24	20-24, 22	20-23, 22	18-26, 20	18-21, 20
Depth at BPV	14-18, 17	12-17, 15	16-18, 17	14-19, 15	14-16, 15
Depth at AMPM	9-12, 10	8-12, 10	9-10, 10	9-13, 11	9-11, 10
Width at BPE	15-20, 17	14-18, 15	13-15, 13	14-18, 16	16-18, 17
Width at OP1	14-19, 17	13-18, 17	12-16, 13	17-22, 19	17-19, 18
Width at OD	12-20, 16	10-19, 16	11-12, 11	11-21, 15	13-16, 15
Width at BPV	9-13, 11	7-13, 10	7-10, 9	8-14, 11	9-14, 11
Width at AMPM	4-7, 5	3-6, 5	4-6, 4	5-7, 5	4-5, 5

[a] Eye diameter = (AS to PE)-(AS to AE).
[b] Ignore differences in maximum values because they may be affected by developmental state at hatching.
[c] Ignore differences in minimum values because they may be affected by developmental state at hatching.
[d] OD for protolarvae and early flexion mesolarvae is approximated at one-half of standard length (AS to PHP).
[e] Applicable only to specimens with a full complement of dorsal-fin pterygiophores or principal rays.
[f] Dorsal-fin base = (AS to ID)-(AS to OD).
[g] Caudal-fin length = (AS to PC)-(AS to PHP), total length minus standard length.

Size relative to acquisition of eye, body, and peritoneal pigmentation

Table 71. Comparison of size (mm SL) relative to melanophore pigmentation in the eyes, on the bodies for protolarvae, and on the lateral to ventral peritoneum for metalarvae (M) and early juveniles (J, ≤40 mm SL) of the native cyprinids of the Upper Colorado River Basin. (For peritoneal pigmentation, size is preceded by initials for the applicable developmental intervals. Rare values are given in parentheses.)

Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Eye pigmentation, protolarvae					
Unpigmented	6(7) [a]	5-6 [a]	[a]	[a]	(5) [a]
Light to moderate, in general	6-8 [a]	5-6 [a]	7-9 [a]	(5)6-7 [a]	(5-7) [a]
Dark	≥8	≥(6)7	≥(8)9	≥7 [a]	≥(5-)7
Light to moderate, patterned	–	–	–	–	5-7 [a, b]
Body pigmentation, protolarvae					
Unpigmented	6-8 [a]	5-7(8) [a]	7-8(9) [a]	(5)6-7 [a]	5 [a]
Sparsely to moderately pigmented with ≤12 melanophores on dorsum	7-8	7-8	8-9	(6)7-9	5-6 [a]
Moderately to well pigmented with ≥13 melanophores on dorsum	≥8	≥(7)8	≥(8)9	≥7	≥6
Peritoneal pigmentation, metalarvae and juveniles [c]					
Lateral aspects					
Absent	MJ ≤21	–	M ≤15	MJ ≤20(-24)	M ≤11
Sparse or patchy	MJ ≤21	M all	M ≤17(18)	MJ 11-20(-24)	MJ (9-)11-20(-24)
Uniformly speckled	–	M ≥14	–	–	M (13-15)
Uniformly light	–	–	–	–	–
Uniformly dark	–	–	–	–	–
Obscured by overlying tissues	J ≥21	MJ ≥(19)20	MJ ≥(17)18	MJ ≥21	MJ ≥(17)18
Ventrolateral aspects					
Absent	MJ ≤44	M ≤15	MJ ≤28	MJ ≤34(-38)	MJ ≤12(-18)
Sparse, patchy, or uniformly speckled	MJ 15-≤44	MJ ≤23	–	–	MJ (12)13-20(-24)
Uniformly light	–	–	–	–	–
Uniformly dark	–	–	–	–	–
Obscured by overlying tissues	J ≥31	MJ ≥22	J ≥24	J ≥(21-)23	J ≥21
Ventral aspects					
Absent	MJ ≤44	MJ ≤34	MJ ≤34	MJ ≤41	MJ ≤14(-18)
Sparse, patchy, or uniformly speckled	MJ (15)20-≤44	MJ 13-≤34	–	–	MJ (12)13-20(-32)
Uniformly light	–	–	–	–	–
Uniformly dark	–	–	–	–	–
Obscured by overlying tissues	J ≥34	J ≥(32-)34	J ≥34	J ≥41	J ≥21

[a] (Or) before hatching.
[b] Pigment forming or most intense as a diagonal band across the eye.
[c] Pigmentation of the peritoneum is subsurface and should not be confused with surface or cutaneous pigmentation; some near-surface pigmentation in protolarvae and mesolarvae becomes distinguishable as peritoneal pigment in metalarvae. Also, pigment is usually apparent in the dorsal and dorsolateral aspects of the peritoneum of smaller metalarvae (and earlier larvae) and should not be interpreted as pigment in the lateral region. In juveniles, possibly including specimens smaller than recorded, melanophore pigmentation in the peritoneum may be obscured by overlying muscle or, especially in living and alcohol-preserved specimens, integument with a silvery lining of iridophores.

Table 72. Comparison of size (mm SL) relative to melanophore pigmentation in the eyes, and on the bodies for protolarvae, and on the lateral to ventral peritoneum for metalarvae (M) and early juveniles (J, ≤40 mm SL) of the more common non-native cyprinids of the Upper Colorado River Basin. (For peritoneal pigmentation, size is preceded by initials for the applicable developmental intervals. Rare values are given in parentheses.)

Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Eye pigmentation, protolarvae					
Unpigmented	[a]	[a]	[a]	[a]	4 [a]
Light to moderate, in general	(4-5) [a]	3(4) [a]	3(4) [a]	(4) [a]	4(5) [a]
Dark	≥(4)5 [a]	≥(3)4	≥(3)4 [a]	≥4 [a]	≥(5)6
Light to moderate, patterned	–	–	(3-4) [a, b]	–	(4)5 [b]
Body pigmentation, protolarvae					
Unpigmented	[a]	3-4 [a]	[a]	[a]	4-5 [a]
Sparsely to moderately Pigmented with ≤12 melanophores on dorsum	(4) [a]	4-5 [c]	3-4 [a]	4-5(6) [a]	5-6
Moderately to well pigmented with ≥13 melanophores on dorsum	≥(4)5 [a]	– [c]	≥4	≥5-6	≥6
Peritoneal pigmentation, metalarvae and juveniles [d]					
Lateral aspects					
Absent	–	M ≤9(10)	MJ ≤15	M ≤10	–
Sparse or patchy	MJ ≤20(-23)	MJ (9)10-12(-14)	MJ 9-14(15)	MJ ≤16	MJ ≤28(29)
Uniformly speckled	J (21)22(-24)	(M)J 12-25(-29)	MJ 9-16(-31)	(J ≤32)	(MJ 11-27)
Uniformly light	–	J (25-)29-33(-35)	–	(M)J (11-)16-20(-22)	–
Uniformly dark	–	–	–	J ≤38(39)	–
Obscured by overlying tissues	(M)J ≥(15-)21	J ≥(15-)18	J ≥(15)16	J ≥(15-)19	J ≥(28)29
Ventrolateral aspects					
Absent	(J 22-24)	M ≤9(10)	MJ ≤16	M(J) ≤12(-15)	M ≤14(-20)
Sparse, patchy, or uniformly speckled	MJ ≤23(24)	MJ (9)10-25(-29)	MJ (10)11-16(-31)	MJ (8-)11-27(-32)	MJ ≤28(29)
Uniformly light	–	J (25-)29-33(-35)	–	(M)J (11-)15-24	–
Uniformly dark	–	–	–	J 19-34(-39)	–
Obscured by overlying tissues	J ≥(21-)24	J ≥(15-)18	J ≥(16)17	J >(24)25	J ≥(28)29
Ventral aspects					
Absent	MJ ≤22(-29)	MJ ≤14	MJ ≤16(-31)	MJ ≤16	MJ ≤22
Sparse, patchy, or uniformly speckled	MJ (13)14-22(-29)	J (14)15-33(-35)	MJ (10)11-32	MJ 11-27(-32)	MJ ≤28(29)
Uniformly light	–	–	–	J (16)17-33(34)	–
Uniformly dark	–	–	–	J 25-34(-39)	–
Obscured by overlying tissues	J ≥(22)23	J ≥(15-)18	J ≥(16-)31	J ≥(34)35	J ≥(27-)29

[a] (Or) before hatching.
[b] Pigment forming or most intense as a diagonal band across the eye.
[c] Most sparsely pigmented 4-mm and some 5-mm-SL protolarvae without melanophores on dorsum, and when present often only on dorsum of head; all 5-mm and some 6-mm-SL flexion mesolarvae with some but still fewer than 13 melanophores on dorsum (sometimes also only over head).
[d] Pigmentation of the peritoneum is subsurface and should not be confused with surface or cutaneous pigmentation; some near-surface pigmentation in protolarvae and mesolarvae becomes distinguishable as peritoneal pigment in metalarvae. Also, pigment is usually apparent in the dorsal and dorsolateral aspects of the peritoneum of smaller metalarvae (and earlier larvae) and should not be interpreted as pigment in the lateral region. In juveniles, possibly including specimens smaller than recorded, melanophore pigmentation in the peritoneum may be obscured by overlying muscle or, especially in living and alcohol-preserved specimens, integument with a silvery lining of iridophores.

Table 73. Comparison of size (mm SL) relative to melanophore pigmentation in the eyes, on the bodies for protolarvae, and on the lateral to ventral peritoneum for metalarvae (M) and early juveniles (J, ≤40 mm SL) of the less common non-native cyprinids of the Upper Colorado River Basin. (For peritoneal pigmentation, size is preceded by initials for the applicable developmental intervals. Rare values are given in parentheses.)

Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
Eye pigmentation, protolarvae					
Unpigmented	4-5 [a]	3(4) [a, b]	3(4) [a]	4(5) [a]	5(6) [a]
Light to moderate, in general	4-5 [a]	–	3-4 [a]	(4-6) [a]	(5)6(7)
Dark	≥(4)5	≥(4)5	≥4 [a]	≥(5)6	≥(6)7
Light to moderate, patterned	–	(3)4 [a, b]	–	(4)5(6) [a, c]	–
Body pigmentation, protolarvae					
Unpigmented	4-5 [a]	3(4) [a]	3(4) [a]	4-5(6) [a]	5-6(7) [a]
Sparsely to moderately pigmented with ≤12 melanophores on dorsum	4-5 [a]	(3)4 [a]	3-4 [a]	(4)5(6) [a]	6-7
Moderately to well pigmented with ≥13 melanophores on dorsum	≥(4)5	≥(3)4	≥4 [a]	≥(5)6	≥(6)7
Peritoneal pigmentation, metalarvae and juveniles [d]					
Lateral aspects					
Absent	–	–	M ≤16	M 10(11)	M 11(12)
Sparse or patchy	MJ ≤28(29)	M ≤11(12)	M ≤16	MJ ≤26	MJ ≤21(-24)
Uniformly speckled	MJ 12-20(-29)	MJ ≤17	–	(M 14-16)	–
Uniformly light	(J 25-31)	MJ ≤15(-17)	–	–	–
Uniformly dark	–	MJ ≥(15)16	–	–	–
Obscured by overlying tissues	J ≥29	J ≥(36-)39	J ≥16	J ≥(25-)27	J ≥(20)21
Ventrolateral aspects					
Absent	M ≤13	M ≤11(12)	M ≤16	M ≤11(12)	M ≤12
Sparse, patchy, or uniformly speckled	MJ ≤32(-38)	MJ ≤18(19)	J 16-22	MJ ≤26	MJ 12-32
Uniformly light	–	(MJ 15-17)	–	–	–
Uniformly dark	–	J ≥16	–	–	–
Obscured by overlying tissues	J ≥(32)33	J ≥(36-)39	J ≥(16-)23	J ≥(25-)27	J ≥(20)21
Ventral aspects					
Absent	M ≤15(16)	MJ ≤15	M ≤16	MJ ≤16(-26)	M ≤12(13)
Sparse, patchy, or uniformly specked	MJ 16-32(-38)	MJ 13-29	J ≥16	MJ 14-26	MJ (12)13-33(-40)
Uniformly light	–	J (16)17-23(-29)	–	–	–
Uniformly dark	–	J ≥17	–	–	–
Obscured by overlying tissues	J ≥(32)33	J ≥(36-)39	–	J ≥(25-)27	J ≥21

[a] (Or) before hatching.
[b] Unpigmented to moderately pigmented internally (retinal pigment) with several distinct melanophores scattered over the dorsal to dorso-lateral surfaces of the eyes (and head).
[c] Pigment forming or most intense as a diagonal band across the eye.
[d] Pigmentation of the peritoneum is subsurface and should not be confused with surface or cutaneous pigmentation; some near-surface pigmentation in protolarvae and mesolarvae becomes distinguishable as peritoneal pigment in metalarvae. Also, pigment is usually apparent in the dorsal and dorsolateral aspects of the peritoneum of smaller metalarvae (and earlier larvae) and should not be interpreted as pigment in the lateral region. In juveniles, possibly including specimens smaller than recorded, melanophore pigmentation in the peritoneum may be obscured by overlying muscle or, especially in living and alcohol-preserved specimens, integument with a silvery lining of iridophores.

Selected melanophore pigmentation patterns

Table 74. Comparison of selected melanophore pigmentation patterns for larvae and juveniles (≤40 mm SL) of the native cyprinids of the Upper Colorado River Basin. (Key to characters and their states is given below; character numbers correspond to those used in the computer-interactive key. Rare character states are enclosed in parentheses. NA = not applicable.)

Character number	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Protolarvae (after pigment is well established)					
25.	1	1	1	1	1
26.	1(2)	1	1	1	1-2
27.	1	NA,1	1	NA,1	(NA),1-2
28.	1-2	NA,(2,4)	1-2	NA,1	(NA),1-3
29.	3-4	NA,3	3-4	NA,3	(NA),3-4
35.	1-2	1-2	2-3	1-2,(3)	1-2,(3)
38.	1,(2)	1,(2)	2	1,(2-4)	1,(2-3)
39.	1,3	(1),3,6	1,2,3,6	1-3,(6)	1,3
43.	1-2,(7)	1	1,7,8	1,(5,7)	1,(2-4,7)
51.	1	1	1	1	1,(2)
52.	1	1	1	1	1
53.	1	1	1	1,(2)	1
54.	1	1	1	1	1
55.	1-2	1-2	1-2	1-2	1,(2),3
56.	1-2,(4,7)	1-2	1-2	1-2	1,(2)
57.	NA,2,(4)	NA,2	NA,2	NA,(3),4	NA,(2)
58.	NA,(1)	NA	NA	NA	NA
59.	NA,(1-2)	NA	NA	NA	NA
Flexion mesolarvae					
24.	1,(2-3)	1,(2),3	1-3	1	1-2,(3)
25.	1,(2-3)	1-2	1-2	1,(2)	1-2
26.	1-2	1-2	2	1-2	2
27.	1	1,(4)	1	1,(4)	1-2
28.	1,(2),3-4	1-2,(3)	2-3	(1),2-3	(1),2-3
29.	3-4	(2),3	4	(1),3-4	3-4
35.	2,(3)	2,(5)	2-3	(1-3),4	2-3
37.	1-2,(3)	1-3	1-3	1	1-2
38.	2-3	1-2,4	3-4	2,4	4,(5)
39.	(1-2),3,6	3,6	3,6	(1),3,6	3,6
40.	1	1	1	1-2	1-2
41.	1	1	1-2	1	(1),3
42.	1	1	1	1	(1),2-3
43.	(1),2,(6),7	1,(2),7	6-8	1-2,(5,7)	2,(5,7)
44.	1-2,(3)	1,(2)	1-3	1-2	1
51.	1	1	1	1	1
52.	1	1	1	1,(2)	1,(2)
53.	1	1	1	1,(2)	1
54.	1	1	1	1	1
55.	1-2	2-3	2-4	(1),2,(3)	(2),3,(5)
56.	1,(2),4	1-2	1-2,4,7	1,(2)	1
57.	NA,(2)	NA,2	NA,2,4	NA,(2)	NA
58.	NA	NA	NA,1	NA	NA
59.	NA,2,(3)	NA	NA,2,4	NA	NA
Postflexion mesolarvae					
24.	(1),2-3	3	(1),3	2-3	2-3
25.	(1),2-3	(1),2	1-2	1-4	1-2
27.	1-2	1	1	1	1-2
28.	3,(4),5	(2),3	3	3,5	2
29.	3-4	3-4	4	3-4	3-4
35.	2-3,(4)	2	1-2,(3)	(3),4	1-3
37.	2-3	(2),3	2-3	2-3	2-3
38.	2-4	4	(3),4	4	4-5
39.	(1-3),6	6-7	6	3,6	1,3,6
40.	1,(2-3)	1-2	1-2	1,3	1-2

(continued)

Table 74. Continued.

