RECLAMATION

Managing Water in the West

Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California: A Guide to Early Life Histories

Volume 44 – Special Publication

U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

December 2010

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
December 2010	Final	

4. TITLE AND SUBTITLE
Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California: A Guide to Early Life Histories.

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Johnson C.S. Wang

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Environmental Sciences, Inc.
Clayton, CA 94517

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation
Tracy Fish Collection Facility
16650 Kelso Road, Byron, CA 94514

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service (NTIS)
Operations Division, 5285 Port Royal Road, Springfield, VA 22161

13. SUPPLEMENTARY NOTE

14. ABSTRACT
The early life stages and histories, taxonomy, and ecology of fishes in the Sacramento-San Joaquin Delta and its adjacent waters are described in this report. Information for 48 species representing 22 families is included. For each species, information pertaining to spawning, life stage taxonomic characteristics, life history, and ecological status is presented. The objective of this report is to provide information that will allow a clear identification of all early life stages of each fish species present in the study area. More attention is given to indigenous sympatric species. Species' current ecological roles in the fish community and their importance to the public are explained.

15. SUBJECT TERMS
Sacramento-San Joaquin River Delta, Sacramento-San Joaquin River Estuary, California, early life history, taxonomy, fish ecology, fish community, anadromous fishes, estuarine fishes.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		411	Donald E. Portz, Ph.D.
					19b. TELEPHONE NUMBER *(Include area code)* 303-445-2220

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

In Memory of Randall L. Brown

Tracy Fish Facility Studies California

Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California: A Guide to Early Life Histories

Volume 44 – Special Publication

by

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COVER

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Design by Doug Craft.

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Executive Summary

The Sacramento-San Joaquin River Delta (Delta) on the west coast of California is a rich habitat for fish and wildlife and a major component of the Sacramento-San Joaquin Estuary. This study area encompasses the eastern edge of the San Pablo Bay and Napa River eastward to the Carquinez Strait, Suisun Bay, west Delta, central Delta, and south Delta. The study area extends to Red Bluff of the Sacramento River in the north and to the Tracy Fish Collection Facility located at the Old River (a bypass of the San Joaquin River) in the south. The confluence of the Sacramento River and San Joaquin River creates a vast system of sloughs, levees, wetlands, and farmlands that makes up the Delta. Principal tributaries, reservoirs, and ponds adjacent to the Delta were also sampled.

Fishes in different stages of development and life cycle are found in the Delta. Anadromous fishes such as sturgeons, American shad (*Alosa sapidissima*), salmon, and striped bass (*Morone saxatilis*) are found from the Delta to the ocean, using freshwater as their spawning and nursery habitats. The early life stages of marine fishes such as starry flounder (*Platichthys stellatus),* white croaker (*Genyonemus lineatus),* and Pacific herring (*Clupea pallasii)* use the upper estuary and the Delta as their nursery ground before returning to the ocean as juveniles. Estuarine fishes such as longfin smelt (*Spirinchus thaleichthys),* delta smelt (*Hypomesus transpacificus*), and some gobies have a relatively short lifespan (1–3 years) and reside mainly in the estuary and the Delta venturing to coastal waters occasionally. Freshwater species such as carps, minnows, suckers, catfishes, and sunfishes are the most abundant fishes in both numbers and species in the Delta and its adjacent waters.

Fish populations in the study area fluctuate with environmental changes and are affected by human activities related to water resource management. Increasing water exports from the Delta have affected its ecology. As examples, declines of native species such as the delta smelt, longfin smelt, Chinook salmon (*Oncorhynchus tshawytscha*), and some nonnative fish such as striped bass and threadfin shad (*Dorosoma petenense)* are sometimes attributed to increasing water exports. Furthermore, fishes and other organisms introduced into the study area from elsewhere in North America and other countries, whether intentionally or accidentally, have negatively impacted the well being of native species.

This report offers information on fish early life stages, life histories, taxonomy, and ecology and serves as a reference and study tool for fishery biologists. Information used for this revised version of the Interagency Ecological Program Technical Report 9 titled *Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories* was collected from the various field studies conducted by federal and state natural resources agencies, academic institutions, consulting firms, and individuals from 1986–2009. A total of 48 species from 22 families is included in this report. The families of Cyprinidae (11 species) and Centrarchidae (11 species) were

published separately by Johnson C.S. Wang and René C. Reyes and family Osmeridae (4 species) by Johnson C.S. Wang.

INTRODUCTION

This document is a modified and revised version of the Interagency Ecological Program (IEP) Technical Report 9 titled *Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories* published in 1986. This document contains descriptions of the eggs, larvae, and juveniles of 48 of the 74 species of fishes from the Sacramento-San Joaquin Delta (Delta) and adjacent waters. The taxonomy of early life stages, life histories, and ecological information are also included.

Study Area

The study area includes specifically, the watershed from the eastern edge of the San Pablo Bay and tidal portion of the Napa River, eastward to the Suisun Bay, west Delta, the Delta, the Sacramento River up to the U.S. Bureau of Reclamation (Reclamation) Red Bluff Research Pumping Project (RBRPP), and the south Delta up to Reclamation's Central Valley Project/Tracy Fish Collection Facility (CVP/TFCF; Figure 1).

The Delta is a complex aquatic ecosystem and a principal component of the Sacramento-San Joaquin Estuary. It covers over 1,000 km of sloughs where freshwaters and brackish waters converge creating an enormous habitat for marine, estuarine, and freshwater fishes. This large and dynamic aquatic ecosystem is heavily influenced by seasonal outflow, such as rainfall and snowmelt and by controlled flows such as dams and diversion projects. This vast mixing ground of nutrients from inland rivers and saline waters carried by the tide from the San Francisco Bay and the Pacific Ocean creates an ecologically diverse habitat that supports one of the largest fish fauna assemblages to be found on the California coast, including two fish species found exclusively in the Delta, delta smelt (*Hypomesus transpacificus*) and splittail (*Pogonichthys macrolepidotus*).

Fishes in different stages of development and life cycle are found in the Delta. Some fish inhabit the system year round (residents) while others use it during their spawning migrations (anadromy and catadromy). Anadromous species such as sturgeons, American shad (*Alosa sapidissima*), salmon, and striped bass (*Morone saxatilis*) are found from the Delta to the ocean, using freshwater as their spawning and nursery habitats. Early life stages of marine fishes such as starry flounder (*Platichthys stellatus),* white croaker (*Genyonemus lineatus)*, and Pacific herring (*Clupea pallasii)* use the upper estuary and the Delta as their nursery ground before returning to the ocean as juveniles. Estuarine fishes such as longfin smelt (*Spirinchus thaleichthys)*, delta smelt, and some gobies reside mainly in the estuary and the Delta, venturing to coastal waters occasionally. They have a relatively short lifespans (1–3 years). Freshwater species such as carps, minnows, suckers, catfishes, and sunfishes are the most abundant fishes in both numbers and species in the Delta and its adjacent waters.

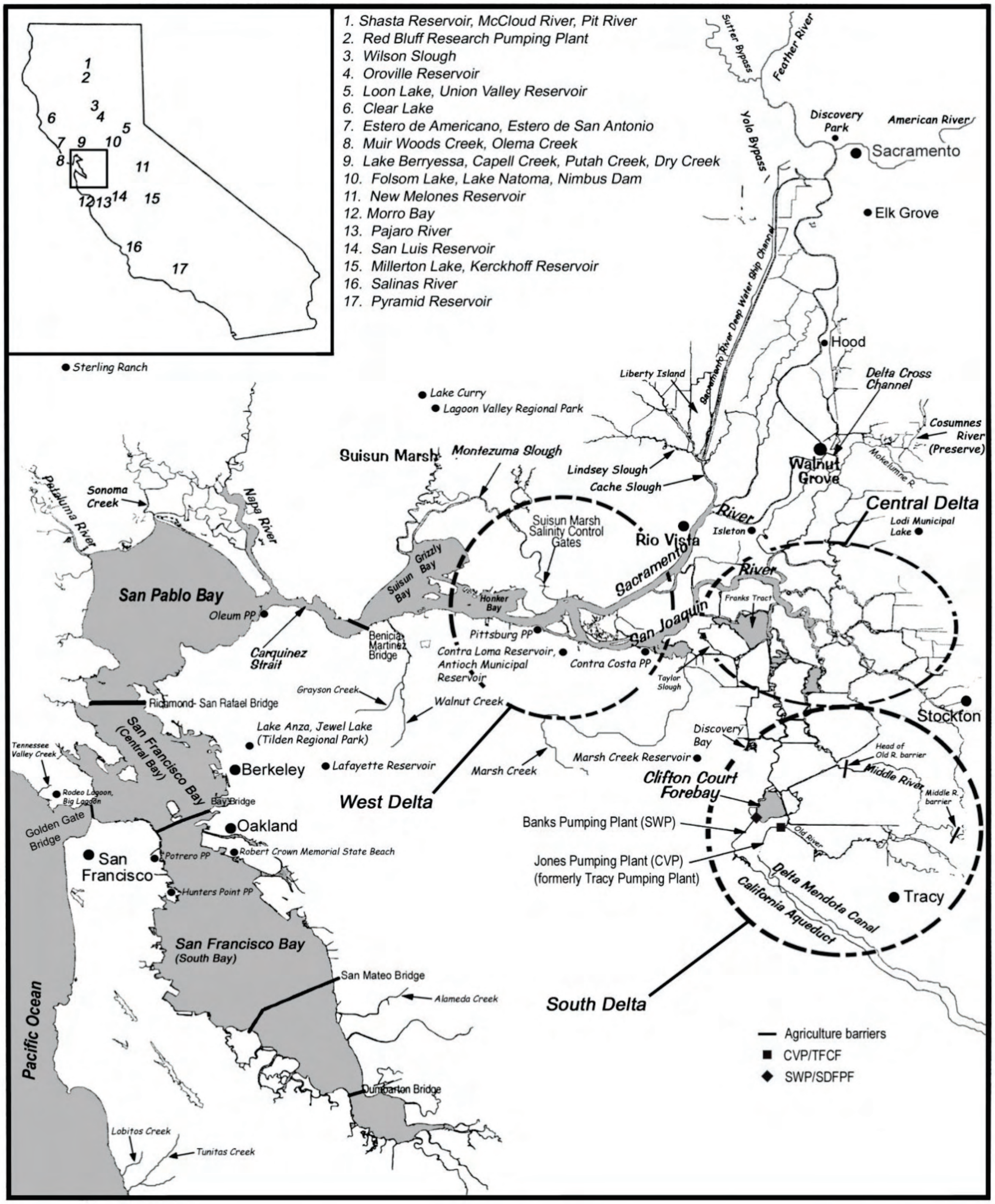


Figure 1.—Map of the study area.

Fish populations in the study area fluctuate with environmental changes and are affected by human activities related to water resource management. Increasing water exports from the Delta have affected its ecology. As examples, declines of native species including delta smelt, longfin smelt, and Chinook salmon (*Oncorhynchus tshawytscha*), and some non-native fish such as striped bass and threadfin shad (*Dorosoma petenense*) are sometimes attributed to increasing water exports. Furthermore, fishes and other organisms introduced into the study area from elsewhere in North America and other countries, whether intentionally or accidentally, have negatively impacted the well being of native species.

METHODS AND MATERIALS

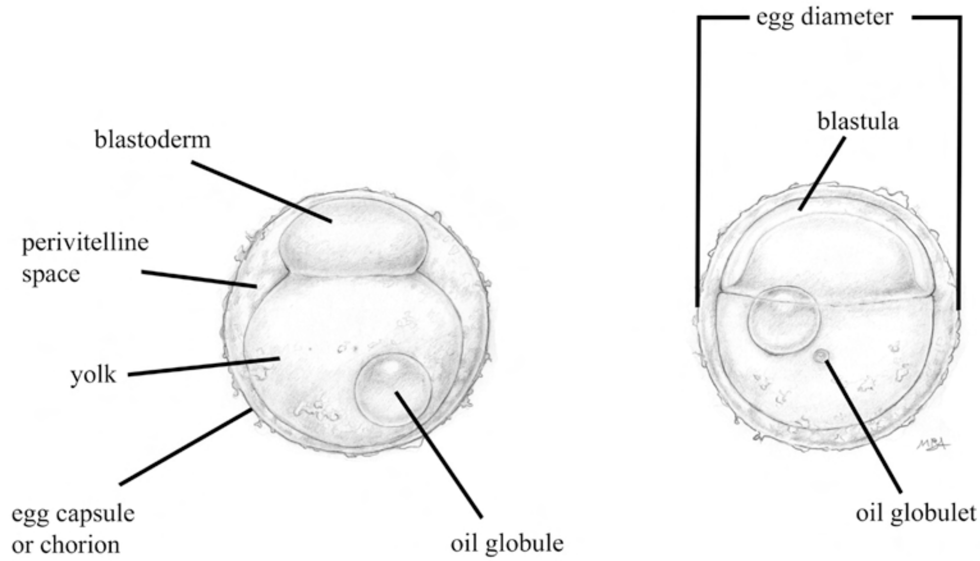
The information presented in this study comes from the sampling efforts and research programs conducted by federal and state resource agencies, academic institutions, environmental consulting firms and biologists over the last two decades. A detailed chronological accounting of these studies and efforts can be found in Appendix 1. In the text, abbreviations (initials) for many of these research programs, agencies, and institutions are used to save space. An explanation for abbreviations used in the text can be found in Appendix 2. Much information was also gained through personal communications with other biologists and researchers. References, in text, to these communications include the name of the individual and approximate dates; complete contact information for these many colleagues can be found in the Literature Cited section. Live larval specimens used in the descriptions that follow were obtained using light traps, fine mesh seines, and through the salvage operations at the CVP/TFCF (Appendix 3). Eggs for most species were obtained from both the wild and propagation in the laboratory.

Terminology

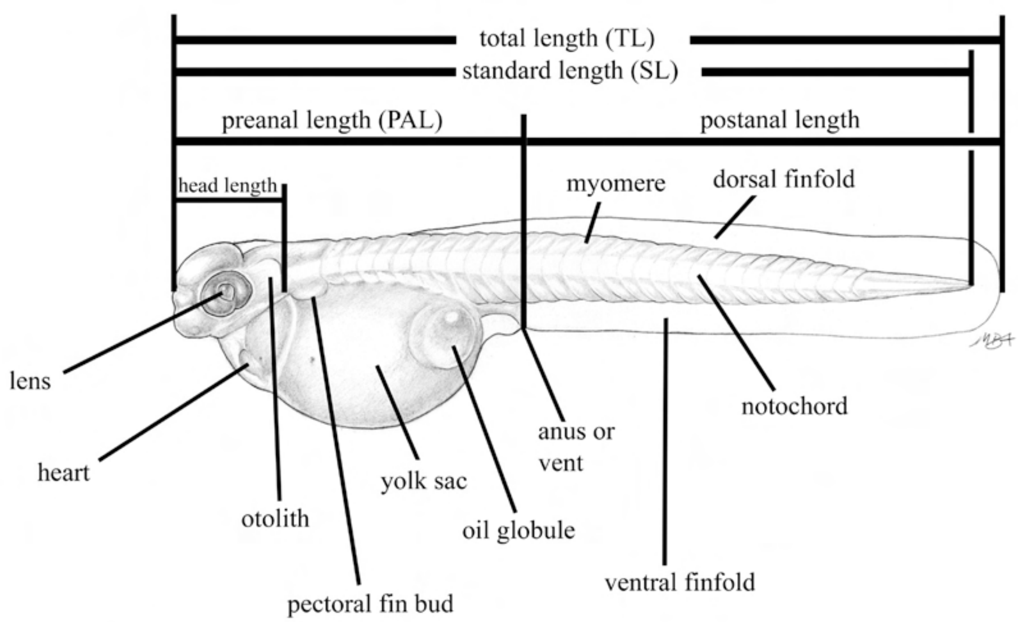
Early life stages described in this study include egg, prolarva to early postlarva, postlarva to prejuvenile, and early juvenile (Figures 2 and 3). Developmental stage definitions following Wang and Kernehan (1979), Wang (1986), Wang (2007), and Wang and Reyes (2007) are as follows: egg stage—from time of fertilization to hatching; prolarval stage—from hatching to complete yolk absorption; postlarval stage—larvae with no yolk; late postlarval to prejuvenile stage—from flexion and finbud formation to the stage when larvae have almost fully developed fins and fin rays; early juvenile stage—all fin rays are developed and scales may or may not be completely developed.

Laboratory Techniques

Morphological development of the early life stages of each species was observed and recorded using Leica™ model MZ8 dissecting microscopes (Leica Microsystems, Bannockburn, Illinois) with a Polaroid™ digital camera (PLR IP Holdings, LLC, Minnetonka, Minnesota) and Image Pro© image analysis software (Media Cybernetics,



Egg



Prolarva

Figure 2.—Anatomical features of fish eggs and prolarvae.

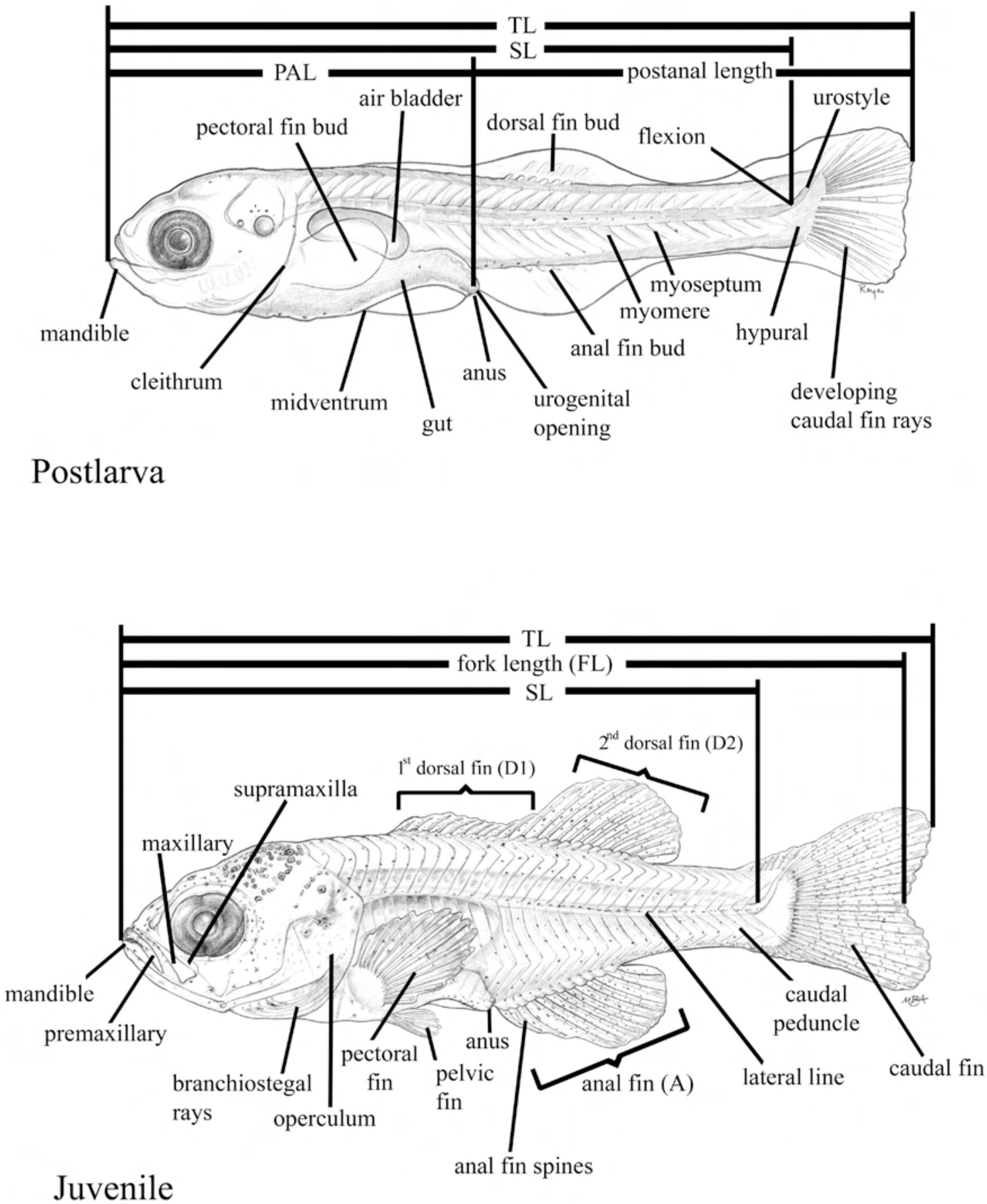


Figure 3.—Anatomical features of fish postlarvae and juveniles.

Inc., Bethesda, Maryland). Additional images were obtained using Hitachi™ and Sony™ Color Video Printer connected to a Leica™ MZ7 dissecting scope with a Panasonic Acucam camera. Line drawings by Mark Adams and Johnson Wang were borrowed from IEP Technical Report No. 9 (Wang 1986). Additional illustrations and photographs were made of live specimens by René C. Reyes.

Body structures of larval fishes are transparent and translucent, and low-contrast transmitted light (bright field) is best for counting myomeres and for observing internal structures and pigmentation. For most prejuvenile and juvenile stages, reflected light from above with little or no light from below the specimen (dark field) is necessary for observing structures since their bodies are more opaque. For most larvae, a magnification range of 10–12.5X was suitable for measuring fish length and structures; higher magnifications (30–50X) were also used for more detailed observations.

Format

Results of these studies are presented in two sections: 1) General Reproductive Biology and Early Life Histories of Fish Families Present in the Study Area and 2) Species Accounts.

General Reproductive Biology and Early Life Histories of Fish Families Present in the Study Area (pages 9–33). Information included in this section comes from the literature and original data and information collected by the author. Scientific and common names for the families follows Nelson *et al*. (2004) and Jelks *et al.* (2008). For each family, the following information is provided: a list of species present in study area; a general description of early life stages of species in the family (includes schematic drawings of eggs, larvae, and juveniles and verbal descriptors accentuating important characters); a general account of life history strategies for members of the family; and ecological status (general comments regarding the well being of family members within the study area).

Species Accounts (pages 34–305). The species accounts provide spawning information, taxonomic characteristics for each life stage, and life histories. An introduction to the family is presented before the species accounts. For families with more than one species, a table with descriptions of taxonomic characteristics or a dichotomous key for identifying young stages is included. At the end of each account, when available, schematic illustrations and digital images are presented showing the early development of the species. Lengths, descriptions, comments, and other information without citation are from this study. Format and general content of each species account is as follows:

COMMON NAME, *scientific name*

SPAWNING

Location	Specific geographic locations and general habitat types.

Season	Months.
Temperature	Upper and lower preferred.
Salinity	Preference for freshwater and (or) brackish water (oligohaline, mesohaline).
Substrates	Observed substrates, including rock, gravel, sand, mud, vegetation, and manmade structures.
Fecundity	Estimate based on subsamples or counts of mature eggs in ovaries.
EGGS	
Shape	Fertilized egg spherical, oval, or elongated.
Size	Diameter of fertilized eggs measured across the maximum outer chorion diameter or long and short axes for distinctly oval eggs.
Yolk	Color, texture, and shape.
Oil globule(s)	Size, number, and color.
Chorion	Smoothness, thickness, transparency, and elasticity.
Perivitelline space	Width of vitreous space between the chorion and the yolk measured in early developmental stages.
Egg deposition	Fish eggs deposited individually or in clusters.
Adhesiveness	Most demersal eggs have some degree of adhesiveness; pelagic eggs are not adhesive.
Buoyancy	Pelagic eggs are floating or neutrally buoyant, demersal eggs are negatively buoyant.
LARVAE	
Length at hatching	Total length (TL in mm), tip of snout to tip of tail.
Snout to anus length	Percentage of the total length (the location of anus may change with developmental stage) measured to center of anus.
Yolk-sac	Size, shape, and location.
Oil globule(s)	Size, color, number, and location.
Gut	Length, shape (straight, curled, or coiled), and thickness depending on development stage of larvae.
Air bladder	Location, shape (narrow, shallow, inflated in spherical or oval), size, and pigmentation on top of air bladder.
Teeth	Type, size, and number of rows of teeth on upper jaw and lower jaw (pharyngeal teeth formations are not included).

Size at absorption of yolk	TL when the yolk has been completely absorbed.
Total myomeres	The number of myomeres between the most anterior myoseptum and the most posterior (true) myoseptum (preanal plus postanal myomeres).
Preanal myomeres	Number counted from a line perpendicular to the long axis of fish's body at the center of the anus to the most anterior myoseptum.
Postanal myomeres	Counted from the first completed myomere behind the perpendicular line at the center of the anus to the most posterior myoseptum.
Last fin(s) to complete development	Name of the fin(s) that develop last indicating onset of juvenile stage.
Pigmentation	Melanophores and chromatophores in all shapes and sizes on head, body, and finfolds.
Distribution	Both general geographic distribution and specific range are discussed.
JUVENILES	
Dorsal fin rays	The number of spiny rays or hardened rays in Roman numerals; soft rays in Arabic numerals (Example III-10).
Anal fin rays	As for dorsal fin.
Pectoral fin rays	A similar description as dorsal and anal fins.
Mouth	Mouth location (inferior, superior, terminal) and size (large, small, slanted).
Vertebrae	Total number of vertebrae including weberian ossicles.
Distribution	Both general geographic distribution and specific information on habitats are included.
LIFE HISTORY	
Geographic distribution	Range, origin, and local records of distribution.
Spawning biology	Includes spawning runs or movements, habitats and substrates, period and frequency of spawn, sexual dimorphism, and other pertinent characteristics.
Characteristics of eggs	Includes incubation time period, development, and temperature requirements.
Characteristics of newly-hatched yolk-sac larvae and postlarvae	Includes habitat, behavior, movement, and biology.
Characteristics of juvenile fish	Includes habitat, stratum, behavior, movement, feeding, and biology.

Sexual maturity, size, and economic or other value	Includes comments on the ecological status.

RESULTS

Information on the reproductive strategies and early life histories for 48 species of fishes representing 22 families present in the study area is presented in this report. Wang and Reyes (2007, 2008) published similar reports for the families Cyprinidae (11 species) and Centrarchidae (11 species), and Wang (2007) similarly described the early life histories of the osmerids (4 species).

General Reproductive Biology and Early Life Histories of Fish Families Present in the Study Area

PETROMYZONTIDAE, Lampreys

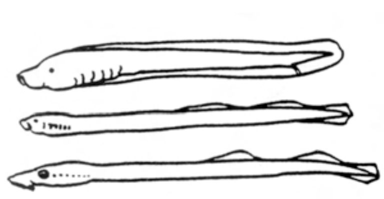
Lampreys Present in the Study Area

River lamprey *Lampetra ayresii* (Günther)
Kern brook lamprey *Entosphenus hubbsi* Vladykov and Kott
Western brook lamprey *Lampetra richardsoni* Vladykov and Follett
Pacific lamprey *Entosphenus tridentatus* (Gairdner)

General Descriptions of Early Life Stages

Eggs

Slightly elliptical to irregular.
Cream to pale green.
Holoblastic cleavage.
Demersal, adhesive.



Larvae/Juveniles (Ammocoetes)

Body elongate, laterally compressed.
Anus very posterior, near caudal region.
Jawless, mouth inferior, eyes small and underdeveloped.
Tail myotomes congested.

General Life History

River lamprey and Pacific lamprey are parasitic as adults in the ocean and nonparasitic during ammocoete stage in freshwater. Spawning occurs in streams and rivers. Death occurs after spawning. Western brook lamprey or Kern brook lamprey are nonparasitic, inhabiting foothill streams. Kern brook lamprey inhabit the western slope of the San Joaquin River drainage.

Ecological Status

All lampreys inhabiting California are native. Populations of both river and Pacific lampreys have declined in recent years; little is known of the western brook lamprey or Kern brook lamprey, and more new species may be possible.

ACIPENSERIDAE, Sturgeons

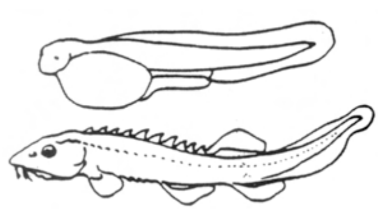
Sturgeons Present in the Study Area

Green sturgeon *Acipenser medirostris* Ayres
White sturgeon *Acipenser transmontanus* Richardson

General Descriptions of Early Life Stages

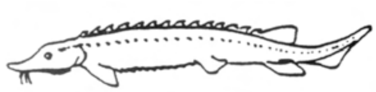
Eggs

Spherical, very large.
Opaque, gray to black.
Modified holoblastic cleavage.
Demersal, adhesive.



Larvae

Body gray, chunky, large size at hatching.
Large yolk-sac.
Anus slightly posterior.
Eyes small, underdeveloped.
Caudal fin becoming asymmetrical.
Barbels developing.



Juveniles

Body shape similar to sharks.
Elongate snout, inferior mouth, barbels present.
Bony plates.

General Life History

Green sturgeon are known to spawn in the Klamath River although spawning in the Delta is likely. White sturgeon spawn in the upper Sacramento River and the lower Sacramento River during wet years. Juveniles mostly remain in the estuarine waters of the Sacramento-San Joaquin system. Migration pattern along the Pacific coast is irregular for both species. Sturgeon have prolonged longevity, and maturity requires at least 10 years in the wild.

Ecological Status

White sturgeon and green sturgeon are native to the west coast of North America. White sturgeon supports an important sport fishery (for meat) and is cultured locally for caviar. Green sturgeon provide an important fishery for Native American tribes. Both species are decreasing in the wild. The southern green sturgeon population, which includes the Sacramento and San Joaquin Rivers, was federally listed as threatened in 2007.

ENGRAULIDAE, Anchovies

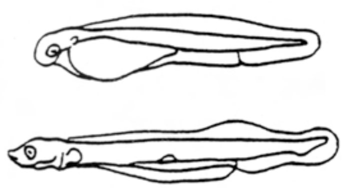
Anchovy Present in the Study Area

Northern anchovy *Engraulis mordax* Girard

General Descriptions of Early Life Stages

Eggs

Elliptical.
Yolk granular, yellowish-whitish.
Meroblastic cleavage.
Pelagic in coastal waters.



Larvae

Body elongate with finfolds.
Thoracic yolk-sac.
Anus posterior (but not as far as clupeids).
Dashed melanophores in thoracic and midventral regions.

Juveniles

Body elongate, laterally compressed.
Snout pointed, mouth inferior, maxillary extends past eye.
Origin of anal fin overlaps insertion of dorsal fin.

General Life History

Northern anchovy is a euryhaline species, residing along the Pacific coast and in the San Francisco Bay. Two spawning peaks are observed in the bay in mesohaline and polyhaline waters in winter and summer. Eggs are pelagic, drifting into oligohaline waters of Suisun Bay and west Delta.

Ecological Status

Eggs and larvae were common in Suisun Bay and the west Delta from the late 1970s to early 1980s; seldom observed after mid-1980s.

CLUPEIDAE, Herrings

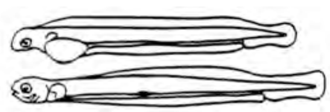
Herrings Present in the Study Area

American shad *Alosa sapidissima* (Wilson)
Pacific herring *Clupea pallasii* Valenciennes
Threadfin shad *Dorosoma petenense* (Günther)

General Descriptions of Early Life Stages

Eggs

Spherical.
Yolk yellowish to whitish, usually granular.
Meroblastic cleavage.
Demersal to semidemersal.



Larvae

Body thin, very elongate.
Yolk-sac small, thoracic.
Anus near caudal region.
Dashed melanophores along thoracic and midventral regions.

Juveniles

Body elongate, highly compressed laterally.
Origin of anal fin very posterior to insertion of dorsal fin.
Deeply forked caudal fin.
Large cycloid scales.

General Life History

American shad spawn in the Sacramento River and Feather River in spring and summer; larvae remain in the river and juveniles migrate to the Pacific Ocean in fall and winter. Pacific herring spawn in the San Francisco Bay and San Pablo Bay in winter months. Majority of larvae drift to the ocean by tide; some move to the Napa River and Suisun Bay for a longer nursery stay. Mature fish return to waters where they were spawned; populations are well defined. Threadfin shad, one of the most abundant fish in the system, is a late spring and summer spawner.

Ecological Status

American shad and threadfin shad were both introduced from east coast drainages. Pacific herring is a native fish along the coasts of the Pacific Ocean. Populations of all three species have declined over the years, especially threadfin shad. The decline has disrupted the food chain that includes the striped bass (*Morone saxatilis*), a species that relies on shad for prey. It has also affected the Pacific herring commercial fishery that is now strictly regulated by the California Department of Fish and Game (CDFG). A seasonal sport fishery for the American shad exists in upper Sacramento River and Feather River. Currently, American shad ecological status draws little attention.

CYPRINIDAE, Carps and Minnows

Note: Information for Cyprinidae family was published earlier by Wang and Reyes (2007).

Cyprinids Present in the Study Area

Goldfish *Carassius auratus* (Linnaeus)
Red shiner *Cyprinella lutrensis* (Baird and Girard)
Common carp *Cyprinus carpio* Linnaeus
California roach *Hesperoleucus symmetricus* (Baird and Girard)
Hitch *Lavinia exilicauda* Baird and Girard
Hardhead *Mylophardon conocephalus* (Baird and Girard)
Golden shiner *Notemigonus crysoleucas* (Mitchill)
Sacramento blackfish *Orthodon microlepidotus* (Ayres)
Fathead minnow *Pimephales promelas* Rafinesque
Splittail *Pogonichthys macrolepidotus* (Ayres)
Sacramento pikeminnow *Ptychocheilus grandis* (Ayres)

General Descriptions of Early Life Stages

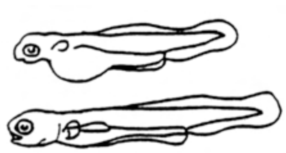
Eggs

Spherical.

Yolk yellowish. Generally no oil globules.

Meroblastic cleavage.

Demersal and adhesive (with exception of hitch eggs).



Larvae

Body elongate, heavy pigmentation.

Yolk-sac elongate, tear-drop shape.

Anus posterior (but <70% of total length).

Juveniles

Body elongate, heavy pigmentation.
Mouth terminal.
Single dorsal fin.
Anal fin ray count <15.

General Life History

Cyprinids are spring and summer spawners and can spawn more than one clutch of eggs per season. Eggs, for all species listed except hitch, are deposited and fertilized on substrate. Only fathead minnow tend their eggs. Planktonic larvae have a short window for dispersal. Juveniles are demersal and mostly associated with aquatic vegetation. Some juveniles form large schools. Splittail is the only cyprinid that inhabits both freshwater and oligohaline waters.

Ecological Status

Cyprinids are the most abundant fishes in the Delta. California roach, hitch, hardhead, Sacramento blackfish, splittail, and Sacramento pikeminnow are native to the Delta; the remaining were introduced from the eastern United States. Splittail is the most common native cyprinid but populations have declined in recent years. Sacramento pikeminnow and Sacramento blackfish are common, the former in large rivers and tributaries of the Delta while the latter is common in reservoirs, lakes, and less so in the Delta. California roach, hitch, and hardhead are seldom observed in the Delta and are often outcompeted by introduced cyprinids and centrarchids.

CATOSTOMIDAE, Suckers

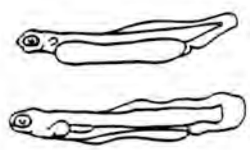
Sucker Present in the Study Area

Sacramento sucker *Catostomus occidentalis* Ayres

General Descriptions of Early Life Stages

Eggs

Spherical, large (~3 mm in diameter).
Yolk yellowish, granular.
Meroblastic cleavage.
Demersal, adhesive.



Larvae

Body elongate, heavily pigmented.

Yolk-sac very elongated; forms three segments.

Anus near caudal region (>70% of total length).

Juveniles

Body elongate.
Mouth inferior.
Air bladder has two chambers.

General Life History

Spawning occurs in streams and rivers in winter and early spring. Larvae remain in the streams and juveniles return to deep water and Delta sloughs.

Ecological Status

Sacramento sucker is the only catostomid fish in the Delta. They are an important forage fish. Introduced cyprinids and centrarchids have occupied some of their habitat; however, because Sacramento suckers spawn earlier, they may not have to compete for food.

ICTALURIDAE, North American Catfishes

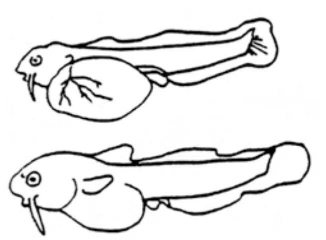
North American Catfishes Present in the Study Area

White catfish *Ameriurus catus* (Linnaeus)
Black bullhead *Ameiurus melas* (Rafinesque)
Brown bullhead *Ameiurus nebulosus* (Lesueur)
Channel catfish *Ictalurus punctatus* (Rafinesque)

General Descriptions of Early Life Stages

Eggs

Spherical, large (~3 mm in diameter).
Yolk yellowish, granular, no oil globules.
Meroblastic cleavage.
Demersal, highly adhesive, forms clusters.



