CATOSTOMID FISH LARVAE AND EARLY JUVENILES OF THE UPPER COLORADO RIVER BASIN — MORPHOLOGICAL DESCRIPTIONS, COMPARISONS, AND COMPUTER-INTERACTIVE KEY

STATE OF COLORADO – DIVISION OF WILDLIFE

Cover. Razorback sucker (*Xyrauchen texanus*) postflexion mesolarvae. About 15 mm TL, 4 weeks after hatching, 5 weeks after fertilization. Reared at 18-19° C in March and April 1990 by the Larval Fish Laboratory from artificially fertilized eggs provided by Dexter National Fish Hatchery (New Mexico).

CATOSTOMID FISH LARVAE AND EARLY JUVENILES OF THE UPPER COLORADO RIVER BASIN – MORPHOLOGICAL DESCRIPTIONS, COMPARISONS, AND COMPUTER-INTERACTIVE KEY

(Retitled update and expansion of
Colorado Division of Wildlife Technical Publication No. 38
DESCRIPTIONS AND IDENTIFICATION OF RAZORBACK, FLANNELMOUTH, WHITE, UTAH, BLUEHEAD, AND MOUNTAIN SUCKER LARVAE AND EARLY JUVENILES)

by

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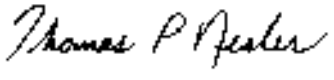
FOREWORD

One of the mysteries that cloud the full understanding of the life history and ecology of many fish species is found in that segment of the life cycle from hatching as larvae to the stage at which juveniles can be readily caught and identified. Understanding that ephemeral piece of life history for a fish species has been the primary goal and career pursuit for the Larval Fish Laboratory and Darrel Snyder at Colorado State University. While perhaps not the most exciting field of fishery science to young, new professionals, understanding larval and early juvenile fish population ecology is recognized by conservation and sport fishery managers alike as fundamental. Most limiting factors determining recruitment success and year class strength exert themselves at this life stage.

Comparison of the June 1990 publication of the identification key for the early life stages of sucker species in the Colorado River Basin with this new edition demonstrates the characteristic persistence of scientific endeavor and the skillful adaptation of computer technology. Instead of a book that sits on a shelf until needed, opened, read, and oft-times interpreted, this revised edition carries a compact disk that provides a new identification tool to update and replace the former printed key and transform one's involvement into a flexible interactive experience. The user can define the set of candidate species and selects characters to be evaluated from a continually updated list of best available characters. The book is still there for comparison of specimens with detailed descriptive information and illustrations, but new generations of field biologists consider their computer as integral to field work as nets, seines and electro-fishing boats. Also new is the addition of another sucker species not covered in the 1990 publication, the longnose sucker, *Catostomus catostomus*. Passed over as the lowest information priority in 1990, this introduced species in the Colorado River Basin has shown up more frequently in the past decade in rivers targeted for reintroduction of the federally-endangered razorback sucker. Our low priority became a "need-to-know" information gap.

What has not changed is quality of the product. The definitive information is still there and has been improved with new information from a decade of continuing research by the CSU Larval Fish Lab and others. The 1990 publication was predicted to be invaluable to the community of researchers and biologists working in the Upper Colorado River Basin for native fish conservation and endangered fish recovery. Indeed, that publication was soon sold out and copies required replacement binding from continual use. A small supply of nearly 100 copies was recently discovered in boxes in the Division of Wildlife warehouse. They were made available upon request, and were gone within a week. Good prediction.

What distinguishes this and the previous publication are the extraordinary drawings and pictures that accompany and clarify the extensive technical jargon required to navigate your way through identification of organisms that can be wholly draped over your thumbnail. The drawings of the fish and pictures of the skeletal features are what one actually sees of these semi-transparent fish under the light of a dissection microscope. A key to successful conservation of native and endangered fishes starts with the survival of the larval fish as they emerge from the gravels of Colorado River Basin Rivers, are swept downstream to nursery habitats, and face high mortality from a myriad of sources. Are the fish you collected the endangered razorback sucker or the abundant flannelmouth sucker? This identification tool, this software program, this publication gets you there with clear and credible support and documentation.



Thomas P. Nesler
Native Fishes Conservation Program Manager
Colorado Division of Wildlife

PREFACE

This publication is an expanded, updated, and retitled edition of our 1990 guide (Snyder and Muth 1990) to the larvae and early juveniles of six of seven catostomid fishes in the Upper Colorado River Basin (UCRB). Recognizing that morphological criteria for identification change dramatically as fish larvae grow and develop, and that diagnosis becomes especially difficult and complicated when species are very similar in appearance, the 1990 guide included 60 pages of keys, detailed descriptions (species accounts), and a comparative summary. For over a decade, that publication served well as a taxonomic reference for Larval Fish Laboratory, Colorado Division of Wildlife, Upper Colorado River Endangered Fish Recovery Program, San Juan River Basin Recovery Implementation Program, and other regional researchers. But species coverage was incomplete for the UCRB, new observations revealed the need to update certain descriptive data, and errors had been found in the printed keys, which also needed to be updated, expanded (for the seventh species), and, if possible, made easier to use.

Longnose sucker (*Catostomus catostomus*) was not included in the 1990 guide because of budgetary limitations and the improbability of encountering its larvae or early juveniles in Recovery Program collections. However, with collection of juvenile longnose sucker and larvae suspected to be longnose sucker or hybrids in the lower Gunnison River in 1993, confidence in identification of those and other catostomids (including the progeny of reintroduced razorback sucker, *Xyrauchen texanus*) was compromised, and the need to comparably describe and incorporate the last of the UCRB catostomids in the keys became evident. To address this need and facilitate more accurate identification, larvae and early juveniles of longnose sucker were reared to supplement previously preserved developmental series, and their morphological development was documented in a new species account, a revised comparative summary, and a computer-interactive key which replaces the 1990 printed keys.

As a modern alternative to long and intricate dichotomous or polychotomous keys, such as those in the 1990 guide, computer-interactive keys are much easier to prepare, update, and expand. They are also far more flexible for the user. Among other features, users can limit consideration to only likely candidate species, have available characters listed in the most diagnostic order for remaining candidates, and select from that list in any desired sequence–bypassing characters that are unfamiliar, difficult to assess, or based on structures that are damaged or missing.

The new species account, comparative summary, and key, along with a list of corrections and other updates to the 1990 guide, were included in a manuscript for publication as a supplemental update (Snyder 2003). But rather than publish the supplement, along with a limited reprint of the 1990 guide, sponsors agreed that incorporation of the new and revised content in a new edition of the guide would be no more costly and considerably more desirable and convenient for users.

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ACKNOWLEDGMENTS

This publication is the culmination of a quarter century of work by the Larval Fish Laboratory (LFL) on early life stages of the species covered. It and the preceding edition (Snyder and Muth 1990), are built upon earlier descriptions and keys sponsored by the (U.S.) Bureau of Land Management (BLM, Colorado Office), Colorado Division of Wildlife (CDOW, former Non-Game Section), Colorado State University Experiment Station, Ecosystem Research Institute (Logan, Utah), U.S. Fish and Wildlife Service (USFWS, Colorado River Fishery Project and Reno Fisheries Assistance Office), and Utah Division of Wildlife Resources (UDWR). Preparation and publication of the preceding edition were sponsored by CDOW (Endangered Fishes Investigations SE-3) and USFWS (Division of Federal Aid). Preparation of the updates, new description (longnose sucker), and computer-interactive key for this new edition, and publication thereof, was jointly sponsored by CDOW and the Upper Colorado River Endangered Fish Recovery Program (UCRP) through the (U.S.) Bureau of Reclamation (BR, Upper Colorado Regional Office, Salt Lake City). The San Juan River Basin Recovery Implementation Program (SJRIP), via BR, also helped fund publication. The UCRP is a joint effort of the USFWS, BR, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, the Colorado River Energy Distributors Association, and the National Park Service. Participants in the SJRIP are the Jicarilla Apache and Navajo Nations, Southern Ute Indian and Ute Mountain Ute Indian Tribes, states of Colorado and New Mexico, U.S. Bureau of Indian Affairs, BLM, BR, and USFWS.

Most collected specimens used for developmental study were taken or processed by LFL for various agencies working in the Upper Colorado River Basin (CDOW, UDWR, BLM, USFWS). Additional reared or collected specimens were donated by or borrowed from William Hauser (Alaska Department of Fish and Game, Anchorage), Philip Harrison (CSU), Arizona State University Center for Environmental Studies (Tempe, via Daniel Langhorst and Paul Marsh), Bio/West Inc. (Logan, Utah, via Paul Holden), Ecosystem Research Institute (Logan, Utah, via Richard Valdez and John Carter), Museum of Southwestern Biology (Albuquerque, New Mexico, via Howard Brandenburg, Steven Platania, and Alexandra Snyder), Utah Cooperative Fish and Wildlife Research Unit (Utah State University, Logan, via Timothy Modde and Neal Muirhead), UDWR (Salt Lake City, via Randy Radant and Dennis Shirley), and USFWS–Colorado River Fishery Project (Grand Junction, Colorado, and Vernal, Utah, via Lynn Kaeding and Harold Tyus), Fisheries Assistance Office (Reno, Nevada via Donald King and Gary Scoppetone), and Dexter National Fish Hatchery (New Mexico, via Roger Hamman). Parental stock for white sucker (*Catostomus commersoni*) culture was obtained from a local pond owned by Louis Swift. Study specimens (except those returned to lenders) are maintained as part of the LFL Collection.

Developmental studies at LFL have depended on the assistance and cooperation of many individuals, including Colorado State University (CSU) students serving as Larval Fish Laboratory volunteers or employees. Edmund Wick (LFL) was responsible for obtaining fertilized eggs and rearing developmental study series of many of the species studied. Marian Allen, Kevin Bestgen, Daniel Beyers, Nick Bezzerides, Robert Compton, Sean Seal, and Koreen Zelasko of LFL, and Daniel Brauch, Steve Braylee, Kevin Rogers, and most successfully, Kenneth Kehmeier and crew of CDOW assisted with efforts to capture ripe longnose sucker (*Catostomus catostomus*) for our most recent culture effort. Dale Brown, Mark Castagneri, Albert Davis, Gary Dean, Keith Fulsos, Carol Jefferson, Philip Harrison, David Herbet, Jeffrey Pearson, and Sean Seal (Brown and Fulsos via summer CETA Youth Program) assisted with culture or organization of reared or collected specimens for study. James Barrowman, C. Lynn Bjork, William Emerson, Lyndon Evans, Stephanie Salyer, Diane Miller, Sean Seal, and Edmund Wick assisted with descriptive analysis of specimens. Timothy Hill, Jack Piccolo, Steven Platania, and Sean Seal cleared and stained some specimens. Sean Seal captured digital images for illustration of skeletal features for longnose sucker.

C. Lynn Bjork prepared Figures 1, 3, 4, 5, and 6, (and variants of Figs. 3, 4, and 5 used in the computer-interactive key) and all original and previously published drawings of larval and early juvenile fish in the species accounts except selected drawings of white sucker larvae which were

reproduced with permission from Buynak and Mohr (1978) and Fuiman (1979, drawings by C. Komar Outlaw). Drawings of adult catostomids in the species accounts were reproduced with permission from drawings by Joseph Tomelleri, many of which were published in Tomelleri and Eberle (1990) and Sigler and Sigler (1996).

Michael Dallwitz (formerly of CSIRO Division of Entomology, Canberra, Australia) provided copies of DELTA system computer programs and manuals to aid key production, assisted with the initial versions of the computer-interactive key, and provided periodic guidance in the use of *Intkey* and other DELTA programs. Steve Meismer, Jack Ruppert, Mark Williams, and Kevin Bestgen helped edit the printed keys for the previous edition (Snyder and Muth 1990) of this guide. Sean Seal assisted with preparation of the data set for the computer-interactive key included with this edition, and he, Tasha Sorenson, Koreen Zelasko, and other LFL staff test-used interim and near-final versions of the key.

Some sections of text, species-account data, and many illustrations herein were extracted with little or no modification from Snyder (1981, 1983a) or Snyder and Muth (1988). Anita Martinez, Kenneth Tiffan, Maryann Snyder, and Clarence Carlson reviewed draft manuscripts for the previous 1990 edition. A few text errors were identified in a review of that publication by Fuiman (1991) and some errors in the printed keys and likely range extensions for characters in the keys, descriptive comparisons, and species accounts were brought to our attention by various users of the guide. Most corrections or updates incorporated herein are documented in a Recovery Program final report by Snyder (2003). Sean Seal and Maryann Snyder proof-read and Tom Czapla, Steve Meismer, Howard Brandenburg, and members of UCRP Biology Committee reviewed draft versions of that final report, much of which is incorporated in this guide. Chuck McAda, Steve Platania, and Kevin Bestgen contributed recent information and references on status and distribution of catostomids in the Upper Colorado River Basin. Maryann Snyder and Sean Seal proof-read the manuscript for this CDOW Technical Publication.

Frontispiece. Yearling razorback sucker (Xyrauchen texanus). Top – interneural bones of cleared and stained specimen, 65 mm TL. Bottom – predorsal keel barely evident immediately behind the head of a living specimen, 85 mm TL. Reared by the Larval Fish Laboratory from eggs artificially fertilized on June 8, 1980, from adults collected in gravel pits connected to the Colorado River near Clifton, Colorado.

CATOSTOMID FISH LARVAE AND EARLY JUVENILES OF THE UPPER COLORADO RIVER BASIN – MORPHOLOGICAL DESCRIPTIONS, COMPARISONS, AND COMPUTER-INTERACTIVE KEY

Darrel E. Snyder and Robert T. Muth

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. To facilitate identification of larvae and early juveniles of the seven species of Catostomidae in the Upper Colorado River Basin (UCRB), developmental series of reared and collected specimens were studied for differences in morphology, meristics, pigmentation, size relative to developmental state, and skeletal features. The results are documented in detailed descriptive species accounts, a comparative summary, and a computer-interactive key, the first application of such to fish larvae.

Early larvae of the endangered razorback sucker (*Xyrauchen texanus*) are most similar to bluehead sucker (*Catostomus discobolus*), whereas later larvae and early juveniles appear most like flannelmouth sucker (*C. latipinnis*). Criteria for distinguishing razorback sucker from the early larvae of most species include early yolk absorption, few or no melanophores along the ventral midline between heart and vent, and generally sparse dorsal pigmentation. Criteria for diagnosis of later larvae and juveniles include up to 16 principal dorsal-fin rays, a correspondingly long dorsal fin base, a large, fan-shaped, first interneural bone, and a large, oval-shaped, frontoparietal fontanelle.

Larvae of bluehead sucker and mountain sucker (*C. platyrhynchus*), both subgenus *Pantosteus*, are best characterized by early scattering of dorsal pigmentation, early folding of the gut, early formation of dark peritoneal pigmentation, and relatively few dorsal-fin rays. The midventral line of pigment from heart to vent is often complete in mountain sucker larvae but highly variable in bluehead sucker. Early juveniles of both species have a small, blocky, first interneural bone, a narrow fontanelle, moderate to small scales, lips well divided at the corners of the mouth, and a shallow incision separating lower lip lobes.

The remaining four species represent subgenus *Catostomus*. Flannelmouth sucker larvae are distinguished from most other UCRB catostomids by their generally large size at hatching, yolk absorption, and onset of other developmental events; also by a relatively high count of dorsal-fin rays, delayed gut folding, moderate to few midventral melanophores anterior to the vent, and lines of dorsal pigment parallel to the midline that sometimes include obliquely oriented pairs of melanophores resulting in a distinctive herringbone pattern that is sometimes shared only by white sucker (*C. commersoni*); juveniles develop small scales. White sucker larvae have greater than 20 melanophores in a typically complete midventral line from before or over the heart to the vent; juveniles have large scales, usually well outlined with pigment, and typically develop a distinctive series of three eye-size lateral spots (behind head, above pelvic fins, and on caudal peduncle). Utah sucker (*C. ardens*) larvae, like flannelmouth sucker, usually have much less midventral pigmentation than white sucker, sometimes none, like some razorback and bluehead sucker; dorsal pigmentation is often sparse like razorback sucker. Juvenile Utah sucker often have larger eyes relative to head length than the other catostomids and, like white sucker, have large scales, but they develop no distinctive eye-size lateral spots or rarely just the anterior two. Early larvae of longnose sucker (*C. catostomus*) are most similar to bluehead, mountain, and white suckers. All typically have a complete middorsal line of melanophores from head to tail, but longnose sucker larvae develop pelvic-fin buds earlier, and, unlike white sucker, they seldom have complete lines of melanophores lateral to the dorsal midline and sometimes have much less midventral pigmentation. Juveniles have smaller scales and develop no distinct eye-size lateral spots except sometimes one near the base of the caudal fin.

INTRODUCTION

Importance of Early Life History Investigations and Identification

For most fishes, larval and early (young-of-the-year) juvenile development includes a few to several 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 more effectively monitoring, protecting, or managing fish populations and habitat. Such knowledge is particularly valuable in assessing environmental impacts and recovering endangered species.

The collection and study of fish eggs, larvae, and early juveniles are or should be integral parts of many fish and aquatic ecology investigations. Their spatial and temporal distribution and densities are indicative of spawning and nursery areas, spawning 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, or habitat.

Research or monitoring based on collections of fish larvae usually requires accurate identification of collected specimens. Inland fishery managers and researchers often exclude potentially critical larval-fish investigations specifically because they haven't done it before or they don't have the taxonomic tools needed for the job. Unfortunately, adequate description of larvae, determination of taxonomic criteria, and development of keys for identification are time-consuming and expensive tasks. Although the inventory of such information is gradually increasing, much descriptive and taxonomic research is piecemeal, uncoordinated, and often "a labor of love."

Of approximately 800 species of freshwater and anadromous fishes in the United States and Canada (Lee et al. 1980, Robins, et al. 1991) less than 25% have been adequately described as larvae for identification purposes (Snyder 1996, extrapolated from 15% reported by Snyder 1976a). In a relatively comprehensive listing of regional larval-fish guides, keys, and comparative descriptions by Simon (1986), only about 80 of 230 citations (35%) pertain to freshwater species. Kelso and Rutherford (1996) listed 18 regionally oriented larval-fish identification manuals for or including North American freshwater species (some for the same regions and all incomplete in coverage at the species level). Not included in the list were guides by Sturm (1988), Snyder and Muth (1988, 1990– probably treated as comparative descriptions rather than regional guides), and most recently, Simon and Wallus (2004). No guides to or including North American freshwater fish larvae were published between 1994 and 2004.

This Guide and Prior Descriptions

The purpose of this publication is to describe and better facilitate identification of the larvae and early juveniles of Catostomidae (suckers) in the Upper Colorado River Basin (UCRB, Fig. 1)–the native razorback, flannelmouth, bluehead, and mountain suckers, and non-native white, longnose, and Utah suckers (*Xyrauchen texanus*, *Catostomus latipinnis*, *C. discobolus*, *C. platyrhynchus*, *C. commersoni*, *C. catostomus*, and *C. ardens* respectively; common and scientific names used herein follow Robins et al. 1991). All belong to subfamily Catostominae and tribe Catostomini. *Xyrauchen* is a monotypic genus. Among the *Catostomus* species, bluehead sucker and mountain sucker belong to subgenus *Pantosteus*, a distinctive group known as "mountain suckers" and treated as a separate genus prior to study by Smith (1966); the others belong to subgenus *Catostomus*, the "valley suckers" (Smith 1987).

Winn and Miller (1954) published the earliest comparisons of larvae for native cyprinid

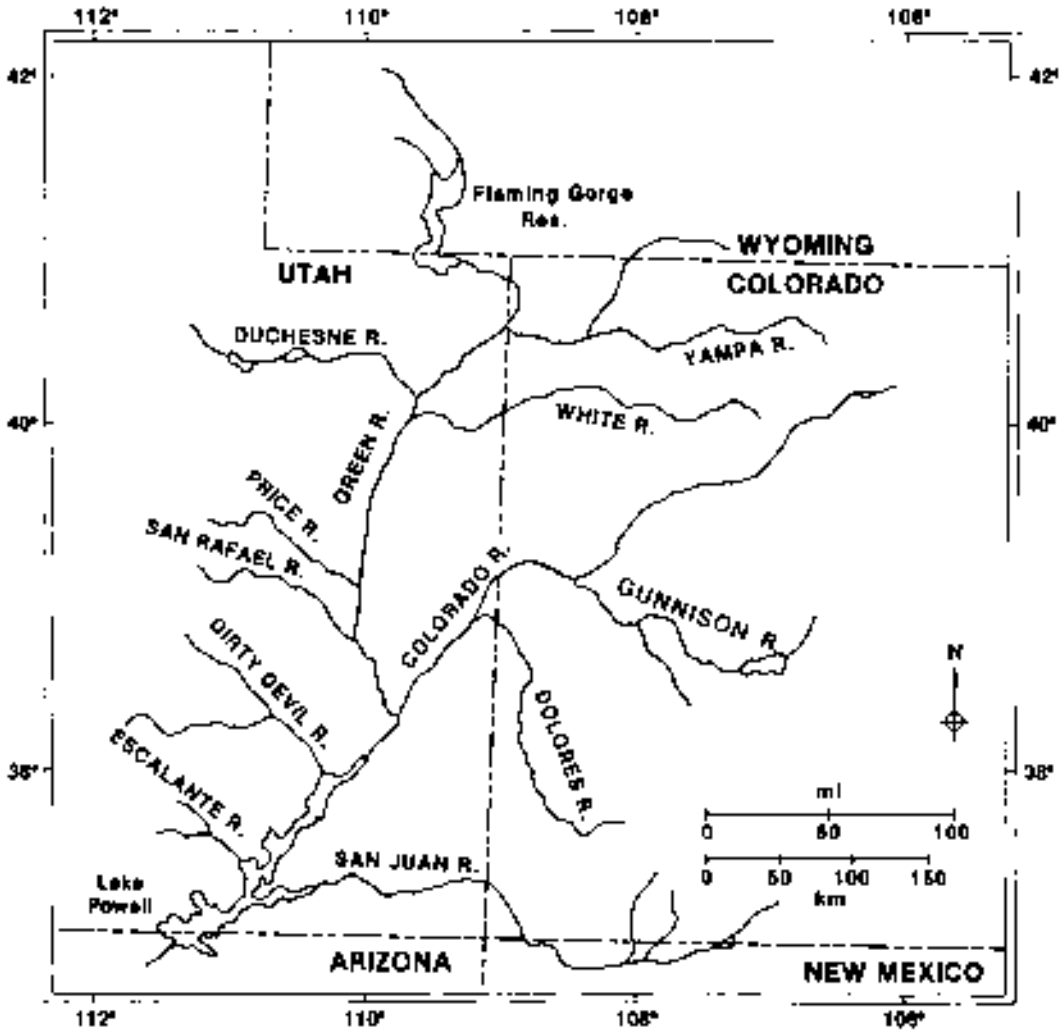


Fig. 1. The Upper Colorado River System.

(minnow) and catostomid fishes of the American southwest. Their photograph-illustrated key for the Lower Colorado River Basin below Lake Mead was limited to mesolarval stages (developmental intervals defined below), but included razorback sucker, flannel-mouth sucker, and *Pantosteus* species. All of their *Pantosteus* larvae, some of which were illustrated as bluehead sucker and desert sucker (*Catostomus clarki*), have since been recognized as desert sucker by Smith (1966). Although pigmentation of bluehead and mountain sucker mesolarvae of like size is typically similar to that documented by Winn and Miller (1954) for desert sucker, it can vary greatly, with dorsal and lateral pigmentation occasionally being indistinguishable from that illustrated and described by Winn and Miller (1954) for razorback sucker.

Few authors other than Winn and Miller (1954) and ourselves have provided descriptive information on the early life stages of native species covered in this guide. Minckley and Gustafson (1982) chronicled early development of razorback sucker, but their illustrations are sketchy and include only lateral views. Douglas (1952) published photographs of a razorback sucker protolarva (or recently transformed mesolarva) without yolk and a 10-cm specimen labeled as a juvenile razorback sucker, but, as

noted by Winn and Miller (1954), the subject of the latter photograph is actually an adult speckled dace (*Rhinichthys osculus*). In the process of documenting hybridization among several catostomids, Hubbs et al. (1943) published descriptive information for young-of-the-year juveniles (and some larvae) of flannelmouth, white, bluehead, and mountain suckers. Hubbs and Hubbs (1947) did the same for flannelmouth and bluehead suckers.

In contrast, larvae and early juveniles of the non-native white and longnose suckers (both widely distributed elsewhere in the United States (U.S.) and Canada) have been well described by other authors and included in other guides. Early life stages of white sucker have been described by Crawford (1923), Stewart (1926), Fish (1929, 1932), Long and Ballard (1976), Buynak and Mohr (1978), Fuiman (1978, 1979), Loos et al. (1979), and McElman and Balon (1980), and included identification manuals by Mansueti and Hardy (1967), Lippson and Moran (1974), Jones et al. (1978), Wang and Kernehan (1979), Auer (1982, section on Catostomidae by Fuiman), Holland-Bartels et al. (1990), and Kay et al. (1994). The pattern of three large lateral spots often observed on early juveniles was recognized at least as early as Ellis (1914). Longnose sucker larvae and early juveniles have been described by Fuiman and Witman (1979) and Sturm (1988) and included in guides by Auer (1982) and Kay et al. (1994). Although Metcalf (1966) suggested that there is little rationale for subspecies designations of white sucker (e.g., *C. commersoni suckeyi* for western white sucker), descriptive information and illustrations herein for white sucker (except four larval illustrations) and longnose sucker are based mostly on specimens from Colorado populations rather than previous descriptions from eastern or northern U.S. populations. This was necessary in part because prior descriptions, despite being very good and detailed, lacked much of the specific information needed to directly compare them with our descriptions of other species in the UCRB. Larvae and early juveniles of the third non-native species, Utah sucker, had not been previously described except by us.

All UCRB species except Utah sucker are covered to some degree in larval and early juvenile descriptions and a preliminary key to metalarvae by Snyder (1981) and an unpublished provisional key to protolarvae and mesolarvae prepared by Snyder in 1984 for the Colorado Division of Wildlife and Ecosystems Research Institute of Logan, Utah (definitions of developmental intervals in later section). However, except for flannelmouth sucker, descriptive species accounts in the 1981 publication are incomplete, and the tentative keys in both documents are based on limited descriptive information. Mountain sucker was further described in a comparison with Tahoe sucker (*Catostomus tahoensis*) and cui-ui (*Chasmistes cujus*) by Snyder (1983a) and completely described (to the extent herein), along with Utah sucker, in a comparison with June sucker *(Chasmistes liorus*) by Snyder and Muth (1988). Snyder and Muth (1990) then completed descriptive accounts for all UCRB catostomids except for longnose sucker (and a couple three-view illustrations of white sucker) and included those species in a comparative summary and 60-page key. As an expanded, updated, and retitled edition of that 1990 publication, this guide completes and updates coverage for all species and replaces the printed keys with a more flexible, easier-to-use, computer-interactive key, the first application of such to fish larvae.

Status and Distribution of the Fish

Identification of larval and early juvenile fishes, or any organism, is largely a process of elimination, and often the list of possible species can be immediately reduced by knowledge of what species are present in the waters sampled. Since 1980, the general distribution of catostomid and other fishes in the UCRB has been reviewed by Snyder (1981), Behnke et al. (1982), Carlson and Carlson (1982), Miller et al. (1982b), Tyus et al. (1982), Woodling (1985), Carlson and Muth (1989), Platania (1990), Sublette et al. (1990), Baxter and Stone (1995), Sigler and Sigler (1996), and Wheeler (1997).

Razorback sucker is an endangered species (federal and state of Colorado), and in the UCRB, its recovery is one objective of intensive, multiple-agency, multiple-species efforts by the Upper Colorado River Endangered Fish

Recovery Program and the San Juan Basin Recovery Implementation Program. The only remaining population of (partially) wild razorback sucker inhabits the lower through middle Green River and lower Yampa River, but despite evidence of successful reproduction through the annual capture of larvae and supplementation with hatchery-reared fish, it continues to decline (Bestgen et al. 2002). Elsewhere in the UCRB, wild fish have not been collected since 1981 in the lower Gunnison River, 1995 in the Colorado River near and downstream of its confluence with the Gunnison River, and 1988 in the middle and lower San Juan River (McAda 2003, Platania et al. 1991), but small populations have been maintained or reintroduced by stocking in those reaches (Ryden 1997, Burdick 2003). Continued presence in the lower ends of other tributaries to Lake Powell (Bestgen 1990) is unknown. Monitoring of larval production has documented recent razorback sucker reproduction, presumably by stocked fish, in both the lower Gunnison River (Osmundson 2002) and the middle and lower San Juan River (Brandenburg et al. 2003).

Flannelmouth, bluehead, and white suckers are the most widely distributed catostomids in the UCRB. Flannelmouth sucker and bluehead sucker remain common in the main-stem rivers and larger tributaries below Flaming Gorge Reservoir, but some populations are declining and both species are of special concern in Utah and Wyoming (Bezzerides and Bestgen 2002). White sucker is common in the Colorado, Gunnison, Yampa, and middle and upper Green Rivers, especially in upstream reaches. It also has been reported in the Duchesne River and in and below Navajo Reservoir at the upper end of the San Juan River.

The status and distribution of the remaining UCRB catostomids are poorly documented and less certain. Mountain sucker, a Colorado species of special concern, is mostly restricted to headwater tributaries throughout much of the Green River Subbasin. Although rarely found in main-stem rivers, individual specimens of mountain sucker had been reported in the Green River near the confluence with the Yampa River and in the White River near and above the confluence with Piceance Creek. In the Colorado River Subbasin, it has been reported in headwaters of Dirty Devil River (Fremont River) in Utah and the Colorado River in or below Lake Granby, Colorado, but its historical or continued presence at the latter location remains unconfirmed. Utah sucker is restricted largely to portions of the Duchesne River drainage and upper reach of the Fremont River, with incidental occurrences reported in the Green River in or below the lower end of Dinosaur National Monument. Longnose sucker is reported or presumed present in most middle and upstream portions of the Gunnison River Basin and is especially common in reservoirs of the Aspinall (Curecanti) Unit, but it has been collected as far downstream as River Kilometers 48 to 67 (Burdick 1995). It also has been reported in headwaters of the Colorado River in and above Lake Granby and probably is present in the river and tributaries for some distance below the lake. Longnose sucker no longer appears to be present in the upper reaches or tributaries of the Green River above Flaming Gorge Reservoir as historically reported.

The distribution and ecology of catostomid larvae and young-of-the-year juveniles in the UCRB have not yet been summarized, except for razorback sucker in the Green River by Muth et al. (1998). However, selected information can be found in various publications and reports by regional researchers (e.g., McAda 1977, Carlson et al. 1979, Miller et al. 1982a, Haynes et al. 1985, Carter et al. 1986, Tyus et al. 1987, Gutermuth et al. 1994, Burdick 1995, Muth and Snyder 1995, Modde 1996, Bestgen et al. 2002, Bezzerides and Bestgen 2002, Osmundson 2002, Brandenburg et al. 2003).

A Combined Developmental Interval Terminology

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 com-

monly 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 by Snyder (1983b) and Kelso and Rutherford (1996). During a workshop on standardization of such terminologies, held as part of the Seventh Annual Larval Fish Conference (Colorado State University, January 16, 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. 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) 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 below 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. Since 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 since 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 all phase subdivisions designated, 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 are 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–essential features and terms of the original terminologies have been retained.

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.)

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.

Characteristics Useful in Identification of Cypriniform Fish Larvae

The following discussion of taxonomically useful characters is reprinted with minor modification from Snyder (1981) and Snyder and Muth (1988). Fishes of the families Cyprinidae (minnows and carps) and Catostomidae (suckers) are closely related and morphologically similar. Together the two families account for nearly half of over 50 species in the Upper Colorado River System. Generalizations with respect to the order Cypriniformes refer specifically to North American species of these families. Figures 2 and 3 identify the more obvious morphological features and structures of catostomid (and cyprinid) eggs and larvae.

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 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.

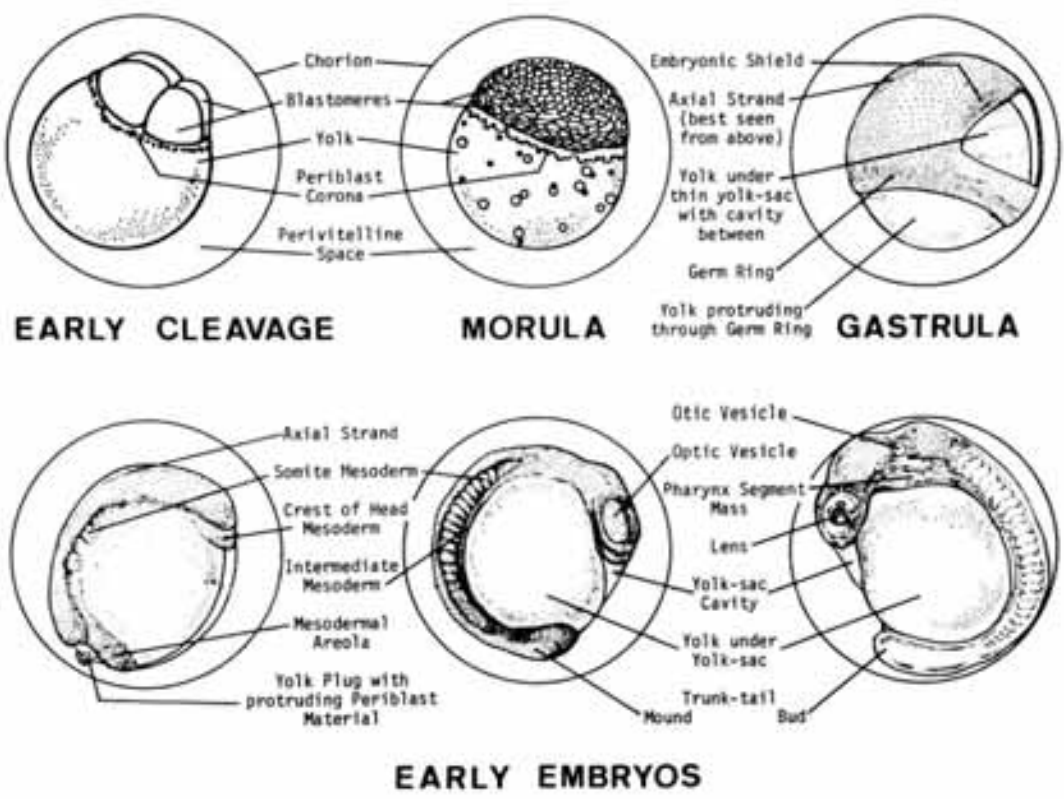


Fig. 2. Selected anatomical features of cypriniform fish eggs and embryos (from Snyder 1981; based on drawings from Long and Ballard 1976).

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 cited in Snyder (1983b) and Kelso and Rutherford (1996) are most useful in this respect. Auer (1982) is particularly recommended since it covers all families and some species in the Upper Colorado River Basin. The pictorial guide to families in Wallus et al. (1990) and Kay et al. (1994) and discussions of taxonomic characters by Berry and Richards (1973) and Kendall et al. (1984) are also recommended.

In the Upper Colorado River System, cypriniform larvae are readily categorized as 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 of Colorado River System catostomids. For the latter, specific identification 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).

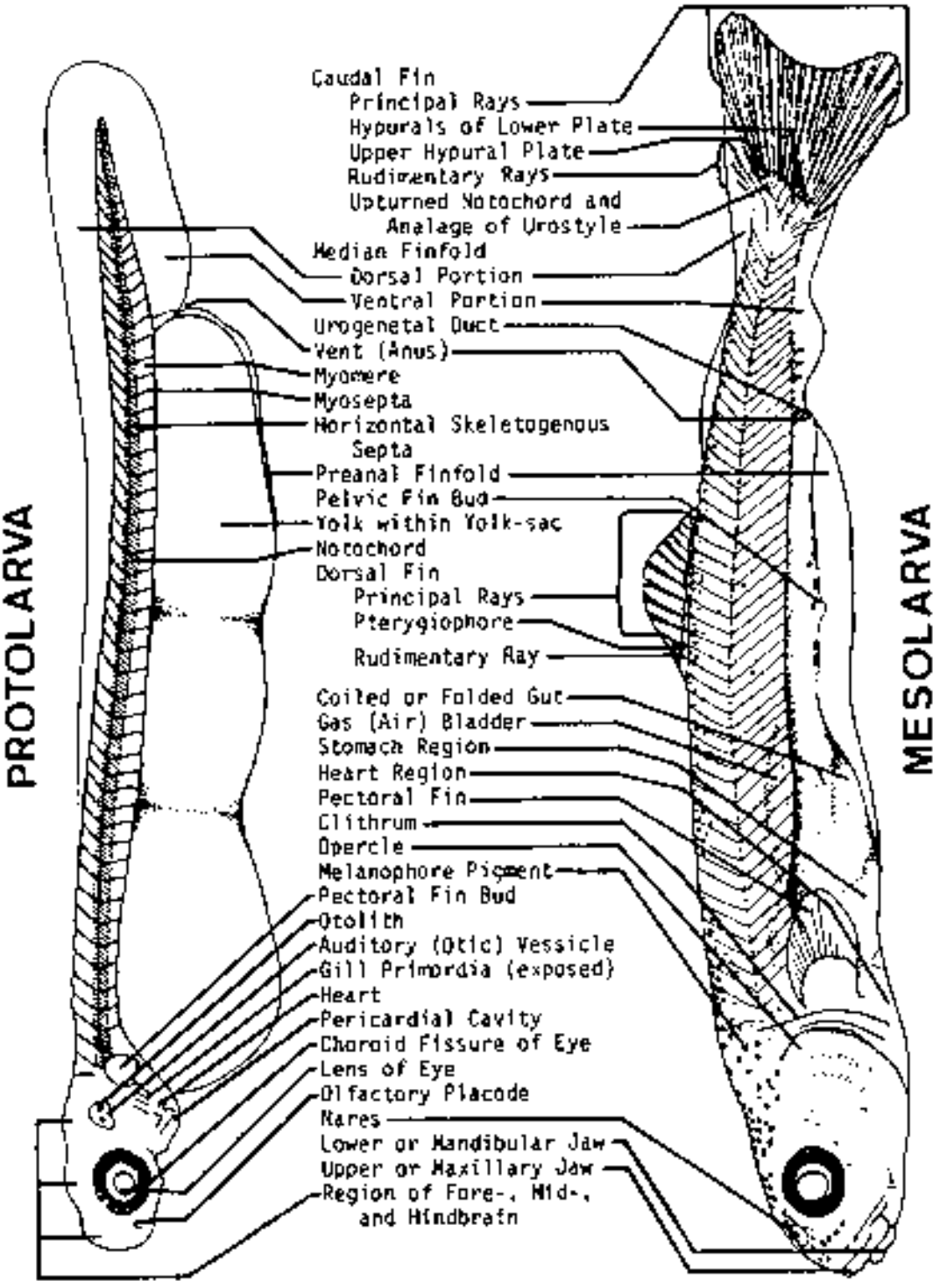


Fig. 3. Selected anatomical features of cypriniform fish larvae (from Snyder 1981).

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

Myomeres

Myomeres, because they are obvious morphological features and relatively consistent in number and position, 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). Snyder (1979) and Conner et al. (1980) summarized myomere and vertebral counts for many cypriniform fishes.

The most anterior and most posterior myomeres are frequently difficult to distinguish. The most anterior myomeres are apparent only in the epaxial or dorsal half of the body; the first is often deltoid in shape and is located immediately behind the occiput. The most posterior myomere is defined 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. 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 authors, 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 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. 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. For cypriniform fishes in the Upper Colorado River System the degree of overlap in total and preanal myomere counts is less and larvae with fewer than 42 total or 32 preanal myomeres can be cyprinids only.

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. The sequence

and timing of fin development, fin lengths, and basal lengths of the dorsal and anal fins are also useful.

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 most 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 and nine on inferior hypurals), and catostomids usually have 18 principal rays (nine and nine respectively).

Dorsal and ventral rudimentary rays of the caudal fin begin forming sequentially in an anterior direction immediately after all or nearly all principal caudal-fin rays are formed. They are often the last group of fin rays among all fins to form their full adult complement. Accordingly, counts of rudimentary caudal-fin rays are usually ignored in larval fish identification, but they may be of taxonomic 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 aggregates in vicinity of the future fin, and basal structures or pterygiophores soon become evident. The latter structures permit limited use of dorsal and anal fin position and meristics about midway through the mesolarval phase. Anterior principal fin rays develop first and subsequent rays are added in a posterior direction. The first rudimentary fin rays (anterior to the principal rays) are frequently evident before all the principal fin rays form. Rudimentary fin rays are added in an anterior direction.

The first or most anterior principal ray in both dorsal and anal fins remains unbranched while all other principal fin rays branch distally as or after ray segmentation becomes evident. The last or most posterior principal ray in each fin is considered to be divided at the base and therefore usually consists of two elements that, except for their close proximity and association with the same pterygiophore, might otherwise be considered as separate fin rays.

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 of cyprinids and dorsal-fin rays of catostomids. Positions of dorsal-fin origin (anterior attachment) and insertion (posterior 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 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.

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, 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 when most of the principal median-fin rays are present. With the exception of rudimentary caudal-fin rays, the rays of pectoral fins are often the last to establish their full complement. 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

tically (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). 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. 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 in alcohol than in formalin preservatives.

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), data can be easily converted to percent TL (% TL) 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 anterior margin of the snout to 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 (*Cyprinus carpio*) and occasionally mesolarvae of Colorado pikeminnow (*Ptychocheilus lucius*). 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 since 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 observe, 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 insertion) 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 somewhat approximates the

position of the cleithrum (part of its supporting structure), and it more nearly approximates the posterior margin of the operculum than does the posterior margin of the auditory vesicle. Accordingly, we recommend this definition of head length (Snyder 1983b) 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, 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). It is often desirable to approximate position of reference points in larvae prior to formation of the referenced structure (e.g., origin of dorsal fin in protolarvae and flexion mesolarvae based on 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 to 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 characters are especially useful in distinguishing postflexion mesolarvae, metalarvae, and early juveniles of certain catostomids.

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 interregional 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. 1977), 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 highly 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. 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 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 a difference in chromatophore distribution. Chromatophores without pigment cannot contribute to the visible 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. While whole-specimen clearing and cartilage- and bone-staining techniques are relatively simple (see Methods), 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 in many parts of the skeleton can have diagnostic value, even for closely related species. Use of osteological characters for identification of fish larvae has received little attention, but its potential value is great, particularly for confirmation of questionable identities and for species in which external characters are diagnostically inadequate.

METHODS

In the years since publication of the first edition of this guide (Snyder and Muth 1990), corrections have been noted, character-range extensions recorded for most described species, and better drawings for two larval stages of white sucker (Snyder 1998) became available. These revisions, descriptive information for longnose sucker, and a computer-interactive key to UCRB catostomids were documented by Snyder (2003) and have been incorporated in this updated and expanded edition of the guide.

Specimens Examined

Cultured specimens were analyzed for each species. Developmental series for all but Utah sucker were reared by the LFL from artificially fertilized eggs of Colorado origin during 1978 through 1981 and 2001. Parental stock for culture of razorback sucker was collected from a gravel pit off the Colorado River near Clifton; flannelmouth sucker from the Yampa River near Juniper Springs; bluehead sucker from the White River near Rio Blanco Lake; mountain sucker from Willow Creek, a headwater tributary of the Elk River northwest of Steamboat Springs; white sucker from a private pond southwest of Fort Collins; and longnose sucker from Parvin Lake, Larimer County, and Upper Big Creek Lake, Jackson County. Razorback sucker larvae and juveniles were reared also by Dexter National Fish Hatchery, New Mexico, in 1982 from Lake Mohave stock in Arizona. Utah sucker specimens were reared by the Utah Cooperative Fish and Wildlife Research Unit in 1987 from Bear Lake stock.

Wild or field-collected larvae and juveniles of positive identity for all species, except Utah sucker, also were analyzed. These included: razorback sucker collected from Arizona's Lake Mohave, probably in the early 1980's, and Salt River, at Horseshoe Bend in 1984 (the latter specimens were reared at Dexter National Fish Hatchery and stocked a week prior to capture on March 20); flannelmouth, bluehead, and white sucker larvae and juveniles from Colorado's Yampa River west of Milner to the Lily Park area below Cross Mountain Canyon in 1976 through 1979; flannelmouth and bluehead suckers from Colorado's White River between Rio Blanco Lake and Spring Creek in 1976 through 1979, with cursorily examined specimens from Colorado's Colorado River between Palisade and the Utah border and Colorado's Gunnison River between Whitewater and Redlands Dam in 1977 through 1979; mountain sucker from Colorado's Willow Creek (and Ways Gulch, Routt County) in 1981 and Utah's Provo and Spanish Fork Rivers in 1982 through 1986, with cursorily examined specimens from Nevada's Truckee River and Pyramid Lake in 1973 through 1982 and Montana's Rocky Creek, Madison River, and Flathead Creek (tributaries of the Missouri River) in 1966 and 1967; and longnose sucker from Colorado's Gunnison River between Peeples and Escalante (Delta County) in 1993 and 1995.

Most specimens were killed and fixed in 10% formalin, then stored in marble-chip- or phosphate-buffered 3% formalin. Some longnose sucker reared by LFL in 2001 were preserved and stored directly in 95 to 100% ethanol. Some mountain sucker specimens from the Truckee River in Nevada were fixed in formalin then stored in 50% isopropanol. Some additional specimens were stored in alcohol (70% or 95% ethanol or 50% isopropanol), prior to clearing and staining for skeletal study. Due to excessive dehydration and shrinkage, none of the alcohol-stored specimens were analyzed for morphometrics or size relative to developmental state.

Most specimens analyzed or otherwise examined for descriptions are maintained as part of the LFL Collection and are available for examination. Some specimens were lost or inadequately labeled (e.g., only external labels which lost adhesion) prior to cataloging. Descriptive data (e.g., counts and measures) for each analyzed specimen are stored in computer spreadsheet files, also maintained by LFL, and can be linked with individually cataloged "full-analysis" specimens, including those used for drawings. Catalog numbers for all available study specimens are as follows:

Utah sucker, *Catostomus ardens*
Full Analysis: LFL 83444-83492.
Drawings: LFL 83447, 83451, 83461, 83463, 83471, 83484, 83492.
Cleared and Stained (from which all or many specimens were used for skeletal study): LFL 83493-83497.
Additional Reference (from which selected specimens were cursorily examined): LFL 83498-83576.
Updates (specimens on which character range extensions since Snyder and Muth 1990 were based): LFL 13.

Longnose sucker, *Catostomus catostomus*
Full Analysis: LFL 6690, 6837, 26446, 678220-67278, 81460-81495.
Drawings: LFL 6690, 6837, 67222-67223, 67228-67230, 67235-67237, 67243-67245, 67253-67257, 67261-67265, 81460-81462.
Cleared and Stained: LFL 81496-81526.
Additional Reference: LFL 67168-67219, 78003, 81190-81459, 81527-81528.

White sucker, *Catostomus commersoni*
Full Analysis: LFL 69104-69229.
Drawings: LFL 69218, 69221, 69225, 69228-69229.
Cleared and Stained: LFL 69230-69276.
Additional Reference: LFL 70244-70401.

Bluehead sucker, *Catostomus discobolus*
Full Analysis: LFL 68748-68815, 69678-69708.
Drawings: LFL 68816-68826.
Cleared and Stained: LFL 68827-68834.
Additional Reference: LFL 69710-69948.
Updates: LFL 69713, 69923, 80454.

Flannelmouth sucker, *Catostomus latipinnis*
Full Analysis: LFL 68987-69059.
Drawings: LFL 69060-69078.
Cleared and Stained: LFL 69079-69087.
Additional Reference: LFL 69949-70243.
Updates: LFL 69949-69952, 69975, 83957.

Mountain sucker, *Catostomus platyrhynchus*
Full Analysis: LFL 83577-83626.
Drawings: LFL 83578, 83580, 83585, 83605, 83612, 83619, 83625.
Cleared and Stained: LFL 83627-83628.
Additional Reference: LFL 83629-83673.

Razorback sucker, *Xyrauchen texanus*
Full Analysis: LFL 69401-69512, 69523-69524.
Drawings: LFL 69466, 69485, 69513-69519.
Cleared and Stained: LFL 69520-69522.
Additional Reference: LFL 69400, 70403-70550.
Updates: LFL 80501-80504, 80506, 80508-80509, 80513, 80515-80516 (also, specimen in Museum of Southwestern Biology, Accession number 2001-IV:17, WJB01-134).

Specimen Data, Observations, and Illustrations

Specimens were analyzed for counts, measures, developmental state, structural differences, and pigment distribution. 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 TL, one 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 specimens studied prior to 1992 (all except longnose sucker), morphometric analysis was 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 (i.e., longnose sucker), most measurements were made using multiple digital images of the specimens captured through the microscope and a computer image-analysis and measurement program (Optimas 5.1, Optimas Corp., Seattle). Most measurements other than SL and TL are summarized by developmental phase as % SL, but are readily converted percent TL (% TL) by dividing the length of interest (as % SL) by TL (AS to PC, as % SL), and multiplying by 100. Some meristic data were obtained from specimens cleared and stained for skeletal study and from available adults.

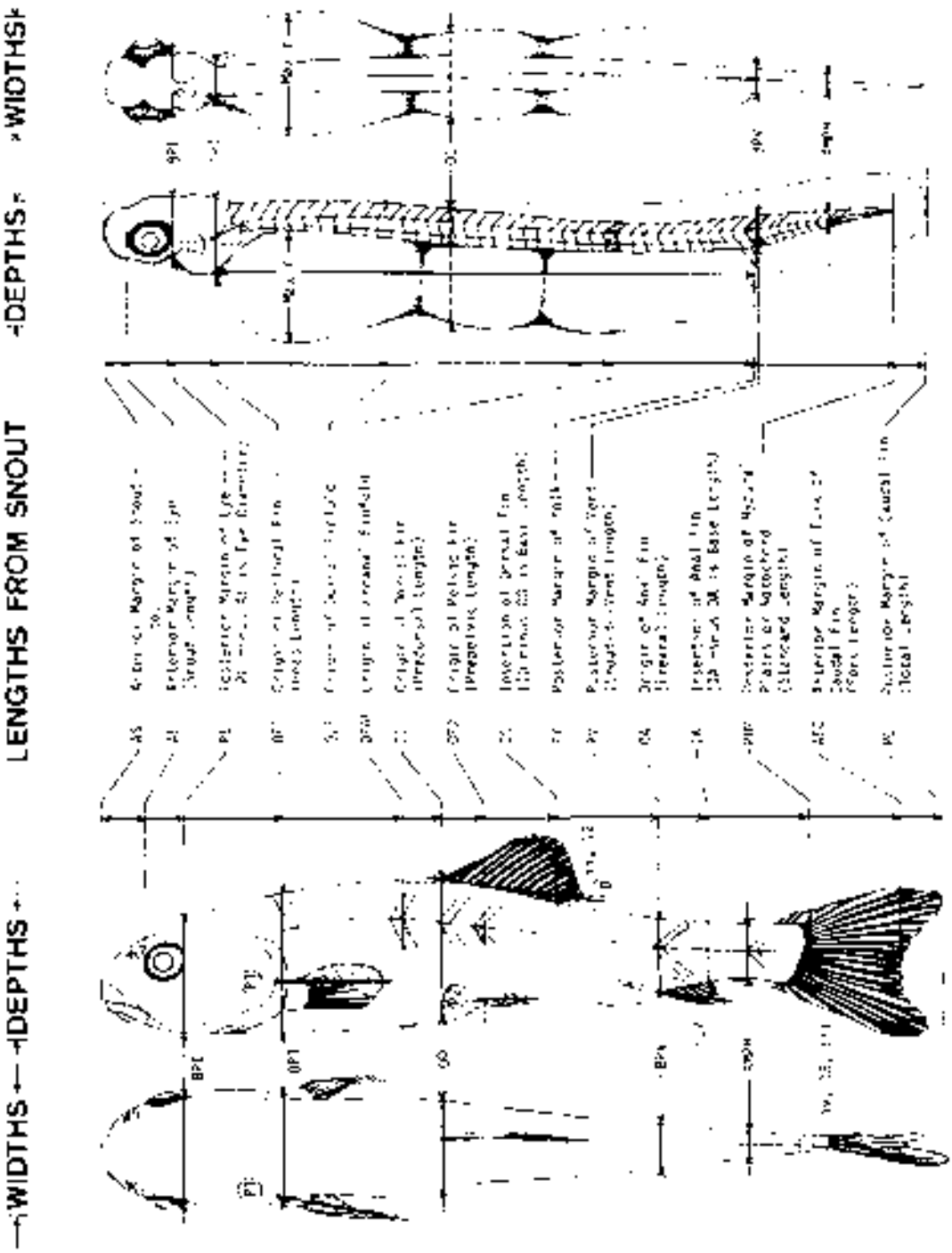


Fig. 4. Measures and counts for larval and early juvenile fishes. Yolk sac and pterygiophores are included in width and depth measures but fins and finfolds are not. "B" in BPE and BPV means immediately behind. AMPM is anterior margin of most posterior myomere. Location of width and depth measures at 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. 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.)