Character number	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
41.	1-2,(3)	1-2	1-3	1,(2),3	3
42.	1-2,(3)	1	1,(2-3)	1,(2),3	2-3
43.	(2),5-7,(8)	(5),6,(7)	(4,6),7	1,5-6	2-5
44.	2-3	2-3	2-3	3	1-2
45.	1	1	1	1-2	1
47.	1	1	1	1	1
51.	1-2	1	1	1-2	1
52.	1-2	1	1,(2)	1-2	1
53.	1	1	1	1-2	1
54.	1	1	1	1	1
55.	(1),2-3	2,(3)	1-2,(3)	1-2	1,3,5
56.	1,(2),4,(6-7)	4,(6)	1-2,4	1-2,4	1
57.	NA,2	NA,(2,4)	NA,2,(4)	NA,4	NA
58.	NA,(1)	NA,1	NA	NA	NA
59.	NA,(1),2-3	3,(4)	NA,3	NA,3	NA
63.	1,(2),3	1-2	1,(2),3	1,(2),3	1,(2),3
64.	1,(2)	1	1	1	1
65.	1-2	1,(2)	1-2	1	1-2
Metalarvae					
30.	1,3	1,3	1,3	(1),3	1
31.	1	1	1	1	1
32.	1-2	1-2	1,(2-4)	1-2	1-3(4)
33.	1,5	5,(6)	1,5,(6)	3,5	(2),3,5-6
34.	5	5	5	5	2,(3-4),5
36.	1	1	1	1	(1),2
37.	2-3	3	3	2-3	3
38.	4	4	4	4	4
41.	1-3	3	(1-2),3	1,(2-3)	3
42.	1,(2),3	(1-2),3	1,(2),3	1-2,(3)	3
44.	(1),2-3	(1),2-3	1-3	1-3	1
45.	1	1-2	1	1-2,(3)	1-2,(3)
46.	1	1	1,(2)	1	1
47.	1	1	1	1	1,3,(5)
51.	1-2	1,(2)	1,(2)	1	1
52.	1	1	1	1,(2)	1
53.	1	1	1	1	1
54.	1	1	1	1	1,(2)
55.	1-2	1-2,(3)	1	1	1,(2),5
56.	1-2,4	1-2,4	1,(4)	1	1,(2)
57.	NA,4	NA,4	NA	NA	NA,(4)
58.	NA	NA	NA	NA	NA
66.	1,3	1	1,(3)	1,(3)	1
67.	1,(2),3	1,(2),,3	1,(2-3)	1,(3)	1-2,(3)
68.	1	1	1	1,(2)	1
69.	1-3	2-3	1-2,(3)	1,(2-3)	1-2,(3)
70.	1,(2)	1-2	1	1,(2)	1,(2)
Juveniles					
30.	1	1	1	1,(3)	1,(2)
31.	1,(2)	1	1	1	1
32.	(1),2	2	(1),2	2	1,3-4
33.	5	5	5	(3),5	(3),4-5
34.	(1),5-6	1,5	1,5,(6)	(2),5	(1),2,(3-6)
36.	1	1	1	1	(1),2
45.	1-2,(3)	1,(2)	1,(2)	2-3	1,(2),3
46.	1	1	1	1	1
47.	1-2,(4)	1,(4)	1-2	1	(2-3),5
48.	(1),2-3	3	3	1,(2),3	1,(2),3
49.	1,(2),3	1-3	(1),2-3	1,3	2-3
50.	1-2	(1)-2	1	1,(2)	1
51.	1-2,(3)	1,(2)	1	1-2	1
52.	1	1	1	1	1

(continued)

Table 74. Continued.

Character number	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
53.	1	1	1	1	1
54.	1,(2)	1	1,(2)	1	1,(2)
55.	1,(2)	1	1	1	1,(2-3,5)
56.	1,(2)	1-2	1,(7)	1	1
57.	NA,(4)	NA,4	NA,(4)	NA	NA
58.	NA	NA	NA,(1)	NA	NA
66.	1	1	1	1,(3)	1,(2)
67.	1,3	3	1,(2),3	(1),2-3	1,(2),3
68.	1	1	1	1,(2)	1
69.	1,(2),3	3	1-3	1,(2),3	1,(2),3
70.	1-2	1-2	1	1-2	1-2

Key to pigment characters and states (applicable developmental phases in brackets – pr = protolarvae, fm = flexion mesolarvae, pm = postflexion mesolarvae, mt = metalarvae, ej = early juveniles):

24. Snout (above upper lip or margin of upper jaw and exclusive of nares) [fm-pm]
    1. unpigmented.
    2. pigmented with 1–5 melanophores.
    3. pigmented with 6 or more melanophores.
25. Pigmentation in or along margin of nares (nasal pits) [pr-pm]
    1. absent.
    2. sparse to moderate.
    3. extensive without strong emphasis on anterior and medial margins.
    4. extensive with strong emphasis on anterior and medial margins.
26. Dorsal surface of head [pr-fm]
    1. unpigmented or pigmented only over hindbrain (posterior to middle of eyes).
    2. pigmented over both mid- and hindbrain (anterior and posterior to middle of eyes).
27. Pigmentation across dorsal surface of body between head and last myomere (for specimens with greater than 12 melanophores on dorsal surface of body) [pr-pm]
    1. not scattered or sparsely scattered with at least a partial, distinct, lengthwise line or narrow band of melanophores on or lateral to dorsal midline.
    2. densely scattered over all or most of back with at least a partial, distinct, lengthwise line or narrow band of melanophores on or lateral to dorsal midline.
    3. densely scattered over all or most of back with no distinct, lengthwise lines or narrow bands of melanophores [characters 28 and 29 NA].
    4. otherwise (e.g., sparsely scattered with no distinct lengthwise lines).
28. Pigmentation on , or distinctly visible subsurface pigment below, dorsal midline behind head to origin of the dorsal fin (first pterygiophore) or its approximate future origin (about half of standard length) (for specimens with >12 melanophores on dorsal surface of body) [pr-pm; NA if character 27 is state 3]
    1. absent.
    2. present only as sparsely to moderately scattered melanophores not forming a distinct mid-line of any length.
    3. present in a short but distinct, continuous or discontinuous line or series of several well-spaced melanophores extending to no more than half the distance.
    4. present in a distinct but discontinuous line or series of at least several well-spaced melanophores extending to or nearly to full length.
    5. present in a distinct continuous or nearly continuous line to or nearly to full length.
29. Pigmentation on dorsal surfaces lateral to midline from shortly behind head to about 2/3 distance to last myomeres (for specimens with >12 melanophores on dorsal surface of body) [pr-pm; NA if character 27 is state 3]
    1. absent.
    2. sparsely to densely scattered with no distinct, lengthwise lines or narrow bands of melanophores on either side.
    3. scattered or not but with a distinct, short or discontinuous (well separated segments) line or narrow band of melanophores along one or both sides of dorsal midline.
    4. scattered or not but with a distinct, continuous or nearly continuous, full-length line or narrow band of melanophores along each side.
30. Pigmentation on dorsal surface of body between head and last myomere [mt-ej]
    1. scattered more or less evenly (with or without emphasis on distinct lines of melanophores or melanophore clusters on or lateral and parallel to dorsal midline).
    2. scattered in a blotchy or mottled pattern (with or without emphasis on distinct lines of melanophores or melanophore clusters on or lateral and parallel to dorsal midline).
    3. not notably scattered, mostly in two or three lines or narrow bands down the back.
31. Distinct spot or aggregation of pigment at origin of dorsal fin [mt-ej]
    1. absent (or indistinct).
    2. prominent.

(continued)

Table 74. Continued.

32. Pigment on or between pterygiophores of dorsal fin [mt-ej]
    1. absent or not obvious (essentially white).
    2. obvious (light to strong) without a distinct spot or dash.
    3. with an obvious spot or dash over posterior two-thirds to half of pterygiophores with some scattered pigment before and/or after.
    4. with an obvious spot or dash over posterior two-thirds to half of pterygiophores with obvious unpigmented spot or area immediately before and/or after.
33. Pigmentation under or immediately along base of dorsal fin [mt-ej]
    1. absent.
    2. present only under or along middle portion, often forming a distinctive "dash" of pigment.
    3. present only under or along middle and posterior portions.
    4. present under or along posterior two-thirds to full length of base with greater intensity and concentration at posterior end.
    5. present full length.
    6. otherwise.
34. Pigmentation under or immediately along base of anal fin [mt-ej]
    1. absent.
    2. present only under or along middle portion, often forming a distinctive "dash" of pigment.
    3. present only under or along middle and posterior portion.
    4. present under or along posterior two-thirds to full length of base with greater intensity and concentration at posterior end.
    5. present full length.
    6. otherwise.
35. Pigmentation around end of notochord or urostyle (uroneural) [pr-pm]
    1. absent.
    2. present but sparse—just a few melanophores.
    3. moderate but not prominent–does not stand out.
    4. present with a prominent series of melanophores along dorsal side only.
    5. present with a prominent series of melanophores along dorsal side, around end, and ventral side.
36. Dark bar of pigment on lateral surface of snout anterior to eye [mt-ej]
    1. absent.
    2. present (usually as a continuation of an intense lateral band from eye to tail).
37. Lateral surface of head posterior to eyes [fm-mt]
    1. unpigmented.
    2. pigmented with 1–5 melanophores.
    3. pigmented with more than 5 melanophores.
38. Pigmentation of horizontal myosepta [pr-mt]
    1. absent.
    2. sparse.
    3. moderate to strong line only along middle of body.
    4. moderate to strong line only along middle and posterior body.
    5. moderate to strong line along entire body (except sometimes immediately behind head).
    6. moderate to strong narrow band along entire body (except sometimes immediately behind head; precursor of a broader lateral band).
    7. mostly or entirely obscured by or incorporated in a moderate to wide lateral band.
39. Line or narrow band of internal to near-surface pigment over dorsal and dorsolateral surfaces of posterior gut and air bladder (if present), as visible from lateral view [pr-pm]
    1. absent, obscure, or indistinct (can't tell), except possibly over air bladder (if present).
    2. does not extend anteriorly to head.
    3. continues anteriorly to head but not beyond.
    4. continues anteriorly in head to or towards anterior margin of auditory vesicle behind eye and has obvious horizontal-y-forming branch extending down behind base of pectoral fin or bud then forward to throat region.
    5. continues anteriorly in head beyond anterior margin of auditory vesicle towards eye and has obvious horizontal-y-forming branch.
    6. continues anteriorly in head to or towards anterior margin of auditory vesicle behind eye but without obvious horizontal-y-forming branch.
    7. continues anteriorly in head beyond anterior margin of auditory vesicle towards eye but without obvious horizontal-y-forming branch.
40. Internal to near-surface pigmentation over dorsal to dorsolateral surfaces of gut or visceral cavity under air bladder as visible from lateral view [fm-pm]
    1. absent.
    2. sparse, up to several melanophores.
    3. moderate in coverage or intensity.
    4. continuous and dark.
41. Lateral surface of body above horizontal myosepta (lateral midline) and below dorsolateral surface (exclusive of pigmentation associated with horizontal myosepta) [fm-mt]
    1. unpigmented.
    2. pigmented with 1–5 melanophores.
    3. pigmented with more than 5 melanophores.

(continued)

Table 74. Continued.

42. Lateral surface of body below horizontal myosepta (or lateral midline) but anteriorly above gut and visceral cavity (exclusive of pigmentation associated with horizontal myosepta and air bladder) [fm-mt]
    1. unpigmented.
    2. pigmented with 1–5 melanophores.
    3. pigmented with more than 5 melanophores.
43. Pigmentation on lateral surface over visceral cavity (exclusive of, but often posteriorly overlying, internal near-surface pigment on dorsal and dorsolateral surfaces of gut) [pr-pm]
    1. absent.
    2. sparsely scattered, up to 5 melanophores not forming a line.
    3. moderately scattered with no distinct line or band.
    4. scattered anteriorly to below middle of air bladder with a line or narrow band extending along lateral to dorsal aspect of posterior gut from below posterior portion of air bladder (if present), or shortly behind, to or near vent.
    5. scattered or not, but with a continuous or discontinuous line or series of melanophores extending nearly horizontally from behind pectoral fin to under posterior portion of air bladder, then extending as a line or narrow band along lateral to dorsal aspect of posterior gut to or near vent.
    6. scattered or not, but with a continuous or discontinuous line or series of melanophores under posterior air bladder, continuing a diagonal series from heart on ventral or ventrolateral surface, and extending posteriorly as a line or narrow band along lateral to dorsal aspects of gut to or near vent.
    7. absent or sparsely scattered anteriorly with a line or narrow band extending along lateral to dorsal aspects of posterior gut from below posterior portion of air bladder, or shortly behind, to or near vent.
    8. otherwise.
44. Basicaudal spot (distinctive pigment spot on lower hypural bones) [fm-mt]
    1. absent.
    2. faint, or light.
    3. dark and prominent.
45. Caudal spot (distinctive spot of pigment at the middle base of the caudal fin, about the size of the pupil or larger, sometimes present as the enlarged end of the lateral band, sometimes extending onto the base of the middle caudal rays) [pm-ej]
    1. absent.
    2. faint, or light.
    3. dark and prominent.
46. Distinctive, large, square melanophores on lateral surface of body [mt-ej]
    1. absent.
    2. present (coverage few to extensive).
47. Lateral band of pigment from head to tail [pm-ej]
    1. absent.
    2. faint to dark and narrow on posteriorly, absent anteriorly.
    3. faint to moderate intensity, sometimes broadening anteriorly, not continuing on lateral surface of head.
    4. dark and narrow posteriorly, becoming much broader (diffuse) and slightly lighter to faint (dusky) anteriorly.
    5. dark and consistently wide for full body length, beginning on lateral surface of head, sometimes ending posteriorly in a slightly wider or disjunct caudal spot.
48. Pigmentation on lateral surfaces of body above bottom-of-eye level and anterior to vent (exclusive of melanophores associated with horizontal myosepta, air bladder, visceral cavity peritoneum, or gut) [ej]
    1. scattered only partially down to the horizontal myoseptum (lateral midline) or lateral band if present, leaving an unpigmented zone above all or most of the horizontal myosepta or lateral band.
    2. scattered fully and evenly down to the horizontal myoseptum or lateral band with few if any melanophores below the myoseptum or band.
    3. scattered evenly or in mottled pattern (continuous with dorsal and dorsolateral surface pattern) down to horizontal myoseptum or lateral band and at least partially below to bottom-of-eye level.
49. Pigmentation on lateral to ventrolateral surfaces of body below bottom-of-eye level (exclusive of melanophores associated with horizontal myosepta, air bladder, visceral cavity peritoneum, or gut) [ej]
    1. absent including caudal peduncle.
    2. absent except on caudal peduncle.
    3. present.
50. Pigmentation outlining scales [presence; ej]
    1. absent.
    2. light (barely evident).
    3. moderate.
    4. bold.
51. Pigmentation under chin (mid-ventral region of lower jaw) [pr-ej]
    1. absent.
    2. present with one melanophore or more but not in a midline row.
    3. present with two or more melanophores in a midline row.

(continued)

Table 74. Continued.

52. Melanophores on ventral to ventrolateral surfaces or margins of preopercles or opercles over branchiostegal rays (below to behind posterior half of eyes) [pr-ej]
    1. absent.
    2. present, but not consisting of or including a distinct oblique row of 3 or more melanophores near or along the margin of either preopercle.
    3. consisting of or including a distinct oblique row of 3 or more melanophores near or along the margin of one or both preopercles.
53. Melanophores on ventral surface anterior to heart in branchial (gular) region (between opercles and branchiostegal membranes) [pr-ej]
    1. absent.
    2. present.
54. Melanophores on ventral surface of heart region exclusive of outer margins [pr-ej]
    1. absent.
    2. present.
55. Internal (subsurface) pigmentation outlining heart cavity [pr-ej]
    1. absent (or obscured).
    2. sparse, or light with ≤5 melanophores.
    3. moderate, at least laterally.
    4. bold along lateral margins only.
    5. bold along lateral and posterior margins.
56. Pigmentation on ventral surface between heart and vent [pr-ej]
    1. absent [characters 57, 58, and 59 NA].
    2. present only as scattered melanophores over all or part of surface [characters 58 and 59 NA].
    3. present only as a partial to continuous line, narrow band, or series of well spaced melanophores along the ventral midline [characters 57 and 59 NA].
    4. present only as partial to continuous lines, narrow bands, or linear series of well-spaced melanophores laterally outlining at least the anterior visceral cavity from behind or lateral to the heart and extending posteriorly onto ventrolateral to lateral surfaces [characters 57 and 58 NA].
    5. present only as partial to continuous lines, narrow bands, or linear series of well-spaced melanophores both on the ventral midline and laterally outlining the anterior visceral cavity [character 57 NA].
    6. present as combination of scattered melanophores with a partial to continuous line, narrow band, or well-spaced linear series of melanophores on the ventral midline and/or outlining the anterior visceral cavity.
    7. otherwise.
57. Scattered pigmentation on ventral surface between heart and vent [pr-ej; NA if character 56 is state 1, 3, 4, or 5]
    1. absent.
    2. restricted to anterior region behind heart.
    3. widely spaced and covering most of ventral surface.
    4. otherwise.
58. Pigmentation along ventral midline from shortly behind heart region to near vent [pr-ej; NA if character 56 is state 1, 2, or 4]
    1. absent [potentially applicable only if character 56 is state 6].
    2. present only as a full or partial series of widely spaced melanophores.
    3. present as a full length (or nearly so) continuous or nearly continuous line or narrow band of melanophores.
    4. present as a continuous or nearly continuous line or narrow band of melanophores only under all or most of the preanal finfold.
    5. present as a short continuous or nearly continuous line or narrow band of melanophores extending from the heart towards the origin of the preanal finfold (sometimes in combination with oblique lines of pigment to each side forming a trident-like pattern).
    6. otherwise.
59. Ventral lines, narrow bands, or linear series of well-spaced melanophores laterally outlining at least the anterior visceral cavity from behind or lateral to the heart and extending posteriorly onto ventrolateral to lateral surfaces [pr-pm (generally obscured or lost in mt-ej); NA if character 56 is state 1, 2, or 3]
    1. absent [potentially applicable only if character 56 is state 6].
    2. present but continue only a short distance onto ventrolateral surfaces.
    3. continue onto ventrolateral and lateral surfaces and then along gut to vent.
    4. otherwise.
63. Pigmentation in developing dorsal fin [pm]
    1. absent.
    2. sparse with 5 or fewer melanophores.
    3. at least moderate with 6 or more melanophores.
64. Pigmentation in developing anal fin [pm]
    1. absent.
    2. present.
65. Pigmentation in developing pectoral fins [pm]
    1. absent.
    2. present.

(continued)

Table 74. Continued.