Larvae

Newly-hatched larvae large, chunky.
Anus midway or slightly anterior.
Yolk-sac yellowish, very large.
Barbels.

Juveniles

Body cylindrical, large head.
Four pairs of barbels: two on maxillary, two on lower chin.
Dorsal and pectoral fins with spines.

General Life History

All catfishes known to California were introduced from rivers east of the Rocky Mountains. Catfishes spawn in shallow warm waters in spring and summer. White catfish and channel catfish are dominant in the open waters of the Delta while black bullhead and brown bullhead are often observed in small sloughs, ponds, and tributaries of the Delta. Male catfish guard the nest and newly-hatched larvae. Juveniles and adults, both bottom feeders, share the same habitat.

Ecological Status

White catfish is the most abundant ictalurid in the Delta with channel catfish a distant second. Both species are considered sportfish. Black bullhead and brown bullhead are smaller fish and are seldom observed in the Delta, but they can be overcrowded in some small earthen ponds.

OSMERIDAE, Smelts

Note: Information for Osmeridae family was published earlier by Wang (2007).

Smelts Present in the Study Area

Wakasagi *Hypomesus nipponensis* McAllister
Surf smelt *Hypomesus pretiosus* (Girard)
Delta smelt *Hypomesus transpacificus* McAllister
Longfin smelt *Spirinchus thaleichthys* (Ayres)

General Descriptions of Early Life Stages

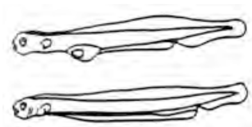
Eggs

Spherical.

Yolk yellowish-whitish, granular, with many oil globules.

Meroblastic cleavage.
Demersal.

Outer layer of chorion forms attachment to substrate.



Larvae

Body thin, elongate.

Yolk-sac small; posterior to thoracic region, with single oil globule.

Single row of dashed melanophores along midventral region.

Juveniles

Body elongate, laterally compressed.

Origin of anal fin very posterior to insertion of dorsal fin.

Adipose fin.

General Life History

Osmerids are mainly winter spawners but may extend spawning with more than one clutch of eggs when water temperature is favorable. Delta smelt usually have a 1-year lifespan but may live to spawn a second year. Surf smelt juveniles may use the Delta as a nursery, and then return to the ocean; however, delta smelt and longfin smelt spend most, if not all, of their lives in the Delta. Wakasagi spawn in and inhabit freshwater year round. All osmerids have planktonic larvae.

Ecological Status

All osmerid species in the Delta are native, except Wakasagi, a species introduced from Japan. In response to the rapid decline of 20-mm delta smelt since 2004 (record lows in 2006–2009; Reclamation salvage records), south Delta’s state and federal pumping plants have curbed pumping. Longfin smelt have also declined in recent years. Surf smelt is an abundant osmerid often harvested commercially. Wakasagi descended from upstream reservoirs in the 1990s and is well established in the Delta, especially in the lake-like environment of the Sacramento Deep Water Ship Channel. Hybridization between the delta smelt and wakasagi is possible; however, offspring are likely sterile.

SALMONIDAE, Trouts and Salmons

Salmonids Present in the Study Area

Rainbow trout/anadromous rainbow trout or steelhead *Oncorynchus mykiss* (Walbaum)
Chinook salmon *Oncorynchus tshawytscha* (Walbaum)

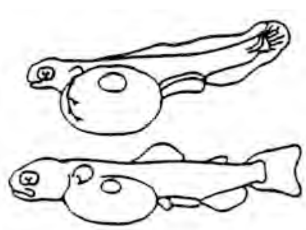
General Descriptions of Early Life Stages

Eggs

Spherical, very large (4 mm in diameter).

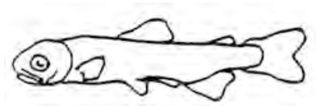
Yolk yellowish-orange, with many oil globules.

Meroblastic cleavage.
Demersal, adhesive.



Larvae

Newly-hatched larvae have extremely large yolk-sac with single oil globule.



Anus posterior.
Adipose fin.

Juveniles

Body elongate but chunky.
Parr marks on sides of body.
Adipose fin.

General Life History

There are two forms of rainbow trout: steelhead (anadromous form) and rainbow trout (freshwater form). Spawning occurs in streams in winter extending to spring depending on water temperature. After spawning, steelhead return to sea for 1–2 years before returning to their natal spawning grounds. Some steelhead are repeat spawners. Chinook salmon, an anadromous fish, has four known races: fall, late fall, winter, and spring; therefore spawning occurs almost year round at water temperatures of approximately 10–15°C. Larvae hatch and remain in the river until the yolk-sac is absorbed. Juvenile migration peaks in May and June; but residency may vary due to different spawning time of the races. Most Chinook salmon stay in the ocean for 4–5 years, return to their natal streams to spawn, and die after spawning. Steelhead and Chinook salmon develop "smolting" life stages, physiological readiness for entering the ocean.

Ecological Status

Both rainbow trout and Chinook salmon are native to California and are valued for sport and nutrition. Although Chinook salmon runs observed in the upper Sacramento River have recently been good, populations of both species have been declining along the west coast of North America.

BATRACHOIDIDAE, Toadfishes

Toadfish Present in the Study Area

Plainfin midshipman *Porichthys notatus* Girard

General Descriptions of Early Life Stages

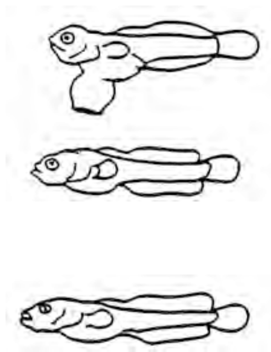
Eggs

Spherical, very large (4 mm in diameter).

Yolk bright yellow to pinkish-yellow, hard.

Chorion thick, eggs change shape during incubation.

Meroblastic cleavage.
Demersal and adhesive.



Larvae

Body short and chunky.
Anus near thoracic region.
Yolk-sac larval stage attached to substrate.

Juveniles

Body elongate, trunk and tail taper off.
Head large, flat.
Dorsal and anal fins elongate.
Photophores on head and body.

General Life History

Plainfin midshipman spawn in spring and summer, mostly in Richardson Bay. Larvae attach to substrate and juveniles are epibenthic. Some juveniles ascend to the lower Napa River and Suisun Bay to forage. Information on size or age of maturity is incomplete.

Ecological Status

Plainfin midshipman is common in the San Francisco Bay and is an important food for seals and sea lions. Spawning migration occurs from coastal water into the San Francisco Bay annually.

MUGILIDAE, Mullets

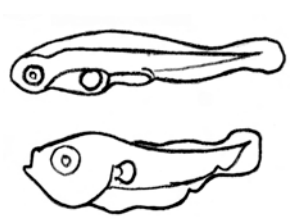
Mullet Present in the Study Area

Striped mullet *Mugil cephalus* Linnaeus

General Descriptions of Early Life Stages

Eggs

Spherical.
Yolk homogeneous, with single oil globule.
Fine striations cover chorion.
Meroblastic cleavage.
Pelagic, near surface or nuestonic.



Larvae

Newly-hatched larvae small, with heavy pigments except near caudal.
Anus located midway or slightly posterior.

Body robust in development.

Juveniles

Body cylindrical, short, and stubby.
Large head and large eye.
Development of adipose eyelid.
Anal fin spines change from II to III at 30–40 mm TL.

General Life History

Striped mullet spawn offshore of southern California. Larvae swim toward the coast and use estuaries as their nursery. Juveniles migrate northward along the California coast when cold California currents retreat during El Niño years.

Ecological Status

Striped mullet is found in warm waters worldwide. They are an important food fish in developing countries. In southern California, striped mullet has a minor importance as a sport and commercial species.

ATHERINOPSIDAE, New World Silversides

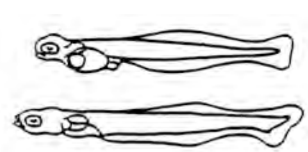
New World Silversides Present in the Study Area

Topsmelt *Atherinops affinis* (Ayres)
Jacksmelt *Atherinopsis califoriensis* Girard
California grunion *Leuresthes tenuis* (Ayres)
Inland silverside *Menidia beryllina* (Cope)

General Descriptions of Early Life Stages

Eggs

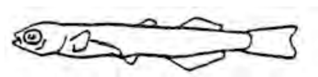
Spherical.
Yolk yellowish, granular, with one or more oil globules.
Various elongate chorion filaments.
Meroblastic cleavage.
Demersal, nonadhesive, suspended on substrate.



Larvae

Body thin, elongate, with single oil globule.
Anus thoracic.
Long tail.

Large stellate melanophores cover top of head, dashed melanophores along lateral line.



Juveniles

Body elongate.
Head and snout relatively flat.
Two dorsal fins well separated.
Anus shifts to posterior.

General Life History

Jacksmelt spawn in winter; topsmelt, California grunion, and inland silverside spawn in spring and summer. Eggs of jacksmelt, topsmelt, and inland silverside have filaments that aid in attachment to algae and plants; however, eggs of the California grunion do not have filaments and are instead buried in sandy beaches during the highest tides and hatch when washed back to the ocean by the next high tide. California grunion larvae and juveniles use nearshore and polyhaline waters as nurseries. Juvenile jacksmelt and topsmelt often ascend to the Napa River and Suisun Bay before returning to coastal waters. Inland silverside is mainly a freshwater species.

Ecological Status

Jacksmelt, topsmelt, and California grunion are native to California. Inland silverside, introduced and now abundant in the Delta, may be contributing to the decline of delta smelt by preying on delta smelt eggs and larvae. Jacksmelt and topsmelt are abundant along the coast and a food source for other fishes, seabirds, and humans. California grunions are vulnerable during their spawning run and capture by the public is prohibited by CDFG during their peak spawning (April through May); they may be collected during the open season only by hand. California grunion has been protected by CDFG since 1927.

FUNDULIDAE, Topminnows

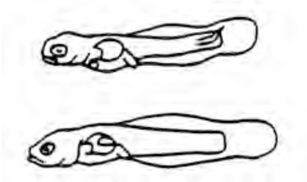
Topminnow Present in the Study Area

Rainwater killifish *Lucania parva* (Baird and Girard)

General Descriptions of Early Life Stages

Eggs

Spherical.
Yolk yellowish with oil globules.
Fine filaments cover chorion.
Meroblastic cleavage.
Demersal, suspended by filaments attached to substrate.



Larvae

Body short, stubby, generally heavily pigmented.

Anus slightly anterior.

Caudal rays visible in newly-hatched larvae.

Juveniles

Body short, stubby, tapers off, heavily pigmented.

Head large and flat.

Mouth superior.

Dorsal fin anterior to anal fin.

Tail round.

General Life History

Rainwater killifish may spawn in either saline or freshwater, mainly in summer. Both migratory and nonmigratory populations may exist.

Ecological Status

Rainwater killifish, introduced from the Atlantic coast, are valued for mosquito control and forage. Because rainwater killifish are uncommon and have a patchy distribution, they probably play only a minor role in the ecology of local fish communities.

POECILIIDAE, Livebearers

Livebearer Present in the Study Area

Western mosquitofish *Gambusia affinis* (Baird and Girard)

General Descriptions of Early Life Stages

Eggs (embedded in ovaries of females)

Spherical.

Yolk bright yellow, with many oil globules.

Meroblastic cleavage.

Larvae (embedded in ovaries of females)

Body curled, pigmented.

Anus in thoracic position.

Scales developed.

Juveniles

Body short, stubby, fully scaled.

Head flat.

Mouth superior.

Origin of dorsal fin posterior to origin of anal fin.

General Life History

Western mosquitofish complete their life cycle in warm brackish to freshwater in summer and often die during winter. This species inhabits lentic environments, such as shallow coves of ponds, reservoirs, and ditches.

Ecological Status

Western mosquitofish is native to Illinois southward to Texas and eastward to the Atlantic coast. They have been introduced into California for mosquito control.

GASTEROSTEIDAE, Sticklebacks

Stickleback Present in the Study Area

Threespine stickleback *Gasterosteus aculeatus* (Linnaeus)

General Descriptions of Early Life Stages

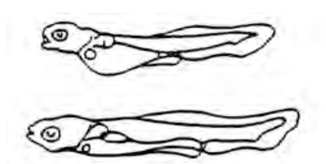
Eggs

Spherical.

Yolk yellowish, clear, with oil globules.

Meroblastic cleavage.

Demersal, adhesive, clustered.



Larvae

Body short and stubby, heavily pigmented.

Anus midway.

Elongate yolk-sac, with single oil globule.

Juveniles

Body short, narrow caudal peduncle.

First spiny dorsal fin develops into separate spines.

Bony plates develop on sides of body.

General Life History

Threespine stickleback spawn in spring and summer in the wild but reportedly spawn year-round in laboratory conditions. Newly-hatched planktonic larvae stay close to dense vegetation for shelter and nursery. Juveniles, with developed armored body plates and spines, move to pools and open waters and may overpopulate a single area. Sexual maturity is reached in 1–2 years; several clutches of eggs per breeding season have been observed.

Ecological Status

Threespine stickleback is abundant in polluted and nonpolluted streams and watersheds with shallow pools. It is abundant in the Delta and found in association with native fish species such as California roach and Sacramento sucker, as well as with introduced species. It is preyed upon by other fishes and seabirds.

SYNGNATHIDAE, Pipefishes

Pipefish Present in the Study Area

Bay pipefish *Syngnathus leptorhynchus* (Girard)

General Descriptions of Early Life Stages

Eggs (embedded in males' pouches)

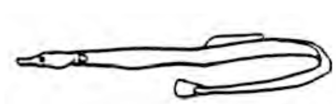
Spherical to oval.

Yolk bright yellow to orange, with many oil globules.

Meroblastic cleavage.
Demersal and clustered.

Larvae (embedded in males' pouches)

Body curled.
Yolk-sac large, spherical, thoracic.
Anus anterior.



Juveniles

Body elongate, covered with bony rings.
Mouth tubular, small.
Head bony.

General Life History

Male bay pipefish mate with and accept eggs from different females and carries the eggs and young almost year round. This species is mostly associated with shallow and open waters with vegetation.

Ecological Status

Bay pipefish is common in the San Francisco Bay and San Pablo Bay and sometimes ascends to Suisun Bay and west Delta. It is not sought after for sport, but is used as an ingredient in Asian medicine.

COTTIDAE, Sculpins

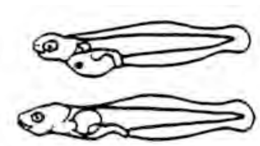
Sculpins Present in the Study Area

Prickly sculpin *Cottus asper* Richardson
Riffle sculpin *Cottus gulosus* (Girard)
Pacific staghorn sculpin *Leptocottus armatus* Girard

General Descriptions of Early Life Stages

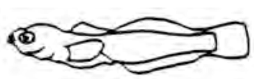
Eggs

Spherical, large (1.5 mm in diameter).
Yolk yellow, orange, green to various colors, with single oil globule.
Meroblastic cleavage.
Demersal and clustered.



Larvae

Body elongate.
Large thoracic yolk-sac.
Anus in thoracic region.
Long tail.
Gut coiled, air bladder absent.



Juveniles

Body elongate.
Mouth terminal with large, sharp teeth.
Gut straight.
Two dorsal fins.

General Life History

All cottids have marine origins but some have adapted to freshwater. Spawning occurs in winter and spring and may extend year round in foothill streams with low water temperatures. Sculpins have no air bladder; newly-hatched larvae hang at neuston level by water surface tension. Juveniles become epibenthic or take shelter in crevices of rocks. Prickly sculpin and riffle sculpin complete their life cycles in freshwater. Pacific staghorn sculpin is a euryhaline species.

Ecological Status

Cottids are important as forage for other fishes and aquatic birds. The prickly sculpin is particularly abundant in the Delta and is often used for bait.

MORONIDAE, Temperate Basses

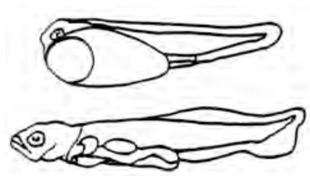
Temperate Bass Present in the Study Area

Striped bass *Morone saxatilis* (Walbaum)

General Descriptions of Early Life Stages

Eggs

Spherical, large (3 mm in diameter).
Yolk yellowish, with single oil globule.
Large perivitelline space.
Meroblastic cleavage.
Semidemersal.



Larvae

Body elongate, chunky.
Yolk-sac large, oval, with a single oil globule.
Anus midway.
Sharp teeth.
Low total myomere count (~25).

Juveniles

Body elongate.
Mouth terminal and large, with sharp teeth.
Gut straight.
Two dorsal fins.

General Life History

Striped bass spawn in the Sacramento River mostly in spring months. Eggs are buoyant and larvae are planktonic. Juveniles inhabit various habitats in freshwater as well as in brackish estuarine waters. The majority of striped bass populations in the Delta and adjacent waters are anadromous; however, some may remain in the bay and Delta all their life.

Ecological Status

Striped bass was introduced from the east coast over 130 years ago. It is the most valuable game fish in the Delta. The population declined in the 1960s, bounced back in 1980s, dropped sharply in the early 2000s, and has been low since.

CENTRARCHIDAE, Sunfishes

Note: Information for the Centrarchidae family was published earlier by Wang and Reyes (2008).

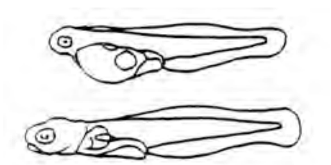
Centrarchids Present in the Study Area

Sacramento perch *Archoplites interruptus* (Girard)
Green sunfish *Lepomis cyanellus* (Rafinesque)
Pumpkinseed *Lepomis gibbosus* (Linnaeus)
Warmouth *Lepomis gulosus* (Cuvier)
Bluegill *Lepomis macrochirus* Rafinesque
Redear sunfish *Lepomis microlophus* (Günther)
Smallmouth bass *Micropterus dolomieu* Lacepède
Spotted bass *Micropterus punctulatus* (Rafinesque)
Largemouth bass *Micropterus salmoides* (Lacepède)
White crappie *Pomoxis annularis* Rafinesque
Black crappie *Pomoxis nigromaculatus* (Lesueur)

General Descriptions of Early Life Stages

Eggs

Spherical.
Yolk yellowish, granular, with single large oil globule.
Meroblastic cleavage.
Demersal, highly adhesive.



Larvae

Body elongate.
Thoracic yolk-sac, with single oil globule.
Anus slightly anterior.
Gut coiled or twisted, air bladder distinctive.

Juveniles

Body deep to elongate, laterally compressed.

Anus midway.
Two connected dorsal fins.

General Life History

Centrarchids spawn mainly in spring. Males usually construct and guard the nest and may mate with more than one female, and some allow other centrarchids to deposit eggs into their nest. Larvae have a very short planktonic life and settle in lentic environments with vegetation.

Ecological Status

Sacramento perch is the only centrarchid native to California. It was an abundant fish in the Delta before the introduction of other centrarchids from the east. The less aggressive Sacramento perch was outcompeted and disappeared from the Delta around the 1980s or early 1990s. It is now present mostly in alkaline lakes outside of its native range. Among introduced centrarchids, bluegill is most abundant, redear sunfish is expanding its range. Largemouth bass is the most sought after species by anglers.

PERCIDAE, Perches

Perch Present in the Study Area

Bigscale logperch *Percina macrolepida* Stevenson

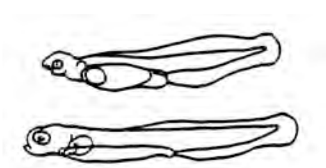
General Descriptions of Early Life Stages

Eggs

Spherical.

Yolk yellowish, clear, with single oil globule.

Demersal, adhesive.

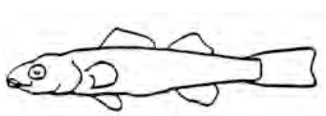


Larvae

Body elongate.

Yolk-sac elongate, thoracic, with single oil globule.

Anus slightly posterior.
Gut elongate, straight.
High myomere count (~40).



Juveniles

Body elongate, cylindrical.
Two separated dorsal fins.

General Life History

Bigscale logperch is common in the Delta, particularly in sloughs. Spawning occurs in late winter and early spring. Eggs adhere to leaves of aquatic vegetation and also under gravel. Larvae have no air bladder until early juvenile stages.

Ecological Status

Bigscale logperch, introduced from the eastern United States, is used as forage and as bait. Its distribution has expanded outside of the Delta through bait release.

SCIAENIDAE, Drums and Croakers

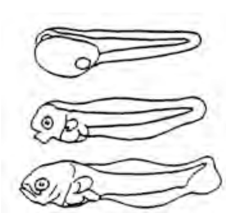
Sciaenid Present in the Study Area

White croaker *Genyonemus lineatus* (Ayres)

General Descriptions of Early Life Stages

Eggs

Spherical, small (~1 mm in diameter).
Yolk yellowish-whitish, clear, with single oil globule.
Meroblastic cleavage.
Pelagic in coastal waters.



Larvae

Body short, high finfolds.
Head large, body tapers off.
Anus thoracic.
Teeth sharp.

Juveniles

Body deep.
Caudal fin pointed.

General Life History

White croaker spawn near the coast of San Francisco Bay and possibly in the bay in winter months. Larvae use estuaries as nursery habitat, some drifting with the tide to Napa River, Suisun Bay, and Delta. Juveniles return to the ocean.

Ecological Status

White croaker are found along the coast of California. This species is often used as bait and is valued in Asian markets.

EMBIOTOCIDAE, Surfperches

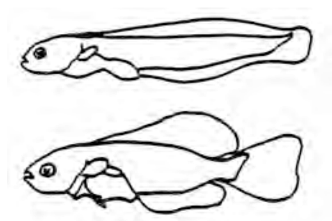
Surfperches Present in the Study Area

Shiner perch *Cymatogaster aggregata* Gibbons
Tule perch *Hysterocarpus traskii* Gibbons

General Descriptions of Early Life Stages

Eggs (embedded in ovaries of females)

Spherical, small.
An oil globule may be present.
Modified holoblastic or meroblastic cleavage.



Larvae (embedded in ovaries of females)

Body elongate (similar to tadpoles), with elongate unpaired fin rays.
Anus midway or anterior.
Large hind gut.

Juveniles

Body deep, elongate unpaired fin rays.
Two connected dorsal fins.
Body with sparse or no pigmentation.

General Life History

Embiotocids mostly inhabit the ocean, sometimes entering estuaries, with one species known to inhabit freshwater (tule perch). Mating occurs throughout the year but mainly in summer. Females give birth in spring and summer. Embiotocids reach sexual maturity within a few months of birth.

Ecological Status

Embiotocids are livebearers and are native to the coast of California. Populations of both shiner perch and tule perch have declined in recent years due to habitat loss. Tule perch is currently being used as an environmental indicator species. Both shiner perch and tule perch are valued as food fish.

GOBIIDAE, Gobies

Gobies Present in the Study Area

Yellowfin goby *Acanthogobius flavimanus* (Temminck and Schlegel)
Arrow goby *Clevelandia ios* (Jordan and Gilbert)

Tidewater goby *Eucyclogobius newberryi* (Girard)
Longjaw mudsucker *Gillichthys mirabilis* Cooper
Cheekspot goby *Ilypnus gilberti* (Eigenmann and Eigenmann)
Bay goby *Lepidogobius lepidus* (Girard)
Blackeye goby *Rhinogobiops nicholsii* (Bean)
Shokihaze goby *Tridentiger barbatus* (Günther)
Shimofuri goby *Tridentiger bifasciatus* Steindachner
Chameleon goby *Tridentiger trigonocephalus* (Gill)

General Descriptions of Early Life Stages

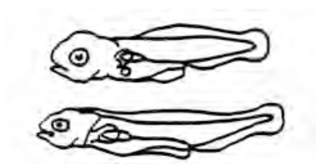
Eggs

Elliptical or tear-drop shape.

Yolk yellowish, granular, with oil globules.

Meroblastic cleavage.

Demersal and attached to roof of burrow.



Larvae

Body short.
Spherical, thoracic yolk-sac, with single oil globule.
Anus midway.
Melanophores along postanal region.
Mostly pelagic.

Juvenile

Body elongate, cylindrical.
Pelvic modified into sucking disc.
Two separated dorsal fins.
Mostly benthic.

General Life History

Gobiids spawn during different times of the year depending on species, producing multi-clutches of eggs per season. Elongated eggs attach to substrate in a single layer. Newly-hatched larvae (2–3 mm TL) are planktonic. Larvae becomes epibenthic when body is pigmented. Juveniles move upstream with the help of tides. The Delta is an important nursery ground for most gobiids, except for the chameleon goby and blackeye goby that reside in marine environments.

Ecological Status

Four species of gobiids known to the study area were introduced from Asia including yellowfin goby, chameleon goby, shimofuri goby, and Shokihaze goby. Of the native species, the tidewater goby is most at risk of extinction due to the habitat changes; it requires freshwater inflow from coastal streams which is mostly diverted for livestock. Tidewater goby was listed as federally endangered in its entire range in 1994. Yellowfin goby and shimofuri goby are the most abundant gobiid in the Delta. Gobies are probably the most used bait fishes in the Delta.

PARALICHTHYIDAE, Sand Flounders

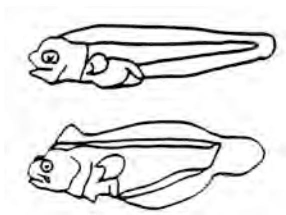
Sand Flounder Present in the Study Area

Speckled sanddab *Citharichthys stigmaeus* Jordan and Gilbert

General Descriptions of Early Life Stages

Eggs

Spherical.
Oil globule present or absent.
Meroblastic cleavage.
Pelagic or demersal.



Larvae

Both thin, slender, bilaterally symmetrical, high finfolds.
Anus near thoracic region.
Long tail.
Gut coiled.

Juveniles

Body deep, flat, asymmetrical.
Eyes usually on left side.
Very elongate dorsal and anal fins, separated from caudal fin.

General Life History

Speckled sanddab use the Delta as part of their nursery ground. Spawning occurs in deeper coastal waters in fall and winter. Larvae mostly inhabit coastal waters; however, some enter the bay and estuary (such as Napa River and Suisun Bay), especially during dry years.

Ecological Status

Speckled sanddab prefer the cooler San Francisco Bay water; few were seen in the Delta. This is a smaller-sized flatfish sold in Asian fish markets on occasion.

PLEURONECTIDAE, Righteye Flounders

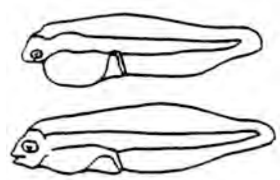
Righteye Flounders Present in the Study Area

English sole *Parophrys vetulus* (Girard)
Starry flounder *Platichthys stellatus* (Pallas)

General Descriptions of Early Life Stages

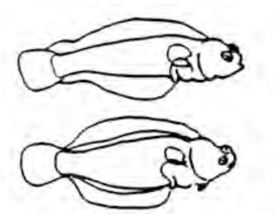
Eggs

Spherical.
Oil globule may be present.
Meroblastic cleavage.
Pelagic or demersal.



Larvae

Body elongate, bilaterally symmetrical, high finfolds, pigmentation on body and finfolds.
Anus midway or thoracic.
Gut coiled.



Juveniles

Body deep, flat, asymmetrical.
Eyes usually on right side.
Dorsal and anal fins elongated, separated from caudal fin.

General Life History

The juvenile life stages of the English sole and starry flounder are found in the Delta. Spawning occurs in coastal waters, but may also occur in the bay during winter months. Larvae are planktonic in coastal waters with some drifting into estuaries. The Delta is often used as an extended nursery. Most flounders eventually return to the ocean as adults.

Ecological Status

Both species are common in the San Francisco Bay and support both commercial and sport fisheries.

Species Accounts

Petromyzontidae – Lampreys — Lampreys are eel-like vertebrates that have no jaws or paired fins. Parasitic and nonparasitic lampreys are found in California, and at least three species are present in the Delta and its watershed. Pacific lamprey (*Entosphenus tridentatus*) is a parasitic lamprey in Pacific coastal waters; the river lamprey (*Lampetra ayresii*), also parasitic, is less common. The distribution of the river lamprey is mostly in the lower portion of the Sacramento and San Joaquin Rivers. The ammocoetes of either western brook lamprey (*L. richardsoni*) or Kern brook lamprey (*E. hubbsi*) have been collected in the upper San Joaquin River in Millerton Lake. An adult Kern brook lamprey was collected at the Friant-Kern Canal in 1988 (P.B. Moyle 1982, 1987, personal communication), but no adult western brook lampreys have been reported. Western brook lamprey, a nonparasitic freshwater species described by Vladykov and Follett (1958), is mainly found in the Sacramento River drainage, but also occurs in the San Joaquin drainage. The Kern brook lamprey, also a nonparasitic and a freshwater species, was described by Vladykov and Kott (1976) and has a known distribution from Millerton Lake southward along the western slope of the Central Valley (Brown and Moyle 1993). Specimens collected in the San Joaquin River drainage may have been misidentified as western brook lamprey. Vladykov (1973) described a new nonparasitic lamprey species (*L. pacifica*) in California and Oregon, but this species was not recognized by the American Fisheries Society (Nelson *et al.* 2004).

Populations of parasitic lampreys on the west coast of North America are in decline due to unknown or overlooked reasons (Moyle 2002, Close *et al.* 2002). Understanding the life histories of nonparasitic lampreys is difficult due to their elusive life styles and geographic isolation in some watersheds.

RIVER LAMPREY *Lampetra ayresii* (Günther)

SPAWNING

Location	Small freshwater streams of the Delta and its watershed, such as Sonoma River, Napa River, Alameda Creek, Russian River, Salmon Creek (Moyle 2002); Napa River and Sonoma River.
Season	February to May (Moyle 2002), mostly in April.
Temperature	~13.0–13.5°C (recorded at spawning site in Sonoma River; Wang 1986).
Salinity	Freshwater.
Substrate	Rocks and gravels, mixed with sands.
Fecundity	Estimated at 37,300 for a specimen at 17.5 cm TL and 11,400 at 23 cm TL (Vladykov and Follett 1958);

	11,398–37,288 from specimens 175–230 mm long (Scott and Crossman 1973).

EGGS

Size	0.7 mm in diameter (Vladykov and Follett 1958).

AMMOCOETES

Snout to anus length	~84–86% of TL for ammocoetes 15.6–20.6 mm TL, ~73–75% of TL for ammocoetes 128–130 mm TL (Wang 1986).
Gill slits	7 with separated exterior openings.
Mouth	Inferior, disk-like funnel, with lip.
Teeth	None at this life stage.
Total myomeres	120 or more from the last gill slits to the caudal (hard to count at the tip of the caudal).
Trunk myomeres	65–70 (Vladykov and Follett 1958); 60–70 (Moyle 2002); mostly 70.
Pigmentation	Snout, head, and upper dorsal half covered with light pigmentation. Ventral half of body covered with little or no pigmentation.
Distribution	Free swimming or benthic (head is above bottom of substrate and body is buried) in the Delta and tributary systems. Ammocoetes were observed at the CVP/TFCF occasionally in late winter and spring.

TRANSFORMING AND NEWLY TRANSFORMED ADULT

Teeth	Supraoral lamina has two sharp to not so sharp cusps; infraoral lamina has 7–10 small sharp cusps (Vladykov and Follett 1958); inner laterals usually have 3 rows of cusps; anterior field has at least 3 layers of cusps.
Trunk myomeres	60–71 (Vladykov and Follett 1958); 62–71 (Moyle 2002).
Dorsal fin	2, separated, but touching with a low membrane of connective tissue.
Distribution	Transforming adults are free-swimming; newly transformed adults are free-swimming or parasitic. In the Delta, distribution of adults is similar to that of the ammocoetes. More adults were observed at the CVP/TFCF in late winter and spring months.

LIFE HISTORY

The anadromous river lamprey is found in coastal streams from San Francisco to the Taku River and Lynn Canal, Alaska (Vladykov and Follett 1958). River lamprey have been reported in Mill Creek, Tehama County (Vladykov and Follett 1958), San Pablo Bay (Ganssle 1966), Carquinez Strait (Messersmith 1966), Napa River, Sonoma Creek, Alameda Creek, tributaries to San Francisco Bay, and adjacent coastal streams, such as Salmon Creek and Russian River (Moyle 2002). During this study, river lamprey have been observed in Sonoma Creek (both below and above the spillway near Glen Ellen), Napa River (just below Yountville), Sacramento River at the RBRPP located at the Red Bluff Diversion Dam, and at the CVP/TFCF.

Vladykov and Follett (1958) stated that river lamprey spawn in small streams in April and May. Moyle (2002) described the spawning from February through May. Spawning was observed in the Sonoma Creek and Napa River. The dorsal half of the body is much darker for spawning river lampreys.

River lamprey ammocoetes are morphologically similar to those of Pacific lamprey. This, coupled with overlapping distributions of the two species, makes positive identification of ammocoetes very difficult and has limited the knowledge of life history and abundance information for river lamprey. No information concerning egg incubation and development time exists. Ammocoetes are reported to burrow into sandy or muddy substrates near the bank (Scott and Crossman 1973, Hart 1973) and have also been observed in shallow banks below eddies filled with mostly decayed leaves (Wang 1986). The ammocoete stage lasts several years (Hart 1973). The transformation process or metamorphosis (from ammocoete to young adult) takes about 9–10 months, and total lifespan is about 6–7 years (Moyle 2002). Ammocoetes have no teeth, feeding on microscopic plants and animals (Scott and Grossman 1973, Hart 1973).

Large ammocoetes, transforming adults, and newly transformed adults apparently spend some time in the water column as free swimmers, since they were collected in various sampling gears, in rivers and the Delta in late winter and spring months. Some young adults move into salty water (Ganssle 1966, Messersmith 1966), and eventually all descend into the ocean in the late spring (Moyle 2002). Adults will remain in the ocean for 3–4 months before returning to the freshwater. Spawning was also recorded above the Sonoma Creek (near Glen Ellen) spillway indicating that some river lamprey might spend their life in freshwater.

River lamprey has no commercial value (Fry 1973). The adults are parasitic in rivers of California (Withler 1955, Kimsey and Fisk 1964, Hart 1973); however, fish collected at the CVP/TFCF carried no obvious scars. There is no accurate assessment of the damage to other fish species and populations.

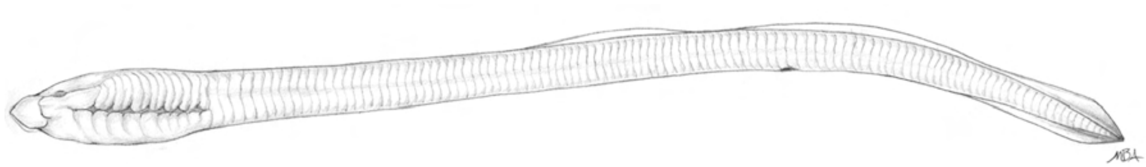


Figure 4.—*Lampetra ayresii*, river lamprey ammocoete, 133 mm TL (Wang 1986).

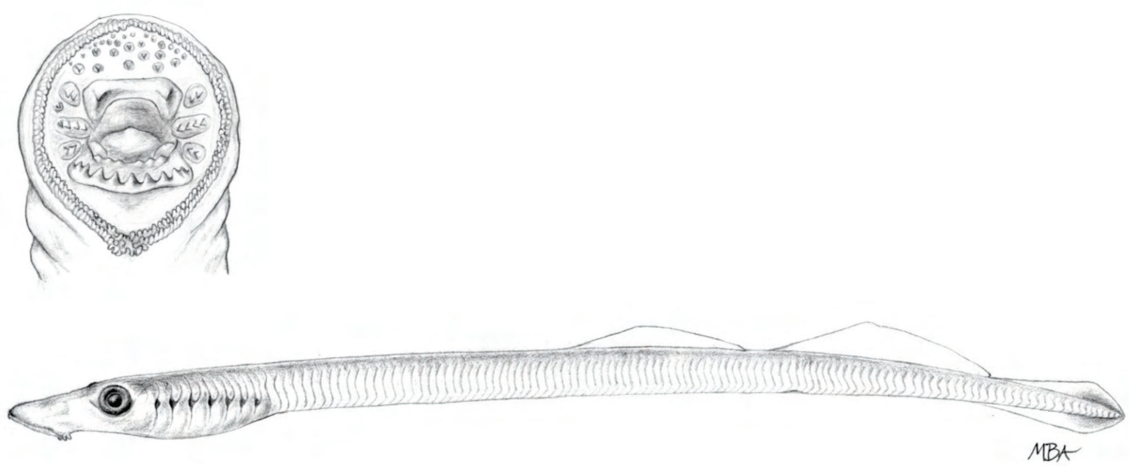


Figure 5.—*Lampetra ayresii*, river lamprey adult, 127 mm TL (Wang 1986).