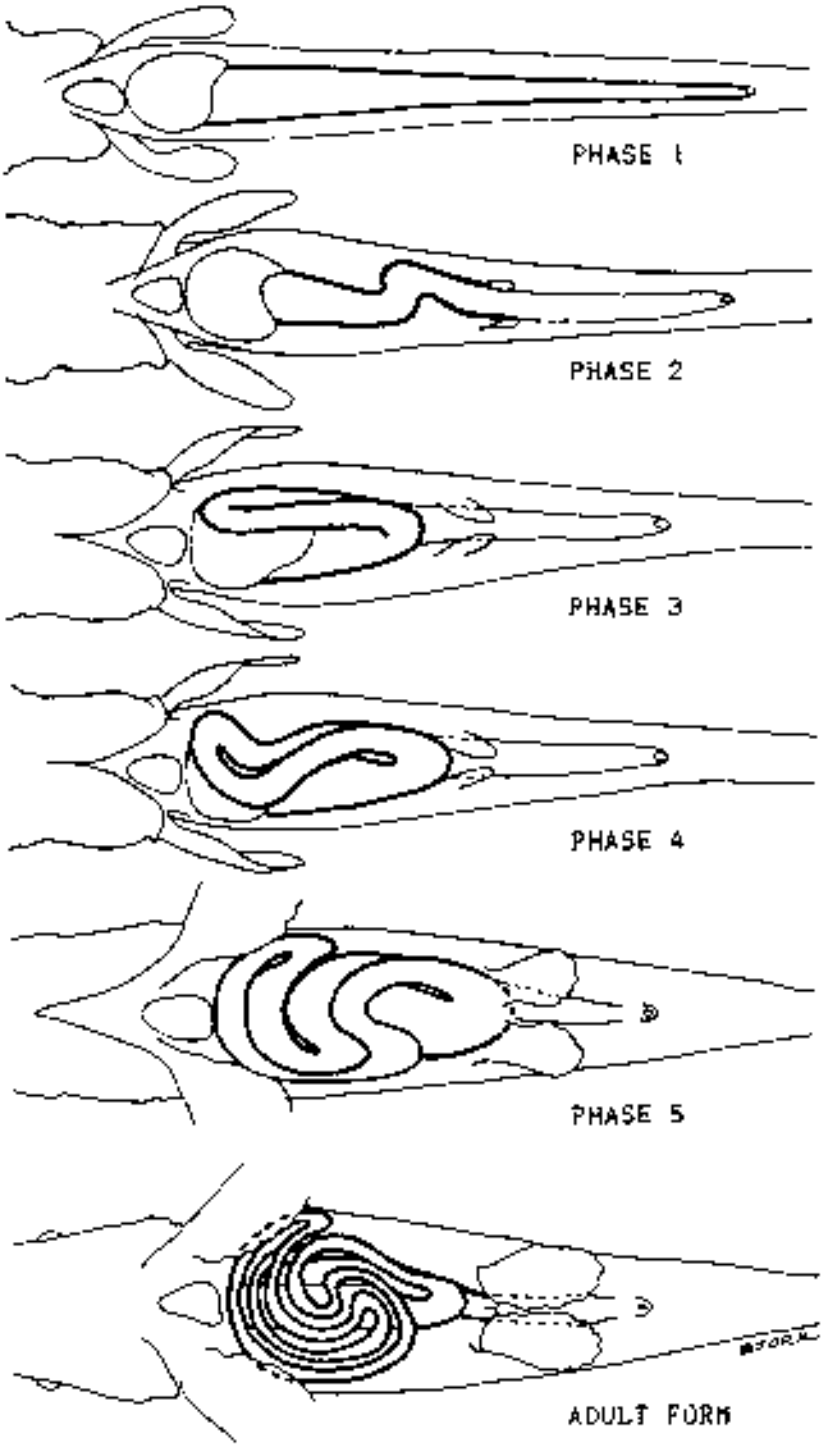


Fig. 5. Phases of gut coil development in catostomid fish larvae and early juveniles with comparison to adult form in *Catostomus commersoni* (latter modified from Stewart 1926). Phase 1 – essentially straight gut. Phase 2 – initial loop formation (usually on left side), begins with 90° bend. Phase 3 – full loop, begins with straight loop extending to near anterior end of visceral cavity. Phase 4 – partial fold and crossover, begins with crossing of first limb over ventral midline. Phase 5 – full fold and crossover, begins with both limbs of loop extending fully to opposite (usually right) side, four segments of gut cross nearly perpendicular to the body axis. Later in Phase 5 and in adult form, outer portions of gut folds or coils extend well up both sides of visceral cavity.

Size at apparent onset of selected developmental events was documented for fully 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 fins, formation of first and last fin rays in the paired fins, formation of first and last rudimentary rays of the caudal fin, and initial and complete formation of lateral scales on the body.

Among other characters considered, developmental phase and extent of gut folding were determined for all analyzed and many other specimens. Gut folding was classified as one of five gut phases (Fig. 5). Changes in mouth position, lower-lip-lobe separation, and other structures were noted when appropriate. Variation in pigmentation patterns was studied by sketching or categorizing observed patterns and noting their frequency.

Continuous-tone graphite and black-ink drawings of all species (except four drawings of white sucker by other authors) were prepared to 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. Black ink was used only for surface or near-surface pigmentation to distinguish it from deeper pigmentation, other structure, and shading. Each drawing consists of dorsal, lateral, and ventral views. 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 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 drawing specimens.

Selected specimens were cleared and stained for examination of potential osteological characters and vertebra counts, as well as to verify fin meristics. Postflexion mesolarvae were stained with alcian blue for cartilage, and they, metalarvae, and juveniles with alizarin red for bone using procedures given below. Shape and size of the frontoparietal fontanelle, interneurals, and anterior-dorsal maxillary projections; position of mandibles relative to maxillae; and (to a less consistent extent) the angle at which the base of the postcleithra extends from the cleithra were found to be diagnostically useful (Fig. 6). Changes in the state of these characters were documented photographically for each species.

All descriptive data are summarized in species accounts with associated illustrations or the comparative summary of diagnostically useful characters. Most of those data are also used by, and accessible in, the computer-interactive key.

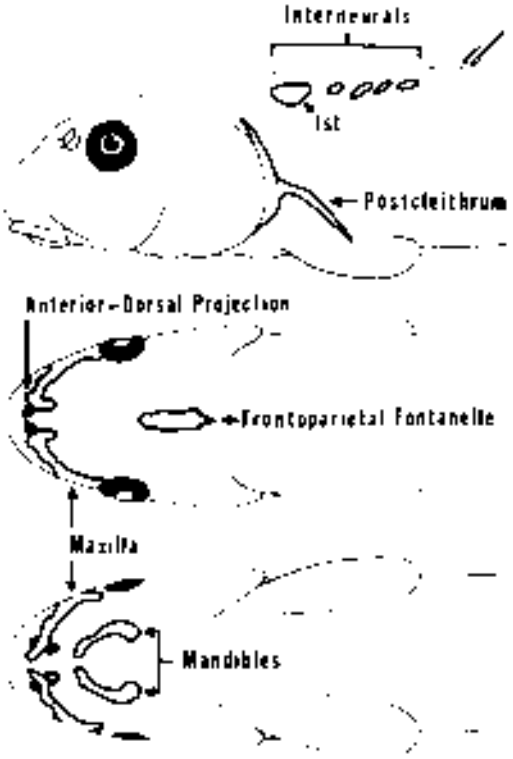


Fig. 6. Location of selected skeletal features of metalarval and early juvenile catostomids. Top – lateral view. Middle – dorsal view. Bottom – ventral view.

The printed polychotomous keys in the first edition of this guide (Snyder and Muth 1990) were produced with the aid of DELTA (DEscriptive Language for TAxonomy) programs for taxon description and keys (Dallwitz 1974, 1980; Dallwitz and Paine 1986). Characters were encoded using the DELTA format (a powerful, flexible, and widely accepted method for recording descriptive taxonomic data for computer processing) then transformed for use by the program *Key*. Due to limitations of the *MS-DOS* version of *Key* and the numerous overlapping characters of the species considered, output was generated in segments, each restricted to a select set of characters and species. These were then edited to remove repeated branches and phrases and assembled into a complete key for each developmental phase.

However, in 1993, it became clear that the guide and keys needed to be expanded to include longnose sucker. Correction, update, and expansion of the printed keys to include this remaining UCRB species would have been a long and arduous task and any further corrections or updates in the future similarly difficult. Fortunately, our prior experience with the DELTA suite of programs had afforded us an opportunity to experiment with an earlier DOS version of *Intkey*, a DELTA program for computer-interactive keys, which we found not only easier to prepare, update, and expand than traditional printed keys, but much more flexible for the user. Even as we prepared the printed keys, we considered preparation of data sets for *Intkey* as an alternative, but at the time, conventional printed keys were still deemed more appropriate for publication and general use. Since then, computer use has become pervasive and computer-interactive keys have become more common, especially for very similar appearing and difficult to distinguish organisms. Accordingly, we decided to adopt the modern alternative. In anticipation of this update, a visit was made in 1995 to M. Dallwitz (Commonwealth Scientific and Industrial Research Organization Department of Entomology, Canberra, Australia), the senior author of *Intkey* and other DELTA programs, for assistance with preparation of preliminary *Intkey* data sets, one for each developmental interval through juveniles up to 40 mm SL.

Most computer-interactive keys are data sets designed to be used with specific commercial, public-domain, or proprietary host programs. The features and flexibility of several alternative computer-interactive key programs were compared to *Intkey*. Based on this comparison and our prior experience with *Intkey*, we decided to continue developing our updated and expanded keys for that program. The latest versions of *Intkey* (Dallwitz et al.1993 onwards, 1995 onwards), *DELTA Editor* (Dallwitz et al. 1999 onwards), and associated programs and files were downloaded from the Internet (http://biodiversity.uno.edu/delta/). *DELTA Editor* was used to develop and refine a progressive series of data sets for UCRB catostomid larvae and the derived data files required by *Intkey*. Rich-text files to be accessed through *Intkey* for background information, beginning instructions, and other information were prepared or modified with a word processor. Image files used by *Intkey* were created or modified from scanned files with a computer drawing or presentation program.

Like the former printed keys and as mentioned above, early and intermediate versions of the computer-interactive key were actually a set of six keys, one for each developmental period or phase (including a single-character key for embryos–egg diameter). The intermediate versions were demonstrated and discussed with opportunities for hands-on experimentation at three technical meetings in 2002 (Recovery Program Researchers Meeting, Colorado-Wyoming Chapter of the American Fisheries Society, and Larval Fish Conference). The interest generated in these keys, and computer-interactive keys in general, during these presentations and hands-on sessions was encouraging. Participant feedback, however, suggested that the keys could be best improved by combining them into one key covering all developmental intervals.

Accordingly, the separate data sets and keys were combined into one with either characters or taxa subdivided according to developmental interval and size. Near final versions of the data set and key were prepared with subdivided taxa,

mostly because subdivided characters incurred more character-dependency problems (availability of certain characters depending on the character state selected for a controlling character–e.g., if yolk is not present, yolk-related characters should be made unavailable).

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 key nor logistically and budgetarily feasible for this expanded update of the guide (if there is enough interest and support, they could be prepared and incorporated at some future date). Also, such images can require a considerable amount of storage memory and at times a strictly text key may be preferable, especially for the experienced user or when using a slower computer with limited memory. Instead, the printed illustrations herein are referenced extensively and should be available when using the key. However, as examples of how character-state-selection images function, such illustrations were prepared and included in the key for developmental phase, SL, and phases of gut development.

Interim and near final versions of the key were subjected to in-house testing, mostly in the routine processing of UCRB collections, and refined accordingly. Based on reviews and user feedback, future refinements of the key will likely be implemented and made available over the Internet.

Clearing and Staining Procedures for Skeletal Study of Small Fish

These instructions are modified from Snyder and Muth (1988) and based on procedures detailed by Fish (1932, Method III), Taylor (1967), Potthoff (1984), and Taylor and Van Dyke (1985). See Taylor (1967) and Taylor and Van Dyke (1985) for detailed explanations and discussions of the various steps, factors affecting them, and alternatives.

The procedures that follow are for differential staining of cartilage and bone beginning with living specimens. If using previously preserved specimens, staining only for cartilage, staining only for bone, or clearing (making transparent) without staining, skip the irrelevant steps.

Minimum and maximum times given in the procedures are approximate for single specimens measuring 10 and 25 mm TL, respectively, and processed in 20 ml vials. Times for other sizes and numbers of specimens can be approximated accordingly. Vertebrates as large as 500 mm have been cleared and stained by these procedures but time requirements are considerably greater; clearing alone can take several weeks. Potthoff (1984) provides a diagram of approximate times for specimens 10 to 500 mm SL. Specimens larger than 30 mm with scales or thick skin may need to be scaled or skinned, or selectively and carefully punctured over the body with a sharp needle, prior to clearing and staining. Some larger specimens may need to be eviscerated. Fatty or oily specimens may need "degreasing" in xylene before staining or clearing and specimens with large amounts of guanine or similar white or silvery substances may need soaking in 2% or stronger potassium hydroxide solution after clearing by the enzyme method (Taylor and Van Dyke 1985).

Specimens should never occupy more than 25% of solution volume during fixation; lesser percentages (e.g., 10%) are recommended. During clearing and staining, results will be better and time requirements may be less if specimens occupy much less than 10% of solution volumes (e.g., down to 2% of solution volume during neutralization and clearing). For specimens 30 mm TL or less, most or all steps can be carried out conveniently in 20 ml or similar-size vials. During each step, periodically turn or move specimens to minimize solution stratification and aid penetration of solutions into tissues of specimens being processed.

For the most reliable results begin with freshly fixed and preserved specimens. Older museum specimens may or may not clear and stain properly depending on original fixative, preservative, and subsequent care. However, properly fixed and preserved specimens should clear and stain nearly as well as fresh material, even after a few decades.

With specific regard to fish embryos and larvae, Taylor and Van Dyke (1985) made the following observations. "The presence of cartilage in embryos and larval fishes is readily determined by this method [differential staining with enzyme clearing]. But, determining the

presence and time and/or degree of osteogenesis is more difficult because newly deposited bone mineral is much more labile than mineral that has been deposited for some time. The presence of bone mineral is usually indicated by staining with alizarin Red S. This color may be faint, pink, or bright red in larval fishes with ages from unhatched embryos through those with complete absorption of the yolk sac or even older. To state in the absence of the red color that osteogenesis or bone development is not present at any of these developmental stages may be incorrect without microscopic examination of tissue structure because bone may be in an early stage of development or the mineral may have been removed during fixation, clearing or staining steps." They further observed that fish larvae with obvious bone, often lose bone stain while in enzyme clearing solution, but that much of it remains in specimens cleared in potassium hydroxide solutions. Accordingly, they recommend that fish larvae be fixed in neutral-buffered (pH 6.5-7.2) formalin and that some be differentially stained for bone and cartilage, while others are stained for bone only and cleared with potassium hydroxide (instead of enzymes) soon after fixation.

Safety

Many of the chemicals and solutions used in clearing and staining can be hazardous and should be handled and disposed of accordingly.

Chemicals

Abbreviations for applicable procedures are: FP = fixation and preservation; BL = bleaching; IC = initial clearing, protein digestion; CS = cartilage staining; BS = bone staining; FC = final clearing and storage (final preservation).

Alcian blue (powder) CS
Alizarin red S (powder) BS
Distilled water ALL
Ethanol (absolute ethanol preferred, denatured or 95% will suffice) CS
if used as preservative FP, FC
Formalin (saturated formaldehyde sol.) FP
Glacial acetic acid CS
Glycerin (glycerol), if used for storage FC
Hydrogen peroxide, 3% solution BL
Potassium hydroxide (KOH) BL, IC, FC, BS
Sodium borate (powder) CS, IC
Sodium phosphate monobasic FP
Sodium phosphate dibasic (anhydrous) FP
Thymol (crystals), if glycerin is used for storage FC
Trypsin powder (pancreatic protease, pancreatin; sufficiently purified to be free of collagenase and elastase; trypsin from pig pancreas with an activity of 300 units/mg produces a clear, highly effective solution, but other trypsin preparations with activities as low as 80 units/mg have also been used successfully) IC

Stock solutions

Abbreviations for applicable procedures are the same as for chemicals.

10% buffered formalin solution—
In distilled water; buffer to pH 7.0 with 4.0 g sodium phosphate monobasic and 6.5 g sodium phosphate dibasic per liter of formalin solution (recommended by Taylor and Van Dyke 1985), or to pH 6.8 with 4 g each of monobasic and dibasic sodium phosphate per liter of formalin solution. The latter is about twice the 1.8 g each of monobasic and dibasic per liter recommended by Markle (1984) for 5% formalin solutions. Formalin solutions can be buffered with excess marble or limestone chips or limestone powder to near neutral, but phosphate buffering is more precise and reliable; borax (sodium borate) buffered formalin is not recommended (Taylor and Van Dyke 1985). FP

3-5% buffered formalin solution—
In distilled water; buffer with 1.8 g sodium phosphate monobasic and 1.8 g sodium phosphate dibasic per liter of formalin solution (Markle 1984). Alternatively, fixed specimens can be stored in alcohol (e.g., 75% ethanol via a graded series of concentrations), but expect greater shrinkage, deformation, and, if examined periodically, fading of melanophore pigmentation than if stored in dilute formalin solutions. FP

50% ethanol solution—
In distilled water. CS
And if used in graded series for specimen preservation (storage). FP, FC

75% (or 70%) ethanol solution—
In distilled water; if used for specimen preservation (storage). FP, FC

Alcian blue stain solution—
20 mg alcian blue per 100 ml of 30% glacial acetic acid in ethanol (solution will keep at room temperature for 3-4 weeks). CS

Saturated sodium borate solution—
Excess sodium borate powder in distilled water; mix well and allow excess sodium borate to settle; use clear supernatant solution. CS, IC

1% Potassium hydroxide solution—
By weight in distilled water. BL, IC, FC, BS

2% Potassium hydroxide solution—
By weight in distilled water; if KOH is used for clearing. IC, FC

Bleaching solution—
15% of 3% hydrogen peroxide solution in 1% KOH solution. BL

Trypsin solution—
About 0.1-0.2 g (depending on strength or activity level of trypsin) per 100 ml of 30% saturated sodium borate solution in distilled water; mix well but do not allow to froth (Taylor and Van Dyke 1985). Make a fresh solution for each use; it does not keep well. If enzyme clearing used. IC

Alizarin red stain solution—
Dissolve enough alizarin red powder in 1% KOH to turn the solution deep purple (about 0.1 g per 100 ml). Or mix about 1 ml of a saturated alizarin red solution per 100 ml of 1% KOH (saturated alizarin red solution is prepared by dissolving excess alizarin red powder in small amount of distilled water, about 1.5-2.0 g per 20 ml). Alizarin red stain solution will keep at least one week. BS

40% glycerin solution—
In 1% KOH (preferred) or distilled water; if glycerin used for storage. FC

70% glycerin solution—
In 1% KOH (preferred) or distilled water; if glycerin used for storage. FC

Fixation and preservation

1. Kill and fix specimens in 10% buffered formalin for 24-48 hours.
2. If specimens are to be stored more than a couple days before clearing and staining, preserve them in 3-5% buffered formalin or alcohol (preferably via a graded series of concentrations, e.g., 50% ethanol for 6-24 hours then 75% ethanol). Do not soak in water between fixative and preservative solutions.

Cartilage staining procedure

3. Dehydrate formalin-fixed and preserved specimens in 50% ethanol solution for 6-24 hours, then in 100% or absolute ethanol for 12-24 hours. Replace the absolute ethanol and leave at least another 12-24 hours. A more gradual series of alcohol concentrations can be used (e.g., 50%, 75%, and 100%), but is usually unnecessary. If specimens were preserved in alcohol, skip the 50% ethanol step. For embryos and larvae, dehydration is essential to assure minimal loss of bone while in the acid stain for cartilage.
4. Stain specimens in alcian blue stain solution for 6-24 hours, no longer than necessary to adequately stain all cartilage.
5. Rinse specimens in saturated sodium borate solution then soak in fresh saturated sodium borate solution for 6-24 hours to neutralize (change body fluid pH from acid to alkaline).

Bleaching (optional)

6. If specimens are heavily pigmented (such that pigments would obscure desired structures), bleach specimens by placing them in bleaching solution and exposing them to strong light until chromatophore pigment is notably faded, about 20 minutes to a few hours.

Initial clearing

7. *Enzyme method*—If specimens were not processed for cartilage staining, soak them in saturated sodium borate solution for 2-12 hours to remove remaining formalin or alcohol and adjust body fluids to well above pH 7. Soak specimens in trypsin solution until 75-90% of the muscle tissue is cleared, typically 1-5 days at 20-30° C, possibly longer depending on specimen volume relative to solution volume and activity or strength of trypsin. Use a volume of trypsin solution at least 10 to 40 times the volume of specimens. Completely change trypsin solution every 2-3 days. This method is preferred for all fish except embryos and larvae in which some critical bone mineral may be lost. For both freshly fixed and long preserved material, the enzyme method generally provides more consistent results with firmer whole specimens than the KOH method.

   or

   KOH method—Soak specimens in 2% KOH solution until muscle tissue begins to clear, typically 1 to 12 hours (use 1% KOH for very small and delicate specimens). Monitor specimens closely–this method of clearing is simpler, less expensive, and tends to be faster than the enzyme method, but it is also more likely to result in fragile specimens with skin that literally splits at the seams if the specimens are inadequately fixed or if digestion of tissues is allowed to go too far. Results are usually better and more consistent if specimens are freshly fixed than if they were preserved and stored for a long time (Taylor and Van Dyke 1985).

Bone staining procedure

8. Stain specimens in alizarin red stain solution until bones are adequately stained, a few hours to one day; monitor specimens closely. Rinse specimens briefly in distilled water.

Final clearing and storage

9. Return specimens to clearing agent (trypsin solution or 1 or 2% KOH solution) until remainder of muscle is adequately transparent (some final clearing will take place in glycerin series if used for storage). Change solution after an hour or two to remove excess stain and continue clearing if necessary. If clearing in KOH solution, monitor specimens closely (this procedure is usually faster and less forgiving than the enzyme method).
10. Specimens may be stored in alcohol (e.g., 75% ethanol), in which they are easier to handle, but "to attain uniformity in clearing and avoid storage problems" (Taylor 1967), most researchers store cleared and stained specimens in pure or 100% glycerin. Glycerin also will reduce or eliminate cloudiness due to water in the remaining soft tissues. In either case, work specimens through at least a minimal graded series to the final concentration, 4-24 hours in each solution (e.g., 50% and 75% ethanol or 40%, 70%, and 100% glycerin). If specimens are not as transparent as desired at this point, try adding a 20% glycerin in 1% KOH step to the beginning of the graded glycerin series. Add a few thymol crystals to containers with 100% glycerin to prevent fungus growth.

RESULTS AND DISCUSSION

Results are divided into three interrelated sections–Species Accounts, Comparative Summary, and Computer-Interactive Key. For identification purposes, users should become familiar with and use all three taxonomic tools.

Although prepared for use by UCRB biologists, these taxonomic tools, and other information provided herein, may also be useful to early life history investigators working elsewhere. Allowing for potential population differences in developmental morphology, these descriptions and the key can be used for identification of covered species wherever they may occur. For example, white and longnose sucker are common throughout much of Colorado (the only *Catostomus* species in east-slope drainages), and indeed much of North America. Bluehead, flannelmouth, and razorback suckers occur in portions of the Lower Colorado River Basin; bluehead sucker also in portions of the Bonneville Basin; and mountain sucker in mountainous regions throughout much of western United States and southwestern Canada. Where two or more of these species 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 and effectively becoming a key for that region, site, or circumstance.

Although 553 specimens were analyzed in detail for morphometrics and meristics, and hundreds more were documented for size, developmental state, skeletal characters, and pigmentation patterns, there are undoubtedly rare specimens with character extremes beyond the ranges recorded herein. Indeed, many of the descriptive data updates incorporated herein are verified character-state extensions reported or brought to our attention by users of the earlier edition of this guide (Snyder and Muth 1990).

Because of the similarity among larvae of UCRB catostomids, 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., "*Xyrauchen* texanus?", preferably with a footnote on other possibilities), or by leaving the identity at family level (e.g., "unidentified Catostomidae"), or genus (i.e., *Catostomus* sp.) if other genera can be eliminated. Some inconclusive specimens may be hybrids.

Hybridization among Colorado River System catostomids is well documented (e.g., Holden and Stalnaker 1975, Hubbs et al. 1943, Hubbs and Hubbs 1947, Hubbs and Miller 1953, McAda 1977, McAda and Wydoski 1980, Prewitt 1977, and Smith 1966). Intermediacy of characters for white X bluehead sucker hybrids as small as 25 mm SL and flannelmouth X bluehead sucker hybrids as small as 34 mm SL were documented by Hubbs et al. (1943) and Hubbs and Hubbs (1947) respectively. Based on the key or diagnostic criteria summarized herein, some hybrid metalarvae and early juveniles may be least tentatively identified as such by more experienced users, but because of fewer characters, hybrid protolarvae and mesolarvae, will likely be identified as the parental species they most closely resemble or remain questionable.

Species Accounts

The following descriptive species accounts, except that for longnose sucker, are reproduced or updated from the earlier edition of this guide (Snyder and Muth 1990). Each 8-page account begins with an illustration of the adult fish, map of its distribution in the Colorado River Basin, brief summaries of adult diagnosis, reproduction, and early life history, and a table of adult meristics. Much of this information was extracted from literature (and occasionally personal communications) listed 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 4 pages illustrate eight stages of development from just hatched protolarvae through early juveniles about 30 mm SL. The last two pages of each account consist of illustrations of selected skeletal characters and a table of frontoparietal fontanelle dimensions.

Regarding reproduction, all seven catostomids are classified according to Balon's (1975a, 1981) reproductive guilds as non-guarding, open-substrate, lithophils. Lithophils prefer to spawn over predominately rock or gravel substrates. Their recently hatched larvae are photophobic and usually hide or remain in the substrate for at least a few days before emerging and drifting with the current. Although considered broadcast spawners, razorback sucker in reservoirs prepare discrete, nest-like depressions or redds (Bozek et al. 1984), which suggests a tendency toward a brood-hiding guild.

Fig. 7. *Catostomus ardens* adult (© Joseph R. Tomelleri).

Adult Description: Back without conspicuous predorsal keel. Caudal peduncle deep, about 8-10% of body length. Mouth inferior but well forward. Lips relatively small with papillae, without notches at outer corners; lower lip with deep medial cleft, lobes usually adjacent and not reaching a perpendicular from nostrils. No prominent cartilaginous ridge on anterior margin of lower jaw. Nodules of gill rakers slightly to un-branched. Scales relatively large. Dorsal fin membranes well pigmented. Fontanelle wide. Total length usually 25-35 cm, up to 65 cm. (Also, Table 1.)

Reproduction: Non-guarding, open-substrate lithophil. Spring, usually late May to mid June, ≥18°C. Tributary streams, inlets, or rocky shoals near shore of lakes; sometimes over sand or gravel in water <60 cm deep. Observed in spawning aggregations of 400-500. Water-hardened eggs 2.9-3.2 mm diameter, demersal, initially adhesive.

Young: Hatch in 8-9 days at 17°C. Swim-up 7-8 days after hatching. Young mostly in spawning streams or near shore in shallow water. Observed to graze on filamentous algae or algae on fixed objects.

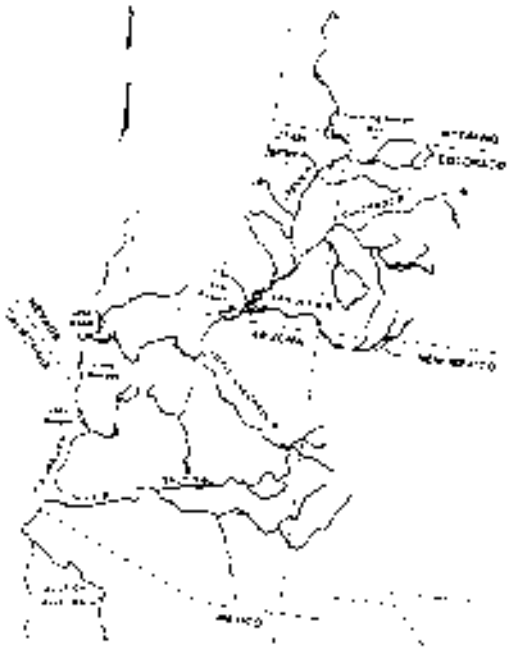


Fig. 8. Recent distribution of *Catostomus ardens* in Colorado River Basin.

Table 1. Selected juvenile and adult meristics for *Catostomus ardens*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	(10)11-12-13(14)	11-13	Dorsal Fin Rays - R:	2-5	
Anal Fin Rays - P:	7-8	7	Anal Fin Rays - R:	2-4	
Caudal Fin Rays - P:	(17)18		Caudal Fin Rays - RD:	(8)9-10-11	
Pectoral Fin Rays:	(14)15-17		Caudal Fin Rays - RV:	(6)7-8-9	
Pelvic Fin Rays:	10		Lateral Scales:	(57-)62-68	54-60-70(-79)
Vertebrae:	47-48		Gill Rakers:		28-31-34

Table 2. Size at apparent onset of selected developmental events for *Catostomus ardens*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	(7)8-11	(7)8-11	Dorsal - P:	13-15	14-16	14-16	17-19
Eyes Pigmented:	9-10 or *	9-10 or *	Anal - P:	14-15	16-18	15-17	17-19
Yolk Assimilated:	12-13	12-14	Caudal - P:	12-13	12-14	13-14	14-15
Finfold Absorbed:	19	23	Caudal - R:	14-15	15-17	19-20	23
Pectoral Fin Buds:	(7) or *	(7) or *	Pectoral:	14-15	16-18	15-18	17-22
Pelvic Fin Buds:	13-14(15)	14-15(16)	Pelvic:	14-17	17-19	18-19	(19-)22
* before hatching			Scales:	21-23	26-28	24-28	29-35

References: Andreasen and Barnes 1975, Baxter and Simon 1970, Baxter and Stone 1995, Jordan and Gilbert 1881, Jordan and Evermann 1896, La Rivers 1962, Lee et al. 1980, McConnell et al. 1957, Miller 1952, Miller and Smith 1981, Minckley 1973, Sigler and Miller 1963, Sigler and Sigler 1987, Simon 1946, Simpson and Wallace 1978, Tyus et al. 1982, Wheeler 1997. ***Personal communication:*** 1981–T.C. Modde.

Table 3. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus ardens*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	12-13	12-14	2 - 90° bend:	14-17	17-19
Postflexion Mesolarva:	13-14	14-15	3 - Full loop:	18-19	(19-)22-24
Metalarva:	15-17	17-19(20)	4 - Partial crossover:	20-22	26-27
Juvenile:	19-20	23	5 - Full crossover:	27-28	34-35

Table 4. Summary of morphometrics and myomere counts by developmental phase for *Catostomus ardens*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=10)			Flexion Mesolarvae (N=5)			Postflexion Mesolarvae (N=12)			Metalarvae (N=12)			Juveniles (N=12)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm:	11	1	9-13	13	1	12-14	15	1	13-17	17	1	15-19	25	4	19-36
TL, mm:	11	1	9-14	13	1	12-15	16	2	14-19	21	2	17-23	32	6	24-45
Lengths %SL:															
AS to AE	2	0	2-3	2	1	1-4	4	1	3-5	6	1	4-8	7	1	6-8
PE	8	1	7-9	8	1	7-10	11	1	10-12	14	1	12-16	15	1	14-16
OP1	15	1	12-17	17	2	15-19	20	1	19-23	26	1	23-27	26	1	25-28
OP2							52	1[b]	50-53	56	1	53-57	56	1	55-58
PY	75	2	72-78	70	2[a]	69-72									
OPAF	41	19	22-67	25	1	22-26	28	2	25-31	41	7[c]	30-51			
ODF	33	2	29-36	35	2	31-36	39	1	37-41	44	3[a]	42-47			
OD							49	1[c]	47-50	50	1	49-52	49	1	48-51
ID							62	1[d]	60-63	65	1	64-67	65	1	64-66
PV	78	1	76-80	76	1	75-77	79	1	76-80	77	1	76-78	75	1	73-76
OA							79	[e]	79-79	77	1	76-78	76	1	74-78
IA							84	[e]	84-84	84	1	84-86	83	1	82-85
AFC							109	1	107-110	112	1[c]	111-114	116	1	114-118
PC	103	1	102-104	105	1	104-106	112	3	109-117	120	2	118-122	125	1	123-128
Y	57	5	49-64	16	22	0-43									
P1	5	3	1-8	10	1	8-11	11	1	9-13	14	2	12-17	20	2	15-22
P2							2	3	0-6	11	1	8-12	14	1	12-16
D							15	1[d]	14-16	19	1	18-20	24	2	21-26
A							7	[e]	7-7	10	1	9-12	15	2	12-18
Depths %SL:															
at BPE	9	1	7-10	10	1	9-12	13	1	11-15	16	1	15-18	18	0	17-18
OP1	10	1	9-13	10	1	9-12	14	1	12-17	18	1	16-20	20	1	18-21
OD	11	1	10-12	9	1	8-9	12	2	9-15	17	1	16-20	20	1	16-22
BPV	5	1	4-6	5	0	5-6	7	1	6-9	10	1	9-12	12	1	10-14
AMPM	3	0	2-3	3	0	3-4	5	1	4-6	7	0	6-8	8	0	7-8
Max. Yolk	7	2	3-11	0	1	0-2									
Widths %SL:															
at BPE	8	1	6-10	9	1	9-10	12	1	10-13	15	1	14-16	16	1	15-16
OP1	6	1	4-8	7	1	6-9	10	1	9-11	13	1	11-15	16	1	14-17
OD	7	1	5-9	5	0	5-6	7	1	5-10	12	1	9-13	15	1	12-17
BPV	3	0	3-4	3	0	3-4	5	1	4-6	6	1	5-7	8	1	6-10
AMPM	2	0	2-2	2	0	2-2	3	0	2-3	3	0	3-4	4	0	3-5
Max. Yolk	8	3	5-14	1	1	0-2									
Myomeres:															
to PY	35	1	34-36	33	1[a]	32-33									
OPAF	15	11	4-32	6	0	6-7	6	1	5-7	12	4[c]	6-17			
OP2							21	1[b]	19-22	21	1	20-22	22	0[d]	21-22
ODF	12	1	10-13	12	0	11-12	13	1	12-14	15	2[a]	13-16			
OD							18	1[c]	17-19	17	1	16-18	17	1[d]	16-18
PV	37	1	36-38	36	1	36-37	37	1	35-38	36	1	34-37	35	1[d]	35-36
Total	46	1	45-47	46	1	45-47	46	1	45-48	45	1	43-47	46	1[d]	45-47
After PV	9	1	8-10	10	1	9-10	9	1	7-10	9	1	8-10	10	1[d]	9-11

[a] N = 2, [b] N = 10, [c] N = 11, [d] N = 5, [e] N = 1.

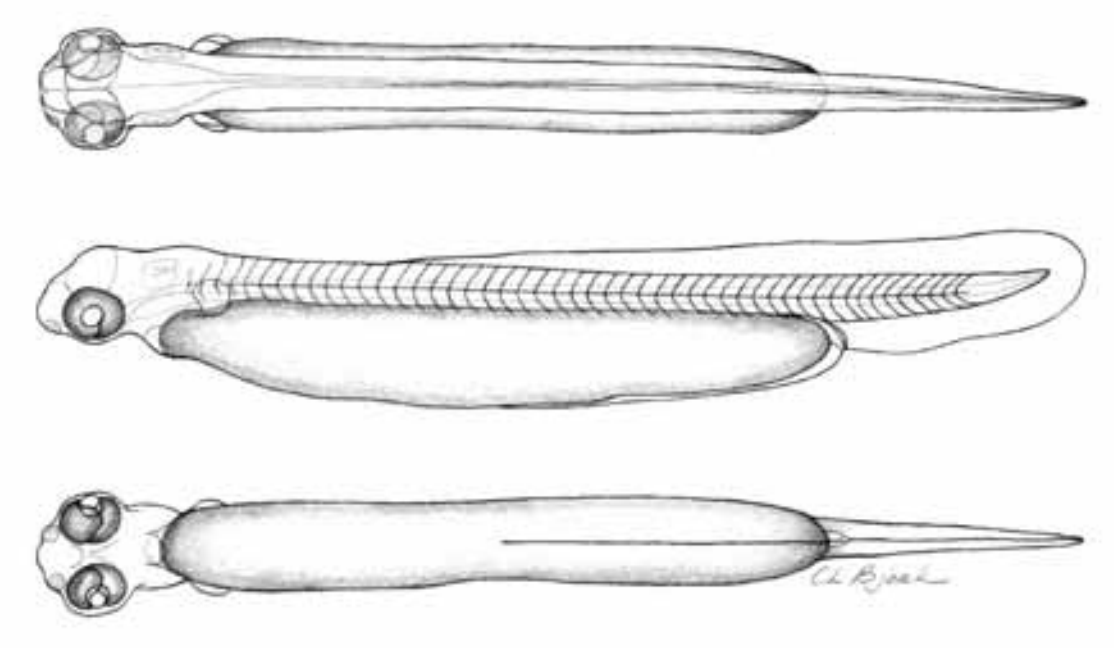


Fig. 9. *Catostomus ardens* protolarva, recently hatched, 10.5 mm SL, 10.8 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

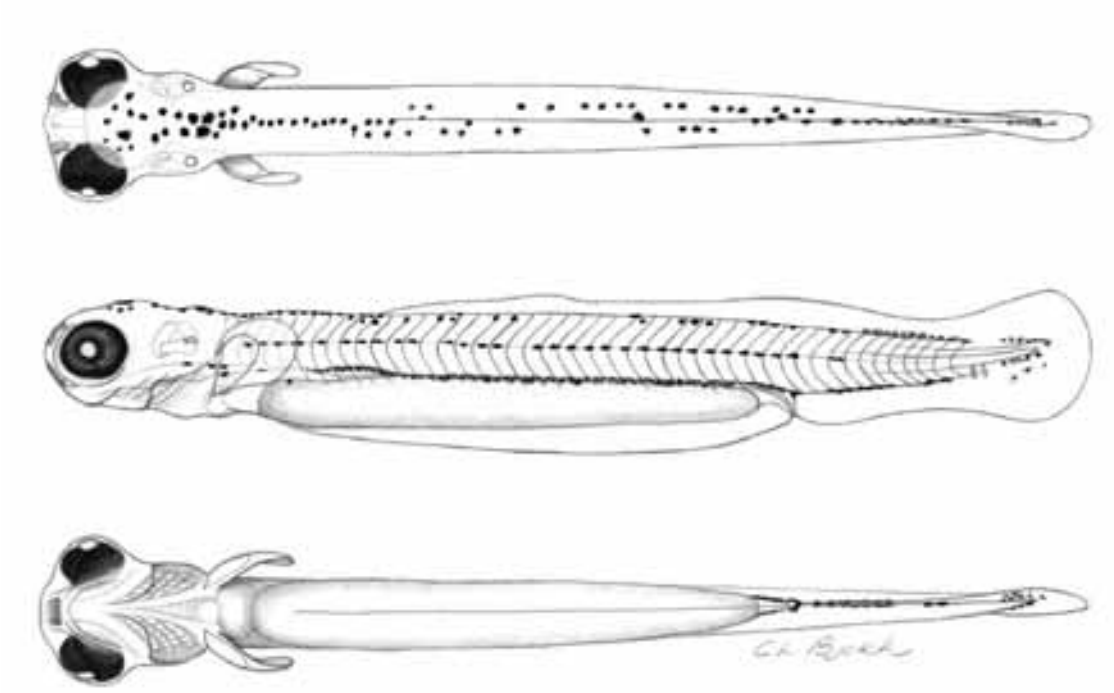


Fig. 10. *Catostomus ardens* protolarva, 11.4 mm SL, 11.9 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

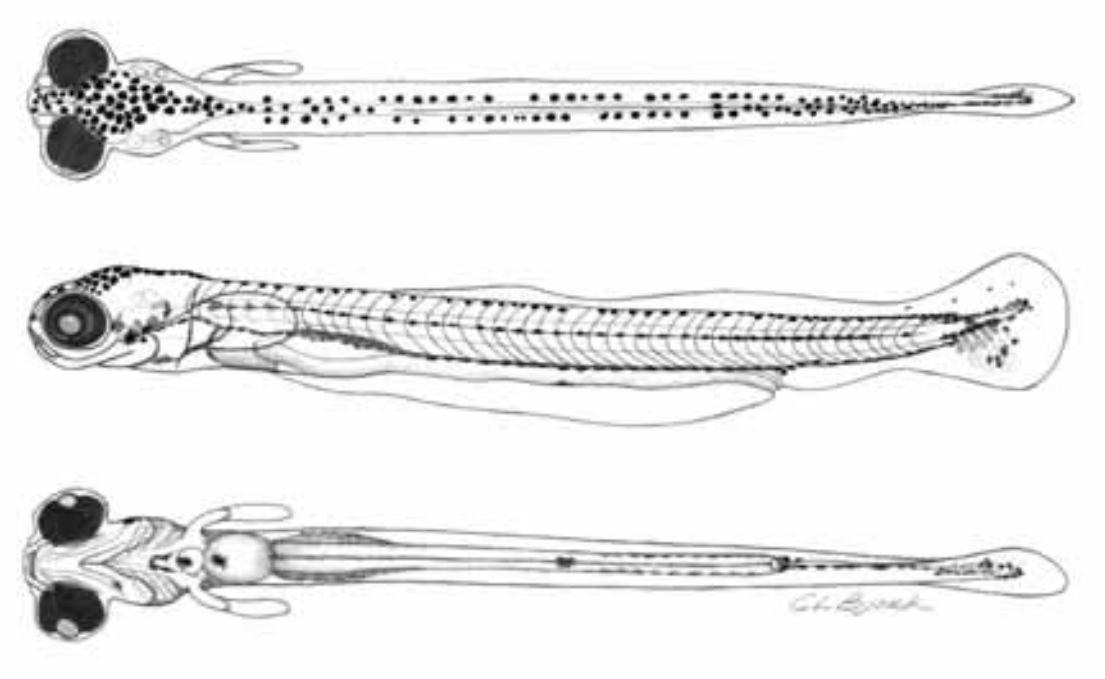


Fig. 11. *Catostomus ardens* flexion mesolarva, recently transformed, 12.2 mm SL, 12.8 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

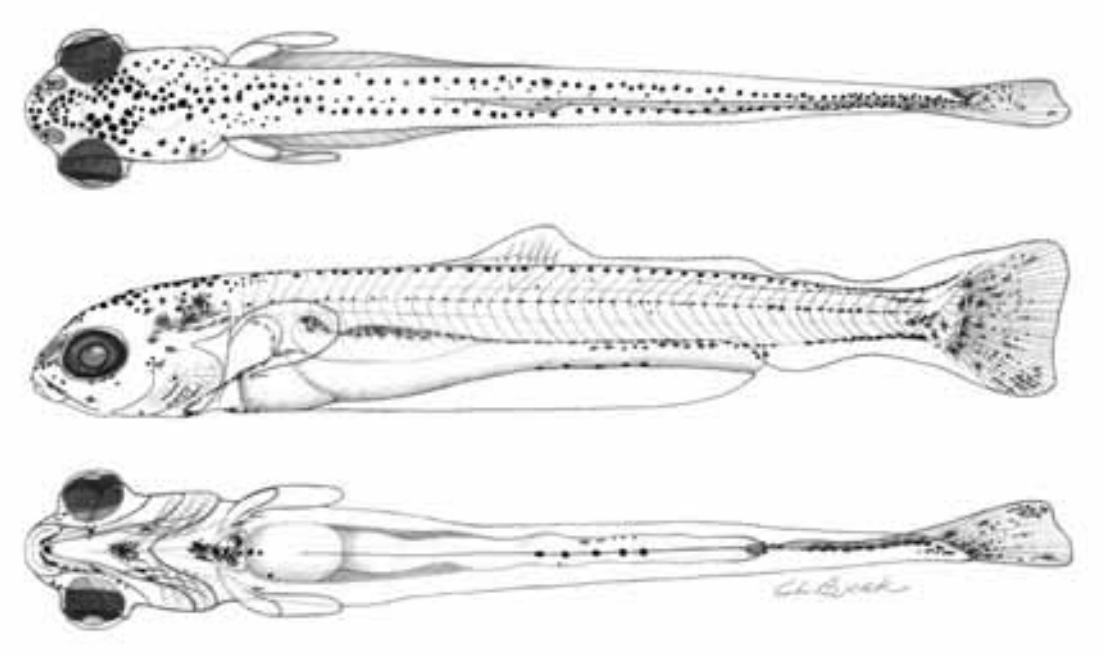


Fig. 12. *Catostomus ardens* postflexion mesolarva, 14.2 mm SL, 15.7 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

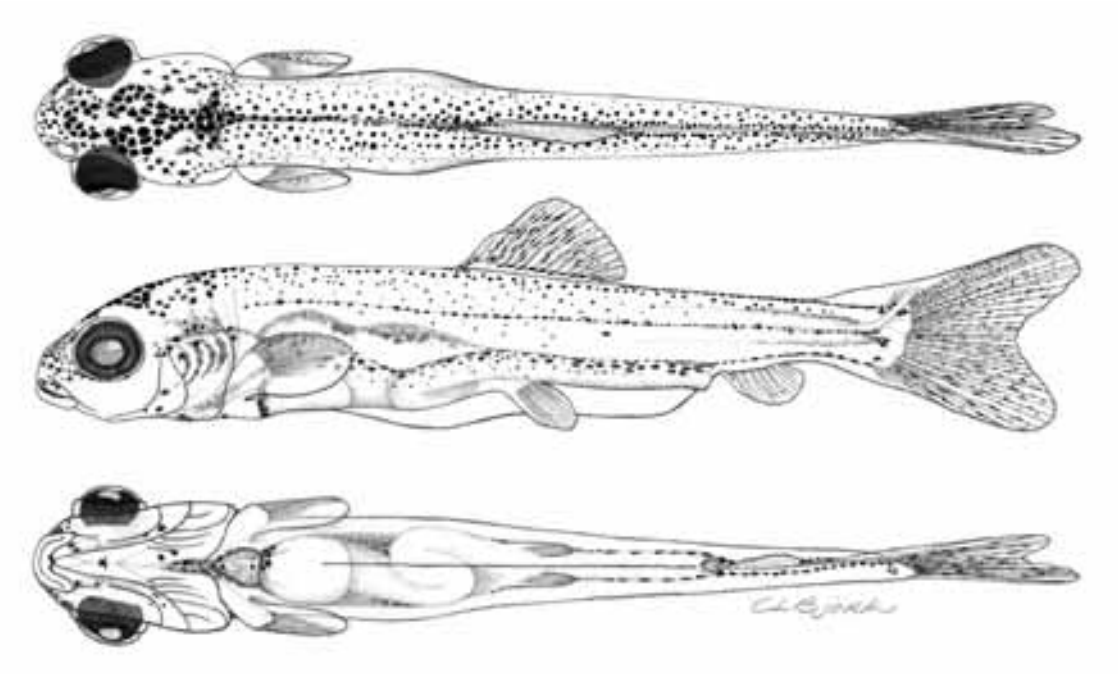


Fig. 13. *Catostomus ardens* metalarva, recently transformed, 15.9 mm SL, 18.7 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

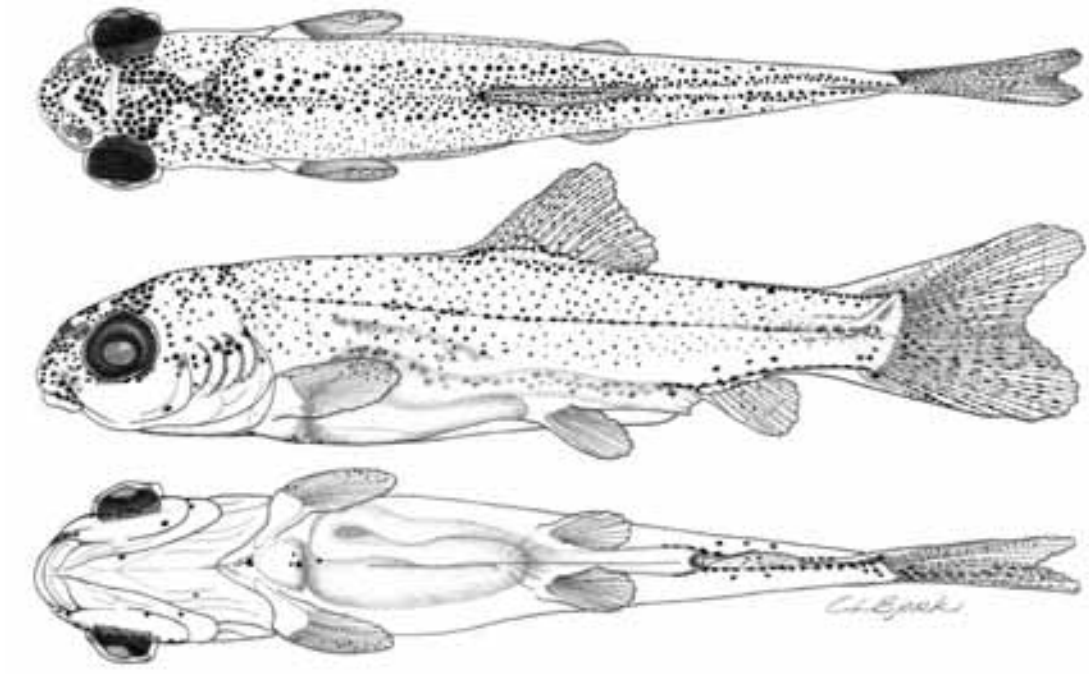


Fig. 14. *Catostomus ardens* metalarva, 17.8 mm SL, 21.5 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

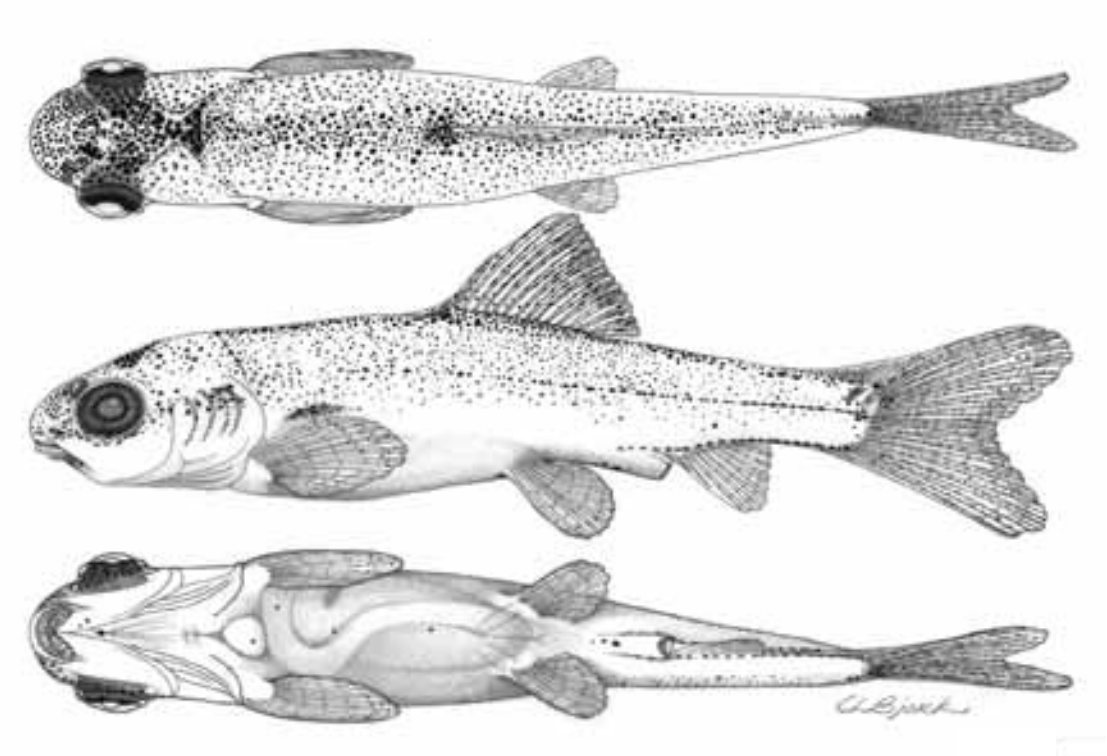


Fig. 15. *Catostomus ardens* juvenile, recently transformed, 21.8 mm SL, 26.9 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

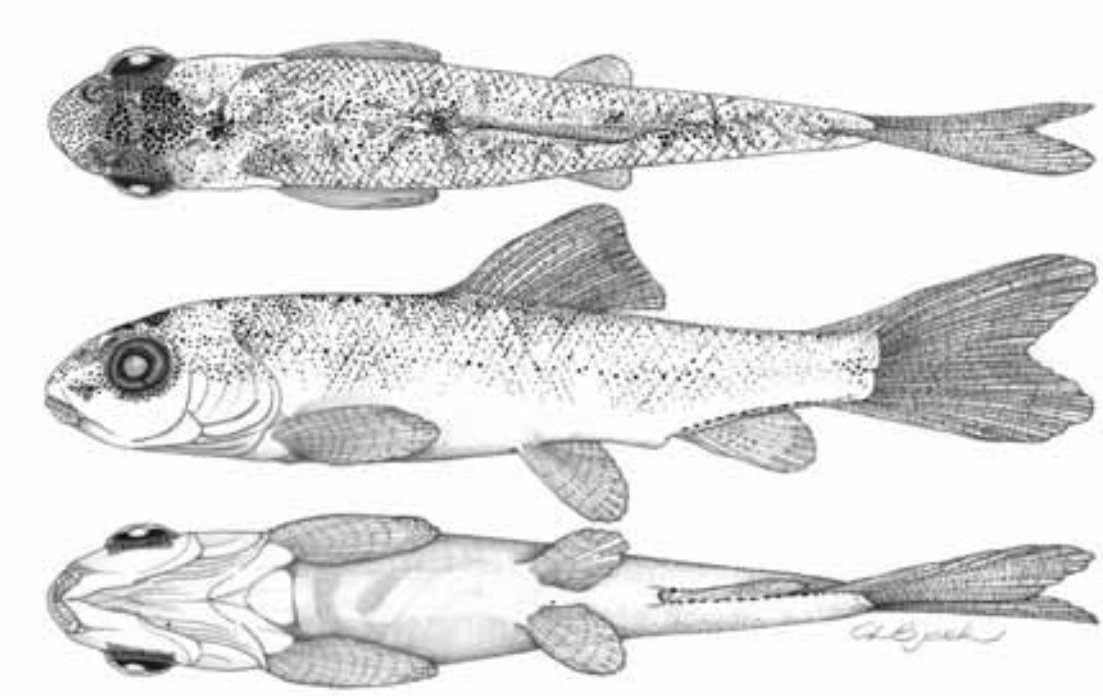


Fig. 16. *Catostomus ardens* juvenile, 28.2 mm SL, 35.6 mm TL. Cultured in 1987 with stock from Bear Lake, Utah.