66. Pigmentation in dorsal fin [mt-ej]
    1. present to extensive along principal fin rays with few, if any, melanophores on membranes between rays (but might be present on membranes between branches of rays).
    2. extensive along principal fin rays and notably present (more than just a few melanophores) to extensive on at least a portion of membranes between some or all principal rays (might also be present on membranes between branches of rays).
    3. absent both along and between rays.
67. Pigmentation in anal fin (melanophores are sometimes very linear along margins of fin rays and easily overlooked) [mt-ej]
    1. absent.
    2. present but very light with 5 or fewer melanophores.
    3. present but more prominent with 6 or more melanophores.
68. Pigmentation in caudal fin [mt-ej]
    1. present to extensive along principal fin rays with few, if any, melanophores on membranes between principal rays (but might be present on membranes between branches of rays).
    2. extensive along principal fin rays and notably present (more than just a few melanophores) to extensive only on proximal portions of membranes between at least some principal rays (often part of caudal spot on or extending onto base of rays).
    3. extensive along principal fin rays and notably present (more than just a few melanophores) to extensive on middle or (and) distal portions of membranes between some or all principal rays (might also be present on membranes between branches).
    4. extensive along principal fin rays and notably present (more than just a few melanophores) to extensive over most of membranes (proximal to distal portions) between at least some principal rays.
    5. extensive along entire middle rays, and sometimes on membranes between, but only along, and sometimes between, middle to distal portions of principal rays above and below (proximal portions of these mostly unpigmented).
69. Pigmentation in pectoral fins [mt-ej]
    1. absent.
    2. present but very light with up to 5 melanophores.
    3. present but more prominent with greater than 5 melanophores.
70. Pigmentation in pelvic fins [mt-ej]
    1. absent.
    2. present (but seldom with more than a few melanophores).

Table 75. Comparison of selected melanophore pigmentation patterns for larvae and juveniles (≤40 mm SL) of the more common non-native cyprinids of the Upper Colorado River Basin. (See Table 74 for key to characters and their states; character numbers are those used in the computer-interactive key. Rare character states are enclosed in parentheses. NA = not applicable.)

Character number	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Protolarvae (after pigment is well established)					
25.	1-2	1	1	1,(2)	1
26.	2	1	1-2	1-2	1,(2)
27.	1,(2)	NA	NA,1	NA,1	NA,1
28.	1-2	NA	NA,1,(2-4)	NA,1(2)	NA,1
29.	(2),3,(4)	NA	NA,(2),3,(4)	NA,3,(4)	NA,(3),4
35.	1,3	1-2	1	1-3	1-2,(3)
38.	1,(2)	1,3	2-3,(5)	(1),2,4,(5)	1-2,(3)
39.	4-6	1-2	2-3,(6)	(1),2	1-2,(3),6
43.	(1),2-3	2,6-8	3-4,(7),8	2-3,(7)	1,(2),5,7
51.	1,(2)	1	1	1	1
52.	1	1	1	1,(2),3	1,(2)
53.	1,(2)	1-2	1	1	1
54.	1-2	1	1-2	1,(2)	1
55.	1-2	1-3	1-3,(4)	1,(2-4)	1-2,(5)
56.	1-2	2,4	2,6	(1),2,6	1,(7)
57.	NA,(2),3-4	NA,3-4	3-4	(NA),3-4	NA,(4)
58.	NA	NA	NA,(1,6)	NA,1,(4)	NA,(1,6)
59.	NA	NA,2	NA,4	NA,2	NA,(1)
Flexion mesolarvae					
24.	3	1	1-2	1-3	1,(2)
25.	1-3	1	1-2	1-2,(3)	1-2
26.	2	1-2	2	1-2	(1),2
27.	1-3	NA,1	1	NA,1,(2)	1
28.	NA,1-2	NA,3	1-2	NA,(2-4)	1,(2)
29.	NA,3-4	NA,4	3-4	NA,4	4
35.	3	1-2	1	1-2,(3)	(1),3
37.	2-3	1-2	2-3	2-3	2-3
38.	1-2,4	2-4	4-5	(4),5	2-4
39.	4-5	1-2	6	2-3	(2),6
40.	1-2	1	1	1	1-2
41.	1-3	1	1	1,(2),3	1
42.	1-3	1	1	1	1
43.	2-3,5,7-8	7	2-5	2,(3,6)	7
44.	1-3	1	1-2	1,(2-3)	1-2
51.	1-2	1-2	1	1-2,(3)	1,(2-3)
52.	1	1	1	3	1-3
53.	1	1-2	1-2	1-2	1-2
54.	1	1	1-2	1,(2)	1-2
55.	1-2	2-4	3	2,(3),4	(3),4-5
56.	2	2,4	2	(4),6	(1-2),3,7
57.	3	NA,2	3	(NA),3,(4)	NA,(1-2),4
58.	NA	NA	NA	(NA),1	NA,(1),5,(6)
59.	NA	NA,2-3	NA	2,(3)	NA,1
Postflexion mesolarvae					
24.	3	1	1-3	1-3	2-3
25.	2-3	1	1-2	1-2	(1),2
27.	2-3	1	1	1-3	1
28.	NA,2,5	3	3-4	1-3	1-2
29.	NA,2,4	1-3	3-4	2-4	4
35.	1,3	1	1	1-2	(1),3
37.	3	1-3	2-3	2-3	2-3
38.	2,4-5	2-4	2,4	4-5	4
39.	1,5	1	2-3,6	1-3,6	6
40.	1-3	1	1-2	1	1-2
41.	3	1	1	1-3	1-2

(continued)

Table 75. Continued.

Character number	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
42.	3	1	1	1-2	1
43.	1,3,5	7	4-5,8	1-4,6	(2),5-6,(7)
44.	3	1-3	1-2	1-3	2,(3)
45	1-3	1	1	1	1
47	1	1	1	1	1
51.	2	1-2	1	2-3	1-2
52.	1-3	1-2	1	2-3	(1),2,(3)
53.	1	1-2	1-2	1-2	1-2
54.	1	1	1-2	1-2	1-2
55.	2-3	2-3	2-3	1,3-5	(3),5
56.	1-2	2,4	2	2,6-7	1,(5),7
57.	NA,3	NA,2	3	1,3	NA,1
58.	NA	NA	NA	NA,1,6	NA,(5),6
59.	NA	NA,2	NA	NA,2-3	NA,1,3
63.	1-3	1	1-2	1-3	1
64.	1-2	1	1	1-2	1
65.	1-2	1	1-2	1-2	1-2
Metalarvae					
30.	1	3	1,3	1,3	1,3
31.	1	1	1	1	1
32.	2	1,(2)	1,4	1-2	1-2
33.	5	1,5-6	1-2,6	1,(3),5	5
34.	5	5	5	5	5
36.	1	1	1	1	1
37.	3	(1)2-3	2-3	3	3
38.	4-5	(3),4	4-5	4-5	(4),5
41.	3	1	1-2	1,(2),3	1-3
42.	3	1	1-2	1-3	1-3
44.	2-3	1-2,(3)	1-2	1-2	1,(2),3
45.	1(3)	1	1	1	1
46.	1	1	1	1	1
47.	1	1	1	1	1,3,(4)
51.	1-2	1-3	1	1-3	1-3
52.	1	1,(2)	1-2	(1-2),3	1-3
53.	1	1-2	1-2	1-2	1-2
54.	1	1	1	1-2	1-2
55.	1,(2-3)	1-3	2-3	1,(2),3	1,(2),3,5
56.	1,(2)	(1),4,(6-7)	1-2	1-2,6	1-3,6-7
57.	NA,(2)	NA,(1-2)	NA,3-4	NA,(2),3-4	1,(2),3,(4)
58.	NA	NA,1	NA	NA,1	5-6
66.	1-2	1	1,3	1	1,(3)
67.	(1),3	1-2,(3)	1	1-3	1-3
68.	1,3	1	1	1	1
69.	1,(2),3	1,(3)	1-3	1,(2),3	1-3
70.	1	1	1	1,(2)	1-2
Juveniles					
30.	1	1,3	1,3	1	1
31.	1	1	1-2	1	1
32.	2	1-2	(2),3-4	(1),2-3	1-2
33.	5	5,(6)	(1),2-4,(6)	3-5	5
34.	(1),5-6	(1),5	(1,3),4-5,(6)	1,3,5,(6)	5,(6)
36.	1	1	1	1	1,(2)
45.	1,(2-3)	1	1,(2),3	1-2,(3)	1-2
46.	1	1	1	1	1
47.	1	1-2	1-3	1,(2),3,5	(3),4-5
48.	3	1,(2),3	1-2,(3)	1,(2),3	1-3
49.	2-3	1,3	1-2	1,(2),3	1,3
50.	1-3	1,(2),3-4	1,(2),3,(4)	1-3,(4)	1-2,(3)
51.	1,(3)	1-3	1-2	1-3	1-2
52.	1	1	1-2	1-2,(3)	1,(3)

(continued)

Table 75. Continued.

Character number	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
53.	1	1,(2)	1,(2)	1-2	1
54.	1,(2)	1	1	1,(2)	1
55.	1	1	1,(2)	1,(2-3,5)	1
56.	1,(2)	1,(2,7)	1-2,7	1-2	1,(3)
57.	NA,(2)	NA,(1,4)	NA,(2),3-4	NA,3,(4)	NA
58.	NA	NA,(6)	NA,1	NA	NA,(6)
66.	2	1,(2)	1,3	1	1
67.	3	1-2,(3)	1,(2-3)	1,(2),3	(1),2-3
68.	3-4	1	1	1	1
69.	1-3	1,(2),3	1,(2),3	(1-2),3	(1-2),3
70.	1-2	1,(2)	1	1-2	(1),2

Table 76. Comparison of selected melanophore pigmentation patterns for larvae and juveniles (≤40 mm SL) of the less common non-native cyprinids of the Upper Colorado River Basin. (See Table 74 for key to characters and their states; character numbers are those used in the computer-interactive key. Rare character states are enclosed in parentheses. NA = not applicable.)

Character number	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
Protolarvae (after pigment is well established)					
25.	1	1,(2)	1	1	1
26.	1-2	(1),2	1-2	1-2	1-2
27.	(NA),1,(4)	(NA),1	NA,1	NA,1	1
28.	NA,1-2,(3)	(NA),1-2,(3)	NA,1-3	NA,2,(3,5)	1,(2)
29.	NA,(3),4	(NA),3-4	NA,3-4	NA,4	3-4
35.	1,(2),3	1,3,5	1,(2),5	1-2,(3)	1,(3)
38.	1-2	(1),2-3,(4-5)	1,(2),3	1,(2),3	1,(2),3,(5)
39.	3-4,6	(1-3),6,(7)	1,(2),7	1,(2),3,6	1-2,6
43.	(1),2,4-6	1-2,(7)	1-2,7	1-2,(5),6	1-2,(6)
51.	1	1	1	1	1
52.	1-2	1,(2),3	1	1	1
53.	1	1,(2)	1	1	1
54.	1-2	1-2	1-2	1-2	1,(2)
55.	1,(2),3,(4),5	1-2,4	1,(2-3,5)	1,3	1,(3)
56.	1,(2),4	1,(2),3,6	1,(2),3,(6)	1,(2),4,(5)	1,(2,6)
57.	NA,(2)	NA,2,(3-4)	NA,(2-3)	NA,(2)	NA,2
58.	NA	NA,(2),3,(5),6	NA,3,(4)	NA,(1,6)	NA,(1)
59.	NA,(2-3)	NA,1	NA,(1)	NA,(1-2),3	NA,(3)
Flexion mesolarvae					
24.	2-3	3	3	1(2)	1,(2)
25.	1	1-2	1-2	1-2	1-2
26.	2	2	2	2	2
27.	1	1	1	1	1
28.	2	2-3	1-3	(1),2,(4)	1-2
29.	4	4	(3),4	4	4
35.	2-3	3,(4)	(3),4-5	(1),2-3	2-4
37.	2-3	(2),3	2-3	(2),3	2-3
38.	1-2,4	3,(4),5	3-5	3-4	3,5
39.	3-4,6	6	(1,6),7	6	7
40.	1-2,(3-4)	1-2	1	1,(2)	1,(2)
41.	1	1,(2-3)	1	1	1,(2)
42.	1	1	1	1	1
43.	6	(3),5-7	3,(5),7,(8)	(2),5-6	(2),6-7,(8)
44.	1-2	1-2,(3)	1	1-2	1-2
51.	1-2	1-2	1-2,(3)	1,(2)	1-2,(3)
52.	1-2	3	(2),3	1,(2-3)	1-2,(3)
53.	1	1-2	(1),2	1-2	1-2
54.	1-2	2	2	1-2	1-2
55.	3,5	3	1-2	(3),5	3
56.	4,6	(3),6	3,(6)	1,(3),4-5	5-6
57.	NA,2	(NA),2,4	NA,(2)	NA	NA,2
58.	NA,1	(2),3,6	3,(4)	NA,5	5
59.	2-3	(NA),1,(3)	NA,(4)	NA,3	2-3
Postflexion mesolarvae					
24.	1-3	3	3	3	1-2,(3)
25.	1-2	2,(3)	(1),2-3	2-3	(1),2
27.	1	1-2	1-2	1-3	1,(2)
28.	3,(4-5)	2-3,(4),5	3-4	1-3,(5)	1-3
29.	4	4	4	3-4	4
35.	2-3	2-3	(3),4,(5)	(1),2-3	(2),3-4
37.	(2),3	3	(2)3	(2),3	(2),3
38.	2,(3),4	5	4-5	4-5	(3),4-5,(6),7
39.	(4),5-7	6	(1),7	6	7
40.	2-3	1-3	1-2	1-2	1-2
41.	1,(2),3	(1-2),3	1,(2),3	(1),2-3	1,(2),3

(continued)

Table 76. Continued.

Character number	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
42.	1	1-3	1,(2),3	1-2	1,(2),3
43.	6	(4),5-6,(7)	3,5,(7-8)	(4),5-6,(7)	6,(7)
44.	1-2,(3)	2-3	1-2	1-2,(3)	1
45	1	1	1	1,(2)	1-3
47	1	1	1	1	1,3,(4),5
51.	1,(2)	1-3	1-2,(3)	1-3	(1-2),3
52.	1-2	3	3	1-3	2-3
53.	1	1-2	1-2	1-2	(1),2
54.	1-2	2	2	1,(2)	1-2
55.	(3),5	(2),3,5	1,(2),3	3-5	3-5
56.	4	3,(5),6	3,5-6	(1-2),4-5,(6)	5-6
57.	NA	NA, 2,(4)	NA,2	NA,(2,4)	NA,2
58.	NA	(2),3,6	3,(4,6)	NA,(1),5	1,5,(6)
59.	3	NA,1,(2),3	NA,(1),3,(4)	NA,3	(2),3
63.	1-3	(1),2-3	1,(2),3	1-2,(3)	1,(2),3
64.	1	1-2	1-2	1	1-2
65.	1-2	2	1-2	1-2	1-2
Metalarvae					
30.	1,3	1	1,3	1,(3)	1,3
31.	1	1	1	1	1
32.	1,(2)	1-2	1,(2)	(2),3-4	(1),2
33.	(1),3,5,(6)	5-6	5	(2),5-6	(1),5
34.	5	5	5	5	5
36.	1	1	1	2	(1),2
37.	3	3	3	3	3
38.	4-5	4-5	4-5,(7)	4-6	7
41.	2-3	3	(1-2),3	(2),3	3
42.	1-3	(1-2),3	(1-2),3	2-3	3
44.	1-2	(1),2-3	1-2	1,(2)	1,(2)
45.	1	1	1	(1),2-3	2-3
46.	1-2	1	1	1	1
47.	1	1,(2)	(1),3-4	1,3,(5)	5
51.	1-3	3	(1),2-3	1-2,(3)	2-3
52.	1-2	3	(2),3	1-3	(2),3
53.	1	(1),2	1-2	1	1-2
54.	1-2	(1),2	2	1-2	1-2
55.	1,3,(4),5	1,(2-4),5	(1),2-3	1,3,(4),5	(1),2-3,(4)
56.	1-2,4,6	3,(5),6	(3),5-6	1,(2-3),4-5,(6)	(2-3),5-6
57.	NA,2-4	NA,(2-3),4	NA,2,(4)	NA,2	NA,2,(3)
58.	NA,1	2-3,6	3,(4)	NA,1,5	(NA),1,5
66.	1	1	1	1	1
67.	1	2-3	2-3	1-2	(2),3
68.	1	1	1	1,(5)	1,(2)
69.	1-2,(3)	2-3	(1),2-3	1-2	2-3
70.	1	1-2	1-2	1	1,(2)
Juveniles					
30.	1	1	1	1	1
31.	1	1	1	1	1
32.	(1),2	2	2	3-4	2
33.	5	5	5	2,(4),6	5
34.	(1,3),5	(3),5	4-5	1-2,(4),5-6	1,5,(6)
36.	1	1	1-2	2	2
45.	1	1	1	(1),2-3	2-3
46.	1,(2)	1	1	1	1
47.	1	1-3	3,5	(4),5	5
48.	3	3	1-3	1,(2),3	1-3
49.	1-3	1,3	1,3	1,(2),3	1-3
50.	1	1-3,(4)	1-3	1-3	2-3
51.	1-3	2-3	1-2	1,(2)	(1),2-3
52.	1,(2)	1-3	1-2	1,(2)	1,3

(continued)

Table 76. Continued.

Character number	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
53.	1	1-2	1-2	1	1
54.	1,(2)	1-2	1	1	1,(2)
55.	1,3,(4)	1,(2-3)	1	1,(3)	1,(3)
56.	1,(2)	1,(2),3,(7)	1	1,(4)	1,(2),3,(5)
57.	NA,(3)	NA,(4)	NA	NA	NA,(2)
58.	NA	NA,(2-3,6)	NA	NA	NA,2,(5)
66.	1	1	1	1	1
67.	1,(2),3	(2),3	3	1-3	(1),2-3
68.	1	1	1	1,(2,5)	1,(2)
69.	2-3	(2),3	3	1-3	(1-2),3
70.	1-2	1-2	1-2	1-2	1-2

Diagnostic eye, mouth, and fin position characters

Table 77. Comparison of diagnostic eye, mouth, and fin position characters for larvae and juveniles (≤40 mm SL) of the native cyprinids of the Upper Colorado River Basin. (Key to characters and their states is given below. Rare character states are enclosed in parentheses.)