KERN BROOK LAMPREY *Entosphenus-hubbsi* Vladykov and Kott

SPAWNING

Location	At the upper San Joaquin River between Kerckhoff Dam and logjam (floating logs due to winter storms) at the upper reaches of Millerton Lake (Wang 1986), foothill streams between Merced River and Kings River (Brown and Moyle 1993).
Season	From July to September based on collection of ammocoetes (Wang 1986); in spring months (Moyle 2002).
Temperature	15.0–17.5°C (in Millerton Lake; Wang 1986).
Salinity	Freshwater.

AMMOCOETES

Snout to anus length	~88–90% of TL for ammocoetes 7.3–9.1 mm TL; ~84–87% of TL for ammocoetes 9.2–12.2 mm TL (Millerton Lake specimens).
Gill slits	7, opening separately to exterior.
Mouth	Inferior, funnel-like, with hood or lip on lateral and dorsal sides.
Gut	Straight, bending ventrally in anal region.
Teeth	None at this stage.

Total myomeres	~80+ for specimens 8.5–9.1 mm TL; ~90+ at 10.3 mm TL; ~100+ at 12.2 mm TL (Wang 1986).
Trunk myomeres	53–58 (Wang 1986).
Pigmentation	Scattered melanophores on snout, head, midorsum, gill slits, lateral surface of gut, and postanal regions for specimens <10 mm TL; pigmentation is much lighter for specimens >10 mm TL.
Distribution	Upper San Joaquin River below Kerckhoff Dam; may descend to Millerton Lake and further south via Friant-Kern Canal.

TRANSFORMED ADULTS

Teeth	Supraoral plate with 2 cups; lateral oral teeth: 3–4 (Vladykov and Kott 1976).
Trunk myomeres	51–57 (Vladykov and Kott 1976, Brown and Moyle 1993).
Distribution	East side of San Joaquin Valley, lower Merced, Kaweah, and Kings Rivers (Brown and Moyle 1993).

LIFE HISTORY

Kern brook lamprey were first observed at the Friant-Kern Canal by Vladykov and Kott (1976) and were reported in waters draining to the Central Valley, such as Merced, Kaweah, and Kings Rivers by Brown and Moyle (1993).

Spawning season is estimated to be between July and September. A total of 87 ammocoetes (7.3–12.2 mm TL) was collected from July to September 1979–1982 (Ecological Analysts, Inc.) and 60 ammocoetes from July to September 1984–1991 (National Environmental Services, Inc.) from the upper San Joaquin River below the Kerckhoff Dam and Millerton Lake. Larger ammocoetes, transforming individuals, and adults were not collected. Digestive tract contents of the ammocoetes found in the Millerton Lake included fine plant materials and detritus.

The trunk myomere counts (53–57) of specimens from the San Joaquin River fits the description for ammocoetes of either the western brook lamprey, known to inhabit the upper San Joaquin River prior to the construction of the Friant Dam (Rutter 1907, Dill 1946) , or the Kern brook lamprey (Vladykov and Kott 1976). In 1988, many Kern brook lamprey ammocoetes and adults were collected from the siphons of the Friant-Kern Canal by Moyle (2002). The Friant-Kern Canal is connected to Millerton Lake at the base of Friant Dam. These observations may lead to the following possibilities:

- Some Kern brook lampreys use the Millerton Lake as nursery habitat. Spawning occurs in upper river (below the Kerckhoff Dam) riffles with sands, gravel substrates, and nearby pools. The ammocoetes disperse by river current into the lake where they grow and mature. Many ammocoetes were collected by plankton net from Millerton

Lake in the first 3 years of this study (87 total between 1979 and 1982). Nearly 150 ammocoetes have been collected in this 12-year study, and it is assumed that Kern brook lamprey spawn in the upper San Joaquin River between Kerckhoff Dam and K-2 discharge.

- The Western brook lamprey reported by Rutter (1907) and Dill (1946) may actually have been Kern brook lamprey before it was reclassified as a different species by Vladykov and Kott (1976); Brown and Moyle (1993) observed only the Kern brook lamprey in the watersheds between Merced and Kings Rivers; the sympatric characteristics of these two species can cause taxonomic confusion.
- Kern brook lamprey may expand its range further south of the Central Valley watershed via the Kern Canal.

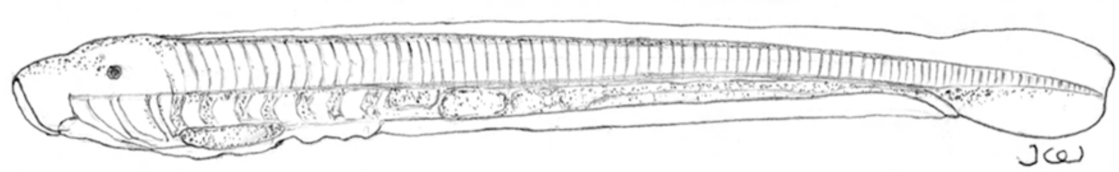


Figure 6.—*Lampetra* spp., Pacific brook lamprey or Kern brook lamprey ammocoete, 10.4 mm TL (Wang 1986).

WESTERN BROOK LAMPREY *Lampetra richardsoni* Vladykov and Follett

SPAWNING

Location	Upper Sacramento River, above Red Bluff; may occur in tributaries along the valley floor to the foothills in the Sacramento-San Joaquin River system.
Season	March–April in Coyote Creek (Hubbs 1925); March–June (Pletcher 1963); February to July (Wydoski and Whitney 2003); spring and summer in upper Sacramento River drainages.
Temperature	10°C (Schultz 1930); ~10–15°C (Wydoski and Whitney 2003).
Salinity	Freshwater.
Substrates	Rock, sand or gravel bottoms (Wydoski and Whitney 2003); gravel (Moyle 2002).
Fecundity	1,836 eggs removed from a single female 135 mm TL, collected at the RBRPP on June 1, 1997.

EGGS

Shape	Round to oval, but may be slightly irregular in shape (mature, unfertilized eggs).
Diameter	Long axis, ~1.2 mm; short axis ~1.0 mm (mature, unfertilized eggs).
Yolk	Pale yellow (mature, unfertilized eggs).
Oil globule	None (mature, unfertilized eggs).
Chorion	Clear, hard (mature, unfertilized eggs).
Egg deposition	Mature loosely arranged in the ovary, very likely deposited singly.
Adhesiveness	Slightly adhesive (mature, unfertilized eggs).

AMMOCOETES

Length at hatching	No information.
Snout to anus length	No information.
Gill slits	7, open separately to exterior.
Mouth	Slightly inferior, with lip or hood on side and dorsal.
Teeth	None at this stage.
Total myomeres	~80+ for specimens <10 mm TL; ~100+ for specimens >10 mm TL.
Trunk myomeres	52–58 for California population (Moyle 2002); 53–58 (Wang 1986).
Pigmentation	Scattered melanophores on upper part of the body, and light on the ventral side.
Distribution	Upper drainages of Sacramento River (Moyle 2002); upper Sacramento River. Ammocoetes and adult were collected at Reclamation's RBRPP and Sonoma Creek. A single ammocoete with 54 trunk myomeres was collected in Dry Creek in 1997 (M.P. Marchetti 1998, personal communication).

ADULTS

Teeth	Supraoral lamina (or plate): 2 cusps (Moyle 2002); 2 pointed cusps at each end the supraoral plate. Circummoral: 3 plates (Moyle 2002); 2–3 separated packs of cusps, some not well developed. Infraoral plate: 7–9 tooth-like cusps (Moyle 2002), 8–9 dull cusps (flat crown as molar teeth) in semicircular formation.
Trunk myomeres	52–67 (Moyle 2002); 53–62.
Dorsal fin	2, separated, but touching by a low membrane.

Distribution	Tributaries of the Sacramento River and Sonoma River (Moyle 2002); tributaries of the Sacramento River (below Shasta Dam); Sacramento River at Reclamation's RBRPP; Sonoma River, and possible in Dry Creek (above Putah Creek). Also this species was recorded in the upper San Joaquin River in early literature (Rutter 1907, Dill 1946).

LIFE HISTORY

Western brook lamprey is distributed along the Pacific coast in streams and inland tributaries of large rivers, from Alaska to California (Vladykov 1973, Morrow 1980). Spawning begins at 10°C (Schultz 1930). They may spawn in late spring in the cold upper Sacramento River water, judging by a gravid female collected from Red Bluff in early June 1997. The ammocoetes of the western brook lamprey, Pacific lamprey, and river lamprey are common in the entrainment samples of the RBRPP in the spring and summer months (Borthwick *et al*. 1999, Borthwick and Weber 2001).

Moyle (2002) commented that "the western brook lamprey are difficult to collect and easy to overlook." In general, the nonparasitic lampreys all have remote freshwater habitat for their life stages (ammocoetes, transforming, and adult). Adult lampreys are identified by examining the plate and cusp in the oral disc and it is easy to overlook the detail of the line-ups in the oral disc, when the lamprey is still alive. Western brook lamprey recorded in the Millerton Lake prior to the construction of the Friant Dam (Dill 1946) might possibly have been Kern brook lamprey (not known to exist there at that time). Only Kern brook lamprey were collected in the San Joaquin River drainages on the western slope of the Sierra in recent years (Brown and Moyle 1993).

Western brook lamprey ammocoetes are filter feeders with poorly developed eye pits. They feed on very small plant and animal matter, and the large sized ammocoetes can be used as fish bait (Wydoski and Whitney 2003).

PACIFIC LAMPREY *Entosphenus tridentatus* (Gairdner)

SPAWNING

Location	Upper drainages of the Sacramento-San Joaquin River system; below Friant Dam on the San Joaquin River (Moyle and Nichols 1974); below Nimbus Dam and above Howe Avenue bridge crossing of the American River; above Red Bluff Dam and below Shasta Dam; Sacramento River tributaries such as Butte Creek and Feather River; upper Napa River and its tributaries; below Boyes Spring Historical Park spillway of Sonoma Creek; above Concord Avenue road bridge crossing of Walnut Creek.
Season	April through July in British Columbia (Pletcher 1963); April through July (Moyle 1976); in spring (Kimsey and

	Fisk 1964); April through June (Wang 1986); in American River, it ranges from January to May, with a peak in early April (Hannon and Deason 2005, Reyes 2008).
Temperature	15°C (Hart 1973); 13–18°C (Moyle 2002); 13.0–18.5°C (Wang 1986); 10–13°C (Reyes 2008); 10–15°C (Close *et al.* 2002).
Salinity	Freshwater.
Substrate	Mostly gravel and rocks (Scott and Grossman 1973, Hart 1973); rocks and cobbles (Moyle 2002); occasionally in sand, such as in Walnut Creek (Wang 1986).
Fecundity	10,000–106,000, with an average of 34,000 (Pletcher 1963); 20,000–200,000 eggs (Moyle 1976); as high as 98,000–238,400 (Kan 1975).

EGGS

Shape	Oval (Pletcher 1963); slightly elliptical and irregular (Wang 1986).
Diameter	Long axis 1.12–1.24 mm; short axis 1.06–1.09 mm (Pletcher 1963); long axis 1.3–1.4 mm; short axis 1.1–1.3 mm. Chorion dilated, up to 1.5 mm in diameter prior to hatching (Reyes 2008).
Yolk	Pale yellow to pale greenish.
Oil globule	None.
Chorion	Clear and hard in early incubation; thinner and flexible prior hatching.
Perivitelline space	Very narrow.
Egg deposition	Deposited singly.
Adhesiveness	Adhesive (Scott and Crossman 1973); slightly adhesive to the substrates.

AMMOCOETES

Length of hatching	~4.0–5.0 mm (Wang 1986; Reyes 2008).
Snout to anus length	~85–90% of TL for ammocoetes 8.7–12.1 mm TL; ~82–84% of TL for ammocoetes 20.5–27.2 mm TL; ~70% of TL for ammocoetes 133 mm TL (Wang 1986); in newly-hatched ammocoete, the anus is near the end of the curled tail (Reyes 2008).
Gill slits	Total 7 on each side, open separately to exterior.
Mouth	Inferior, with lip or hood.
Teeth	None at this stage.
Trunk myomeres	64–70 (Moyle 1976); 68–70 (Wang 1986).

Pigmentation	Melanophores on top of head, middorsum, dorsal area of gut, and gill slits.
Distribution	Free-swimming or benthic (anchoring in the mud or sand of an oxbow habitat) in the Sacramento-San Joaquin Rivers and tributaries.

TRANSFORMING AND NEWLY TRANSFORMED ADULTS

Teeth	Supraoral lamina has 3 cusps; infraoral lamina has 5 cusps (Hart 1973, this study); 5–8 cusps in infraoral lamina (Scott and Crossman 1973); 4 inner lateral plates (Moyle 2002); 4 rows of inner lateral teeth or circumoral teeth.
Trunk myomeres	63–70 (Wang 1986); 62–71 (Moyle 2002).
Dorsal fin	Two dorsal fins separated by a wide space (Eddy 1969); separated abruptly by a cleft (Scott and Crossman 1973); 2 dorsal fins slightly separated and second dorsal fin is continuous with first dorsal fin (Moyle 2002).
Distribution	Transforming adults are free-swimming. Newly transformed adults are free-swimming and become parasitic on fish when they reach the ocean. They range widely in the Delta, rivers, and estuary; commonly seen at the RBRPP (Borthwick *et al.* 1999, Borthwick and Weber 2001).

LIFE HISTORY

The Pacific lamprey, a parasitic anadromous species, ranges from Point Canoas, Baja California to Bering Sea and Japan (Fry 1973, Hart 1973, Miller and Lea 1972). In Japan, it is present along the coast southward to Yuhutu River of Hokkaido (Wydoski and Whitney 2003). There are early catch records of Pacific lamprey in the ocean from Japan to Baja California (Hubbs 1967, McPhail and Lindsey 1970). This species is found along the Pacific coast from Monterey northward, and was once most abundant in the Eel River (Moyle 1976); abundance has declined in recent years (Close *et al.* 2002, Moyle 2002). Pacific lamprey was first reported in the Sacramento-San Joaquin River system by Rutter (1907). It has been taken by trawl in San Francisco Bay (Alpin 1967), San Pablo Bay (Ganssle 1966), and Carquinez Strait (Messersmith 1966). In this study, Pacific lamprey were observed in Cache Slough, Lindsey Slough, Suisun Bay, American River (up to Nimbus Dam), upper Sacramento River (S.M. Borthwick 1996–1999, personal communication), Napa River, Sonoma River, and Walnut Creek. In the San Joaquin River drainage, Pacific lamprey were collected at the State Water Project (SWP) and the CVP/TFCF, often in late winter and early spring. Pacific lamprey nests were not observed below the Friant Dam in the San Joaquin River from 1979–1991.

In California, spawning takes place in riffle areas of moderate to swift current. Both sexes construct a nest in gravel or occasionally in sandy substrate. The depth of water at the nest site is usually less then 1 m, often barely covering the dorsal fins of the spawners. The diameter of the nest is about 54–58 cm (Scott and Crossman 1973), or

30–82 cm (Moyle 2002). The nest is slightly larger than the total length of lampreys. Some nests are deeper, with more gravel on the downstream side than the upstream edge.

During mating, the female attaches to a large rock on the upstream side of the nest, and the male attaches to the head of the female (Scott and Crossman 1973), or both attach to rocks and lie close to each other. During the spawning act, both sexes "vibrate" rapidly for a few seconds when the milt and eggs are released (Scott and Crossman 1973). Eggs are slightly adhesive and are washed into crevices in the gravel on the downstream side of the nest. Hatching occurs in about 19 d at 15°C (Hart 1973); 19–21 d at 10–13°C in the laboratory (Reyes 2008). A holoblastic cleavage occurs in the early development of Pacific lamprey eggs; a similar embryological development has been reported for the east coast sea lamprey *Petromyzon marinus* (Piavis 1961, Reyes 2008). Males may mate with more than one female in different nests (Pletcher 1963), or the same nest. In the American River, many lamprey nests were found in close proximity to each other. During disturbances, the lampreys move between adjacent nests tentatively. Adults die after spawning (Scott and Crossman 1973, Wang 1986, Moyle 2002).

The eggs of Sacramento sucker, Sacramento pikeminnow, and steelhead have been observed in Pacific lamprey redds in the American River (Reyes 2008). In smaller tributary streams, such as in the Sonoma Creek and Napa River, the eggs of Sacramento sucker and California roach were occasionally observed in redds.

Newly-hatched ammocoetes of Pacific lamprey remain in the crevices of the redd with their caudal region initially bent ventrally; straightens within 3–4 d (Reyes 2008). A few days after hatching, ammocoetes swim up to the current and are washed downstream to suitable nursery areas of soft sand or mud (Moyle 2002). They are often observed in the oxbows of rivers or streams enriched with soft mud and decayed tree leaves. Burrowing usually begins 12–14 d after hatching when the ammocoetes reach ~9 mm TL (Reyes 2008). Most ammocoetes burrow vertically or diagonally, but some take cover in detritus. Ammocoetes filter feed on organic matters and algae (Moyle 2002). Different sizes of ammocoetes may be found in an area of substrate, suggesting different age-classes. Since ammocoete eyes are poorly developed, movement is likely aided by other sensory organs. The ammocoete stage may last 4–6 years (Pletcher 1963, Kan 1975), 5–6 years (Scott and Crossman 1973), or 5–7 years (Moyle 2002). During the period 1996–1999, Pacific lamprey ammocoetes were observed year round in the upper Sacramento River (S.M. Borthwick 1996–1999, personal communication), apparently moving from one habitat to another. They are often observed at the CVP/TFCF during winter and spring high flow seasons.

McPhail and Lindsey (1970) described the physical changes of transformation of ammocoetes into predatory adults, which occur at about 14–16 cm TL. The simple lip or oral hood becomes an oral sucking disc, flanked by a series of leaf-like lamellae on the margin of the disc. Horny plates (or teeth, or cusps) appear in the oral cavity, the eyes enlarge, and snout elongates. When the transformation is complete, the newly formed adults migrate downstream in spring (Hart 1973) into fall (Close *et al.* 2002).

Pacific lamprey assumes a parasitic life style when they arrive in the ocean. The parasitic life of the Pacific lamprey lasts 1–2 years before they return to freshwater (Scott and Crossman 1973, Moyle 1976) and may extend to 40 months (Kan 1975). In the Trinity River, upstream migration occurs from July into September (Moffett and Smith 1950, Scott and Crossman 1973). There have been instances when Pacific lamprey migrated to freshwater rivers and streams several months earlier before actual spawning. For example, in mid-October 1979, Pacific lamprey adults were observed migrating in Napa River during a wine spill near Krug Winery. These "intoxicated" (erratic, whirling swimming) adult lampreys were likely spawners for the following year.

The Pacific lamprey during its parasitic life stage causes damage to marine fishes, including striped bass, salmon (Kimsey and Fisk 1964), rockfish (*Sebastes spp.*), and flounder (Close *et al.* 2002); however, the mortality is low. Fry (1973) commented that west coast fish and lampreys have lived with (and on) each other for many generations and are well adjusted to the relationship. Pacific lampreys have no commercial value to the general public, but are a highly esteemed food item for Pacific coast Native Americans (Kroeber and Barrett 1960, Close *et al.* 2002).

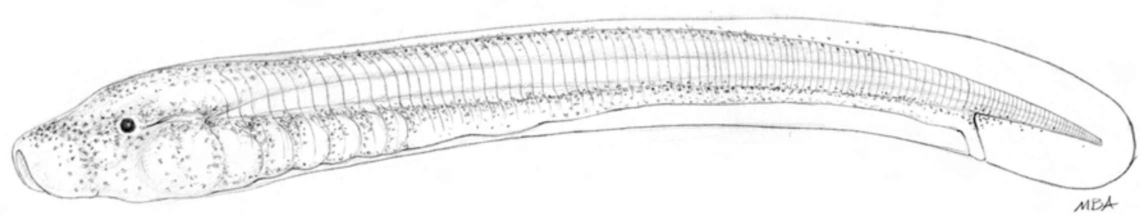


Figure 7.—*Entosphenus tridentatus*, Pacific lamprey ammocoete, 8.7 mm TL (Wang 1986).

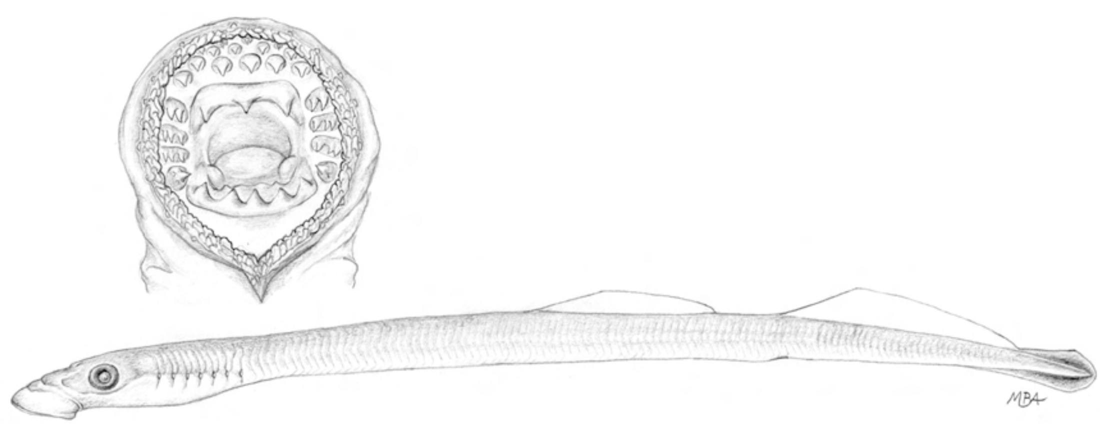


Figure 8.—*Entosphenus tridentatus*, Pacific lamprey adult, 170 mm TL (Wang 1986).

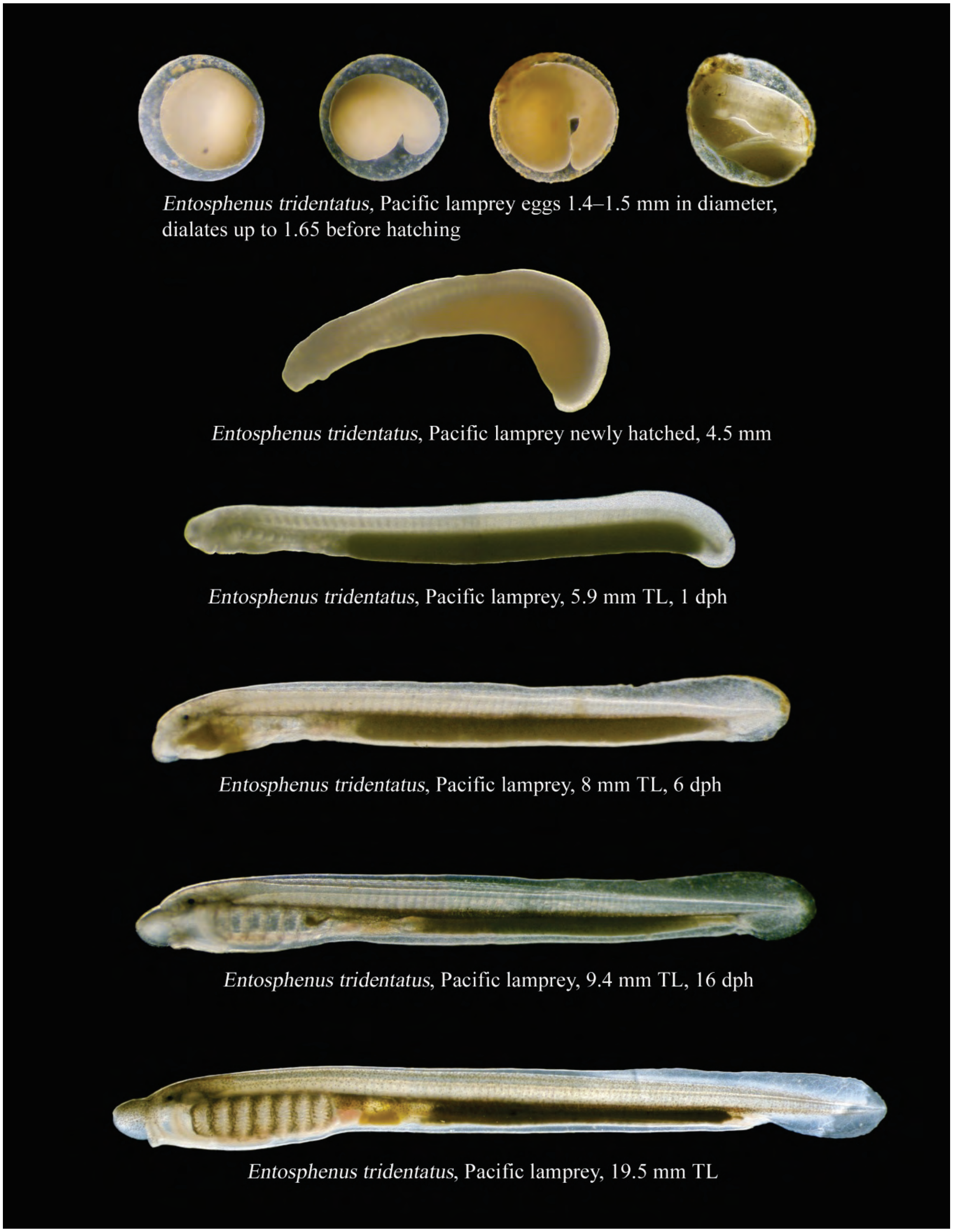


Figure 9.— *Entosphenus tridentatus*, Pacific lamprey.

Taxonomic Characteristics of Lampreys Present in the Study Area

Ammocoetes

	Trunk myomeres	Caudal pigmentation[1]
River lamprey	65–70	Pigmented
Pacific lamprey	62–71	Pigmented/lightly pigmented
Western brook lamprey	52–58	Darkly pigmented
Kern brook lamprey	51–57	(Information unavailable)

Adults

	Trunk myomeres	Supraoral cusps	Infraoral cusps
River lamprey	60–71	2	7–10
Pacific lamprey	62–71	3	5–8
Western brook lamprey	52–67	2	7–10
Kern brook lamprey	51–57	2	5

Acipenseridae – Sturgeons — Seven species of sturgeon occur in North America, and two are found in California waters: green sturgeon (*Acipenser medirostris*) and white sturgeon (*A. transmontanus*). Both are anadromous and native to the Delta and estuarine system (Jordan and Snyder 1906, Pycha 1956, Skinner 1962, Shapovalov *et al.* 1981). Green sturgeon are not common in the estuary; a few juveniles have been collected in the Feather River, Sacramento River above Red Bluff, the Delta, and the CVP/TFCF water intake (impinged and collected from the trashracks). Adult green sturgeon is rare in the study area. One adult (>2 m TL) was caught at the CVP/TFCF intake in spring 2003. The spawning of the green sturgeon is poorly understood in the estuary. The early embryonic development and early life growth rate of the green sturgeon were documented by Deng (2000) using brood stocks obtained from the Klamath River. The life history of white sturgeon, on the other hand, has been well documented (Doroshov *et al.* 1983, Conte *et al.* 1988). Commercial fish farming of the white sturgeon was established in the 1980s in California initially for meat production (K.E. Beer 1981–1985, personal communication) and more recently for caviar production.

GREEN STURGEON *Acipenser medirostris* Ayres

SPAWNING

Locations	In upper Klamath River (Fry 1973); in the Sturgeon Hole of Klamath River just above Orleans (Moyle 1976); lower Klamath River (Deng 2000). Spawning may occur in the upper Sacramento River and Feather River (Fry 1973, Moyle *et al.* 1995). Juveniles were collected at the CVP/TFCF; however, it is unclear if they came from the Sacramento River or the San Joaquin River.

[1] Wang 1986, Bayer *et al*. 2001, Meeuwig *et al*. 2004.

Season	March to July in the Klamath River (Moyle 2002); May in the Klamath River by artificial method onsite (Deng 2000); eggs from Klamath River sturgeon were obtained from UC Davis in May 2004.
Temperature	8.0–14.0ºC (Moyle 2002); 15.7ºC in laboratory (Deng 2000).
Substrate	Large cobble, sand, and bedrock (Moyle 2002).
Fecundity	60,000–140,000 (Moyle 2002); total of 52,000 and 82,000 ova for a 38-kg female (estimated 25 years old) and a 48-kg female (estimated 32 years old), respectively (Van Eenennaam *et al.* 2001); relative fecundity ranged 2,000–4,000 (Van Eenennaam *et al.* 2006).

EGGS

Shape	Spherical (Deng 2000); fertilized eggs can be spherical, oval, and irregular.
Diameter	Newly fertilized eggs 4.2–4.5 mm in diameter (Deng 2000); 3.7–4.0 mm in short axis and 4.0–4.3 mm in long axis.
Yolk	Newly fertilized eggs gray in general, animal pole whitish with dark center, vegetable pole darker than animal pole (Deng 2000).
Oil globule	None.
Chorion	Clear and not thick (Deng 2000); thin, clear.
Perivitelline space	Overall narrow.
Egg deposition	Large numbers broadcasted in a short time into deep and fast running water (Moyle 2002).
Adhesiveness	Weak adhesiveness (Deng 2000); some loss of adhesiveness prior to hatching, chorion dilated and developed into web-like texture.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	12.6–14.5 mm TL (Deng 2000); average 13.7 mm TL (Deng *et al.* 2002); larvae 8–19 mm long (Emmett *et al.* 1991); 15.5–17.2 mm TL.
Snout to anus ratio	~62% of TL for newly-hatched prolarvae, decreasing to ~50% of TL 15 d after hatching; ~55% of TL 28–45 d after hatching (Deng 2000); newly-hatched, ~60–61% of TL.
Yolk-sac	Ovoid, large.
Oil globule	None.

Gut	Straight.
Size at absorption of yolk	25.6–27.1 mm TL (Deng 2000); ~25.0–30.0 mm TL.
Teeth	None.
Total myomeres	63–71 (Deng 2000).
Preanal myomeres	36–41 (Deng 2000).
Postanal myomeres	27–31 (Deng 2000).
Last fin(s) to complete development	Pelvic and anal fins at ~35 mm TL.
Pigmentation	Grayish in trunk and yellowish in the ovoid yolk-sac; gray to dark in upper trunk and entire postanal regions, ventrum head and midventrum of body are whitish; overall pigmentation is much lighter than white sturgeon of similar life stage (Deng *et al*. 2002).
Distribution	Larvae are likely to be present in the upper Sacramento River and Feather River. Newly-hatched green sturgeon tend to stay on the bottom (R.C. Reyes 2003–2009, personal communication) before showing nocturnal pelagic behavior at about 6 days post hatching (dph; Deng *et al*. 2002).

JUVENILES

Dorsal fin rays	33–42 (Miller and Lea 1972); 33–35 (Scott and Crossman 1973); 33–36 (Hart 1973, Moyle (1976); 40–44 (Deng 2000).
Anal fin rays	22–29 (Miller and Lea 1972); 22–28 (Scott and Crossman 1973, Hart 1973, Moyle 1976); 26–32 (Deng 2000).
Pectoral fin rays	I, 31–34, 2–3 pectoral rays are fused to form a pectoral spine; 33–38 (Deng 2000).
Dorsal bony plates	8–11 (Miller and Lea 1972, Moyle 1976); 9–11 (Scott and Crossman 1973); 7–11 (Hart 1973); 8–10 (Deng 2000); 9 and started to develop at ~25 mm TL.
Lateral body plates	23–30 (Miller and Lea 1972, Scott and Crossman 1973, Hart 1973, Fry 1973, Moyle 1976, Wydoski and Whitney 1979); 24–28 (Deng 2000).
Ventral body plates	7–10 (Miller and Lea 1972, Scott and Crossman 1973; Moyle 1976); 7–11 (Hart 1973); 5–6 (Deng 2000); 5–6 and developed at ~30–35 mm TL.
Mouth	Ventral, directed down, transverse (Hart 1973); toothless, protractible, sucker–like, and located ventrally beneath the eyes (Hart 1973); mouth located ventrally slightly behind the eye in juveniles.

Distribution: The Delta (including the south Delta in the vicinity of the CVP/TFCF), Suisun Bay, San Pablo Bay, and San Francisco Bay.

REFERENCE SPECIMENS USED

- Klamath River sturgeon eggs (obtained from UC Davis by Reclamation's René Reyes in 2004).
- Adults from CVP/TFCF intake trashrack during periods 1991–2005 (mostly in winter months).
- Juvenile specimens from RBRPP in the Sacramento River during periods 1996–1999 (obtained from Reclamation's Sandy Borthwick).

LIFE HISTORY

Green sturgeon ranges from Ensenada, Mexico, to the Bering Sea and Japan (Miller and Lea 1972) and also along the North Pacific coasts of Korea, China, and the Amur River of Russia (Berg 1948, Hart 1973). There is also a closely related species of green sturgeon called the Sakhalin sturgeon ranging as far south as Taiwan (Matsubara 1955, Moyle 2002). Green sturgeon have been reported in the San Francisco Bay (Aplin 1967), San Pablo Bay (Ganssle 1966, Miller 1972a), the lower San Joaquin River, and the Delta (Radtke 1966). There is indirect evidence that green sturgeon spawn in the Sacramento River and the Feather River (Fry 1973, Moyle *et al.* 1995). Green sturgeon also have been reported in Tomales Bay (Bane and Bane 1971) and Bodega Bay (Standing *et al.* 1975), waters adjacent to San Francisco Bay.

Based on collections of larvae in salmon out-migrant traps, Moyle (2002) suggested that green sturgeon might spawn in the lower Feather River and the main-body of the upper Sacramento River. However, green sturgeon were not collected in rotary screw trap and beach seining studies in the Feather River during the period 1999–2001 (Seesholtz *et al.* 2004). During the period 1996–1999, small green sturgeon were reported in the vicinity of the Red Bluff area of the Sacramento River (S.M. Borthwick 1996–1999, personal communication); however, spawning locations (egg deposit sites) have not been observed in this area.

Embryonic development, hatching size, and growth rate of the green sturgeon (brood stock obtained from Klamath River) were described by Deng (2000) under laboratory conditions. The incubation period is 10 d at 15.7ºC. Newly-hatched green sturgeon are large (~12–15 mm TL), compared to white sturgeon (~10–11 mm TL) and have a shorter preanal length (~60–62% of TL), compared to white sturgeon (~68–70% of TL). Larval green sturgeon swim near the bottom (Deng 2000), a pelagic behavior contrary to that of the white sturgeon. In the laboratory, newly-hatched yolk-sac larvae swim actively near the bottom of the hatching jar, resting dorso-ventrally and occasionally on their side. In the wild, green sturgeon larvae reside in the crevices of rocks on the spawning ground (Deng 2000). At ~25–30 mm TL, they feed at the bottom when yolk still exists otherwise swim to the surface when they are hungry. Historically, the smallest green sturgeon collected were 20–22 mm FL and were captured by gill net and trawl during the period 1954–1963 (Radtke 1966). Most small sturgeons collected were lumped as the *Acipenser* spp. or perhaps misidentified as white sturgeon.

Juvenile green sturgeon reach full metamorphosis at about 74 mm TL (Deng 2000, Deng *et al.* 2002). Large juveniles are distributed in scattered patterns in the bay and Delta. Collections have been made at Suisun Bay and west Delta areas by various resource agencies and private consulting firms (such as Ecological Analysts, Inc., 1978–1981). Only 28 green sturgeon (compared to 730 white sturgeon), mostly juveniles, were captured in trammel nets in San Pablo Bay and Suisun Bay by the CDFG in 2006 (Donellan and Gingras 2007). Based on data collected by the CDFG between 1954 and 1987 in the Sacramento-San Joaquin Rivers system, Moyle (2002) estimated the green sturgeon population ranged from 140 to 1,600. This region is believed to be the southern extremity of its reproductive range; however, life history of this species in the system is still very sketchy at present.

Juvenile green sturgeon consume mostly amphipods and mysid shrimps in the Delta (Radtke 1966). At elevated temperatures of 19–24°C, in the laboratory and with sufficient food and oxygen, green sturgeon larvae can attain juvenile stage faster with no adverse physical effect (Allen *et al.* 2006).