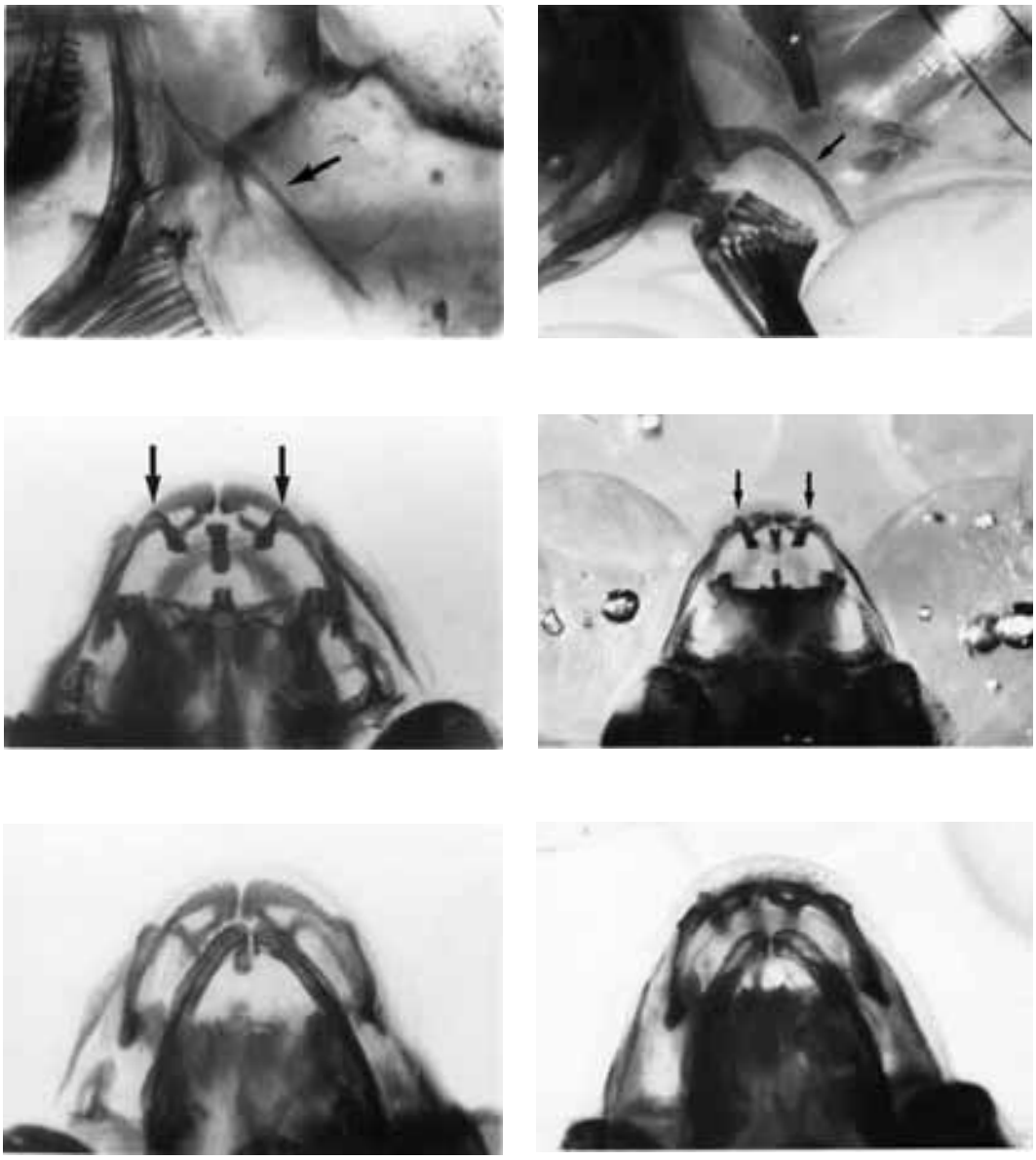


Fig. 17. Selected skeletal features of *Catostomus ardens* juvenile, 21.4 mm SL, 26.2 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

Fig. 18. Selected skeletal features of *Catostomus ardens* juvenile, 39.5 mm SL, 45.4 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

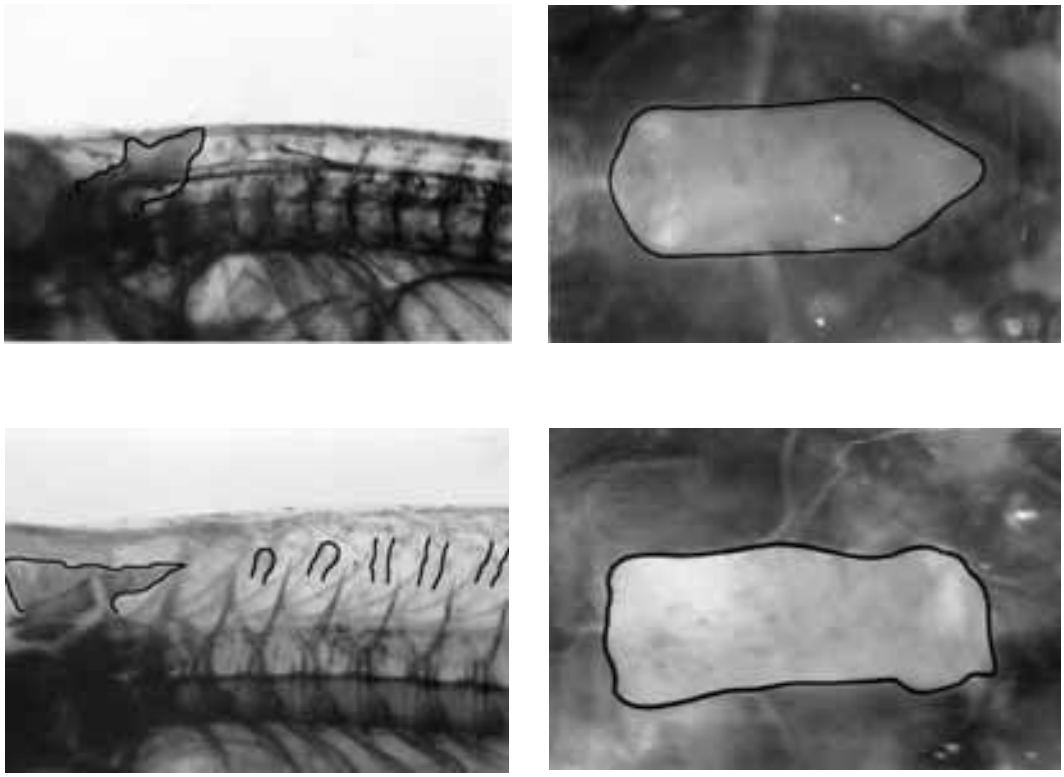


Fig. 20. Frontoparietal fontanelle of *Catostomus ardens*. Top – juvenile, 21.4 mm SL, 26.2 mm TL. Bottom – juvenile, 39.5 mm SL, 45.4 mm TL.

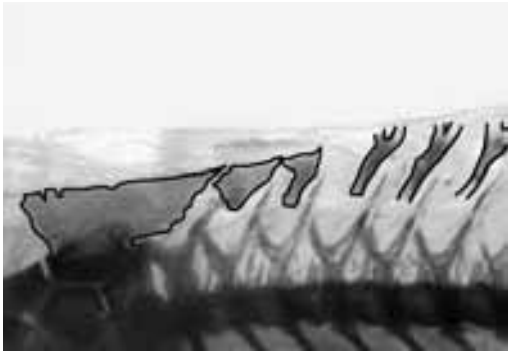


Fig. 19. Interneurals of *Catostomus ardens*. Top – postflexion mesolarva, 16.8 mm SL, 19.2 mm TL. Middle – juvenile, 21.4 mm SL, 26.2 mm TL. Bottom – juvenile, 39.5 mm SL, 45.6 mm TL.

Table 5. Dimensions of frontoparietal fontanelle for *Catostomus ardens* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	2	1.0-1.2	2.0-2.2	45-60
20-21	1	0.9	2.0	43
22-25	2	0.9-0.9	2.3-2.4	38-39
26-34	3	1.0-1.0	2.3-2.4	42-43
35-46	1	1.2	2.8	43
76-81	0			

Fig. 21. *Catostomus catostomus* adult (© Joseph R. Tomelleri).

Adult Description: Elongate, cylindrical body with deep caudal peduncle and no predorsal keel. Long, bulbous, somewhat pointed snout extending well beyond ventral mouth. Cartilaginous ridge along lower jaw but not hard and prominent. Mouth moderate in size but with large, fleshy, coarsely papillous lips, not notched at corners; lower lips flaring widely well behind mouth, medially divided to base or single row of papillae. Dorsal fin short, not falcate. Pelvic axillary process present but small. Scales small. Gill rakers relatively few, short, and fleshy. Fontanelle long and relatively narrow. Peritoneum variable, silvery or dusky with silvery areas to uniformly black. TL usually 30–43 cm, up to 64, possibly 76 cm. (Also, Table 6.)

Reproduction: Non-guarding, open-substrate lithophil. April through July, probably May to early July in Upper Colorado River Basin. Migrate at >5°C. Spawn mostly at 10–15°C for 1–3 weeks, usually <10 d. Spawn primarily in small tributary or inlet streams at depths of 15–30 cm over gravel with a current of 30–45 cm/sec; occasionally in lakes over sand, gravel, or rocks at depths of 1.5–76 cm. Eggs (2.2–) 2.4–3.0 mm diameter, demersal, initially adhesive.

Young: Hatch in 5–14 days at 18–10°C, remain in gravel 1–2 weeks, then emerge and begin drifting downstream at 10–12 mm TL, usually at night. Young occupy low velocity shoreline areas in streams or lakes, often with aquatic vegetation. Aggregate in top 15 cm of water within 2 m of shore. Those 11–18 mm TL feed on plankton, 20–90 mm graze on weeds and solid surfaces and feed on larger organisms.

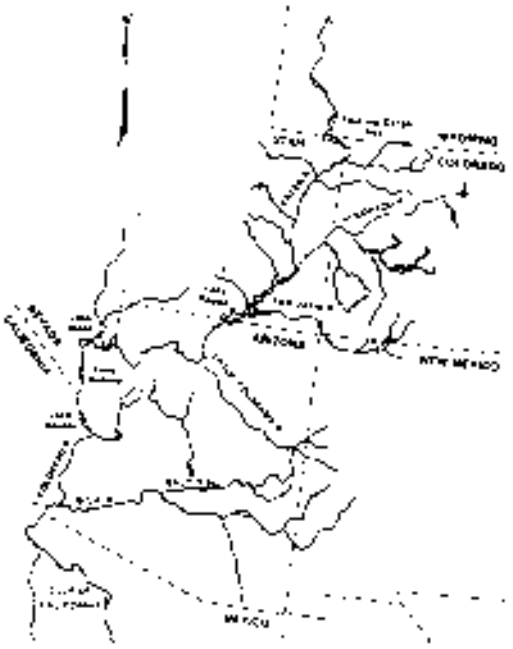


Fig. 22. Recent distribution of *Catostomus catostomus* in Colorado River Basin.

Table 6. Selected juvenile and adult meristics for *Catostomus catostomus*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	(9)<u>10</u>-11	9-<u>10</u>-11(12)	Dorsal Fin Rays - R:	2-<u>3</u>	
Anal Fin Rays - P:	7(8)	7(-9)	Anal Fin Rays - R:	2-<u>3</u>	
Caudal Fin Rays - P:	18(-20)	18	Caudal Fin Rays - RD:	<u>10-11</u>-12(-14)	
Pectoral Fin Rays:	15-<u>16</u>-17(18)	16-18	Caudal Fin Rays - RV:	9-10(-12)	
Pelvic Fin Rays:	<u>9-10</u>(11)	9-11	Lateral Scales:	103-<u>105</u>-110(116)	(85-)90-<u>95-115</u>-120
Vertebrae:	46-47	45-47(48)	Gill Rakers:		23-30

Table 7. Size at apparent onset of selected developmental events for *Catostomus catostomus*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	(7)8-10	(7)8-10	Dorsal - P:	13-14	(14)15	(13)14(15)	(15)16
Eyes Pigmented:	(7)8 or *	8 or *	Anal - P:	(13)14(15)	(15)16	15-16(17)	(17)18-19(20)
Yolk Assimilated:	10-11(12)	10-12(13)	Caudal - P:	11	11-12	12-13	13-14
Finfold Absorbed:	21-22	26-27	Caudal - R:	13-14	15	21	25-26
Pectoral Fin Buds:	*	*	Pectoral:	13-14	15-16	20-21	24-25
Pelvic Fin Buds:	12	13	Pelvic:	14(15)	16-17	(16-)18-19(-21)	(19-)22-23(-25)
* before hatching			Scales:	27-28	33-34	(30)31	37-38

References: Auer 1982, Baxter and Simon 1970, Baxter and Stone 1995, Becker 1983, Beckman 1952, Carlander 1969, Eddy and Underhill 1974, Everhart and Seaman 1971, Fuiman and Witman 1979, Geen et al. 1966, Harris 1962, Hubbs et al. 1943, Jordan and Evermann 1896, Kay et al. 1994, Lee et al. 1980, Nelson and Paetz 1992, Morrow 1980, Scarola 1973, Scott and Crossman 1973, Simpson and Wallace 1978, Smith 1979, Smith 1985, Snyder 1981, Sturm 1988, Tomelleri and Eberle 1990, Tyus et al. 1982, Wheeler 1997, Wiltzius 1978, Woodling 1985, Wydoski and Whitney 1979. ***Personal Communications:*** 2001–D. Brauch, P. Martinez, R. Radant, F. Rahel, R. Remmick, R. Schneidervin.

Table 8. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus catostomus*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	11	11-12	2 - 90° bend:	14	16
Postflexion Mesolarva:	12-13	13-14	3 - Full loop:	16-17	20-21
Metalarva:	15-16(17)	(17)18-19(20)	4 - Partial crossover:	18-21(22)	22-25(-27)
Juvenile:	21-22	26-27	5 - Full crossover:	(19)20-23(-25)	(23)24-28(-31)

Table 9. Summary of morphometrics and myomere counts by developmental phase for *Catostomus catostomus*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=16)			Flexion Mesolarvae (N=11)			Postflexion Mesolarvae (N=19)			Metalarvae (N=26)			Juveniles (N=26)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm:	9	1	7-11	12	1	11-13	14	1	12-17	18	2	15-21	30	6	22-41
TL, mm:	10	1	8-12	13	1	11-14	16	2	13-20	21	3	17-26	36	8	27-50
Lengths %SL:															
AS to AE	3	1	2-4	3	1	3-4	4	1	3-6	6	1	4-9	8	1	6-11
PE	9	1	8-10	9	1	8-11	12	2	9-14	13	1	11-16	15	1	13-18
OP1	16	1	15-18	18	1	16-21	23	2	19-26	25	2	22-28	27	1	24-30
OP2				51	1[a]	50-52	52	1	50-54	56	2	53-59	57	1	55-59
PY	76	2[b]	71-80	71	[c]	71-71									
OPAF	39	19	22-72	27	2	23-31	32	4	25-40	49	9	35-66			
ODF	43	3	39-49	42	1	39-44	45	1	42-47	46	0[d]	46-47			
OD				48	0[a]	48-49	48	1[e]	47-49	49	1	47-52	50	1	49-53
ID							62	1[f]	60-63	63	1	60-66	64	1	62-65
PV	79	1	76-81	78	1	75-79	78	1	77-80	77	1	75-79	76	1	74-78
OA							78	1[g]	76-78	76	1	74-78	76	1	75-77
IA							84	1[h]	82-85	84	1	83-85	84	1	82-85
AFC				106	1[e]	105-107	112	2[e]	107-115	116	1	114-119	116	1	115-118
PC	104	1	103-106	106	1	105-109	114	3	108-118	120	1	117-122	121	1	119-123
Y	52	15	0-64	3	10	0-34									
P1	7	2	4-11	11	1	11-12	13	1	11-15	16	2	13-19	17	1	15-19
P2				1	2	0-4	6	2	3-11	11	2	6-13	13	1	11-15
D							16	1[f]	14-18	19	1	17-21	20	1	18-22
A							8	1[i]	7-9	11	1	9-13	14	1	12-16
Depths %SL:															
at BPE	9	1	8-11	11	1	9-13	14	2	11-18	17	2	14-19	17	1	16-19
OP1	11	1	10-12	12	1	10-14	16	2	11-19	19	2	16-22	20	1	18-22
OD	12	2[b]	8-15	10	1	8-11	14	2	11-19	18	3	13-22	20	1	19-22
BPV	6	1	3-7	6	1	5-7	7	1	6-10	10	2	7-13	12	1	11-13
AMPM	3	1	2-4	4	1	3-5	6	1	5-8	7	1	5-9	9	1	7-10
Max. Yolk	7	4	0-13	0	1	0-2									
Widths %SL:															
at BPE	9	1	7-11	11	1	10-13	14	1	12-16	16	1	14-17	17	1	15-19
OP1	6	1	6-8	8	1	6-10	11	2	9-15	15	2	11-18	17	1	16-18
OD	7	2[b]	5-12	6	1	5-7	9	3	6-14	13	3	8-18	16	2	13-19
BPV	4	0	3-4	4	0	4-5	5	1	4-7	7	2	4-10	9	1	7-10
AMPM	2	0	2-3	2	0	2-3	3	1	2-5	4	1	2-5	4	1	3-6
Max. Yolk	8	4	0-14	0	1	0-3									
Myomeres:															
to PY	35	1[b]	33-37	33	[c]	33-33									
OPAF	14	10	5-31	6	1	6-7	8	1	6-11	16	6	9-27			
OP2				21	1[a]	20-22	21	1	19-22	22	1	19-25			
ODF	15	1	13-17	16	1	14-17	16	1	13-18	16	0[d]	16-16			
OD				19	0[a]	19-19	18	1[e]	16-20	17	1	15-19			
PV	37	1	36-39	38	1	37-39	38	1	36-39	36	1	34-38			
Total	47	2	45-49	47	1	45-49	47	1	45-49	46	1	44-48			
After PV	10	1	8-11	9	1	8-11	9	1	8-10	10	1	9-11			

[a]N = 3, [b]N = 15, [c]N = 1, [d]N = 4, [e]N = 18, [f]N = 11, [g]N = 16, [h]N = 9, [i]N = 8.

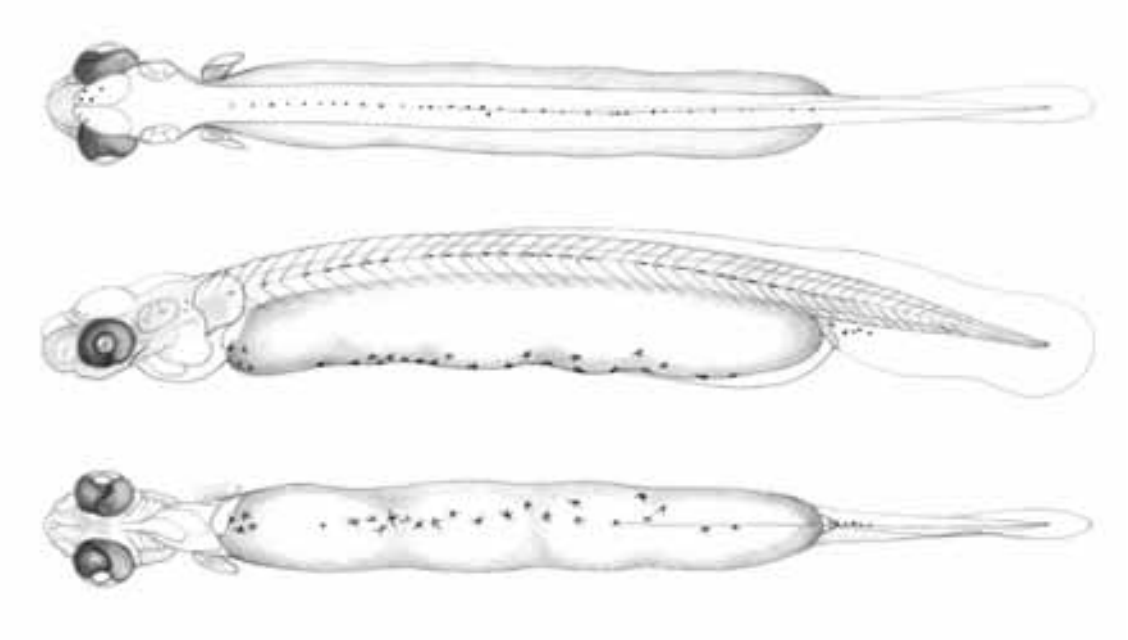


Fig. 23. *Catostomus catostomus* protolarva, recently hatched (day 1), 8.2 mm SL, 8.5 mm TL. Cultured in 1979 with stock from Parvin Lake, Larimer County, Colorado.

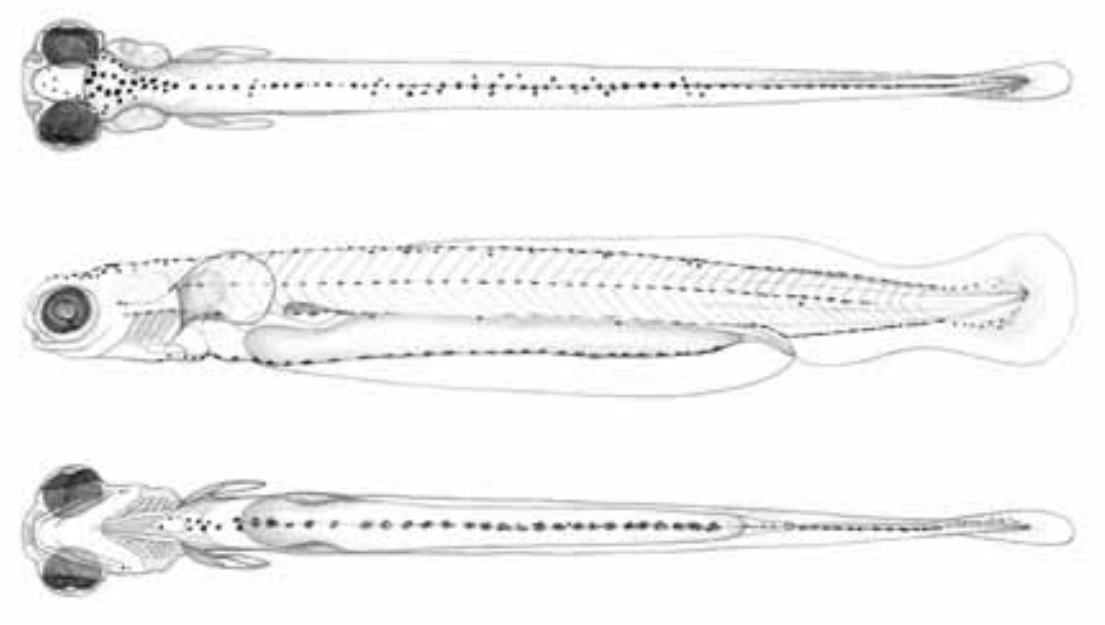


Fig. 24. *Catostomus catostomus* protolarva, 10.2 mm SL, 10.6 mm TL. Cultured in 1979 with stock from Parvin Lake, Larimer County, Colorado.

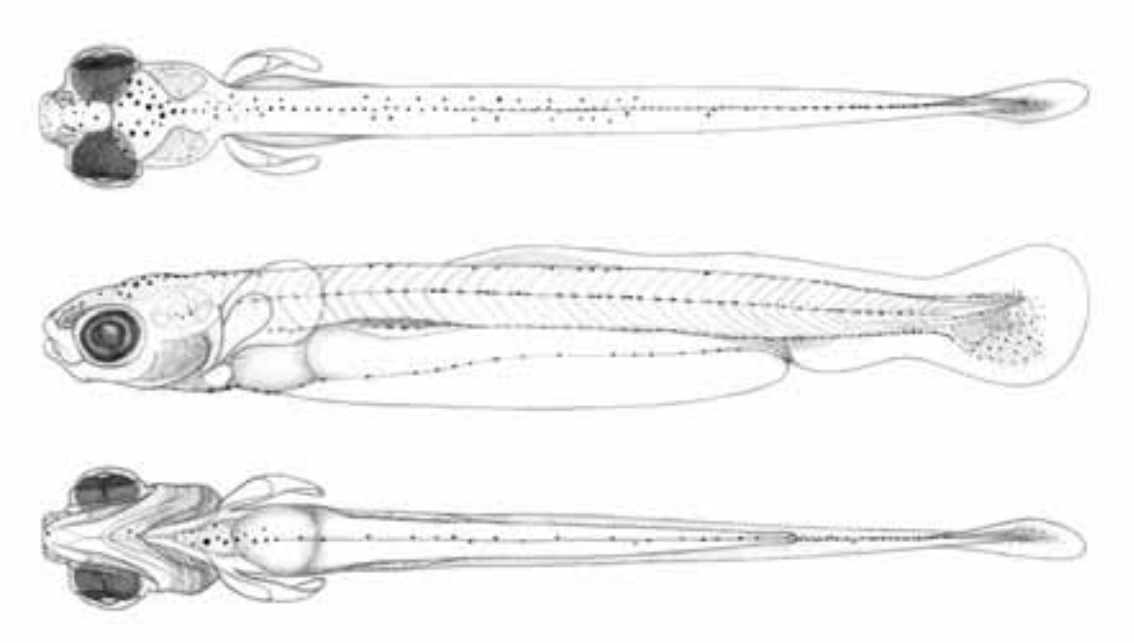


Fig. 25. *Catostomus catostomus* flexion mesolarva, recently transformed, 11.9 mm SL, 12.5 mm TL. Cultured in 1979 with stock from Parvin Lake, Larimer County, Colorado.

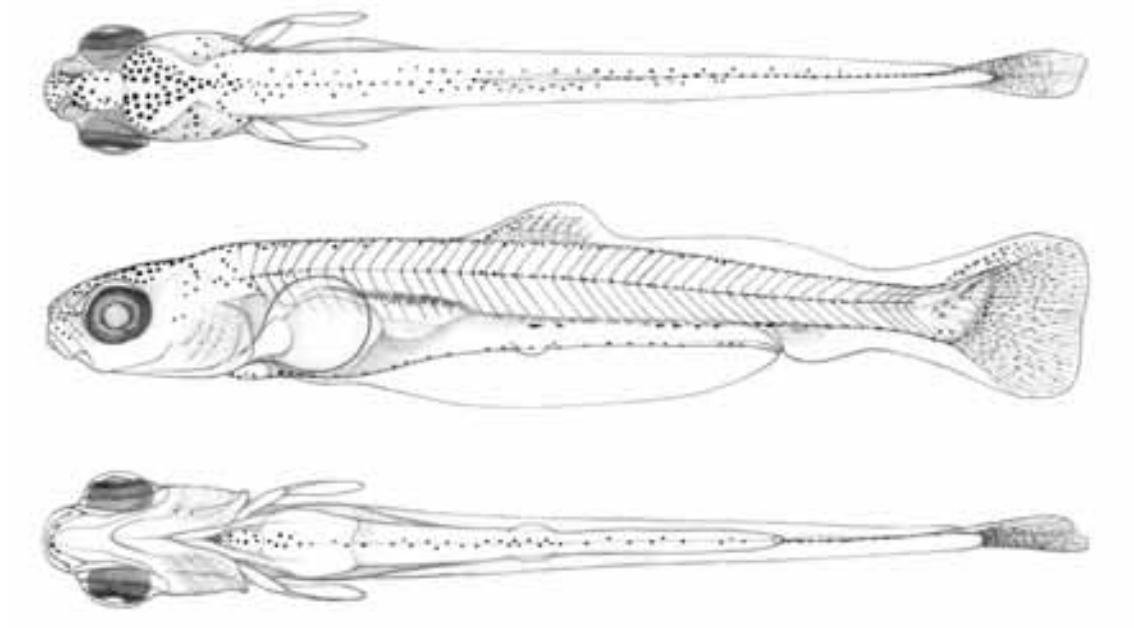


Fig. 26. *Catostomus catostomus* postflexion mesolarva, 13.5 mm SL, 15.1 mm TL. Cultured in 1979 with stock from Parvin Lake, Larimer County, Colorado.

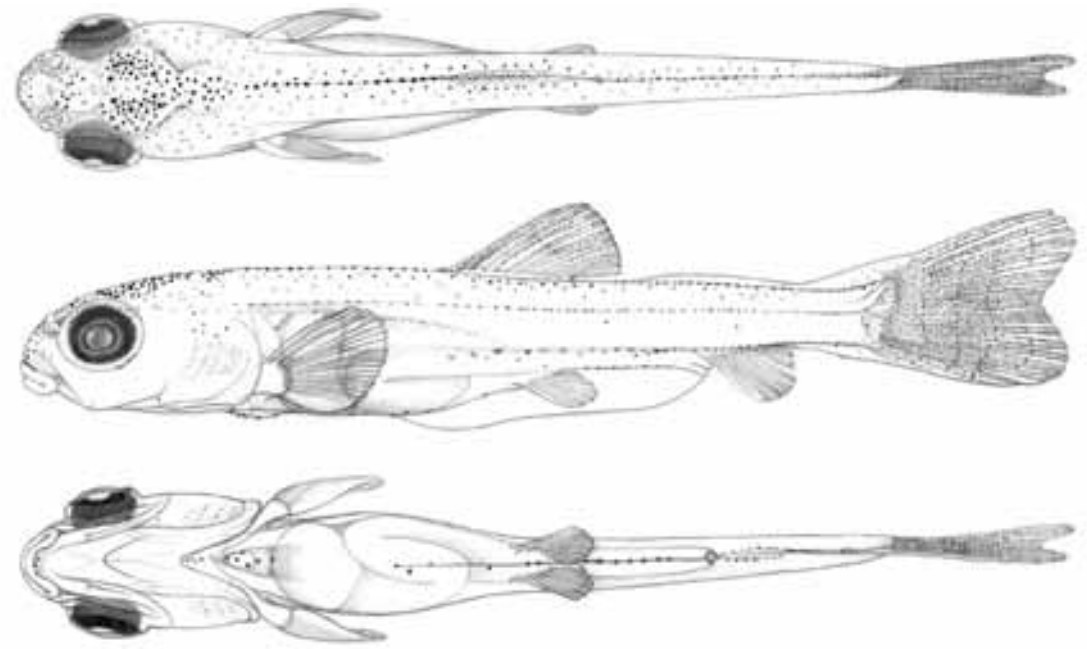


Fig. 27. *Catostomus catostomus* metalarva, recently transformed, 14.6 mm SL, 17.5 mm TL. Cultured in 1979 with stock from Parvin Lake, Larimer County, Colorado.

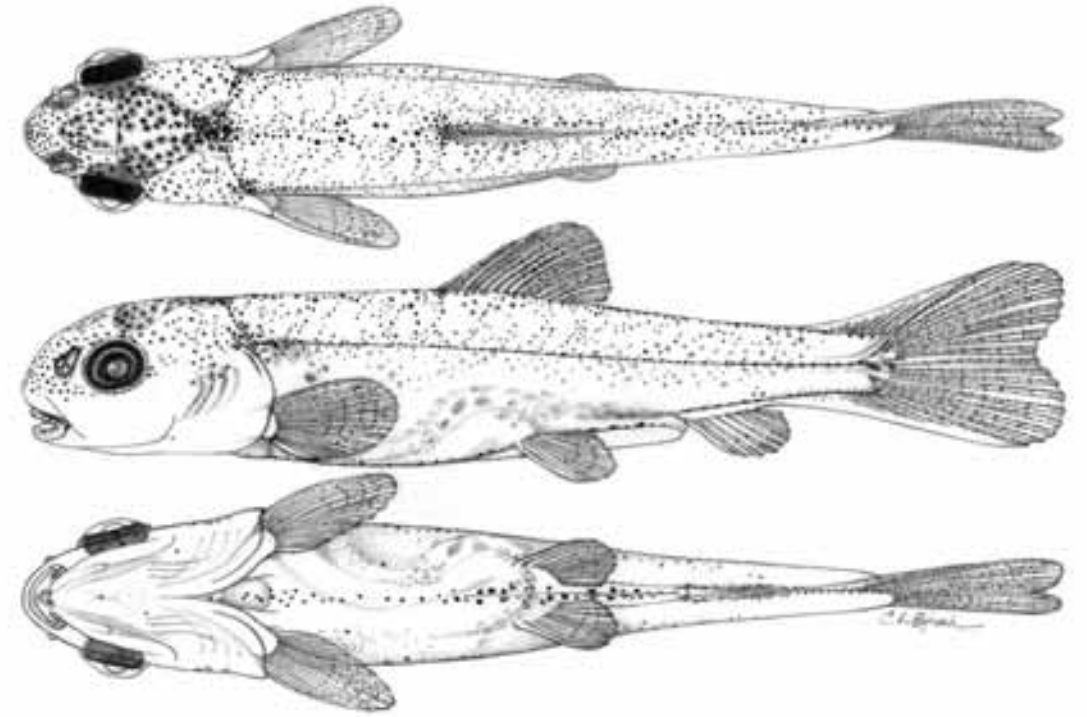


Fig. 28. *Catostomus catostomus* metalarva, 18.7 mm SL, 22.5 mm TL. Cultured in 2001 with stock from Upper Big Creek Lake, Jackson County, Colorado.

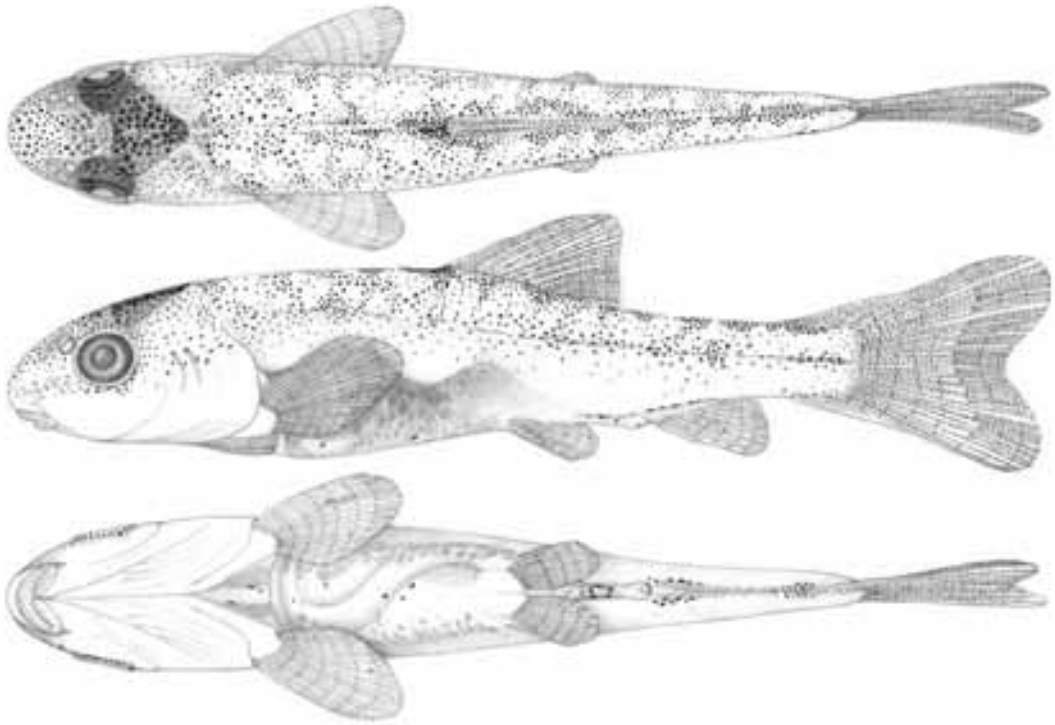


Fig. 29. *Catostomus catostomus* juvenile, recently transformed, 22.9 mm SL, 27.8 mm TL. Collected 21 September 1995 from Gunnison River, Kilometer 94.0, near Escalante, Delta County, Colorado.

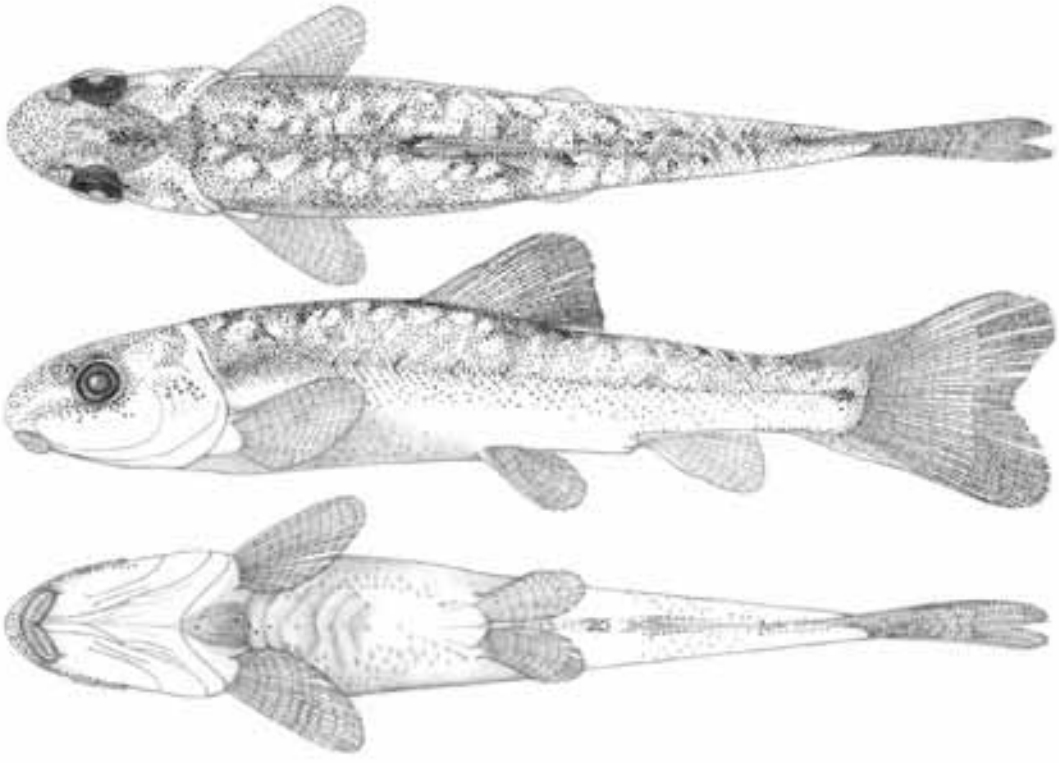


Fig. 30. *Catostomus catostomus* juvenile, 30.5 mm SL, 37.0 mm TL. Collected 21 September 1993 from Gunnison River, Kilometer 96.1, near Escalante, Delta County, Colorado.

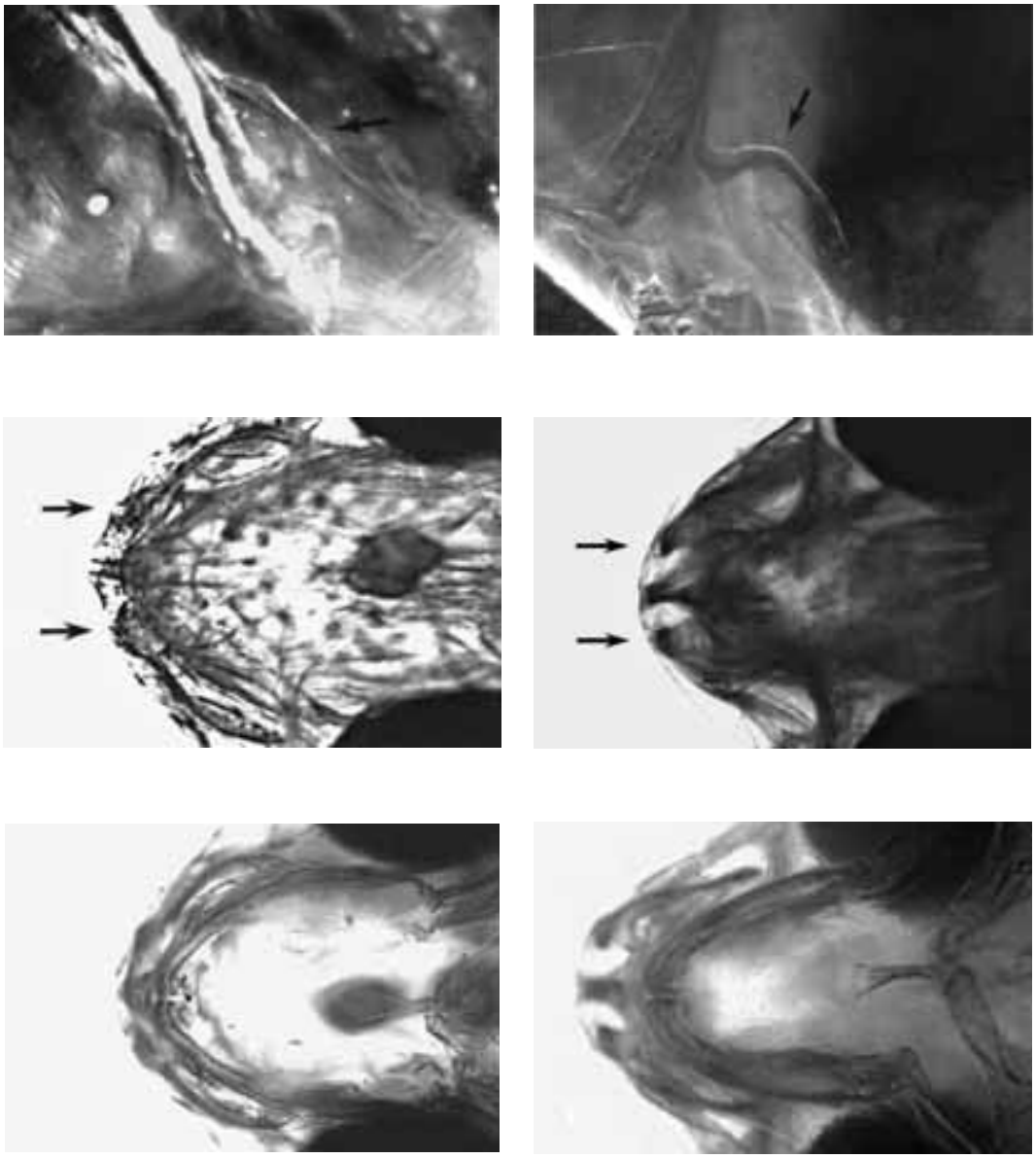
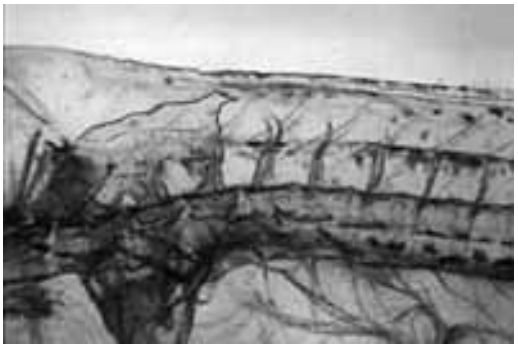
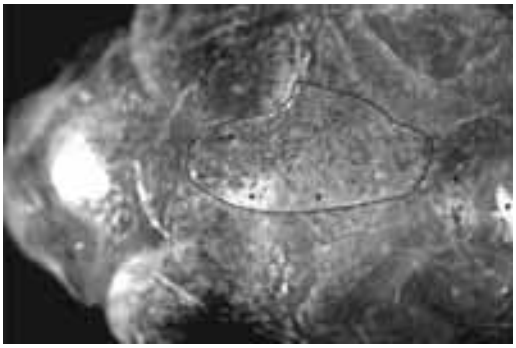
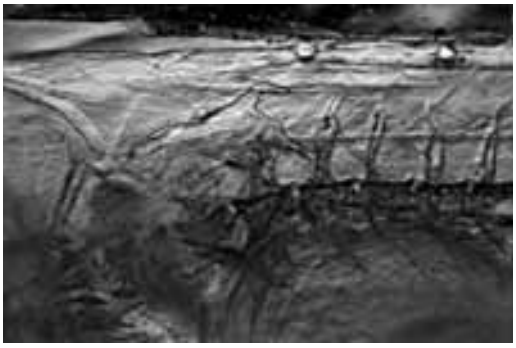


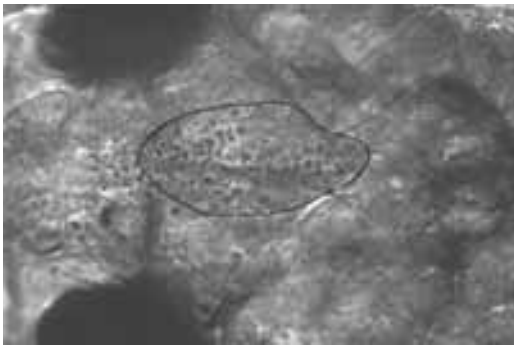
Fig. 31. Selected skeletal features of *Catostomus catostomus* metalarva, 20 mm SL, 24 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

Fig. 32. Selected skeletal features of *Catostomus catostomus* juvenile, 41 mm SL, 49 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.









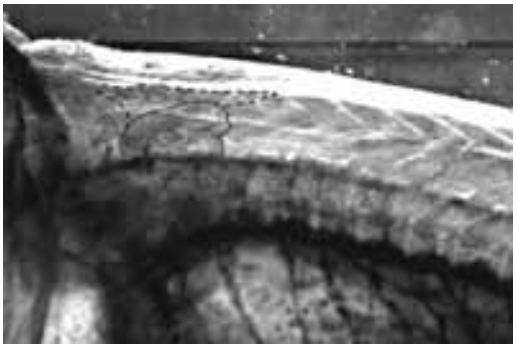


Fig. 33. Interneurals of *Catostomus catostomus*. Top – postflexion mesolarva, 15.0 mm SL, 18.0 mm TL. Middle – metalarva, 20.5 mm SL, 24.4 mm TL. Bottom – juvenile, 41.0 mm SL, 49.0 mm TL (dashed line– possible unstained portion).

Fig. 34. Frontoparietal fontanelle of *Catostomus catostomus*. Top – metalarva, 22 mm SL, 26 mm TL (head angled downward giving false impression that fontanelle is more anterior than it should be). Bottom – juvenile, 29 mm SL, 35 mm TL.

Table 10. Dimensions of frontoparietal fontanelle for *Catostomus catostomus* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	2	1.5-1.5	1.8-2.1	71-83
20-21	2	1.5-1.7	2.0-2.1	75-79
22-25	3	0.9-1.5	2.1-2.3	39-68
26-34	3	1.1-1.4	2.7-3.0	40-47
35-46	2	1.1-1.4	3.2-3.8	29-44
47-75	2	1.1-1.4	3.8-4.5	29-31
76-87	1	1.5	4.8	31

Fig. 35. *Catostomus commersoni* adult (© Joseph R. Tomelleri).