Character	*Gila cypha*	*Gila elegans*	*Gila robusta*	*Ptychocheilus lucius*	*Rhinichthys osculus*
Eye Shape					
Protolarvae	(1),2-3	1-2	(1),2,(3)	1-2	1-2
Flexion Mesolarvae	2-3	1-3	(1),2-3	1-2,(3)	1-2,(3)
Postflexion Mesolarvae	3	2-3	(1),2-3	2-3	(2),3
Mouth Position					
Protolarvae	4-5	(2-3),4-5	4-5	(2),4-5	(3),4-5
Flexion Mesolarvae	2,4	2,(3)	2,(4)	2,(3-4)	2-4
Postflexion Mesolarvae	2-3,(4)	2	2	2	(2),3-4
Metalarvae	2-3	2,(3)	2,(3)	2,(3)	(2-3),4
Juveniles	(2),3-4	2	2	(2),3	4
Posterior Corner of Mouth					
Protolarvae	3-4	(2),3-4	3-4	3-4	3-4
Flexion Mesolarvae	3,(4)	2-3	2-3	(2),3	(2),3,(4)
Postflexion Mesolarvae	2-4	2-3	(1),2-3	2-3	3,(4)
Metalarvae	(2),3	2-3	2-3	2-3	(2),3
Juveniles	2-3	2-3	(2),3	(1),2-3	(1),2-3
Frenum					
Postflexion Mesolarvae	2-3	2-3	2-3	2,(3)	(2),3
Metalarvae	3	3	2-3	(2),3	(2),3
Juveniles	3	3	3	3	3
Origin of Dorsal Fin					
Metalarvae	3	3	(1-2),3	3	3
Juveniles	(2),3	3	(2),3	3	3
Insertion of Dorsal Fin					
Metalarvae	1-3	1-3	1-3	1-2	(1),2-3
Juveniles	1-3	2-3	1-3	1-2	2-3

Key to special characters and states (applicable developmental phases in brackets – pr = protolarvae, fm = flexion mesolarvae, pm = postflexion mesolarvae, mt = metalarvae, ej = early juveniles):

Eye shape [pr-pm]
1. Strongly to moderately oval (dorsoventrally flattened).
2. Slightly but distinctly oval.
3. Round (or very nearly so).

Mouth position [all]
1. Superior–strongly oblique with anterior end of upper lip above middle-of-eye level, lower jaw usually most anterior margin of snout (portion of head anterior to eyes).
2. Terminal–moderately oblique with anterior end of upper lip above bottom- to middle-of-eye level, lips usually even with or the most anterior margin of snout (sometimes slightly behind anterior margin of snout).
3. Low terminal–slightly oblique to horizontal with anterior end of upper lip at or below bottom-of-eye level and either even with or the most anterior margin of snout.
4. Subterminal–slightly oblique to horizontal with anterior margin of upper lip at or below bottom-of-eye level and lips preceded or overhung by anterior margin of snout.
5. Inferior–horizontal (or nearly so) and distinctly on underside of head with lips well behind anterior margin of snout.

Posterior corner of mouth (including lips) relative to eye [all]
1. Distinctly anterior to anterior margin of eye.
2. Below anterior margin of eye, or nearly so.
3. Distinctly posterior of anterior margin of eye but anterior to pupil.
4. Below at least anterior margin of pupil.

Frenum (bridge of tissue between anterior upper lip and rest of snout, no crease between anterior portion of upper lip and portion of snout above, upper lip not protrusible) [pm-jv]
1. Lip not sufficiently developed to assess.
2. Present.
3. Absent (lip completely separated from snout above).

Origin of dorsal fin relative to origin of pelvic fins [mt-jv] &
Insertion (posterior end of base) of dorsal fin relative to posterior margin of vent [mt-jv]
1. Distinctly anterior.
2. Over or very nearly so (difference no more than ± 2% SL).
3. Distinctly posterior.

Table 78. Comparison of diagnostic eye, mouth, and fin position characters for larvae and juveniles (≤40 mm SL) of the more common non-native cyprinids of the Upper Colorado River Basin. (Key to characters and their states is given below. Rare character states are enclosed in parentheses.)

Character	*Cyprinus carpio*	*Cyprinella lutrensis*	*Notropis stramineus*	*Pimephales promelas*	*Richardsonius balteatus*
Eye Shape					
Protolarvae	2-3	1,(2)	1	1-2,(3)	1-2,(3)
Flexion Mesolarvae	2-3	1	1	2,(3)	2,(3)
Postflexion Mesolarvae	(2),3	1	1,(2)	2-3	2-3
Mouth Position					
Protolarvae	2-5	2,(4),5	2-5	2-5	(2),4-5
Flexion Mesolarvae	2-3	2	2	2	2
Postflexion Mesolarvae	2-3	2	2	2	2
Metalarvae	2-3	1-2	2	2,(3)	2
Juveniles	2-3	1-2	2-3	2	2
Posterior Corner of Mouth					
Protolarvae	2-4	3-4	2-4	1-4	(3),4
Flexion Mesolarvae	(1),2-3	2-3	(1),2	1-3	(2),3,(4)
Postflexion Mesolarvae	(1),2,(3)	(1),2-3	(1),2	1-2	(2),3
Metalarvae	1-2	1-2	2,(3)	1,(2)	2,(3)
Juveniles	1	1-2	2,(3)	1	2,(3)
Frenum					
Postflexion Mesolarvae	3	2,(3)	2	3	2-3
Metalarvae	3	(2),3	2-3	3	(2),3
Juveniles	3	3	3	3	3
Origin of Dorsal Fin					
Metalarvae	1-2	(2),3	1-2,(3)	(1),2-3	3
Juveniles	1,(2)	(1),2-3	1-3	(1),2	3
Insertion of Dorsal Fin					
Metalarvae	3	1-3	1,(2)	1	(1),2-3
Juveniles	3	(1),2-3	1-2	1,(2)	(2),3

Key to special characters and states (applicable developmental phases in brackets – pr = protolarvae, fm = flexion mesolarvae, pm = postflexion mesolarvae, mt = metalarvae, ej = early juveniles):

Eye shape [pr-pm]

1. Strongly to moderately oval (dorsoventrally flattened).
2. Slightly but distinctly oval.
3. Round (or very nearly so).

Mouth position [all]

1. Superior–strongly oblique with anterior end of upper lip above middle-of-eye level, lower jaw usually most anterior margin of snout (portion of head anterior to eyes).
2. Terminal–moderately oblique with anterior end of upper lip above bottom- to middle-of-eye level, lips usually even with or the most anterior margin of snout (sometimes slightly behind anterior margin of snout).
3. Low terminal–slightly oblique to horizontal with anterior end of upper lip at or below bottom-of-eye level and either even with or the most anterior margin of snout.
4. Subterminal–slightly oblique to horizontal with anterior margin of upper lip at or below bottom-of-eye level and lips preceded or overhung by anterior margin of snout.
5. Inferior–horizontal (or nearly so) and distinctly on underside of head with lips well behind anterior margin of snout.

Posterior corner of mouth (including lips) relative to eye [all]

1. Distinctly anterior to anterior margin of eye.
2. Below anterior margin of eye, or nearly so.
3. Distinctly posterior of anterior margin of eye but anterior to pupil.
4. Below at least anterior margin of pupil.

Frenum (bridge of tissue between anterior upper lip and rest of snout, no crease between anterior portion of upper lip and portion of snout above, upper lip not protrusible) [pm-jv]

1. Lip not sufficiently developed to assess.
2. Present.
3. Absent (lip completely separated from snout above).

Origin of dorsal fin relative to origin of pelvic fins [mt-jv] &
Insertion (posterior end of base) of dorsal fin relative to posterior margin of vent [mt-jv]

1. Distinctly anterior.
2. Over or very nearly so (difference no more than ± 2% SL).
3. Distinctly posterior.

Table 79. Comparison of diagnostic eye, mouth, and fin position characters for larvae and juveniles (≤40 mm SL) of the less common non-native cyprinids of the Upper Colorado River Basin. (Key to characters and their states is given below. Rare character states are enclosed in parentheses.)

Character	*Gila atraria*	*Hybognathus hankinsoni*	*Notemigonus crysoleucas*	*Rhinichthys cataractae*	*Semotilus atromaculatus*
Eye Shape					
Protolarvae	(1),2-3	1-2	1-3	(1),2	1
Flexion Mesolarvae	2-3	1-2	2,(3)	2	1-2,(3)
Postflexion Mesolarvae	(2),3	2-3	2,(3)	2,(3)	2-3
Mouth Position					
Protolarvae	(2),3-5	2,(4),5	2,(4),5	4-5	4-5
Flexion Mesolarvae	2,(3)	2	2	4	2-4
Postflexion Mesolarvae	2	2	2	(2),4	2
Metalarvae	2	2	(1),2	4	2
Juveniles	2	2,4	1-2	4	2-3
Posterior Corner of Mouth					
Protolarvae	(1-2),3-4	(2),3-4	(1),2,(3),4	3-4	3-4
Flexion Mesolarvae	2,(3)	1-3	1,(2)	3	(2),3
Postflexion Mesolarvae	(1),2	1	1-2	3	2-3
Metalarvae	2,(3)	1	1,(2)	3	2-3
Juveniles	(1),2,(3)	1	1	1-3	2-3
Frenum					
Postflexion Mesolarvae	(2),3	2-3	2	2	2-3
Metalarvae	3	3	2-3	2	3
Juveniles	3	3	3	2	3
Origin of Dorsal Fin					
Metalarvae	1-2,(3)	1-2,(3)	3	(2),3	(2),3
Juveniles	1-2,(3)	1	3	(2),3	3
Insertion of Dorsal Fin					
Metalarvae	1	1	1-2,(3)	1	1,(2)
Juveniles	1	1	2-3	1-2	(1),2

Key to special characters and states (applicable developmental phases in brackets – pr = protolarvae, fm = flexion mesolarvae, pm = postflexion mesolarvae, mt = metalarvae, ej = early juveniles):

Eye shape [pr-pm]
1. Strongly to moderately oval (dorsoventrally flattened).
2. Slightly but distinctly oval.
3. Round (or very nearly so).

Mouth position [all]
1. Superior–strongly oblique with anterior end of upper lip above middle-of-eye level, lower jaw usually most anterior margin of snout (portion of head anterior to eyes).
2. Terminal–moderately oblique with anterior end of upper lip above bottom- to middle-of-eye level, lips usually even with or the most anterior margin of snout (sometimes slightly behind anterior margin of snout).
3. Low terminal–slightly oblique to horizontal with anterior end of upper lip at or below bottom-of-eye level and either even with or the most anterior margin of snout.
4. Subterminal–slightly oblique to horizontal with anterior margin of upper lip at or below bottom-of-eye level and lips preceded or overhung by anterior margin of snout.
5. Inferior–horizontal (or nearly so) and distinctly on underside of head with lips well behind anterior margin of snout.

Posterior corner of mouth (including lips) relative to eye [all]
1. Distinctly anterior to anterior margin of eye.
2. Below anterior margin of eye, or nearly so.
3. Distinctly posterior of anterior margin of eye but anterior to pupil.
4. Below at least anterior margin of pupil.

Frenum (bridge of tissue between anterior upper lip and rest of snout, no crease between anterior portion of upper lip and portion of snout above, upper lip not protrusible) [pm-jv]
1. Lip not sufficiently developed to assess.
2. Present.
3. Absent (lip completely separated from snout above).

Origin of dorsal fin relative to origin of pelvic fins [mt-jv] &
Insertion (posterior end of base) of dorsal fin relative to posterior margin of vent [mt-jv]
1. Distinctly anterior.
2. Over or very nearly so (difference no more than ± 2% SL).
3. Distinctly posterior.

Computer-Interactive Keys

Computer-interactive keys to the eggs, larvae, and early juveniles of UCRB cyprinids covered herein (Snyder and Seal 2015 onwards) and the families of all larvae in the basin (as well as most other freshwater and anadromous fishes in the United States and Canada; Snyder and Seal 2008 onwards) can be downloaded from the Internet as instructed below or accessed from the compact disc (CD) in the pocket on the inside rear cover of print publication versions of this guide. These keys consist of data sets with associated image, text, and controlling files for use with the DELTA program, *Intkey* (Dallwitz et al. 1993 onwards, 1995 onwards). The current version of the host program, *Intkey5* (also downloadable from the Internet or provided on the CD) runs under Microsoft *Windows 95* and later *Windows* operating systems. A color display with at least 800 x 600 pixel resolution (SVGA) is recommended (higher resolutions are preferred), but 640 x 480 pixel resolution (VGA) will work (less text is displayed without scrolling).

Intkey is one of the longer-standing, more highly evolved, and more widely used programs for interactive keys on personal computers (Dallwitz 1993). Many other interactive-key programs are available (e.g., *IdentifyIt, LucID, MEKA, Navikey, ONLINE, PollyClave,* and *XID*–Dallwitz 1996 onwards), and some may have worked as well for these keys. However, the complementary catostomid key prepared for Snyder and Muth (2004), the first ever published for fish larvae, uses *Intkey* and it was decided to stay with that program rather than start over with a new program and system for storing and formatting data. Also, on the condition that it is not used or distributed for financial gain, *Intkey* is available free over the Internet—an important consideration for potential users of this key. In addition to its function as an interactive key, *Intkey* has a vast array of other options for information retrieval, including output of full or partial "natural-language" descriptions of, or differential comparisons among, selected taxon-items. Once installed, use of *Intkey* is not limited to the data sets associated with this guide, the complementary data set for catostomid fish larvae of the UCRB (Snyder 2003 onwards for Snyder and Muth 2004) and similar data sets for early life stages of cypriniform fishes in the Gila River Basin (Snyder and Seal 2004a onwards and 2004b onwards for Snyder et al. 2005). It can be used also with data sets for published keys to a wide array of other taxa (e.g., salamanders, crustaceans, beetles, butterflies, polychaetes, flowering plants, grasses, viruses) as listed at http://delta-intkey.com/ under "data" or "references."

Installation

If a CD included with a print version of this guide is available, the keys can be used directly from the "Delta" directory (folder) on the CD or installed on your computer's hard-drive using the compressed *Intkey* program (Intk32.exe, a self-extracting file), an optional but recommended test update of the *Intkey* program and two associated files (intkey.zip, to be used after original program installation), and data set distribution files (Cyp-ucrb.zip, Fam-na.zip) on the CD. Installation of *Intkey* on your hard drive is recommended if (or when) you anticipate downloading and using future updates of this data set or using *Intkey* with data sets for other taxa (e.g., the complementary key to UCRB catostomid larvae). The "Delta" directory on the CD can be copied to and used on your hard drive (or other computer-memory device), and additional key data sets added as subdirectories, but without installation from the program distribution file, *Intkey* would not be registered within the *Windows* operating system, listed in your start menu under

programs, or set up as a helper file for your Internet browser.

In the absence of the CD, "Intk32.exe" and "inkey.zip" can be downloaded from the DELTA Home Page on the Internet (http://delta-intkey.com/ — select "Programs and documentation" then under programs, select "*Intkey*" and also click on "Test versions of the programs" and select "intkey.zip"). "Cyp-ucrb.zip," and "Fam-na.zip" can be similarly downloaded from the LFL website (http://warnercnr.colostate.edu/lfl-downloadable-keys-guides-and-bibliography — under "Upper Colorado River Basin", select "Key to the cyprinids" and under "North America", select "Key to the families"). Future updates of these data sets will likely be available only over the Internet. Users should periodically check the download site for subsequently updated copies of the zip-files, as indicated by a later file date or revision number.

Install *Intkey* by double clicking on "Intk32.exe" from the CD or its downloaded location and following on-screen instructions. Installation in a directory (folder) named "Delta" under either the computer's root directory or "Program Files" is recommended. In addition to the program and an array of bitmap and other files used by *Intkey*, the distribution file also includes and installs a "doc" subdirectory for the user's guide (intkey.doc, a Microsoft *Word* document, but readable by most other word processors) and separate text files regarding installation (install.txt), conditions of use (use.txt), and registration (register.txt–*Intkey* can be used without registration, but remains subject to other conditions of use). The full set of program and related files will require about 2.2 Mb of storage memory. After this initial installation, the recommended program update files can be extracted from "intkey.zip" (double click or right click and select "Extract All") to your Delta directory, overwriting three originally installed files.

Once *Intkey* is installed, extract the key data sets from the distribution files "Cyp-ucrb.zip" and "Fam-na.zip" to your "Delta" directory. They expand respectively as subdirectories "Cyp-ucrb" and "Fam-na," each including five files and two further subdirectories containing "images" and rich-text files, "RTF," used by or accessible via the *Intkey* program (also a "readme" file with instructions similar to these). The two data sets and associated files require about 3.3 Mb of storage memory.

Use

As noted above, the *User's Guide to Intkey* (Dallwitz et al. 1995 onwards) is included as "intkey.doc" in the folder "delta/doc" on the CD included with printed versions of this guide, as well as in the *Intkey* distribution package on the Internet. A more recent PDF version of the user's guide (intkey-ug.pdf) is also included on the CD for your reference or available online at http://delta-intkey.com/ under "Programs and Documentation." Although all information needed for use of *Intkey* is included in program help files, first-time users are encouraged to read the user's guide, at least the first few pages through "Information Retrieval." To start the program and use either key directly from the CD (or a copy on your hard drive), open the "Delta" directory and double click on "intkey5.exe." *Intkey* should open with the data-set names listed in an index window (startup dialog box); just select the key of interest and click on "OK" to open the data set. If not listed, click on "Browse" and in the appropriate subdirectory (Cyp-ucrb or Fam-na) click on and open the corresponding startup file, "intkeyuc.ink" or "intkey-fam.ink."

To run *Intkey* after it is installed on your computer's hard drive, press the *Windows* "Start" button, then select "Programs," "Delta," and "Intkey" (for convenience, a startup icon can be placed on your *Windows* desktop). The startup index window will be displayed. If the

desired data-set name is listed, select it and click on "OK" to open the data set. If the data-set name is not yet listed in the index window (as upon first use after installation), browse for the appropriate subdirectory (Cyp-ucrb or Fam-na) and select and open the corresponding startup file (intkeyuc.ink or intkey-fam.ink); upon closing the data set or program, you will be given an opportunity to add the data set to the startup index (you can later modify the descriptive name for the data set, or make other changes to the startup index, from within the *Intkey* program by selecting “advanced mode” in the file menu and then selecting “edit index” in that file menu).