Green sturgeon are harvested by commercial fishermen and Native Americans in the Columbia River and Klamath River (Fry 1973, Moyle 2002). Locally, sportfishing anglers catch this species occasionally identifying it only as ‘sturgeon.’ Four distinct populations of green sturgeon are recognized along the west coast of North America: Klamath River, Columbia River, San Pablo Bay, and Rogue River (Israel *et al.* 2004). Genetic work is ongoing. In 2006, the National Marine Fisheries Service in 2006, ruled that the southern populations of green sturgeon, including the Sacramento and Feather River populations, be listed as threatened. The northern populations of Klamath River and Oregon region are currently listed as Species of Special Concern.

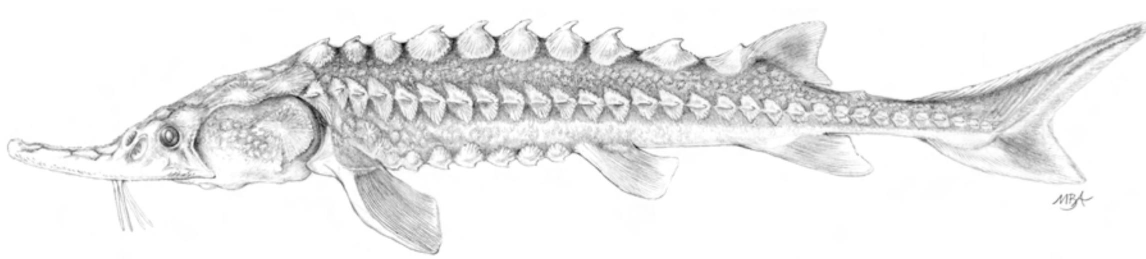


Figure 10.—*Acipenser medirostris*, green sturgeon juvenile, 275 mm TL (Wang 1986).

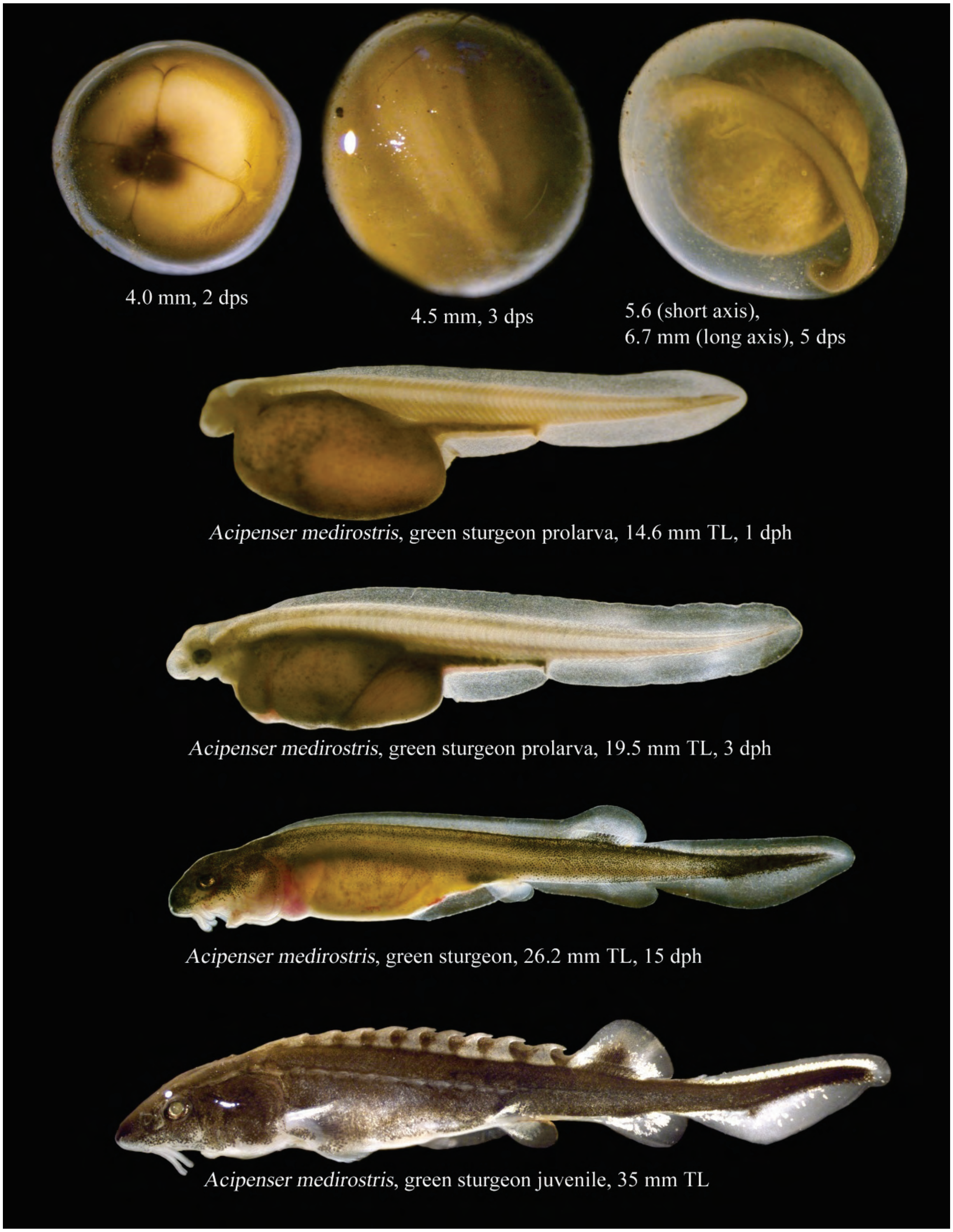


Figure 11.—*Acipenser medirostris,* green sturgeon.

WHITE STURGEON *Acipenser transmontanus* Richardson

SPAWNING

Locations	Upper Sacramento River and lower Feather River (Stevens and Miller 1970); Sacramento River above the Delta (Fry 1973); mostly in Sacramento River between Knights Landing and Colusa (Kohlhorst 1976); some may spawn in San Joaquin River (Kohlhorst 1976, Kohlhorst *et al.* 1991); eggs were collected in the Sacramento River between Freeport and Rio Vista; during the period 1982–1985, major spawning occured between Freeport and Colusa on Sacramento River (P. Lutes 1982–1985, personal communication); eggs and larvae were collected in the upper Sacramento River, up to Colusa; some white sturgeon eggs and larvae were observed in Cache Slough in the mouth of the Sacramento River, and larvae were collected in the vicinity of Port Chicago at Suisun Bay (CDFG fish E and L survey, 1988–1995; North Bay Aqueduct (NBA) fish E and L survey, 1993–2004).
Season	Mid-February to late May (Kohlhorst 1976); late February to early June (Moyle 2002); somewhat late in the northern Pacific coastal rivers, in May and June (Scott and Crossman 1973). Eggs and larvae were collected in the CDFG's fish E and L survey in the Sacramento River drainage in March and April; major spawning occurs in late winter and early spring.
Temperature	7.8–17.8ºC, peaking at 14.4ºC (Kohlhorst 1976); 8–19ºC (Moyle 2002); ambient temperature in hatchery 12–16ºC (Beer 1981); in UC Davis hatchery 1982–1985, 12–19ºC (P. Lutes 1982–1985, personal communication); in the field, peak of catch of *Acipenser* spp. larvae at 14–15ºC (Stevens and Miller 1970); estimated at 13.0–13.5ºC based on egg collections (Wang 1986); at 15.7ºC, eggs will hatch in ~176 h (Deng 2000).
Salinity	Freshwater.
Substrates	Gravel and rock bottoms (Moyle 2002); over sandy or muddy bottoms (S.I. Doroshov 1980, personal communication); hard clay and other various substrates (P. Lutes 1982–1985, personal communication); various available substrates in high flow channel.
Fecundity	3–4 million (Migdalski 1962); 700,000 (Scott and Crossman 1973); ~3 million eggs for a 3-m-long 50-year-old female (Dees 1961); a 1.5-m FL female contained over 200,000 eggs (Moyle 2002); 3,000–12,000 eggs/batch, and

	several batches of eggs can be produced by a single female during spawning (P. Lutes 1982–1985, personal communication).

EGGS

Shape	Spherical, oval, or slightly irregular (Beer 1981); slightly pear-shaped in early development due to holoblastic and unequal cleavages.
Diameter	Fertilized eggs with a thick layer of jelly coat, short axis 3.8 mm and long axis 4.0 mm (Beer 1981); fertilized eggs 3.3–3.5 mm with long axis 3.5–4.0 mm (Wang 1986); field collections 3.2–3.8 mm (CDFG samples); 3.7–4.2 mm in short axis and 4.1–4.3 mm in long axis (laboratory brood stock obtained from UC Davis).
Yolk	Overall, slate gray, animal pole whitish (Beer 1981); brown (Scott and Crossman 1973); dark gray brown with light yellow spots at animal pole for hatchery stock (Wang 1986); overall dark gray in field collections.
Oil globule	None (Cheer and Clark 1982).
Chorion	Clear, thick with 4 layers (Cherr and Clark 1982); twice as thick as green sturgeon (Deng 2000); clear, with multiple layers.
Perivitelline space	Prominent at animal pole (Beer 1981); overall, very narrow (Wang 1986).
Egg deposition	Assumed broadcasted singly, and spawn in batches (P. Lutes 1982–1985, personal communication).
Adhesiveness	Adhesive (Beer 1981); sticky (Scott and Crossman 1973); more substrates attached to vegetable pole; egg diameter dilated as early as late morula stage and becomes less adhesive. Egg can dilate up to 7.0–7.5 mm prior to hatching and chorion turns into web-wrinkled texture.
Buoyancy	Negatively buoyant or demersal; eggs can be carried downstream in fast current or high flow after chorion dilates and detaches from the substrates (CDFG samples collected in lower Sacramento River, 1993 and 1995).

LARVAE

Length at hatching	Mean length 11.0 mm TL (Beer 1981); 10.0–11.1 mm TL (Wang 1986); 10.7–11.3 mm TL for batch of hatchery stock obtained from UC Davis; 11.1 mm TL was the smallest larva collected in the field at sampling station 726 in Miner Slough on February 23, 1997 (CDFG/NBA fish E and L survey).

Snout to anus length	~68–70% TL for prolarvae 10.0–11.1 mm TL; ~56–59% for late prolarvae 16.7–17.8 mm TL; ~53% of TL for juvenile 31.0 mm TL (Wang 1986); newly-hatched (0–1 d old) ~66–69%, decreasing to ~56–57% TL for 10- to 15-d-old larvae; ~60% of TL for 21- to 45d-old larvae (Deng 2000).
Yolk-sac	Ovoid, light pigmentation on ventral surface, and dark pigmentation on dorsal and posterior portion (Beer 1981); very large, gray-yellow in coloration, and extends from jugular to mid-abdominal region (Wang 1986).
Oil globule	None.
Gut	Straight.
Size at absorption of yolk	~15.5–15.8 mm TL (Beer 1981); 17.6–18.5 mm for yolk-sac *Acipenser* spp. larvae (Stevens and Miller 1970, Kohlhorst 1976); 18–20 mm TL.
Total myomeres	Newly-hatched larvae with 55–60 somites (Beer 1981); ~60 to 70+ for sturgeon <31 mm TL, estimation due to the postanal myomeres jammed at the end of the tail (Wang 1986).
Preanal myomeres	37–40 (Wang 1986); ~40–45.
Postanal myomeres	25 to 30+ (up to the base of urostyle; Wang 1986).
Last fin(s) to complete development	Pelvic and anal.
Pigmentation	Newly-hatched larvae have scattered melanophores on sides of body and head (Beer 1981); prolarvae have scattered melanophores on head, body, and lateral portion of the yolk-sac; postanal region may have a dark band and a dark stripe along the ventrum of urostyle; eye is a dark pit; late prolarvae have melanophores on head, body, and the finfolds except the ventral side of yolk-sac and barbels; in postlarvae, pigment covers entire body.
Distribution	Initially pelagic (Beer 1981, Deng 2000); becoming demersal when pectoral fins are fully developed (Beer 1981, Deng 2000); channels and deep waters near the bottom in lower reaches of the Sacramento and San Joaquin Rivers, and the Delta (Stevens and Miller 1970); near the bottom in upper Sacramento River (Kohlhorst 1976); based on larval collections, distribution mostly in the deeper waters from the town of Colusa (Colusa County) on the Sacramento River to Port of Chicago at Suisun Bay, uncommon on the San Joaquin River side of the Delta (CDFG fish E and L survey, 1988–1995); from laboratory observations, larvae swim at various levels in the water column.

JUVENILES

Dorsal fin rays	44–48 (Miller and Lea 1972, Scott and Crossman 1973, Hart 1973, Moyle 1976); 40–44 (Deng 2000).
Anal fin rays	28–31 (Miller and Lea 1972, Hart 1973, Moyle 1976); 28–30 (Scott and Crossman 1973); 26–32 (Deng 2000).
Pectoral fin rays	33–38 (Deng 2000); I, 35–39. The pectoral spine consists of at least 3 fused pectoral rays.
Dorsal bony plate rays	11–14 (Miller and Lea 1972, Scott and Crossman 1973; Hart 1973); 10–12 (Deng 2000).
Lateral body plates	38–48 (Miller and Lea 1972, Scott and Crossman 1973, Moyle 1976, Wydoski and Whitney 1979); 34–40 (Deng 2000).
Ventral bony plates	9–12 (Miller and Lea 1972, Scott and Crossman 1973, Moyle 1976); 8–11 (Deng 2000).
Mouth	Ventral, toothless, wide and transverse (Scott and Crossman 1973, Hart 1973); on ventral side, a short distance behind the eyes (Fry 1973).
Distribution	From San Francisco Bay to Sacramento and San Joaquin Rivers and the Delta, most of them concentrating in the upper Estuary (Wang 1986).

REFERENCE SPECIMENS USED

- Eggs, larvae, and research information were obtained from Ken Beer, The Fisheries, Inc., 1981–1982 and Xing Deng, 2000– 2001.
- Wild-caught eggs and larvae came from CDFG fish E and L survey, 1988–1995, and NBA fish E and L survey, 1995–2004.
- Eggs obtained from Stolt Sea Farm California LLC by Reclamation's René Reyes, 2004 and 2006.

LIFE HISTORY

White sturgeon are found from Ensenada, Mexico, northward to the Gulf of Alaska (Miller and Lea 1972, Bean 1881); from Monterey, California to Cook Inlet in northwestern Alaska (Wydoski and Whitney 1979); rare south of Monterey (Fry 1973). Locally, white sturgeon have been reported in San Francisco Bay (Aplin 1967), San Pablo Bay (Pycha 1956, Ganssle 1966), Carquinez Strait (Messersmith 1966), the lower reaches of the Sacramento and San Joaquin Rivers and the Delta (Radtke 1966; Stevens and Miller 1970; Miller 1972a, b, c); the Sacramento River drainage (Kohlhorst 1976), and at the CVP/TFCF intake channel mostly in winter and spring months.

Spawning occurs from February through June (Kohlhorst 1976, Moyle 1976). Suitable water temperatures are 12–15ºC (Beer 1981); also known from 8–19ºC (McCabe and Tracy 1994). The major spawning locations in the study area are in the Sacramento River between Freeport and Colusa (Kohlhorst 1976; P. Lutes 1982–1985, personal communication). Spawning may also occur in the Feather River (Kohlhorst 1976). Based on the number of white sturgeon eggs collected in Cache Slough and the mouth of the Sacramento River near Collinsville, spawning apparently occurred in the lower Sacramento River as a result of high flows during the wet years of 1993, 1995, and 1998. Most eggs were observed in the deeper river channels suggesting white sturgeon may seek deeper waters to spawn. In 1978, Wang (1986) collected white sturgeon eggs and yolk-sac larvae in the channel of the Sacramento River between Freeport and Rio Vista at a water depth of 10 m.

White sturgeon eggs are adhesive (Scott and Crossman 1973, Beer 1981). The chorion is very thick and has 3–15 micropyles (Cheer and Clark 1982). The details of the embryonic development and early life stages of the white sturgeon are well documented by Beer (1981). Eggs hatch in a little over 4 d at 16ºC (Beer 1981) or 8–12 d at 12ºC (P. Lutes 1982–1985, personal communication); 5–6 d at 18–20ºC. The sizes of white sturgeon eggs and larvae artificially spawned and hatched are identical to those collected from the wild.

Average total length of newly-hatched larvae is 11.0 mm. The yolk-sac is large and the eyes small and under-developed (Beer 1981). In this study, newly-hatched larvae were 10.7–11.3 mm TL. Newly-hatched larvae began to swim vertically and then switch to horizontal position in the same day. The initial behavior of vertical swimming is believed to be the result of downstream drifting (Beer 1981) similar to other sturgeon species except the green sturgeon. When the pectoral fin is well developed, the white sturgeon larvae swim near the bottom (Beer 1981). The yolk-sac is absorbed after 7–10 d, depending upon water temperature.

The majority of the white sturgeon larval population is believed to be in the upper Sacramento River. Stevens and Miller (1970) collected 85 yolk-sac larvae and larvae of *Acipenser* spp. in the lower reaches of the Sacramento River, the lower San Joaquin River, the Delta, and Suisun Bay during their 1966–1967 sturgeon survey; Kohlhorst (1976) collected 9 eggs and 246 larvae of *Acipenser* spp. between the mouth of Feather River and Colusa on the Sacramento River in 1973. The majority of those collections are believed to be the white sturgeon (Stevens and Miller 1970, Kohlhorst 1976). Wang (1986) reported that 2 sturgeon eggs and 11 larvae were collected between Freeport on the Sacramento River and Suisun Bay; most of these specimens were collected in the reach of river between Freeport and Rio Vista in April and May 1978, a wet-water year. Sturgeon larvae were also collected between Colusa and near Port Chicago of Suisun Bay (Wang and Reyes 2007). More white sturgeon larvae were observed in Suisun Bay and Montezuma Slough in wet years. Sturgeon eggs were also observed in the lowest reaches of the Sacramento River indicating that spawning also occurs in the lower Sacramento River. White sturgeon eggs and larvae were uncommon in the lower San Joaquin River during the period 1988–1995 compared to earlier samplings (Kohlhorst 1976).

In the wild, juvenile white sturgeon develop a full complement of bony plates at about 40 mm TL and in the laboratory at about 30 mm TL. Specimens this size and larger were commonly captured by trawl in Montezuma Slough, the vicinity of the Contra Costa and Pittsburg Powerplants, and from the lower reaches of the Sacramento-San Joaquin River system (Wang 1986). Larger juveniles were annually collected at the CVP/TFCF in late winter and spring. Pycha (1956) reported that young sturgeon are nonmigratory, but Bajkov (1951) and Scott and Crossman (1973) have suggested that juveniles move upriver in late summer and fall and move downriver in spring and summer, the primary purpose of the movement possibly for feeding. Moyle (1976) reported young sturgeon living mostly in the upper reaches of the estuary. Young sturgeon's preference for the upper reaches of the estuary indicates their ability to adjust to salinity increases with increased size (McEnroe and Cech 1987). Juvenile white sturgeon were occasionally observed in the upper Napa River.

White sturgeon is an anadromous species; however, their migration patterns are only now becoming understood. Individuals tagged and released in San Pablo Bay (Chadwick 1959) and the Columbia River (Wydoski and Whitney 1979) moved randomly or not at all.

Juvenile white sturgeon feed on mysid shrimps, amphipods (Schrieber 1962), small clams, polychaetes, fish eggs (Ganssle 1966, Radtke 1966), and overbite clams *Potamocorbula amurensis* (Moyle 2002). Juveniles feed mainly at night, resting during the day (P. Lutes 1982–1985, personal communication).

Males, in general, reach sexual maturity at a smaller size (Moyle 1976). Females mature at 12–16 years, males at 10–12 years (Kohlhorst *et al.* 1991). In captivity, male white sturgeons reach sexual maturity as early as 3–4 years, females at about 5 years (P. Lutes 1982–1985, personal communication). A white sturgeon female will not spawn if a large amount of energy needed for developing ovum is not met. Scott and Crossman (1973) reported that the interval between spawning is about 4 years for young females and 9–11 years for older females. Moyle (2002) suggested that a small fraction of adults may spawn each year depending on abundance of food.

White sturgeon support an important sport fishery in the Delta and estuary. There is also an illegal fishery for the caviar of this species. White sturgeon has been successfully cultured and a market for its caviar is now established in the Sacramento area (K.E. Beer 1981–1985, personal communication).

Figure 12.—*Acipenser transmontanus*, white sturgeon egg at 4-cell stage (left), long axis 3.8 mm, short axis 32.6 mm and morula stage (right), long axis 3.9 mm, short axis 3.3 mm (Wang 1986).

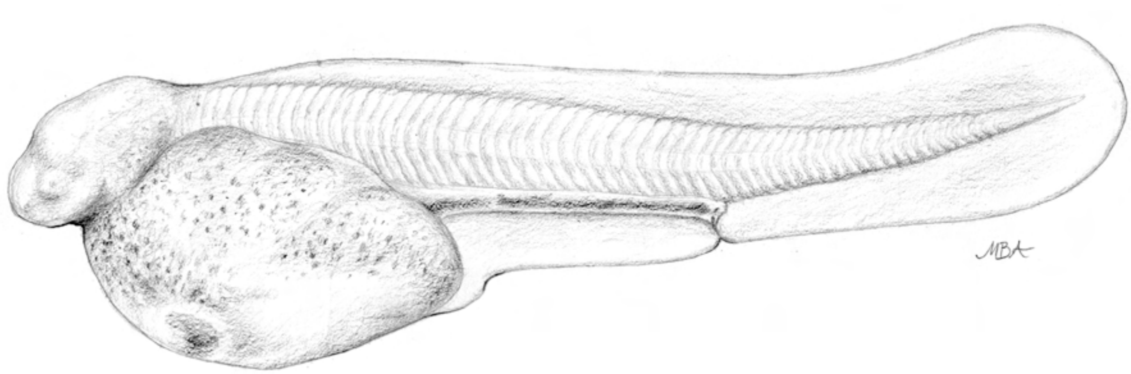


Figure 13.—*Acipenser transmontanus*, white sturgeon prolarva, 11.6 mm TL (Wang 1986).

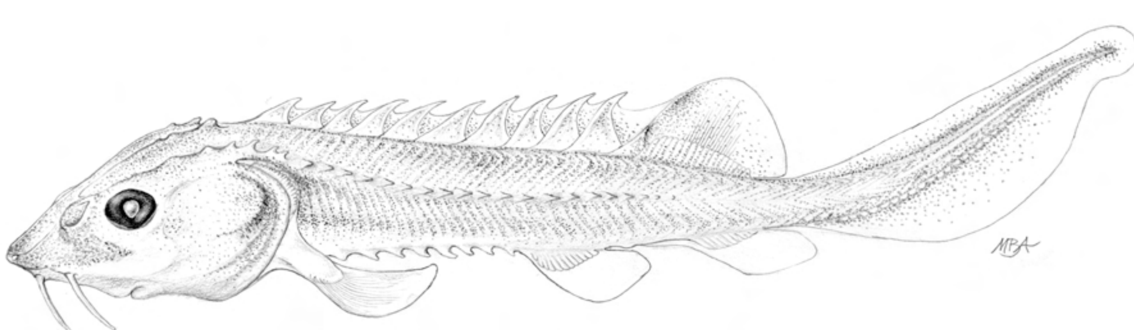


Figure 14.—*Acipenser transmontanus*, white sturgeon prejuvenile, 31 mm TL (Wang 1986).

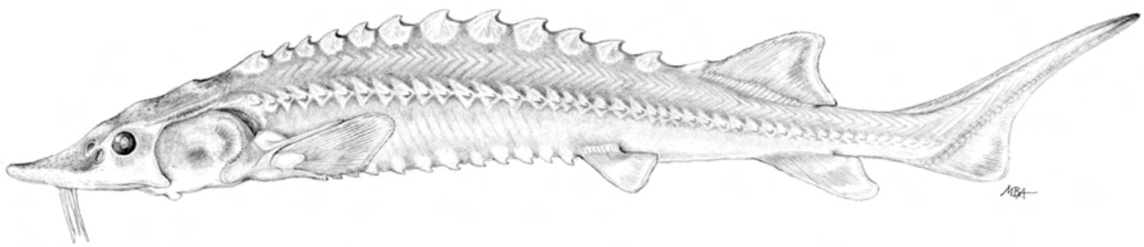


Figure 15.—*Acipenser transmontanus*, white sturgeon juvenile, 237 mm TL (Wang 1986).

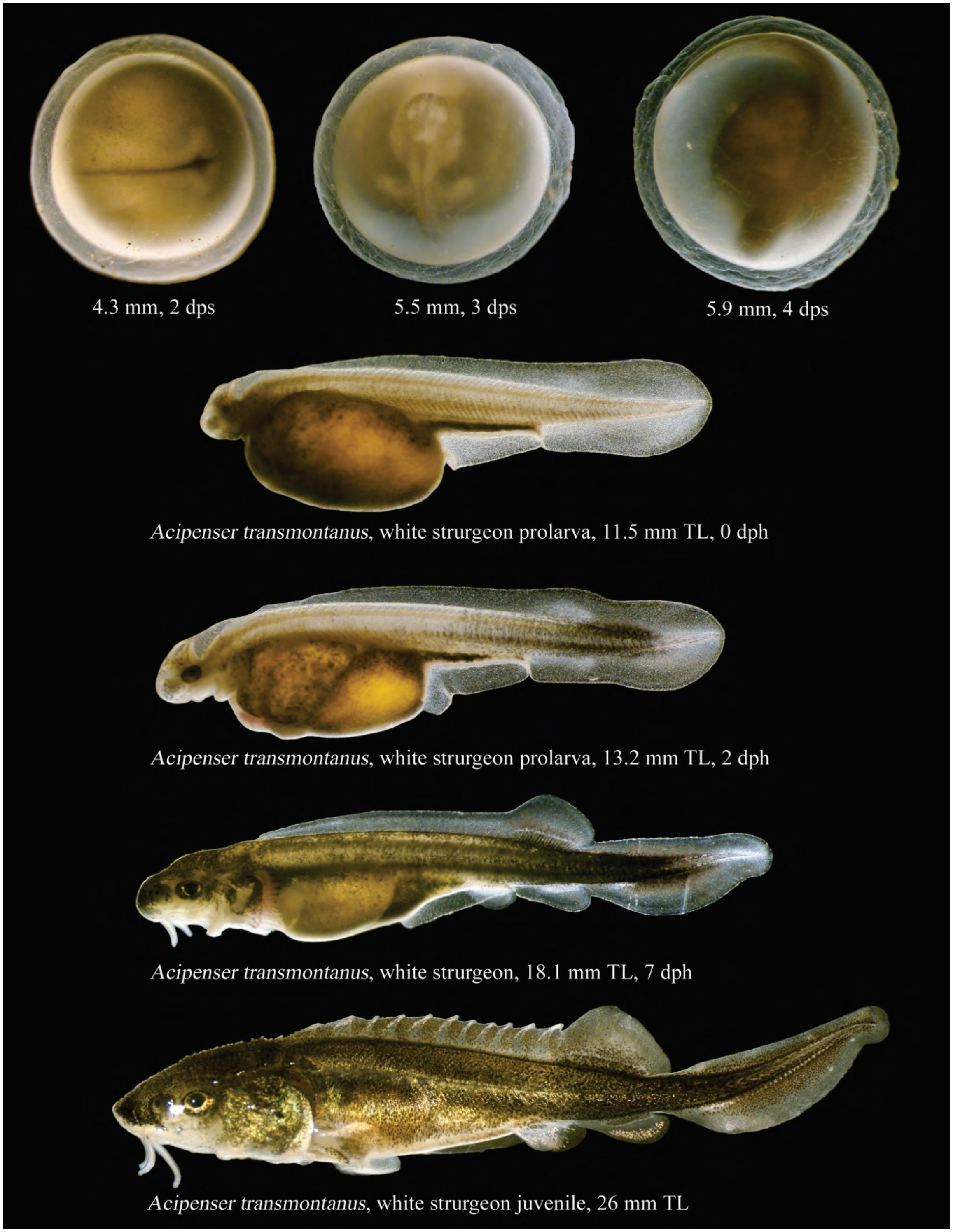


Figure 16.— *Acipenser transmontanus*, white sturgeon.

Taxonomic Characteristics of Sturgeons Present in the Study Area

	Green sturgeon	**White sturgeon**
Eggs		
Diameter	3.7–4.0 mm (short axis) 4.0–4.3 mm (long axis)	3.7–4.2 mm (short axis) 4.1–4.2 mm long axis)
Larva		
Hatching size	~12 mm TL	~11 mm TL
Ratio of gut length/TL	~61–62%	~66–69%
Eye	Well developed (with lens)	Poorly developed (with eye pit)
Yolk-sac	Very large, ovoid (distal end closer to anus)	Small, ovoid (distal end not close to anus)
Juveniles		
Lateral body bony plates	23–30	38–48
Barbels	4, near mouth	4, near snout
Shape of snout	Narrow, elongate, crocodile-like	Wide, triangular, alligator-like)
Skin	Smooth (Deng *et al.* 2002)	Rough (Deng *et al.* 2002)

Engraulidae – Anchovies — Northern anchovy (*Engraulis mordax*) is found in the west Delta and westward down the bay. It is widely distributed along the Pacific coast, and three subpopulations were described by McHugh (1951) and supported by Vrooman *et al.* (1981). Hubbs (1925) identified a separate subspecies, *E.m. nanus*, in the brackish waters of San Francisco Bay. Information in this report is based on collections of anchovy made from San Francisco Bay, San Pablo Bay, Napa River, Suisun Bay (including Montezuma Slough), and west Delta. Additional specimens from Tomales Bay and Moss Landing Harbor-Elkhorn Slough are included for comparison. All specimens used in this study are grouped together as a single species, the northern anchovy (*E. mordax*).

NORTHERN ANCHOVY *Engraulis mordax* Girard

SPAWNING

Location	Open waters of San Francisco Bay, San Pablo Bay, and Richardson Bay (Eldridge 1977); Suisun Bay and Montezuma Slough in drought years (CDFG 20-mm fish survey, 1988–1995); Moss Landing Harbor (Nybakken *et al.* 1977; Wang 1981, 1986); Tomales Bay (Bane and Bane 1971); eggs were abundant in the near shore of Sausalito (Tenera Environmental, Inc., 2005–2007).
Season	Throughout the year (Bolin 1936); two spawning peaks , February to April and July to September (Wang 1981, 1986); July and August offshore, and may spawn all year round in southern part of range (Bane and Bane 1971); extends to October during drought years.

Temperature	10.0–23.3°C, preferring 13.0–17.5°C (Ahlstrom 1965).
Salinity	From seawater to mesohaline, occasionally found in oligohaline, such as Suisun Bay and Honker Bay; in lower Napa River.
Substrates	None required.
Fecundity	20,000–30,000 annually (Baxter 1967); up to 130,000 annually (Hunter and Macewicz 1980).

EGGS

Shape	Ellipsoid or oval (Bolin 1936, Ahlstrom 1965); oval.
Diameter	Long axis 1.23–1.55 mm; short axis 0.65–0.82 mm (Bolin 1936); ~1.2–1.3 mm long axis, and ~0.8 mm short axis.
Yolk	Pale yellow whitish, coarse, granular (Wang 1986); clean and translucent (Bolin 1936).
Oil globule	None.
Chorion	Transparent and smooth.
Perivitelline space	Very narrow along short axis.
Egg deposition	Broadcast in water column in large quantities (Hunter and Macewicz 1980).
Adhesiveness	None.
Buoyancy	Pelagic, near surface (Bolin 1936).

LARVAE

Length at hatching	~3.0 mm TL (Bolin 1936); 2.5–3.0 mm SL (Ahlstrom 1965).
Snout to anus ratio	70–75% TL for prolarvae; decreasing to 60–67% TL for postlarvae.
Yolk-sac	Large, teardrop shape, extending from abdominal region past head.
Oil globule	None.
Gut	Straight and thin in prolarvae; thickened with segmentation in postlarvae.
Air bladder	Small, oval, behind pelvic fins.
Teeth	Sharp, pointed on both jaws.
Size at absorption of yolk	~3.5–4.0 mm TL.
Total myomeres	40–46.
Preanal myomeres	27–31.
Postanal myomeres	12–15.

Last fin(s) to complete development	Pectoral.
Pigmentation	No pigmentation in prolarvae; in postlarvae, melanophores along postanal region, dashed melanophores on isthmus, 2 rows of dotted melanophores in midventral region (on side of gut anterior to pelvics and dorsally on gut posterior to pelvics).
Distribution	Throughout water column in San Francisco Bay and San Pablo Bay, Moss Landing Harbor-Elkhorn Slough, and Tomales Bay (Wang 1986); Suisun Bay (Baxter *et al.* 1999); Napa River, Suisun Bay, and Montezuma Slough (CDFG Napa River 20-mm fish survey, 1995–2006; UC Davis Suisun Marsh Study, 1995–2002; Stillwater Sciences, Inc., Napa River survey, 2001–2002).

JUVENILES

Dorsal fin rays	14 (Clothier 1950); 14–16 (Bane and Bane 1971, Hart 1973); 14–19 (Miller and Lea 1972).
Anal fin rays	22 (Clothier 1950); 20–23 (Bane and Bane 1971, Hart 1973); 19–26 (Miller and Lea 1972).
Pectoral fin rays	13–20 (Miller and Lea 1972); 17 (Hart 1973).
Mouth	Subterminal (Bane and Bane 1971), inferior, very large, maxillary extends behind the eye (Hart 1973).
Vertebrae	44–47 in southern California (Clothier 1950); average 45 in British Columbia (Taylor 1940); 43–47 (Miller and Lea 1972).
Distribution	Richardson Bay (Green 1975), San Francisco Bay (Aplin 1967, Ganssle 1966); Carquinez Strait (Messersmith 1966), and Suisun Bay (Ganssle 1966); Napa River, Suisun Marsh, Montezuma Slough, and upstream to Contra Costa Powerplant (Wang 1986).

LIFE HISTORY

Northern anchovy range from Cape San Lucas, Baja California to Queen Charlotte Island, British Columbia (Miller and Lea 1972, Hart 1973). It is one of the most prolific fish in terms of numbers and biomass along the northeast coastal waters of the Pacific Ocean. Based on meristic differences in dorsal and pectoral finrays, vertebrae, and gill rakers, three subpopulations of northern anchovy are recognized (McHugh 1951, Frey 1971). The northern subpopulation ranges from Vancouver Island, British Columbia, to central California. A central subpopulation ranges from southern California to northern Baja California, and the other subpopulation is known off central and southern Baja California. Within the estuarine waters of the Sacramento-San Joaquin River system, a subspecies, *E.m. nanus*, was described by Hubbs (1925). Aplin (1967) reported that northern anchovy was the most abundant species in San Francisco Bay, constituting 85% of all fish collected. It was also common in San Pablo Bay and Suisun Bay (Ganssle 1966, Messersmith 1966). In this study, northern anchovy eggs were collected from Suisun Bay during the summer months, as seawater intruded upriver. In the ocean, eggs have been found up to 300 miles offshore, but are most abundant inshore (Ahlstrom 1965). Bolin (1936) described schools of northern anchovy broadcasting their eggs into the water during the night. A similar spawning behavior was observed for the bay anchovy (*Anchova mitchilli*) in Indian River Estuary, Delaware (author's observation 1974–1976). An individual anchovy can spawn two to three times a year (Brewer 1978).

Northern anchovy eggs are oval in shape and are found floating near the surface. Initially, their major axis is perpendicular to the surface, but this orientation changes to a horizontal position prior to hatching (Bolin 1936). Ahlstrom (1956) observed northern anchovy eggs in waters of 9.9–23.2°C. Eggs hatched in 2–4 d, newly-hatched larvae are 2.5–3.0 mm SL, and the yolk-sac is absorbed in 36 h (Bolin 1936). Eldridge (1977) reported northern anchovy to be the third most abundant taxa in Richardson Bay. Postlarvae swim near the surface. They are abundant in San Francisco Bay and San Pablo Bay. As the salt wedge moves up to the estuary in summer months, larvae were found in Suisun Bay (Meng and Matern 2001) and eastward closer to the confluence of the Sacramento and San Joaquin Rivers in the vicinity of Pittsburg and Contra Costa Powerplants (Ecological Analysts, Inc., 1978–2002). A larva (~4.0 mm TL) with residual yolk was collected at lower Cordelia Creek (UC Davis Suisun Marsh Study, May 2001). Based on collections of yolk-sac larvae, minor spawning may occur in oligohaline water in summer months. Northern anchovy larvae are abundant in summer and fall months in the upper estuary, some possibly ascending to the upper estuary from the lower bay with tidal movement. They were also common in the Napa River (CDFG 20-mm fish survey, 1995–2006; Stillwater Sciences, Inc., 2001–2005) but were seldom observed in the vicinity of Pittsburg and Contra Costa (Tenera Environmental, Inc., 2007–2009).