Adult Description: Back without conspicuous predorsal keel. Robust. Caudal peduncle depth about 6.5-8.6% TL. Inferior, slightly overhung mouth; no hard, prominent, cartilaginous ridges along inside of jaws. Lips relatively small, papillose, without notches at corners; lower lip wider than long with a deep median cleft, usually without rows of papillae (sometimes 1 or 2) spanning the two lobes. Dorsal fin not large and falcate. Scales large. Gill rakers relatively few, somewhat knobbed. Peritoneum pale or lightly speckled. TL usually 30-50 cm, up to 64 cm. (Also, Table 11.)

Reproduction: Non-guarding, open-substrate lithophil. April or May to August, 7-19°C, usually >10°C; mostly June to mid-July in the Upper Colorado River Basin. Frequently in large aggregations migrate to streams or lake shores to spawn in shallow water, usually <0.3 m, and moderate currents, mostly 30-49 cm/sec, over sand or gravel; often over riffles in streams. Water-hardened eggs 2.6-3.3 mm diameter, demersal, initially adhesive.

Young: Hatch in 5-11 days at 18-10°C, remain in gravel 1-2 weeks, drift as late protolarvae and mesolarvae, usually at night, and subsequently occupy low velocity shoreline areas, often over sand and gravel or in aquatic vegetation.

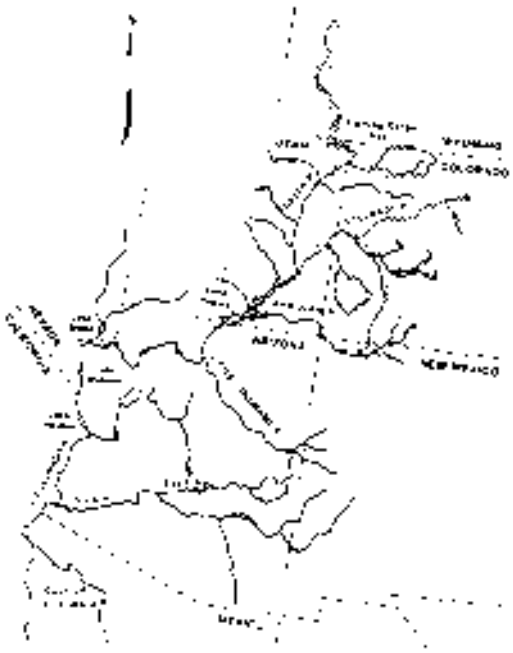


Fig. 36. Recent distribution of *Catostomus commersoni* in Colorado River Basin.

Table 11. Selected juvenile and adult meristics for *Catostomus commersoni*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	10-11-12(13)	(9)10-13(-15)	Dorsal Fin Rays - R:	2-3-4(5)	
Anal Fin Rays - P:	(5-)7(8)	(6)7-8	Anal Fin Rays - R:	2-3	
Caudal Fin Rays - P:	18	18	Caudal Fin Rays - RD:	10-11-13	
Pectoral Fin Rays:	13-15-16(17)	13-19	Caudal Fin Rays - RV:	8-10	
Pelvic Fin Rays:	8-10	9-11	Lateral Scales:	56-59-68-72	53-56-70-76(-85)
Vertebrae:	45-46-48	44-48	Gill Rakers:		20-27

Table 12. Size at apparent onset of selected developmental events for *Catostomus commersoni*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	(7)8-10	8-10	Dorsal - P:	12-14(15)	14-15(16)	14-16	16-17
Eyes Pigmented:	(7)8 or *	8 or *	Anal - P:	14-16	16-17	15-16(17)	18-19(20)
Yolk Assimilated:	10-12(-14)	(10)11-13(-15)	Caudal - P:	10-12(13)	10-13	(12)13-15	(13)14-16
Finfold Absorbed:	(17-)19-20	(21-)23-24	Caudal - R:	13-15	14-16	(17)18	(21)22-23
Pectoral Fin Buds:	(7)8 or *	8 or *	Pectoral:	14-16	16-17	16(-20)	19(-24)
Pelvic Fin Buds:	13-15	(14)15-16	Pelvic:	15-16	18-19	16-18	19-22
* before hatching			Scales:	22(23)	27	29-31	36-37

References: Auer 1982, Baxter and Simon 1970, Baxter and Stone 1995, Beckman 1952, Carlander 1969, Carlson et al. 1979, Ellis 1914, Fuiman 1979, Fuiman and Trojnar 1980, Geen et al. 1966, Hubbs et al. 1943, Jones et al. 1978, Jordan and Evermann 1896, Lee et al. 1980, Lippson and Moran 1974, Miller 1952, Minckley 1973, Prewitt 1977, Reighard 1920, Scott and Crossman 1973, Smith 1985, Stewart 1926, Sublette et al. 1990, Twomey et al. 1984, Wheeler 1997, Woodling 1985.

Table 13. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus commersoni*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	10-12(13)	10-13	2 - 90° bend:	14-15(16)	(16)17(18)
Postflexion Mesolarva:	(12)13-15	(13)14-16	3 - Full loop:	(16)17-18	(19)20-21(22)
Metalarva:	15-16(17)	18-19(20)	4 - Partial crossover:	19-20(21)	(22)23-24(-26)
Juvenile:	(17-)19-20	(21-)23-24	5 - Full crossover:	(20)21-25	(24)25-30(31)

Table 14. Summary of morphometrics and myomere counts by developmental phase for *Catostomus commersoni*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=11)		Flexion Mesolarvae (N=16)		Postflexion Mesolarvae (N=9)		Metalarvae (N=18)		Juveniles (N=25)	
	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range
SL, mm:	10 1	8-12	12 2	10-15	14 1	12-16	17 1	15-20	25 6	19-39
TL, mm:	10 1	9-12	13 2	10-16	16 2	14-19	21 2	18-24	30 7	23-48
Lengths %SL:										
AS to AE	2 0	2-3	2 1	2-3	4 1	2-6	6 1	4-8	8 1	6-10
PE	8 1	8-9	8 1	7-10	11 1	9-14	14 1	12-15	15 1	13-16
OP1	16 1	13-19	18 1	16-20	22 2	19-25	26 2	20-30	28 1	24-29
OP2					53 1[b]	52-54	56 2	54-59	57 2	52-59
PY	70 12	47-80	63 10[a]	50-75						
OPAF	31 15	22-73	25 1	23-27	30 2	25-33	48 10	32-68		
ODF	37 2	34-42	38 2	35-43	44 3[c]	38-48				
OD					50 1[b]	49-51	51 1	48-53	51 1	48-53
ID					63 1[d]	61-64	65 2	61-67	65 1	61-68
PV	78 2	76-82	79 1	76-81	80 1	78-81	77 1	75-79	76 1	72-78
OA					80 1[d]	79-80	78 1	76-79	77 1	73-79
IA					85 1[d]	84-86	85 1	83-86	84 1	79-86
AFC					110 2	108-113	113 2	110-119	115 1	113-117
PC	104 1	101-106	106 1	104-109	114 4	109-120	121 2	116-126	122 1	119-124
Y	51 13	26-63	18 21	0-50						
P1	7 4	2-12	11 1	10-12	12 1	11-14	15 2[e]	12-19	17 1	15-20
P2					2 2	0-6	9 3	4-16	12 1	10-15
D					17 1[d]	16-17	19 2	15-22	20 1	18-24
A					7 0[d]	7-7	11 2	7-14	13 2	10-16
Depths %SL:										
at BPE	9 1	7-11	10 1	9-11	13 1	11-15	16 1	14-19	17 1	16-19
OP1	11 1	9-12	1 11	10-13	16 2	14-18	18 1	16-20	20 1	18-22
OD	10 2	8-13	9 1	8-10	12 2	9-16	16 2	13-20	19 1	17-22
BPV	5 1	3-6	5 0	5-6	7 1	6-9	9 1	7-11	11 1	10-14
AMPM	3 1	2-3	4 0	3-4	5 1	4-7	7 1	5-8	8 1	7-9
Max. Yolk	6 3	1-11	1 1	0-3						
Widths %SL:										
at BPE	9 2	7-11	10 1	9-12	13 1	11-15	15 1	13-17	16 1	14-18
OP1	6 1	5-7	7 1	6-8	10 1	8-12	13 1	11-14	16 2	13-20
OD	6 1	5-9	5 0	5-6	7 1	5-9	10 2	8-14	13 2	10-16
BPV	4 0	3-4	4 0	3-4	5 1	4-6	6 1	4-8	8 1	7-10
AMPM	2 0	2-2	2 0	2-2	3 0	2-3	3 1	2-4	4 0	4-5
Max. Yolk	6 3	1-10	1 2	0-4						
Myomeres:										
to PY	33 7	18-38	28 6[a]	21-35						
OPAF	9 7	4-30	6 1	5-8	6 1	5-8	16 6	7-28		
OP2					21 1[b]	19-22	21 1	20-23	21 1[f]	20-22
ODF	13 1	12-14	14 1	12-17	15 2[d]	12-17	14 2[a]	11-17		
OD					19 1[b]	17-20	17 1[e]	16-19	17 1[f]	16-18
PV	38 2	35-40	37 2	34-40	38 1	36-40	35 1	34-37	35 1[f]	33-36
Total	47 1	44-48	46 1	43-48	46 1	45-49	45 1	44-47	45 1[f]	43-47
After PV	9 1	8-10	9 1	7-11	9 1	8-9	10 1	8-12	10 1[f]	9-12

[a] N = 8, [b] N = 7, [c] N = 8, [d] N = 3, [e] N = 17, [f] N = 20.

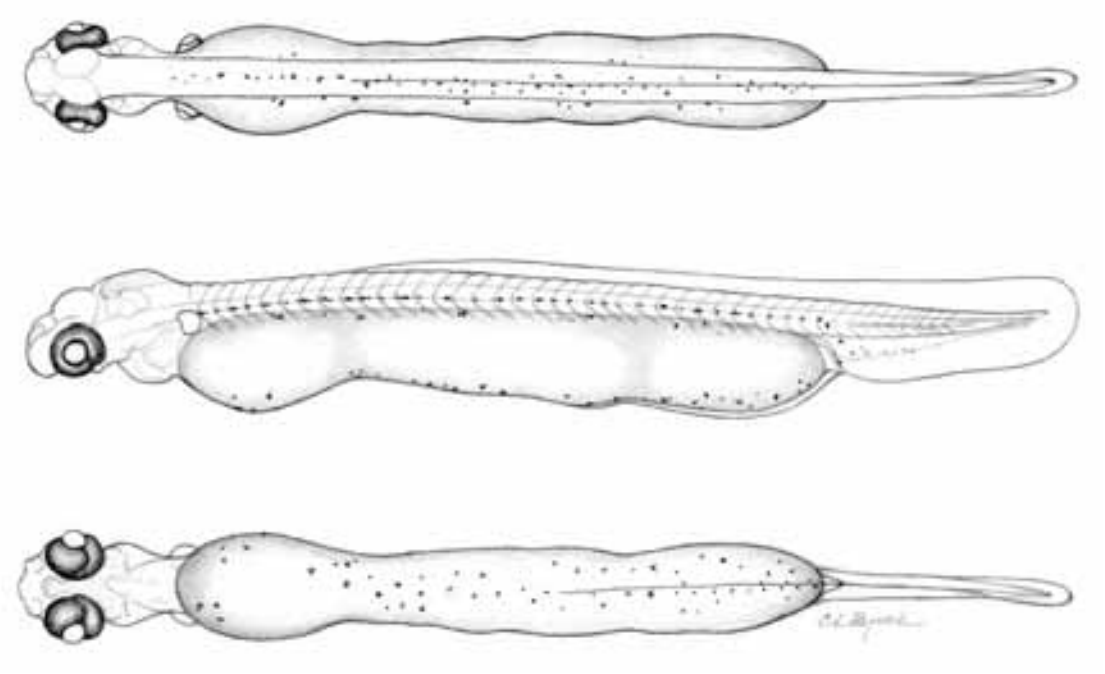


Fig. 37. *Catostomus commersoni* protolarva, recently hatched (day 1), 9.3 mm SL, 9.6 mm TL. Cultured in 1979 with stock from a private pond (Louis Swift), Fort Collins, Colorado.

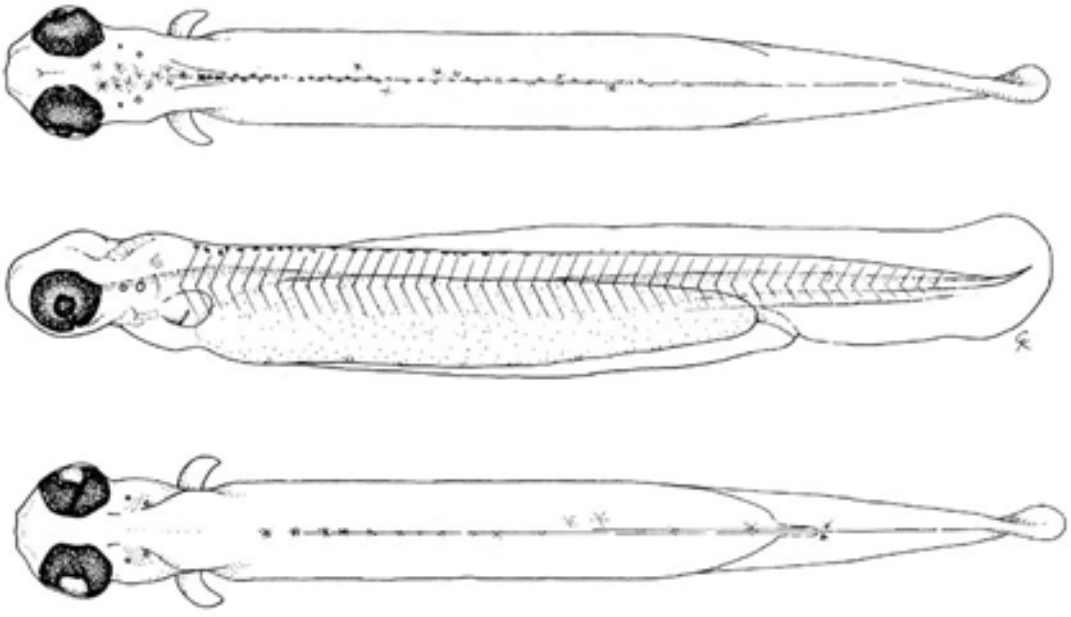


Fig. 38. *Catostomus commersoni* protolarva, 10.5 mm SL, 10.7 mm TL (from Fuiman 1979).

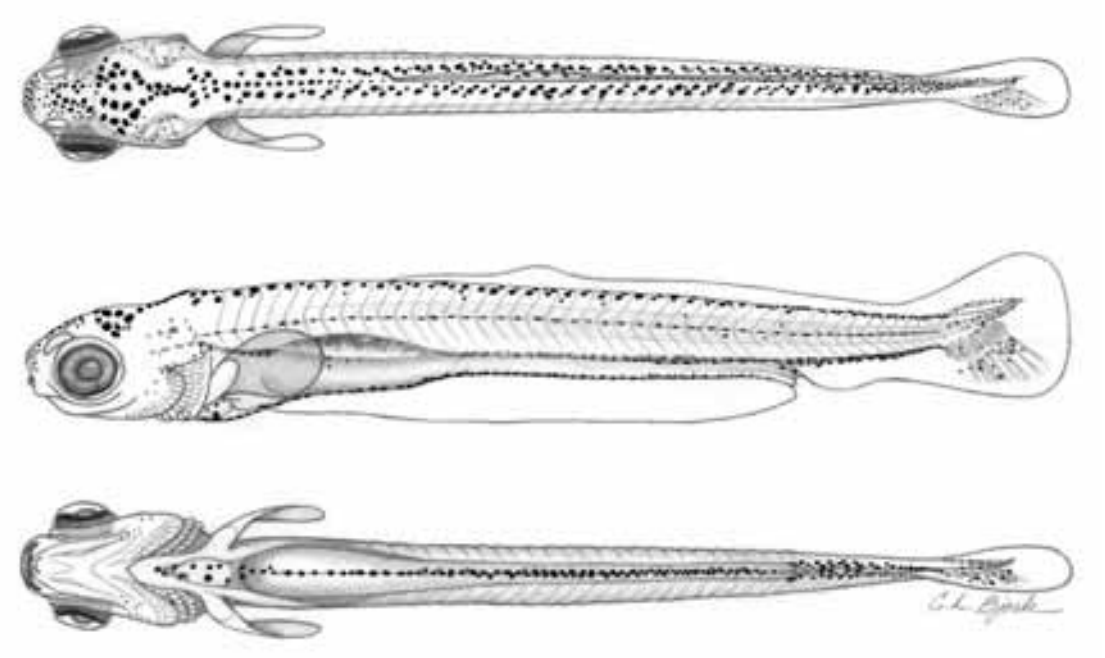


Fig. 39. *Catostomus commersoni* flexion mesolarva, recently transformed, 12.8 mm SL, 13.4 mm TL. Collected in 1977 from the Yampa River, Colorado.

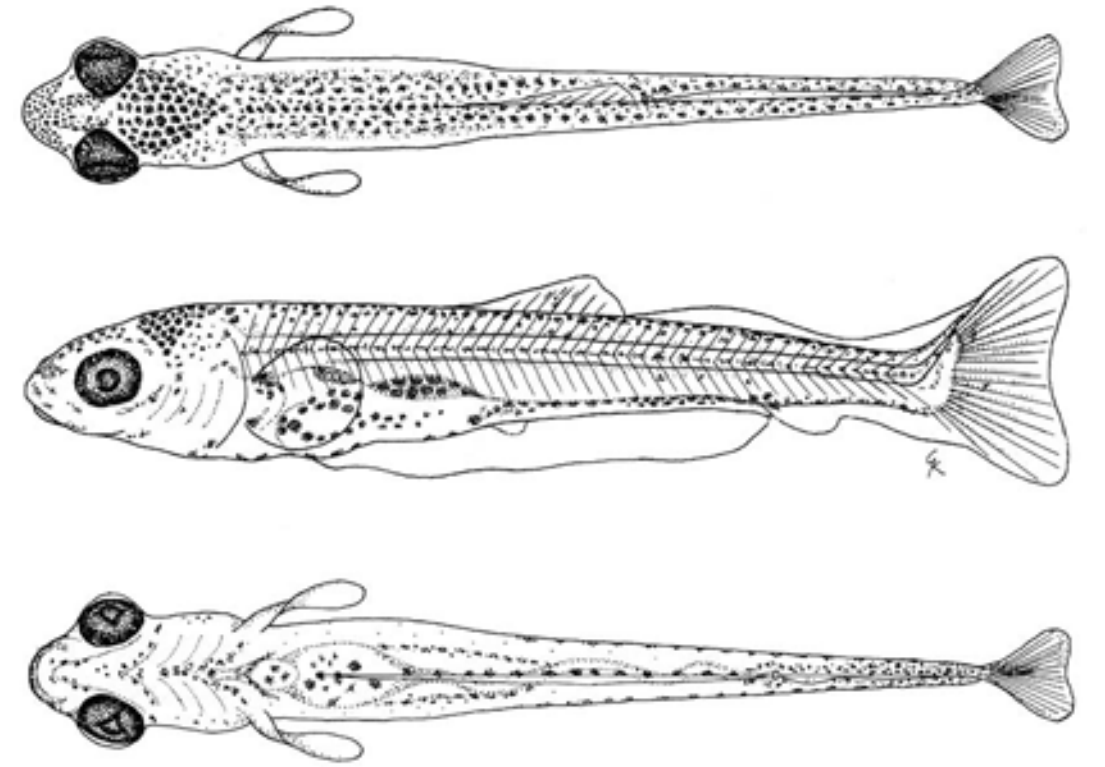


Fig. 40. *Catostomus commersoni* postflexion mesolarva, 16.3 mm SL, 18.2 mm TL (from Fuiman 1979).

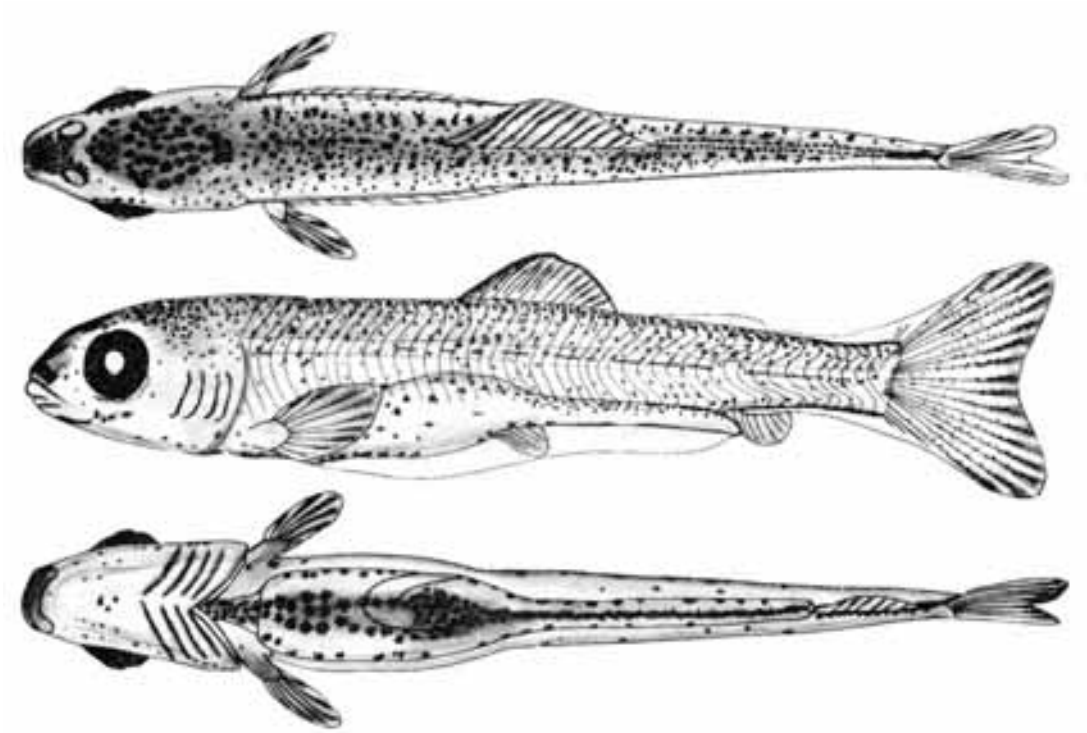


Fig. 41. *Catostomus commersoni* metalarva, recently transformed, 17.8 mm SL, 20.4 mm TL (from Buynak and Mohr 1978).

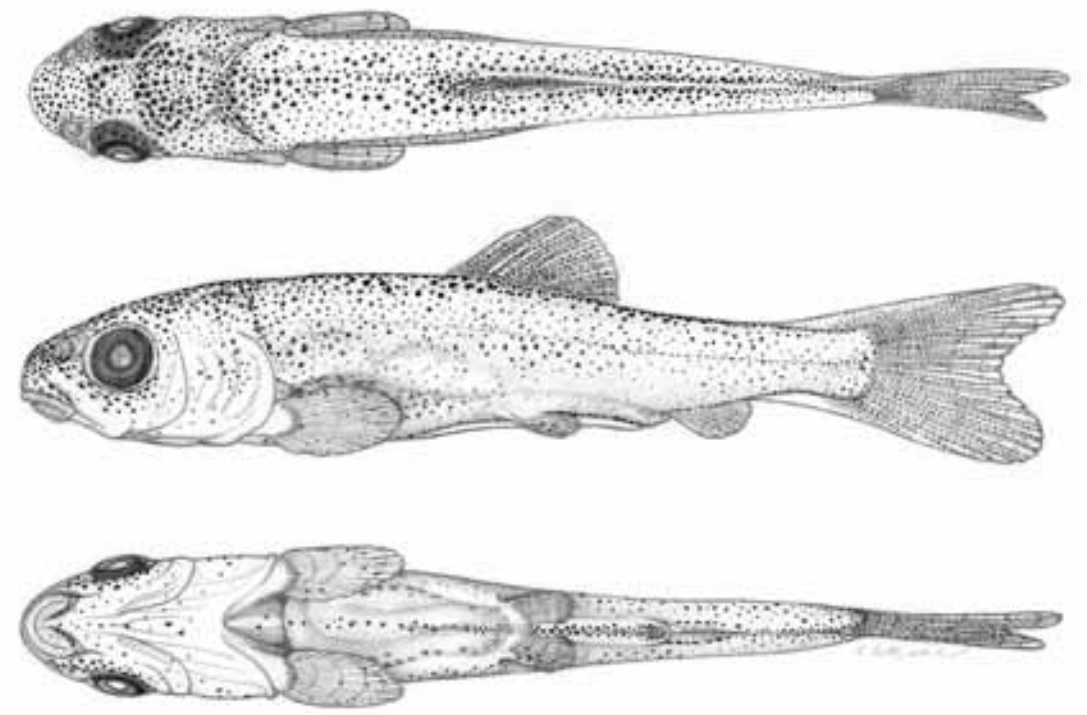


Fig. 42. *Catostomus commersoni* metalarva, 19.2 mm SL, 23.1 mm TL. Collected in 1977 from the Yampa River, Colorado.

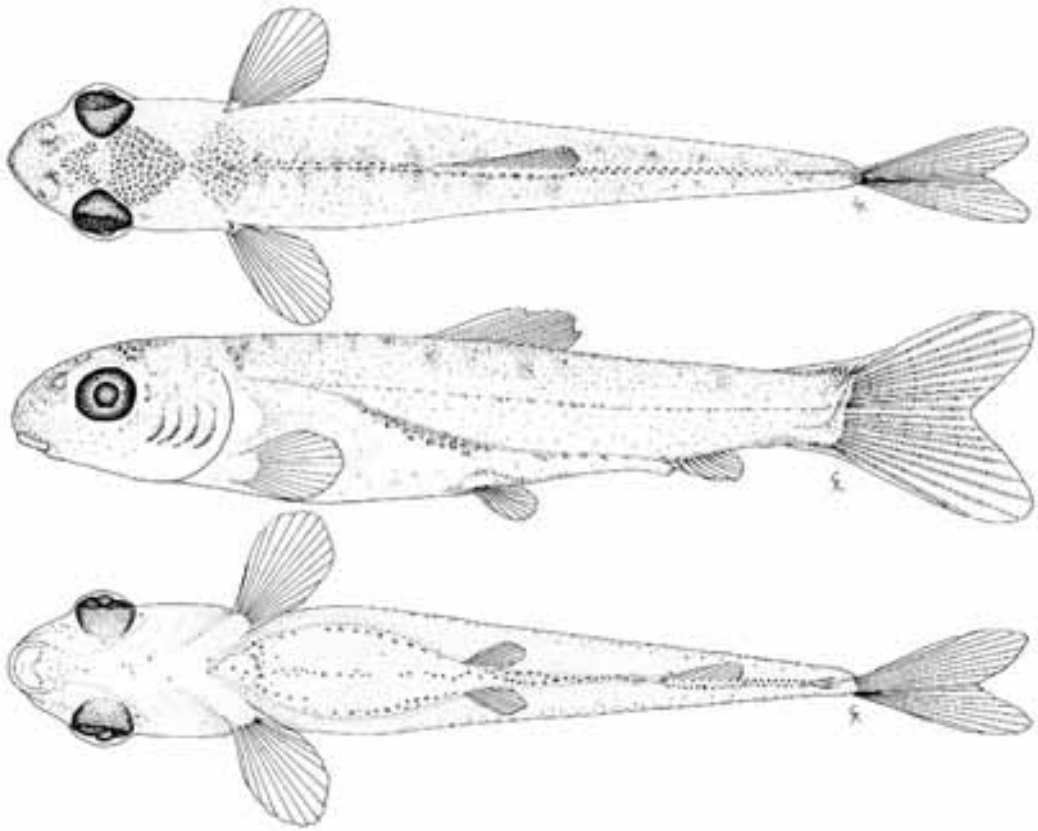


Fig. 43. *Catostomus commersoni* juvenile, recently transformed, 21.3 mm SL, 25.8 mm TL (from Fuiman 1979).

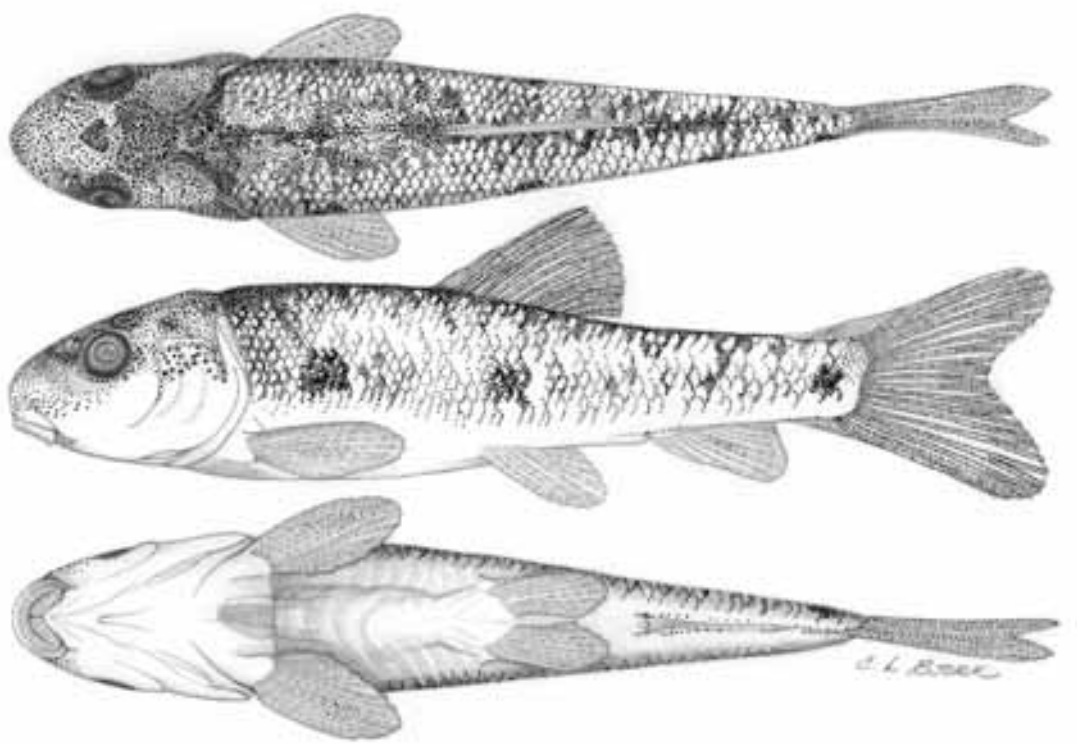


Fig. 44. *Catostomus commersoni* juvenile, 30.8 mm SL, 37.9 mm TL. Collected in 1977 from the Yampa River, Colorado.

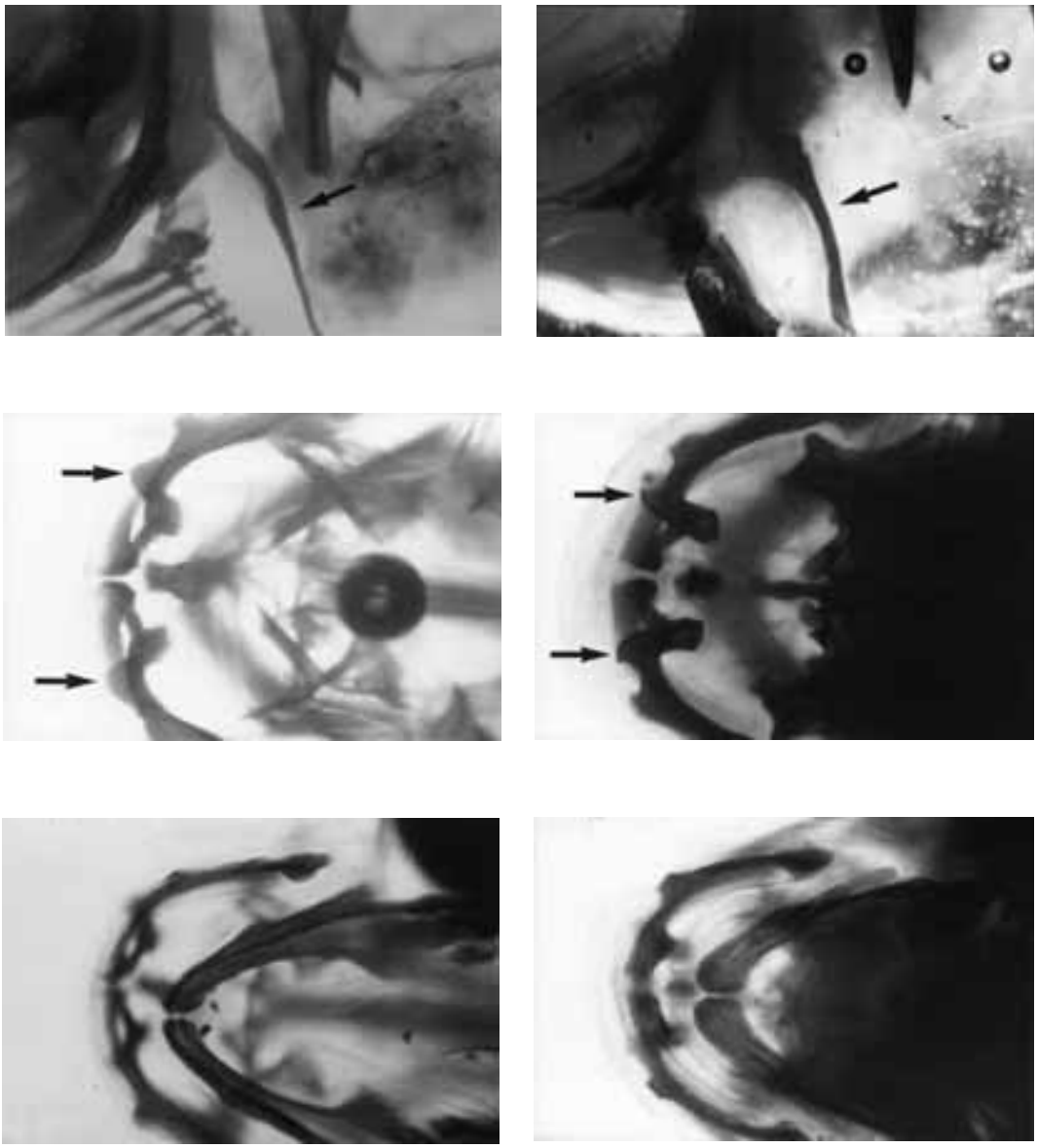
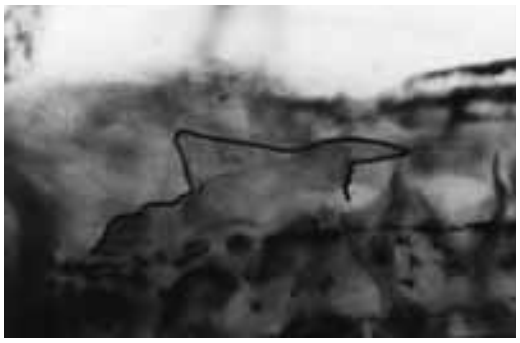
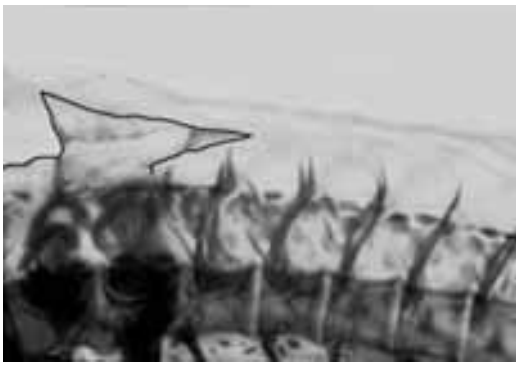


Fig. 45. Selected skeletal features of *Catostomus commersoni* juvenile, 20.4 mm SL, 25.0 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

Fig. 46. Selected skeletal features of *Catostomus commersoni* juvenile, 42.6 mm SL, 52.5 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.





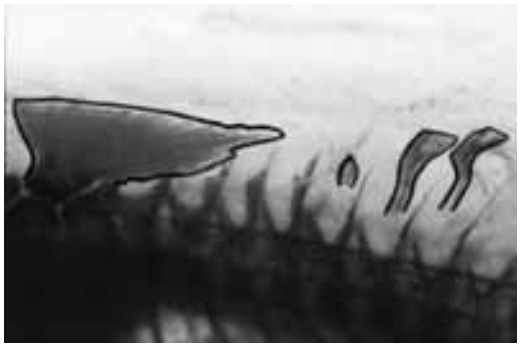
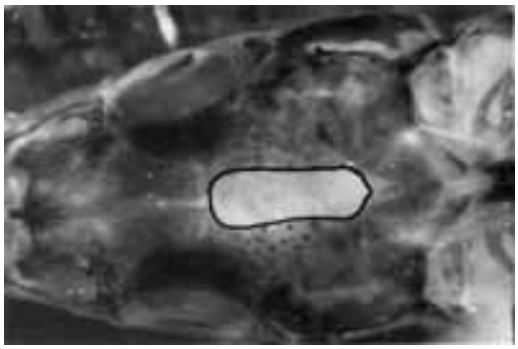


Fig. 47. Interneurals of *Catostomus commersoni*. Top – postflexion mesolarva, 14.7 mm SL, 17.0 mm TL. Middle – juvenile, 20.4 mm SL, 25.0 mm TL. Bottom – juvenile, 42.6 mm SL, 52.5 mm TL.



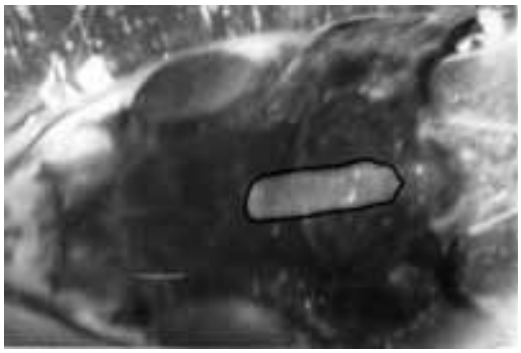


Fig. 48. Frontoparietal fontanelle of *Catostomus commersoni*. Top – juvenile, 28.0 mm SL, 34.8 mm TL. Bottom – juvenile, 39.8 mm SL, 49.0 mm TL.

Table 15. Dimensions of frontoparietal fontanelle for *Catostomus commersoni* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	2	0.8-1.0	2.0-2.2	40-45
20-21	2	0.6-0.8	1.9-2.1	32-38
22-25	1	0.8	2.0	40
26-34	2	0.8-0.8	2.3-2.6	31-35
35-46	1	0.9	3.0	30
76-81	1	0.8	3.1	26

Fig. 49. *Catostomus discobolus* adult (© Joseph R. Tomelleri).

Adult Description: No conspicuous predorsal keel. Caudal peduncle slender to deep, 3.2-10% SL, often correlated with habitat. Mouth inferior and well back. Hard, truncate, cartilaginous ridges along inside of jaws, especially prominent on lower jaw. Lips large with notches at outer corners, papillose except on outer face of upper lip; lower lip with shallow cleft, lobes broadly connected by 3 or more rows of papillae usually concentric with the anterior margin of the lip. Fontanelle typically closed. Pelvic axillary process absent or a simple fold. Interradial membranes of caudal fin well pigmented. Peritoneum black to dusky. TL usually 25-35 cm, up to 40 cm. (Also, Table 16.)

Reproduction: Non-guarding, open-substrate lithophil. May to September, usually June and July, at 15-18°C (sometimes also in fall or winter in Lower Colorado River Basin based on observations of ripe fish and collections of larvae). Water-hardened eggs 3.3-3.5 mm diameter, demersal, initially adhesive.

Young: Later stage protolarvae and mesolarvae drift, predominately at night. Young typically occupy slow, shallow waters, often <0.5 m, near shore and in backwaters; sometimes trapped in cut-off pools or channels. Often associated with juveniles of other species.

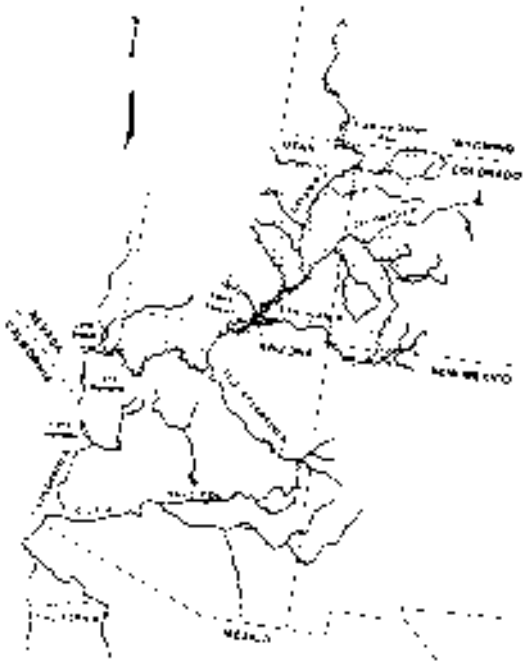


Fig. 50. Recent distribution of *Catostomus discobolus* in Colorado River Basin.

Table 16. Selected juvenile and adult meristics for *Catostomus discobolus*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	(9)10-11(12)	9-10-11-12	Dorsal Fin Rays - R:	2-3	
Anal Fin Rays - P:	7	7(8)	Anal Fin Rays - R:	2(3)	
Caudal Fin Rays - P:	(17)18		Caudal Fin Rays - RD:	(10)11-12	
Pectoral Fin Rays:	14-15-16		Caudal Fin Rays - RV:	9-10(11)	
Pelvic Fin Rays:	8-9-10	(7)8-9-10(11)	Lateral Scales:		(78-)86-115(-122)
Vertebrae:	47-49	45-47-49-50	Gill Rakers:		28-35-44

Table 17. Size at apparent onset of selected developmental events for *Catostomus discobolus*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes in parentheses.

Event or	Onset or Formation		Fin Rays	First Formed		Last Formed	
Structure	mm SL	mm TL	or Scales	mm SL	mm TL	mm SL	mm TL
Hatched:	(8)9-10(11)	(8)9-11	Dorsal - P:	(11-)13(14)	(12-)14(15)	(14)15	(16)17-18
Eyes Pigmented:	9-10 or *	(9)10 or *	Anal - P:	14-15	16-17	(15-)17	(18-)20
Yolk Assimilated:	(10-)12-14	(11)12-14(15)	Caudal - P:	10-12(13)	11-12(13)	(11)12-13(14)	(12)13-14(15)
Finfold Absorbed:	21-22(23)	26-27(28)	Caudal - R:	14	15	19-20	23-25
Pectoral Fin Buds:	(8) or *	(8) or *	Pectoral:	14-15	16-17	16-18(19)	18-21(23)
Pelvic Fin Buds:	14	(15)16	Pelvic:	(15)16	18-19	19-20	23-25
* before hatching			Scales:	28-34	(34)35-42	30-39	36-48

References: Andreasen and Barnes 1975, Baxter and Simon 1970, Baxter and Stone 1995, Beckman 1952, Behnke et al. 1982, Bezzerides and Bestgen 2002, Carlson et al. 1979, Cope 1872, Douglas and Douglas 2000, Holden 1973, Hubbs and Hubbs 1947, Hubbs et al. 1943, Jordan and Evermann 1896, Lee et al. 1980, McAda 1977, Miller 1952, Minckley 1973, Prewitt 1977, Sigler and Miller 1963, Smith 1966, Sublette et al. 1990, Tyus et al. 1982, Vanicek 1967, Wheeler 1997, Woodling 1985.

Table 18. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus discobolus*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	10-12(13)	11-12(13)	2 - 90° bend:	14(15)	15-16(17)
Postflexion Mesolarva:	(11)12-13(14)	(12)13-14(15)	3 - Full loop:	15(16)	17-18
Metalarva:	(15-)17	(18-)20	4 - Partial crossover:	(16)17	18-20
Juvenile:	21-22(23)	26-27(28)	5 - Full crossover:	(16)17-19(-21)	(18)19-23(-25)

Table 19. Summary of morphometrics and myomere counts by developmental phase for *Catostomus discobolus*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=6)		Flexion Mesolarvae (N=7)		Postflexion Mesolarvae (N=16)		Metalarvae (N=22)		Juveniles (N=16)	
	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range
SL, mm:	11 1[f]	10-13	13 1[c]	10-14	14 2[i]	11-17	19 2	17-22	28 6	21-40
TL, mm:	12 1[f]	10-13	13 1[c]	11-15	16 2[i]	12-20	23 2	20-28	34 8	26-50
Lengths %SL:										
AS to AE	2 0	2-2	3 1	2-4	5 1	3-6	7 1	5-8	8 1	6-9
PE	7 0	6-7	9 1	8-10	11 1	9-13	13 1	12-15	14 1	12-16
OP1	14 1	13-15	18 1	17-19	22 2	19-25	25 1	24-27	25 1	23-27
OP2					55 1[b]	53-57	58 2	55-61	58 1	56-60
PY	78 1	77-79	66 12[a]	50-74	58 1[j]	57-59				
OPAF	40 14	29-62	26 5	22-37	32 4	26-40	54 10	42-70		
ODF	34 6	27-43	39 3	36-43	46 2[c]	43-49				
OD					51 1[d]	49-53	52 1	49-54	51 1	47-54
ID					62 1[e]	61-64	64 1	63-66	64 1	62-66
PV	80 0	79-81	77 2	74-79	79 1	76-81	76 1	75-78	75 1	72-76
OA					78 1[f]	76-80	77 1	76-78	76 1	73-77
IA					83 1[f]	82-85	84 1	82-86	83 1	81-84
AFC					110 1[g]	107-112	114 1	112-115	115 1	113-116
PC	104 1	103-104	106 1	105-107	113 3	109-116	121 2	116-124	123 1	120-124
Y	63 3	61-67	22 24[c]	0-53	2 4[i]	0-15				
P1	5 1	3-6	10 1	9-11	12 1	11-13	15 1	13-19	18 1	15-20
P2					2 2	0-5	9 2	5-11	13 1	11-15
D					15 2[b]	11-17	19 1	17-21	21 1	19-23
A					7 1[f]	6-8	11 2	8-13	14 1	12-16
Depths %SL:										
at BPE	8 1	6-9	11 1	9-11	13 2	11-15	15 1	14-16	16 1	14-17
OP1	10 1	9-13	12 1	11-13	15 2	12-17	19 1	16-21	19 1	18-21
OD	14 2	12-17	10 1	9-12	11 3	8-17	17 2	14-20	19 1	16-21
BPV	5 1	4-6	6 0	5-6	7 1	5-8	10 1	9-11	11 1	10-14
AMPM	2 0	2-3	3 0	3-4	5 1	4-6	7 0	6-7	7 0	7-9
Max. Yolk	9 2[f]	6-12	2 3[c]	0-7	0 1[i]	0-2				
Widths %SL:										
at BPE	8 1	6-9	10 0	10-11	12 1	10-14	15 1	14-16	15 1	14-16
OP1	6 1	4-7	8 0	7-9	10 2	8-13	14 1	13-17	16 1	15-18
OD	10 1	8-12	6 0	5-6	7 2	6-10	12 2	9-15	15 1	12-17
BPV	3 1	3-5	4 0	3-5	5 1	4-6	6 1	5-7	8 1	6-9
AMPM	2 0	1-2	2 0	2-2	2 0	1-3	3 0	2-3	3 1	2-4
Max. Yolk	12 2[f]	9-15	3 4[c]	0-8	0 1[i]	0-2				
Myomeres:										
to PY	38 1	37-39	31 8[a]	23-37	24 1[i]	23-24				
OPAF	16 7	10-27	7 4	5-15	8 1	6-12	20 7	11-33		
OP2					23 1[f]	21-25	24 1	20-26	23 1[c]	22-24
ODF	13 3	8-18	15 1	14-18	18 2[e]	15-20				
OD					19 2[h]	17-22	19 1	17-21	18 0[e]	18-19
PV	39 1	39-40	39 1	37-40	39 1	38-39	37 1	35-38	36 1[c]	35-38
Total	48 1	47-48	48 1	47-49	48 0	48-49	47 1	47-48	48 1[c]	47-48
After PV	8 1	8-9	9 1	8-11	10 1	9-10	10 1	9-12	11 1	10-12

[a] N = 5, [b] N = 10, [c] N = 9, [d] N = 14, [e] N = 8, [f] N = 7, [g] N = 15, [h] N = 13, [i] N = 18, [j] N = 2.

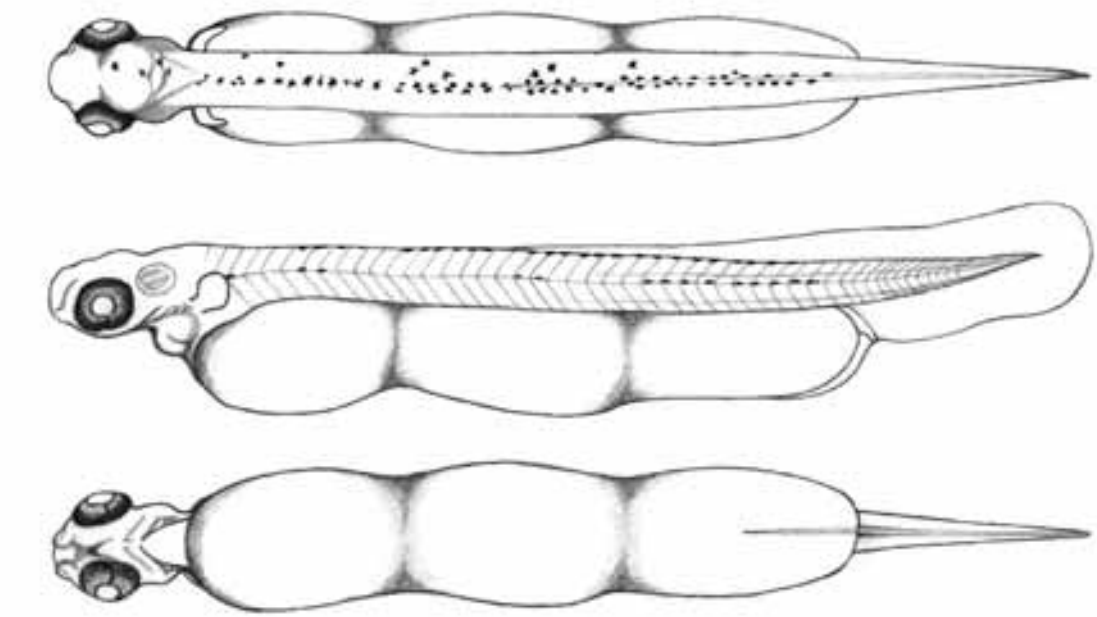


Fig. 51. *Catostomus discobolus* protolarva, recently hatched, 10.5 mm SL, 11.1 mm TL. Cultured in 1978 with stock from the White River, Colorado.