Upon opening a data set, a startup image with the name of the key and author will be displayed. Press enter or click on the screen to close the image and start the key. The standard interactive-key screen will be overlaid initially with introductory and instructional text windows. After reading their contents, close or minimize the text windows (if closed, they can be redisplayed by selecting the desired text file from the "information" index–click on the book icon in the top left corner of the screen beneath "File"). Upon closing the text files, the standard screen will be revealed with its main menu, character and taxon-item toolbars, and four integral windows (available or best-remaining characters in upper left, used characters in lower left, remaining taxon items in upper right, and eliminated or non-matching taxon items in lower right). The relative size of the four windows can be changed at any time by moving the dividers between them.

For general instructions on use of the *Intkey* program, select or click on "Introduction" under the "Help" menu (upper left, main menu). As directed therein, for description of the various toolbar buttons and their use, click on the "↖?" help button in the upper right corner of the screen, above the end of the taxon-item toolbar, then on the desired toolbar button. Doing so for the "restart button" (curved arrow, left-most button in the upper right toolbar of "Best Characters" window) reveals the basic steps for proceeding with the key.

Before beginning identification, limit taxon possibilities (candidate species in the cyprinid key, families in the family key) by selecting the pertinent predefined subset of taxa, only the species (or families) likely to be present in the waters sampled, or just those remaining if you've already eliminated some possibilities. Click on the "use subset of taxa" button (green oval icon, second from the right in the "Remaining Taxa" toolbar, upper right window), then in the special window brought up by that button, select the appropriate subset of taxa. In the cyprinid key, taxa can be limited to just those in specific HUC subbasins (e.g., 1401 Colorado headwaters, 1404 Upper Green, 1405 White-Yampa, or 1408 San Juan; Fig. 1) or sets of individually selected species. In the family key, select “Families in Upper Colorado River Basin” or just the candidate families if you’ve already eliminated some possibilities. Taxa to be considered in the key can be changed at any time with results to that point updated accordingly.

Inappropriate or unfamiliar characters can be simply ignored and skipped over, but if desired, specific subsets of characters can also be selected (e.g., a subset without morphometric characters if the user is unable to make such measurements). To select or deselect subsets of characters, click on the "use subset of characters" button (yellow oval icon, second from right in the "Best Characters" or "Available Characters" toolbar, upper left window). Proceed with identification as per basic instructions (click on the "help" (↖?), then "restart" buttons).

Except in a couple circumstances, all characters in these keys are based on external or externally visible morphology and pigmentation and can be assessed without dissection or destructive treatment. For the cyprinid key, most character states were extracted from the descriptive species accounts and comparative summary tables of this guide.

When likely to be observed, myomere count ranges for some developmental phases were extended, for purposes of the key, to those of adjacent phases. Pigmentation characters used in these keys (and referenced in comparative summary tables) refer only to the black or brown pigment of melanophores (melanin-bearing cells). The pigment of most other chromatophores is difficult to preserve and has not been assessed. However, in living, freshly euthanized, and alcohol-preserved metalarvae and juveniles (not first fixed in formalin), melanophore pigmentation of the peritoneum (membrane lining the visceral cavity), as well as the degree of gut coiling, is often obscured by a layer of silvery iridophores. Similarly, in later juveniles, these characters may be obscured by muscle or thicker skin and scales, regardless of preservative. In such cases, it may be necessary to cut open the visceral cavity to examine the inner surface of the peritoneum and folds of the gut.

The cyprinid key is generally limited to specimens 40 mm or less in SL. However, some larger early (young-of-the-year) juveniles can be successfully identified with these keys by treating them as 40-mm-SL juveniles. Meristic characters such as fin-ray and scale counts in these keys are also applicable to all later juveniles and adults but may not be sufficient for definitive identification of these larger fish. The family key covers only the larval period.

As noted in the "Introduction" under the "Help" menu, the program opens in "normal mode" which limits users to preset options and is generally recommended for beginning or less-experienced users. However, depending on screen resolution, text for some character-state options might not be fully displayed. Increasing the width of the "Best Characters" or "Available Characters" window will increase the amount of text displayed in each line, but sometimes not enough. In these few cases, the user's only option is to cancel the selected character, switch to "advanced mode" under the "File" menu, again select the desired character, and in the character display box, click on the button for "Full Text" which is then displayed in a separate window. Unfortunately, this option is not currently available in "normal mode."

Taxonomic keys are tools for specimen identification, but the responsibility for accurate determinations remains with the user. Computer-interactive keys are simply easier-to-use and much more flexible tools than traditional printed keys, but as such they should facilitate more accurate identifications by the user. In the case of these keys, even with their extensive character sets, the identity of closely related fish larvae of similar developmental state and size cannot always be resolved to a single species; and even when it is, the results may not necessarily be conclusive because true character ranges may extend beyond those observed for description, and because of possible errors by the author or user. As discussed earlier in this guide, the possibility of hybrids among candidate taxa can further confound or reduce confidence in the resulting identification. Upon resolution of identity to a single taxon or if no matches are found, *Intkey* provides a help file with suggestions for confirming identity or allowing for some mismatches (increasing error tolerance) and continuing with the key. By allowing a couple of mismatches, even when identity is resolved to a single species, the user can base his or her identification on more characters and be more confident of the results. To further confirm the identity suggested by the key, users should also critically compare the specimen in question with descriptive information and illustrations in the species accounts and comparative summary tables of the guide, and, if available, with preserved reference specimens. As noted earlier, identities that cannot be resolved with reasonable certainty should be either treated tentatively as the most likely species with a question mark following the determination

(and perhaps with an explanatory footnote) or identified conservatively only to genus or family (e.g., *Gila* sp. or unidentified cyprinid).

Please report any problems, discrepancies, errors, or observed character-range extensions for future updates of these computer-interactive-key data sets directly to: Darrel E. Snyder, Larval Fish Laboratory, Colorado State University, 1474 Campus Delivery, Fort Collins, Colorado 80523-1474 (Phone: 970-491-5295, Fax: 970-491-5091, E-mail: Darrel.Snyder@ColoState.edu).

If these keys are to be referenced separately from their inclusion in this guide, the suggested citations using Transactions of the American Fisheries Society journal format for Internet sources (and replacing the date in parentheses at the end of each citation with the date you personally last accessed the site and verified presence of the file) are:

Snyder, D. E., and S. C. Seal. 2015 onwards. Computer-interactive key to eggs, larvae, and early juveniles of cyprinid fishes in the Upper Colorado River Basin (data set for use with DELTA *Intkey*). Larval Fish Laboratory, Colorado State University, Fort Collins. Available: http://warnercnr.colostate.edu/lfl-downloadable-keys-guides-and-bibliography (August 2015)

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APPENDIX I

Glossary

(Reprinted with minor edits from Snyder et al. 2005)

This glossary is a supplemented combination of most glossary terms and definitions listed by Hardy et al. (1978, including volume 1 by Jones et al. 1978), Auer (1982), and Simon and Wallus (2004; mostly from Wallus et al. 1990) as indicated by superscript numbers 1, 2, and 3, respectively. Terms and definitions from other sources end with a corresponding citation. Author modifications, definitions, and comments on usage in this guide are enclosed in brackets. Many terms included in this glossary are not used in this guide, but are provided for more general reference. For developmental-interval terminology used herein, see discussion and definitions provided in the introduction. For a review of other developmental-interval terminologies, including terms not included in this glossary, see Snyder (1976b). Terms for many anatomical features, methods and abbreviations for morphometrics and fin-ray and myomere counts, and definitions for phases of gut-coil development are illustrated in Figures 2–5.

A – Abbreviation for anal fin.[1]

Abbreviate heterocercal – Tail in which the vertebral axis is prominently flexed upward, only partly invading upper lobe of caudal fin; fin fairly symmetrical externally.[1,3]

Actinotrichia – Fin supports which are precursors of fin rays or spines; also [mistakenly] called lepidotrichia.[2,3] Spiny fin rays; horny rays in the form of spines, which develop, embryonically at least, in all bony fish fins, and may persist as the spines in the spiny-rayed fishes (Acanthopterygii) [or are replaced by, or transformed into, scaly or soft rays called lepidotrichia in soft-rayed fishes (Malacopterygii) or the soft-rayed fins or parts of fins of spiny-rayed fishes] (Lagler et al. 1962, pp. 59 and 186).

Adherent – Attached or joined together, at least at one point.[1,3]

Adhesive egg – An egg which adheres on contact to substrate material or other eggs; adhesiveness of entire egg capsule may or may not persist after attachment.[1,3]

Adipose fin – A fleshy rayless median dorsal structure, located behind the true dorsal fin.[1,3]

Adnate – Congenitally united; conjoined.[1,3] Joined to; grown together.[2] Keel-like.[3]

Adnexed – Flaglike.[3]

Adult – Sexually mature as indicated by production of gametes.[1,3]

Air bladder – See gas bladder; swim bladder.

Alevin – A term applied to juvenile catfish, trout, and salmon after yolk absorption; exhibiting no post yolk-sac larval phase.[3] [However, if loss of finfold and acquisition of the minimum adult count of rays in all fins, including rudimentary rays, are required for transition to the juvenile period, most, if not all, of these fish do indeed have a post yolk-sac larval phase and the term is no longer useful as defined.]

Allopatric – Having separate and mutually exclusive areas of geographical distribution.[3]

Anadromous – Fishes which ascend rivers from the sea to spawn.[1,3]

Anal – Pertaining to the anus or vent.[1,3]

Anal fin – Unpaired median fin immediately behind anus or vent.[1,3]

Anal fin origin – Anterior-most point at which the anal fin attaches to the body.[1]

Anlage – Rudimentary form of an anatomical structure;[1,2,3] primordium.[1,3] Incipient.[3]

Antero-hyal – Anterior bone to which branchiostegal rays attach; formerly ceratohyal.[2,3]

Anus – External orifice of the intestine; vent [when opening also includes the end of the urogenital duct].[1,3]

Auditory vesicle – Sensory anlage from which the ear develops; clearly visible during early development.[1,3]

Axillary process – Enlarged accessory scale attached to the upper or anterior base of pectoral or pelvic fins.[1,3]

Barbel – Tactile process arising from the head of various fishes.[1,3]

Basibranchials – Three median bones on the floor of the gill chamber, joined to the ventral ends of the five gill arches.[2,3]

Bicuspid – Having or ending in two points; a tooth with two points.[2]

BL – Abbreviation for body length.[1]

Blastocoel – Cavity of the blastula; segmentation cavity.[1]

Blastoderm – *Sensu strictu,* early embryonic tissue composed of blastomeres; more generally, embryonic tissue prior to formation of embryonic axis.[1]

Blastodisc – Embryo-forming area of egg prior to cleavage.[1]

Blastomeres – Individual cells formed during cleavage.[1]

Blastopore – Opening formed by and bordered by the germ ring as it extends over the yolk.[1]

Blastula – Stage in embryonic development which represents the final product of cleavage stages, characterized by formation of the blastocoel.[1] A hollow ball of cells formed early in embryonic development.[3]

Body depth at anus – Vertical depth of body at anus,[2,3] not including finfolds.[3]

Body length – A specialized method of measuring, generally applied only to billfishes, and defined by Rivas (1956) as the distance from the tip of the mandible (with jaws closed) to the middle point on the posterior margin of the middle caudal rays.[1]

Branched ray – Soft ray with two or more branches distally.[1,3]

Branchial arches – Bony or cartilaginous structures supporting the gills, filaments, and rakers.[1,3] gill arches.[3]

Branchial region – In petromyzontids, area between the anterior margin of the first gill opening and the posterior margin of the last.[2] The pharyngeal region where branchial arches and gills develop.[3]

Branchiostegal rays, branchiostegals – Struts of bone inserting on the hyoid arch and supporting, in a fanwise fashion, the branchiostegal membrane.[1,3] Bony rays supporting the membranes which close the gill (branchial) cavity under the head.[2]

Buoyant egg – An egg which floats free within the water column; pelagic.[1,3]

C – Abbreviation for caudal fin.[1]

Caeca – Finger-like outpouchings at boundary of stomach and intestine.[1,3]

Calcareous – Composed of, containing, or characteristic of calcium carbonate.[3]

Cardiform – Brush-like; referring to teeth of uniform length in patches or bands.[2]

Catadromous – Fishes which go to sea from rivers to spawn.[1,3]

Caudal fin – Tail fin.[1,3]

Caudal peduncle – Area lying between posterior end of anal fin base and base of caudal fin.[1,3]

Cement glands – Discrete or diffuse structures which permit a larva to adhere to a substrate.[2,3]

Cephalic – Pertaining to the head.[2,3]

Ceratohyal – See antero-hyal.[3]

Cheek – Lateral surface of head between eye and opercle, usually excluding preopercle.[1,3]

Chevron-shaped – The earliest developmental form of myomeres in larvae; describing the

angle formed by the epaxial and hypaxial portions of the myosepta.[2]

Choroid fissure – Line of juncture of invaginating borders of optic cup; apparent in young fish as a trough-like area below lens.[1,3] A cleft in outer layers of the eye visible in early larvae.[2]

Chorion – Outer covering of egg; egg capsule.[1,3] After water hardening, the outermost membrane of a fish egg.[2]

Chromatophores – Pigment-bearing cells;[1,2,3] frequently capable of expansions and contractions which change their size, shape, and color.[1,3]

Cirrus – Generally small, dermal, flap-like or tentacle-like process on the head or body.[1]

Cleavage stages – Initial stages in embryonic development where divisions of blastomeres are clearly marked; usually include 1st through 6th cleavages (2-64 cells).[1,3]

Cleithrum – Prominent bone of pectoral girdle, clearly visible in many fish larvae.[1,3] Large bone of support for the pectoral fins.[2]

Coelomic – Pertaining (belonging) to the body cavity.[2,3]

Confluent – Coming together to form one.[2,3]

Ctenoid scale – Scales with comb-like margin; bearing cteni.[1,3] Scales having small, needle-like projections on the posterior margin.[2]

Cycloid scale – Scales with evenly curved free border, without cteni.[1,3]

D – Abbreviation for dorsal fin.[1]

Deciduous – Referring to scales that are easily rubbed off and thus not firmly attached.[2]

Demersal – Refers to aquatic organisms living on or in close association with the substrate (bottom) (Bond 1996).

Demersal egg – An egg which remains on the bottom, either free or attached to substrate.[1,3] An egg which rests upon the substrate as a result of deposition or settling.[2] [An egg which sinks to the bottom in still water (negatively buoyant); in currents, unattached demersal eggs may be buoyed upward and carried down current.]

Dentary – Major bony element of the lower jaw, usually bearing teeth.[2,3]

Dorsal fins – Median, longitudinal, vertical fins located on the back.[1,3]

Dorsal fin origin – [Anterior-most] point where first dorsal ray or spine attaches to body.[1]

Early embryo – Stage in embryonic development characterized by formation of embryonic axis.[1,3]

Egg capsule – Outer-most encapsulating structure of the egg, consisting of one or more membranes; the protective shell.[1,3]

Egg diameter – In nearly spherical eggs, greatest diameter; in elliptical eggs given as two measurements, the greatest diameter or major axis and the least diameter or minor axis.[1,3]

Egg pit – The pit or pocket in a redd (nest) into which a trout female deposits one batch of eggs.[3]

Emarginate – Notched but not definitely forked, as in the shallowly notched caudal fin of some fishes.[1,3] Caudal fin possessing a slight notch or indentation.[2]

Embryonic axis – Primitive differentiation of the embryo; an elongate thickening of blastodermal tissue.[1]

Embryonic shield – Thickened shield-like area of the blastoderm at caudal edge of the germ ring.[1]

Emergence – The act of leaving the substrate and beginning to swim; swim-up.[2,3]

Epaxial – Portion of the body dorsal to the horizontal or median myoseptum.[2,3]

Epihyal – See postero-hyal.

Epurals – Modified vertebrae elements which lie above the vertebrae and support part of the caudal fin.[2,3]

Erythrophores – Red or orange chromatophores.[1,3]

Esophagus – Alimentary tract between pharynx and stomach.[1,3]

Eye diameter – Horizontal measurement (distance) of the iris of the eye.[2,3] [Horizontal diameter of the externally visible eye.]

Falcate – Deeply concave as a fin with middle rays much shorter than anterior and posterior rays.[1,3] Scythe-shaped; referring to an anal fin.[2]

Fin insertion – [As used herein,] posterior-most point at which the fin attaches to the body.[3] [More generally refers to entire margin of fin attachment to the body, the fin base.]

Fin origin – Anterior-most point at which the fin attaches to the body.[3]

Finfold – Median fold of integument which extends along body of developing fishes and from which median fins arise.[1,3]

FL – Abbreviation for fork length.[1]

Flexion larva – Phase between hatching and upward flexing of the tip of the notochord [or appearance of first caudal fin rays] (Ahlstrom et al. 1976).

Flexion mesolarva – Among fishes with homocercal tails, subphase of mesolarval development characterized by an incomplete adult complement of principal caudal-fin rays (posterior portion of notochord flexes upward and standard length measured to end of notochord) (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier).

Focal point – Location of a fish maintaining a stationary position on or off the substrate for at least a 10-second period.[3]

Fontanelle – A gap or space between bones in the roof of the skull covered only by a membrane.[2]

Foramen – An opening through a bone.[2]

Fork length – Distance measured from the anterior-most point of the head to the end of the central caudal rays.[1,3] Distance from the most anterior point on the snout to the end of the shortest central caudal fin ray.[2]

Frenum – A fold of skin that limits movement of the upper jaw.[2,3] [Bridge of tissue tightly connecting anterior portion of upper lip to fleshy portion of snout above (rather than being fully separated by a crease or groove between) and making premaxillaries non-protractile (upper lip not protrusible).]

Ganoid scales – Diamond- or rhombic-shaped scales consisting of bone covered with enamel.[1,3]

Gape – The border of the mouth.[2] Distance between the tips of the open jaws of vertebrates (Pennak 1964). Width of gape is the greatest transverse distance across the opening of the mouth (Hubbs and Lagler 1958).