Schooling juvenile of northern anchovy are collected from seawater to freshwater in the Sacramento-San Joaquin River system when they are common in July and August (Wang 1986, Baxter *et al.* 1999). Abundance in the upper estuary (from Suisun Bay and up) declined in the 1990s in contrast to the 1980s; however, in 2006, northern anchovy seemed to rebound (Greiner *et al.* 2007). Juveniles used inshore central San Francisco Bay as a nursery ground (Baxter *et al.* 1999) and occasionally ascended to the west Delta during summer months (Tenera Environmental, Inc., 2008–2009). Juveniles, with their large inferior mouths, generally consume small crustaceans (Hunter 1976) and other zooplankton as well as algae (Bane and Bane 1971). Northern anchovy are preyed upon by Chinook salmon, rockfishes, striped bass, white croaker, and surfperches (Wang 1986, Baxter *et al.* 1999).

Clark and Phillips (1952) reported that a few northern anchovy are mature at 1–2 years, about half at 2–3 years, and all are mature at 4 years. Collins (1969) reported them maturing at 12 months, Hart (1973) 1–3 years, and Bane and Bane (1971) between 2–3 years. They can live and spawn to age 7 (Baxter 1967). In this study, the majority of northern anchovy were mature at age 2. Apparently some are able to complete their life cycle within the estuary. The anchovies have replaced the once important sardine in both commercial and bait fisheries (Messersmith 1966, Bane and Bane 1971, Talbot 1973).

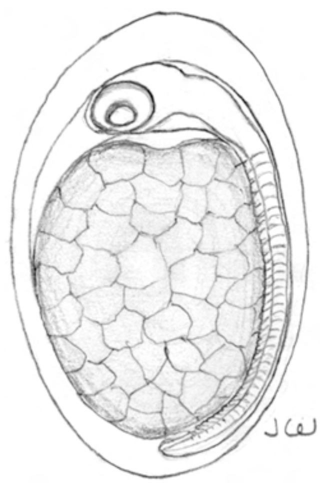


Figure 17.—*Engraulis mordax*, northern anchovy egg, long axis 1.4 mm, short axis 0.9 mm (Wang 1986)

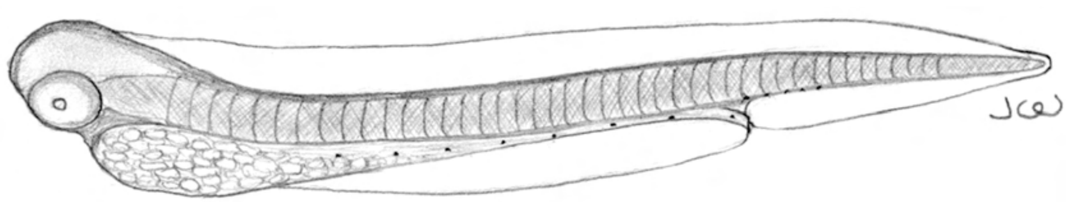


Figure 18.—*Engraulis mordax*, northern anchovy prolarva, 3.6 mm TL (Wang 1986).

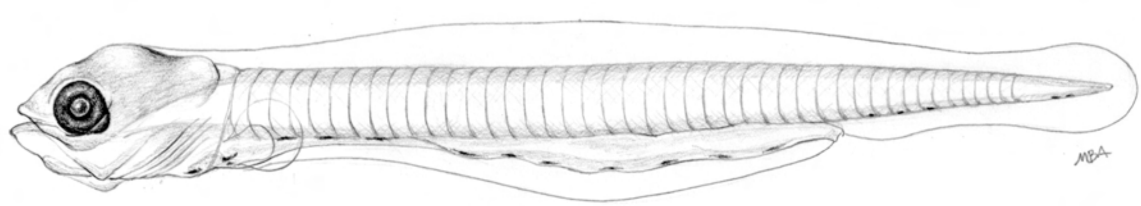


Figure 19.—*Engraulis mordax*, northern anchovy postlarva, 3.9 mm TL (Wang 1986).

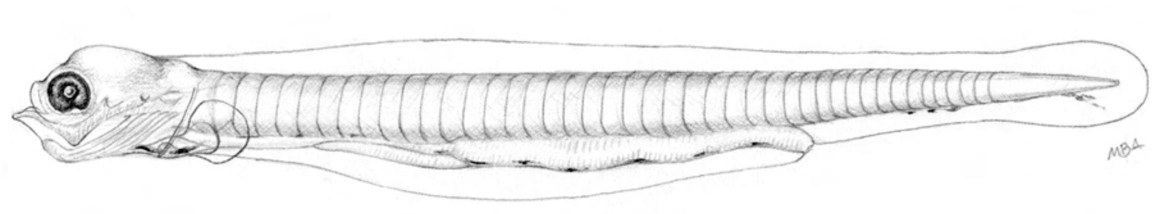


Figure 20.—*Engraulis mordax*, northern anchovy postlarva, 6.0 mm TL (Wang 1986).

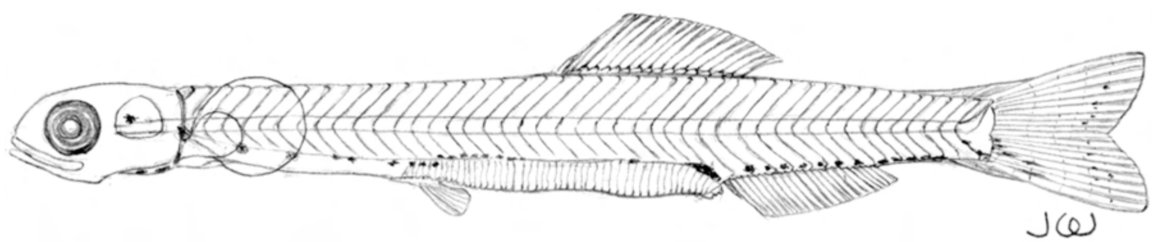


Figure 21.—*Engraulis mordax*, northern anchovy juvenile, 27.5 mm TL (Wang 1986).

Clupeidae – Herrings — Four species of clupeids occur in the study area: American shad (*Alosa sapidissima*), an introduced anadromous fish from the east coast of the United States; Pacific herring (*Clupea pallasi*), a native Pacific coastal marine fish; threadfin shad, an introduced euryhaline species from the Mississippi River drainage; and Pacific sardine (*Sardinops sagax*), a native coastal marine species. Pacific sardine is occasionally observed in the polyhaline waters of San Francisco Bay (Baxter *et al.* 1999), but this species has not been reported from San Pablo Bay or further upstream in the Delta. Life history descriptions follow for American shad, Pacific herring, and threadfin shad.

AMERICAN SHAD *Alosa sapidissima* (Wilson)

SPAWNING

Location

Main channel of the Sacramento River, up to Red Bluff (Skinner 1962, Stevens 1972). Some individuals reach Keswick Dam on the Sacramento River (R. Painter 1979, personal communication); the lower reaches of the Feather River, Yuba River, and American River; the lower reaches of the San Joaquin River and its tributaries; and the Mokelumne and Stanislaus Rivers (Skinner 1962, Moyle 1976); a land-locked population has been found in the upper San Joaquin River in Millerton Lake downstream of

	PG&E's Kerckhoff 2 hydroelectric powerhouse (Wang 1986).
Season	Ripe females have been observed from February through June (Ganssle 1966); May through June (Erkkila *et al.* 1950); March through July (Skinner 1962, Stevens 1972); April through July, peaking in June and July in the Sacramento-San Joaquin River system; as late as September in the upper San Joaquin River at Millerton Lake (Wang 1986).
Temperature	Water temperatures of 8–26°C (Walburn and Nichols 1967); maximum 15–20°C (Skinner 1962, Stevens 1972); ~12–17°C in Millerton Lake; spawning occurs usually at higher temperatures, 17–24°C in the Sacramento River (Moyle 2002); ~14°C in American River (R.C. Reyes 2003–2009, personal communication).
Salinity	Freshwater.
Substrate	None. Survival of eggs is apparently higher when they are deposited over sandy and gravel areas with flow; eggs were collected over sandy and bare rock areas in Millerton Lake.
Fecundity	155,000–410,000 (Reintjes and Hettler 1967); 2,000–150,000 (Scott and Crossman 1973); 116,000–225,000 (MacKenzie *et al.* 1985).

EGGS

Shape	Spherical (Ryder 1887).
Diameter	2.5–3.8 mm (Marcy and Jacobson 1976); 2.9–3.7 mm in the American River (R.C. Reyes 2003–2009, personal communication); 2.5–4.4 mm.
Yolk	Pale amber to pink (Mansueti 1955); granular (Bigelow and Welsh 1925, Lippson and Moran 1974); pale yellow to yellow, with coarse, granular yolk.
Oil globule	No oil globule (Lippson and Moran 1974, Wang and Kernehan 1979).
Chorion	Transparent (Mansueti 1955); transparent, smooth, and very thin.
Perivitelline space	Very wide, ~½ egg radius (Bigelow and Welsh 1925).
Egg deposition	Broadcast singly.
Adhesiveness	Initially adhesive (Chittenden 1969; Wang and Kernehan 1979), with fine particles attached (Wang and Kernehan 1979); later, nonadhesive (Hildebrand 1963).

Buoyancy	Semi-demersal (Mansueti 1955, Hildebrand 1963); semi-demersal or slightly heavier than freshwater, suspended by water current (Wang and Kernehan 1979).

LARVAE

Length at hatching	5.7–10.0 mm TL (Marcy and Jacobson 1976); 7.0–10.0 mm TL (Lippson and Moran 1974); ~6.5 mm TL (Wang and Kernehan 1979); 7.5–9.7 mm TL in the American River (R.C. Reyes 2003–2009, personal communication); ~6.5–10.0 mm TL.
Snout to anus ratio	~80–83% TL for prolarvae; ~73–80% TL for postlarvae.
Yolk-sac	Spherical, head detached from yolk (Ryder 1887); spherical to oval; positioned in thoracic region.
Oil globule	None.
Gut	Straight, elongated, intestine wall appears segmented.
Air bladder	Apparent in postlarval stage; shallow, located midway between pectoral and anus.
Teeth	None on jaw, one row develops in the middle of tongue in late postlarvae.
Size at completion of yolk-sac stage	9–12 mm TL (Lippson and Moran 1974); ~10–12 mm TL.
Total myomeres	55–57 (Lippson and Moran 1974); mainly 53–58 for west coast population.
Preanal myomeres	41–47 (Lippson and Moran 1974); 41–49.
Postanal myomeres	10–16 (Lippson and Moran 1974); 8–16.
Last fin (s) to complete development	Pectoral and pelvic.
Pigmentation	Single row (one on each side) of dashed melanophores along jugular to thoracic region; stellate or dotted melanophores in the midventral and dorsal gut region; scattered melanophores also found in postanal and caudal regions.
Distribution	Pelagic (Marcy and Jacobson 1976); remaining in the freshwater during larval stage (Moyle 2002); pelagic in lower reaches of Sacramento River, Delta, Mokelumne River, upper San Joaquin River (mainly above the logjam at Millerton Lake). American shad larvae were also observed in the Suisun Bay, Montezuma Slough, and Napa River in high flow wet-water years.

JUVENILES

Dorsal fin rays	15–19 (Miller and Lea 1972); 17–19 (Hildebrand and Schroeder 1928); mostly 17–18 (Moyle 2002).
Anal fin rays	18–23 (Miller and Lea 1972); 18–25 (Hill 1959); 18–24, usually 20–22 (Moyle 2002).
Pectoral fin rays	13–18 (Carscadden and Leggett 1975, Hill 1959).
Mouth	Terminal, upper jaw as long as lower jaw (Scott and Crossman 1973); terminal, pointed, maxillary reaches to middle of eye.
Vertebrate	55–58 for west coast population (Miller and Lea 1972); 51–60 (Leim 1957, Hill 1959); 53–59 (Leim and Scott 1966); often >55.
Distribution	Inshore as well as open water. Some move from freshwater closer to the saltwater in summer and fall (Moyle 2002). Most juveniles enter the sea in fall and winter. All sizes of American shad except prolarvae, are observed at CVP/TFCF intake at various times of the year.

LIFE HISTORY

American shad is anadromous and native to the Atlantic coast (Leim and Scott 1966). This species was first introduced into the Sacramento River during the period 1871–1881 (Skinner 1962). Once established, American shad spread quickly along the west coast. Their current distribution is from Todos Santos Bay, Baja California, to Alaska and Kamchatka, Russia (Miller and Lea 1972, Hart 1973). In this study, American shad were found in the Sacramento River system, the Delta, and San Joaquin system, and a successfully reproducing land-locked population was investigated in Millerton Lake from 1979 to 1991 by this author.

Prior to spawning, American shad begin to enter estuarine waters as early as fall (Stevens 1972). Potential spawners were captured in gill nets near Montezuma Slough and the vicinity of the Contra Costa and Pittsburg Powerplants. Many shad were observed at CVP/TFCF water intake in the fall, particularly during wet-water years, presumably seeking suitable spawning habitat. Major spawning season is April to July (Stevens 1972). Sometimes spawning season will be extended to late summer due to cold hypoliminion water discharge from water storage reservoirs upstream, such as Millerton Lake (Wang 1986) and Oroville Reservoir on the lower reaches of Feather River.

Spawning behavior was closely monitored in the Millerton Lake American shad population. American shad spawned when flow was sufficient (~20–60 cm/s) in tailrace of the powerhouse, and mostly at nighttime. Usually a ripe female was followed by several males. Mating occurred near shore in shallow water. Splashing due to spawning activity was sporadic. Spawning activity peaked at midnight to early morning hours when the Kerckhoff 2 powerhouse released the largest volume of the water. As water velocity subsided, tell-tale splashing of spawning activity became less frequent. Spawning was more frequent when the moon was present suggesting a relationship to lunar phase. Various developmental stages of ova observed in American shad ovaries suggest it is a fractional spawner that spawns many times during the spawning season. Females may have the residuals of immature eggs left at the distal end of the ovary at the end of the spawning season.

Principal spawning grounds in the estuary were located above Rio Vista on the Sacramento River and its tributaries, the Feather River, Yuba River, and American River (Moyle 2002). Eggs were observed in the confluence of the Sacramento and San Joaquin Rivers during wet-water years. The lower reaches of the San Joaquin River have not been used extensively for spawning. Smaller runs were observed in the Mokelumne River, Cosumnes River, and Stanislaus River (Moyle 2002). A few American shad eggs and larvae were collected in the central Delta in May 1993; however, eggs were neither collected in the central and south Delta by the CDWR (Spaar 1990a, 1990b, 1991, 1992, 1993; Spaar and Wadsworth 1994) nor at the CVP/TFCF in the 1990s (Hiebert *et al.* 1995, Siegfried *et al.* 2000). Also, American shad eggs and larvae were not taken in larval fish collections from the Old River in the early 2000s (M. Healey 2001, personal communication). Reproduction of American shad in the south Delta may have declined in recent years (D. Hansen 2001, 2007, personal communication).

Eggs are semi-demersal (Mansueti 1955), a moderate current (about 0.5–1.0 m/s) will keep them floating (Wang 1986). Eggs hatch in 17 d at 12°C (Ryder 1887), or 8–12 d at 11–15°C (Scott and Crossman 1973). In Millerton Lake, live eggs were collected in the tailrace of the K2 hydroelectric powerhouse over mostly rocky and some sandy bottoms. Riverflow is a requirement to keep eggs floating and bouncing. Based on collections of ~40–45-mm TL early juvenile shad at CVP/TFCF intake in late December 2003–2004, spawning apparently extends to the fall season in areas where water temperature is cool, such as at Feather River downstream of Oroville Reservoir Dam (B. Bridges 2005, personal communication).

Newly-hatched American shad larvae are pelagic and most abundant at the water's surface (Marcy and Jacobson 1976). In the study area, some larvae moved downstream from the spawning ground soon after hatching, but the majority of the larvae remained in the river and the Delta for several months (Stevens 1972).

The majority of small juveniles (~40–50 mm TL) move directly through the estuary in the summer months (Stevens 1972, Moyle 1976); some stay longer and grow larger (≥70 mm TL) in the Delta; some are diverted into the south Delta by the federal and state pumping stations; a majority will move out into the Pacific Ocean eventually. Many American shad spend from 3–5 years in the ocean before they return to coastal rivers to spawn (Leim 1957, Moyle 1976). However, some may remain in the estuary for 1–2 years (Stevens *et al.* 1987) and some may stay in the estuary throughout their lifespan (R. Painter 1979, personal communication). Since different ages of American shad are observed in the estuary throughout the year, inmigrating and outmigrating populations are hard to differentiate.

Juvenile shad feed on copepods, related crustaceans, and insect larvae while in freshwater (Scott and Crossman 1973) and mysid shrimps and amphipods when they are in the estuary (Stevens 1966). Larvae have a higher survival rate when raised in newly built and newly fertilized earthen ponds (T. Robbins 1985–1988, personal communication).

By 1879, a commercial fishery for American shad developed in the Sacramento-San Joaquin River system, but commercial fishing was banned by the State of California in 1957 (Moyle 1976). A seasonal sport fishery has developed for this species in the study area, especially on the American and Feather Rivers.

The life history of the Atlantic coast American shad was investigated extensively by Leim and Scott (1966) and Leggett (1973). On the west coast, substantial amounts of information on the early life history have been compiled by the CDFG as part of the Delta Fish and Wildlife Protection Study (Chadwick 1958; Skinner 1962; Stevens 1966, 1972; Painter *et al.* 1979). However, aspects of the life history of immature American shad in the Pacific Ocean are not well documented.

American shad in Millerton Lake are land-locked, and thus cannot make the ocean-to-river spawning run. Instead, a potadromous migration has been noted between the San Joaquin River and Millerton Lake. Food sources are limited in the lake; therefore, growth rate is slow. Unlike the planktivorous feeding behavior of the anadromous form of American shad (Fish *et al.* 2008), the land-locked population preys heavily on threadfin shad and other small fish. This feeding behavior may boost nutrient intake and enhance sexual maturity. The land-locked American shad population is generally found in the lake and lower Fine Gold Creek (Fresno County), but during the spawning run they move up to the narrow canyon portion of the river, where there is a good flow from PG&E's Kerckhoff 2 hydroelectric powerhouse. This is the only known land-locked population in North America and their life stages and life histories have been documented. Limited sportfishing during their spawning run is recommended by the CDFG in order to protect this unique fish population. American shad have also been reported in San Luis Reservoir (Hess *et al.* 1995), imported from the Delta via the Delta Mendota Canal, but there is no evidence that spawning has occurred in San Luis Reservoir.

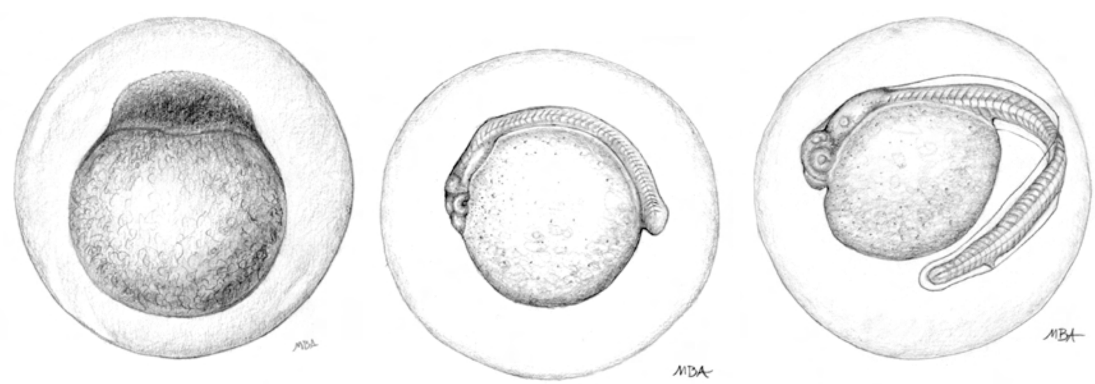


Figure 22.—*Alosa sapidissima*, American shad eggs: (left to right) morula 3.5 mm; early embryo 3.2 mm; late embryo 3.5 mm (Wang 1986).

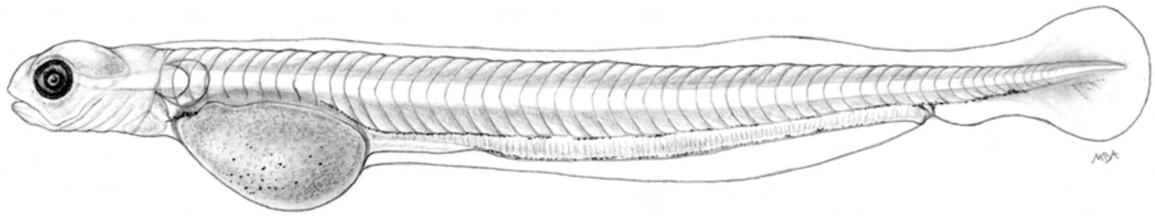


Figure 23.—*Alosa sapidissima*, American shad prolarva, 10 mm TL (Wang 1986).

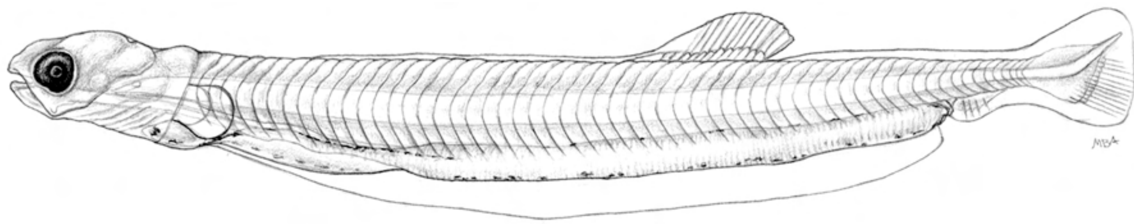


Figure 24.—*Alosa sapidissima*, American shad postlarva, 12.2 mm TL (Wang 1986).

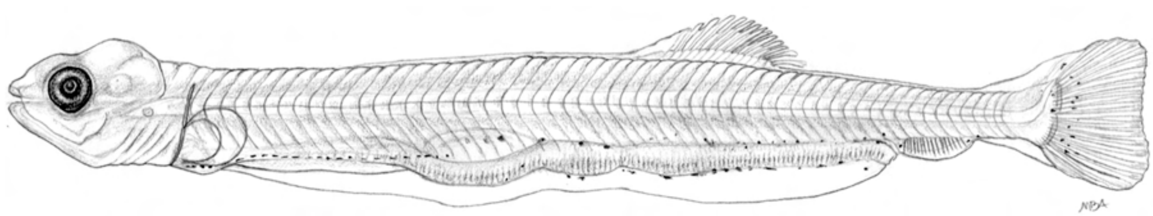


Figure 25.—*Alosa sapidissima*, American shad postlarva, 16.5 mm TL (Wang 1986).

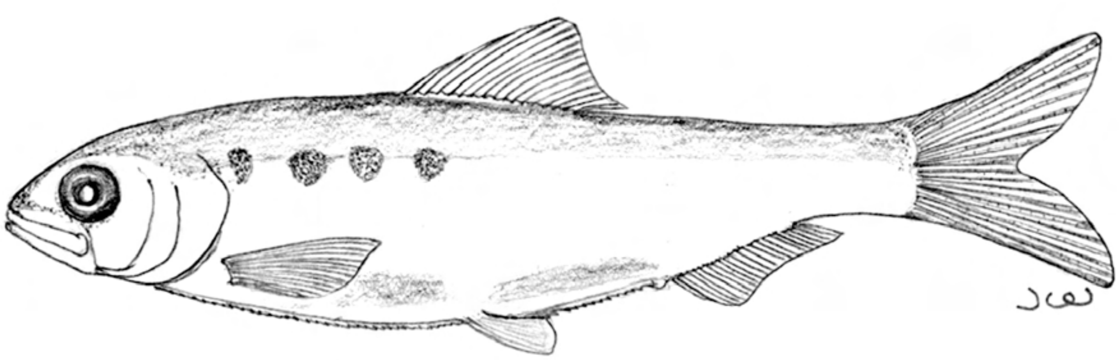


Figure 26.—*Alosa sapidissima*, American shad juvenile, 83 mm TL (Wang 1986).

Figure 27.—*Alosa sapidissima,* American shad.

PACIFIC HERRING *Clupea pallasi* Valenciennes

SPAWNING

Location	Shallow intertidal and subtidal, estuaries, and coastlines (Miller and Schmidtke 1956, Eldridge and Kail 1973). Specific locations in San Francisco Bay include the north end of Golden Gate Bridge, Sausalito, Tiburon, Angel Island, Alcatraz Island, Treasure Island, and Point of Richmond (Miller and Schmidtke 1956, Spratt 1981); minor spawning is also known in the vicinity of San Mateo Point of south San Francisco Bay (Miller and Schmidtke 1956); in the vicinity of Hunters Point Powerplant; Point San Pablo to Redwood City (Watters *et al.* 2004); San Pablo Bay and Carquinez Strait during dry-water years (Miller and Schmidtke 1956); and in the vicinity of Carquinez Strait based on collections of yolk-sac larvae. In Tomales Bay, spawning occurs mostly in the northern half of the bay along the shore (Miller and Schmidtke 1956); from Marconi Cove and north inshore jetty rocks (Wang 1986); in Moss Landing Harbor and Elkhorn Slough, larvae were taken mostly in Elkhorn Slough (Nybakken *et al.* 1977, Wang 1981). Spawning sites may vary naturally from year to year due to environmental factors. At Elkhorn Slough in the 1990s, highway reconstruction altered spawning sites resulting in a decline in Pacific herring spawning activity.
Season	December–June (Miller and Schmidtke 1956); December–March (Hardwick 1973); October–June (Eldridge and Kail 1973); November– March (Spratt 1981); November–April in San Francisco Bay and Tomales Bay, peaking January–February (Wang 1986); November–July in Moss Landing Harbor and Elkhorn Slough (Wang 1986); October–April, and peaking December to February in San Francisco Bay (Watters *et al.* 2004). Beginning of spawning can vary, and heavy rainfall in the fall may be an environmental cue.
Temperature	5–10°C (Alderdice and Velsen 1971); 3–12.3°C (Hart 1973); 6–15°C in San Francisco Bay; 10–18.2°C in Moss Landing Harbor-Elkhorn Slough when yolk-sac larvae were taken (Wang 1981, 1986).
Salinity	Range of 8–18 ppt (Alderdice and Velsen 1971); seawater-mesohaline.
Substrate	Mostly on eelgrass and seaweed (Miller and Schmidtke 1956); other substrates include rocks, jetties, sandy beach, and submerged objects such as pilings (Hardwick 1973, Eldridge and Kail 1973, Watters *et al.* 2004); on *Salicornia*

	spp. and on the wall of a metal culvert in upper Elkhorn Slough (Wang 1986).
Fecundity	19,000 and 29,500 for 192.5-mm and 223-mm SL specimens (Hart and Tester 1934); mean fecundity 15,800 (Katz 1968), 18,000–22,000 (Nagasaki 1958), 22,300 (Paulson and Smith 1977), or 60,700 (Ambroz 1931).

EGGS

Shape	Spherical.
Diameter	1.3–1.8 mm (Miller and Schmidtke 1956); 1.2–1.5 mm (Hart 1973); 1.2–1.7 mm (Watson and Sandknop 1996a); 1.3–1.6 mm.
Yolk	Yellowish, granular.
Oil globule	None.
Chorion	Transparent, thick, tough, and elastic.
Perivitelline space	Relatively wide, ~0.2–0.3 mm in width in early embryo stages.
Egg deposition	Eggs are broadcast over substrates, where they adhere in one or several layers or clusters (Blaxter 1956, Eldridge and Kail 1973). Multi-layers of eggs are deposited by different females on intertidal rocks at Tiburon in Richardson Bay.
Adhesiveness	Highly adhesive (Miller and Schmidtke 1956, Taylor 1964) forming one or more flat attaching disc.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	6.5–8.8 mm TL (Alderdice and Velsen 1971); average 7.5 mm TL (Hart 1973); 5.6–7.5 mm TL for specimens taken at Richardson Bay.
Snout to anus length	78–84% TL for prolarvae and early post larvae; decreasing to ~75–80% TL for late postlarvae, 20 mm TL.
Gut	Straight and very thin in prolarvae; convoluted or segmented structure of intestine apparent in postlarvae.
Teeth	Pointed on premaxillary and hooked on maxillary, conical teeth on lower jaw.
Size at absorption of yolk	~8–10 mm TL.
Total myomeres	45–55.
Preanal myomeres	37–44.
Postanal myomeres	7–13.

Last fins(s) to complete development	Pectoral and pelvic.
Pigmentation	Dashed melanophores in middle of jugular to thoracic region; two rows of dashed or dotted melanophores along dorsum of gut and midventral region; some melanophores are present at tip of notochord.
Distribution	Pelagic, top of water column off coast (Blaxter 1956); in Richardson Bay (Eldridge 1977); in San Francisco Bay, San Pablo Bay, Napa River. Some ascend to Suisun Bay, Montezuma Slough and its tributaries (Wang 1986); they are also known in Moss Landing Harbor-Elkhorn Slough (Nybakken *et al.* 1977) and Tomales Bay (Wang 1986).

JUVENILES

Dorsal fin rays	15–21 (Miller and Lea 1972, Hart 1973).
Anal fin rays	13–20 (Miller and Lea 1972); 14–20 (Hart 1973).
Pectoral fin rays	17 (Hart 1973).
Mouth	Terminal and upward, maxillary extends to mid-eye (Hart 1973).
Vertebrae	46–55 (Hubbs 1925, Miller and Lea 1972), 51–53 (Tester 1937), 46–58 (Watson and Sandknop 1996a).
Distribution	Pelagic, most of them leaving the bay or estuary and returning to the ocean (Eldridge and Kail 1973); some were collected in the San Francisco Bay, remaining in the bay for longer time (Wang 1986); juveniles were collected in Napa River, Suisun Bay, and west Delta in winter and return down bay to ocean in spring (CDFG striped bass E and L survey 1988–2005; UC Davis Suisun Marsh E and L study ~1980–2004; Stillwater Science/U.S. Army Corps of Engineers Napa River Flood Control Study 2000–2001).

LIFE HISTORY

The overall distribution of the Pacific herring is from northern Baja California to Toyama Bay, Japan, and westward on the shores of Korea, Liaodong Peninsula, and the Yellow Sea of China (Svetovidov 1948). In North America, Pacific herring have been recorded from northern Baja California to Port Clarence, Alaska (Alderdice and Velsen 1971, Miller and Lea 1972, Hart 1973). In this study, Pacific herring were collected seasonally in San Francisco Bay, San Pablo Bay, Tomales Bay, and Moss Landing Harbor-Elkhorn Slough.

Mature fish return to the bays approximately 2 months before they spawn (Eldridge and Kail 1973). In Tomales Bay, Hardwick (1973) observed Pacific herring entering the bay in late November and early December. Pacific herring spawning activities were observed in the Tiburon area as early as November in 1978 and 1980. The spawning activity seems to be stimulated by rainy weather; early rainfalls moving the spawning earlier. The peak spawning period in San Francisco Bay and Tomales Bay is from January to March (Miller and Schmidtke 1956). Recently, however, peak spawning in the San Francisco Bay occurred from December to February (Watters *et al.* 2004). Miller and Schmidtke (1956) also noticed Pacific herring spawning in the summer in Monterey Bay and Morro Bay. Similar observations were made in this study; eggs and yolk-sac larvae were collected in Moss Landing Harbor-Elkhorn Slough from November through July in 1978 and 1979. Larvae were also observed in Morro Bay in the vicinity of Diablo Canyon Nuclear Powerplant in a similar time period (E. Calix 1999–2005, personal communication). In the southern reaches of its range, two modes of reproduction were observed for Pacific herring, one in winter and another in summer. Water temperature was 18°C when Pacific herring larvae were collected at Elkhorn Slough in July. Alderdice and Velsen (1971) found the maximum observed temperature for Pacific herring spawning in British Columbia to be 10°C. In San Francisco Bay, the majority of spawning starts at ~10°C. Apparently, Pacific herring has adapted to different spawning temperatures depending on locations. Occuring mostly at night, large schools of Pacific herring spawn over a period of 1–7 d (Miller and Schmidtke 1956). At least 2–3 cohorts are produced in the San Francisco Bay each year (Bollens and Sanders 2004).

Pacific herring eggs are spawned in the intertidal and subtidal areas (Miller and Schmidtke 1956, Hart 1973). The eggs are adhesive, often attaching to eelgrass and occasionally to algae. In San Francisco Bay, where eelgrass is not as abundant, Pacific herring are known to broadcast eggs on rocks, rocky jetties, pilings, sandy beaches, and other submerged objects (Eldridge and Kail 1973). Some eggs deposited on the high tide marks of pilings in Elkhorn Slough are able to survive in the air during tidal changes. An individual can spawn only once during the season, and spent female returns to the ocean immediately after spawning (Miller and Schmidtke 1956). The late spawners will use the same area for spawning as was used by earlier spawners. Consequently, egg masses are deposited in layers up to 5 cm in depth on the substrate (Hardwick 1973, Eldridge and Kail 1973). Eggs in the bottom layers turn white and eventually die due to suffocation. Eggs in San Francisco Bay have been reported to hatch in 6–11 d at 8–10°C (Miller and Schmidtke 1956). In this study, eggs in the early morula stage collected at Tiburon jetty hatched in the laboratory in 6–7 d at 11.8–13.5°C.

Newly-hatched larvae remain on the bottom for a short time. As the pigment develops in their eyes, they eventually swim to the surface. Eldridge and Kail (1973) described larvae moving out of the bay soon after hatching. Large numbers of Pacific herring larvae were collected at Potrero and Hunters Point Powerplants in south San Francisco Bay, Napa River, eastern San Pablo Bay, Montezuma Slough and its tributaries, and Suisun Bay up to the Pittsburg Powerplant. Some larvae remain in the upper estuary until April and May, a much longer stay than reported by Eldridge and Kail (1973).

This study substantiated that some juvenile Pacific herring (at least those occurring in the San Francisco Bay) remain in the estuary. Young-of-the-year (YOY) herring have been observed in the vicinity of Port Chicago, Pittsburg, and False River (Ganssle 1966; Wang and Brown 1993; Baxter *et al.* 1999; J. Chu 2008–2009, personal communication) and the south San Francisco Bay. Small juveniles were collected in the Napa River (CDFG 20-mm fish survey; Stillwater Sciences, Inc.) and Montezuma Slough throughout the spring (UC Davis Suisun Marsh Study). Juvenile Pacific herring is one the most abundant fishes in Napa River during spring. Some of these juveniles appear to be staying in the estuary instead of moving to sea, a pattern of behavior also reported in Canada. Hart (1973) documented larvae and postlarvae in the area of the Strait of Georgia influenced by the Frazer River. He further noted that juveniles remained in coastal waters until fall, eventually disappearing into the ocean. Depending on geographical location, the accessibility of food sources in the estuary may delay emigration. The majority of age-0 herring in the San Francisco Bay also leave the estuary in fall (Baxter *et al.* 1999).

The diet of juvenile herring includes copepods, barnacle larvae, molluscan larvae, bryozoans, rotifers, and small fish (Hart 1973); majority of diets are tintinnids and copepoids (Bollens and Sanders 2004).

Pacific herring reach maturity in 1–4 years, depending on individual populations (Paulson and Smith 1977, Miller and Schmidtke 1956, Hart 1973). The maximum lifespan is known to be 9 years for the San Francisco Bay population and 6 years for the Tomales Bay population. Much longer lifespans have been reported for northern populations (Miller and Schmidtke 1956). Pacific herring come from distinct populations, depending on their locations. Members of each population have a special homing instinct (Rounsefell 1930, Stevenson 1955, Hardwick 1973). Within even as short a distance as that separating Tomales Bay and San Francisco Bay, there are two distinct spawning populations (Hardwick 1973).

The Pacific herring is an important part of the diet for cetaceans and humans, particularly along the Alaskan coast. Locally, there is a fishery in San Francisco Bay and Tomales Bay during the winter spawning season regulated by the state to ensure that the resource is not damaged. However, due to warm water temperatures and other factors, the fishery has been dwindling in recent years (Watters *et al.* 2004). The decreasing productivity and profitability of the Pacific herring fishery may also help explain smaller commercial catch of this species (Greiner *et al.* 2007). Most of the herring roe is exported to Japan and other Asian countries as caviar (Spratt 1992), and a small amount is used domestically. Pacific herring are considered tasty but they are very bony.