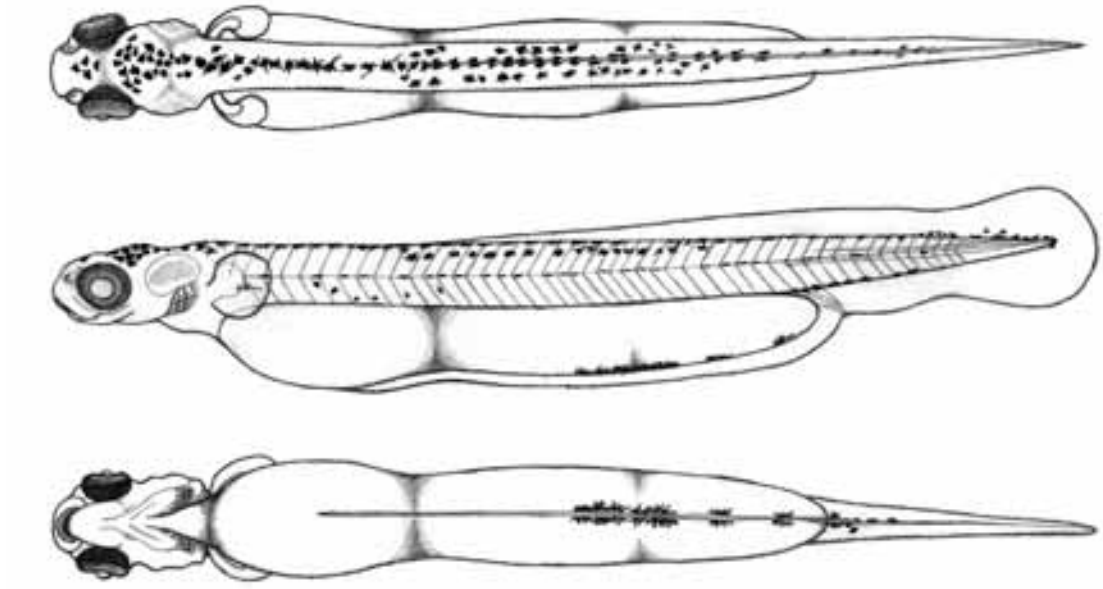


Fig. 52. *Catostomus discobolus* protolarva, 12.0 mm SL, 12.5 mm TL. Cultured in 1978 with stock from the White River, Colorado.

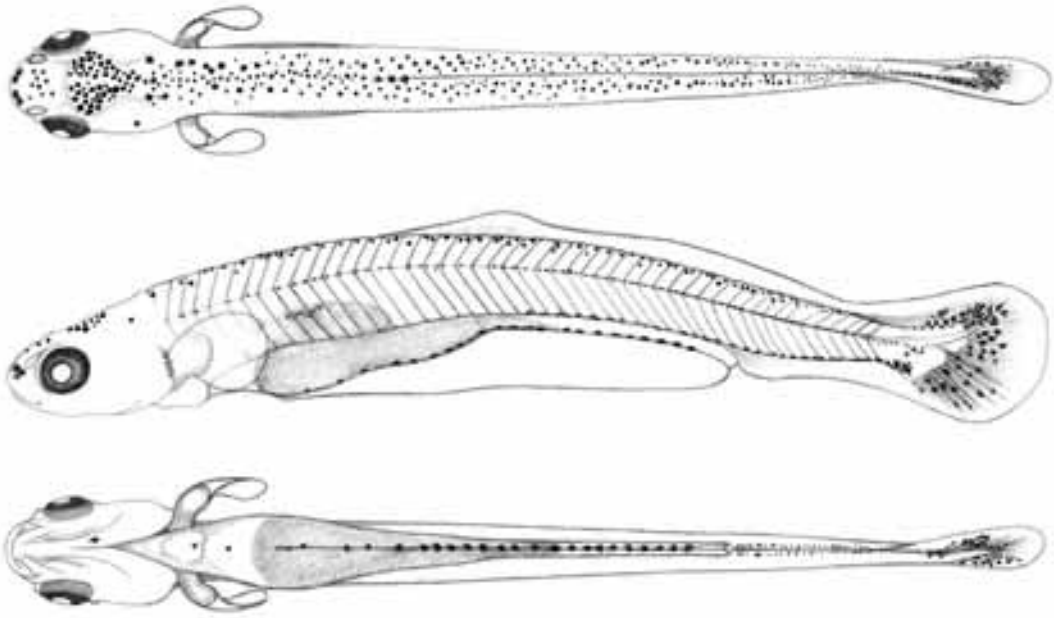


Fig. 53. *Catostomus discobolus* flexion mesolarva, recently transformed, 13.2 mm SL, 14.1 mm TL. Cultured in 1978 with stock from the White River, Colorado.

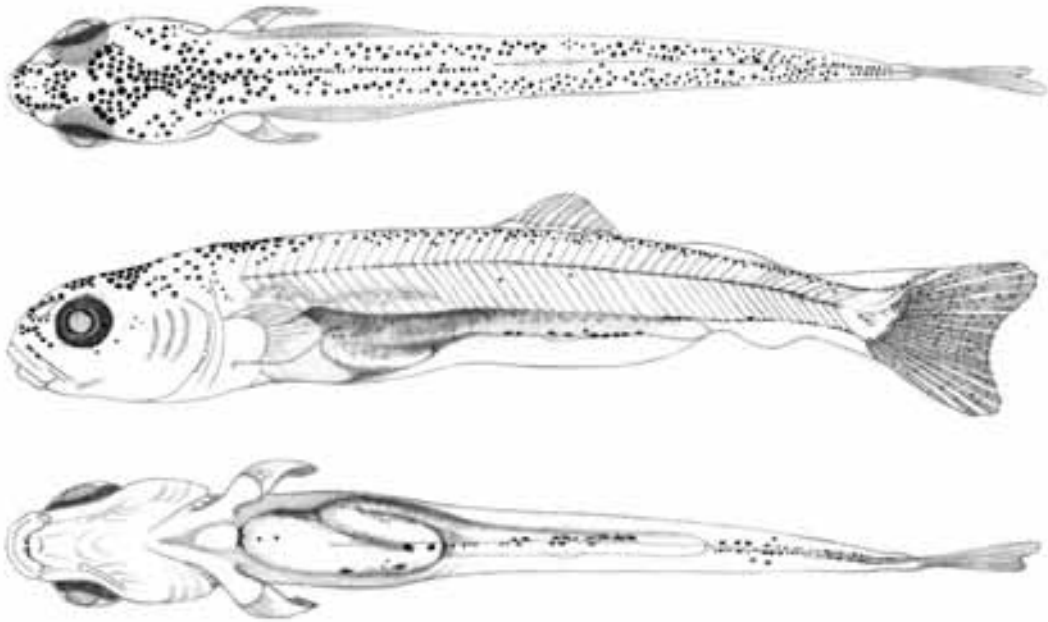


Fig. 54. *Catostomus discobolus* postflexion mesolarva, 14.3 mm SL, 16.4 mm TL. Collected in 1976 with stock from the White River, Colorado.

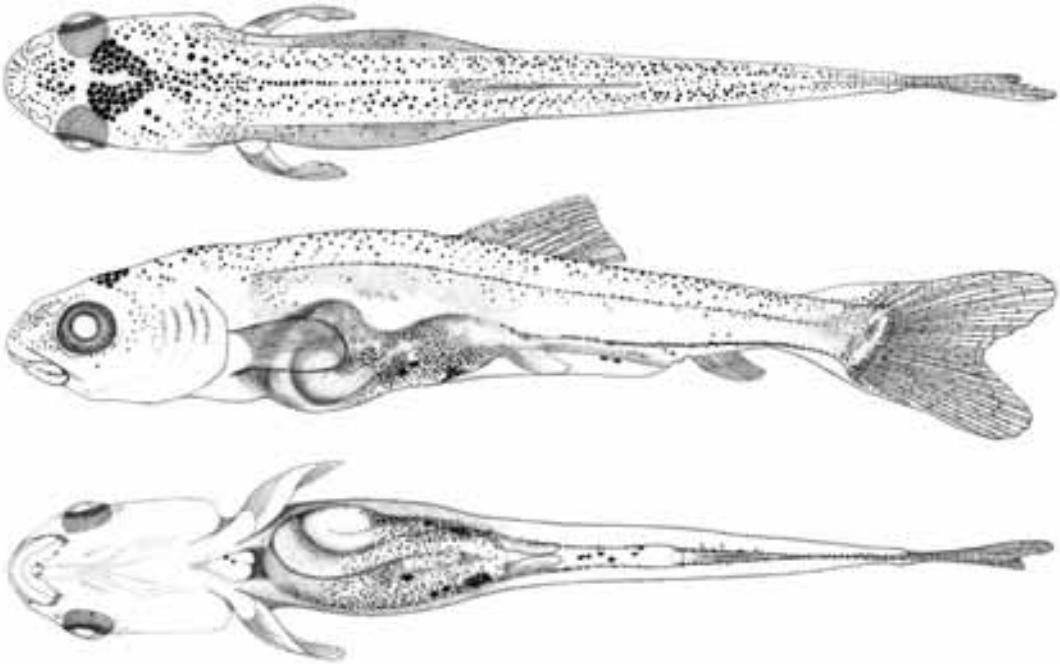


Fig. 55. *Catostomus discobolus* metalarva, recently transformed, 15.4 mm SL, 18.2 mm TL. Collected in 1976 from the White River, Colorado.

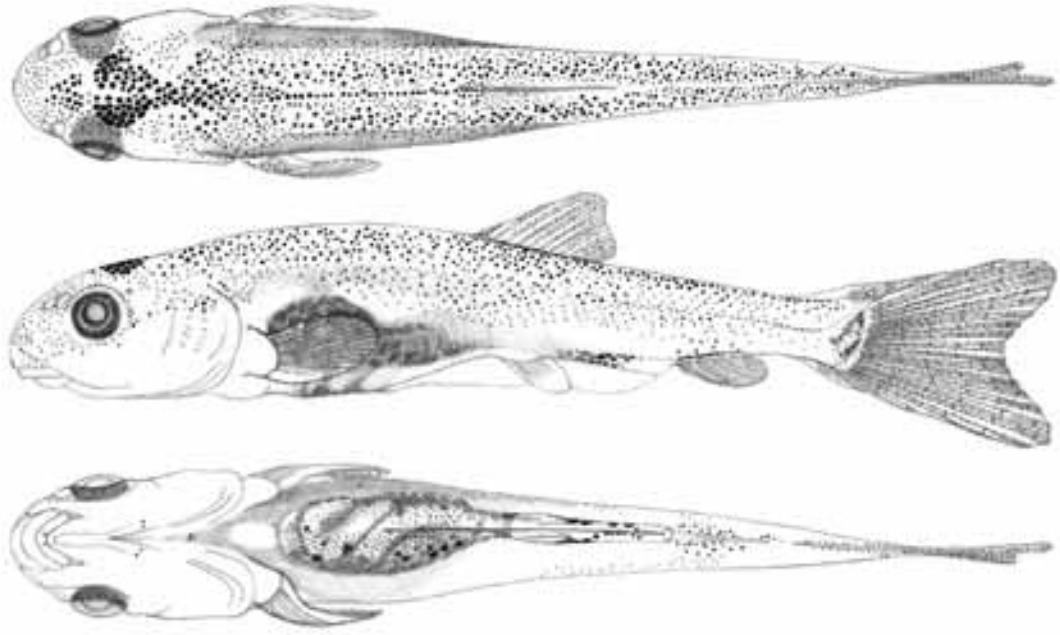


Fig. 56. *Catostomus discobolus* metalarva, 18.1 mm SL, 21.8 mm TL. Collected in 1976 from the White River, Colorado.

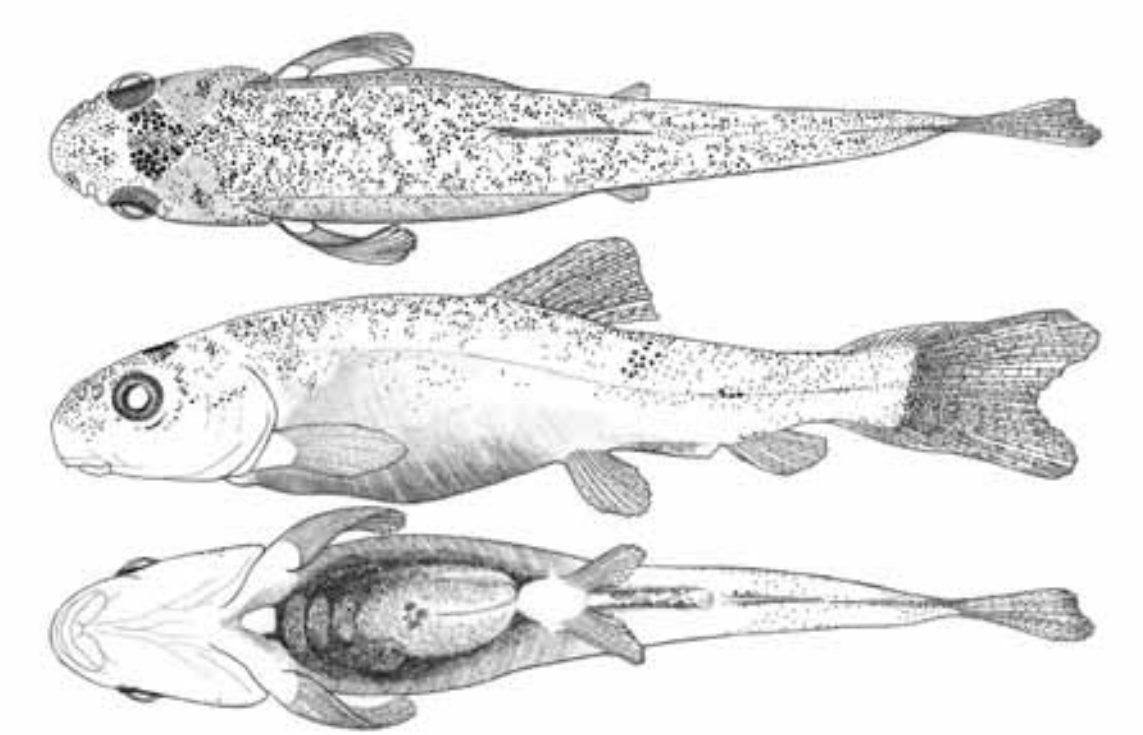


Fig. 57. *Catostomus discobolus* juvenile, recently transformed, 22.7 mm SL, 27.3 mm TL. Collected in 1976 from the White River, Colorado.

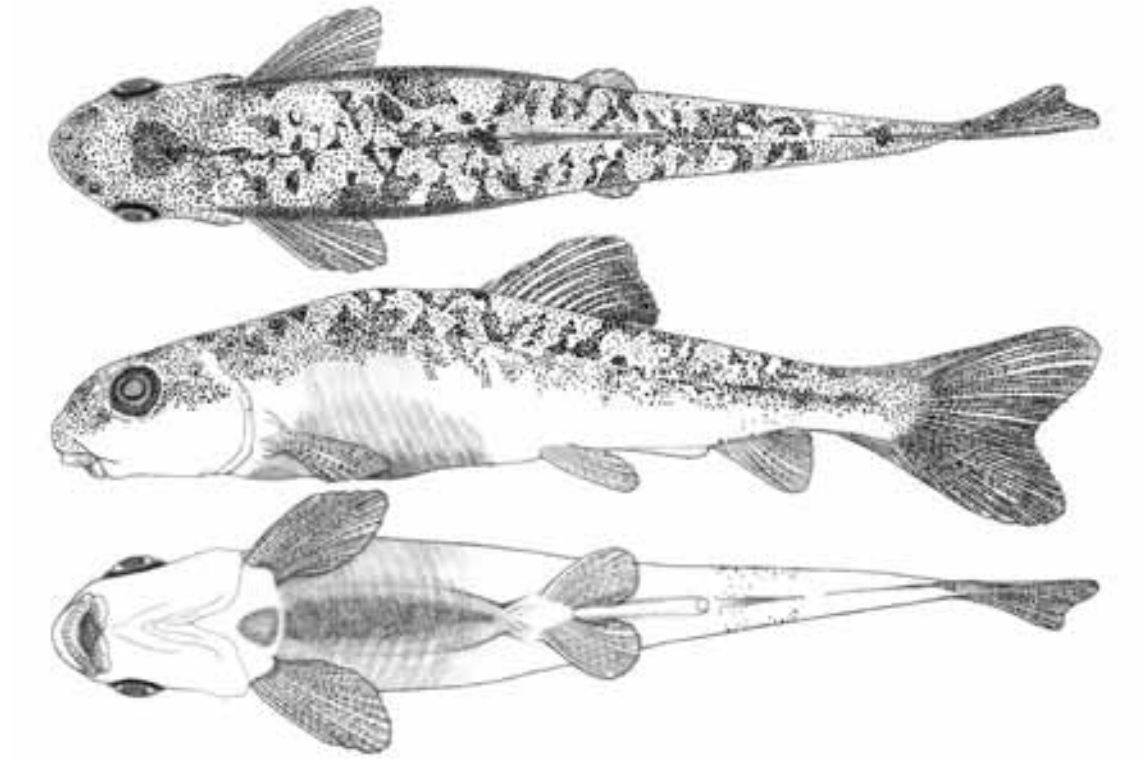


Fig. 58. *Catostomus discobolus* juvenile, 31.8 mm SL, 38.0 mm TL. Collected in 1976 from the White River, Colorado.

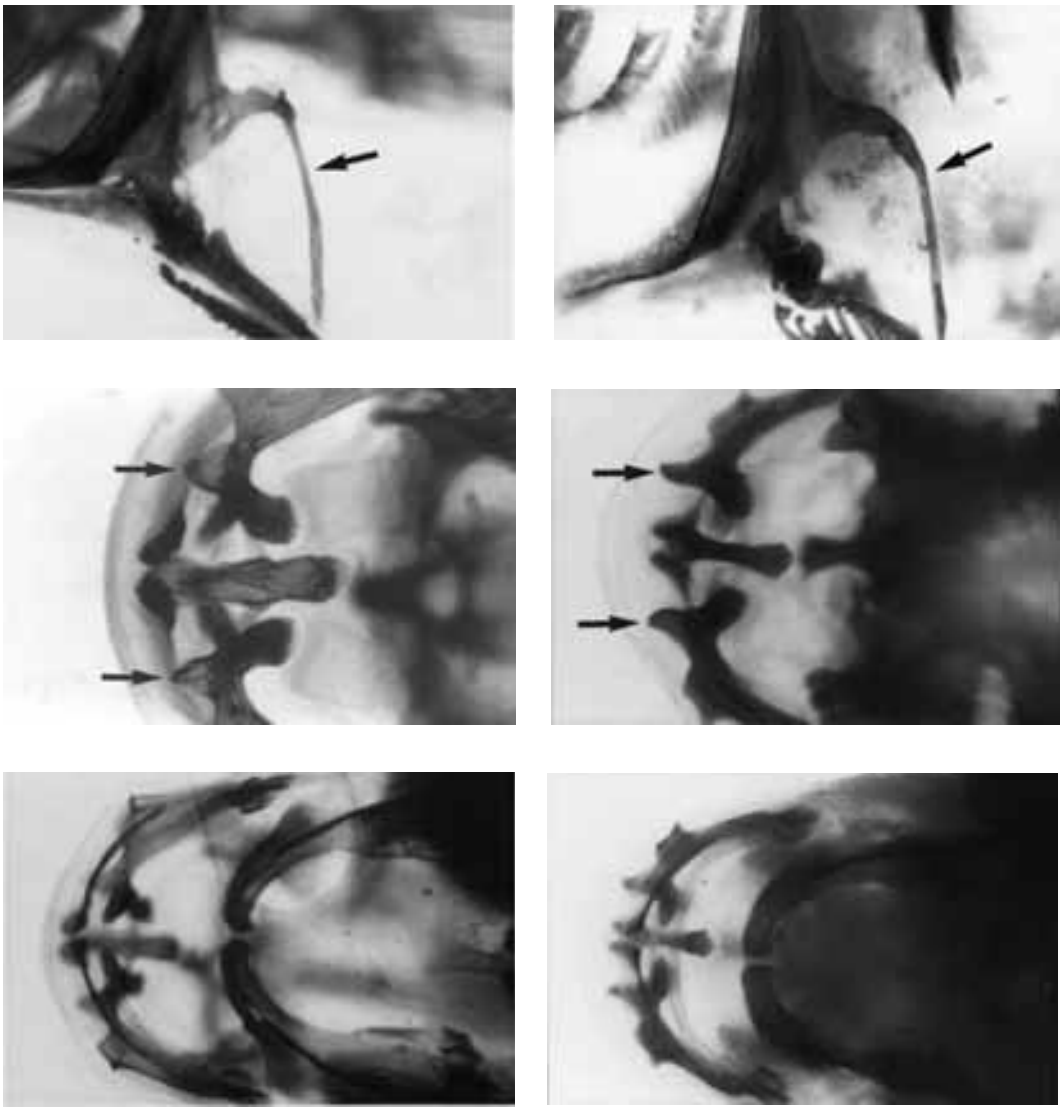
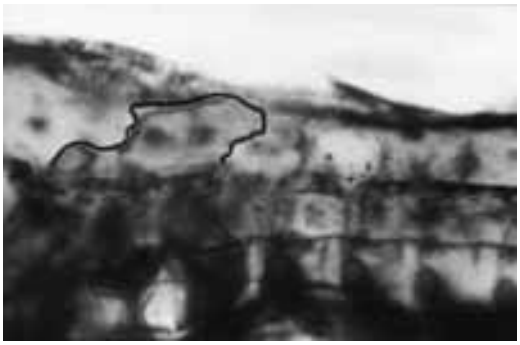
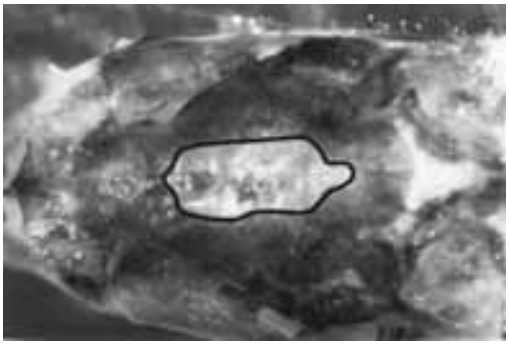
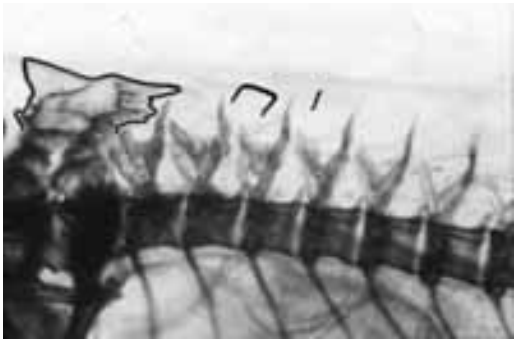


Fig. 59. Selected skeletal features of *Catostomus discobolus* juvenile, 21.8 mm SL, 25.5 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections (similar to and represented here by similar-size *C. platyrhynchus*). Bottom – mandible position.

Fig. 60. Selected skeletal features of *Catostomus discobolus* juvenile, 43.0 mm SL, 52.5 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.







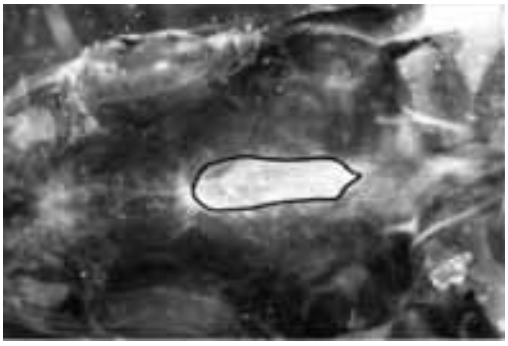


Fig. 62. Frontoparietal fontanelle of *Catostomus discobolus*. Top – juvenile, 27.1 mm SL, 32.5 mm TL. Bottom – juvenile, 32.4 mm SL, 38.5 mm TL.

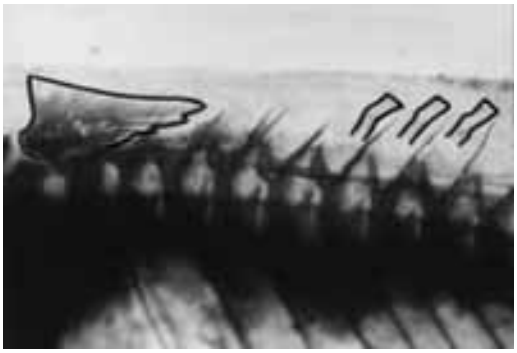


Fig. 61. Interneurals of *Catostomus discobolus*. Top – postflexion mesolarva, 15.3 mm SL, 17.0 mm TL. Middle – metalarva, 21.8 mm SL, 25.5 mm TL. Bottom – juvenile, 43.0 mm SL, 52.5 mm TL.

Table 20. Dimensions of frontoparietal fontanelle for *Catostomus discobolus* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	4	0.6-0.9	1.4-1.8	41-50
20-21	2	0.5-0.9	1.7-1.7	29-35
22-25	3	0.5-0.8	1.3-2.8	29-38
26-34	2	0.6-0.7	2.0-2.2	27-35
35-46	1	0.7	2.7	26
76-81	1	0.7	3.7	19

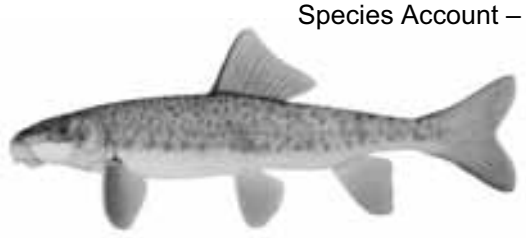


Fig. 63. *Catostomus latipinnis* adult (© Joseph R. Tomelleri).

Adult Description: Back without conspicuous predorsal keel. Caudal peduncle slender, typically ≤6% SL. Mouth inferior, moderate in size; no hard, prominent, cartilaginous ridges along inside of jaws. Lips large, fleshy, profusely papillose, without notches at corners; lower lip with a deep median cleft allowing one or no rows of papillae to span the two lobes; lobes extend beyond vertical from nostrils, often to eyes. Dorsal fin large and falcate. Scales small. Fontanelle present. TL usually 30-40 cm, up to 60 cm. (Also, Table 21.)

Reproduction: Non-guarding, open-substrate lithophil. April to August, mostly May to early July, 6 to at least 13° C (possibly also early fall in Lower Colorado River Basin). Usually over gravel-cobble bars or riffles, or coarse gravel under <1.2 m of water. May or may not migrate to spawning grounds. Water-hardened eggs 3.8-3.9 mm diameter, demersal, initially adhesive.

Young: Larvae, predominately mesolarvae, drift, mostly at night. Young typically occupy slow to quiet and shallow waters along shore and in backwaters or pools; often in the marginal areas of swift-flowing streams; not common in sluggish, very warm areas.

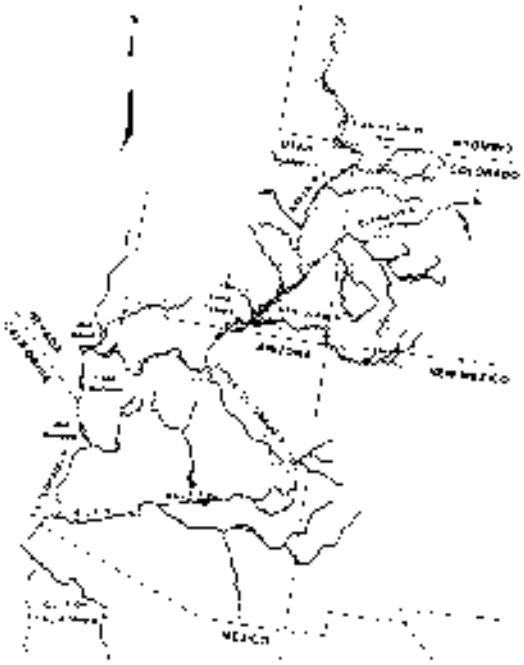


Fig. 64. Recent distribution of *Catostomus latipinnis* in Colorado River Basin.

Table 21. Selected juvenile and adult meristics for *Catostomus latipinnis*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	(11)12-13(14)	(10)11-12-13-14(15)	Dorsal Fin Rays - R:	3-4	
Anal Fin Rays - P:	7	7(8)	Anal Fin Rays - R:	(1)2-3	
Caudal Fin Rays - P:	18		Caudal Fin Rays - RD:	10-11-14	
Pectoral Fin Rays:	15-16-17	18	Caudal Fin Rays - RV:	9-10-11	
Pelvic Fin Rays:	(9)10(11)	9-10-11	Lateral Scales:		89-98-105-116(-120)
Vertebrae:	47-50		Gill Rakers:		25-27-31-32(-35)

Table 22. Size at apparent onset of selected developmental events for *Catostomus latipinnis*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	(8-)10-11	(8-)10-11	Dorsal - P:	15	16	17-18	20-22
Eyes Pigmented:	(9)10 or *	(9)10 or *	Anal - P:	17	18-19	19-20(21)	23-24
Yolk Assimilated:	(14)15(16)	(15)16-17	Caudal - P:	13	13(14)	(14)15(16)	(15)16(17)
Finfold Absorbed:	23-24(25)	28-29(31)	Caudal - R:	(15-)17	(16-)18(19)	23	28-29
Pectoral Fin Buds:	(9) or *	(9) or *	Pectoral:	17	18-19	19-22	22-27
Pelvic Fin Buds:	(15)16(17)	17-18	Pelvic:	17-18	19-20	23	(28)29
* before hatching			Scales:	(36)37-39	(44)45-49	39-42	48-51

References: Baird and Girard 1854, Baxter and Stone 1995, Behnke et al. 1982, Beckman 1952, Bezzerides and Bestgen 2002, Carlson et al. 1979, Douglas and Douglas 2000, Holden 1973, Hubbs and Hubbs 1947, Hubbs and Miller 1953, Hubbs et al. 1943, Jordan and Evermann 1896, Joseph et al. 1977, La Rivers 1962, Lee et al. 1980, McAda 1977, Miller 1952, Minckley 1973, Prewitt 1977, Sigler and Miller 1963, Sublette et al. 1990, Tyus et al. 1982, Wheeler 1997, Woodling 1985. ***Personal communication:*** 2004–G. A. Mueller.

Table 23. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus latipinnis*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	13	13(14)	2 - 90° bend:	(17)18(-20)	(20)21(-24)
Postflexion Mesolarva:	(14)15(16)	(15)16(17)	3 - Full loop:	(19-)21-25(-27)	(23-)26-30(-33)
Metalarva:	19-20(21)	23-24	4 - Partial crossover:	(22)23-32(-37)	(27)28-39(-46)
Juvenile:	23-24(25)	28-29(-31)	5 - Full crossover:	(29-)35-42	(36-)40-51

Table 24. Summary of morphometrics and myomere counts by developmental phase for *Catostomus latipinnis*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=9)		Flexion Mesolarvae (N=10)		Postflexion Mesolarvae (N=20)		Metalarvae (N=15)		Juveniles (N=19)	
	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range	$\bar{x}$ ±SD	Range
SL, mm:	11 1	10-13	14 1	13-15	17 2[m]	14-20	22 1	20-25	32 6	23-43
TL, mm:	12 1	11-13	14 1	14-16	19 3[m]	15-24	27 2[h]	24-31	40 7	29-53
Lengths %SL:										
AS to AE	2 0	2-3	3 1	3-4	6 1	3-7	7 1	6-8	8 1	7-10
PE	7 1	6-9	9 1	8-10	12 1	9-14	13 1	12-14	14 1	13-15
OP1	14 1	12-16	18 1	16-19	23 2	19-27	26 1	24-28	25 1	24-28
OP2					53 1[a]	50-54	55 1	52-57	55 1	52-57
PY	78 2	75-81	69 9	48-75	60 8[b]	50-72				
OPAF	54 19	32-77	26 3	22-32	34 5[c]	27-44	55 11	34-67		
ODF	35 2	33-38	38 2	35-40	44 3[d]	36-48	45 0[i]	45-45		
OD					50 1[a]	49-51	49 1	47-51	48 1	46-49
ID					64 1[e]	62-67	65 1	62-67	65 1	61-66
PV	79 1	77-81	77 1	75-78	78 1	76-80	75 2	74-78	74 1	72-76
OA					78 1[f]	76-80	75 1	74-78	75 1	72-77
IA					84 1[g]	83-84	82 1	81-84	82 1	80-85
AFC					110 2[m]	107-112	113 1	111-114	114 1[j]	112-116
PC	103 1	102-105	105 1	104-107	113 4[m]	107-123	122 2[h]	117-125	123 1	121-125
Y	61 5	54-67	42 17[l]	0-54	7 14[m]	0-46				
P1	6 2	3-9	11 1	9-12	12 1	10-15	16 1	14-18	18 1	16-19
P2					4 2	0-7	11 2	9-13	14 1	11-15
D					18 2[a]	15-21	22 1	20-24	24 1	23-26
A					8 1[d]	5-9	12 2	9-14	14 1	12-16
Depths %SL:										
at BPE	8 1	7-9	10 1	9-11	13 1	11-16	16 1	15-17	16 1	15-17
OP1	9 1	8-10	11 1	10-12	16 2	13-18	19 1	16-21	19 1	17-22
OD	14 1	13-15	11 1	9-13	14 3[e]	10-19	19 2	16-22	19 1	17-22
BPV	5 1	4-6	6 0	5-6	8 1	6-10	11 1	9-12	11 1	10-13
AMPM	3 1	2-3	3 0	3-4	6 1	4-7	7 0	6-8	7 0	7-8
Max. Yolk	12 3	9-16	5 3[l]	0-9	0 1[m]	0-3				
Widths %SL:										
at BPE	8 1	6-9	10 1	9-12	13 1	10-15	16 1	14-17	15 1	15-17
OP1	7 1	6-9	7 1	6-8	11 1	8-13	14 1	13-16	16 1	14-17
OD	10 1	7-11	6 1	5-8	8 2	6-12	12 1	10-15	13 2	11-17
BPV	3 0	3-4	4 1	4-6	6 1	4-8	7 1	6-8	8 1	6-9
AMPM	2 0	1-2	2 0	1-2	3 0	2-3	4 0	3-4	4 0	3-5
Max. Yolk	13 3	9-18	5 3[l]	0-9	1 2[m]	0-5				
Myomeres:										
to PY	38 1	37-39	34 5	22-38	28 6[b]	21-35				
OPAF	23 11	10-37	7 2	5-10	9 3[c]	6-15	22 8[e]	9-32		
OP2					21 1[a]	19-23	22 1[e]	21-24	22 1[k]	21-23
ODF	12 2	10-15	13 1	12-15	15 1[h]	12-17	15 1[i]	14-15		
OD					18 1[a]	17-21	18 1[e]	16-19	18 1[k]	17-19
PV	39 1	38-40	39 1	38-40	39 1	37-40	37 1[e]	36-38	37 1[k]	36-38
Total	48 1	47-49	48 1	47-49	48 1	47-49	47 1[e]	46-48	48 1[k]	47-48
After PV	9 1	8-10	9 1	8-11	9 1	8-10	10 0[e]	9-10	11 1[k]	9-12

[a] N = 17, [b] N = 6, [c] N = 19, [d] N = 12, [e] N = 14, [f] N = 15, [g] N = 7, [h] N = 13, [i] N = 2, [j] N = 18, [k] N = 9, [l] N = 11, [m] N = 25.

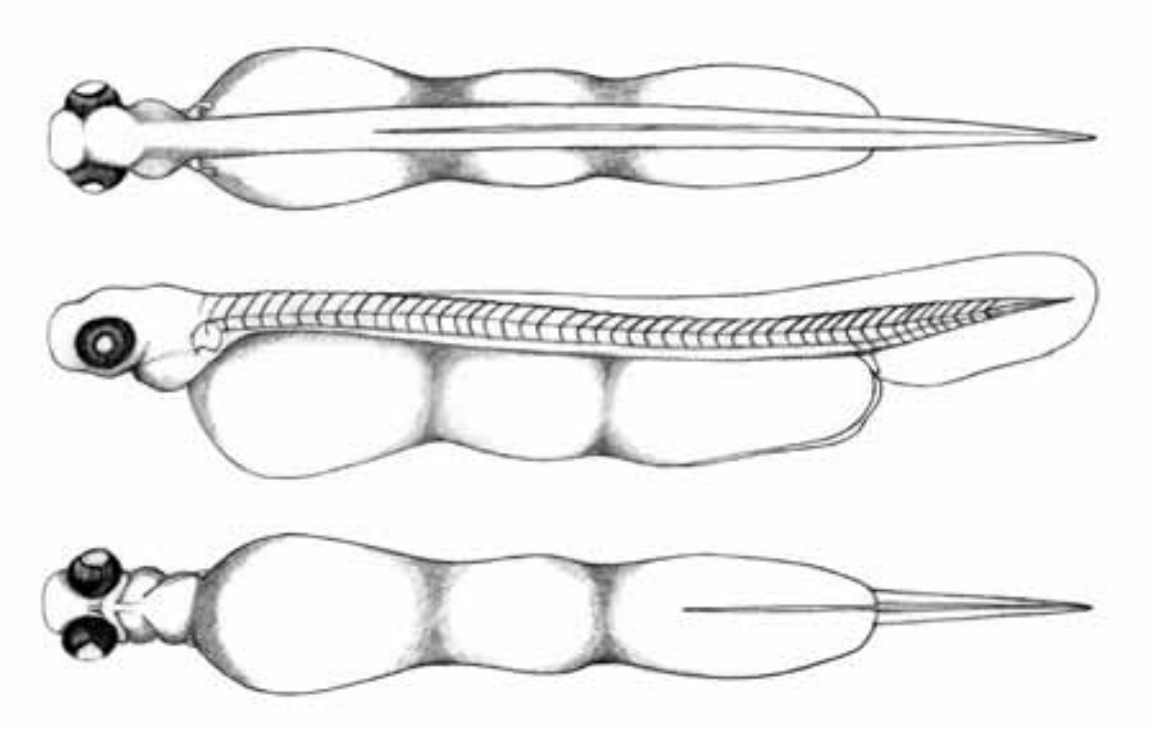


Fig. 65. *Catostomus latipinnis* protolarva, recently hatched, 10.3 mm SL, 10.6 mm TL. Cultured in 1978 with stock from the Yampa River, Colorado.

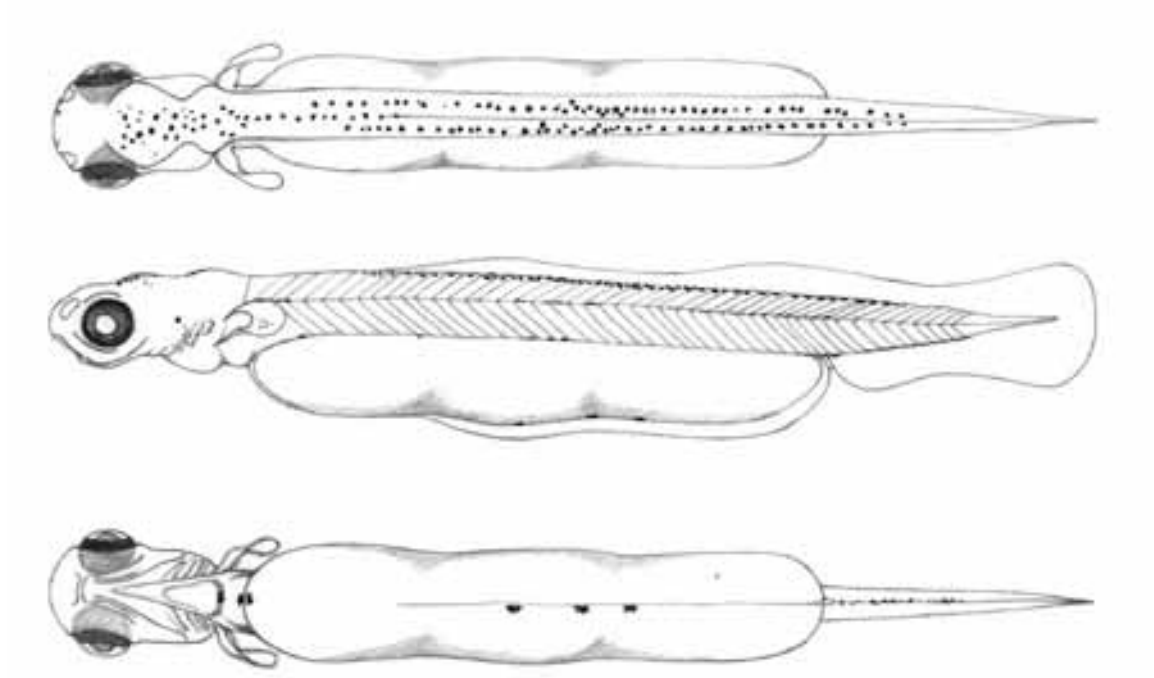


Fig. 66. *Catostomus latipinnis* protolarva, 12.4 mm SL, 12.9 mm TL. Cultured in 1978 with stock from the Yampa River, Colorado.

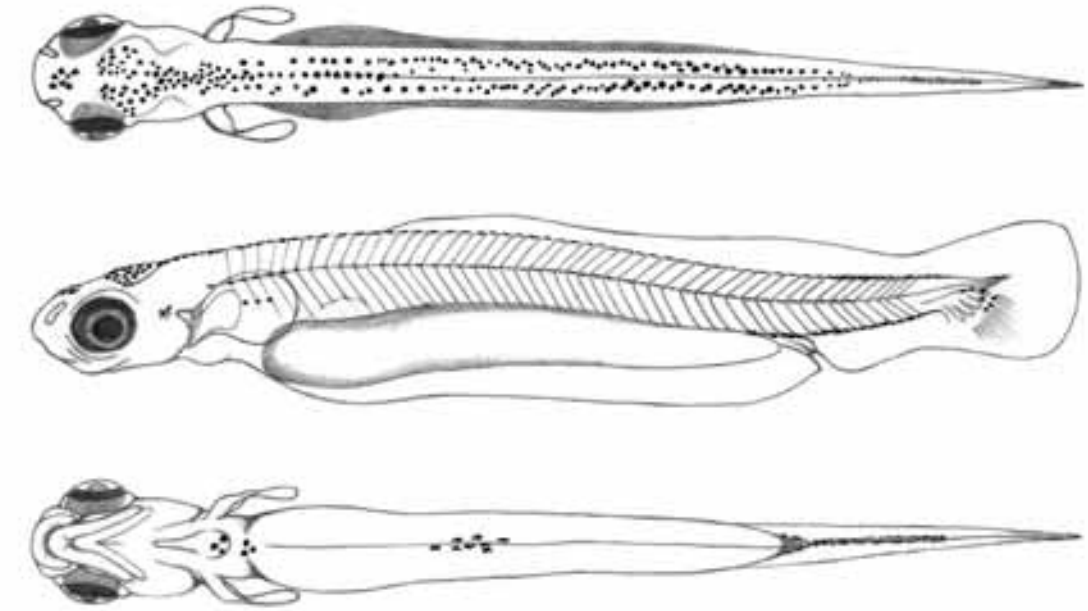


Fig. 67. *Catostomus latipinnis* flexion mesolarva, recently transformed, 13.0 mm SL, 14.0 mm TL. Cultured in 1978 with stock from the Yampa River, Colorado.

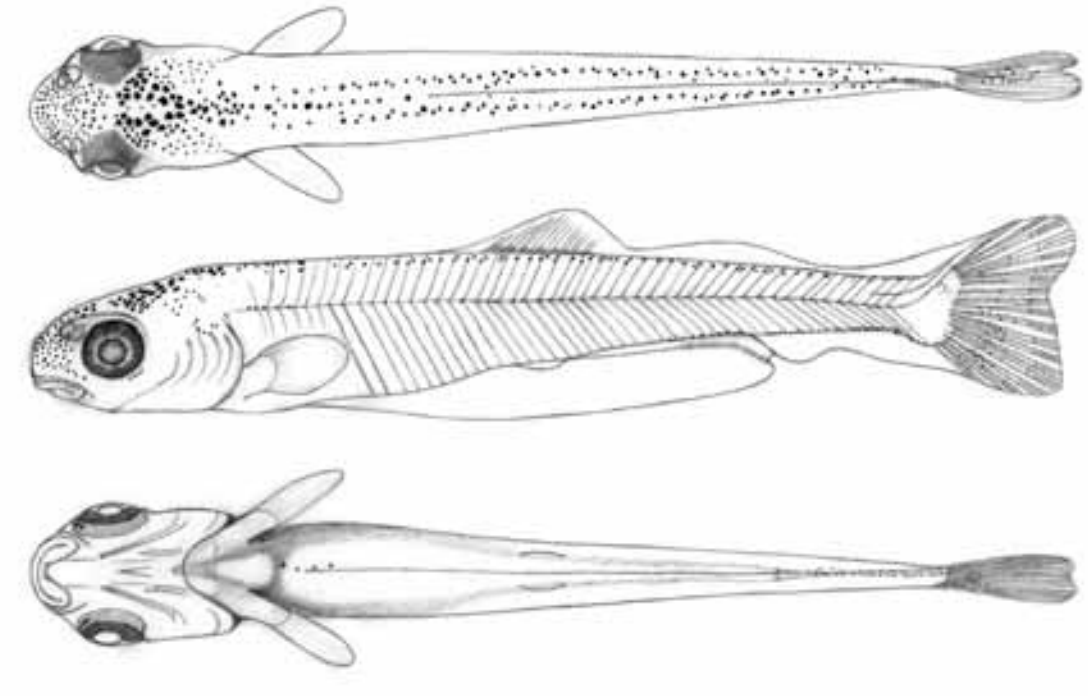


Fig. 68. *Catostomus latipinnis* postflexion mesolarva, 16.8 mm SL, 18.9 mm TL. Cultured in 1976 from the White River, Colorado.

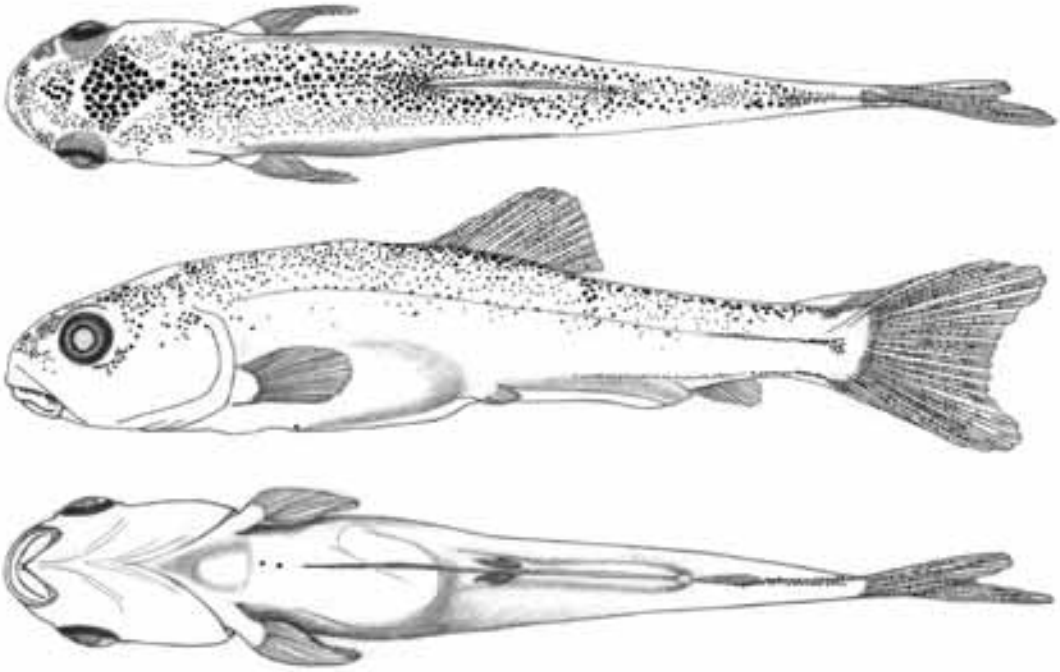


Fig. 69. *Catostomus latipinnis* metalarva, recently transformed, 20.5 mm SL, 24.5 mm TL. Collected in 1976 from the White River, Colorado.

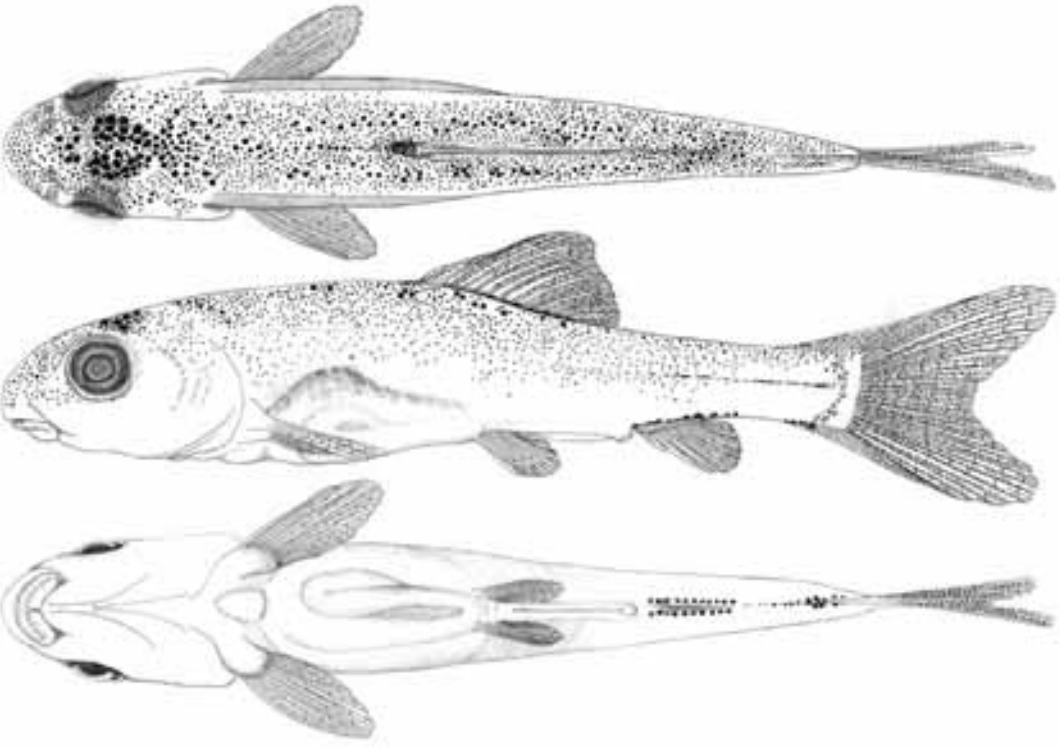


Fig. 70. *Catostomus latipinnis* metalarva, 22.7 mm SL, 27.5 mm TL. Collected in 1976 from the White River, Colorado.

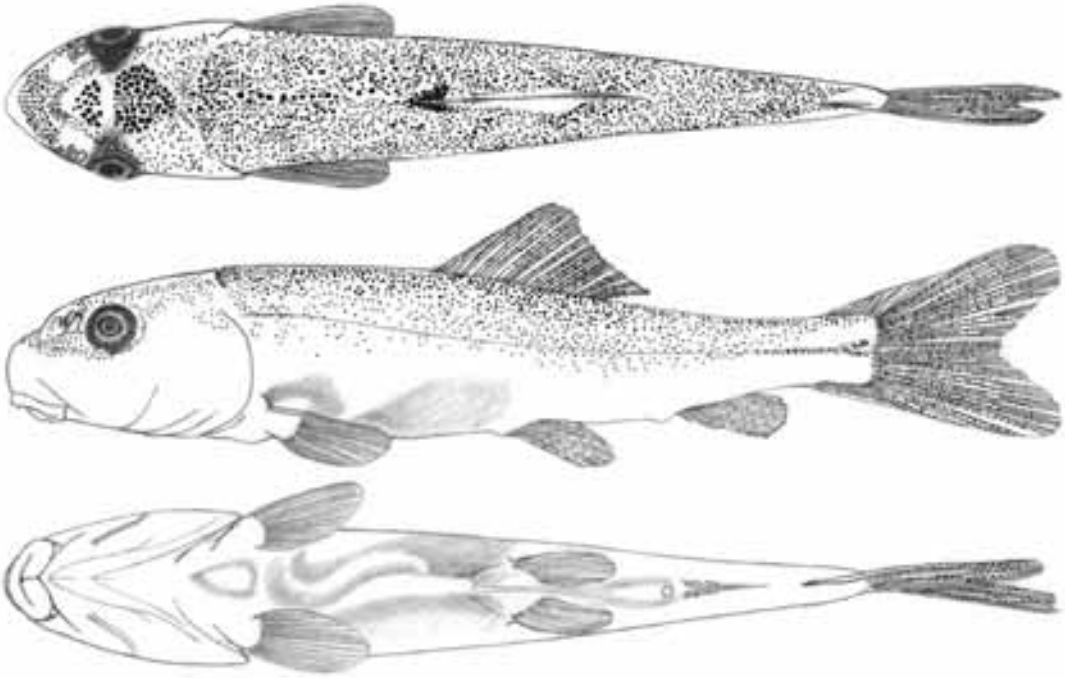


Fig. 71. *Catostomus latipinnis* juvenile, recently transformed, 26.6 mm SL, 32.0 mm TL. Collected in 1976 from the White River, Colorado.