Gas bladder – Membranous, gas-filled organ located between the kidneys and alimentary canal [digestive tract or gut] in teleosts; air bladder or swim bladder.[1,3]

Gastrula – Stage in embryonic development between blastula and embryonic axis.[1,3]

Germ ring – The thickened rim of the blastoderm evident during late blastula and gastrula stages.[1]

Germinal disc – The blastodisc.[1]

Gill arches – See branchial arches.[1,3]

Gill rakers – Variously-shaped bony projections on anterior edge of the gill arches.[1,3] Unless otherwise stated, counts are for all rakers on the first arch [external row] (Hubbs and Lagler 1958).

Glossohyal – A median bone of the tongue.[2]

Granular yolk – Yolk consisting of discrete units of finely to coarsely granular material.[1,3]

Greatest body depth – Greatest vertical depth of the body excluding fins and finfolds.[2,3]

Guanophores – White chromatophores; characterized by presence of iridescent crystals of guanine.[1,3] [= iridophores.]

Gular fold – Transverse membrane across throat.[1,3]

Gular plate – Ventral bony plate between anterior third of lower jaws, as in *Amia calva*.[1] Ventral bony plate on throat, as in

Amia calva.[3] Median ventral bony plate or plates located behind the chin and between the sides of the lower jaw.[2]

Gular region – Throat.[3]

Haemal – Relating to or situated on the side of the spinal cord where the heart and chief blood vessels are placed.[3]

Head length – Distance from anterior-most tip of head to posterior-most part of opercular membrane, excluding spine; prior to development of operculum, measured to posterior end of auditory vesicle.[1,3] Distance from the most anterior point on the snout [including mouth] to the posterior edge of the auditory vesicle, cleithrum or opercle as each develop.[2] [As used herein, measured instead to the origin of the pectoral fin, or prior to formation of the pectoral fin buds, to the cleithrum.]

Head width – Greatest dimension between opercles.[2,3] [Unless measured, as herein, at other specified locations such as middle of eye or just behind posterior margin of eye.]

Heterocercal – Tail in which the vertebral axis is flexed upward and extends nearly to tip of upper lobe of caudal fin; fin typically asymmetrical externally, upper lobe much longer than lower.[1,3]

HL – Abbreviation for head length.[1]

Holoblastic – Type of cleavage in which the entire egg, including the yolk, undergoes division.[1]

Homocercal – Tail in which the vertebral axis terminates in a penultimate vertebra followed by a urostyle (the fusion product of several vertebral elements); fin perfectly symmetrical externally.[1,3]

Horizontal myoseptum – Connective tissue dividing epaxial and hypaxial regions of the body;[2,3] median myoseptum.[3]

Hypaxial – That portion of the body ventral to the horizontal myoseptum.[2,3]

Hypochord – A transitional rod of cells which develops under the notochord in the trunk region of some embryos.[1,3]

Hypochordal – Below the notochord; referring to the lower lobe of the caudal fin.[2,3]

Hypurals – Expanded, fused, haemal spines of last few vertebrae which support the caudal fin.[1,3] The expanded hemal spines of the posterior vertebrae which support most of the caudal fin.[2]

Incipient – Becoming apparent.[2,3]

Incubation period – Time from fertilization of egg to hatching.[1,3]

Inferior mouth – Snout projecting beyond the lower jaw.[2,3] [As used herein, mouth that is horizontal (or nearly so) and distinctly on underside of head with lips well behind anterior margin of snout.]

Insertion (of fin) – See fin insertion.

Integument – An enveloping layer or membrane.[3] Coating or external skin (Pennak 1964).

Internarial – Area between the nares on one side of the head or the other.[2]

Interorbital – Space between eyes over top of head.[1,3]

Interorbital width – Least distance between the orbits across dorsum of head.[2]

Interradial – Area between the fin rays.[2,3]

Interspaces – Spaces between parr marks of salmonids.[2,3]

Iridocytes – Crystals of guanine having reflective and iridescent qualities.[1,3]

Iridophores – See guanophores.

Isocercal – Tail in which vertebral axis terminates in median line of fin, as in Gadiformes,[1,2,3] caudal fin rays arising symmetrically from it.[2]

Isthmus – The narrow area of flesh in the jugular region between gill openings.[1,3] Fleshy space beneath the head and between the gill openings.[2]

Jugular – Pertaining to the throat.[1,3] Gular.[3]

Juvenile – Young fish after attainment of minimum adult fin-ray counts and before sexual maturation.[1] Young fish after attainment of minimum adult fin-ray counts and complete absorption of the median finfold and before sexual maturation.[3]

[Latter definition used herein–see discussion on developmental interval terminology in introduction].

Keeled – With a ridge or ridges.[1,3]

Kupffer's vesicle – A small, vesicular, ventro-caudal pocketing which forms as blastopore narrows.[1]

Lanceolate – Slightly broad at the base and tapering to a point.[2]

Larva – Young fish between time of hatching and attainment of minimum adult fin ray counts.[1] Young fish between time of hatching and attainment of juvenile characteristics.[3] Encompasses both yolk-sac and post yolk-sac phases of development (Wallus et al. 1990). As used herein, period of fish development between hatching or birth and (1) acquisition of adult complement of fin spines and rays (principal and rudimentary) in all fins, and (2) loss beyond recognition of all finfold not retained by the adult (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier).

Late embryo – Stage prior to hatching in which the embryo has developed external characteristics of its hatching stage.[1,3]

Lateral line – Series of sensory pores and/or tubes extending backward from head along sides.[1,3]

Lateral-line scales – Pored or notched scales associated with the lateral line.[1,3] Count of pores in the lateral line, or the number of scales along the line in the position which would normally be occupied by a typical lateral line from the shoulder girdle to the structural base of the caudal fin (scales wholly on the caudal fin base not included in the count, even when well developed and pored) (Hubbs and Lagler 1958). [Second definition: lateral-series scales.]

Lateral-series scales – [Number of rows of scales crossing the midlateral surface or lateral line if complete; see second definition by Hubbs and Lagler (1958) for lateral-line scales.]

Lateral teeth – In petromyzontids, teeth of oral disc lateral to esophageal opening.[2]

Lepidotrichia – Replacements of actinotrichia; soft fin rays or spines.[2] See actinotrichia.[3] Scaly or soft fin rays [typically branched and jointed or segmented, always biserial (laterally divided or paired)]; replacements of [embryonic or larval] actinotrichia in the soft-rayed fishes or the soft-rayed fins or parts of fins of spiny-rayed fishes (Lagler et al. 1962, pp. 59 and 186).

Low-terminal mouth – [As used herein, mouth that is slightly oblique to horizontal with anterior end of upper lip at or below bottom-of-eye level and either even with or the most anterior margin of snout.]

Mandible – Lower jaw, comprised of three bones: dentary, angular and articular.[1,3]

Maxilla – The posterior, lateral bones of the upper jaw.[2]

Maxillary – The dorsal-most of the two bones in the upper jaw.[1,3]

Meckel's cartilage – Embryonic cartilaginous axis of the lower jaw in bony fishes,[1,3] forms the area of jaw articulation in adults.[3]

Melanophores – Black chromatophores.[1,3] [Also brown.] Melanin-bearing pigment cell.[2]

Mental – Pertaining to the chin.[1,3]

Meroblastic – Type of cleavage in which only the blastodisc undergoes division.[1]

Mesencephalon – Midbrain; serves optic functions.[2]

Mesolarva – Phase of larval development characterized by presence of at least one dorsal, anal, or caudal-fin spine or ray but either lacking the adult complement of principal soft rays in at least one median (dorsal, anal, or caudal) fin or lacking pelvic-fin buds or pelvic fins (if present in adult) (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of

yolk indicated by an appropriate modifier; standard length measured to end of notochord or, when sufficiently developed, axial skeleton).

Mesopterygoid – Middle of three dermal bones of the upper jaw.[2]

Metalarva – Phase of larval development characterized by presence of (1) adult complement of principal soft rays in all median fins and (2) pelvic-fin buds or pelvic fins (if present in adult) (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier; standard length measured to posterior end of axial skeleton, hypural elements or plates in fishes with homocercal tails).

Metencephalon – Portion of the brain immediately behind the mesencephalon.[2] [Hind brain.]

Micropyle – Opening in egg capsule through which spermatozoa enter.[1] Principle path of sperm entry through the chorion (vitelline membrane) of an egg.[2]

Molariform – Referring to a tooth with a flat grinding surface.[2]

Morula – Stage in development of egg in which blastomeres form a mulberry-like cluster.[1]

Myomeres – Serial muscle bundles of the body.[1,3] [Total myomere count is sum of preanal (to posterior margin of vent) and postanal (post vent) counts and should approximate the number of vertebrae (including Weberian vertebrae in ostariophysian fishes such as cyprinids, catostomids, and ictalurids).]

Myoseptum(a) – Connective tissue partition(s) separating myomeres.[1,3] Thin partition of connective tissue which joins myomeres.[2]

Nape – Area immediately posterior to occipital region.[1]

Nares – Nostrils, openings leading to the olfactory organs.[2,3]

Narial – Pertaining to the nares.[2,3]

Nasal – Pertaining to region of the nostrils, or to the specific bone in that region.[1,3]

NL – Abbreviation of notochord length.[1]

Notochord – Longitudinal supporting axis of body which is eventually replaced by the vertebral column in teleostean fishes.[1]

Notochord length – Straight-line distance from anterior-most part of head to posterior tip of notochord; used [as standard length] prior to and during notochord flexion.[1,3]

Obtuse – With a blunt or rounded end; an angle greater than 90 degrees.[2,3]

Occipital region – Area on dorsal surface of head, beginning above or immediately behind eyes and extending backwards to end of head;[1,3] occiput.[3]

Oil globule(s) – Discrete sphere(s) of fatty material with-in the yolk.[1,3]

Olfactory buds – Incipient olfactory organs.[1,3]

Ontogeny – Developmental history of an organism from zygote to maturity (Pennak 1964).

Opercle – Large posterior bone of the operculum.[3]

Operculum – Gill cover.[3]

Optic vesicles – Embryonic vesicular structures which give rise to the eyes.[1,3]

Origin (or fin) – See fin origin.

Otoliths – Small, calcareous, secreted bodies within the inner ear.[1,3]

Over yearling – Fish having spent at least one winter in a stream; applies to trout and salmon.[3]

P [or P1] – Abbreviation for pectoral fin.[1]

P2 [or V] – [Abbreviation for the ventral or pelvic fin.]

Palatine teeth – Teeth on the paired palatine bones in the roof of the mouth of some fishes.[1,3]

Palatines – Paired bones on the roof of the mouth, often bearing teeth.[2]

Parapatric – Distribution of species or other taxa that meet in a very narrow zone of overlap.[3]

Paravertebral – Along the same plane as the spinal column.[2]

Parietal – Paired bones of the roof of the skull.[2]

Pectoral [fin] bud – Swelling at site of future pectoral fin; anlage of pectoral fin.[1]

Pectoral fin length – Distance from base to farthest tip of fin.[2]

Pectoral fins – Paired fins behind head, articulating with pectoral girdle.[1,3]

Peduncle – Portion of body between anal and caudal fins.[2,3] [Caudal peduncle.]

Pelagic – Floating free in water column; not necessarily near the surface.[1,3] Living in the open water habitat, as opposed to bottom living or inshore inhabitants.[2]

Pelvic bud – Swelling at site of future pelvic (ventral) fins; anlage of pelvic fin.[1,3]

Pelvic fins – Paired fins articulating with pelvic girdle; ventral fins.[1,3]

Periblast – A layer of tissue between the yolk and cells of blastoderm which is observed as a thin border around blastula.[1]

Pericardium – Cavity in which the heart lies.[2,3]

Peritoneum – Membranous lining of abdominal cavity.[1,2,3]

Perivitelline space – Fluid-filled space between egg proper and egg capsule.[1,3] Fluid-filled space between the chorion and yolk material.[2]

Pharyngeal teeth – Teeth on the pharyngeal bones of the branchial skeleton.[1,3] Bony tooth-like projections derived from the fifth (pharyngeal) gill arch.[2] In cyprinids, both left and right arches bear 1-3 rows of teeth; counts for each row and arch are given in a formula in order from left to right [rows separated by commas, arches by a dash] (Hubbs and Lagler 1958).

Physoclistic – Having no connection between the esophagus and the pneumatic duct [of the swim (air or gas) bladder]; typical of perciform fishes.[3]

Physostomus – Having the swim bladder connected to the esophagus by the pneumatic duct;[2,3] typical of cypriniform fishes.[3]

Plicae – Wrinkle-like folds found on the lips of some catostomids.[2,3]

Post yolk-sac larva – Phase beginning with complete absorption of the yolk and ending when a minimum adult complement of rays is present in all fins and the median finfold is completely absorbed (Wallus et al. 1990).

Postanal length – Distance from posterior margin of anus [or vent] to the tip of the caudal fin,[2,3] or median finfold.[2]

Postanal myomeres – The number of myomeres between posterior margin of anus and the most posterior myoseptums.[1] Number of whole myomeres posterior to an imaginary vertical line at the most posterior point of the anus [vent],[2,3] including one urostylar element; the first postanal myomere is the first myomere behind and not touched by the imaginary line.[3] [The last myomere lies immediately anterior to the most posterior complete myoseptum.]

Postero-hyal – Posterior bone to which branchiostegal rays attach, formerly epihyal.[2,3]

Postflexion larva – Phase following upward flexion of the tip of the notochord [more precisely considered to begin with formation of all principal caudal fin rays] (Ahlstrom et al. 1976).

Postflexion mesolarva – Among fishes with homocercal tails, subphase of mesolarval development characterized by adult complement of principal caudal-fin rays (notochord flexion essentially complete and standard length measured to posterior-most margin of hypural elements or plates) (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier).

Postorbital length – Distance from posterior margin of eye to posterior edge of opercular membrane.[2,3] [Or to origin of pectoral fin, depending on criteria for head length.]

Preanal length – Method of measuring often not stated, assumed to be about equivalent to snout to vent length in larvae.[1] Distance from anterior-most part of head to posterior margin of anus.[2,3] [Snout-to-vent length, herein measured to posterior margin of vent.]

Preanal myomeres – The number of myomeres between the anterior-most myoseptum[1,3] and the posterior margin of anus[1] or an imaginary vertical line drawn at the posterior margin of anus, including any bisected by the line.[3] Number of myomeres from the nape to, and including any myomeres bisected by an imaginary vertical line at the most posterior point of the anus.[2] [As used herein, the most anterior myomere, which is mostly an epaxial unit, is located immediately behind the occiput and often deltoid in shape (somewhat wider at the top), and the last is the most posterior myomere transected by a vertical line from the posterior margin of the vent.]

Prebranchial length – In petromyzontids, distance between the tip of the snout and the anterior margin of the first gill opening.[2]

Predorsal length – Distance from the most anterior point on the snout to the anterior margin of the base [origin] of the first dorsal fin ray when formed.[2]

Predorsal myomeres – Number of myomeres from nape to dorsal origin of median finfold.[2] [Or, to origin of the dorsal fin once anterior-most pterygiophores or fin rays are formed.]

Predorsal scales – Scales along dorsal ridge from occiput to origin of dorsal fin.[1,3]

Preflexion larva – Phase between hatching and upward flexing of the tip of the notochord [or appearance of first caudal fin rays] (Ahlstrom et al. 1976).

Preflexion mesolarva – Among fishes with homocercal tails, subphase of mesolarval development characterized by absence of caudal-fin rays (posterior portion of notochord remains essentially straight and standard length measured to end of notochord; when first median-fin ray is a caudal ray, as in most fishes, larva progresses directly from protolarva to flexion mesolarva) (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier).

Prejuvenile – Developmental stage [phase] immediately following acquisition of minimum fin ray complement of adult and before assumption of adult-like body form; used only where strikingly different from juvenile[1,3] (*cf.* Hubbs, 1958; *Tholichthys* stage of butterflyfishes, querimana stage of mullets, etc.).[1] [Transitional phase.]

Premaxilla, premaxillary – The ventral-most of the two bones included in the upper jaw.[1,3] Primary bone of the upper jaw in most fish, usually bearing teeth.[2]

Preorbital – Large bone anterior to the eye.[2]

Primordium – Rudimentary form of an anatomical structure; anlage.[1,3]

Principal anal- and dorsal-fin rays – In certain fishes, particularly the Cyprinidae and Catostomidae,. . . the principal rays include the branched rays plus one unbranched ray [the anteriorly adjacent, usually longest, unbranched ray]; . . . the last two bases [branched rays, both of which articulate with the most posterior pterygiophore] are counted as one ray (Hubbs and Lagler 1958). [In traditional fin-ray count formulas, represented by Arabic numerals.]

Principal caudal [-fin] rays – Caudal rays inserting on hypural elements; the number of principal rays is generally defined as the number of branched rays plus two [adjacent unbranched rays, one above and one below the branched rays].[1,3] [In traditional fin-ray count formulas, represented by Arabic numerals.]

Procurrent caudal rays – A series of much shorter rays anterior to the principal caudal rays, dorsally and ventrally, not typically included in the margin of the caudal fin.[1,3] [Rudimentary or secondary rays of the caudal-fin; in traditional fin-ray count formulas, represented by lower case Roman numerals (dorsal before and ventral after principal ray count, separated by commas.]

Pronephric ducts – Ducts of pronephric kidney of early developmental stages.[1,3]

Protolarva – Phase of larval development characterized by absence of dorsal-, anal-, and caudal-fin spines and rays (Snyder and Muth 1988, 1990, 2004; see discussion on developmental interval terminology in introduction; presence of yolk indicated by an appropriate modifier; standard length measured to end of notochord).

Protractile – Describing premaxillae which can be extended.[2] [Protrusible.]