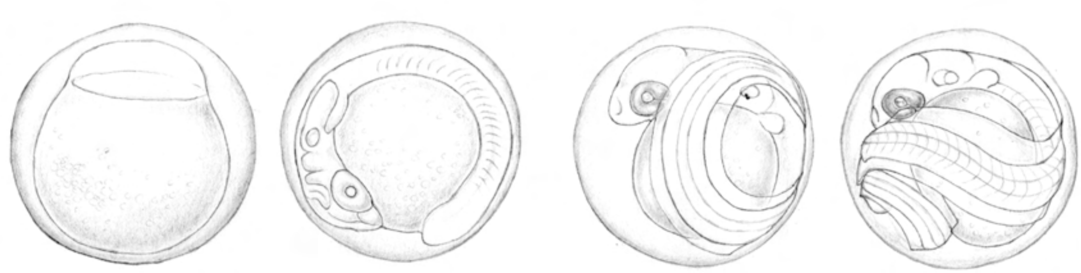


Figure 28.—*Clupea pallasii*, Pacific herring egg (left to right): morula 1.4 mm, late embryo 1.4 mm, late embryo 1.5 mm, late embryo 1.5 mm (Wang 1986)

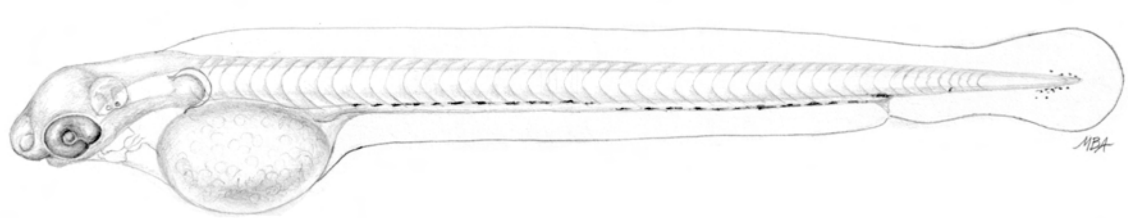


Figure 29.—*Clupea pallasii*, Pacific herring prolarva, 8 mm TL (Wang 1986).

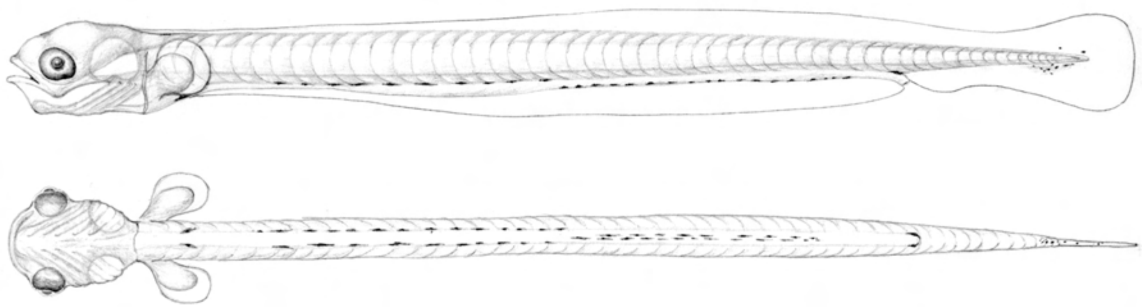


Figure 30.—*Clupea pallasii*, Pacific herring postlarva, 10.3 mm TL, lateral and ventral views (Wang 1986).

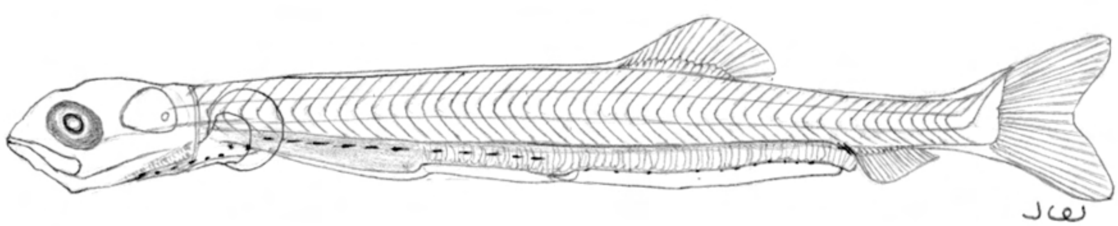


Figure 31.—*Clupea pallasii*, Pacific herring postlarva, 18.8 mm TL (Wang 1986).

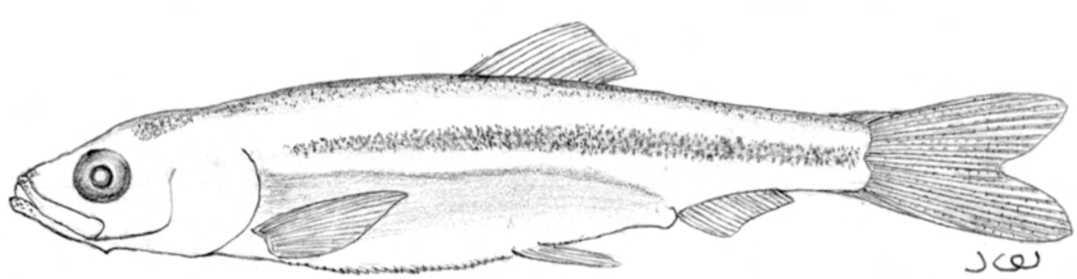


Figure 32.—*Clupea pallasii*, Pacific herring juvenile, 40 mm TL (Wang 1986).

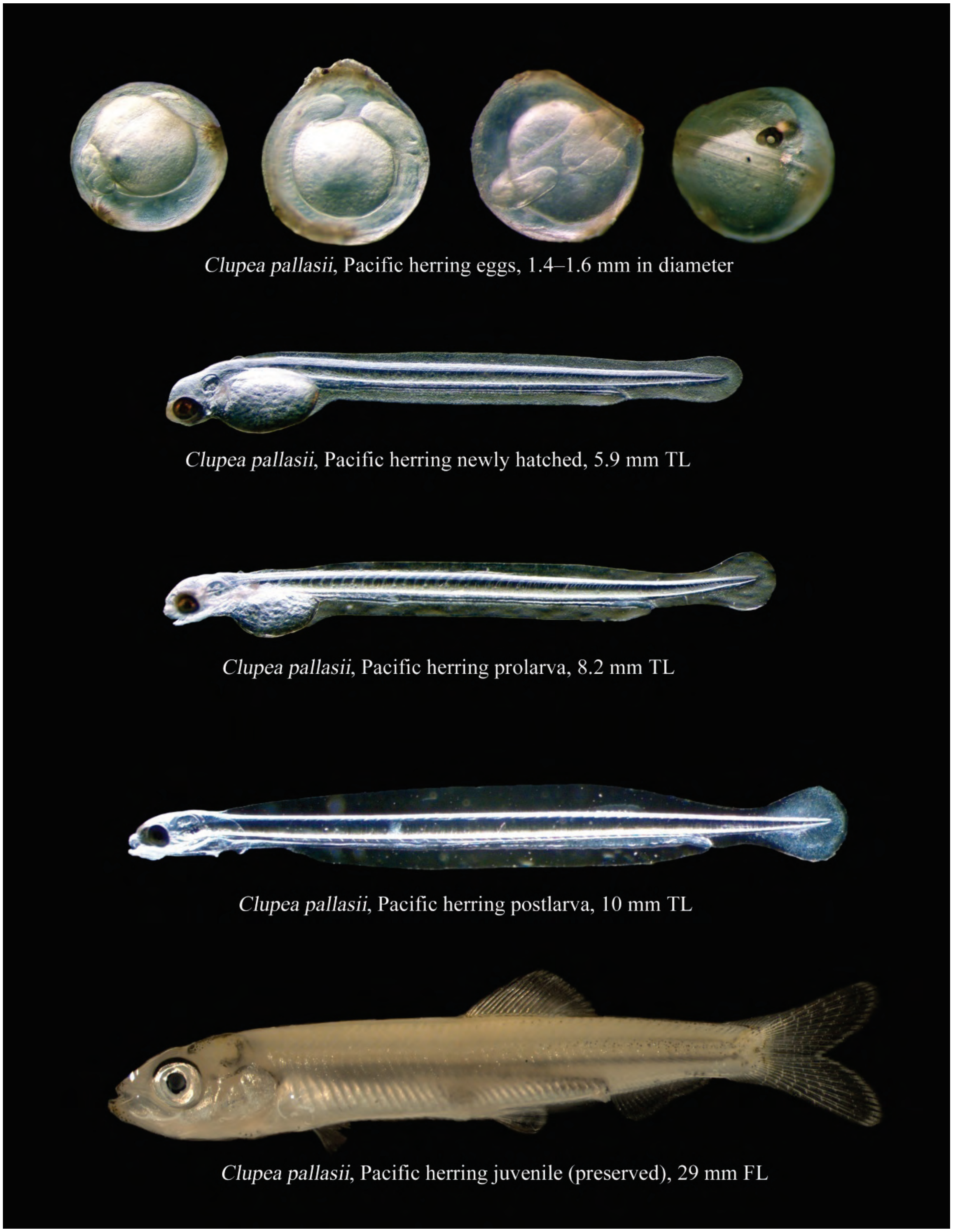


Figure 33.—*Clupea pallasii*, Pacific herring.

THREADFIN SHAD *Dorosoma petenense* (Günther)

SPAWNING

Locations	Shallow water with vegetation just below surface (Taber 1969); shallow sluggish sloughs, ponds, and reservoirs, such as most of the sloughs in the Delta and inshore of Suisun Bay; Clifton Court Forebay, Heather Farm Pond, warm water inshore of Millerton Lake, and Cottonwood Bay of San Luis Reservoir.
Season	From April to the end of summer (Johnson 1969, 1971); April–September (Taber 1969); peak in June (Moyle 1976); April through August and peak in June and July.
Temperature	14–18°C (Rawstron 1964); started at 21°C and higher (Kimsey and Fisk 1964); mostly concentrated at 20–25°C in the warmer waters of Millerton Lake and San Luis Reservoir.
Salinity	Freshwater (Burns 1966); freshwater to oligohaline or higher.
Substrate	Submerged vegetation, floating debris (Rawstron 1964); bushes, stumps, logs (Lambou 1965); filamentous algae, rocks, sticks, grass and other submerged vegetation (Taber 1969); submerged vegetation, floating tree branches, sticks, plant seeds, submerged log, drifted debris, filamentous algae, and egaria.
Fecundity	6,210 and 21,000 in 126-mm and 168-mm SL specimens (Finucane 1965); mature ova, 900–21,000 (Johnson 1970).

EGGS

Shape	Spherical.
Diameter	Fertilized eggs, 0.75 mm (Hubbs and Bryan 1974); 0.9–1.2 mm.
Yolk	Light yellow for mature ova (Finucane 1965); yellowish-whitish, coarse, granular.
Oil globule	Single oil globule, ~0.1–0.2 mm in diameter.
Chorion	Transparent.
Perivitelline space	Wide, ~0.1–0.2 mm.
Adhesiveness	Adhesive (Lambou 1965, Moyle 1976); very adhesive throughout incubation.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	4.1–4.4 mm TL (Taber 1969); 3.2–4.4 mm TL.
Snout to anus length	81–85% TL for prolarvae and early postlarvae; decreasing to 75–80% TL for postlarvae ≥15 mm TL.
Yolk-sac	Spherical to oval, in jugular-thoracic region.
Oil globule	Single, small located posteriorly in yolk-sac.
Gut	Straight, slender in postlarvae, becoming thick and segmented in postlarvae.
Air bladder	Elongated and shallow, above and slightly behind pelvic fins, apparent in postlarval stage, ~10 mm TL.
Size at absorption of yolk	4.5–5.0 mm TL.
Total myomeres	<40 (Kersh 1970); 40–45.
Preanal myomeres	~36 (Taber 1969); 36–40.
Postanal myomeres	4–6.
Last fin(s) to complete development	Pectoral and pelvic.
Pigmentation	Dashed and dotted melanophores in thoracic region; 2 rows of melanophores located dorsally on the gut; dashed or dotted melanophores present mid-ventrally in area of small intestine and postanally.
Distribution	Planktonic (Taber 1969); in shallow and open water of the Delta, Suisun Bay, San Luis Reservoir, and Millerton Lake; also observed in Clear Lake and Lake Pillsbury (Lake County, California; Moyle 2002).

JUVENILES

Dorsal fin rays	11–15 (Taber 1969, Miller and Lea 1972); 14–15 with a range of 11–17 (Moyle 2002).
Anal fin rays	17–27 (Miller and Lea 1972, Jones *et al.* 1978, Moyle 2002).
Pectoral fin rays	12–17 (Miller 1963); mostly 15–16.
Mouth	Terminal (Miller 1963); terminal, small, oblique, and toothless (Moyle 2002).
Vertebrae	40–45 (Miller and Lea 1972); 43–44 (Miller and Jorgenson 1973).
Distribution	Shallow and open water of Sacramento-San Joaquin River system, in the vicinity of the CVP/TFCF of the south Delta; some in estuaries, including the Moss Landing Harbor; also common in reservoirs such as San Luis Reservoir and Millerton Lake.

LIFE HISTORY

Threadfin shad is native to streams flowing into the Gulf of Mexico from Florida to Mexico, and south to Belize (Moyle 2002). They are in Oklahoma, Tennessee, and southern Arkansas in the Mississippi River and its tributaries (Moyle 1976, 2002). Threadfin shad, collected from the Tennessee River, were first introduced into San Diego County by the CDFG in 1953 (Kimsey 1954). Additional threadfin shad were introduced in numerous reservoirs in northern California and in the Sacramento-San Joaquin River system (Kimsey and Fisk 1964). Currently, along the Pacific coast, they have been recorded from Long Beach to Humboldt Bay (Miller and Lea 1972); an additional northern record is known from Yaquin Bay, Oregon (Lee *et al.* 1980). Although this species is found in water of various salinities, it seems to prefer the oligohaline to freshwater ranges (*i.e.*, <5 ppt). It is particularly abundant in warmwater reservoirs (Burns 1966). Threadfin shad was the most abundant clupeid in the Delta and lower saline estuary, reservoirs such as San Luis Reservoir and Millerton Lake, and other ponds and waterways associated with the Delta water systems.

Spawning occurs throughout late spring and summer, with peaks from May to July. Earliest spawning was observed in the thermal plume areas of Contra Costa and Pittsburg Powerplants in April, and the latest was in Millerton Lake, ending in August. At CVP/TFCF threadfin shad larvae have been collected from April to August, with captures occasionally extending to September in warm years.

Female threadfin shad deposit their eggs on submerged vegetation in shallow water (Taber 1969). Large schools have been observed congregating in the shallow Cotton Bay of San Luis Reservoir, in the vicinity of boat ramps, and below logjams of Millerton Lake in early May. Eggs were deposited on submerged substrates, floating debris, logs, sticks, and plant seeds. Deposition of eggs on floating substrates may be an important spawning strategy for reservoir populations, since water level fluctuates due to large volumes of freshwater released daily for irrigation. Eggs adhering to floating substrate will have a better chance of survival, particularly those eggs attached to the underside of substrates. Eggs are in single layers on the substrate, and remain attached throughout the incubation period. Older fish spawn approximately 2 months earlier than younger fish, prolonging the spawning period; however, it is unlikely that an individual fish will breed more than once during the season (Johnson 1971). The incubation period for eggs is 3–6 d (Moyle 1976); about 3 d at 26.7°C (Burns 1966).

Newly-hatched threadfin shad larvae are planktonic and exhibit diel migratory behavior; they are found near the surface during daytime and descend to the mid-depths or lower at night (Taber 1969). Larvae were abundant inshore and also in open water in the vicinity of the Pittsburg and Contra Costa Powerplants. They were most abundant in warm water such as Clifton Court Forebay, Mallard Slough, and Rock Slough. Larvae were also found in smaller ponds such as the Heather Farm Pond (Contra Costa County) and Contra Loma Reservoir. Larvae were observed at the CVP/TFCF from early summer to early fall. The end of threadfin shad spawning marks the end of the spawning season for fishes that reside in the Delta.

Juvenile threadfin shad typically form schools. Ganssle (1966) noted that they were abundant in the Delta and Suisun Bay from September through November. Large schools were noted in Suisun Bay and in the vicinity of the Contra Costa and Pittsburg Powerplants. The thermal plumes of the powerplants keep the water warm during fall which attracts schools of juvenile threadfin shad. In Millerton Lake, large schools frequently move between the warm lake water and the cold river water (the plunge point or the logjams) in the summer and fall months. Young threadfin shad have been found in 15.5 ppt brackish water in the estuary (Miller 1963). Juveniles were collected occasionally on the intake screens at Moss Landing Powerplant, a seawater-cooled powerplant. Large schools of juvenile and adult threadfin shad were also observed at the CVP/TFCF intake from fall to winter. Numbers seem to fluctuate from year to year. Juvenile threadfin shad are plankton feeders; zooplankton and phytoplankton are their major food sources (Turner 1966).

Some threadfin shad mature at the end of their first summer, but the majority reach maturity in their second year (Johnson 1971). They may live up to 4 years (Johnson 1970, 1971). Threadfin shad is an important forage fish for game species such as striped bass, largemouth bass, and other centrarchids (Kimsey and Fisk 1964). Their presence in Millerton Lake may enhance the sexual maturity of striped bass since threadfin shads, like other clupeids, contain beneficial amino acids. However, the role of the threadfin shad in the food chain of the Delta ecosystem is not well understood (Moyle 2002). The threadfin shad population in the Delta has been declining recently along with populations of other pelagic fish species. These declines may be due to several factors such as food web disruption due to introductions of filter feeding clams, anthropogenic stressors such as pesticides, and water diversions by the state and federal water projects. The threadfin shad is generally not consumed by humans because of its small size and its bony morphology; however, it is a desirable forage and bait fish.

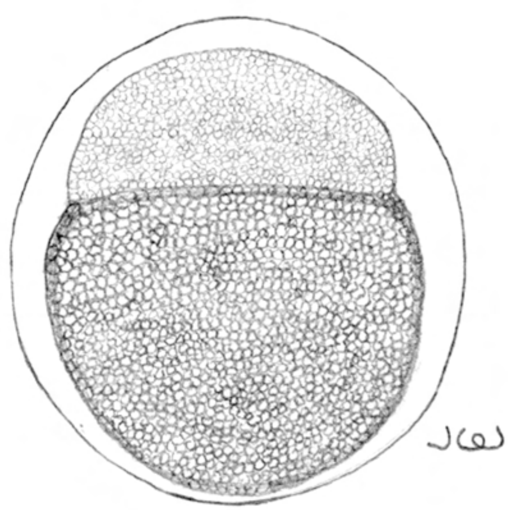


Figure 34.—*Dorosoma petenense*, threadfin shad egg, morula, 0.9 mm (Wang 1986).

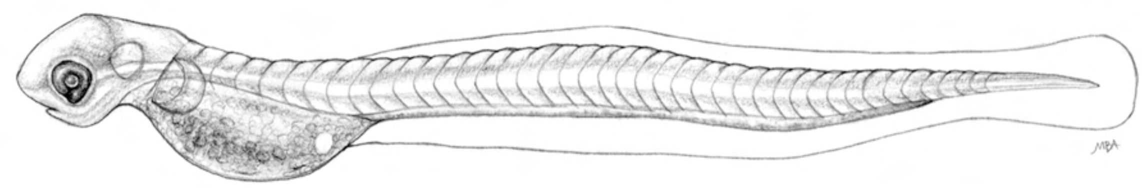


Figure 35.—*Dorosoma petenense*, threadfin shad prolarva, 4.7 mm TL (Wang 1986).

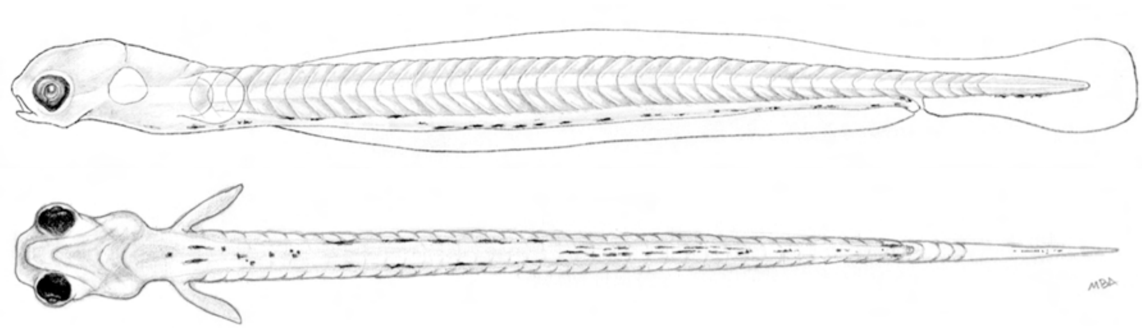


Figure 36.—*Dorosoma petenense*, threadfin shad postlarva, 5.3 mm TL, lateral and ventral views (Wang 1986).

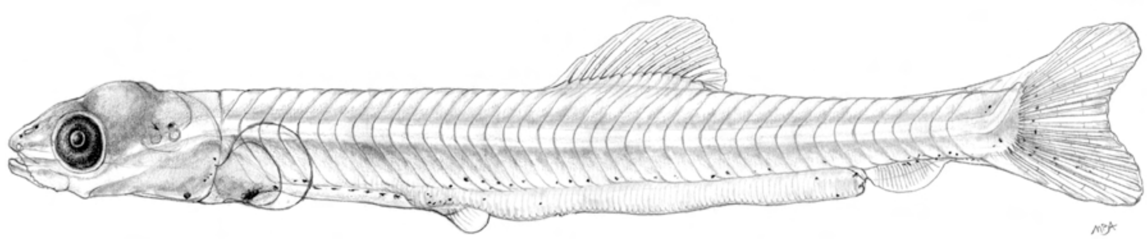


Figure 37.—*Dorosoma petenense*, threadfin shad prejuvenile, 16 mm TL (Wang 1986).

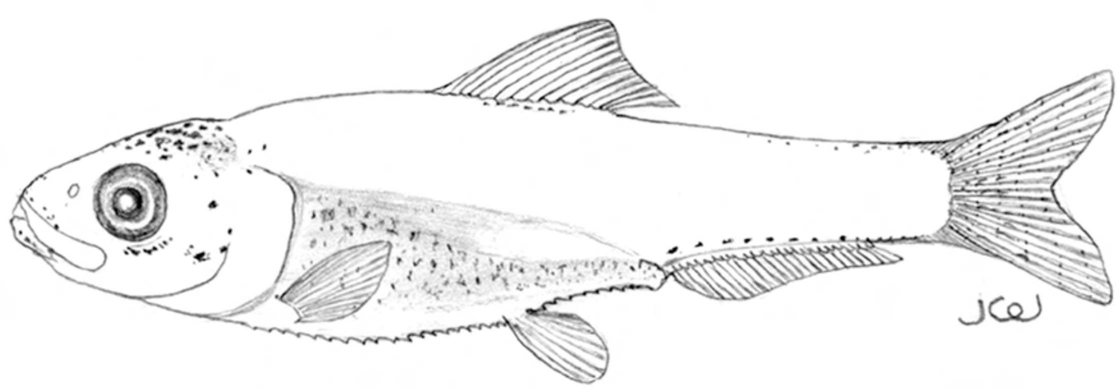


Figure 38.—*Dorosoma petenense*, threadfin shad juvenile, 24.5 mm TL (Wang 1986).

Figure 39.—*Dorosoma petenense*, threadfin shad.

Taxonomic Characteristics of Clupeids Present in the Study Area

	American shad	**Pacific herring**	**Threadfin shad**
Eggs			
Diameter (mm)	2.5–4.4	1.2–1.75	0.75–1.2
Oil globule	None	None	0–2 (Mostly 1)
Adhesiveness	May be initially (later none, deposited singly, semi-buoyant)	Yes (clustered, multi-layered, demersal)	Yes (scattered, single-layered, demersal)
Salinity	Freshwater	Sea water to mesohaline	Freshwater to oligohaline or higher
Larvae			
Hatching size (mm in TL)	5.7–10.0	5.6–8.8	3.2–4.4
Total myomeres	53–58	45–55	40–45
Myomeres between Insertion D and Origin of A	10–14	5–6	4–6
Juvenile			
Last D ray	Normal	Normal	Elongate
Body	Elongate	Elongate	Deep
Suborbital bone	Deep	Shallow	Shallow

Catostomidae – Suckers.— There are at least 13 species of suckers known to, California freshwaters. The majority of these are native, but currently six of the native suckers are rare or have endangered status (Moyle 2002). In the study area of the Sacramento-San Joaquin River system, only the Sacramento sucker (*Catostomus occidentalis*) has been collected.

SACRAMENTO SUCKER *Catostomus occidentalis* Ayres

SPAWNING

Location	Tributary streams (Moyle 1976), cool water rivers and streams with sand, gravel, or cobble bottom.
Specific locations	American River below the Nimbus Dam, in the vicinity of Sailors Bar Park, and just below Fair Oaks; Stony Creek, Cottonwood Creek, Reclamation's RBRPP located at the Red Bluff Diversion Dam, Clear Creek, Mud Creek, Feather River, lower reaches of Capell Creek of Lake Berryessa, at Glen Ellen on Sonoma Creek, Putah Creek, Suisun Creek, Cosumnes River; upper Corte Madera Creek, San Pablo Creek, upper Alameda Creek, upper Walnut Creek, San Ramon Creek, Mt. Diablo Creek, upper San Joaquin River at Millerton Lake, in a tributary of Union Valley Reservoir, Portuguese Cove of San Luis Reservoir.

Season	February–June (Moyle 1976); based on collections of prolarvae in the San Joaquin River above Millerton Lake, at the RBRPP, and from Feather River in August, this species may spawn as early as late-summer when coolwater is released from upper reservoirs.
Temperature	Spawning runs are reported in waters with temperatures ranging from 5.6–10.6°C (Moyle 1976); most of the spawn occurs at ~12.0–18.0°C.
Salinity	Freshwater.
Substrates	Gravel (Moyle 1976); sand, gravel, and cobbles.
Fecundity	4,700–11,000 eggs for fish 28–38 mm FL (Burns 1966); 10,300–32,300 (Villa 1985).

EGGS

Shape	Spherical or slightly irregular.
Diameter	Unfertilized eggs: 2.4–2.7 mm; fertilized eggs: 3.0–3.9 mm.
Yolk	Yellowish, bright yellow, sometimes cream; granular.
Oil globule	None.
Chorion	Transparent, thick and smooth.
Perivitelline space	0.3–0.6 mm in morula and early embryo stages.
Egg deposition	Deposited singly or small clusters.
Adhesiveness	Adhesive (Moyle 1976); initially adhesive, then not very adhesive.
Buoyancy	Negatively buoyant or demersal, sinking into interstices of the gravel (Moyle 1976); may detach from the substrates and bounce (Villa 1985); some eggs drift and bounce downstream by current.

LARVAE

Length at hatching	~10.0–12.0 mm TL (Wang 1986); 11.4–13.2 mm (R.C. Reyes 2003–2009, personal communication).
Snout to anus length	~78% TL for prolarvae; ~70% TL for postlarvae.
Yolk-sac	Very elongate and cylindrical, extending from thoracic region posteriorly to a point about 78% TL. Yolk-sac roughly divided into three sections in newly-hatched prolarvae, quickly reduced into two sections, and then become tube-like in late yolk-sac larvae.
Oil globule	None.

Gut	Straight in prolarva (visible on when specimen is dissected), slightly depressed below the air bladder in postlarvae.
Air bladder	Behind the pectoral fin, shallow, elongate, developing into two chambers (rear one first, then the front) visible by ~16.0 mm TL).
Teeth	None.
Size at absorption of yolk	16–17 mm TL (R.C. Reyes 2003–2009, personal communication).
Total myomeres	45–49.
Preanal myomeres	35–40.
Postanal myomeres	8–12.
Last fin(s) to complete development	Pelvic.
Pigmentation	Newly-hatched larvae have little pigmentation. Later, sparse melanophores are found on head, middorsum, and dorsal surface of gut and dotted melanophores develop along the median myosepta. In postlarvae, pigmentation becomes heavy on head and dorsally on body (two major rows), on dorsal surface of gut and air bladder, and postanal region. Very large melanophores are also found along thoracic and midventrally, and a group of melanophores is present at the base of the tail.
Distribution	Most of the planktonic yolk-sac larvae remain in the nesting area and then disperse into the water column; postlarvae prefer shallow inshore areas or pools, although some swim in the open waters of the Delta and Suisuin Bay.

JUVENILES

Dorsal fin rays	11–15, usually 12 or more (Moyle 2002).
Anal fin rays	7, occasionally 6–8 (Moyle 2002).
Pectoral fin rays	17–18 (Wang 1986).
Mouth	Subterminal, fleshy papillae on lips (Moyle 2002).
Vertebrae	46–50 (Wang 1986).
Distribution	The bulk of the juvenile population is in the cool water nontidal tributaries of the estuary, but they may also be collected in tidal oligohaline and freshwaters, such as in Suisun Marsh, and at the CVP/TFCF intake in late winter and early spring months. They are also found at foothill elevations such as Millerton Lake and the higher elevation Rubicon River and Union Valley reservoir.

LIFE HISTORY

Sacramento sucker is native to California's inland waterways, and it is widely distributed throughout the Sacramento-San Joaquin River system. Adults and large juveniles were collected primarily in open waters such as the American River, the Delta, and Suisun Marsh (fish from Montezuma Slough and its tributaries), whereas larvae and smaller juveniles were more common in the cooler waters of the rivers and streams that drain into the Delta and estuary. Sacramento sucker was not collected in short coastal streams in the San Francisco Bay area such as Tennessee Valley, Rodeo, and Olema Creeks.

Sacramento suckers are mostly potamodromous, migrating from large bodies of freshwater upriver to shallow streams for spawning. Observations of large concentrations of larvae indicate that spawning occurs in the American River below Nimbus Dam, Feather River below Oroville Reservoir Dam, and in the San Joaquin River below Kerkhoff Dam. Larvae were also abundant in smaller creeks such as Putah Creek, Walnut Creek, Sonoma Creek, and Clear Creek, and were also observed in intermittent creeks, such as the Mud Creek. Based on collections of adult fish in breeding color and small larvae taken at the CVP/TFCF in winter months, Sacramento sucker may spawn in the sloughs of the Delta instead of migrating upstream. Sacramento sucker larvae were also collected in the land-locked Loon Lake (without tributaries), where they apparently spawned in inshore habitats of the lake (author's observation, 1982 and 1986). These observations suggest that Sacramento suckers are able to adjust their spawning behavior according to local environments.

Based on the months in which eggs and larvae were collected, the spawning season for Sacramento sucker in the valley floor and low-elevation estuarine tributaries appears to be from February to early June; it may extend through August in the bigger rivers below dams and in foothill streams. During spawning, the male fish exhibits a dark lateral band, and orange-red fins; both sexes may have breeding tubercles on the pelvic, anal, and caudal fins (Moyle 2002). Each female is followed by several males as eggs are deposited over gravel substrate. Nesting sites range from a shallow depression to no depression. Sacramento suckers often deposit their eggs into Pacific lamprey nests, a behavior observed in the American River. Eggs are slightly adhesive and can form small clusters. Some eggs are detached from the substrates, some settle in the crevices of the gravel, and others bounce downstream. The incubation period ranges from 2–4 weeks (Moyle 2002). Eggs in the late morula stage, collected in the American River, at water temperature 15–17°C, hatched out in 11 d (R.C. Reyes 2003–2009, personal communication); total incubation is estimated at 2 weeks. Sacramento sucker eggs in loose form were also collected in Capell Creek and Sonoma Creek; apparently some may not be adhesive throughout the incubation period.

Newly-hatched prolarvae remain on the bottom and lay on their side. In the field, very few were collected in plankton nets, apparently remaining in the interstices of the gravel. As the airbladder develops, postlarvae emerge into the water column (in the upper water column in stagnant aquaria), and can be found in moderate running water to small streams. Large congregations of postlarvae and early juveniles have been seen in pools in American River, upper Putah Creek, Napa River, and Sonoma Creek. Sacramento sucker larvae have a terminal mouth and feed primarily on early instars of aquatic insects (Moyle 1976).

Juvenile Sacramento suckers were most commonly collected in tributary streams (Moyle 1976). Juveniles were also abundant in Suisun Marsh (S.A. Matern and R. Schroeter 1998, personal communication) and sloughs of the Delta. They were also found in irrigation and flood control ditches, arriving from hatching sites and becoming landlocked (T.Wood 1994–1995, personal communication). Juveniles migrate downstream for wider foraging areas and growth before winter. Some juveniles may remain in the streams during the summer and fall and move into the deeper pools, lakes or reservoirs in the winter. The mouth of the juvenile Sacramento sucker transforms from terminal to subterminal, and the intestine becomes elongated (~25 mm TL). Because they are bottom feeders, they spend most of the time near or at the bottom where they browse for detritus, algae, diatoms, and a wide variety of small organisms (Moyle 2002).

Sacramento suckers reach maturity after 4–6 years, and they are repeat spawners, spawning year after year. They can live up to 10 years or longer (Moyle 2002). Sacramento sucker is a bony fish, that can be used for broth, but it is not often sought by fishermen; rather it is one of the important protein sources for predatory fishes, birds, and mammals (Moyle 2002).

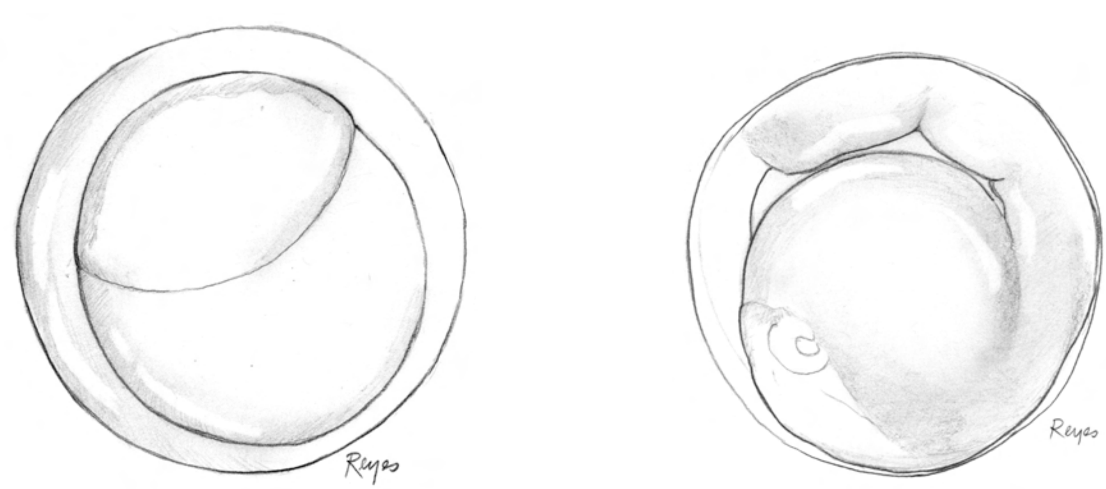


Figure 40.—*Catostomus occidentalis*, Sacramento sucker eggs: morula (left), 3.7 mm; late embryo (right), 3.5 mm.

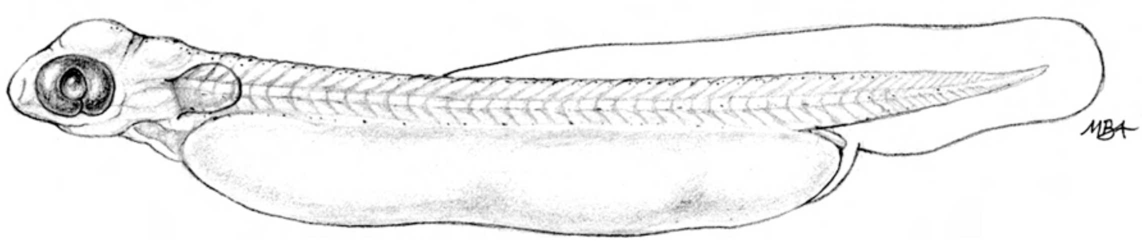


Figure 41.—*Catostomus occidentalis*, Sacramento sucker prolarva, 13 mm TL (Wang 1986).

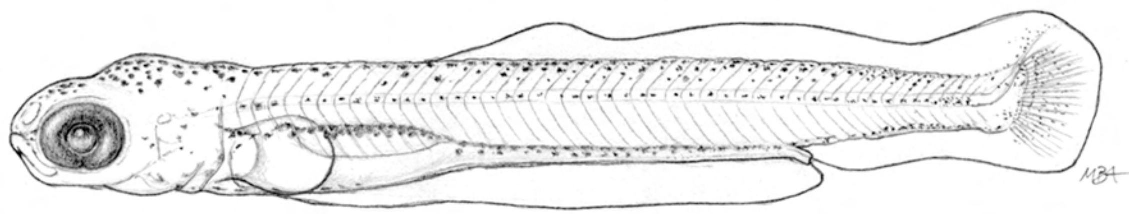


Figure 42.—*Catostomus occidentalis*, Sacramento sucker postlarva, 13 mm TL (Wang 1986).