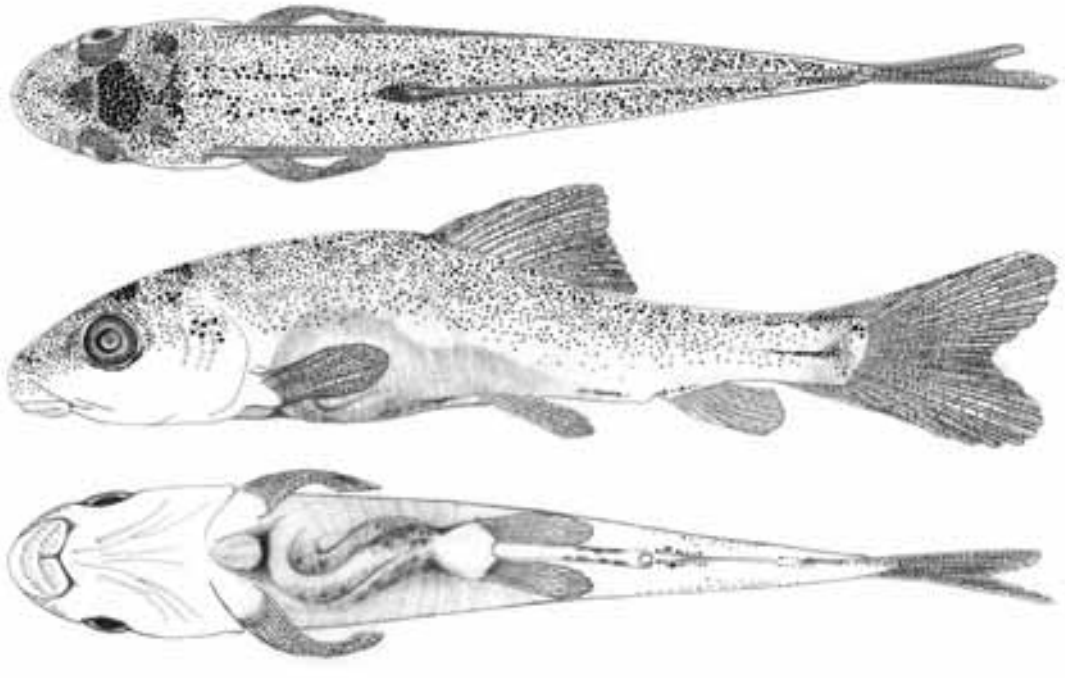


Fig. 72. *Catostomus latipinnis* juvenile, 31.6 mm SL, 38.0 mm TL. Collected in 1976 from the White River, Colorado.

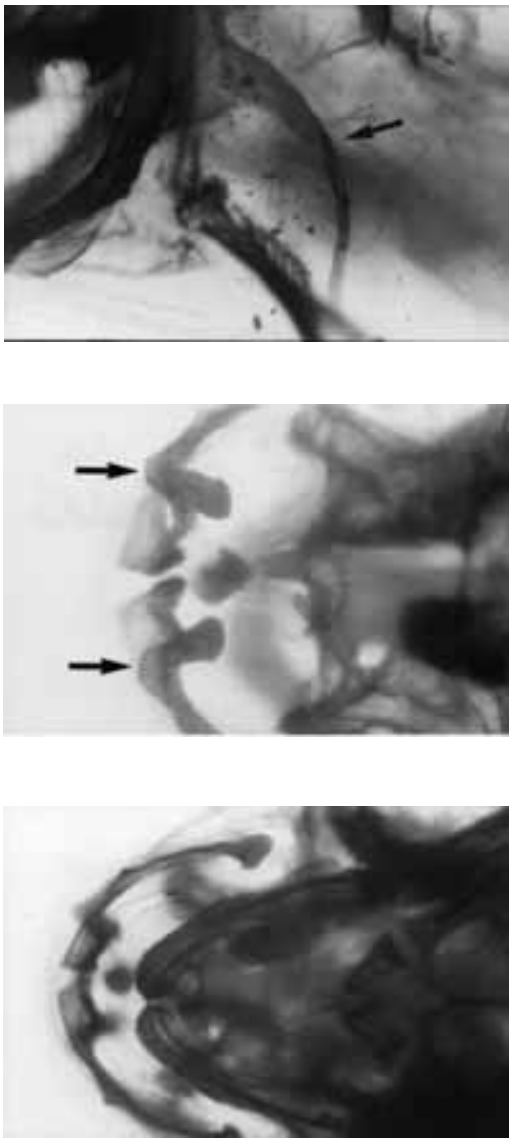


Fig. 73. Selected skeletal features of *Catostomus latipinnis* metalarva, 24.6 mm SL, 29.0 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

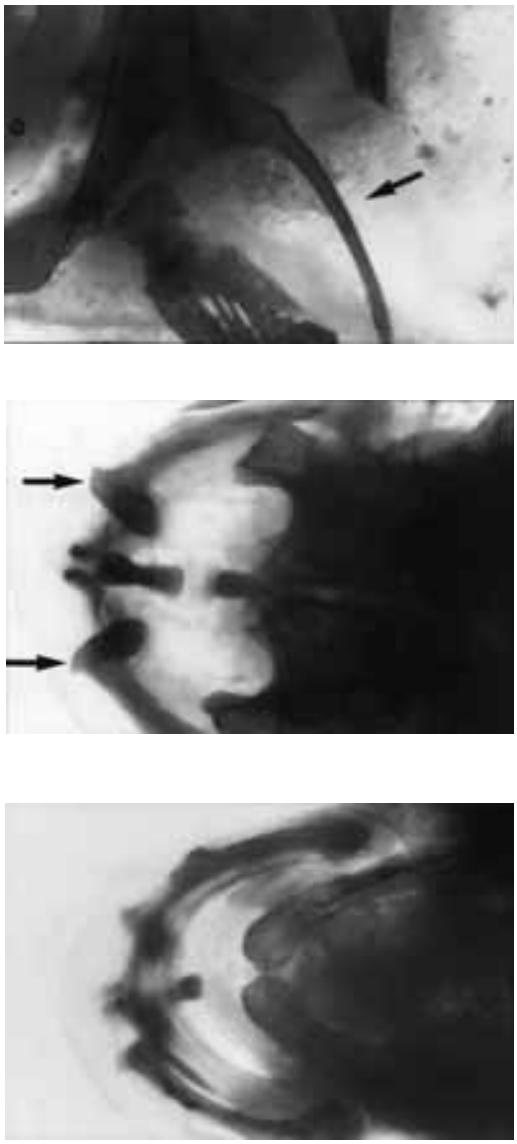
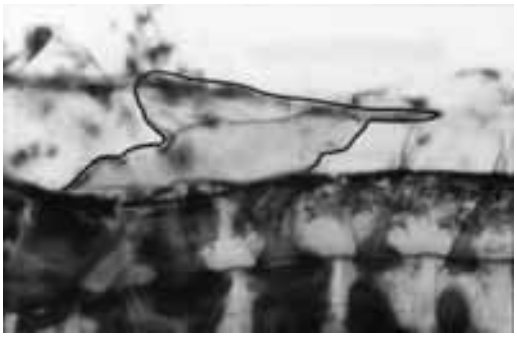


Fig. 74. Selected skeletal features of *Catostomus latipinnis* juvenile, 42.1 mm SL, 52.0 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.



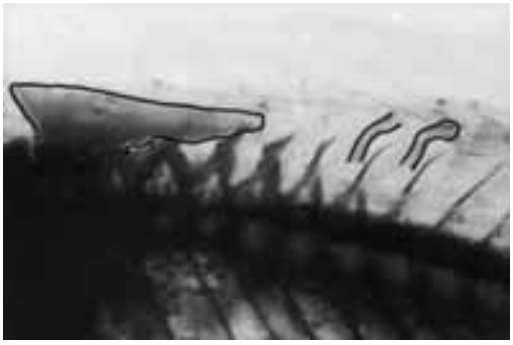
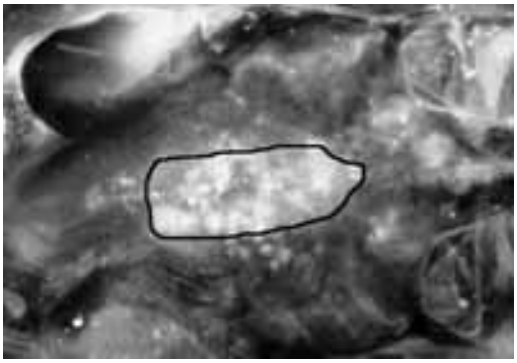


Fig. 75. Interneurals of *Catostomus latipinnis*. Top – postflexion mesolarva, 14.7 mm SL, 17.0 mm TL. Middle – metalarva, 24.6 mm SL, 29.0 mm TL. Bottom – juvenile, 42.1 mm SL, 52.0 mm TL.



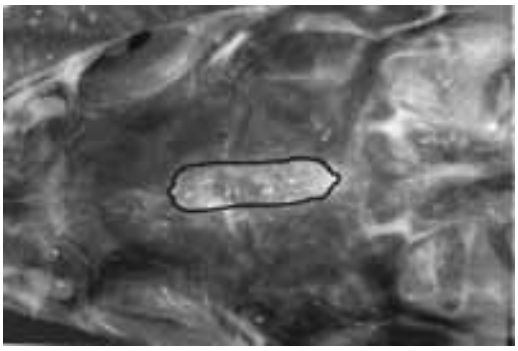


Fig. 76. Frontoparietal fontanelle of *Catostomus latipinnis*. Top – metalarva, 24.6 mm SL, 29.0 mm TL. Bottom – juvenile, 33.1 mm SL, 41.0 mm TL.

Table 25. Dimensions of frontoparietal fontanelle for *Catostomus latipinnis* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	3	0.8-1.2	1.2-2.0	50-67
20-21	3	0.6-0.7	1.8-2.0	33-35
22-25	3	0.8-0.8	1.8-2.1	38-44
26-34	2	0.7-0.8	2.2-2.3	30-36
35-46	1	0.7	2.3	30
76-81	1	1.0	4.0	25

Fig. 77. *Catostomus platyrhynchus* adult (© Joseph R. Tomelleri).

Adult Description: Back without conspicuous predorsal keel. Caudal peduncle deep, 8-10% SL. Mouth inferior and well back. Lips large with notches at outer corners, papillose except on outer face of upper lip and anterolateral corners of lower lip; lower lip with shallow cleft, lobes broadly connected by 3-5 rows of papillae in a convex arch. Prominent, truncate cartilaginous ridge on anterior margin of lower jaw. Fontanelle narrow, rarely closed. Pelvic axillary process well developed. Interradial membranes of caudal fin with little or no pigment. Peritoneum black to dusky. TL up to 25 cm. (Also, Table 26.)

Reproduction: Non-guarding, open-substrate lithophil. Short period during May to mid August, 11-19°C. Resident or tributary streams over gravel riffles, often adjacent to pools of swift mountain streams. Water-hardened eggs 2.3-2.7 mm diameter, demersal, initially adhesive.

Young: Hatch in 7-8 days at about 18°C. Young in streams, occasionally drift into lakes; often found in cover in shallow water of moderate current. Larger young often associated with aquatic plants in quiet backwaters, pools, eddies and intermittent side channels. Specimens <30 mm TL feed largely on invertebrates.

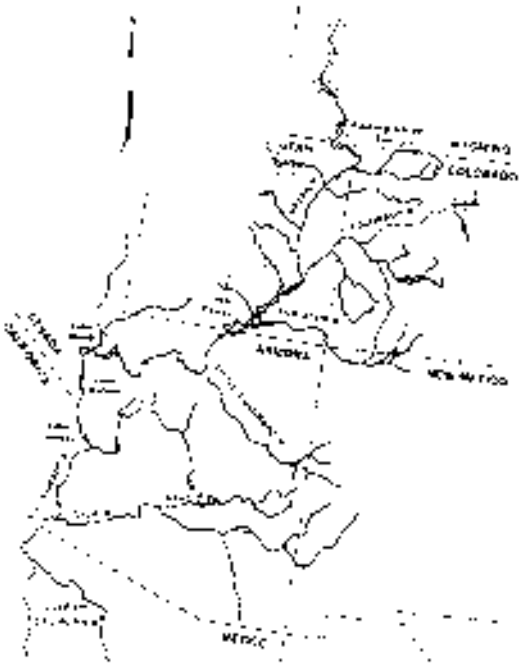


Fig. 78. Recent distribution of *Catostomus platyrhynchus* in Colorado River Basin.

Table 26. Selected juvenile and adult meristics for *Catostomus platyrhynchus*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	9-10-11	(8)9-10-12(13)	Dorsal Fin Rays - R:	(1)2-4	
Anal Fin Rays - P:	(6)7	7	Anal Fin Rays - R:	2-3	
Caudal Fin Rays - P:	(17)18		Caudal Fin Rays - RD:	(9-)11-12	
Pectoral Fin Rays:	14-15-16	15	Caudal Fin Rays - RV:	(7)8-9(11)	
Pelvic Fin Rays:	9-10	8-9-10	Lateral Scales:	76-86	(60-)75-97(-108)
Vertebrae:	46-48(50)	42-44-47(48)	Gill Rakers:		23-37

Table 27. Size at apparent onset of selected developmental events for *Catostomus platyrhynchus*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	(7)8	(7)8	Dorsal - P:	13	14	14-17	16-19
Eyes Pigmented:	8	8	Anal - P:	14-15	16-17	16-17	18-19
Yolk Assimilated:	(10)11	(10)11-12	Caudal - P:	11	11-12	13-14	15
Finfold Absorbed:	21-22	25-27	Caudal - R:	14	15-16	20-21	24-25
Pectoral Fin Buds:	(7) or *	(7) or *	Pectoral:	13-15	15-17	18-20	22-23
Pelvic Fin Buds:	13	14-15	Pelvic:	16	18	18-20	22-23
* before hatching			Scales:	23-24	28-30	32-38	38-45

References: Baxter and Simon 1970, Baxter and Stone 1995, Beckman 1952, Behnke et al. 1982, Cope 1872, Hauser 1969, Hubbs et al. 1943, Jordan and Evermann 1896, Lee et al. 1980, Moyle 1976, Rutter 1903, Scott and Crossman 1973, Sigler and Miller 1963, Sigler and Sigler 1987, Simpson and Wallace 1978, Smith 1966, Tyus et al. 1982, Wheeler 1997, Woodling 1985, Wydoski and Whitney 1979.

Table 28. Size at developmental interval (left) and gut phase (right) transitions for *Catostomus platyrhynchus*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	11	11-12	2 - 90° bend:	14-17	16-19
Postflexion Mesolarva:	13-14	15	3 - Full loop:	16-17	18-21
Metalarva:	16-17	18-19	4 - Partial crossover:	18-20	22-24
Juvenile:	21-22	25-27	5 - Full crossover:	21-23	25-28

Table 29. Summary of morphometrics and myomere counts by developmental phase for *Catostomus platyrhynchus*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=12)			Flexion Mesolarvae (N=9)			Postflexion Mesolarvae (N=11)			Metalarvae (N=9)			Juveniles (N=8)		
	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range	$\bar{x}$	±SD	Range
SL, mm:	10	1	8-11	12	1	11-14	15	1	13-17	19	2	16-22	28	6	21-38
TL, mm:	10	1	8-12	13	1	11-15	16	1	15-19	22	3	18-27	34	7	25-45
Lengths %SL:															
AS to AE	2	0	1-3	3	1	2-4	5	1	4-6	7	1	6-8	8	1	7-9
PE	9	1	8-10	9	1	8-11	12	1	10-13	13	1	12-14	14	1	13-15
OP1	17	1	16-18	19	1	17-21	23	2	20-26	25	1	23-26	25	1	24-26
OP2				54	1[c]	53-54	54	1	52-56	56	2	53-58	57	2	55-60
PY	73	5[a]	62-80	51	1[c]	50-52									
OPAF	32	14	25-73	28	2	26-31	35	4	30-44	50	12	35-68			
ODF	40	3	36-46	41	2	38-43	44	2[e]	41-47	49	[f]	49-49			
OD				50	0[c]	50-50	50	1	49-52	51	1	50-53	50	1	48-52
ID							62	1[b]	61-64	63	1	62-65	63	1	60-64
PV	78	2	75-81	77	1	75-78	79	1	77-80	77	1	75-78	75	1	74-78
OA							79	1[d]	77-79	77	1	76-78	76	1	74-78
IA							83	[f]	83-83	84	1	82-85	84	1	83-85
AFC							111	1	109-114	113	2	110-115	115	1	114-117
PC	104	1	101-106	107	1	105-109	113	2	110-118	118	2	115-120	121	1	119-123
Y	47	17	0-67	3	6	0-14									
P1	9	3	2-11	11	1	10-13	12	1	11-14	14	1	12-16	18	1	15-19
P2				0	0	0-0[h]	4	2	1-8	8	1	6-11	12	1	10-13
D							13	1[e]	11-15	17	1	15-19	20	1	18-21
A							8	1[c]	7-8	10	2	8-13	14	1	12-15
Depths %SL:															
at BPE	11	1	9-12	12	1	11-13	15	1	14-16	16	0	15-16	16	1	15-17
OP1	11	1	10-12	14	1	12-15	17	1	15-18	18	1	16-20	20	1	17-21
OD	12	1[b]	10-14	11	1[b]	10-12	13	1[g]	12-16	17	1	15-19	20	1	18-21
BPV	6	1	3-7	7	0	6-7	8	1	7-9	10	1	9-12	13	1	11-14
AMPM	3	1	2-4	4	0	4-5	6	1	5-6	7	1	6-8	9	0	8-9
Max. Yolk	5	4	0-13	0	1	0-1									
Widths %SL:															
at BPE	10	1	8-11	11	1	10-13	14	1	13-16	15	1	14-16	16	1	15-17
OP1	7	2	6-12	9	1	8-10	12	1	11-13	14	1	13-16	17	1	14-18
OD	8	2[b]	6-11	6	1[b]	5-7	8	1[g]	7-10	12	1	10-14	15	1	13-17
BPV	4	0	3-4	4	0	4-4	5	1	4-5	7	1	6-9	9	1	8-10
AMPM	2	0	2-3	2	0	2-3	3	0	3-4	4	1	3-4	4	0	4-5
Max. Yolk	6	5	0-14	0	1	0-2									
Myomeres:															
to PY	33	3[a]	26-35	23	1[c]	22-23									
OPAF	10	7	5-29	7	1	6-9	9	2	7-13	18	7	9-28			
OP2				21	1[c]	20-21	21	1	19-22	21	1	20-22	22	0[d]	21-22
ODF	14	1	12-16	14	1	13-16	15	1[e]	13-17	15	[f]	15-15			
OD				19	1[c]	18-19	19	1	17-19	18	1	16-19	18	1[d]	17-18
PV	36	1	35-37	36	1	35-37	36	1	34-37	35	1	32-36	34	1[d]	34-35
Total	45	1	44-46	46	1	44-47	45	1	43-46	45	1	43-45	45	1[d]	44-45
After PV	9	1	8-10	10	1	8-11	9	1	7-10	10	1	9-12	10	0[d]	10-11

[a] N = 11, [b] N = 5, [c] N = 2, [d] N = 6, [e] N = 9, [f] N = 1, [g] N = 10, [h] <0.5%.

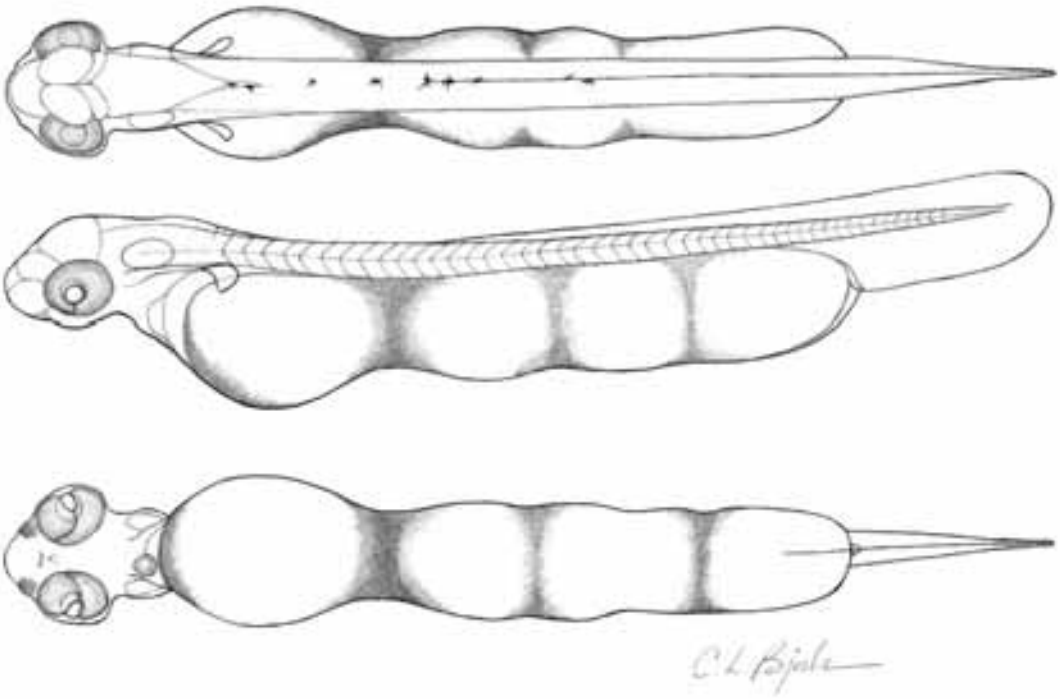


Fig. 79. *Catostomus platyrhynchus* protolarva, recently hatched, 8.1 mm SL, 8.3 mm TL (from Snyder 1983a). Cultured in 1981 with stock from Willow Creek, northwest of Steamboat Springs, Colorado.

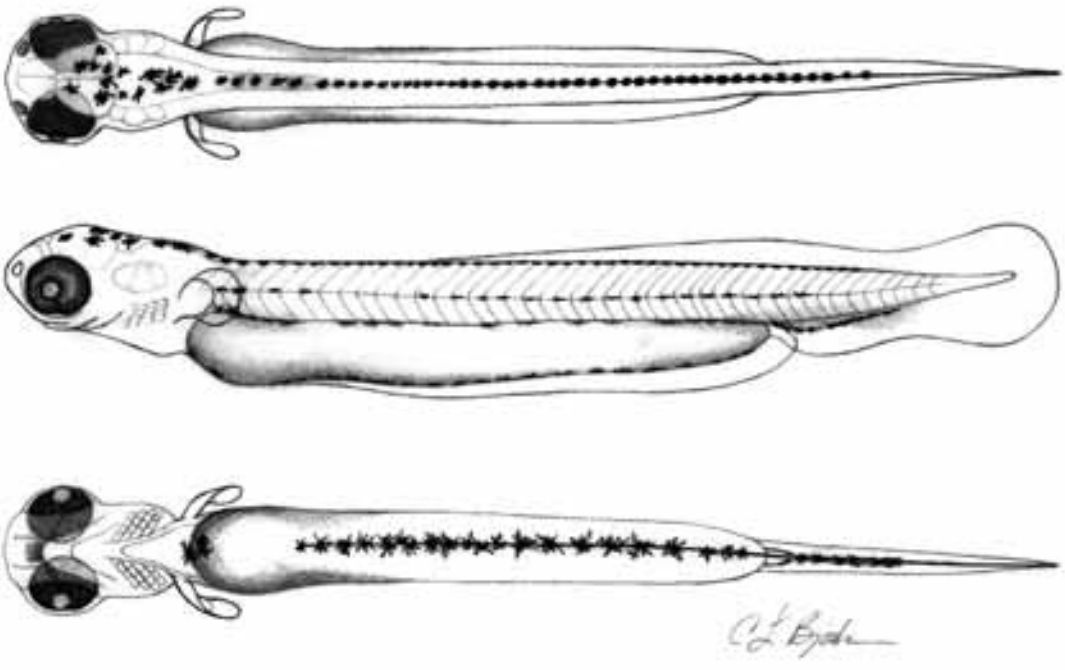


Fig. 80. *Catostomus platyrhynchus* protolarva, 9.5 mm SL, 9.8 mm TL (from Snyder 1983a). Cultured in 1981 with stock from Willow Creek, northwest of Steamboat Springs, Colorado.

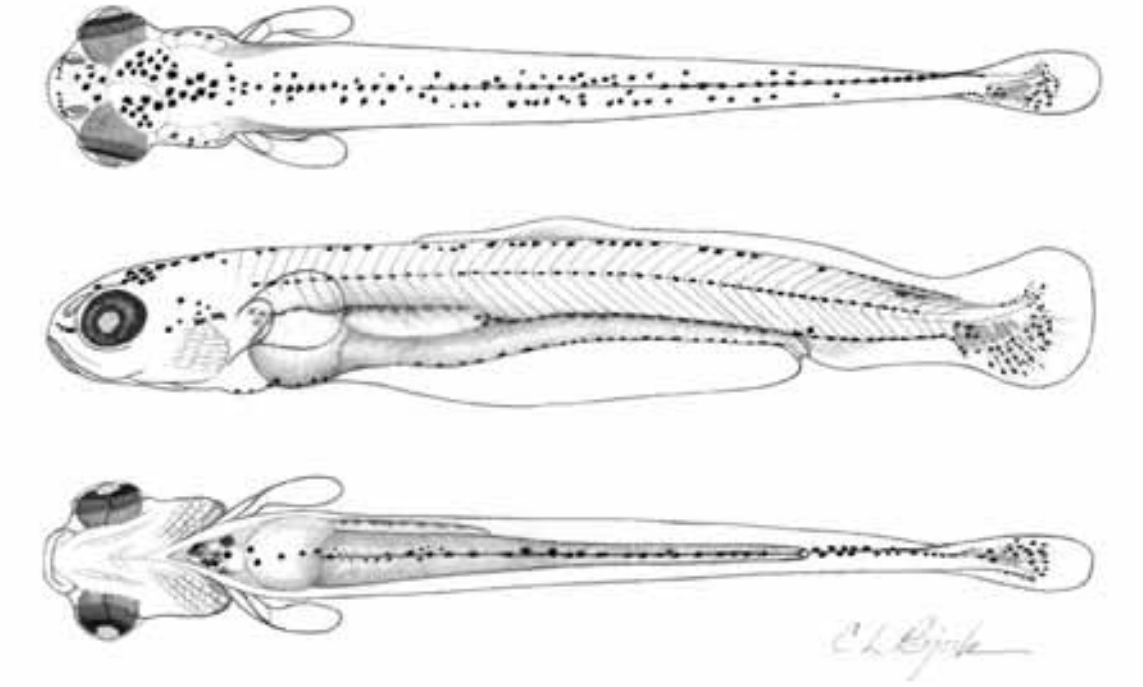


Fig. 81. *Catostomus platyrhynchus* flexion mesolarva, recently transformed, 12.1 mm SL, 12.8 mm TL (from Snyder 1983a). Cultured in 1981 with stock from Willow Creek, northwest of Steamboat Springs, Colorado.

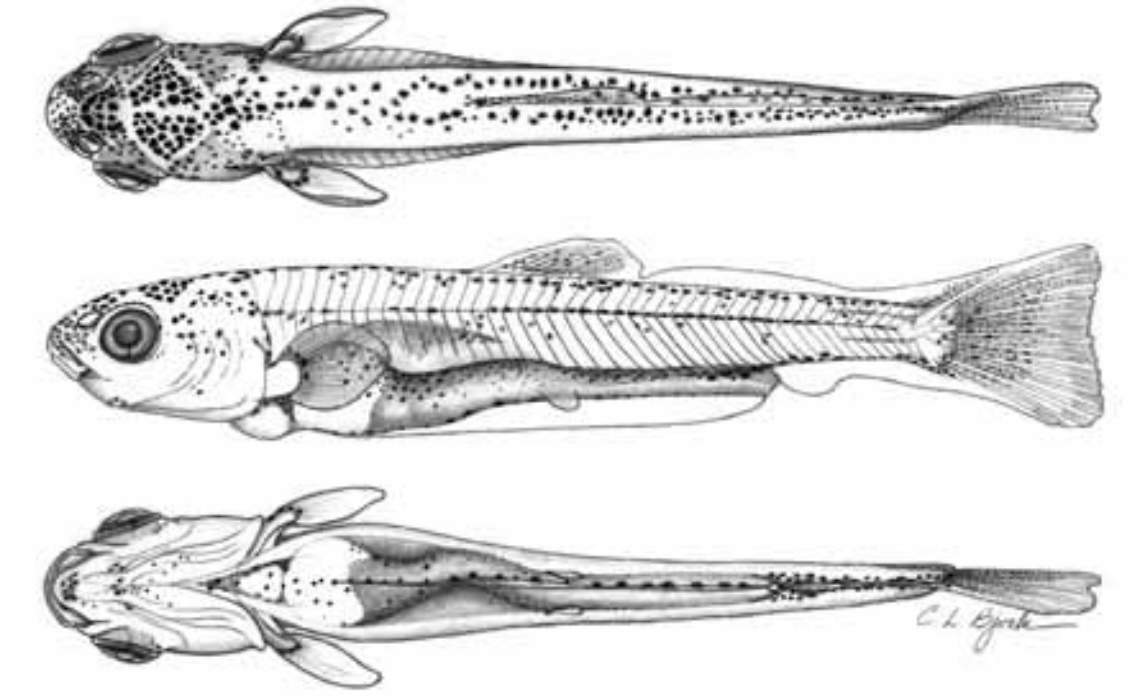


Fig. 82. *Catostomus platyrhynchus* postflexion mesolarva, 13.7 mm SL, 15.6 mm TL. Collected in 1981 from Willow Creek, northwest of Steamboat Springs, Colorado.

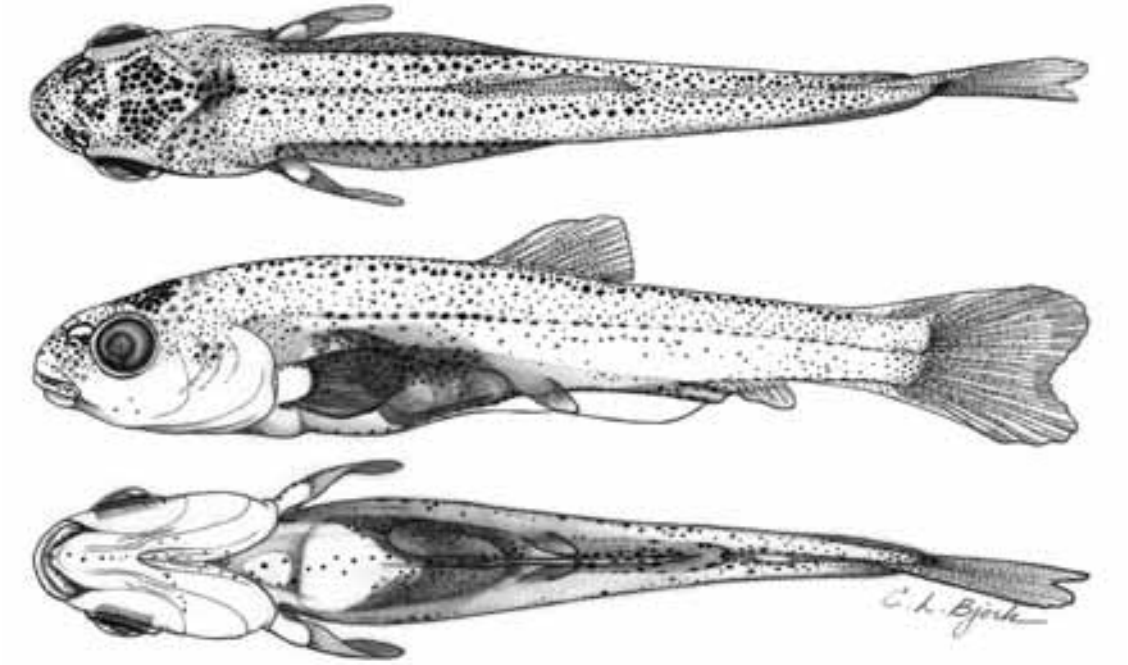


Fig. 83. *Catostomus platyrhynchus* metalarva, recently transformed, 16.3 mm SL, 19.6 mm TL. Collected in 1981 from Willow Creek, northwest of Steamboat Springs, Colorado.

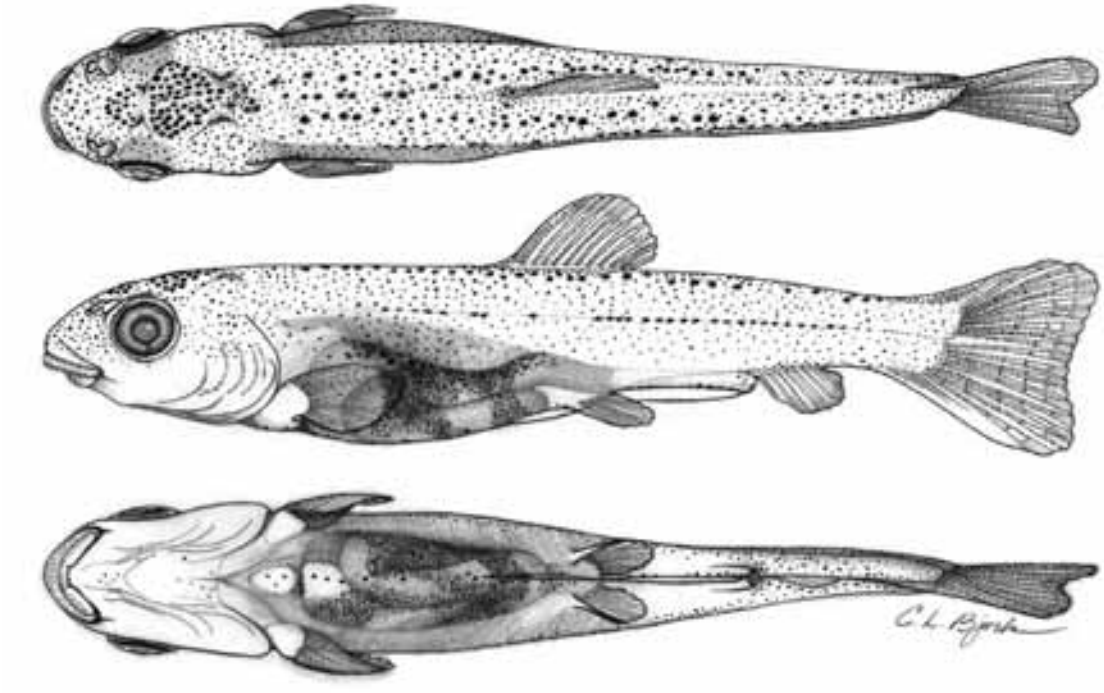


Fig. 84. *Catostomus platyrhynchus* metalarva, 19.6 mm SL, 22.5 mm TL. Collected in 1981 from Willow Creek, northwest of Steamboat Springs, Colorado.

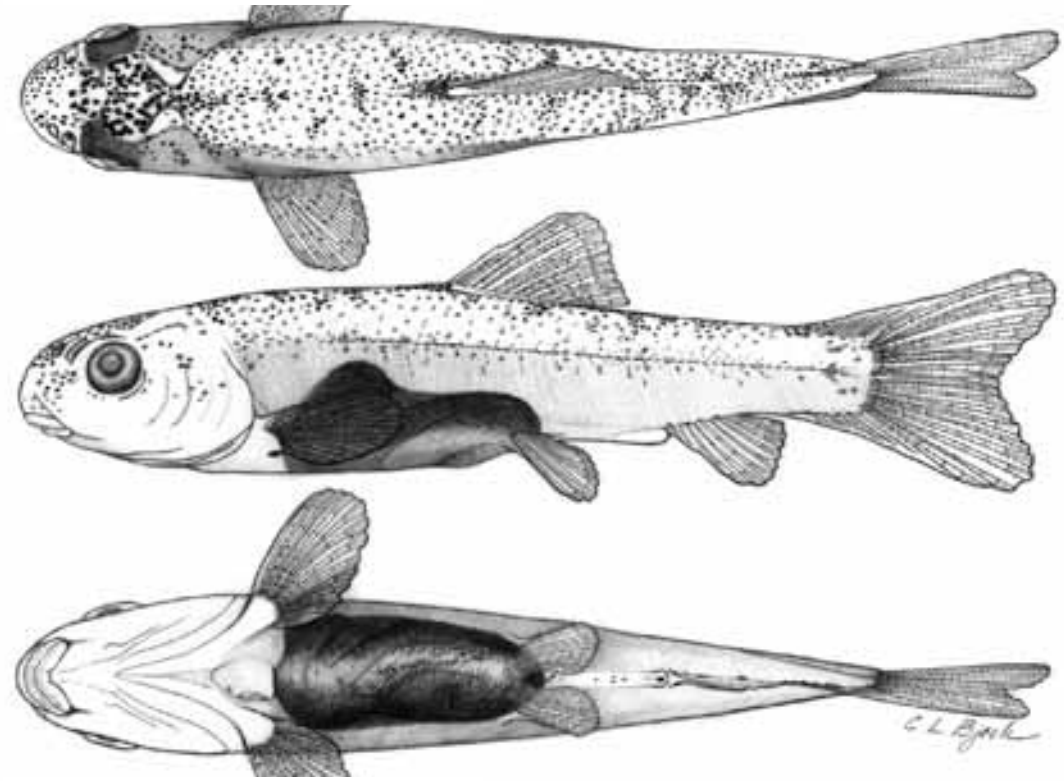


Fig. 85. *Catostomus platyrhynchus* juvenile, recently transformed, 20.6 mm SL, 25.2 mm TL. Collected in 1985 from Spanish Fork River, Utah Lake, Utah.

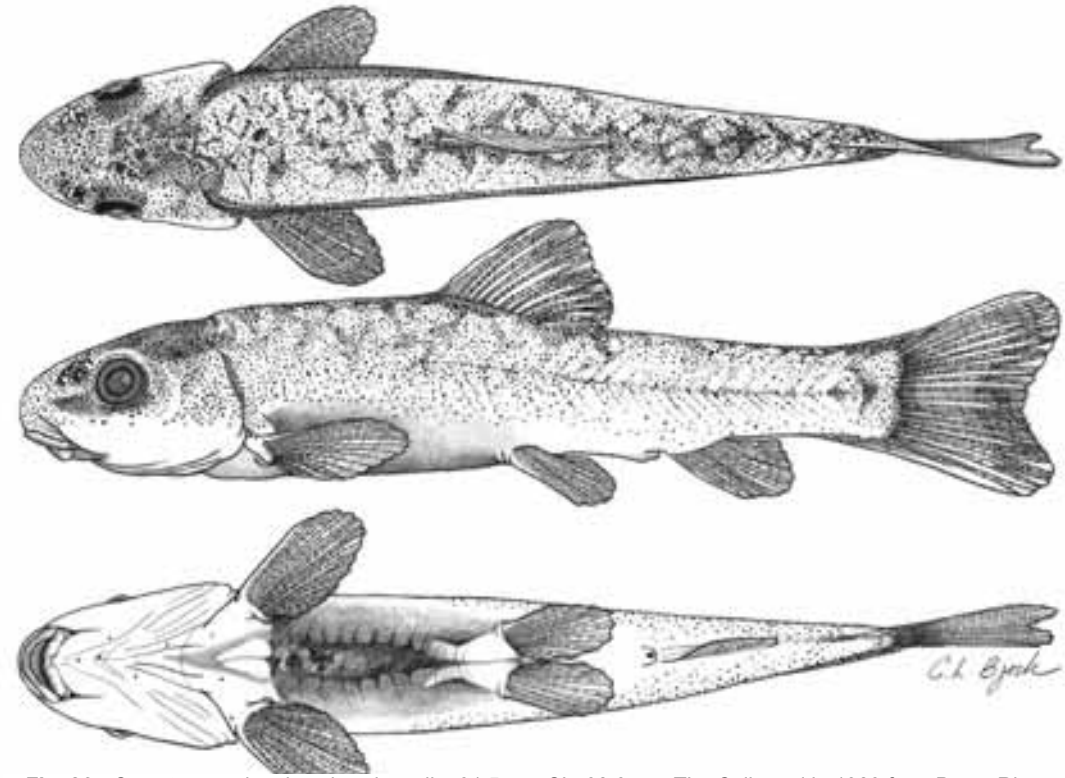


Fig. 86. *Catostomus platyrhynchus* juvenile, 31.5 mm SL, 38.0 mm TL. Collected in 1983 from Provo River, Utah Lake, Utah.

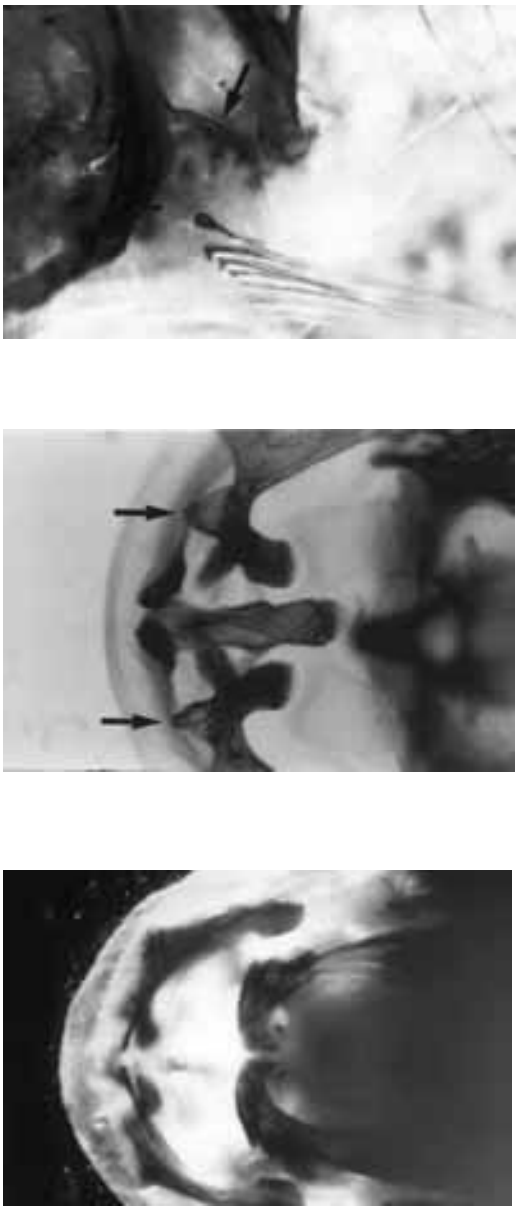


Fig. 87. Selected skeletal features of *Catostomus platyrhynchus* juvenile, 21.2 mm SL, 24.0 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

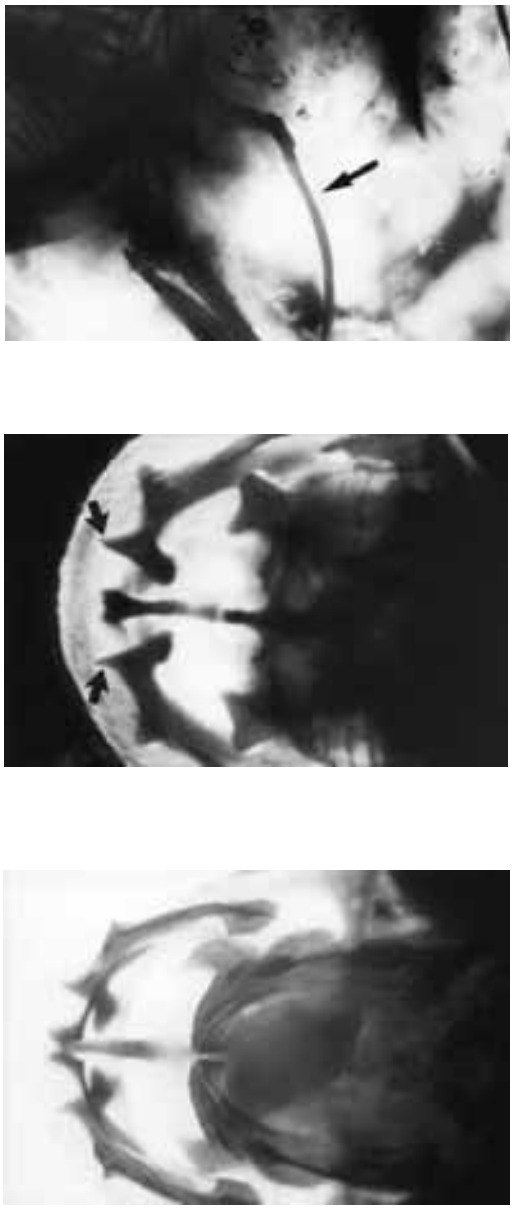
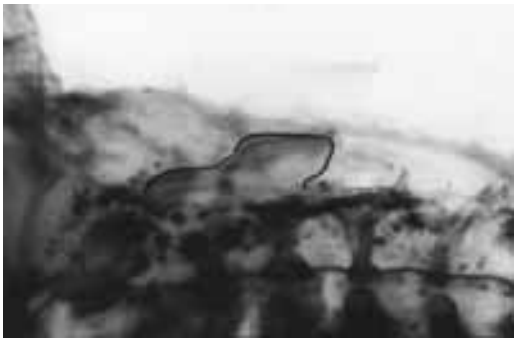


Fig. 88. Selected skeletal features of *Catostomus platyrhynchus* juvenile, 45 mm SL, 53 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.



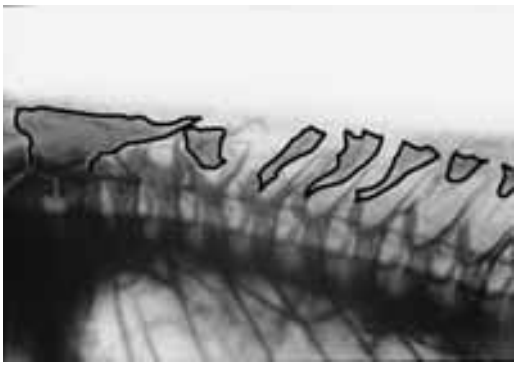
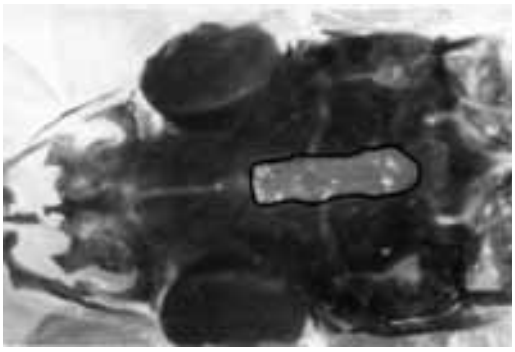


Fig. 89. Interneurals of *Catostomus platyrhynchus*. Top – postflexion mesolarva, 14.8 mm SL, 17.0 m TL. Middle – juvenile, 21.2 mm SL, 24.0 mm TL. Bottom – juvenile, 45 mm SL, 53 mm TL.



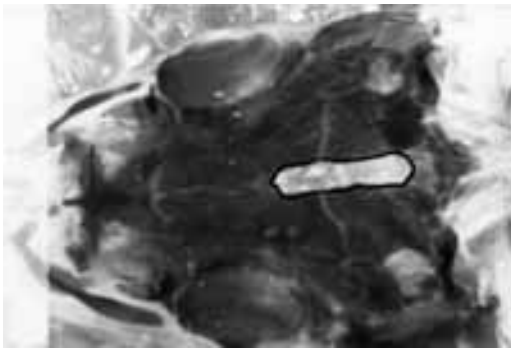


Fig. 90. Frontoparietal fontanelle of *Catostomus platyrhynchus*. Top – juvenile, 21.2 mm SL, 24.0 mm TL. Bottom – juvenile, 45 mm SL, 53 mm TL.

Table 30. Dimensions of frontoparietal fontanelle for *Catostomus platyrhynchus* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	0			
20-21	2	0.6-0.8	2.2-2.2	27-36
22-25	1	0.7	2.2	32
26-34	1	0.5	2.1	24
35-46	2	0.4-0.5	2.5-2.7	15-20
76-81	1	0	0	closed

Fig. 91. *Xyrauchen texanus* adult (© Joseph R. Tomelleri).

Adult Description: Conspicuous predorsal keel. Caudal peduncle deep. Mouth inferior, moderate in size. Lips moderately to weakly papillose, without notches at corners. Lower lip with median cleft that completely separates the two lobes. Fontanelle well developed. Peritoneum black. TL usually 40-60 cm, up to 90 cm. (Also, Table 31.)

Reproduction: Non-guarding, open-substrate lithophil; possible redd creation. May and early June at 6-19°C in the Upper Colorado River Basin; Nov. to May, mostly Jan. to Mar. at 10-21°C in lower basin; usually with rising water levels. Spawn over gravel-cobble bars or riffles in rivers at <1 m/s, or near tributaries, in backwaters or along shore and coves of reservoirs over silt, sand, gravel, and rocks; under <6 m, usually <1 m, of water. Water-hardened eggs 2.5-2.8 mm diameter, demersal, and initially adhesive. Hatching unsuccessful or limited at ≤10°C, best around 20°C.

Young: At 18-20°C, hatch in 6-7, swim up in 12-13, and swim down in 27 days; at 15°C, 11, 17-21, and 38 days respectively. Remain in substrate until ready to migrate. Attracted by light at night. Larvae about 25 mm TL travel in large schools in warm shallows along shore.

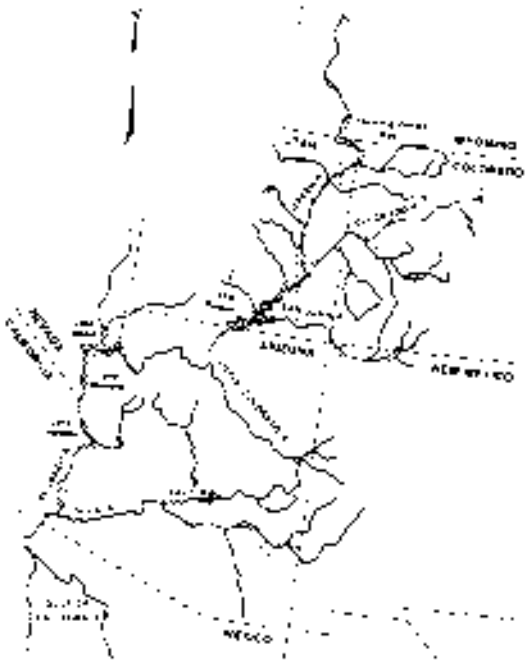


Fig. 92. Recent distribution of *Xyrauchen texanus* in Colorado River Basin, including stocked reaches.