Pterygoid – Dermal bone of the upper jaw.[2]

Pterygiophores – Bones of the internal skeleton supporting the dorsal and anal fins.[2,3]

Redd – An excavated area or nest into which trout spawn.[3]

Retrorse – Pointing backward.[3]

Rostrum – Snout.[3]

Rudimentary fin rays – [In certain fishes, particularly the Cyprinidae and Catostomidae, size-graded series of shorter, unbranched soft rays anterior to the principal rays of the dorsal, anal, and caudal fins; also called secondary rays or, in the case of the caudal fin, procurrent rays; in traditional fin-ray count formulas, represented by lower case Roman numerals and separated from the principal ray count, in Arabic, by commas.]

Saddle markings – Pigment patterns which cover the dorsal and lateral aspects and give an overall appearance of a saddle.[2]

Secondary fin rays – See rudimentary fin rays, and with respect to the caudal fin, procurrent rays.

Scute – A modified, thickened scale, often spiny or keeled.[1,3]

Semibuoyant – Referring to eggs which neither float nor sink, but remain suspended in the water column.[2,3]

Sigmoid heart – The S-shaped heart which develops from the primitive heart tube.[1,3]

SL – Abbreviation for standard length.[1]

Snout – [Portion of head anterior to eyes and, as used herein, including the portion of the mouth anterior to the eyes (often used in reference only to the fleshy anterior extension of the head above the mouth including the nares).]

Snout-to-vent length – Distance from anterior-most part of head to posterior margin of anus [vent]; the precise method of measurement often not stated.[1] [See preanal length.]

Soft rays – Bilaterally paired, usually segmented, fin supports.[1,3] [See lepidotrichia; in traditional fin-ray count formulas, principal soft rays of median fins or all rays of paired fins represented by Arabic numerals.]

Somites – Primitive, segmented, mesodermal tissue along each side of notochord.[1] [Consists in part of future myomeres.]

Spatulate – Having a rounded apex and tapering to a base; spoon-shaped.[2]

Spines – Unpaired [uniserial, not bilaterally divided], unsegmented, unbranched fin supports, usually (but not always) stiff and pungent.[1,3] [In traditional fin-ray count formulas, represented by upper case Roman numerals, and if part of a fin with both spines and soft rays, separated from such by a comma, or if in a fully separated section of the fin (e.g., first dorsal fin of some perciform fishes), separated by a dash.]

Spinous rays – [In certain otherwise soft-rayed fish, soft rays that during embryonic or larval development are thickened, fused, and hardened into spine-like structures, sometimes with moderate to strong serrations or barbs along their posterior

margins (e.g., spines at the anterior margins of the dorsal and pectoral fins in catfishes, order Siluriformes, dorsal and anal fins in goldfish *Carassius auratus* and common carp *Cyprinus carpio*, and dorsal fins of the spiny-rayed cyprinids, tribe Plagopterini, for which the basal portions of certain other dorsal, pelvic, and pectoral fin rays also exhibit spine-like modifications–Hubbs and Lagler 1958, Lagler et al. 1962, and Miller and Hubbs 1960). In formulas for fin-ray counts, fully spinous rays may designated by Roman numerals like true spines.]

Squamation – Covering of scales.[2,3]

Standard length – In larvae, straight-line distance from anterior-most part of head to end of hypural elements; not applicable to larvae prior to [or during] notochord flexion (in juveniles and adults measured from most anterior point of snout or upper lip.)[1] In larvae, straight-line distance from anterior-most part of head to the most posterior point of the notochord or hypural complex.[2,3] [As used herein for fish with homocercal tails, includes notochord length prior to formation of all principal caudal fin rays which signals the end of notochord flexion.]

Stellate – Referring to a melanophore [with pigment] which is expanded into a starlike shape.[2,3]

Stomodeum – Primitive invagination of the ectoderm which eventually gives rise to the mouth.[1,3] Primordial mouth; the anterior pitted portion of the embryonic gut.[2]

Submandibular – Beneath the lower jaw; along the edge of the lower jaw.[2]

Subterminal mouth – [As used herein, mouth that is slightly oblique to horizontal with anterior margin of upper lip at or below bottom-of-eye level and lips slightly to moderately preceded or overhung by anterior margin of snout; between low-terminal and inferior positions.]

Superior mouth – Condition when the lower jaw extends upward and the mouth opens dorsally.[2,3] [As used herein, mouth that is strongly oblique with anterior end of upper lip above middle-of-eye level and lower jaw usually the most anterior margin of snout.]

Supramaxilla – Small dermal bone attached posterior and dorsal to the maxilla.[2]

Supraoral – Above the mouth; referring to the teeth of the oral disc in lampreys which are anterior to the mouth opening.[2]

Supraoral tooth plate – In petromyzontids, tooth plate immediately anterior to esophageal opening.[2]

Swim bladder – See gas bladder.

Sympatric – Species inhabiting the same or overlapping geographic areas.[3]

Tail-bud stage – Stage of embryonic development characterized by a prominent caudal bulge and marked development of cephalic region.[1]

Tail-free stage – Stage of embryonic development characterized by separation of the tail from the yolk.[1]

Tail length – In petromyzontids, distance from cloacal slit to tip of caudal fin.[2]

Teleosts – Bony fishes.[3]

Terminal mouth – Condition when lower and upper jaws are equal in length and the mouth opens terminally.[2,3] [As used herein, mouth that is moderately oblique with anterior end of upper lip above bottom-of-eye to middle-of-eye level, lips usually even with or the most anterior margin of snout (sometimes slightly behind anterior margin of snout).]

Tessellated – Markings or colors arranged into squares.[2]

TL – Abbreviation for total length.[1]

Total length – Straight-line distance from anterior-most part of head to tip of tail.[1,3] Distance from the most anterior point on the snout to the most posterior point on the caudal fin or finfold.[2]

Truncate – Ending abruptly along a vertical line.[2] Terminate abruptly as if the end were cut off.[3]

Trunk length – In petromyzontids, distance between posterior margin of last gill opening and cloacal slit.[2]

Trunk myomeres – In petromyzontids, myomeres between the most posterior gill opening and the cloacal slit.[2]

Urostyle – Terminal vertebral element in higher teleosts, derived from the fusion and loss of several of the most posterior centra of the more primitive forms;[1,3] usually modified for caudal fin support.[3] Final vertebral segment usually modified for caudal fin support.[2]

V [or P2] – Abbreviation for the ventral or pelvic fin.[1]

Vent – Anus.[1,3] [Cloacal aperture, includes both anus and end of the uro-genital duct.]

Ventral fins – Paired fins articulating with the pelvic girdle; pelvic fins.[1]

Vermiculate – Having wormlike markings.[2,3]

Villiform – In the form of finger-like projections.[2]

Vitelline membrane – After water hardening, the membrane surrounding the egg proper (animal and vegetal material).[2]

Vitelline vessels – Arteries and veins of yolk region.[1,3]

Vomer – Anterior, median bone of the roof of the mouth (= prevomer).[2]

Water-hardening – Expansion and toughening of egg capsule due to absorption of water into the perivitelline space.[1,3] Process of membrane delamination and fluid formation which forms the perivitelline space bordered by the chorion and vitelline membrane.[2]

Weberian vertebrae – First four vertebrae in cyprinids, catostomids, and ictalurids which are modified to connect the swim bladder to the inner ear.[2]

Width of perivitelline space – Distance between yolk and egg capsule expressed either as direct measurement or a ratio of the egg diameter.[1] Distance between yolk and outer margin of egg capsule.[3] [Technically, measured instead to the inner surface of the chorion.]

Xanthophores – Yellow chromatophores.[1,2,3]

Yearling – A fish in its second year.[3]

Yolk – Food reserve of embryonic and early larval stages, usually seen as a yellowish sphere diminishing in size as development proceeds.[1,3]

Yolk diameter – Greatest diameter of yolk; more accurately measurable prior to embryo formation.[1,3]

Yolk plug – Yolk within the blastopore.[1]

Yolk sac – A bag-like ventral extension of the primitive gut containing the yolk.[1,3]

Yolk-sac larva – A larval fish characterized by the presence of a yolk-sac.[1,3] Phase of development from the moment of hatching to complete absorption of the yolk (Wallus et al. 1990).

Yolk-sac length – Horizontal distance from most anterior to most posterior margin of yolk sac.[2,3]

Yolk-sac depth – Vertical distance from dorsum to venter of yolk sac.[2]

APPENDIX II

Prior Descriptions of Larvae for Cyprinids in the Upper Colorado River Basin

Prior descriptions, comparisons, or guides for larvae of all cyprinids currently known or suspected to be present in the UCRB are listed below by species and ordered by publication year. Species listed in bold type are covered and further described in this guide. In addition to the listed references, Snyder (1979) and Conner et al. (1980) summarized myomere and vertebra counts for most of these species.

Native cyprinids

***Gila cypha*, humpback chub**—Snyder (1981) and Muth (1990).

***Gila elegans*, bonytail**—Snyder (1981, in metalarval key and meristic summary table only), Muth (1990), and Snyder et al. (2005).

***Gila robusta*, roundtail chub**—Winn and Miller (1954), Snyder (1981), Muth (1990), and Snyder et al. (2005)

***Ptychocheilus lucius*, Colorado pikeminnow**—Winn and Miller (1954, mentioned as similar to roundtail chub), Seethaler (1978), Snyder (1981), and Snyder et al. (2005).

***Rhinichthys osculus*, speckled dace—**Winn and Miller (1954), Snyder (1981), Snyder et al. (2005), and Feeney and Swift (2008, Santa Ana subspecies).

Non-native cyprinids

Carassius auratus, goldfish—Khan (1929), Watson (1939), Battle (1940), Okada (1960), Mansueti and Hardy (1967), May and Gasaway (1967), Nakamura (1969), Lippson and Moran (1974), Jones et al. (1978), Loos et al. (1979), Wang and Kernehan (1979), Heufelder and Fuiman (1982), Fuiman et al. (1983), Gerlach (1983), Wang (1986), Pinder (2001), Wang and Reyes (2007), and Arvidson and Alber (2013). Also, others cited by some of these.

Couesius plumbeus, lake chub—Fuiman and Baker (1981), Heufelder and Fuiman (1982), Fuiman et al. (1983), and Sturm (1988, 2004).

Ctenopharyngodon idella, grass carp—Chen and Lin (1935), Lin (1935), Kryzhanovsky et al. (1951), Yuan (1962), Chen (1963), Nakamura (1969), Soin and Sukanova (1972), Fischer and Lyakhnovich (1973), Nezdoliy and Mitrofanov (1975), Conner et al. (1980), Kilambi and Zdinak (1981), Shireman and Smith (1983), Yi et al. (1988), Nakatani et al. (2001), Chapman (2006), and Korwin-Kossakowski (2008). Also, others cited by some of these.

***Cyprinella lutrensis*, red shiner**—Sakena (1962), Taber (1969), Loos and Fuiman (1978), Perry (1979), Perry and Menzel (1979), Snyder (1981), Fuiman et al. (1983), Wang (1986), Holland-Bartels et al. (1990), Snyder et al. (2005), Wang and Reyes (2007), and Feeney and Swift (2008).

***Cyprinus carpio*, common carp**—Ehrenbaum (1909), Nordqvist (1914), Smallwood and Smallwood (1931), Fish (1932), Smallwood and Derrickson (1933), Hikita (1956), Balon (1958), Bragensky (1960), Okada (1960), Itazawa (1963), Mansueti and Hardy (1967), May and Gasaway (1967), McCrimmon and Swee (1967), Nakamura (1969), Taber (1969), Verma (1970), Hoda and Tsukahara (1971), Lippson and Moran (1974), Hogue et al. (1976), Jones et al. (1978), Jude et al.

(1979), Loos et al. (1979), Wang and Kernehan (1979), Conner et al. (1980), Snyder (1981), Heufelder and Fuiman (1982), Fuiman et al. (1983), Gerlach (1983), Penaz et al. (1983), Wang (1986), McGowan (1988), Holland-Bartels et al. (1990), Scheidegger (1990), Nakatani et al. (2001), Pinder (2001), Snyder et al. (2005), Faber (2006 onwards), Wang and Reyes (2007), Korwin-Kossakowski (2008), and Arvidson and Alber (2013). Also, others cited by some of these.

***Gila atraria*, Utah chub—**Snyder (1981), Valdes-Gonzales (1982), Fuiman et al. (1983).

Gila pandora, Rio Grande chub—Snyder et al. (In Preparation).

***Hybognathus hankinsoni*, brassy minnow—**Perry (1979), Perry and Menzel (1979), Snyder (1981), Heufelder and Fuiman (1982), and Fuiman et al. (1983).

Lepidomeda copei, northern leatherside chub—Larvae undescribed.

Lepidomeda aliciae, southern leatherside chubs—Larvae undescribed.

***Notemigonus crysoleucas*, golden shiner—**Fish (1932, wrong illustration), Fowler (1945), Hogue et al. (1976), Mansueti and Hardy (1967), Lippson and Moran (1974), Snyder et al. (1977), Jones et al. (1978), Loos et al. (1979), Wang and Kernehan (1979), Buynak and Mohr (1980), Faber (1980), Heufelder and Fuiman (1982), Fuiman et al. (1983), McGowan (1984), Conrow and Zale (1985), Wang (1986), McGowan (1988), Holland-Bartels et al. (1990), Scheidegger (1990), Faber (2006 onwards), Wang and Reyes (2007), Scripter (2009), and Arvidson and Alber (2013).

Notropis blennius, river shiner—Conner et al. (1980, flexion mesolarva illustration only), Heufelder and Fuiman (1982, Conner et al. illustration only), Fuiman et al. (1983), and Holland-Bartels et al. (1990).

Notropis dorsalis, bigmouth shiner—Loos and Fuiman (1978), Perry (1979), Perry and Menzel (1979), Heufelder and Fuiman (1982, in Auer 1982), Fuiman et al. (1983), and Holland-Bartels et al. (1990).

Notropis hudsonius, spottail shiner—Fish (1932), Mansueti and Hardy (1967), Lippson and Moran (1974), Dorr et al. (1976), Jones et al. (1978), Loos and Fuiman (1978), Wang and Kernehan (1979), Heufelder and Fuiman (1982), Fuiman et al. (1983), Holland-Bartels et al. (1990), and Arvidson and Alber (2013).

***Notropis stramineus*, sand shiner—**Fish (1932), Loos and Fuiman (1978), Perry (1979), Perry and Menzel (1979), Snyder (1981), Heufelder and Fuiman (1982), Fuiman et al. (1983), and Holland-Bartels et al. (1990).

***Pimephales promelas*, fathead minnow—**Fish (1932), Andrews (1970), Hogue et al. (1976), Snyder et al. (1977), Buynak and Mohr (1979c), Perry (1979), Perry and Menzel (1979), Snyder (1981), Heufelder and Fuiman (1982), Fuiman et al. (1983), Wang (1986), Holland-Bartels et al. (1990), Remple and Markle (2005), Snyder et al. (2005), Faber (2006 onwards), Wang and Reyes (2007), and Feeney and Swift (2008).

***Rhinichthys cataractae*, longnose dace—**Fish (1932, misidentified blacknose dace *R. atratulus*?), Bartnik (1970), Fuiman and Loos (1977), Cooper (1978, 1980), Buynak and Mohr (1979a), Loos et al. (1979), Snyder (1981), Heufelder and Fuiman (1982), and Fuiman et al. (1983).

***Richardsonius balteatus*, redside shiner—**Weisel and Newman (1951), Lindsey and Northcote (1963), and Snyder (1981).

***Semotilus atromaculatus*, creek chub—**Embody (1914), Fish (1932), Buynak and Mohr (1979b), Kranz et al. (1979), Loos et al. (1979), Perry (1979), Perry and Menzel (1979), Snyder (1981), Heufelder and Fuiman (1982), and Fuiman et al. (1983).

APPENDIX III

Specimens Analyzed for this Guide

The following is a list of the total number of specimens analyzed (N, including drawing specimens) for each species and the associated Larval Fish Laboratory (LFL) Collection catalog number for those individually comprising or removed from previously cataloged lots, followed in parentheses by the number of analyzed specimens removed if more than one. Catalog numbers for or including primary drawing specimens are denoted by an asterisk, followed by a superscript number if more than one specimen; those for cleared and stained specimens are denoted by a superscript "cs").

Cyprinella lutrensis, red shiner—N = 115; LFL catalog numbers: 48862(2)*, 72788(3)*, 72789, 72791, 72793, 72794, 72796, 72804, 72822, 72824(2), 72828(4)*, 72831(2), 72833, 72848(2), 97880(2), 97881*, 97898(5)*^{2}.

Cyprinus carpio, common carp—N = 84; LFL catalog numbers: 2974(2), 7218(2), 8515*, 11784, 23421, 26390, 31315*, 31319, 41010, 73048(2)*, 73050, 73051, 73052(2), 73055, 73061, 73063, 73064, 73069, 73077, 82258, 82354*, 82400, 87799*, 88897*.

Gila atraria, Utah chub—N = 92; LFL catalog numbers: 18961, 68738(5)*, 68740(2), 68742.

Gila cypha, humpback chub—N = 270; LFL catalog numbers: 98710^{cs}, 98711^{cs}, 98712–98752, 98783–98788, 98789^{cs}, 98790–98792, 98793^{cs}, 98794^{cs}, 98795, 98796^{cs}, 98797–98799, 98800^{cs}, 98901, 98802, 98803^{cs}, 98804, 98805^{cs}, 98806–98848, 98887^{cs}, 98888^{cs}, 98889–98895, 98896^{cs}, 98897^{cs}, 98898, 98899^{cs}, 98900, 98901, 98902^{cs}, 98903–98930, 98931^{cs}, 98932–98947, 98948^{cs}, 98952^{cs}, 98953–98958, 98959^{cs}, 98960^{cs}, 98961–98963, 98964^{cs}, 98965^{cs}, 98966, 98967^{cs}, 98968^{cs}, 98969–98972, 98973^{cs}, 98974, 98975, 98976^{cs}, 98977–99014, 99528^{cs}, 99529^{cs}, 99551^{cs}, 99554^{cs}, 99557^{cs}, 99558^{cs}, 99609–99632, 99633–9638^{cs}.