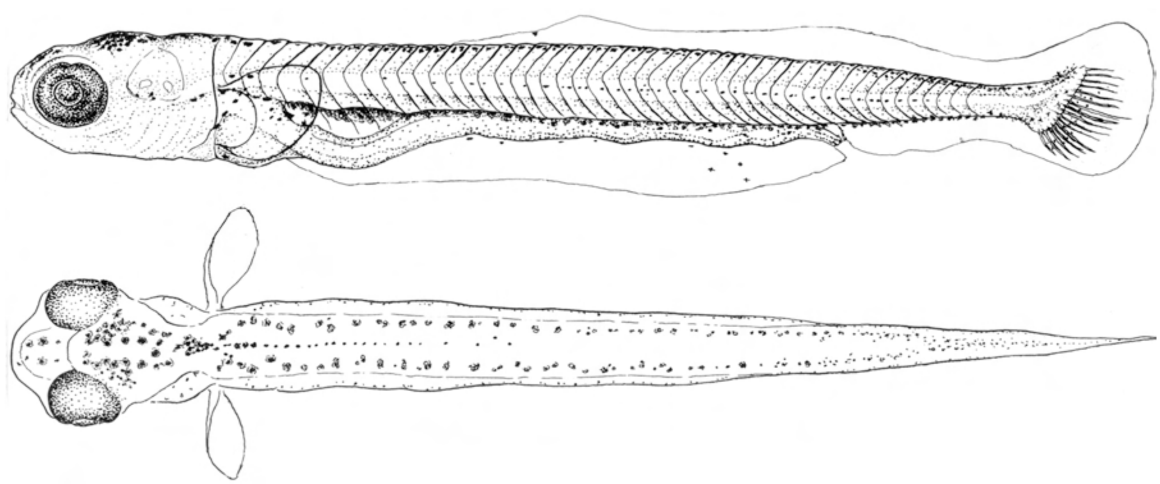


Figure 43.—*Catostomus occidentalis*, Sacramento sucker postlarva, 14 mm TL, lateral and dorsal views (Wang 1986).

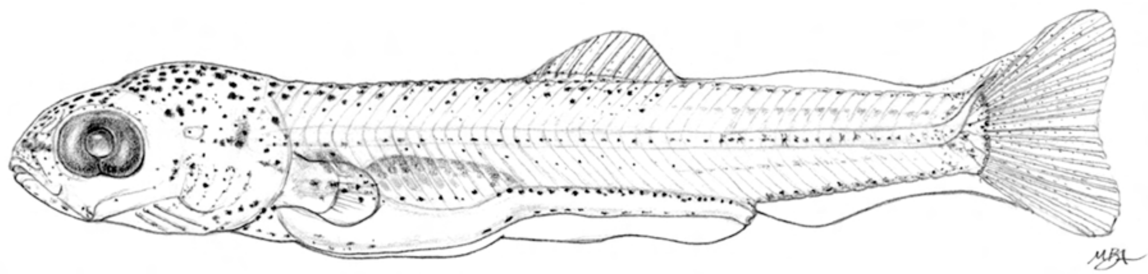


Figure 44.—*Catostomus occidentalis*, Sacramento sucker prejuvenile, 16 mm TL (Wang 1986).

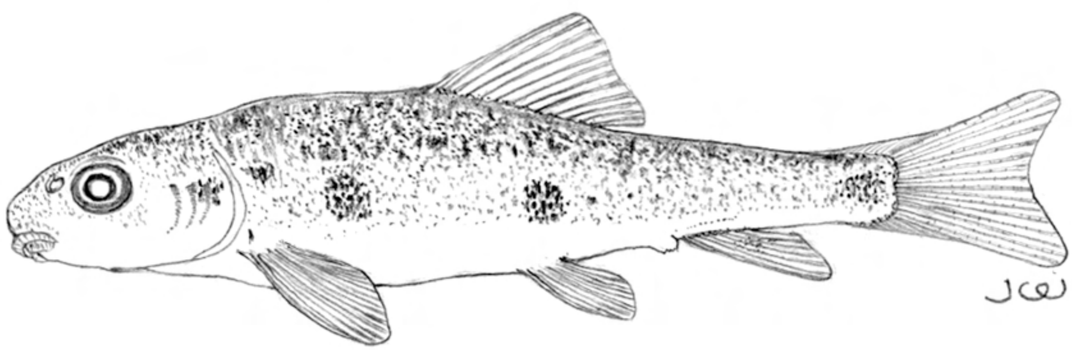


Figure 45.—*Catostomus occidentalis*, Sacramento sucker juvenile, 41 mm TL (Wang 1986).

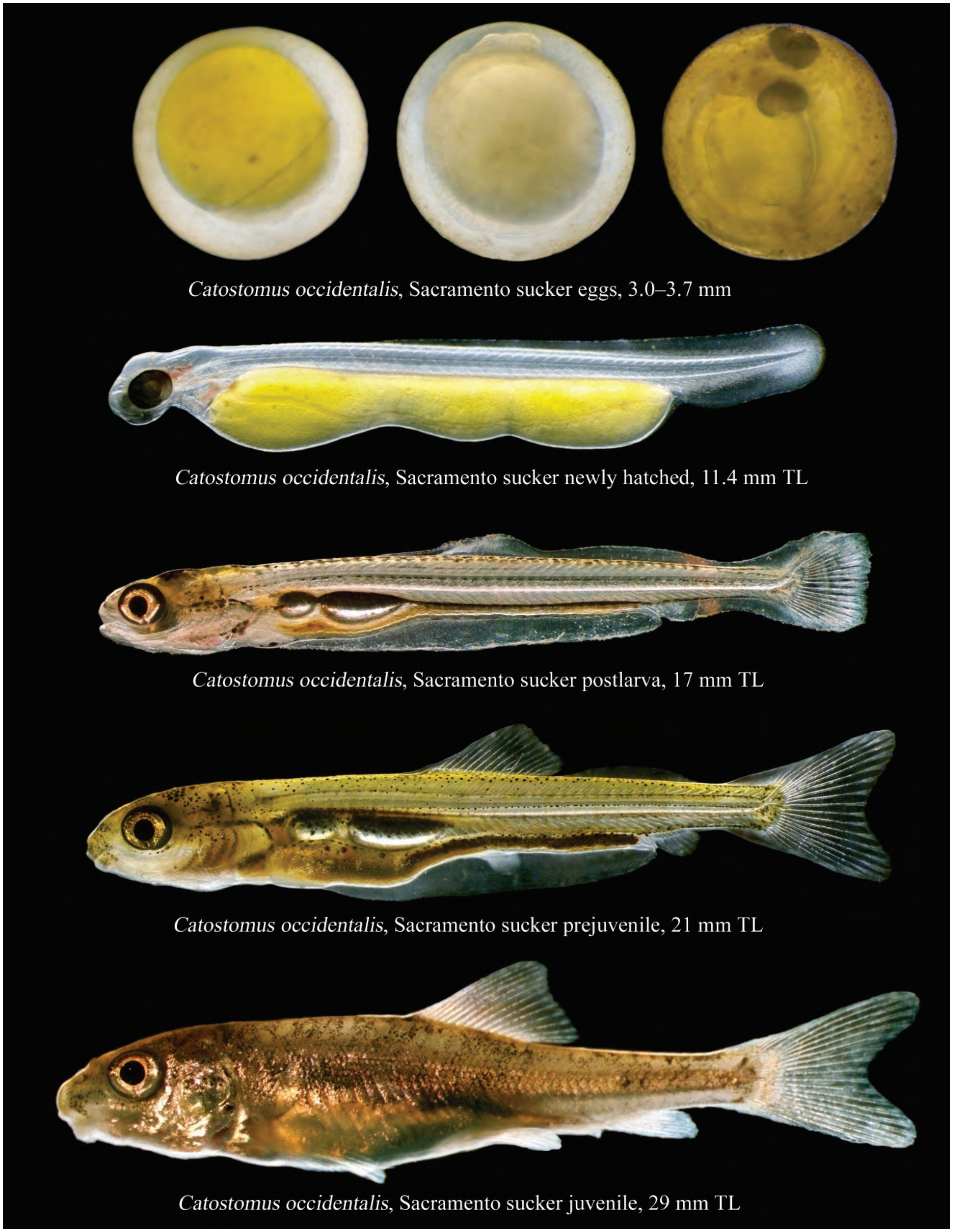


Figure 46.—*Catostomus occidentalis*, Sacramento sucker.

Ictaluridae – North American Catfishes — All species of freshwater catfishes in California were introduced from east of the Rocky Mountains (Dill and Cordone 1997). Six species (Moyle 2002) are present in California: white catfish (*Ameiurus catus*), black bullhead (*A. melas*), brown bullhead (*A. nebulosus*), blue catfish (*Ictalurus fulcatus*), channel catfish (*I. punctatus*), and flathead catfish (*Pylodictis olivaris*).

Of the six catfish species present in California, only white catfish, black bullhead, brown bullhead, and channel catfish are discussed in this chapter. Flathead catfish and yellow bullhead are not in the study area. The flathead catfish are found in southern California on the Imperial Valley (Dill and Cordone 1997, Swift *et al.* 1993) and are established in the lower Colorado River (Moyle 2002). Yellow bullhead (*A. natalis*) is known from Riverside and Orange Counties of southern California (Swift *et al.* 1993). Blue catfish are rarely collected in the Delta. Only a single adult specimen has been collected (Taylor 1980) and few juveniles (Raquel 1986; this study). Blue catfish collected in the Delta likely escaped from aquaculture ponds, such as those in a catfish farm adjacent to the Tuolomne River. This author was involved in the culture of blue catfish, brown bullhead, and channel catfish in China during the periods 1984–1986. The life history of the blue catfish in the Delta is not known.

WHITE CATFISH *Ameiurus catus* (Linnaeus)

SPAWNING

Location	Still or running water; nest is built near sand or gravel banks (Fowler 1917, Jones *et al.* 1978); tidal and nontidal waters in the sloughs of the Delta. Ripe fish were observed at the CVP/TFCF, Pittsburg and Contra Costa Powerplants' intake areas; Barker Slough and Cache Slough areas, most of the reservoirs such as Millerton Lake and Folsom Lake.
Season	Early July in California (Murphy 1951); June and July (Moyle 1976); June through August or early September in some years (Wang 1986).
Temperature	21ºC (Shapovalov and Dill 1950, La Rivers 1962, Miller 1966); ~20ºC (Wang 1986); 24–29ºC (Moyle 2002).
Salinity	Freshwater; may spawn in oligohaline water.
Substrates	Sand or gravel (Jones *et al.* 1978); undercut of tree roots on slough bank, crevices of rocky jetties, and dark hollowed areas such as tubes, cans, empty 30-gal plastic drums.
Fecundity	2,000–3,000 (Moyle 2002); 1,000 (La Rivers 1962); 3,550 (Menzel 1945).

EGGS

Shape	Spherical.
Diameter	Fertilized eggs ~4.2 mm (Eddy 1957); ripe eggs, 4.0–5.5 mm (Wang 1986); 3.9–5.1 mm with an average of 4.4 mm (Reyes 2010).
Yolk	Yellow-white (Fowler 1917); granular (Ryder 1887); pale yellow to bright yellow (Reyes 2010).
Oil globule	None.
Chorion	Transparent to translucent, two layers; outer layer adhesive with gelatinous coat (Ryder 1887).
Perivitelline space	Fertilized eggs, initially ~10–20% of egg diameter (Wang 1986); very narrow in later developmental stages (Ryder 1887).
Egg deposition	Deposited in large clusters.
Adhesiveness	Very adhesive.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	9.0–9.75 mm TL (Jones *et al.* 1978); 9–10 mm TL (Wang and Kernehan 1979); ~10.0 mm TL (Cache Slough specimens); 7.0–11.9 mm TL (Reyes 2010) for white catfish from Discovery Bay, California.
Snout to anus length	~50–53% TL for prolarvae 9.0–9.5 mm TL; 46–48% TL for postlarvae and early juveniles 14–15.5 mm TL (Wang 1986); 47–52% TL for postlarvae 11–15.9 mm TL (Reyes 2010).
Yolk sac	Large, spherical to oval, hard, extending from jugular to abdominal region; slightly overhangs at posterior end.
Oil globule	None.
Gut	Straight, and later twisted.
Air bladder	Spherical to oval, above the base of pectoral fins.
Teeth	None at this stage.
Size at complete absorption of yolk	14 mm TL (Ryder 1887); 14–15 mm TL (Wang 1986); 15–16 mm TL for specimens collected from Cache and Barker Sloughs; 15–16 mm TL for specimens from Discovery Bay, California (R.C. Reyes 2003–2009, personal communication).
Total myomeres	38–44 (Wang 1986); 37–43 (Reyes 2010).
Preanal myomeres	16–20; 16–21.
Postanal myomeres	19–25; 20–25.

Last fin(s) to complete development	Pelvic.
Pigmentation	Newly-hatched larvae have little or no pigmentation; lighter pigmentation covers head, sides of body and finfolds; little to no pigmentation on lower jaw, lower chin barbels, and dorsum of yolk sac.
Distribution	Prolarvae remain in the nesting area, guarded by the male parent (Breder and Rosen 1966). They then disperse into shallow waters with muddy bottoms in both tidal and nontidal areas of Suisun Bay, Delta, sloughs, ditches, creeks, and reservoirs.

JUVENILES

Dorsal fin rays	I, 5–6 (Moyle 1976); soft dorsal rays up to 7 (Frey 1951); the dorsal spine is actually fused from several segments of hardened fin rays in the larval stage.
Anal fin rays	22–25 (Moyle 2002); 22–23 (Hildebrand and Schroeder 1928).
Pectoral fin rays	I, 8–9 (Jones *et al.* 1978, Moyle 2002).
Adipose fin	Long and fleshy.
Mouth	Upper jaw protruding, mouth slightly inferior or subterminal (Jones *et al.* 1978, this study); mouth terminal (Moyle 2002).
Vertebrae	40–41, plus Weberian ossicles, or 43–44 total.
Distribution	Stagnant or slow current habitats in the Sacramento-San Joaquin River system and the Delta including the brackish water of San Pablo Bay, Napa River and Suisun Bay, particular abundant in the south Delta.

LIFE HISTORY

White catfish is native to eastern coastal streams from New York to Texas (Hildebrand and Schroeder 1928). Trautman (1957) reported this species in Pennsylvania; Bailey *et al.* (1954) recorded the white catfish along the Gulf coast to the Escambia drainage system of Mexico. White catfish from New Jersey were introduced to the San Joaquin River near Stockton in 1847 (Shapovalov and Dill 1950, Skinner 1962, Dill and Cordone 1997). White catfish is the most abundant catfish species in the Delta (Turner 1966, CVP/TFCF records) and it has now been introduced into most of California's freshwater systems (Moyle 2002).

Spawning takes place in June and July in the Delta (Miller 1966). Based on the small size of the white catfish collected in the vicinity of the Contra Costa and Pittsburg Powerplants and at the CVP/TFCF in the south Delta, spawning starts as early as June and lasts until the end of August or early September (a fully developed ovary was observed at CVP/TFCF in August); in Millerton Lake, peak spawning is in June and July (Wang 1986). The male catfish builds a nest on sand or gravel substrates (Miller 1966). Nests are located near the shore and are sometimes associated with logs, tree roots, and other sheltering objects. During the breeding season, male fish exhibit darker body coloration, particularly the head, lips, and barbels; the urogential papilla is also swollen. After spawning, the male drives the female away, then guards and aerates the eggs. The male will protect the nest throughout incubation (Gill 1906). White catfish eggs are very adhesive and hatch within 6 or 7 d at 24–29ºC (Prather and Swingle 1960). The spawning behavior of white catfish, in general, is similar to that of the bullheads (Breder and Rosen 1966).

Newly-hatched white catfish larvae have a yellowish, oversized yolk-sac. They remain in the nest until the yolk is absorbed. The male guards the young until they can swim freely. Yolk-sac larvae were often collected at Cache Slough and Barker Slough (CDFG's NBA fish E and L survey) in June and July, perhaps disturbed by the plankton sled and eventually caught in the net. Yolk-sac larvae were also collected at the CVP/TFCF in summer months, indicating catfish nests located near the intake.

White catfish juveniles congregate in large schools near the shoreline or in sheltered coves over muddy bottoms; large juveniles (~40–60 mm TL) gradually become solitary and move into various niches close to the bottom. Large numbers of juveniles were captured by otter trawl (Turner 1966). They are the most abundant ictalurids at the CVP/TFCF in summer and early fall months.

White catfish juveniles can grow at salinity of 11 ppt (Perry and Avault 1969). They are found all over the Delta, Suisun Bay, and Napa River (CDFG 20-mm fish survey) and were captured as far downstream as the Oleum Powerplant in San Pablo Bay (Wang 1986). They have been collected in cool and clear waters of the upper Sacramento River (Reclamation's RBRPP records) and are also common in reservoirs and lakes, such as Millerton Lake and Folsom Lake (Wang 1986). Juveniles in the estuary feed mostly on amphipods, mysid shrimps, chironomid larvae, and small fishes (Turner 1966, Ganssle 1966, CVP/TFCF predatory fish removal/stomach contents analysis).

White catfish have a relatively slow growth rate (Turner 1966, Moyle 1976) in California and reach maturity in 3–4 years (Moyle 1976). This species is one of the most common sportfish in the Delta and upper estuary. White catfish became so abundant in the Delta that it was commercially harvested but was later banned in 1953 (Schaffter and Kohlhorst 1997). In California the number of catfish anglers ranks second only to those who are fishing for trout in cold water (Ryan 1959). Warm waters, such as the vicinity of Contra Costa and Pittsburg Powerplants, Clifton Court Forebay, and the semi-land locked CVP/TFCF canal, create favorable fishing spots for this species.

Predatory fish removal experiments conducted at the CVP/TFCF between April 2004 and December 2005, resulted in a total of 9,038 catfishes captured in 45 sampling efforts. White catfish comprised 94.6% of catch, channel catfish 5.2%, and the two species of bullheads were 0.16% (CVP/TFCF unpublished data).

White catfish is the most dominant catfish species in the Delta throughout the year. Several factors may contribute to its success: 1) it adapts to a broad range of habitat, from clear stream water to muddy slough to brackish water; 2) it has a long spawning season, June to August, extending into September some years; 3) there is a diversity of suitable spawning habitat for this species such as Cache Slough and Barker Slough, areas where there are protective secondary channels that are close to the main channel of the Sacramento River (beneficial for juvenile dispersion); 4) white catfish feed at lower levels of the food chain in the delta mainly on *Corophium* spp., *Gammarus* spp., and detritus, a plentiful item in the Delta.

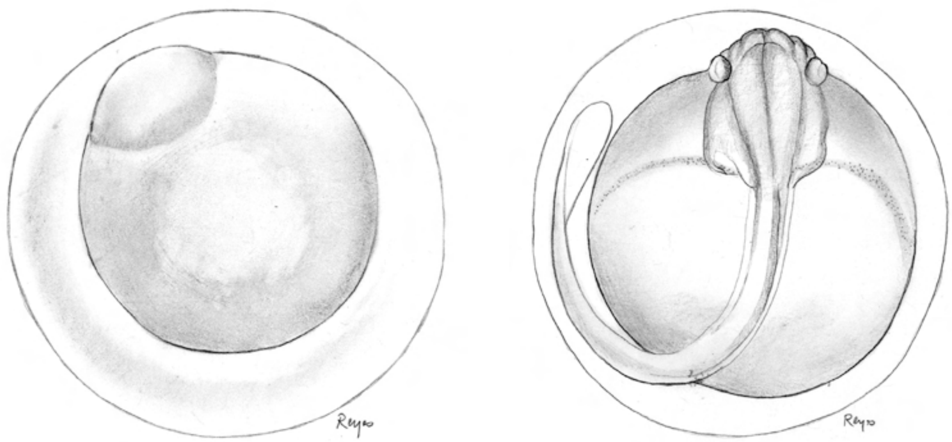


Figure 47.—*Ameiurus catus*, white catfish eggs: 0 dps (left) and 5 dps (right), 4.5 mm.

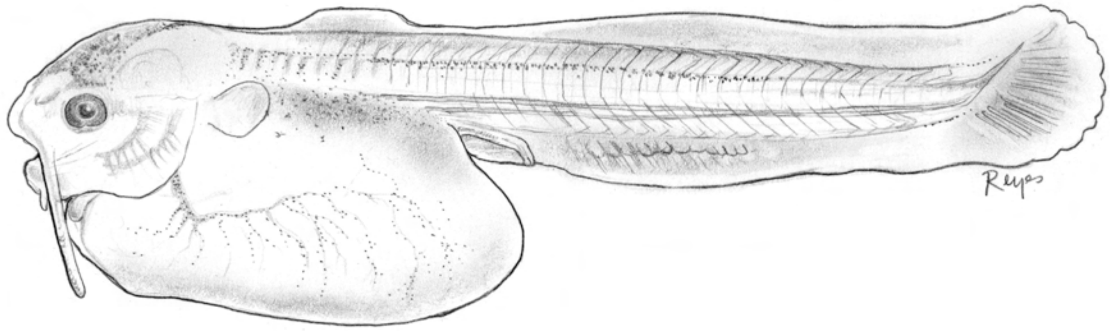


Figure 48.—*Ameiurus catus*, white catfish prolarva, 11.6 mm TL.

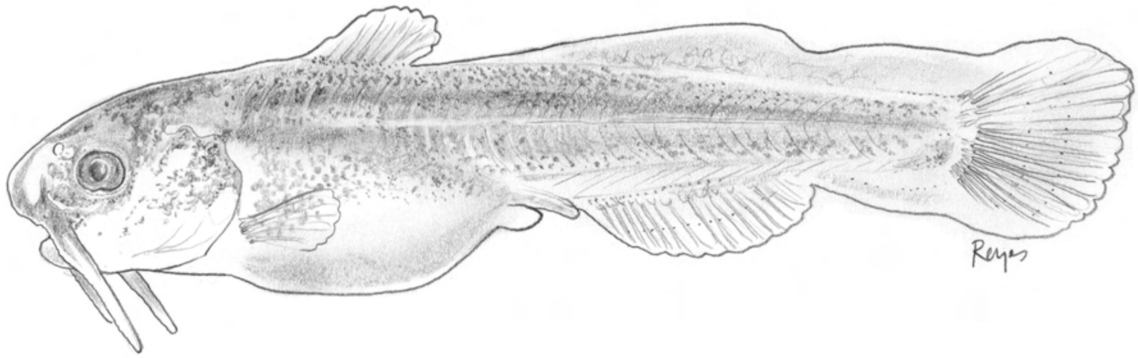


Figure 49.—*Ameiurus catus*, white catfish prolarva, 14.4 mm TL.

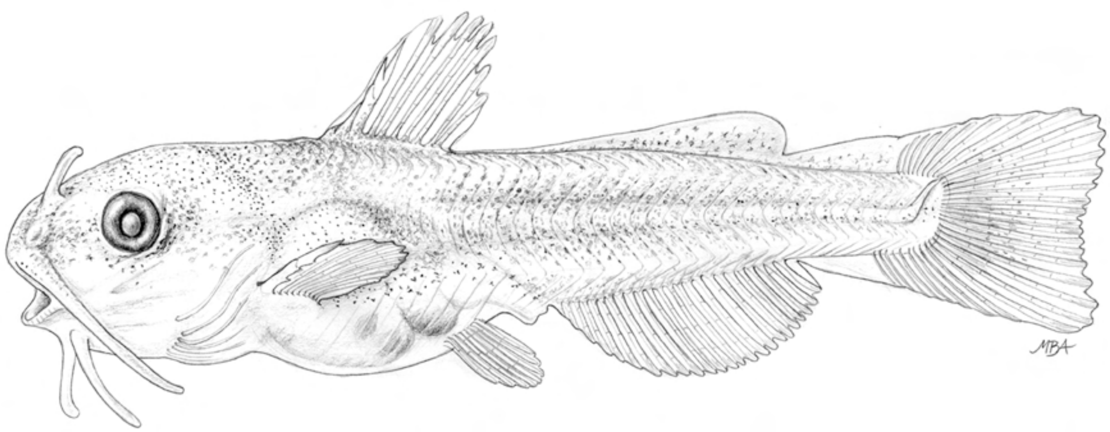


Figure 50.—*Ameiurus catus*, white catfish juvenile, 16.6 mm TL (Wang, 1986).

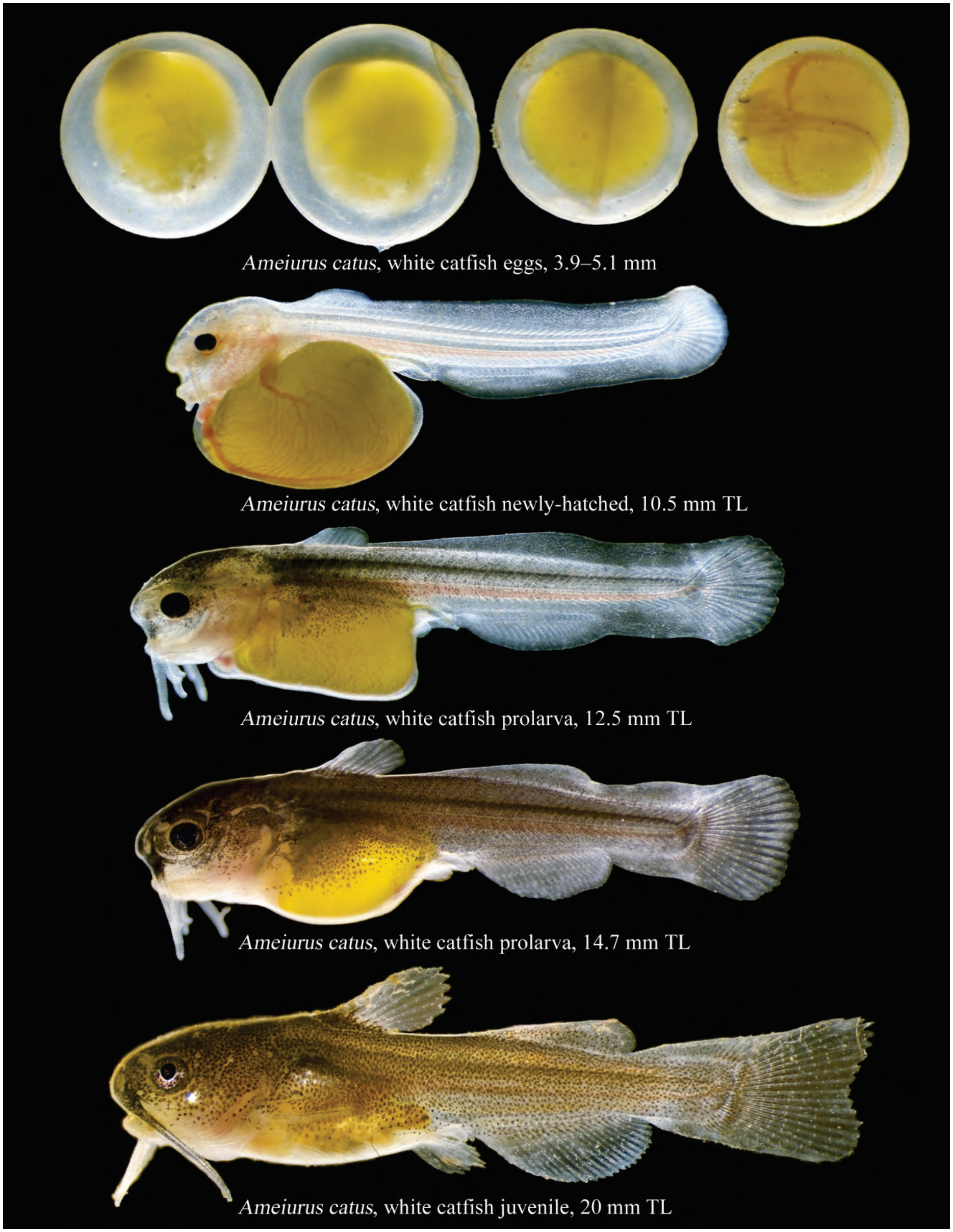


Figure 51.—*Ameiurus catus*, white catfish.

BLACK BULLHEAD *Ameiurus melas* (Rafinesque)

SPAWNING

Location	Adult black bullhead are common in stagnant, dead end sloughs of the Delta, such as Hog, Sycamore, and Indian sloughs (Turner 1966), where they apparently spawn; also in ponds, lakes, rivers with back waters, and pools or streams with muddy bottoms (Moyle 1976). Specific locations include areas such as the lower reaches of Walnut Creek (Leidy 1983) and the CVP/TFCF's abandoned intake canal (now a small lagoon).
Season	June and July (Moyle 1976); May and June in Missouri (Pflieger 1975); May through August in Kansas (Cross 1967); May and June in Canada (Scott and Crossman 1973); small juvenile black bullheads were taken at CVP/TFCF in July and August, suggesting peak spawning in June and July in the south Delta.
Temperature	Exceeding 20ºC (Moyle 1976); 21ºC (Scott and Crossman 1973); 23.7ºC in a 750-L outdoor tank (Reyes 2010).
Salinity	Freshwater; tidal freshwater may contain low salt.
Substrates	Probably over bare mud or clay bottoms, since gravel and debris are pushed out of the nest (Scott and Crossman 1973, Moyle 1976); beneath the matted vegetation or woody debris (Cross 1967); attached to aquatic vegetation (Baxter and Simon 1970); inside smooth surface of a 20.3-cm-diameter PVC pipe (Reyes 2010); in the crevices of rocks in the lagoon of the CVP/TFCF.
Fecundity	2,000–6,000 or more depending upon age and size of females (Harlan and Speaker 1969); 1,000–7,000 (Dennison and Bulkley 1972); 3,000–4,000 (Scott and Crossman 1973); ~300 eggs per batch (Reyes 2010).

EGGS

Shape	Spherical.
Diameter	~3.0 mm (Scott and Crossman 1973); 3.1–3.7 mm with an average of 3.5 mm (Reyes 2010).
Yolk	Yellow (Moyle 1976); pale cream (Scott and Crossman 1973); golden (Cross 1967); golden-yellow (Pflieger 1975); whitish to cream.
Oil globule	None.
Chorion	Translucent, covered with gelatinous coat (Scott and Crossman 1973).

Egg deposition	Deposited in clusters (Moyle 1976, Pflieger 1975, Scott and Crossman 1973); single layered, small cluster (Reyes 2010).
Adhesiveness	Eggs adhere to one another (Cross 1967); adhesive (Scott and Crossman 1973).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	8–9.1 mm (Reyes 2010).
Snout to anus length	47–51% TL for newly-hatched prolarvae, 46–50% TL for postlarvae (Reyes 2010).
Yolk-sac	Large, spherical to oval, close to thoracic.
Oil globule	None.
Gut	Straight, bends vertically at the anal region.
Air bladder	Oval, above base of pectoral.
Teeth	No teeth at this stage.
Size at absorption of yolk	10–12 mm.
Total myomeres	~35–36 (data derived from juvenile fish; Wang 1986); 38–42 (Reyes 2010).
Preanal myomeres	14–15 (data derived from juvenile fish; Wang 1986); 15–18.
Postanal myomeres	21–22 (data derived from juvenile fish; Wang 1986); 21–26.
Pigmentation	First pigments appear dorsally on the head and above the yolk-sac, then gradually covering the entire body, barbels, and fins; dorsal half of the body is darker than the ventral half.
Distribution	It is assumed that black bullhead larvae remain near the nest area during the yolk-sac stage and after yolk absorption disperse into the sloughs of the Delta to forage.

JUVENILES

Dorsal fin rays	I, 5–7 (Scott and Crossman 1973).
Anal fin rays	19–23, including rudimentary rays (Moyle 2002); 17–21 (Cross 1967, Baxter and Simon 1970, Pflieger 1975); 15–19 (Scott and Crossman 1973); 17–20 (Harlan and Speaker 1969).
Pectoral fin rays	I, 8 (Scott and Crossman 1973); I, 7 (Baxter and Simon 1970).
Adipose fin	Long and fleshy (Scott and Crossman 1973).

Mouth	Upper jaw protruding (Pflieger 1975, Moyle 1976); terminal (Scott and Crossman 1973).
Vertebrae	34 or 35, plus Weberian ossicles (Scott and Crossman 1973); 39 or 40 in total counts (Cross 1967).
Distribution	Lower reaches of the Sacramento-San Joaquin River system and Delta (Turner 1966); some are found in the tributaries of the bay and Delta, such as Walnut Creek (Leidy 1983, 1984); rare in the south Delta, and occasionally found in Suisun Bay (Wang 1986).

LIFE HISTORY

Black bullhead is a freshwater species native to central and eastern North America. Its range includes most of the Mississippi drainage to the Gulf of Mexico and northern Mexico; from the St. Lawrence River southward following the western slope of the Appalachians; and in the north, covering Montana to Saskatchewan, Canada, through the Great Lakes (Hubbs and Lagler 1958, Scott and Crossman 1973). Black bullhead was introduced into California waters in 1874 (Curtis 1949, Dill and Cordone 1997). It is found in the sloughs and tributaries of the Delta (Leidy 1983, 1984; Wang 1986).

Based on collections of juveniles, spawning likely occurs in June and July in the Delta (Wang 1986); however, juveniles have been collected in the south Delta as early as May (Reyes 2010). Nests are excavated by the female (Scott and Crossman 1973) or by both parents (Minckley 1973, Pflieger 1975) in shallow waters, sometimes beneath submerged logs (Pflieger 1975) or in cavities (Minckley 1973). Eggs are usually concealed under some protective cover (Cross 1967). One parent may guard and fan the eggs (Baxter and Simon 1970, Pflieger 1975) or both sexes may be involved in protecting the egg mass (Minckley 1973, Scott and Crossman 1973). The eggs adhere more to one another than to the substrate. Eggs hatch in 5–10 d depending on water temperature (Becker 1983). In the laboratory, eggs hatched 8–9 d at 20.5 ± 1°C (Reyes 2010). The reproductive biology of black bullhead has been documented by Breder and Rosen (1966) and Wallace (1967, 1969).

Newly-hatched black bullhead larvae remain in the nest for several days, guarded by their parents at this vulnerable life stage until the oversized yolk-sac is absorbed. In the laboratory, yolk-sac is absorbed by 12 mm. Between 12 and 14 mm, larvae become black and were observed swimming in schools (Reyes 2010). Free-swimming juveniles stay in a tight school moving slowly near shore or near the surface in deeper water and appearing as a constantly moving “black ball” (Forney 1955, Cross 1967). One of the parents accompanies the schooling young for 2–3 weeks. The parents abandon the young when they reach ~25 mm TL. In some cases, the young school throughout their first summer (Forney 1955).

Few juveniles or adult black bullhead were collected in the predatory fish removal experiment at the CVP/TFCF conducted in the summer months. Juveniles (≤35 mm TL) were not collected from the CVP/TFCF salvage operation even though adult black bullheads were collected by electrofishing at the nearby abandoned intake channel (currently a small lagoon). Unlike white catfish and channel catfish, no black bullhead yolk-sac larvae were captured in plankton nets (CDFG fish E and L survey in the Delta and NBA, 1988–2004). Juvenile bullheads were common in the tributaries of the Delta (Leidy 1983, 1984). It is possible that major spawning sites may be located in the creeks instead of Delta sloughs.

Black bullheads are omnivorous bottom feeders, but juveniles feed mainly on small crustaceans (Forney 1955) and aquatic insects (Turner 1966, Baxter and Simon 1970). In the Delta, juvenile bullhead feed mostly on crustaceans, snails, other invertebrates, and fish (Turner 1966). Dawn and dusk are the times of active feeding (Darnell and Meierotto 1965).

Depending on environmental conditions such as availability of food and water temperature, black bullhead mature between 1 and 3 years (Cross 1967) or in 2–3 years (Moyle 2002). The maximum lifespan is 10 years or more, but few live more than 5 years (Pflieger 1975). Black bullheads and brown bullheads were less abundant than white and channel catfish in collections from CVP/TFCF salvage operation. Black bullhead abundance in the entire Delta and adjacent tributaries is unknown, although they seem to be flourishing in disturbed or altered waters (Moyle 2002). Not all black bullheads are black; some of them have a brownish lower half of the body, therefore they are easily mistaken for brown bullheads. Black bullhead is considered a tasty food fish (Baxter and Simon 1970). Most sport fishermen do not distinguish black from brown bullheads, sometimes even calling catfish, in general, “bullheads.”