Table 31. Selected juvenile and adult meristics for *Xyrauchen texanus*. 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. Gill rakers for exterior row of first arch, specimens >70 mm SL. Mean or modal values underlined if known and noteworthy; rare or questionable extremes in parentheses.

Character	Original	Literature	Character	Original	Literature
Dorsal Fin Rays - P:	(12)13-14-15-16	(12)13-14-15-16	Dorsal Fin Rays - R:	3-4(5)	
Anal Fin Rays - P:	(6)7	7	Anal Fin Rays - R:	(1)2-3	
Caudal Fin Rays - P:	18	18	Caudal Fin Rays - RD:	10-11-12-13	
Pectoral Fin Rays:	15-16-17-18	16	Caudal Fin Rays - RV:	7-8-9-10	
Pelvic Fin Rays:	(9)10-11	10	Lateral Scales:		68-76-78-87(-95)
Vertebrae:	45-46-47		Gill Rakers:		44-50

Table 32. Size at apparent onset of selected developmental events for *Xyrauchen texanus*, as observed under low power magnification. P = principal rays; R = rudimentary rays. Scales are lateral series. Rare or questionable extremes 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:	7-9	7-10	Dorsal - P:	13-14	(14)15	15(-17)	17(-20)
Eyes Pigmented:	(7)8(9) or *	(7)8-9 or *	Anal - P:	(13-)15	(14-)17	15-17	18-20
Yolk Assimilated:	(9)10-11	(10)11-12	Caudal - P:	(10)11(12)	11-12	(11)12-13	(13)14
Finfold Absorbed:	(21)22-23(24)	27-30	Caudal - R:	14	15-16	19-20(-24)	23-24(-30)
Pectoral Fin Buds:	7 or *	7 or *	Pectoral:	(13-)15	(15-)17	16-18	20-22
Pelvic Fin Buds:	(13)14	15	Pelvic:	(13-)15-17	(15-)18-20	16-17	20-21
* before hatching			Scales:	24-28	30-35	33-36(37)	42-45

References: Abbott 1860, Baxter and Simon 1970, Beckman 1952, Behnke et al. 1982, Bestgen 1990, Bozek et al. 1984, Burdick 2003, Douglas 1952, Ellis 1914, Hubbs and Miller 1953, Jordan and Evermann 1896, La Rivers 1962, Lee et al. 1980, McAda 1977, Miller et al. 1982, Minckley 1973, Moyle 1976, Ryden 1997, Sigler and Miller 1963, Toney 1974, Tyus et al. 1982 & 1987, Wick et al. 1982, Woodling 1985.

Table 33. Size at developmental interval (left) and gut phase (right) transitions for *Xyrauchen texanus*. See Figure 5 for phases of gut folding. Rare or questionable extremes in parentheses.

Transition to	mm SL	mm TL	Transition to	mm SL	mm TL
Flexion Mesolarva:	(10)11(12)	11-12	2 - 90° bend:	(14)15(-17)	(16)17(-20)
Postflexion Mesolarva:	(11)12-13	(13)14	3 - Full loop:	17	20
Metalarva:	15-17	18-20	4 - Partial crossover:	18-25(26)	22-30(-32)
Juvenile:	(21)22-23(24)	27-30	5 - Full crossover:	(22-)26-28(-31)	(27-)32-35(-38)

Table 34. Summary of morphometrics and myomere counts by developmental phase for *Xyrauchen texanus*. See Figure 4 for abbreviations and methods of measurement and counting. Protolarvae with unpigmented eyes excluded.

	Protolarvae (N=25)		Flexion Mesolarvae (N=13)		Postflexion Mesolarvae (N=25)		Metalarvae (N=30)		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:	10 1	8-11	12 1	11-13	14 1	12-17	19 2	15-24	28 4	22-37
TL, mm:	10 1	9-12	12 1	11-14	16 2	13-20	23 3	18-30	36 6	27-47
Lengths %SL:										
AS to AE	2 0	1-3	2 1	2-3	5 1	3-7	7 1	4-9	8 1	6-9
PE	8 0	7-8	9 1	7-10	11 2	9-14	14 1	12-17	15 1	13-16
OP1	16 1	14-17	18 1	16-20	22 2	20-27	27 1	25-30	28 2	25-31
OP2					52 1[c]	50-54	56 2	51-58	57 2	54-60
PY	76 4	66-82	75 [b]	75-75						
OPAF	30 12	22-66	27 2	24-30	31 3	27-36	42 9	34-69		
ODF	34 2	32-39	37 3	33-44	42 3	36-45	45 2[g]	43-47		
OD					49 1[d]	47-51	49 1	47-51	49 1	46-52
ID					66 1[e]	65-67	67 1	65-69	67 1	65-70
PV	79 2	76-81	79 1	78-81	81 1	78-84	77 2	75-81	77 1	75-80
OA					81 1[f]	79-82	77 1	76-79	78 1	75-80
IA					86 0[f]	85-86	84 1	83-86	84 1	82-86
AFC					110 2	107-114	114 1	111-117	115 1	113-118
PC	105 1	103-106	106 1	104-108	113 4	108-119	123 2	120-128	125 1	123-128
Y	44 23	0-68	4 14	0-50						
P1	7 3	3-11	10 1	9-11	11 1	9-13	15 1	12-18	17 1	15-19
P2					3 3	0-7	12 2	8-14	15 1	12-16
D					19 1[e]	18-21	24 2	21-29	27 1	23-29
A					7 1[g]	5-9	12 1[h]	9-15	15 1	12-16
Depths %SL:										
at BPE	9 1	8-10	11 1	9-13	13 2	11-16	16 1	15-18	18 1	16-20
OP1	11 1	9-12	13 1	10-14	16 2	13-20	20 1	18-23	22 1	20-23
OD	10 2	7-13	9 1	6-11	14 3	9-20	19 2	16-23	23 2	18-27
BPV	5 1	4-6	6 0	5-6	7 1	5-9	11 1	8-14	13 1	11-14
AMPM	3 0	2-4	4 1	3-5	6 1	4-7	8 1	7-9	8 0	7-9
Max. Yolk	5 3	0-9	0 1	0-2						
Widths %SL:										
at BPE	9 1	7-11	11 1	10-12	12 1	11-14	15 1	14-17	16 1	15-18
OP1	6 1	5-8	8 1	6-9	10 2	8-14	15 2	12-17	18 1	15-20
OD	6 2	4-9	5 0	5-6	8 2	5-11	11 2	8-15	16 2	12-20
BPV	3 0	2-4	3 0	3-4	5 1	3-6	6 1	4-9	8 1	6-9
AMPM	2 0	1-3	2 0	2-2	3 0	2-4	3 0	2-4	4 0	3-4
Max. Yolk	5 3	0-9	0 1	0-5						
Myomeres:										
to PY	37 2[a]	30-38	37 [b]	37-37						
OPAF	10 6	5-31	7 0	6-8	7 1	6-9	10 5[i]	6-30		
OP2					20 1[c]	19-22	20 1[i]	19-22		
ODF	12 1	10-16	13 1	12-16	14 1	12-17	14 1[g]	12-15		
OD					18 1[d]	16-20	16 1[i]	15-18		
PV	39 1	37-41	38 1	37-39	39 1	38-40	37 1[i]	36-39		
Total	48 1	46-49	47 1	46-49	47 1	46-49	46 1[i]	44-48		
After PV	9 1	7-10	9 1	8-10	8 1	7-9	9 1[i]	7-12		

[a] N = 20, [b] N = 1, [c] N = 18, [d] N = 17, [e] N = 7, [f] N = 5, [g] N = 6, [h] N = 29, [i] N = 27.

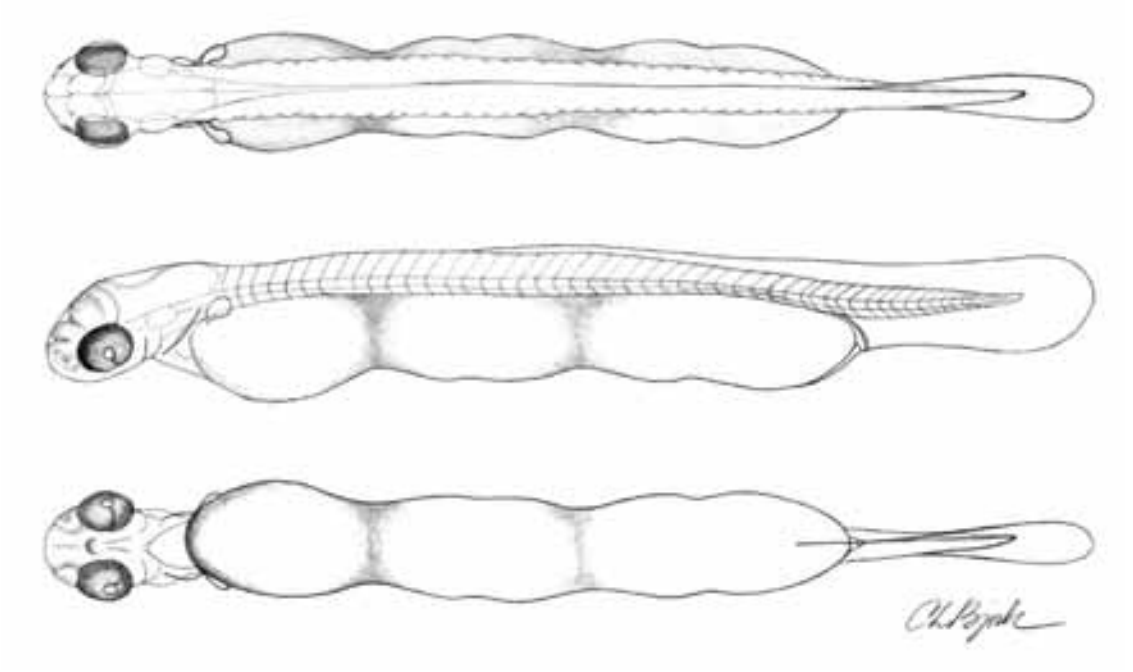


Fig. 93. *Xyrauchen texanus* protolarva, recently hatched, 9.2 mm SL, 9.4 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

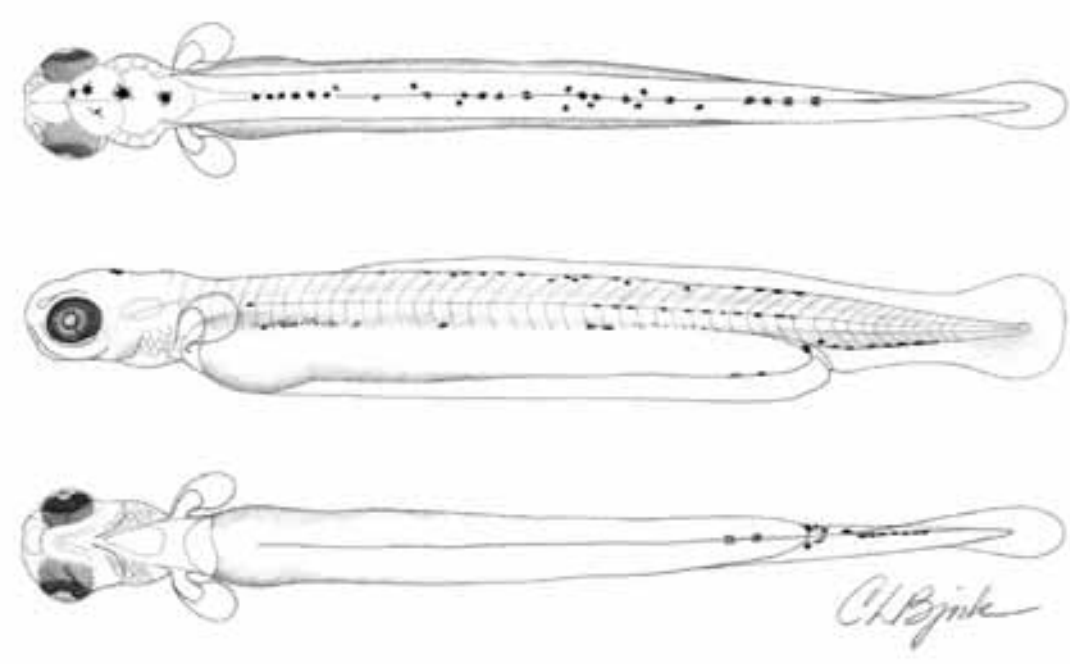


Fig. 94. *Xyrauchen texanus* protolarva, 10.5 mm SL, 10.9 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

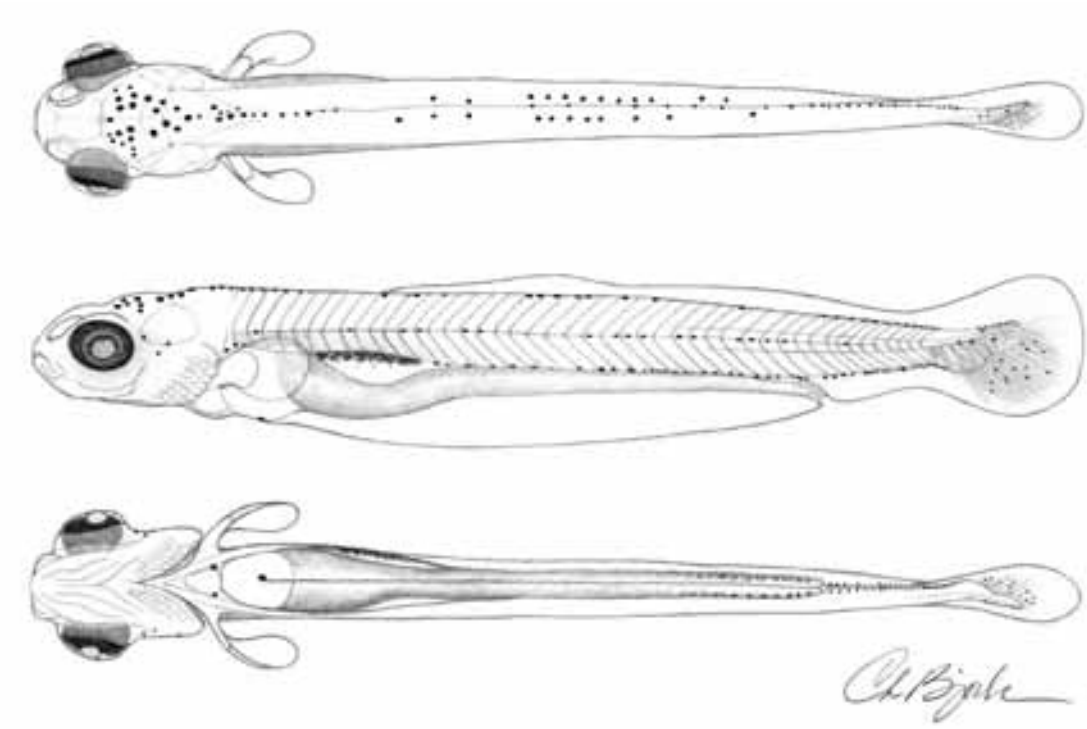


Fig. 95. *Xyrauchen texanus* flexion mesolarva, recently transformed, 12.5 mm SL, 12.9 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

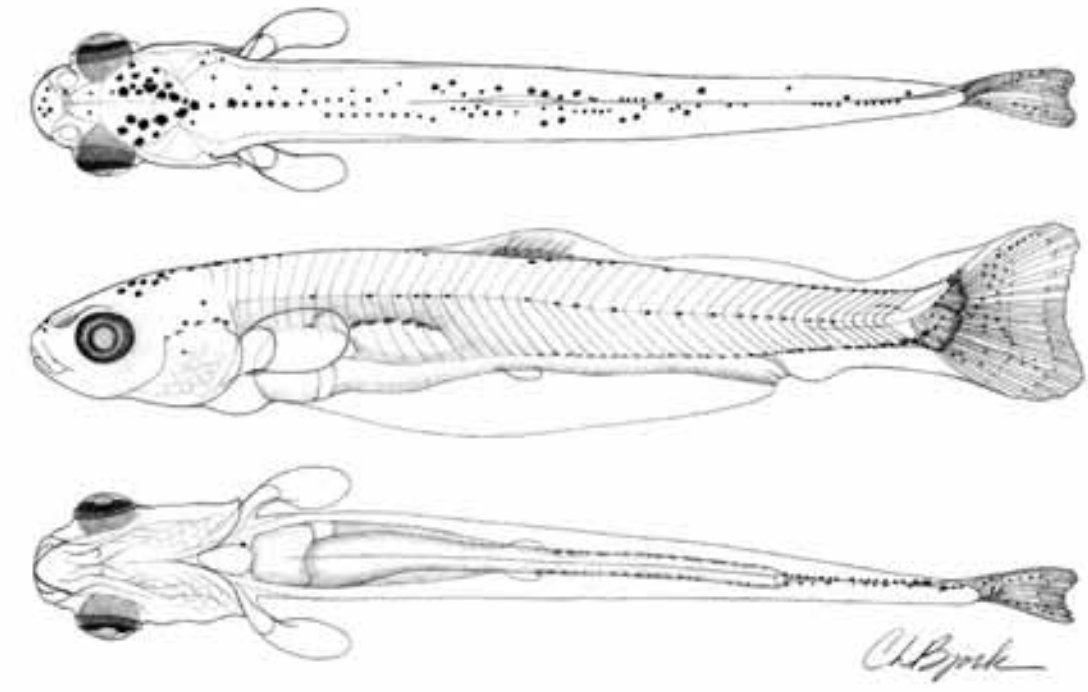


Fig. 96. *Xyrauchen texanus* postflexion mesolarva, 14.4 mm SL, 16.0 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

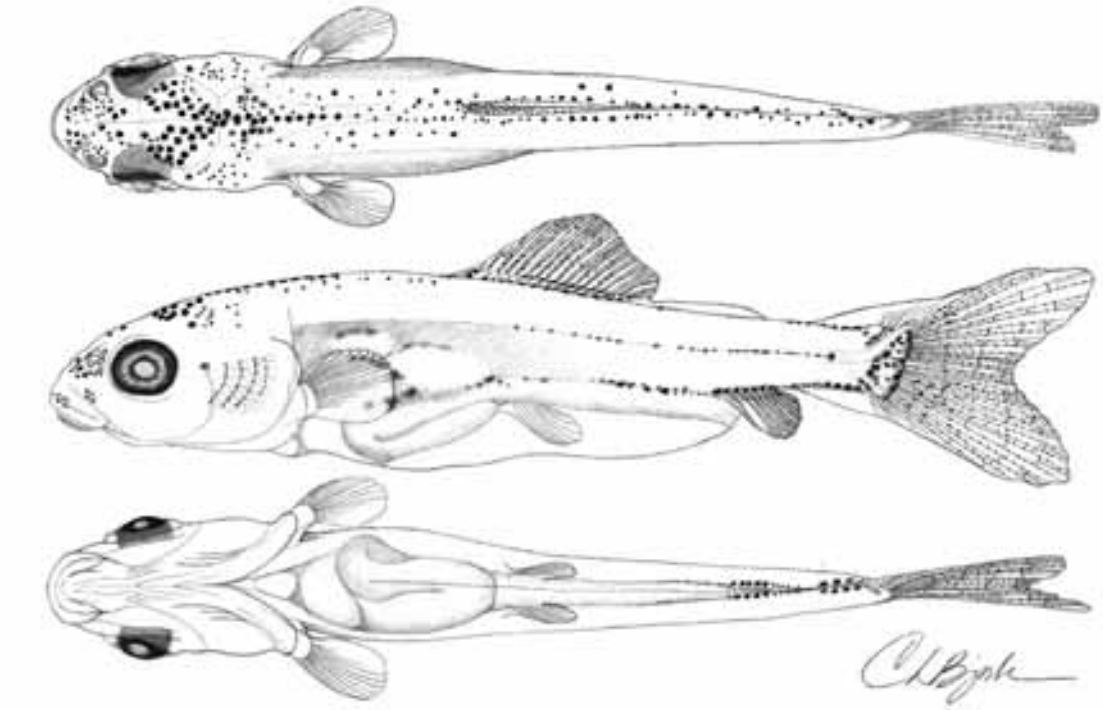


Fig. 97. *Xyrauchen texanus* metalarva, recently transformed, 16.2 mm SL, 19.4 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

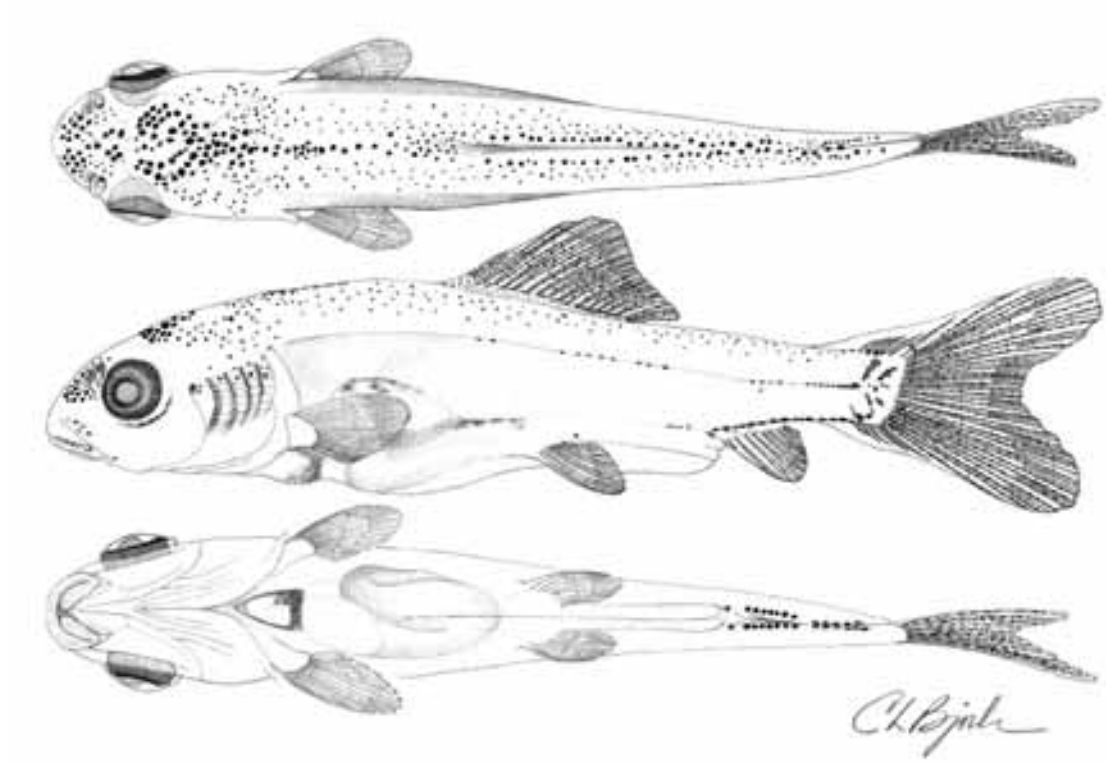


Fig. 98. *Xyrauchen texanus* metalarva, 18.8 mm SL, 22.8 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

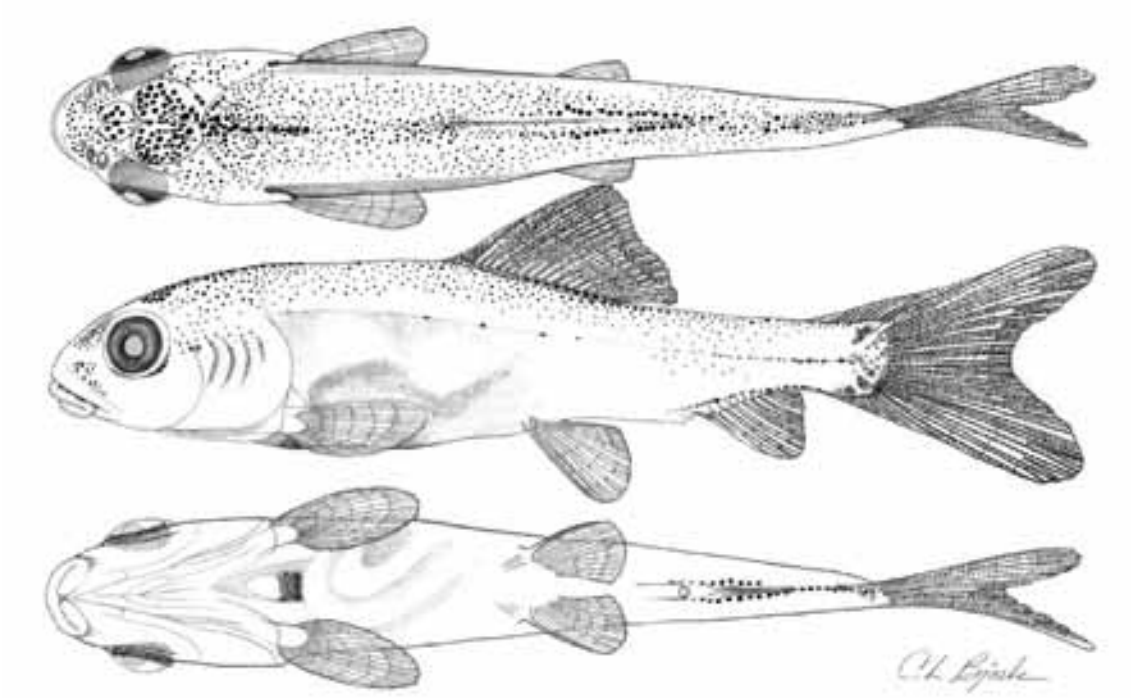


Fig. 99. *Xyrauchen texanus* juvenile, recently transformed, 21.6 mm SL, 27.0 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

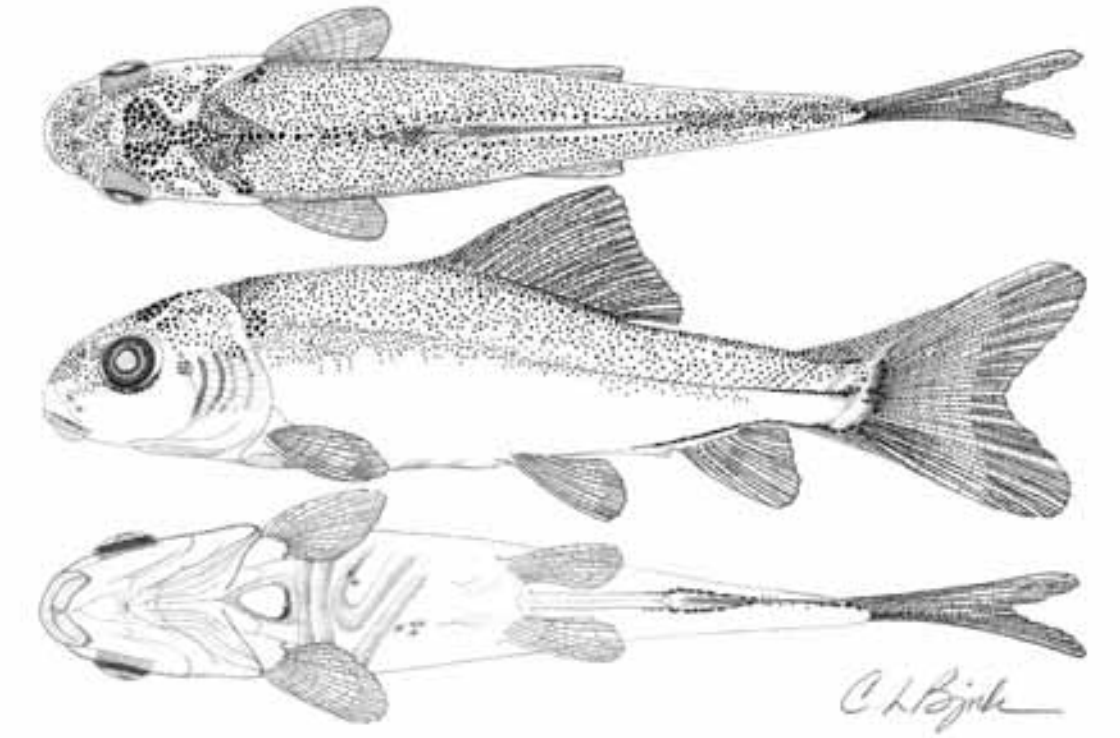


Fig. 100. *Xyrauchen texanus* juvenile, 30.2 mm SL, 37.4 mm TL. Cultured in 1980 from stock in Colorado River gravel pits near Clifton, Colorado.

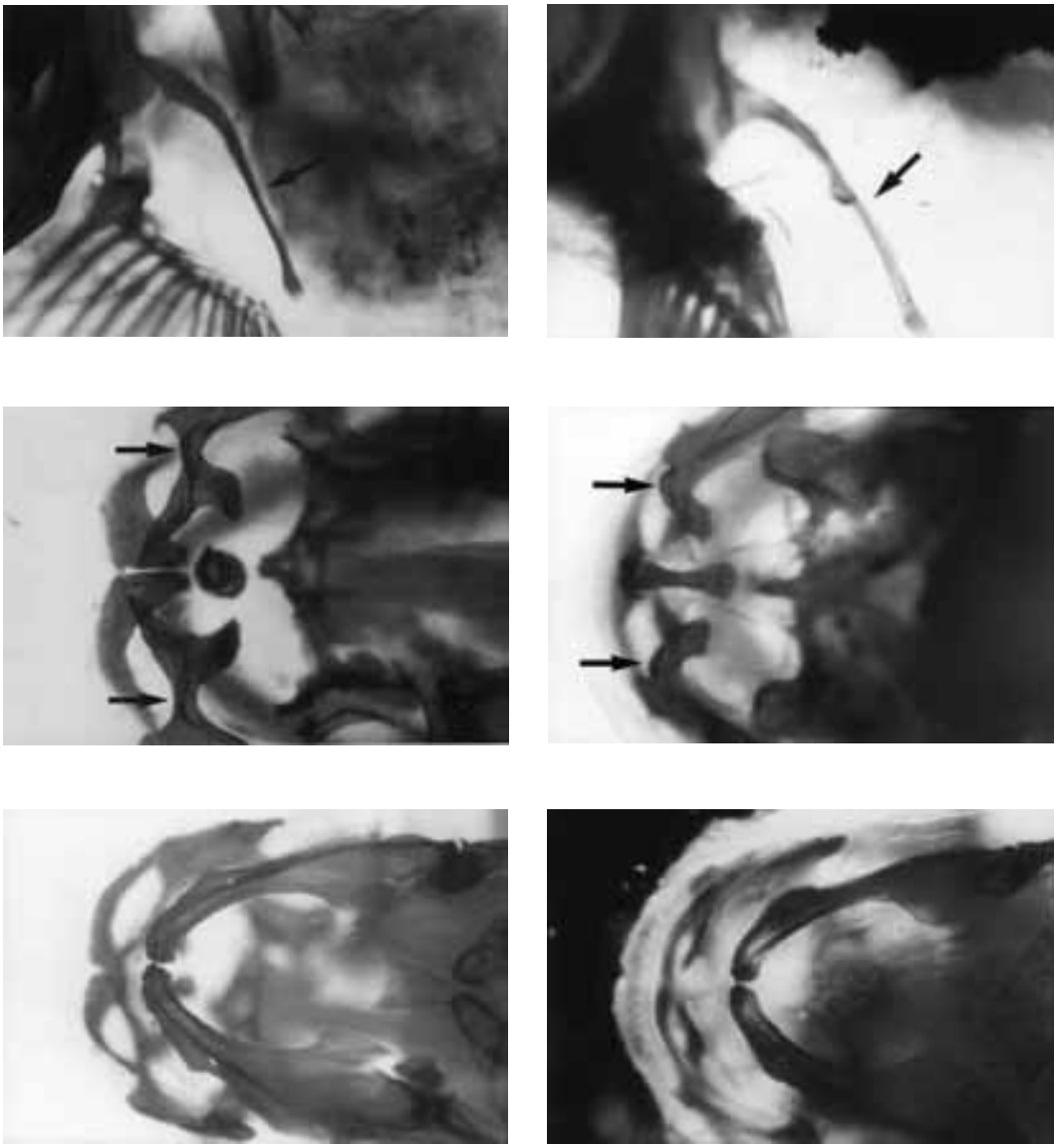


Fig. 101. Selected skeletal features of *Xyrauchen texanus* metalarva, 20.0 mm SL, 23.8 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

Fig. 102. Selected skeletal features of *Xyrauchen texanus* juvenile, 40.5 mm SL, 51.0 mm TL. Top – postcleithrum. Middle – anterior-dorsal maxillary projections. Bottom – mandible position.

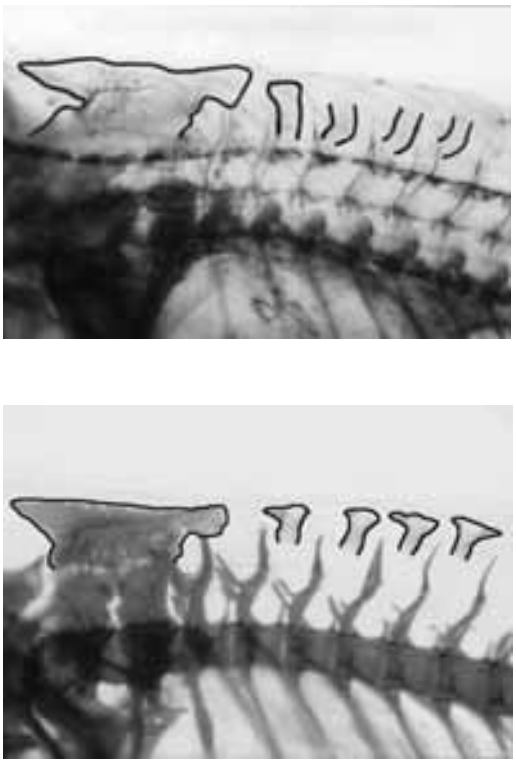


Fig. 103. Interneurals of *Xyrauchen texanus*. Top – postflexion mesolarva, 14.3 mm SL, 17.0 m TL. Middle – metalarva, 20.0 mm SL, 23.8 mm TL. Bottom – juvenile, 40.5 mm SL, 51.0 mm TL.

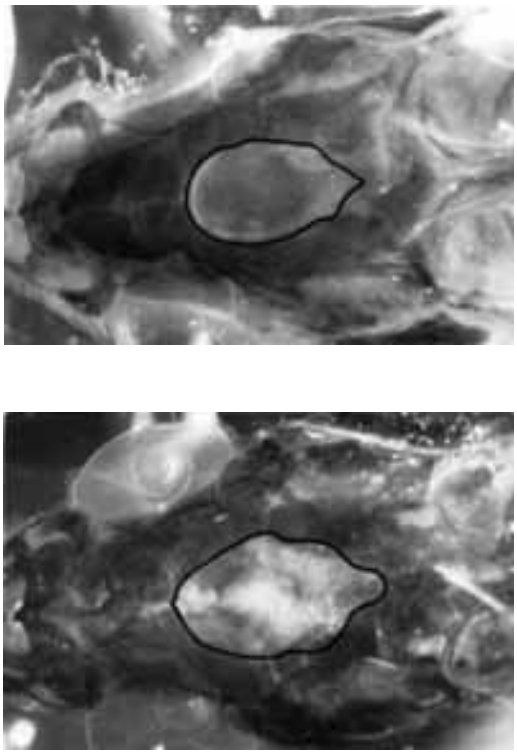


Fig. 104. Frontoparietal fontanelle of *Xyrauchen texanus*. Top – metalarva, 21.5 mm SL, 27.4 mm TL. Bottom – juvenile, 26.1 mm SL, 32.0 mm TL.

Table 35. Dimensions of frontoparietal fontanelle for *Xyrauchen texanus* larvae >16 mm SL, early juveniles, and yearling.

Specimens mm SL	n	Max. width (mm)	Max. length (mm)	Width as % of length
17-19	3	1.0-1.2	1.7-1.9	59-63
20-21	5	1.0-1.3	1.8-2.1	52-68
22-25	2	1.0-1.3	1.9-2.1	53-62
26-34	2	0.9-1.3	2.1-2.3	43-57
35-46	3	1.1-1.7	2.3-3.4	48-50
76-81	1	2.3	5.1	45

Comparative Summary

The diagnostic criteria that follow are included in the computer-interactive key, but like the descriptive species accounts, are provided here to help confirm identities determined through the key or for use as an alternative to the key. Because, as noted earlier, extremes in character states beyond those reported herein are likely, identifications should be based on as many criteria as practical.

Size relative to state of development

Flannelmouth sucker eggs are the largest of UCRB catostomids (3.8-3.9 mm diameter versus 3.3-3.5 for bluehead sucker and 2.3-3.3 for the others) and larvae hatching from them are usually much larger as well. This relative size difference is characteristic of flannelmouth sucker throughout its early development (Table 36). In contrast, razorback, mountain, and some white and longnose sucker eggs are notably smaller (2.3-2.8 mm diameter) than other species and their recently hatched protolarvae and recently transformed mesolarvae tend to be correspondingly small. These species also complete yolk absorption at a much smaller size, usually by 11 or 12 mm SL; flannelmouth sucker larvae finish their yolk at 15 mm SL (rarely 14 mm SL, occasionally 16 mm SL).

Size relative to state of development for all species but flannelmouth sucker is nearly the same by the beginning of the metalarval phase. In general, fin development proceeds fastest (at smaller sizes) for white sucker and slowest (at larger sizes) for flannelmouth sucker. However, pelvic fins develop earliest in longnose sucker. White and Utah suckers acquire the adult complement of all fin rays, lose their preanal finfolds, and become juveniles at the smallest sizes (19-20 mm SL) whereas transformation to the juvenile period for some razorback sucker occurs at sizes nearly as large as for flannelmouth sucker (22-23 and 23-24 mm SL, respectively).

Gut folding or coiling proceeds at a faster rate for most bluehead sucker than for other species and at a much slower rate for nearly all flannelmouth sucker. Although gut folding begins only a little later in razorback larvae than in bluehead larvae, it slows during the metalarval phase. As a result, the upper end of the size range for razorback sucker at transition to gut phase 4 overlaps the lower end of the range for flannelmouth sucker.

The size at first appearance of the full series of lateral scales roughly correlates with scale size. The full lateral series of scales appears as early as 24 mm SL for Utah sucker and 29 mm SL for white sucker, both of which have large scales. But it appears no earlier than 39 mm SL for flannelmouth sucker which has very fine scales.

Meristics and morphometrics

Some character differences determined by comparison of species account summaries of meristics and morphometrics are not included in Tables 37 and 38 because corresponding data for an adjacent phase indicate that the differences might not hold up if additional specimens in the size range of concern are analyzed. When comparing morphometric characters, be aware that some characters, especially depth and width at origin of dorsal fin (OD), are affected by the amount of yolk in early larvae and by health or condition in later larvae and juveniles. Juvenile morphometric data might not be applicable to specimens much greater than 40 mm SL.

The more useful meristics are counts of lateral line (or series) scales for juveniles in which scales are sufficiently formed; principal dorsal-fin rays (and corresponding pterygiophores) and vertebrae for late postflexion mesolarvae, metalarvae, and juveniles; and myomeres, both total and to the posterior margin of the vent (often referred to as preanal myomeres), for all larval phases (Table 37). White and Utah suckers usually have fewer than 75 lateral rows of scales whereas longnose, bluehead, and flannelmouth suckers usually have more than 85, and mountain and razorback suckers typically have counts between 75 and 85. Typical counts of principal dorsal-fin rays are highest for razorback sucker with 14-15 and lowest for longnose and mountain suckers with 10; the other species have typical counts within the 11-13 range. However, when considering observed extremes in these counts, three species have ranges that include the count of 14 and five species include the count of 10.

Table 36. Comparison of size (mm standard length) at onset or transition of developmental intervals, gut phases, and other developmental events for larvae and early juveniles of Upper Colorado River Basin catostomids. Rare extremes in parentheses. * = or before hatching.

Character	*Catostomus ardens*	*Catostomus catostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Egg diameter:	2.9-3.2	(2.2)2.4-3.0	2.6-3.3	3.3-3.5	3.8-3.9	2.3-2.7	2.5-2.8
Phase/period transitions							
Embryo to larva:	(7)8-11	(7)8-10	(7)8-10	(8)9-10(11)	(8-)10-11	(7)8	7-9
Proto- to mesolarva:	12-13	11	10-12(13)	10-12(13)	13	11	(10)11(12)
Flexion to post-flexion mesolarva:	13-14	12-13	(12)13-15	(11)12-13(14)	(14)15(16)	13-14	(11)12-13
Meso- to metalarva:	15-17	15-16(17)	15-16(17)	(15-)17	19-20(21)	16-17	15-17
Larva to juvenile:	19-20	21-22	(17-)19-20	21-22(23)	23-24(25)	21-22	(21)22-23(24)
Gut phase transitions							
1 to 2 (90° bend):	14-17	14	14-15(16)	14(15)	(17)18(-20)	14-17	(14)15(-17)
2 to 3 (full loop):	18-19	16-17	(16)17-18	15(16)	(19-)21-25(-27)	16-17	17
3 to 4 (partial crossover):	20-22	18-21(22)	19-20(21)	(16)17	(22)23-32(-37)	18-20	18-25(26)
4 to 5 (full crossover):	27-28	(19)20-23(-25)	(20)21-25	(16)17-19(-21)	(29-)35-42	21-23	(22-)26-28(-31)
Onset of selected events							
Eyes Pigmented:	9-10 *	(7)8 *	(7)8 *	9-10 *	(9)10 *	8	(7)8(9) *
Yolk Assimilated:	12-13	10-11(12)	10-12(-14)	(10-)12-14	(14)15(16)	(10)11	(9)10-11
Finfold Absorbed:	19	21-22	(17-)19-20	21-22(23)	23-24(25)	21-22	(21)22-23(24)
Pectoral-fin Buds:	(7) *	*	(7)8 *	(8) *	(9) *	(7) *	7 *
Pelvic-fin Buds:	13-14(15)	12	13-15	14	(15)16(17)	13	(13)14
Fin rays first observed							
Dorsal, principal:	13-15	13-14	12-14(15)	(11-)13(14)	15	13	13-14
Anal, principal:	14-15	(13)14(15)	14-16	14-15	17	14-15	(13-)15
Caudal, principal:	12-13	11	10-12(13)	10-12(13)	13	11	(10)11(12)
Caudal, rudimentary:	14-15	13-14	13-15	14	(15-)17	14	14
Pectoral:	14-15	13-14	14-16	14-15	17	13-15	(13-)15
Pelvic:	14-17	14(15)	15-16	(15)16	17-18	16	(13-)15-17
Full fin-ray counts first observed							
Dorsal, principal:	14-16	(13)14(15)	14-16	(14)15	17-18	14-17	15(-17)
Anal, principal:	15-17	15-16(17)	15-16(17)	(15-)17	19-20(21)	16-17	15-17
Caudal, principal:	13-14	12-13	(12)13-15	(11)12-13(14)	(14)15(16)	13-14	(11)12-13
Caudal, rudimentary:	19-20	21	(17)18	19-20	23	20-21	19-20(-24)
Pectoral:	15-18	20-21	16(-20)	16-18(19)	19-22	18-20	16-18
Pelvic:	18-19	(16-)18-19(-21)	16-18	19-20	23	18-20	16-17
Scales, lateral series							
First observed:	21-23	27-28	22(23)	28-34	(36)37-39	23-24	24-28
Full series first observed:	24-28	(30)31	29-31	30-39	39-42	32-38	33-36(37)

As would be expected, vertebra counts (based on specimens on cleared and stained for cartilage or bone) nearly match or fall within the range of total myomere counts (all larval phases combined). The one notable exception, an upper extreme of 50 vertebrae for the mountain sucker is based on one verified observation of more than 48 vertebrae. The greater range in values for myomere counts, especially at the lower end, is due to the far greater number of specimens examined for myomere counts (vertebra counts are based on only a few to several observations per species) and the difficulty in observing first and last myomeres in some specimens, especially metalarvae for which polarizing filters are no longer useful. Probably for the latter reason, both total and to-the-vent myomere counts for metalarvae tend to range one or two myomeres less than for protolarvae and mesolarvae. A slightly more anterior vent position in metalarvae (and juveniles) than in earlier larvae might also account for some of the difference in myomere counts to the posterior margin of the vent (preanal myomere counts).

Table 37. Comparison of the more diagnostic differences in meristics for larvae and early juveniles of Upper Colorado River Basin catostomids. Character range is followed by the mean or more typical range. See Figure 4 for methods of counting myomeres and fin rays. PV = posterior margin of the vent. Vertebra counts include four for the Weberian complex; dorsal-fin-ray counts are of principal rays; scale counts are of the lateral line or series. Data previously published by other authors (cited in species accounts) are given in parentheses.

Character	*Catostomus ardens*	*Catostomus catostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Myomeres to PV							
Proto- & mesolarvae:							
	35-38, 36-37	36-39, 37-38	34-40, 37-38	37-40, 39	37-40, 39	34-37, 36	37-41, 38-39
Metalarvae:	34-37, 36	34-38, 36	34-37, 35	35-38, 37	36-38, 37	32-36, 35	36-39, 37
All larvae:	34-38, 36-37	34-39, 36-38	34-40, 35-38	35-40, 37-39	36-40, 37-39	32-37, 35-36	36-41, 37-39
Myomeres, total							
Proto- & mesolarvae:							
	45-48, 46	45-49, 47	43-49, 46-47	47-49, 48	47-49, 48	43-47, 45-46	46-49, 47-48
Metalarvae:	43-47, 45	44-48, 46	44-47, 45	47-48, 47	46-48, 47	43-45, 45	44-48, 46
All larvae:	43-48, 45-46	44-49, 46-47	43-49, 45-47	47-49, 47-48	46-49, 47-48	43-47, 45-46	44-49, 46-48
Vertebrae:	47-48	46-47 (45-48, 45-47)	45-48, 46 (44-48)	47-49 (45-50, 47-49)	47-50	46-50, 46-48 (42-48, 44-47)	45-47, 46
Dorsal-fin rays:							
	10-14, 11-13 (11-13)	9-11, 10 (9-12, 10)	10-13, 11-12 (9-15, 10-13)	9-12, 11 (9-12, 10-11)	11-14, 12-13 (10-15, 12-13)	9-11, 10 (8-13, 10)	12-16, 14-15 (12-16,14-15)
Lateral line scales:							
	57-68, 62-68 (54-79, 60-70)	103-116, 105 (85-120,95-115)	56-72, 59-68 (53-85, 56-76)	(78-122,86-115)	(89-120,98-105)	76-86 (60-108,75-97)	(68-95,76-87)

Combined total vertebra and total myomere counts are greatest for bluehead and flannelmouth suckers (typically 47 or greater) and least for Utah, longnose, white, and mountain suckers (typically 47 or less); razorback sucker larvae typically have 46 to 48 total vertebrae or myomeres. The number of myomeres to the vent is typically 37 or greater for bluehead, flannelmouth, and razorback sucker and 36 or fewer for mountain sucker; typical ranges for Utah, white, and longnose suckers are intermediate and overlap with 35 or 36 to 37 or 38 myomeres to the vent. Unfortunately, the full ranges of myomere counts for these species generally overlap to a greater degree, thereby further limiting the diagnostic value of myomere counts.

For protolarvae and flexion mesolarvae, most diagnostically useful morphometrics relate to the amount of yolk remaining as the fish grow (Table 38). By the end of the protolarva phase, longnose, mountain, and razorback suckers consume most or all of their yolk. White and Utah suckers also consume most but not all of their yolk, whereas bluehead and especially flannelmouth suckers still retain about half of their original yolk supply by the end of the protolarva phase. All UCRB catostomids, except some flannelmouth suckers and very rarely bluehead suckers, complete yolk absorption by the end of the flexion-mesolarva phase.

For late postflexion mesolarvae, metalarvae, and juveniles, most diagnostic morphometrics relate to the size and position of the dorsal fin. The length of the dorsal fin (from origin of the fin to its most distal margin) and length of the base of the fin correlate well with the number of principal fin rays discussed above. As would be expected, these measurements are greatest for razorback sucker and least for mountain sucker, but not much less than for longnose, white, and bluehead suckers. Length to the insertion of the dorsal fin is also greatest (farthest back) for razorback and least for mountain sucker, whereas length to the origin of the fin is least (most forward) for flannelmouth and razorback suckers and greatest (farthest back) for white, bluehead, and mountain suckers.

Among the remaining morphometrics, only eye diameter is useful for all developmental intervals. As protolarvae, mountain sucker generally have the greatest eye diameters and mountain and longnose suckers the greatest head

Table 38. Comparison of the more diagnostic differences in morphometrics for larvae and juveniles (≤40 mm SL) of Upper Colorado River Basin catostomids. Except as otherwise noted for most eye diameters, all data are given as percentages of standard length. The full range for each character is followed by the mean or more typical range. See Figure 4 for abbreviations and methods of measurement. HL = head length measured to origin of the pectoral fin (AS to OP1).