Gila elegans, bonytail—N = 165; LFL catalog numbers: 99051–99058, 99059^{cs}, 99060, 99061–99063^{cs}, 99064, 99065, 99066–99068^{cs}, 99069–99071, 99072^{cs}, 99073–99085, 99086^{cs}, 99087–99104, 99105*, 99106–99135, 99136*, 99137–99143, 99144^{cs}, 99145–99162, 99163*, 99164, 99209–99211, 99212*, 99530^{cs}, 99559^{cs}, 99560^{cs}.

Gila robusta, roundtail chub—N = 227; LFL catalog numbers: 73230, 73233, 73267, 73276, 73288, 73289(2), 73291, 73293, 73298, 73302, 73305(2), 73306, 99962–99991, 99992^{cs}, 99993–100000, 100001^{cs}, 100002–100004, 100005^{cs}, 100006, 100007^{cs}, 100008–100010, 100011^{cs}, 100012, 100013–100022^{cs}, 100023–100028, 100029^{cs}, 100030–100041, 100042^{cs}, 100043–100085, 100086–100088^{cs}, 100089, 100090–100093^{cs}, 100094–100097, 100098–100105^{cs}, 100106, 100107, 100120–100184, 100334^{cs}, 100340^{cs}.

Hybognathus hankinsoni, brassy minnow—N = 83; LFL catalog numbers: 69282, 69312, 69367(13)*, 69375(3), 69658, 96130, 98463, 98544, 98593, 98630(2), 98632, 98634(7)*^{2}, 98648(2)*, 98684(2).

Notemigonus crysoleucas, golden shiner—N = 39; LFL catalog numbers: (none).

Notropis stramineus, sand shiner—N = 112; LFL catalog numbers: 72688(2)*, 72695,

72701(2)*, 72727(2)*, 72730(2)*, 72732, 72769(2)*, 72777, 97905, 97954, 98179.

Pimephales promelas, fathead minnow—N = 42; LFL catalog numbers: 72860(3)*, 72865(4), 72869(2), 72876, 72877*, 72878(2), 72880(2), 72881, 72899, 72900, 72904, 72909, 72913, 72924, 72930, 72933, 72935, 72959, 72962(3), 72966, 72968, 72976, 82227*.

Ptychocheilus lucius, Colorado pikeminnow—N = 66; LFL catalog numbers: 41741(2)*, 56242*, 56243(2)*[2].

Rhinichthys cataractae, longnose dace—N = 59; LFL catalog numbers: 68648, 80190, 80215, 80239*, 80246, 89551(2), 99726, 99755, 99954(3), 99958, 102857.

Rhinichthys osculus, speckled dace—N = 135; LFL catalog numbers: 11738, 21834, 23403*, 23415, 72554, 72561, 72566, 72569, 72573, 72575(2), 72578, 72591(2), 72594(2), 72618(2), 72620, 72631(2), 72643, 72645, 72650, 72654, 72666, 72671, 72677.

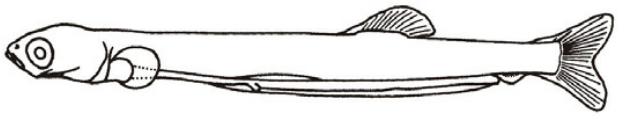
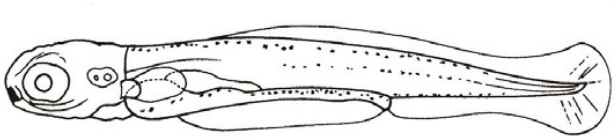
Richardsonius balteatus, redside shiner—N = 168; LFL catalog numbers: 108441, 108456(9).

Semotilus atromaculatus, creek chub—N = 67; LFL catalog numbers: 18409(6)*, 96132, 96160*, 98279(3), 99923, 99941(3), 99952.

Appendix IV

Pictorial Guide to Families of Fish Larvae in the Upper Colorado River Basin

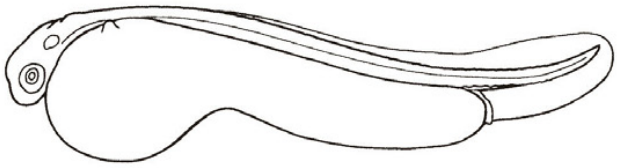
(Modified with permission from Wallus et al. 1990
for only families found in the Upper Colorado River Basin)

Larvae with yolk	Larvae without yolk
CLUPEIDAE—herrings	
• slender, little pigment, transparent • oil may or may not be visible • large oil globule, if present, will be located posteriorly • posterior vent • less than 10 postanal myomeres • dorsal finfold origin anterior, at mid-yolk sac early and just behind head later	• slender, little pigment • posterior vent • anal fin posterior to dorsal fin • [posterior gut vertically striated]
	
CYPRINIDAE—carps and minnows	
• yolk long, cylindrical, initially bulbous anteriorly • pigmentation varies from light to heavy • vent usually slightly beyond midbody	• pigmentation often in rows; dorsolaterally, midlaterally, along ventral margin of myomeres, and midventrally • air bladder obvious, becoming two-chambered, usually pigmented dorsally • single dorsal fin
	

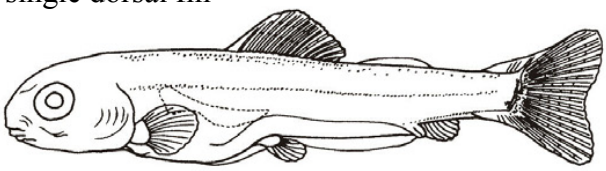
Larvae with yolk	Larvae without yolk

CATOSTOMIDAE—suckers

- yolk long, cylindrical, initially more bulbous anteriorly
- vent posterior, two-thirds to three-fourths back on body

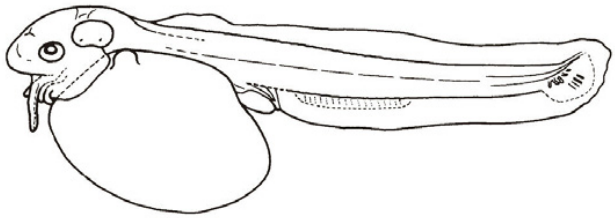


- mouth shape and position varies from terminal and oblique to inferior (later in development)
- pigment variable but often in three rows, dorsally, ventrally, and midlaterally; dorsal pigment may also be in 1–3 rows
- air bladder obvious
- single dorsal fin



ICTALURIDAE—North American catfishes

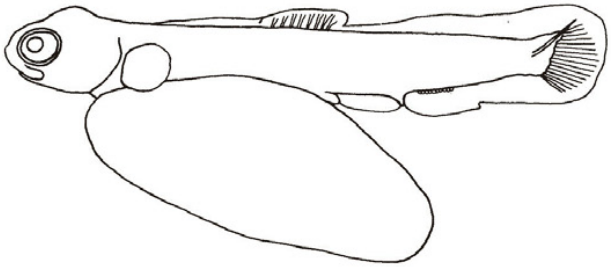
- large bulbous yolk
- barbels evident at hatching
- advanced fin development before complete yolk absorption



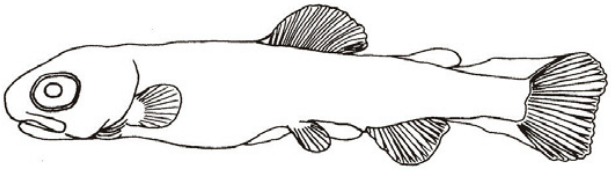
- [sometimes] no post yolk-sac larval phase [earliest juveniles of some still have yolk, but larvae of others may absorb all yolk before the adipose fin is fully differentiated from remnant finfold or all rudimentary caudal-fin rays are formed]

SALMONIDAE—trouts and salmons

- large, greater than 11 mm TL at hatching
- large yolk, initially pendulous
- advanced fin development prior to complete yolk absorption
- vent about two-thirds back on body



- robust
- large, rounded head
- adipose fin

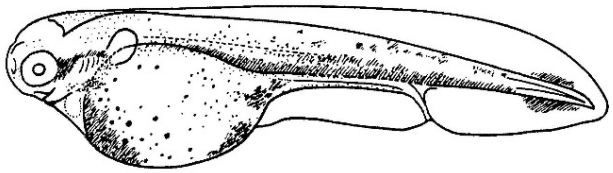


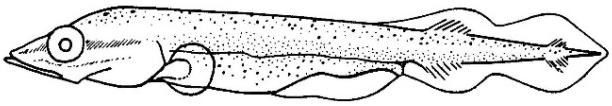
Larvae with yolk	Larvae without yolk

ESOCIDAE—pikes and mudminnows

- darkly pigmented
- vent about two-thirds back on body

- elongate
- extended, depressed, duck-like snout
- posterior dorsal fin

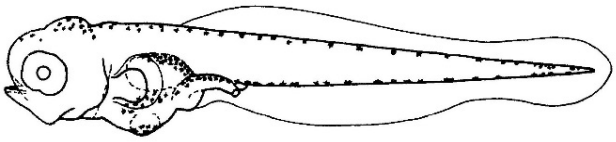


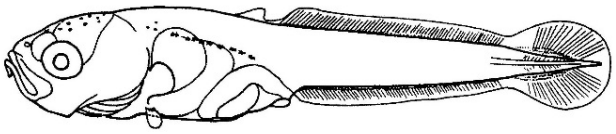


GADIDAE—cods

- more than 50 total myomeres
- large head
- short gut
- anterior vent opens laterally on finfold

- single barbel on chin
- second dorsal fin and anal fin long
- isocercal tail
- pelvic fins positioned under pectoral fins

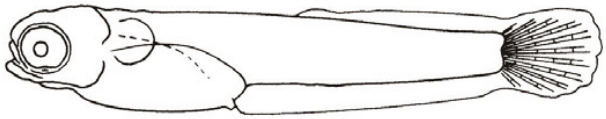




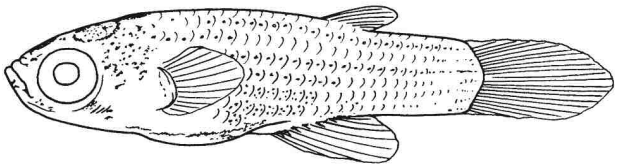
FUNDULIDAE—topminnows

- stubby, robust
- caudal fin with rays at hatching
- vent anterior, near posterior margin of yolk

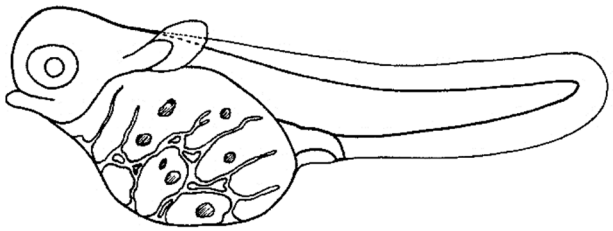
- large head
- superior mouth
- rounded caudal fin
- stocky caudal peduncle
- 10 or more dorsal rays [later larvae]

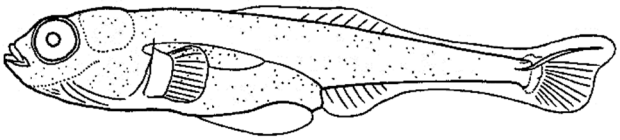


Larvae with yolk	Larvae without yolk
POECILIIDAE—livebearers	
• inside female	• scales present at birth • rays in all fins at birth [except pelvic fins] • superior mouth • dorsal fin short, 7–8 rays

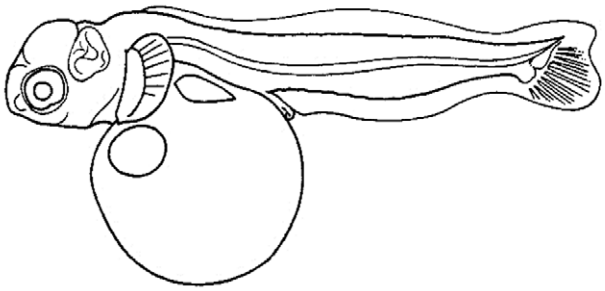


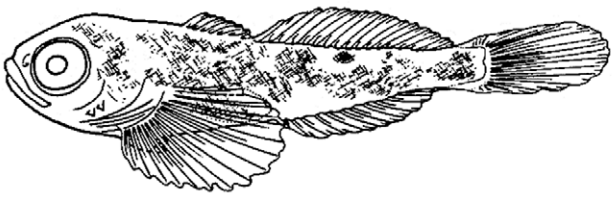
GASTEROSTEIDAE—sticklebacks	
• short (5–6 mm TL), stubby • vent at midbody or slightly posterior • vitelline vessel over yolk • small oil globules present	• sloping head, superior mouth • narrow caudal peduncle





COTTIDAE—sculpins	
• robust with large head and large round yolk sac • fins well developed before yolk absorption is complete • anterior vent	• large pectoral fins • two dorsal fins • second dorsal fin and anal fin long • caudal fin spatulate



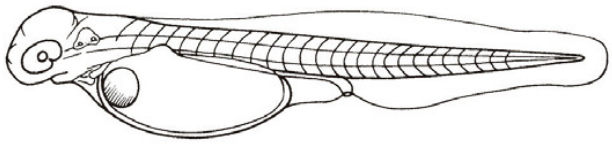


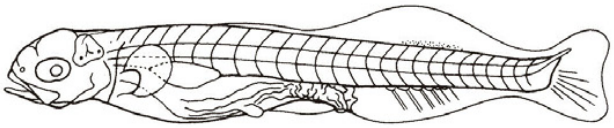
Larvae with yolk	Larvae without yolk

MORONIDAE—temperate basses

- vent slightly posterior to midbody
- single, large, anterior oil globule
- low total myomere count, 25–26 or less

- S-shaped gut
- low myomere count
- late larvae with well developed mouth with teeth
- spinous dorsal fin develops secondarily [later larvae]

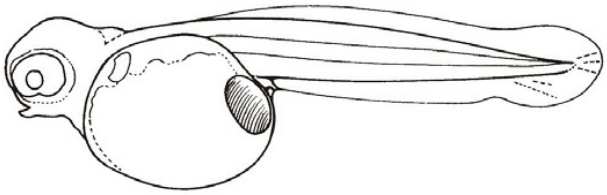


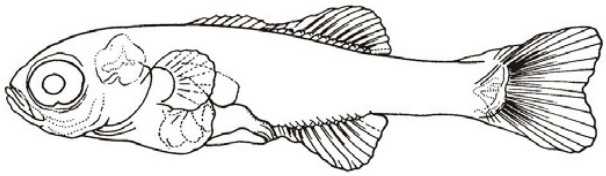


CENTRARCHIDAE—sunfishes

- large, oval yolk sac at hatching
- position of oil globule variable, but usually posterior
- vent anterior to midbody

- usually robust with large head
- air bladder distinct
- gut short, coils with growth
- spinous and soft dorsal fins continuous [later larvae]

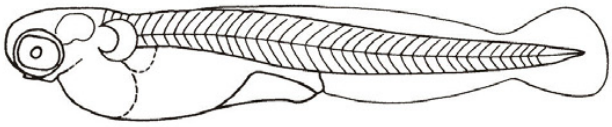


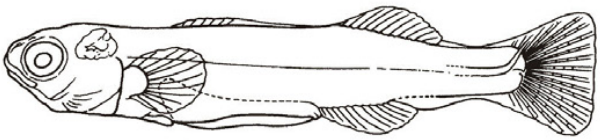


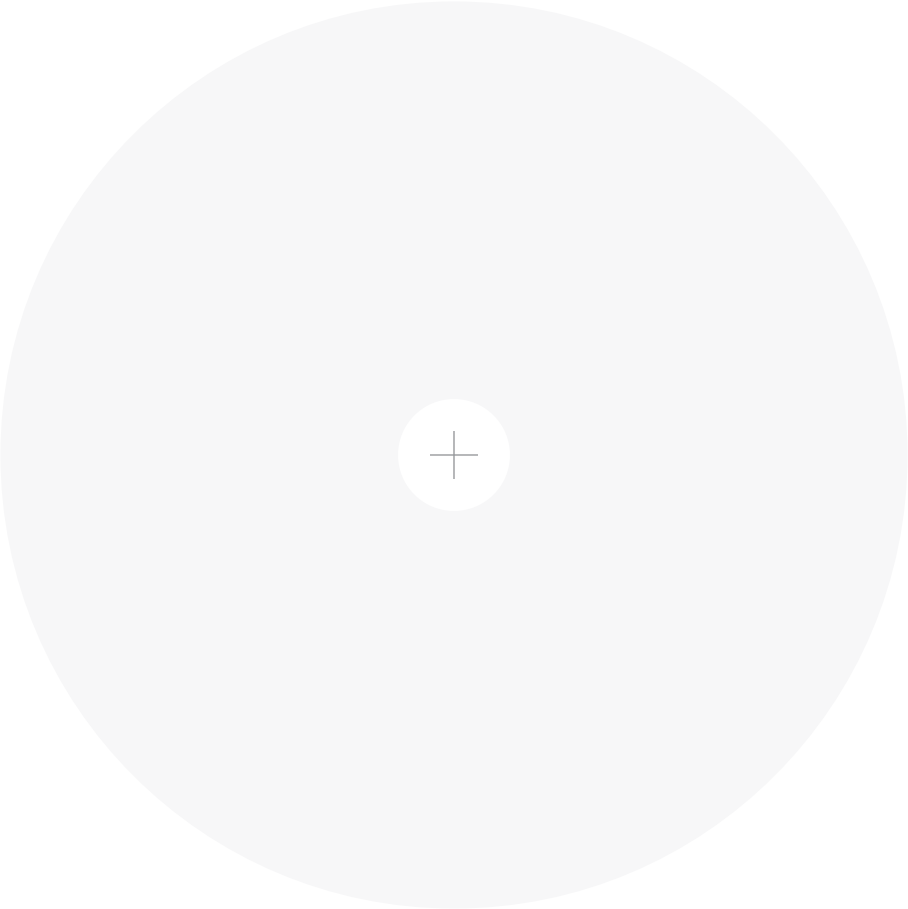
PERCIDAE—perches and darters

- vent near midbody
- large anterior oil globule
- pectoral fins usually well developed at hatching
- total myomere counts higher than in moronids or centrarchids

- large pectoral fins
- spinous dorsal separate from soft dorsal fin [later larvae]







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