Development Phase Character	*Catostomus ardens*	*Catostomus castostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Protolarvae							
Eye diameter:[a]	5-7, 6	5-7, 6	5-7, 6	5-6, 5	5-6, 5	6-8, 7	5-6, 6
AS-to-PE length:	7-9, 8	8-10, 9	8-9, 8	6-7, 7	6-9, 7	8-10, 9	7-8, 8
AS-to-OP1 length:	12-17, 15	15-18, 16	13-19, 16	13-15, 14	12-16, 14	16-18, 17	14-17, 16
Yolk length:[b]	49-64, 57	0-64, 52	26-63, 51	61-67, 63	54-67, 61	0-67, 47	0-68, 44
Pectoral-fin length:[c]	1-8, 5	4-11, 7	2-12, 7	3-6, 5	3-9, 6	2-11, 9	3-11, 7
Depth at OD:[b, d]	10-12, 11	8-15, 12	8-13, 10	12-17, 14	13-15, 14	10-14, 12	7-13, 10
Width at OD:[b, d]	5-9, 7	5-12, 7	5-9, 6	8-12, 10	7-11, 10	6-11, 8	4-9, 6
Max. yolk depth:[b]	3-11, 7	0-13, 7	1-11, 6	6-12, 9	9-16, 12	0-13, 5	0-9, 5
Max. yolk width:[b]	5-14, 8	0-14, 8	1-10, 6	9-15, 12	9-18, 13	0-14, 6	0-9, 5
Flexion mesolarvae							
Eye diameter, % HL:[a]	34-38, 36	32-35, 34	28-38, 34	32-38, 35	32-37, 34	31-38, 35	28-39, 34
AS-to-PV length:	75-77, 76	75-79, 78	76-81, 79	74-79, 77	75-78, 77	75-78, 77	78-81, 79
Yolk length:	0-43, 16	0-34, 3	0-50, 18	0-53, 22	0-54, 42	0-14, 3	0-50, 4
Depth at OD:[d]	8-9, 9	8-11, 10	8-10, 9	9-12, 10	9-13, 11	10-12, 11	6-11, 9
Max. yolk depth:	0-2, 0	0-2, 0	0-3, 1	0-7, 2	0-9, 5	0-1, 1	0-2, 0
Max. yolk width:	0-2, 1	0-3, 0	0-4, 1	0-8, 3	0-9, 5	0-2, 0	0-5, 0
Postflexion mesolarvae							
Eye diameter, % HL:[a]	31-38, 34	29-35, 32	24-34, 31	24-34, 28	24-35, 27	26-35, 30	27-33, 30
AS-to-OP2 length:	50-53, 52	50-54, 52	52-54, 53	53-57, 55	50-54, 53	52-56, 54	50-54, 52
AS-to-ID length:[e, f]	60-63, 62	60-63, 62	61-64, 63	61-64, 62	62-67, 64	61-64, 62	65-67, 66
AS-to-PV length:	76-80, 79	77-80, 78	78-81, 80	76-81, 79	76-80, 78	77-80, 79	78-84, 81
Dorsal-fin (D) length:[f, g]	14-16, 15	14-18, 16	16-17, 17	11-17, 15	15-21, 18	11-15, 13	18-21, 19
Dorsal-fin-base length:[e, f, h]	12-15, 13	12-14, 13	12-14, 13	11-14, 12	12-17, 15	11-13, 12	16-18, 17
Yolk length:	0	0	0	0-15, 2	0-46, 7	0	0
Metalarvae							
Eye diameter, % HL:[a]	28-33, 30	26-34, 29	25-34, 30	22-27, 25	22-25, 24	25-28, 26	24-32, 27
AS-to-OP2 length:	53-57, 56	53-59, 56	54-59, 56	55-61, 58	52-57, 55	53-58, 56	51-58, 56
AS-to-OD length:	49-52, 50	47-52, 49	48-53, 51	49-54, 52	47-51, 49	50-53, 51	47-51, 49
AS-to-ID length:[f]	64-67, 65	60-66, 63	61-67, 65	63-66, 64	62-67, 65	62-65, 63	65-69, 67
Caudal-fin length:[i]	18-22, 20	17-22, 20	16-26, 21	16-24, 21	17-25, 22	15-20, 18	20-28, 23
Dorsal-fin (D) length:[f]	18-20, 19	17-21, 19	15-22, 19	17-21, 19	20-24, 22	15-19, 17	21-29, 24
Dorsal-fin-base length:[f, h]	14-16, 15	12-15, 13	12-15, 14	11-15, 13	14-17, 16	11-14, 12	16-21, 18
Juveniles <40 mm SL							
Eye diameter, % HL:[a]	27-32, 30	20-29, 25	22-28, 25	21-28, 24	19-26, 23	22-25, 24	21-30, 25
AS-to-OP1 length:	25-28, 26	24-30, 27	24-29, 28	23-27, 25	24-28, 25	24-26, 25	25-31, 28
AS-to-OP2 length:	55-58, 56	55-59, 57	52-59, 57	56-60, 58	52-57, 55	55-60, 57	54-60, 57
AS-to-OD length:	48-51, 49	49-53, 50	48-53, 51	47-54, 51	46-49, 48	48-52, 50	46-52, 49
AS-to-ID length:[f]	64-66, 65	62-65, 64	61-68, 65	62-66, 64	61-66, 65	60-64, 63	65-70, 67
AS-to-PV length:	73-76, 75	74-78, 76	72-78, 76	72-76, 75	72-76, 74	74-78, 75	75-80, 77
Caudal-fin length:[i]	23-28, 25	19-23, 21	19-24, 22	20-24, 23	21-25, 23	19-23, 21	23-28, 25
Dorsal-fin (D) length:[f]	21-26, 24	18-22, 20	18-24, 20	19-23, 21	23-26, 24	18-21, 20	23-29, 27
Dorsal-fin-base length:[f, h]	14-17, 16	11-16, 13	13-16, 14	11-16, 13	14-18, 16	12-14, 13	16-20, 18
Depth at OD:	16-22, 20	19-22, 20	17-22, 19	16-21, 19	17-22, 19	18-21, 20	18-27, 23

[a] Eye diameter = (AS to PE)-(AS to AE).
[b] Ignore differences in maximum values since they may be affected by developmental state at hatching.
[c] Ignore differences in minimum values since 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] For *Xyrauchen texanus* with a rare count of only 12 or 13 principal dorsal-fin rays, lengths for this character may be less than the range reported herein (all specimens analyzed for these measures had ≥14 principal dorsal-fin rays or pterygiophores).
[g] Applicable only to specimens with most principal dorsal-fin rays formed; ignore differences in minimum values since some data represent specimens with a few fin rays less than the adult count.
[h] Dorsal-fin base = (AS to ID)-(AS to OD).
[i] Caudal-fin length = (AS to PC)-(AS to PHP), total length minus standard length.

lengths (measured to the origin of the pectoral-fin bud) relative to standard (notochord) length. Bluehead and flannelmouth protolarvae typically have the smallest eyes and heads. For subsequent developmental intervals, differences in eye diameter are best considered as a percentage of head length. For these later stages, Utah sucker usually have the largest eyes whereas flannelmouth sucker continue to average the smallest eyes, although not by much. Head length among juveniles is often greatest for razorback and white suckers and least for bluehead, flannelmouth, and mountain suckers.

In addition to dorsal-fin lengths discussed above, pectoral- and caudal-fin lengths are also useful for specific developmental intervals. Pectoral-fin length is sufficiently diagnostic only for protolarvae, and then only with respect to the maximum values which are greatest for white, longnose, mountain, and razorback suckers and least for Utah and bluehead suckers. Caudal-fin length is sufficiently diagnostic only for metalarvae and juveniles. Among metalarvae, caudal-fin length is greatest for razorback sucker and least for mountain sucker. Among juveniles, it is greatest for razorback and Utah suckers and least for mountain and longnose suckers.

Lengths from snout to origin of the pelvic fin and posterior margin of the vent are the only remaining length characters considered sufficiently diagnostic to include in Table 38. Although the position of pelvic-fin origin remains about the same relative to dorsal-fin origin for all species, snout-to-pelvic-fin-origin length, like snout-to-dorsal-fin-origin length discussed above, is typically greatest (farthest back) for bluehead sucker and least for flannelmouth sucker metalarvae and juveniles. For postflexion mesolarvae, length from snout to origin of the pelvic fin is also greatest for bluehead sucker but least for Utah, longnose, and razorback suckers. Snout-to-vent length is greatest for Utah and razorback sucker postflexion mesolarvae and razorback sucker juveniles.

As noted above, body depth measured at the origin of the dorsal fin reflects the amount of yolk remaining in protolarvae and mesolarvae and the health or condition of fish in later stages. But especially for larger juveniles, it also represents differences in structural depth of the body. The upper end of the range for this measure is notably greater for razorback sucker juveniles than other species and is probably due, at least in part, to enlarging interneural bones behind the head which will eventually form the distinctive predorsal "razor" or keel of older juveniles and adults (see Frontispiece).

Pigmentation

Capture of catostomid larvae prior to initial eye and body pigmentation is rare. If not pigmented at hatching, at least eye and some body pigmentation are usually evident by emergence from the spawning substrate. Longnose, white, and mountain suckers are usually well pigmented by 9 mm SL and Utah, bluehead, and flannelmouth suckers by 11 mm SL (Table 39). Pigmentation throughout early development is generally lightest for flannelmouth sucker and especially razorback sucker.

Of all pigment characters, the most diagnostic for later larvae and early juveniles of bluehead and mountain suckers is the extent of peritoneal pigmentation (Table 39). In the ventrolateral region of the peritoneum, pigmentation is sparse to patchy in some postflexion mesolarvae as early as 14 or 15 mm SL and uniformly dark pigmentation in metalarvae by 20 to 22 mm SL (Figs. 54-58, 83-86). On the ventral aspects of the peritoneum, pigmentation is uniformly dark in all bluehead sucker greater than 25 mm SL and all mountain sucker greater than 34 mm SL. In contrast, uniform peritoneal pigmentation (light or dark) in either ventrolateral or ventral regions was not observed at all in any Utah sucker (Figs. 12-16) and only rarely in white or flannelmouth suckers greater than 34 mm SL. In longnose sucker greater than 17 mm SL, the ventrolateral peritoneal pigmentation was occasionally uniformly light (Fig. 30), but not uniformly dark until 32 mm SL, and then only rarely; on the ventral surface it was rarely uniformly light in specimens greater than 34 mm SL and never uniformly dark. Although ventrolateral peritoneal pigmentation in razorback sucker was rarely uniformly light or dark and then only in specimens greater than 25 mm or 34 mm SL, respectively, such uniform pigmentation on the ventral aspects of the peritoneum was, unexpectedly, a bit more common in specimens as small as 29 mm SL for light pigmentation or 32 mm SL for dark pigmentation. However,

Table 39. Comparison of size (mm SL) relative to pigmental state (melanin) of eyes and bodies for protolarvae and lateral to ventral regions of peritoneum for postflexion mesolarvae (P), metalarvae (M), and early juveniles (J, ≤40 mm SL) of Upper Colorado River Basin catostomids. For peritoneal pigmentation, size is preceded by initials for the applicable developmental intervals. The letter "r" indicates that the condition is rare.

Character	*Catostomus ardens*	*Catostomus castostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Eye pigmentation, protolarvae[a]							
Unpigmented	≤10	7	7	≤10	≤10	≤8	≤9
Light to moderate	9-11	7-10	7-9	9-11	9-11	8-9	7-10
Dark	≥10	≥9	≥8	≥10	≥11	≥8	≥9
Body pigmentation, protolarvae[a]							
Unpigmented	≤11	7	≤9	≤10	≤10	≤8	≤11
1-12 melanophores on dorsum	9-12	7-8	7-9	9-10	9-11	8-9	8-12
≥13 melanophores on dorsum	≥11	≥7	≥8	≥10	≥11	≥8	≥9
Peritoneal pigmentation[b]							
Lateral, P and M only[c]							
Absent	PM all	PM ≤15	PM ≤18	P ≤17	PM ≤22	P ≤14	PM ≤24
Sparse or patchy	PM ≥15	PM ≥14	PM ≥14	PM ≤17	PM ≥19	PM ≤22	PM ≥14
Uniformly light	-	M ≥18	-	M 17-19	-	M ≥21	-
Uniformly dark	-	M ≥18	-	M ≥17	-	M ≥21	-
Ventrolateral surfaces							
Absent (or obscured in J)	PMJ all	PM ≤17	PMJ all	P ≤17	PMJ all	PM ≤16	PMJ all
Sparse or patchy	J ≥19	MJ ≥16,r-15	PMJ 16-37	PM 15-17	MJ ≥23	PM 14-18	MJ 20-37
Uniformly light	-	MJ ≥18,r-15	r-J 35-37	M 17-19	r-J ≥35	M 19-21	r-J 26-37
Uniformly dark	-	r-J ≥ 32	-	MJ ≥17	r-J ≥38	MJ ≥20	r-J 35-37
Ventral surface							
Absent	PMJ all	PM ≤17	PMJ all	PM ≤17	PMJ all	PM ≤21	PMJ all
Sparse or patchy	-	MJ ≥17	J 22-37	MJ 17-25	MJ ≥22	MJ 17-34	J 23-37
Uniformly light	-	r-J ≥35	r-J 35-37	MJ 18-25	r-J ≥38	J 26-34	J ≥29
Uniformly dark	-	-	-	MJ ≥18	r-J ≥38	J ≥26	J ≥32

[a] Some to most specimens of each species will hatch with eyes or eyes and body well pigmented.
[b] Pigmentation of the peritoneum is subsurface and should not be confused with surface or cutaneous pigmentation. Also, pigment might be apparent in the dorsal and dorsolateral portions of the peritoneum of smaller larvae and should not be interpreted as pigment in the lateral region.
[c] In juveniles, lateral pigmentation of the peritoneum usually is obscured by muscle.

uniformly light or dark pigmentation of the ventral peritoneum was not observed in some other razorback sucker juveniles as large as 40 mm SL (as viewed through surface tissues without dissection).

Once melanophore pigmentation is sufficiently established, one of the more useful surface pigment characters is the extent of pigmentation on the ventral midline between the heart region and the vent (Table 40). Longnose, white, and mountain suckers typically have a continuous line of midventral pigment with more than 20 melanophores (Figs. 23-26, 28, 39-41, 43, 81, 82), at least through the larval period. Extension of this pigment line into the branchial region anterior to the heart is common in longnose and white suckers but rare in mountain sucker. Among the others, only bluehead sucker occasionally have as many melanophores along the ventral midline, but the line is either shorter or distinctly discontinuous (Figs. 53, 54). Complete absence of melanophores along the ventral midline is rare among Utah, bluehead, and flannelmouth larvae but common for razorback sucker larvae. Unlike the other species, razorback sucker larvae have not been observed to have more than six melanophores along the ventral midline (Figs. 94-98).

Presence and pattern of melanophores on the ventral to ventrolateral surfaces of the gill covers can also be diagnostic throughout the early development of these fishes. Such pigment is present on some larvae of all developmental intervals for all species except bluehead and flannelmouth sucker. It is rarely present on bluehead flexion mesolarvae and metalarvae or on flannelmouth flexion mesolarvae. This pigmentation is sometimes present as a distinctive oblique row of three or more melanophores along or near the ventral margin of one or both preopercles in longnose, white, and mountain suckers (Figs. 40, 83).

Table 40. Comparison of the more diagnostic melanophore pigmentation patterns for larvae and juveniles (≤40 SL) of Upper Colorado River Basin catostomids. Key to characters and their states is given below. Rare or questionable data are enclosed in parentheses. NA = not applicable.

Character number	*Catostomus ardens*	*Catostomus catostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Protolarvae (after pigment is well established)							
1.	1-3	3-5	4-5	1-4	1-3	3-5	1-2
2.	1-2	1,(2-3)	1-2,(3)	1	1	1-2,(3)	1-2,(3)
5.	1	1	1	1-2,(3)	1	1-2	1
7.	1-2	(2),3	2-3	1-3	1-3	2-3	1-3
8.	1-2	1-2	2-3	1-2	2-3	1-2	2-3
Flexion Mesolarvae							
1.	1-3,(4-5)	3-5	4-5	1-4,(5)	(1),2-3,(4)	(3),4-5	1-2
2.	1-2	1-3	1-3	1	1	1-3	1-3
3.	1-2	2	2	1-2	1-2	2	1-2
4.	1-2	(1),2	1-2	1-2	1	1-2	1-2
5.	1	1	1	2-3	1	1-2,(3)	1
7.	1-2	2-3	1-3	2-3	1-2	2-3	1-3
8.	2-3	(1),2	1-3	1-3	2-3	1-2	2-3
9.	1	1	1-2	1	1-2	1	1
10.	2	2	2	2	2	2	1-2
11.	1-2	1-2	1-2	1-3	1-2	1	1
12.	1-2	1-2	1-2	1-2	1	1	1
13.	2-3	2-3	2-3	1-3	2-3	2-3	1-3
Postflexion Mesolarvae							
1.	(1),2,(3-5)	3-5	(4),5	(1-2),3-4,(5)	(1),2-3,(4)	(2-4),5	1-2
2.	1-2,(3)	1-3	(1),2-3	1,(2)	1,(2-3)	(1),2-3	1-2,(3)
3.	2	2	2	(1),2	1-2	2	(1),2
5.	1-3	1-2	1-3	2-3	1-3	1-3	1,(2-3)
7.	1,(2)	(1),2,(3)	(1),2,(3)	1,(2-3)	1,(2)	(1),2	1-2
8.	1-3	1-2,(3)	1,(2-3)	1-2	1-3	1,(2)	1-2,(3)
9.	1	1	(1-2)	1	(1),2	(1)	1
12.	1-2	1-3	1-3	1-2,(3)	1-2	1-3	1-2
13.	(2),3	(2),3	(2),3	2-3	2-3	2-3	(2),3
18.	1,(2)	1-2	2	1,(2)	1-2	(1),2	(1-2)
Metalarvae							
1.	(1),2,(3)	(2),3-5	4-5	(1-2),3-4	(1),2,(3)	(2),3-5	1,(2)
2.	(1),2	1-2,(3)	1-3	1,(2)	1	1-3	1
3.	(1),2	2	2	1-2	1-2	(1),2	1,(2)
6.	1	1-2	1	1,(2)	1	1	1
11.	3	(1-2),3	3	3	(2),3	3	(1),2-3
12.	(2),3	1-3	(1-2),3	3	(1),2-3	(1-2),3	1-2
19.	1	1	1,(2)	1	1,(2)	1	(1),2
20.	1-2,(3)	1-3	1-2,(3)	1-2	1,(2-3)	1,(2)	(1),2
21.	(1),2-3	1-3	1-2,(3)	1-2,(3)	1,(2)	(1),2-3	1,(2)
22.	1	1	1	1	1	1	1-2
Juveniles							
1.	1-2,(3)	1-3,(4),5	(1-2),3-5	1-3	1-2,(3)	1,(2),3,(4-5)	1-2
2.	1,(2)	1,(2)	1-2,(3)	1	1	1,(2)	1,(2)
14.	3	3	(2),3	3	2-3	2-3	1-3
15.	2-3	1-2,(3)	1-2,(3)	1-2	1-2,(3)	(1),2-3	1-2,(3)
16.	1,(3)	1-2	1,(2),4	1	1	1	1
17.	1,(2)	1-2	1-2	1	1	1,(2)	1
19.	1-2	1-2	1-2	1	(1),2	1-2	2
20.	1-2,(3)	1-3	1-2,(3)	(1),2	1,(2-3)	1-2	1-2,(3)
22.	1-2	1,(2)	1,(2)	1	1-2	1	(1),2

Key to pigment characters and states:

1. Ventral midline from shortly behind heart region to near vent
    1. without melanophore pigment.
    2. with 1-6 melanophores.
    3. with 7-20 melanophores.
    4. with ≥21 melanophores in a short or distinctly discontinuous line.
    5. with ≥21 melanophores in a continuous or nearly continuous, full-length line or narrow band.

Table 40. Continued

2. Pigment over ventral to ventrolateral surfaces of gill covers (opercula)
    1. absent.
    2. present but not consisting of or including a distinct oblique row of 3 or more melanophores near or along margin of either preopercle.
    3. consisting of or including a distinct oblique row of 3 or more melanophores near or along margin of one or both preopercles.
3. Pigment on ventral surface of heart region
    1. absent.
    2. present.
4. Pigment under chin (anterior ventral surface of lower jaw)
    1. absent.
    2. present.
5. Pigmentation on dorsal surface between head and last myomere (for specimens with >12 melanophores on dorsal surface)
    1. not scattered or sparsely scattered with at least a partial distinct lengthwise line or narrow band of melanophores (sometimes in oblique pairs or clusters) 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 (sometimes in oblique pairs or clusters) 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.
6. Dorsal body pigmentation between head and last myomere
    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 but in a blotchy pattern (with or without emphasis on distinct lines of melanophores or melanophore clusters on or lateral and parallel to dorsal midline).
7. Dorsal midline from shortly behind head to near last myomeres
    1. with ≤24 melanophores in a short, discontinuous, or well-spaced line, or (rarely) with no distinct line of melanophores.
    2. with ≥25 melanophores but in a short or distinctly discontinuous line.
    3. with ≥25 melanophores in a distinct continuous or nearly continuous, full-length line.
8. Dorsal surface lateral to midline from shortly behind head to about 2/3 distance to last myomeres
    1. without distinct lines of melanophores (or oblique pairs or clusters of melanophores) along either side of dorsal midline.
    2. with distinctly short or discontinuous lines of melanophores (or oblique pairs or clusters of melanophores) along one or both sides of dorsal midline.
    3. with distinct continuous or nearly continuous, full-length lines of melanophores (or oblique pairs or clusters of melanophores) along (parallel to) each side of dorsal midline.
9. Melanophores in lines lateral (and parallel) to dorsal midline between head and 2/3 distance to last myomeres mostly
    1. mostly in single file.
    2. mostly in obliquely oriented pairs or clusters resulting in a herringbone pattern down the back.
10. Dorsal surface of head pigmented
    1. only over hindbrain (posterior to middle of eyes).
    2. over both mid- and hindbrain (anterior and posterior to middle of eyes).
11. Lateral surface of body above horizontal myosepta (or lateral midline), exclusive of melanophores associated with horizontal myosepta, air bladder, visceral cavity (peritoneum), or gut,
    1. unpigmented.
    2. with 1-5 melanophores.
    3. with ≥6 melanophores.
12. Lateral surface of body below horizontal myosepta (or lateral midline), exclusive of melanophores associated with horizontal myosepta, air bladder, visceral cavity (peritoneum), or gut,
    1. unpigmented.
    2. with 1-5 melanophores.
    3. with ≥6 melanophores.
13. Lateral surface of head posterior to eyes
    1. unpigmented.
    2. with 1-5 melanophores.
    3. pigmented with ≥6 melanophores.
14. 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,
    1. scattered only partially down to the horizontal myoseptum (lateral midline).
    2. scattered fully and evenly down to the horizontal myoseptum with few if any melanophores below the myoseptum.
    3. scattered evenly or in blotchy pattern (continuous with dorsal and dorsolateral surface pattern) down to horizontal myoseptum and at least partially to bottom-of-eye level below.
15. 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,
    1. absent including caudal peduncle.
    2. absent except on caudal peduncle.
    3. present.
16. Midlateral surface of body
    1. with no distinct, near-eye-size spots of pigment.

Table 40. Continued

2. with 1 distinct, near-eye-size spot of pigment on caudal peduncle near base of caudal fin.
3. with 2 distinct, near-eye-size spots of pigment, one between head and dorsal fin and the other between pelvic and anal fins.
4. with 3 distinct, near-eye-size spots of pigment, one between head and dorsal fin, the second between pelvic and anal fins, and the third on the caudal peduncle near the base of the tail.

17. Pigment outlining scales
    1. absent or light.
    2. bold.
18. Developing dorsal fin
    1. with few (≤5) or no melanophores.
    2. with many (≥6) melanophores.
19. Pigment in dorsal fin
    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 on at least a portion of membranes between some or all principal fin rays.
20. Pigment in anal fin
    1. absent.
    2. present but very light with only a few (≤5) melanophores (sometimes very linear along margins of rays and easily overlooked).
    3. present but more prominent with many (≥6) melanophores (sometimes very linear along margins of rays and easily overlooked).
21. Pigment in pectoral fin
    1. absent.
    2. present but very light with only a few (≤5) melanophores.
    3. present but more prominent with many (≥6) melanophores.
22. Pigment in caudal fin
    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 on most or at least the middle or distal portion of membranes between some or all principal fin rays.
    3. extensive along principal fin rays and notably present (more than just a few melanophores) to extensive only on proximal portions of membranes between some or all principal fin rays.

Another obvious diagnostic character for protolarvae and mesolarvae is the melanophore pattern on the dorsal surface from behind the head to about two-thirds of the distance to the last myomeres. Pigment here is scattered with no distinct lines parallel to the dorsal midline in most mesolarvae of bluehead and mountain suckers (Figs. 53, 54, 81, 82). Many flannelmouth sucker and some white sucker mesolarvae have lines of melanophores lateral to the dorsal midline in which the melanophores tend to be in obliquely oriented pairs or groups resulting in a distinctive "herringbone" pattern (Figs. 39, 67).

Extent of lateral body pigmentation is useful for mesolarvae through juveniles. Among flexion mesolarvae, for example, at least a couple melanophores are sometimes present between dorsolateral surface and the horizontal myoseptum of all but mountain and razorback suckers. Even by the metalarval phase, rare specimens of longnose and razorback suckers are still without pigment in this region (Fig. 97). Among juveniles, only white sucker often have three large, distinct, midlateral spots on the body: one anteriorly between the head and dorsal fin; one under the dorsal fin; and one near the end of the caudal peduncle (Fig. 44). Longnose sucker occasionally have a similarly large and distinct caudal-peduncle spot and Utah sucker rarely two comparable spots anterior to the vent (possibly with a faint or indistinct caudal spot). The large, distinct, caudal-peduncle spot observed on many white and some longnose suckers should not be confused with the small but sometimes prominent concentration of pigment sometimes present in the same location on these and most other species. The scales of most white and longnose suckers and some Utah and mountain suckers greater than 30 mm SL are well outlined with pigment (Fig. 44).

Distribution of pigment in various fins can be diagnostic for later larvae and juveniles. Pigment along the rays of the dorsal and caudal fins is typical of all catostomids considered herein. In addition, notable pigmentation (more than just a few melanophores, sparsely scattered to

abundant) on the membranes between principal dorsal-fin and caudal-fin rays is characteristic of most metalarval and nearly all juvenile razorback suckers (Fig. 100). In contrast, the membranes between principal dorsal-fin and caudal-fin rays of all other metalarvae, except rarely in the dorsal fins of white and flannelmouth suckers, are never pigmented with more than a few incidental melanophores. Among other juveniles up to 40 mm SL, the membranes between dorsal-fin and caudal-fin rays of all bluehead sucker and caudal-fin rays of all mountain sucker and nearly all white and longnose suckers are similarly unpigmented.

Mouth characters

Mouth characters are important in the diagnosis of adult catostomids. Unfortunately the mouths are insufficiently developed in all but the latest larvae and certain characters remain indistinct in the earliest juveniles (e.g., the lower lip lobes of some bluehead sucker up to 25 mm SL, Table 41).

Mouth position remains terminal for some metalarvae and juveniles of mountain and razorback suckers up to 25 mm SL, but changes to low terminal before the metalarval phase of longnose and flannelmouth suckers and becomes low terminal or subterminal by 19 mm SL for metalarvae of the remaining species. Some white, flannelmouth, and razorback suckers have low terminal mouths throughout the metalarval phase and early juvenile period, at least up to 40 mm SL (Figs. 99, 100). The first subterminal mouths appear as early as 18 mm SL for longnose and bluehead sucker metalarvae and as late as 32 mm SL for razorback sucker juveniles. All bluehead sucker juveniles and metalarvae over 19 mm SL have subterminal mouths (Figs. 56-58). Likewise for all mountain sucker greater than 25 mm SL, Utah sucker greater than 31 mm SL, and longnose sucker greater than 34 mm SL.

A median cleft divides the lower lip of later metalarvae and juveniles into two distinct lobes. The cleft is deep in most species but bridged at the base by a few rows of papillae and therefore shallow in bluehead and mountain suckers. Once the lower lips are sufficiently formed to distinguish two lobes, the lower lip lobes of most metalarvae and some juveniles of all species are well separated. This separation continues for some Utah, white, and bluehead suckers up to 25 to 31 mm SL (Figs. 56, 57), some razorback sucker up to at least 37 mm SL, and many mountain sucker to at least 40 mm SL (Figs. 84-86). The gap between lip lobes closes much more rapidly in longnose and flannelmouth suckers with all specimens over 18 or 20 mm SL, respectively, having either slightly separated or adjacent lip lobes (Figs. 29, 30, 70-72).

The presence or absence of notches at the corners of the mouth is diagnostic for juveniles as well as adults. For bluehead and mountain suckers, the notches are present and distinctly separate the upper and lower lips (Figs. 57, 58). For the other species, distinct notches do not develop and the upper and lower lips are more-or-less smoothly joined (Figs. 71, 72).

Table 41. Comparison of size (mm SL) relative to mouth position and lower lip lobe separation for metalarvae (M) and juveniles (J, ≤40 mm SL) of Upper Colorado River Basin catostomids. Size is preceded by initials for the applicable developmental intervals; "r" indicates that the condition is rare.

Character	*Catostomus ardens*	*Catostomus castostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
Mouth position							
Terminal, above bottom of eye	M ≤19	-	M ≤18	M ≤17	-	MJ ≤25	MJ ≤25
Low terminal, at or below bottom of eye	MJ ≤31	MJ ≤34	MJ all	M ≤19	MJ all	MJ ≤25	MJ all
Subterminal, low, and not most anterior portion of snout	J ≥23	MJ ≥18	J ≥19	MJ ≥18	MJ ≥22	J ≥23	J ≥32
Lower lip lobes, median separation							
Indistinct	M ≤18	M ≤15	M ≤18	MJ ≤25	-	M ≤22	-
Well separated	MJ ≤25	M 15-18	MJ ≤31	MJ ≤28	M ≤20	MJ all	MJ ≤37
Slightly separated	MJ ≥18	MJ 18-37	MJ 17-31	J ≥22	MJ all	J ≥23	MJ 20-37
None, adjacent	r-J ≥22	MJ ≥18	MJ ≥17	J ≥22	MJ ≥22	r-J ≥26	MJ ≥20

Skeletal features

Osteological features can be conclusively diagnostic for late metalarvae and juveniles of razorback sucker, subgenus *Pantosteus*, and subgenus *Catostomus*. Unfortunately these characters, as well as vertebra counts discussed under meristics, require that specimens be cleared and preferably stained for bone (or that the structures of interest be otherwise exposed). They are therefore best used to confirm or refine identities based on more external characters for which special preparation is not required. The frontoparietal fontanelle (opening between the frontal and parietal bones–covered with connective tissue) and first interneural bone are observable in some late postflexion mesolarvae whereas the remaining skeletal characters considered herein are applicable only to larger metalarvae and juveniles (Fig. 6). Adult descriptions suggest that more detailed study of larval and early juvenile skeletons might reveal additional skeletal differences, but these are probably the more obvious differences.

As the bones of the skull form, an oval to rectangular fontanelle, approximately half as wide as long, forms in postflexion mesolarvae and small metalarvae. By 20 mm SL, the fontanelle narrows to a more rectangular shape and maximum width is less than 50% of maximum length for all but razorback and longnose suckers (Table 42, Fig. 105). Beyond 20 mm SL, fontanelle length increases proportionately with body length, but width and shape vary with species. Width generally also increases in razorback sucker, maintaining a more-or-less oval shape, decreases in mountain sucker, and remains relatively constant in the others (greatest in longnose sucker and least in bluehead sucker). For specimens 26 to 46 mm SL, fontanelle width remains at least 48% of length in most razorback sucker (rarely as low as 43%), drops to less than 25% in mountain sucker, and ranges from 25 to 47% in the others (generally greatest in longnose and Utah suckers and least in bluehead sucker). Observations for Utah sucker may be suspect due to poor culture conditions and growth rates (Appendix C, Snyder and Muth 1988).

Adult descriptions of the subject species reveal that the fontanelle is significantly reduced or lost only in bluehead and mountain suckers. Smith (1966) reported that the fontanelle of bluehead sucker is usually reduced in juveniles and closed in adults, whereas that of mountain sucker adults is usually reduced to a narrow slit and only occasionally obliterated. To preliminarily document changes in fontanelle shape and size toward the adult condition, we cleared and stained one 76 to 81 mm SL yearling for each species except Utah sucker (specimen not available). Based on these solitary observations (Table 42), the fontanelle continues to grow in both length and width in razorback sucker and maintains its larger width-to-length ratio (45%). The fontanelle increases significantly only in length for all other species except mountain sucker, resulting in decreased width-to-length ratios (31% for longnose sucker, 25-26% for white and flannelmouth suckers, and 19% for bluehead sucker). Only in mountain sucker was the fontanelle closed. More yearling and older specimens must be examined to determine if fontanelle closure is typical of mountain sucker populations in the UCRB.

The large, fan-shaped, first interneural bone of razorback sucker metalarvae and juveniles over 16 mm SL readily distinguishes it from the other species (Fig. 106). By late in the metalarval phase, the smaller interneurals posterior to the first also develop enlarged or flared tops. The interneurals eventually form the skeletal basis for the unique predorsal keel or "razor" of the razorback sucker (Fig. 103, Frontispiece). By 20 mm SL, the first interneural generally segregates the remaining species according to subgenera. Most members of subgenus *Catostomus* (at least Utah, white, and flannelmouth suckers) have a moderate to large anvil-shaped first interneural with a moderate to long posterior extension (especially long in flannelmouth sucker). Subgenus *Pantosteus* (bluehead and mountain suckers) have a smaller, somewhat blocky first interneural with a short to moderate posterior extension. The interneurals for similar-size longnose sucker (also subgenus *Catostomus*) examined for this study are less well defined and appear to develop more slowly than for the other species. The first interneural of 40-mm-SL longnose sucker juveniles (Fig. 33) remains small and abbreviated in shape, somewhat like that of subgenus Pantosteus metalarvae or juveniles about 21 to 22 mm SL (Figs. 61, 89, 106). This condition might be associated with the more cylindrical anterior-body

Table 42. Comparison of frontoparietal fontanelle size for selected length groups of larval and juvenile catostomids of the Upper Colorado River Basin. "N" is number of specimens examined.

Size group Character	*Catostomus ardens*	*Catostomus catostomus*	*Catostomus commersoni*	*Catostomus discobolus*	*Catostomus latipinnis*	*Catostomus platyrhynchus*	*Xyrauchen texanus*
17-19 mm SL, n	2	2	2	4	3	0	3
Width, mm	1.0-1.2	1.5-1.5	0.8-1.0	0.6-0.9	0.8-1.2		1.0-1.2
Length, mm	2.0-2.2	1.8-2.1	2.0-2.2	1.4-1.8	1.2-2.0		1.7-1.9
Width/length, %	45-60	71-83	40-45	41-50	50-67		59-63
20-21 mm SL, n	1	2	2	2	3	2	5
Width, mm	0.9	1.5-1.7	0.6-0.8	0.5-0.9	0.6-0.7	0.6-0.8	1.0-1.3
Length, mm	2.1	2.0-2.1	1.9-2.1	1.7-1.7	1.8-2.0	2.2-2.2	1.8-2.1
Width/length, %	43	75-79	32-38	29-35	33-35	27-36	52-68
22-25 mm SL, n	2	3	1	3	3	1	2
Width, mm	0.9-0.9	0.9-1.5	0.8	0.5-0.8	0.8-0.8	0.7	1.0-1.3
Length, mm	2.3-2.4	2.1-2.3	2.0	1.3-2.8	1.8-2.1	2.2	1.9-2.1
Width/length, %	38-39	39-68	40	29-38	38-44	32	53-62
26-34 mm SL, n	3	3	2	2	2	1	2
Width, mm	1.0-1.0	1.1-1.4	0.8-0.8	0.6-0.7	0.7-0.8	0.5	0.9-1.3
Length, mm	2.3-2.4	2.7-3.0	2.3-2.6	2.0-2.2	2.2-2.3	2.1	2.1-2.3
Width/length, %	42-43	40-47	31-35	27-35	30-36	24	43-57
35-46 mm SL, n	1	2	1	1	1	2	3
Width, mm	1.1	1.1-1.4	0.9	0.7	0.7	0.4-0.5	1.1-1.7
Length, mm	2.7	3.2-3.8	3.0	2.7	2.3	2.5-2.7	2.3-3.4
Width/length, %	41	29-44	30	26	30	15-20	48-50
All 22-46 mm SL, n	6	8	4	6	6	4	7
Width, mm	0.9-1.1	0.9-1.5	0.8-0.9	0.5-0.8	0.7-0.8	0.4-0.7	0.9-1.7
Length, mm	2.3-2.7	2.1-3.8	2.0-3.0	1.3-2.8	1.8-2.3	2.1-2.7	1.9-3.4
Width/length, %	38-43	29-68	30-40	26-38	30-44	15-32	43-62
47-75 mm SL, n		2					
Width, mm		1.1-1.4					
Length, mm		3.8-4.5					
Width/length, %		29-31					
76-81 mm SL, n		1	1	1	1	1	1
Width, mm		1.5	0.8	0.7	1.0	0.0	2.3
Length, mm		4.8	3.1	3.7	4.0	0.0	5.1
Width/length, %		31	26	19	25	0	45

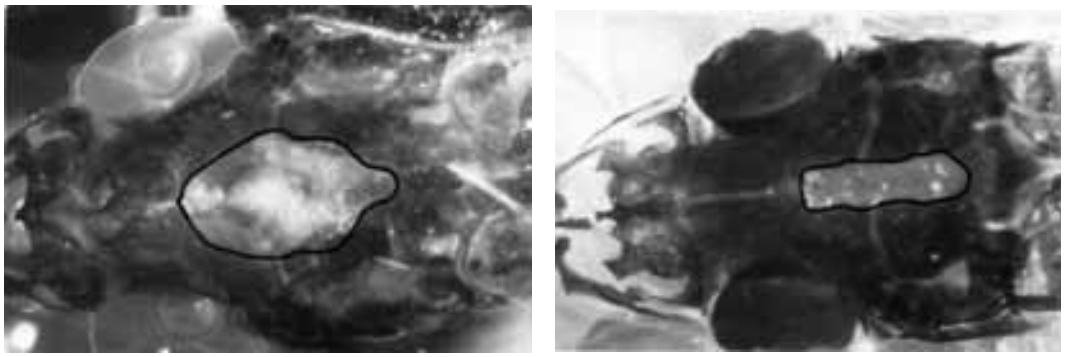


Fig. 105. Frontoparietal fontanelles of early juveniles. Left – *Xyrauchen texanus*; wide and oval. Right – *Catostomus* species; moderately wide to narrow and rectangular.

shape of longnose sucker relative to other members of subgenus *Catostomus*.

The position of mandibles relative to maxillae is also diagnostic for subgenus *Pantosteus*. For juveniles and metalarvae greater than 22 mm SL, the anterior margins of the mandibles are closer to the posterior than anterior ends of the maxillae in bluehead sucker and mountain sucker (Fig. 107). For the other species, they are closer to the anterior ends of the maxillae. However, by about 40 mm SL, at least some flannelmouth suckers have anterior margins of the mandibles positioned about midway between anterior and posterior ends of the maxillae.

Shape and size of anterior-dorsal projections on the maxillae are diagnostic for razorback sucker and subgenus *Pantosteus* greater than 22 mm SL, sometimes smaller. The anterior-dorsal projections of the maxillae are very shallow to almost absent in razorback sucker, relatively long and pointed (at least as deep as wide at the base) in bluehead and mountain suckers, and intermediate (prominent but blunt and less deep than wide at the base) in subgenus *Catostomus* (Fig. 108). By 40 mm SL, these projections grow but relative differences in size and form continue with those of *Pantosteus* and most *Catostomus* projecting forward (Fig. 60) or even a bit outward (Fig. 46). In contrast, the anterior-dorsal projections of the maxillae of longnose sucker grow a bit larger than other members of subgenus *Catostomus* and project forward and uniquely inward or medially (Fig. 32), perhaps facilitating development of a somewhat longer, more conical snout.

The angle at which the postcleithrum extends from the cleithrum was initially suspected to be diagnostic for subgenus *Pantosteus*, about 90° for bluehead and mountain suckers and variable, but usually much less angled for the others (Fig. 109). However, the differences in this character are not always distinct, and perceived postcleithral angle can be affected strongly by angle of view.

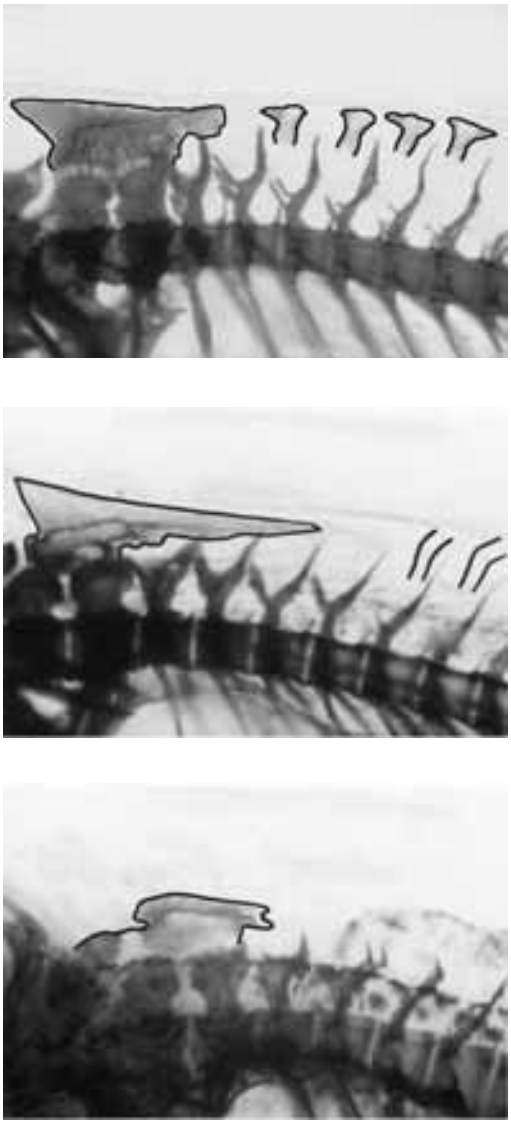


Fig. 106. Interneural bones of late metalarvae and early juveniles. Top – *Xyrauchen texanus*; first interneural large and fan-shaped; posterior interneurals well formed and flared dorsally. Middle – subgenus *Catostomus* (except *C. Catostomus*); first interneural moderate to large, anvil-shaped with prominent posterior extension. Bottom – subgenus *Pantosteus*; first interneural smaller and more blocky with short to moderate posterior projection.

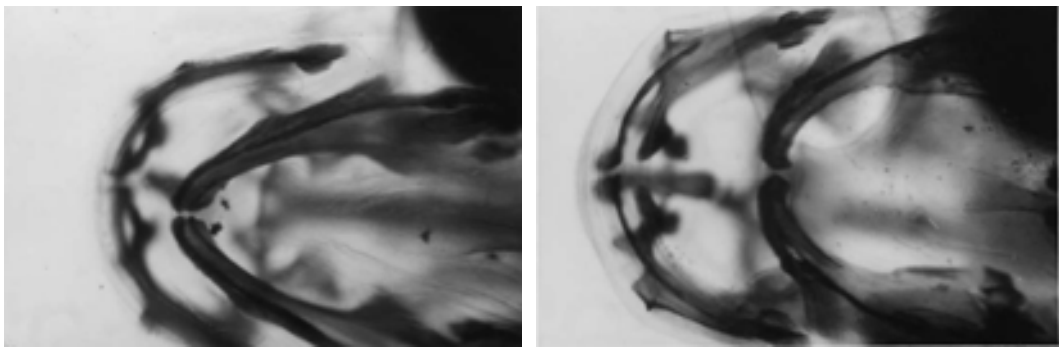


Fig. 107. Position of mandibles relative to maxillae of late metalarvae and early juveniles. Left – *Xyrauchen texanus* and subgenus *Catostomus*; anterior ends of mandibles far anterior to posterior ends of maxillae. Right – subgenus *Pantosteus*; anterior ends of mandibles slightly anterior to posterior ends of maxillae.

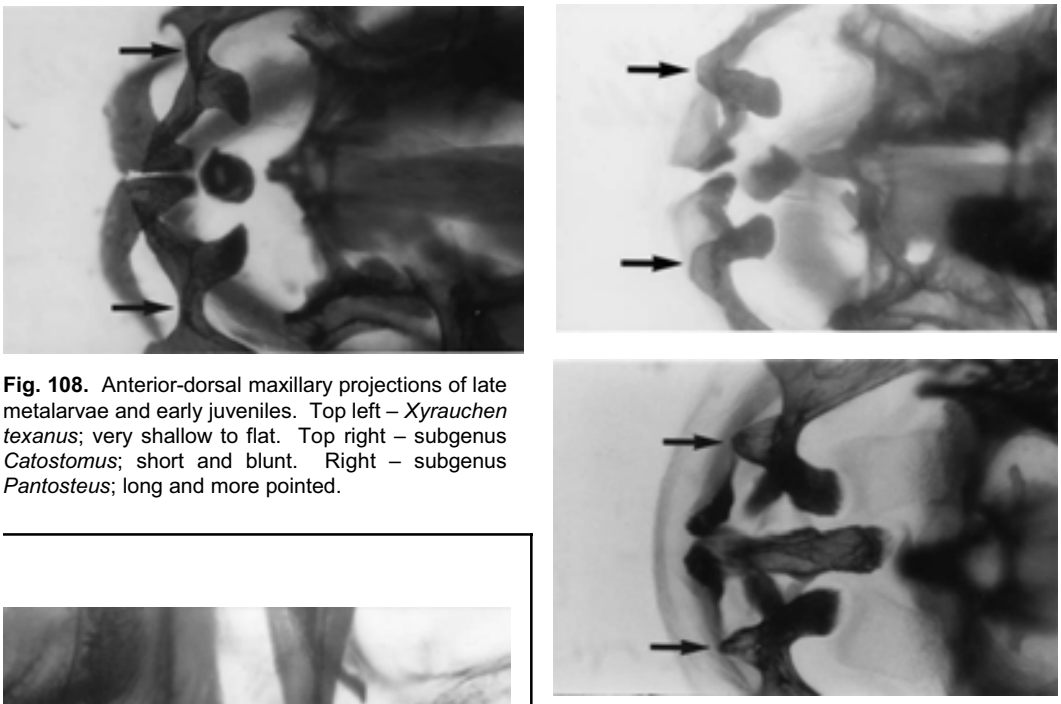


Fig. 108. Anterior-dorsal maxillary projections of late metalarvae and early juveniles. Top left – *Xyrauchen texanus*; very shallow to flat. Top right – subgenus *Catostomus*; short and blunt. Right – subgenus *Pantosteus*; long and more pointed.

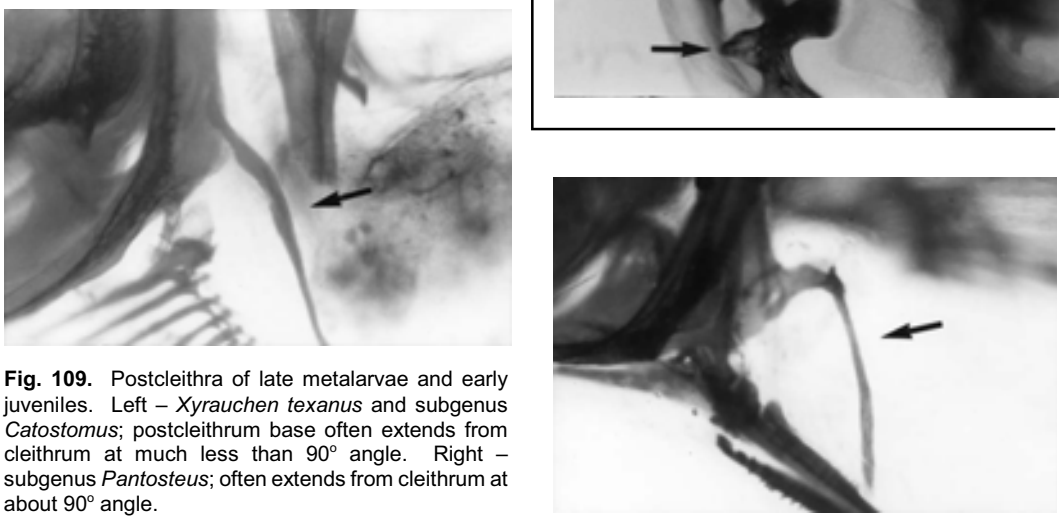


Fig. 109. Postcleithra of late metalarvae and early juveniles. Left – *Xyrauchen texanus* and subgenus *Catostomus*; postcleithrum base often extends from cleithrum at much less than 90° angle. Right – subgenus *Pantosteus*; often extends from cleithrum at about 90° angle.

Computer-Interactive Key

The "Computer-Interactive Key to Eggs, Larvae, and Early Juveniles of Catostomid Fishes in the Upper Colorado River Basin," which replaces printed keys in the earlier edition (Snyder and Muth 1990) of this guide, can be accessed from the compact disk (CD) in a pocket on the inside rear cover of this guide or downloaded from the Internet as instructed below. It consists of a data set of 112 characters and 234 taxon items (species subdivided by developmental interval and size) with associated image, text, and controlling files for use with the DELTA program, *Intkey* (Dallwitz et al. 1993 onwards, 1995 onwards, and 2000 onwards). The current version of the host program, *Intkey5* (also provided) runs under Microsoft *Windows 95* and later *Windows* operating systems. A color display with at least 800 x 600 pixel resolution (SVGA) is recommended and higher resolutions are preferred, but 640 x 480 pixel resolution (VGA) will work (less text is displayed without scrolling). The first version of this key, April 2003, which was provided as part of the final report upon which this updated guide is based, referenced figures in the earlier edition of the guide (Snyder and Muth 1990) as well as longnose sucker illustrations in that final report (Snyder 2003). This version of the key (July 2004) references instead figures herein and is intended to be used along with the preceding species accounts and comparative summary.

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 this key. However, after comparing features and flexibility (in part via Dallwitz 2000 onwards), it was decided to stay with *Intkey* 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 now 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 set provided herein for early life stages of UCRB catostomids; it can be used with a wide array of data sets for other taxa (e.g., salamanders, crustaceans, beetles, butterflies, polychaetes, flowering plants, grasses, viruses) that are available as part of published guides, on CDs, or over the Internet (go to http://biodiversity.bio.uno.edu/delta/ and select "data" or "references" for listed applications).

Installation

The key 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) and data set (cat-ucrb.zip) distribution files on the CD. Installation of *Intkey* on your hard drive is required if (or when) you anticipate downloading and using future updates of this data set or using *Intkey* with data sets for other taxa. The "Delta" directory on the CD can be copied to and used on your hard drive (or elsewhere), 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 (e.g., pdf copies of this publication), "Intk32.exe" can be downloaded from the DELTA Home Page on the Internet (http://biodiversity.uno.edu/delta/—select "Programs and Documentation," then under the programs listing, select *Intkey*). "Cat-ucrb.zip" can be similarly downloaded from the Colorado State University College of Natural Resources FTP site for LFL (go to "ftp://ftp.cnr.colostate.edu/pub/lfl/cik-data/" using your web browser and select the distribution file). Future updates of the data set will probably be available only over the Internet. Users should periodically check the download site for subsequently updated copies of the file, as indicated by a later date.

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 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 in 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.

Once *Intkey* is installed, select the data set distribution file "Cat-ucrb.zip" and using *WINZIP*, or another suitable decompression program, expand the distribution file into the directory in which you've installed *Intkey*. It will expand as a subdirectory called "cat-ucrb" and include five files and two further subdirectories ("images" and "rtf"). The current data set and associated files require about 1 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 this guide, as well as in the *Intkey* distribution package on the CD or the Internet. 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 the key directly from the provided CD, open the "Delta" directory and double click on "intkey5.exe." *Intkey* will open with the data set name highlighted in an index window (startup dialog box). If your CD drive is designated as drive "D," just click on "OK" to open the data set; otherwise, click on Browse and in subdirectory "Cat-ucrb," click on and open "intkey-ucrb.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 data-set name is listed and highlighted, 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 and select "intkey-ucrb.ink" in subdirectory "Cat-ucrb" (upon closing the data set or program, you will be given to the opportunity to add the data set to the startup index).

Upon opening the 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 initially overlaid 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) by selecting the pertinent subset of taxa. 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 by river reach (e.g., Yampa River above Cross Mountain Canyon, Colorado and lower Green Rivers in Utah, San Juan River) or individually from the list of taxa. Taxa to be considered in the key can be changed at any time.

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 skeletal characters if the specimen to be identified has not been cleared, or 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).

With the exception of internal skeletal characters (and the circumstance mentioned in the next paragraph), all characters in this key are based on external or externally visible morphology and pigmentation and can be assessed without dissection or destructive treatment. Internal skeletal characters included for metalarvae and early juveniles are intended for cleared and, preferably, bone-stained specimens, although careful dissection might also reveal the state of those characters.

Pigmentation characters used in this key (and referenced in the comparative summary) 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. 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 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 this key by treating them as 40-mm-SL juveniles. Meristic characters such as fin-ray and scale counts in this key are also applicable to all later juveniles and adults but may not be sufficient for definitive identification of these larger fish.

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 this key, even with its extensive character set, 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, because true character ranges may extend beyond those observed for description, and because of possible errors by the author or user, the results are not necessarily conclusive. As discussed above, 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 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 and, if available, with preserved reference specimens. As noted above, 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., *Catostomus* sp., unidentified catostomid).

Please report any problems, discrepancies, errors, or observed character-range extensions for future updates of this computer-interactive-key data set 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 this key is to be referenced aside from its inclusion in this guide, the suggested citation is:

Snyder, D. E. 2003 onwards. Computer-interactive key to eggs, larvae, and early juveniles of catostomid fishes of the Upper Colorado River Basin (data set for use with DELTA *Intkey*). Larval Fish Laboratory, Colorado State University, Fort Collins. Available: ftp://ftp.cnr.colostate.edu/pub/lfl/cik-data/, select distribution file cat-ucrb.zip ([date you last accessed site to verify presence of file]).

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