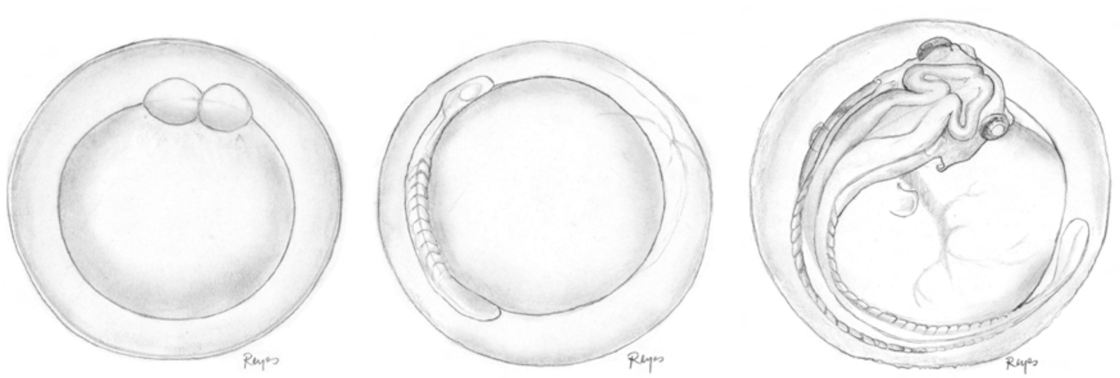


Figure 52.—*Ameiurus melas*, black bullhead eggs: 2-cell stage 3.2 mm (left), tail-bud embryo 3.6 mm (middle), and advanced embryo 3.5 mm (right).

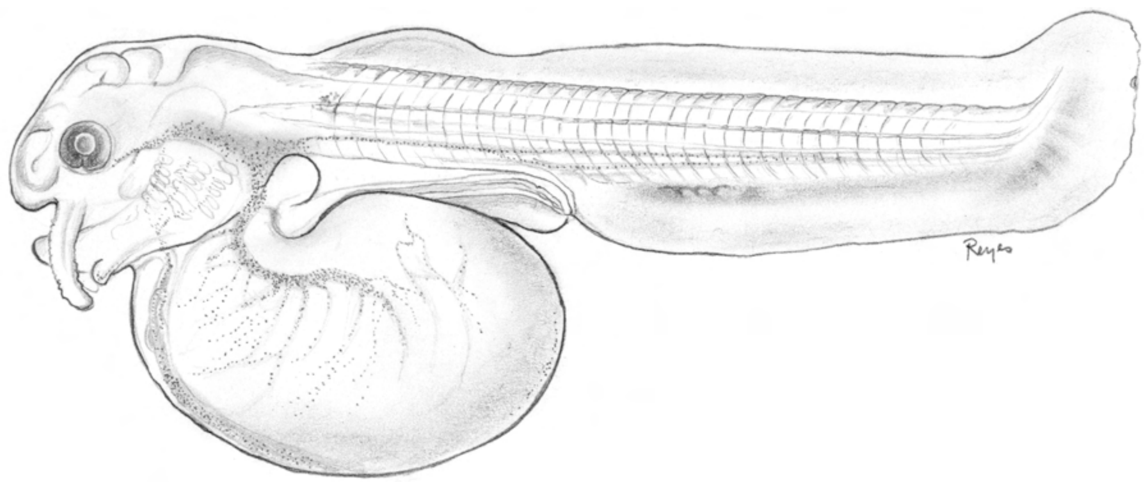


Figure 53.—*Ameiurus melas*, black bullhead prolarva, 8.5 mm TL.

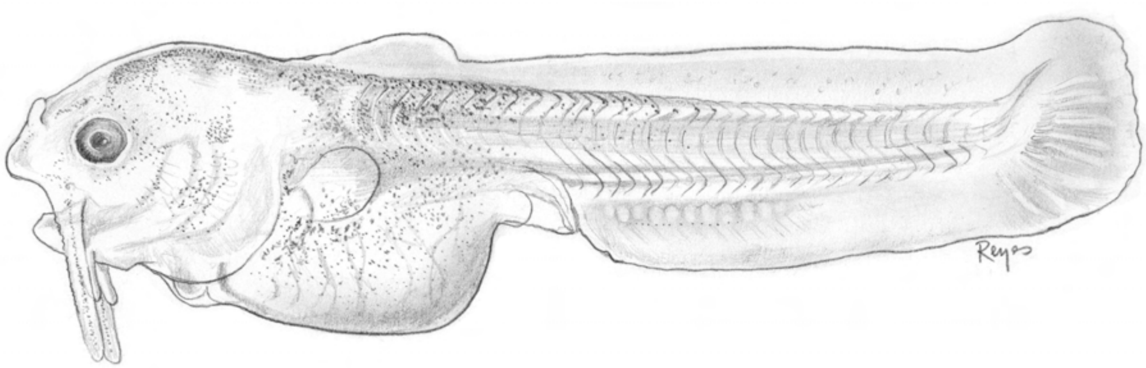


Figure 54.—*Ameiurus melas*, black bullhead prolarva, 11.5 mm TL.

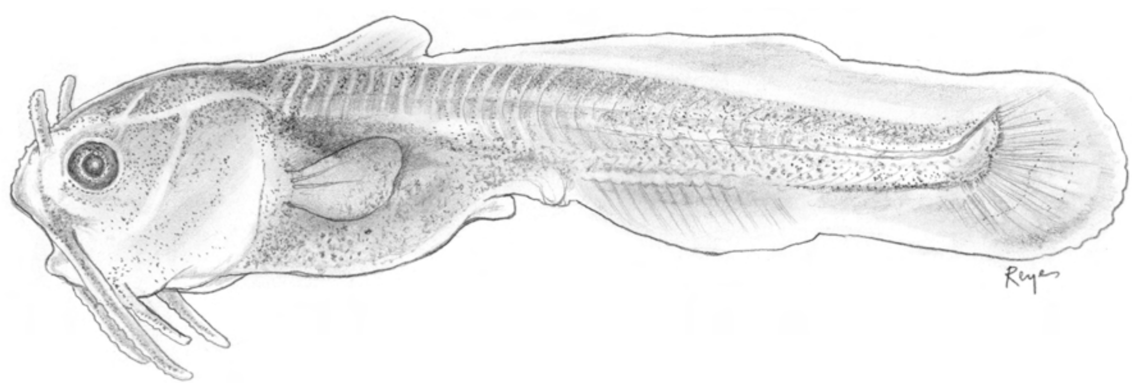


Figure 55.—*Ameiurus melas*, black bullhead prolarva, 12.5 mm TL.

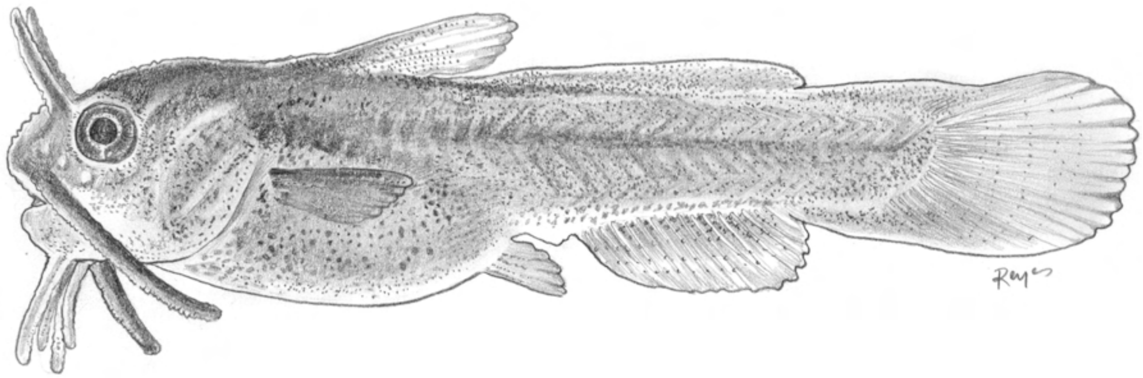


Figure 56.—*Ameiurus melas*, black bullhead juvenile, 17 mm TL.

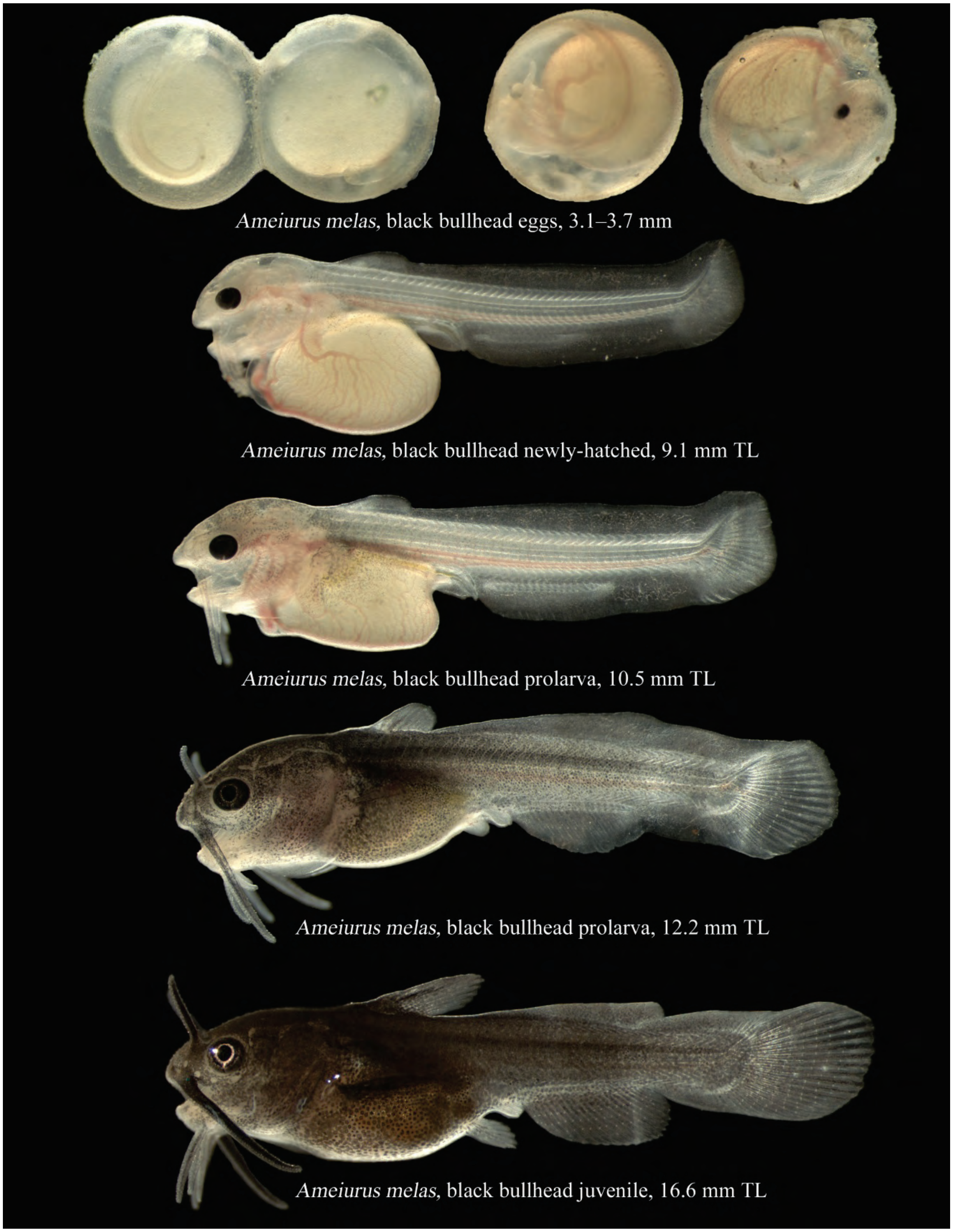


Figure 57.—*Ameiurus melas*, black bullhead.

BROWN BULLHEAD *Ameiurus nebulosus* (Lesueur)

SPAWNING

Location	Weedy streams and lakes (Breder 1935); mostly in the shallow sloughs of the Delta, such as Barker Slough and Cache Slough (CDFG fish E and L survey at the NBA, 1993–2004); in the vicinity of the CVP/TFCF; shallow water of large lakes and reservoirs, such as Millerton Lake and Folsom Lake; upper Napa River in areas choked with aquatic vegetation and stagnant flow; small ponds such as Heather Farm Pond in Walnut Creek (Wang 1986) and a pond in Hill Crest Park, Concord.
Season	In general, April through August (Breder 1935, Carlander 1969); April and May in Iowa (Harlan and Speaker 1969); May through July in Delaware (Wang and Kernehan 1979); May and June in Canada (Scott and Crossman 1973); May and July in California (Becker 1983); based on small juveniles taken in the 1990s, bulk of the spawn in south Delta (CVP/TFCF records) occurred in June and July.
Temperature	21–25ºC (Breder 1935); temperatures reaching 21ºC (Scott and Crossman 1973, Becker 1983).
Salinity	Freshwater.
Substrates	Natural substrates, such as sand, gravel, logs, rocks, and vegetation (Smith 1903, Webster 1942); hollowed bank, log, and piles of rock (Becker 1983); artificial substrates, such as tires (Scott and Crossman 1973); cans and hollowed cement blocks (Wang and Kernehan 1979).
Fecundity	2,000–13,800 (Carlander 1953); 2,000–10,000 or more (Harlan and Speaker 1969); 2,000–13,000 eggs in the ovaries (Scott and Crossman 1973).

EGGS

Shape	Spherical.
Diameter	Ripe unfertilized eggs, 3.0–3.4 mm (Wang 1986); fertilized eggs, ~3.0 mm (Breder 1935).
Yolk	Pale cream yellow (Breder 1935, Scott and Crossman 1973); yellow white, granular.
Oil globule	None.
Chorion	Nearly transparent (Breder 1935); transparent (Armstrong and Child 1962); eggs covered with gelatinous mucus (Scott and Crossman 1973).

Perivitelline space	Fairly wide, ~30% of egg diameter (Armstrong and Child 1962).
Egg deposition	Deposited in clusters (Forbes and Richardson 1920); in clusters, entire clutch of eggs (Carlander 1969).
Adhesiveness	Adhesive (Breder 1935).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	~8.0 mm (Eycleshymer 1901); ~6.0 mm TL (Scott and Crossman 1973).
Snout to anus length	~47–49% TL for prolarvae 7.8–9.0 mm TL.
Yolk-sac	Large, spherical to oval, extends from jugular to abdominal regions.
Oil globule	None.
Gut	Straight, bends vertically in anal region in postlarval stage.
Air bladder	Oval, above base of pectoral.
Teeth	No teeth at this stage.
Size at absorption of yolk	~10–12 mm TL.
Total myomeres	39–42.
Preanal myomeres	14–16.
Postanal myomeres	25–26.
Last fin(s) to complete development	Pelvic.
Pigmentation	Newly-hatched larvae have no pigmentation and are cream white (Breder 1935); dense, dark pigmentation covers head, finfold, and barbels 1–2 d after hatching (Smith 1903, Smith and Harron 1904, Scott and Crossman 1973).
Distribution	Mostly remain in the nesting area for 5 d (Emig 1966) to 7 d (Scott and Crossman 1973); stay as a tight mass at the bottom after hatching out (Adams and Hankinson 1928); probably located in the dead-end shallow sloughs and adjacent tributaries of the Delta; they were collected by plankton net in various locations of the Delta and NBA areas (CDFG fish E and L survey).

JUVENILES

Dorsal fin rays	I, 6 (Fowler 1917); I, 6–7 (Scott and Crossman 1973, Moyle 1976).
Anal fin rays	18–21 (Scott and Crossman 1973); 21–24 (Pflieger 1975, Moyle 1976).
Pectoral fin rays	I, 7–9, usually 8 (Scott and Crossman 1973).

Adipose fin	Long and fleshy (Scott and Crossman 1973); elongate, posterior end of adipose fin connects to caudal finfold in early juveniles, disconnected by large juvenile life stage.
Mouth	Terminal, upper jaw slightly protruding (Scott and Crossman 1973).
Vertebrae	34–39, plus Weberian ossicles (Scott and Crossman 1973); 14 + 26 (Fish 1932).
Distribution	In the backwater and deadend sloughs of the Delta (Turner 1966); stagnant creeks such as Napa River, Walnut Creek; reservoirs, such as Millerton Lake. Juveniles were occasionally collected at the CVP/TFCF during the summer and fall months.

LIFE HISTORY

Brown bullhead is native to the freshwaters of the eastern United States and southern Canada, being found through the Maritime Provinces to southern Florida (Livingstone 1951); in the west from Saskatchewan to central Alabama (Scott and Crossman 1973). This species is also common in brackish tidal creeks along the Atlantic coast (Fowler 1917, Smith 1971); maximum salinity can be up to 10 ppt (Smith 1971) or 13 ppt in Suisun Marsh (Moyle 2002). Brown bullhead was introduced into California in 1874 (Curtis 1949, Dill and Cordone 1997). Collections of brown bullhead are sparse in the Delta (Turner 1966, this study) and were intermittent from various locations (Wang and Reyes 2007). Ecological Analysts, Inc., collected with beach seines brown bullheads in Three Mile Slough near Brannan Island State Recreation Area, Montezuma Slough and its tributaries, lower Walnut Creek, Heather Farm Pond in Walnut Creek, and a small pond in Hill Crest Park, Concord. They have also been collected from large bodies of water such as Folsom Lake and Millerton Lake. Since 1991, brown bullheads seem less commonly collected from the CVP/TFCF salvage operations. The distribution of this species in the Delta is patchy (Moyle 2002).

Brown bullhead spawns from May through mid-July (Moyle 2002); mostly from June to July in foothill streams and reservoirs such as Millerton Lake (Wang 1986). Nests are excavated either by the female (Wallace 1967) or by both parents (Scott and Crossman 1973). They spawn in shallow weedy areas of streams and lakes (Wright and Allen 1913), and most spawning probably occurs in non-tidal freshwater (Wang and Kernehan 1979). Larvae have been collected in CDFG fish E and L surveys in the Delta, indicating that some spawning occurs in tidal freshwaters of the Delta.

The female expels about 30–50 eggs at a time, which are fertilized by the male (Breder and Rosen 1966). Eggs stick to one another and are covered by a gelatinous coating. Eggs are guarded and aerated by one or both parents. Smith and Harron (1904) reported that brown bullheads take the egg mass into their mouth when predators are present. Eggs hatch in 5 d at 25ºC (Smith and Harron 1904) and in 6–9 d at 20.6–23.3ºC (Raney 1967).

Newly-hatched brown bullhead larvae have a very large yolk-sac. The larvae remain in the nest for about a week (Emig 1966, Scott and Crossman 1973) or until the yolk-sac is absorbed. They then swim up in dense schools that appears as pitch black "balls" like those of black bullhead juveniles. These dense schools of young brown bullheads were observed in the Napa River near a sewage treatment plant and in the shallow protected coves of Millerton Lake. When the constantly moving "ball" is disturbed, the young catfish sink from the surface for a short time before resurfacing. Large brown bullhead juveniles were collected from Lindsey Slough, Suisun Bay, and Montezuma Slough, but are less common at the CVP/TFCF. Juveniles consume amphipods, mysid shrimps, and dragonfly nymphs in the Delta (Turner 1966). They also take chironomid larvae, insects, small crustaceans, and small fishes (Moyle 2002).

Brown bullhead is an excellent food fish and supports fisheries in California and in China. Brown bullheads are cultured in small numbers in California (Moyle 2002) where they mature at 3 years of age (Moyle 1976). In China, this author was involved in the culture of brown bullhead in 1984 and 1985. These brown bullheads were cultured in Wuhan, China and reached marketable size and sexual maturity in 2 years instead of 3 years. In Chinese folk medicine, scaleless fishes such as ictalurids are made into a soup and digested to enhance milk production in breastfeeding women.

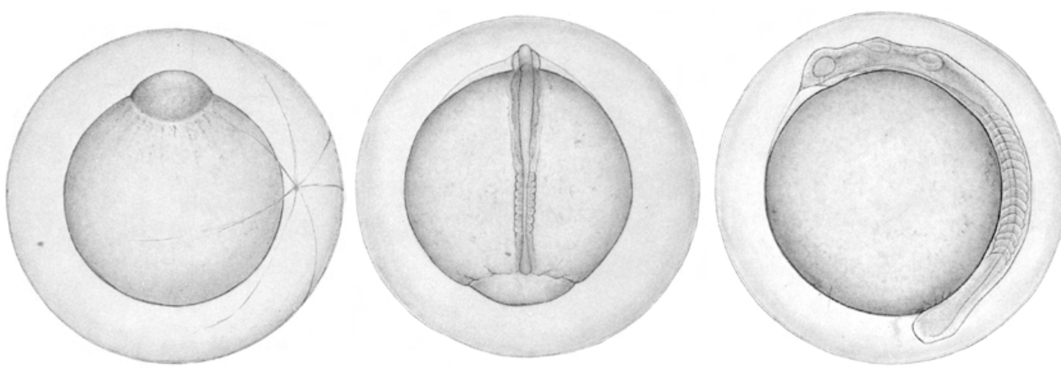


Figure 58.—*Ameiurus nebulosus*, brown bullhead eggs (~3.0 mm): newly fertilized (left), neurula stage (middle), tail-bud stage (right; Armstrong and Child 1962).

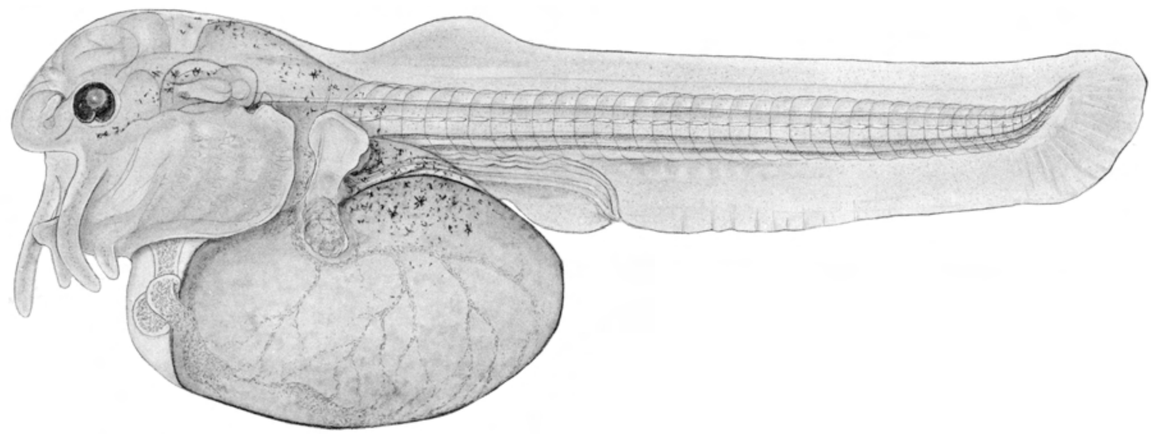


Figure 59.—*Ameiurus nebulosus*, brown bullhead prolarva, size unknown (Armstrong and Child 1962).

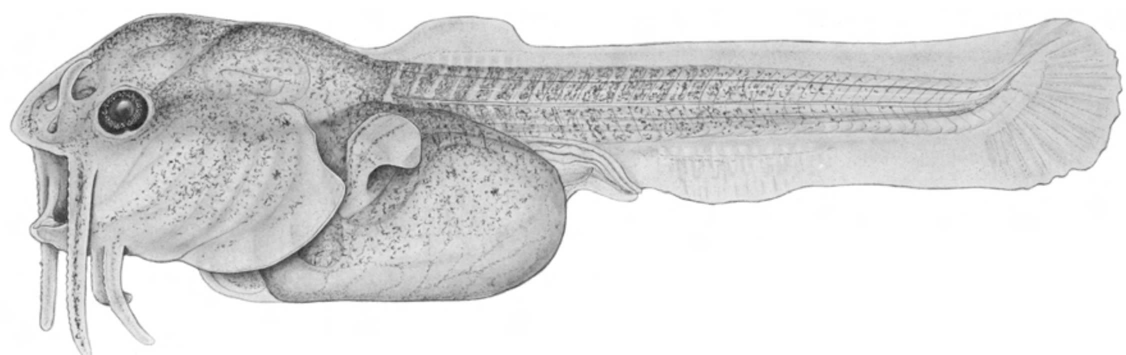


Figure 60.—*Ameiurus nebulosus*, brown bullhead prolarva, size unknown (Armstrong and Child 1962).

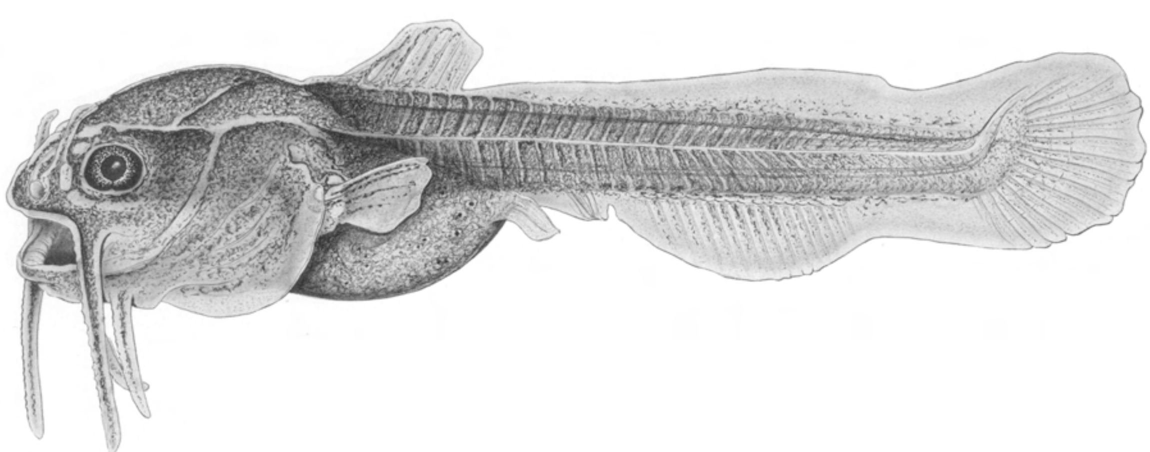


Figure 61.—*Ameiurus nebulosus*, brown bullhead prolarva, size unknown (Armstrong and Child 1962).

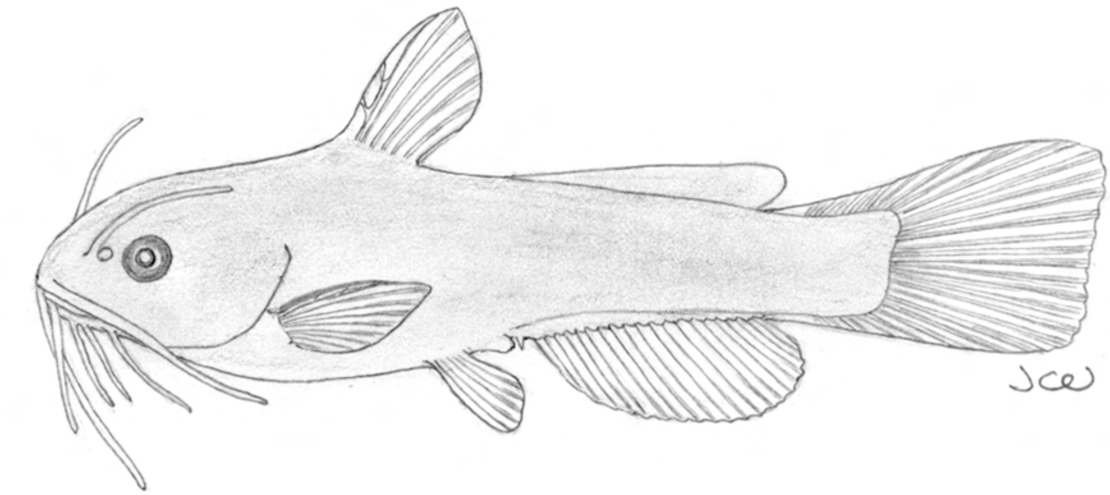


Figure 62.—*Ameiurus nebulosus*, brown bullhead juvenile, 20.8 mm TL (Wang 1986).

CHANNEL CATFISH Ictalurus punctatus (Rafinesque)

SPAWNING

Location	Near lake shores (Fish 1932); in undercut banks (Harlan and Speaker 1969); dark places in lake and stream (Baxter and Simon 1970); mostly in the freshwater portions of the Sacramento-San Joaquin River system with suitable nesting sites, such as holes and cavities of rocky jetties, undercut banks, and peat moss cracks from Pittsburg Powerplant to the CVP/TFCF of the south Delta. Manmade nesting materials include dark plastic buckets, old tires, and containers.
Season	April through June (Moyle 1976); May through late July or early August in the Delta (Wang 1986); June in Lake Erie (Fish 1932); May or June in Oklahoma (Miller and Robison 1973); May through July in Missouri (Marzolf 1957); May through July in Kansas (Cross 1967); April through June in Arizona (Minckley 1973). This species may spawn more than once per year (Dill 1944, Carlander 1953, Miller 1966); spawning extends to September (Kendall 1904, 1910).
Temperature	21–29ºC, optimum at 27ºC (Clemens and Sneed 1957).
Salinity	Mainly in freshwater; 2 ppt of brackish water (Perry 1973).
Substrates	In cave-like dark areas of natural and manmade substrates (see Location above).

Fecundity	Ranged from 1,052 (Jearld and Brown 1971) to 7,000 (Carlander 1953).

EGGS

Shape	Spherical.
Diameter	3.53 mm (Shira 1917); 3.5–4.0 mm (Scott and Crossman 1973); 3.3–4.0 mm, fertilized eggs (Wang 1986); 3.5–4.9 mm with an average of 4.3 mm for eggs collected from Oak Grove Regional Park, San Joaquin County (Reyes 2010).
Yolk	Yellow when laid (Davis 1959, Miller 1966, Scott and Crossman 1973); becoming browner just before hatching (Brown 1942); newly fertilized eggs yellowish and granular.
Oil globule	None.
Chorion	Transparent to translucent, thick, covered with gelatinous mucus (Saksena *et al.* 1961); chorion thick and tough.
Perivitelline space	Fairly wide in newly fertilized eggs and then becoming narrower.
Egg deposition	Deposited in large clusters (Doze 1925, Plosila 1961, Saksena *et al.* 1961).
Adhesiveness	Adhesive.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	~6.4 mm as the minimum size (McClellan 1954); 10.3–11.8 mm TL for 1-d-old specimens (obtained from Ken Beer, The Fisheries, Inc.); 10.3–13.2 mm TL with an average of 10.6 mm TL (Reyes 2010).
Snout to anus length	~47–52% of TL for larvae 10.6–11.8 mm TL; ~45–48% for larvae 13.3–15.0 mm TL (Wang 1986); 45–47% for larvae 11.7–15.7 mm TL (Reyes 2010).
Yolk-sac	Oval, large, extends from anterior jugular to the end of abdominal regions; yolk-sac is pointed at posterior end.
Oil globule	None.
Gut	Initially straight, later twisted.
Air bladder	Oval, above the base of pectoral.
Teeth	None at larval stage.
Size at absorption of yolk	~14–15 mm TL.
Total myomeres	44–46 (Wang 1986); 43–49 (Reyes 2010).
Preanal myomeres	16–21 (Wang 1986); 16–19.

Postanal myomeres	25–28 (Wang 1986); 26–30.
Last fin(s) to complete development	Pelvic (Jones *et al.* 1978); pelvic fin ray development completed at ~17 mm TL.
Pigmentation	Newly-hatched larvae have no pigmentation; 1–2 d later , sparse melanophores appear on head, body, and adipose fin; no pigmentation found in the yolk-sac region.
Distribution	Newly-hatched larvae remain in nesting area, and then disperse into shallow water. They are found throughout the Sacramento-San Joaquin River system, particularly in sloughs of the Delta. In addition, they are commercially farmed in the Sacramento Valley region.

JUVENILES

Dorsal fin rays	I, 5–6 (Moyle 1976); I, 6 (Jordan and Evermann 1902, Scott and Crossman 1973).
Anal fin rays	24–29 (Minckley 1973, Moyle 1976); 23–26 (Scott and Crossman 1973); usually 26 for the channel catfish found in the Delta.
Pectoral fin rays	I, 8–9 (Scott and Crossman 1973); soft pectoral rays up to 10 (Stevens 1959).
Adipose fin	Large in the prejuvenile stages and then small in juvenile.
Mouth	Inferior, lower jaw shorter than upper jaw (Scott and Crossman 1973); upper jaw protruding.
Vertebrae	42–44, plus Weberian ossicles (Scott and Crossman 1973).
Distribution	Throughout the Sacramento-San Joaquin River system and upper oligohaline portion of the estuary. They are common in the south Delta.

LIFE HISTORY

Channel catfish is a freshwater fish native to the Hudson River and along the Atlantic coast drainages to Florida (Hubbs and Lagler 1958, Scott and Crossman 1973). It is also found west of the Mississippi River system to the northwestern part of Mexico and to the east of St. Lawrence River drainages of southern Canada (Scott and Crossman 1973). It has been widely introduced throughout the United States, including the Pacific coast (Moore 1957). The history of the introduction of channel catfish into California, including its introduction in the Sacramento-San Joaquin River system, is not so clear (Moyle 1976, Dill and Cordone 1997). It was first reported in the Sacramento-San Joaquin River in 1942. During a fishery survey in the Sacramento-San Joaquin River system in 1963–1964 by the CDFG, channel catfish was found to be the second most abundant ictalurid (Turner 1966). More recently, it is the second most abundant ictalurid taken in CVP/TFCF salvage operations; however, its numbers are nowhere close to the most abundant ictalurid salvaged, the white catfish. Channel catfish can tolerate the salinity ranges of 19.0 to 21.0 ppt (Magnin and Beaulieu 1966), but they are more likely found in oligohaline water (Perry 1973). Large channel catfish were captured in trawl and fyke nets in Montezuma Slough up to the Pittsburg and Contra Costa Powerplants (Wang 1986). Collections of small juveniles were scattered in the Delta and the NBA areas (CDFG fish E and L survey, 1988–2004).

Channel catfish spawn from April to June in California (Moyle 1976). Based on the collection of small juveniles in this study, spawning occurs from May through August in the Delta, and may begin as early as April in the vicinity of the Contra Costa and Pittsburg Powerplant thermal plumes. Nests are constructed by one or both parents in the crevices and holes of rocky jetties in areas near the powerplants, in the Delta, and in its tributaries. Spawning may also occur in undercut banks, holes in peat moss, hollowed containers, submerged logs, and other secluded or dark places. Eggs are very adhesive, and are deposited in a large, flat, gelatinous mass (Doze 1925); sometimes the egg mass can be scattered in a small, confined container (Wang and Kernehan 1979). During the reproductive season, the male assumes darker body coloration with a thick lip (Minckley 1973). Females pair with males and spawning activity lasts 4–6 h (Perry and Avault 1969). After spawning takes place, the male drives the female out of the nest, and stays to guard and aerate the eggs (Cross 1967). Eggs hatch in 7–10 d at 24–26ºC (Clemens and Sneed 1957), or 6 d at 24ºC (Harlan and Speaker 1969). The spawning behavior of the channel catfish is said to be much like that of the brown bullhead (Clemens and Sneed 1957) and the white catfish. In the Delta, channel catfish probably compete for spawning sites with white catfish since white catfish are extremely abundant. During incubation, the male channel catfish may eat some of the eggs (Brown 1942), an observation not reported for other catfishes.

Newly-hatched channel catfish larvae stay at or near the nest for several days (Cross 1967). The male guards the young until they disperse (Minckley 1973). Similar to other ictalurids, once the yolk-sac is absorbed, fin rays are already developed and the fish is now an early juvenile. Small juvenile channel catfish swim mostly near the surface (Scott and Crossman 1973); many small juveniles (20–60 mm TL) were captured by ichthyoplankton nets at various depths in Suisun Bay, Delta, and NBA areas (CDFG fish E and L survey, 1988–2004). In creeks and streams, juveniles inhabit shallow riffles and turbulent areas near sandbars (Davis 1959). Juveniles school together for several days or even weeks before breaking up (Harland and Speaker 1969). Juveniles <100 mm TL, feed on aquatic invertebrates (Minckley 1973); larger juveniles prey on aquatic insects, crayfish, and fishes (Turner 1966, Miller 1966) including small threadfin shad (this study).

Channel catfish mature between 2–8 years (Carlander 1969) or 2–5 years (Baxter and Simon 1970). Channel catfish is an excellent food fish. It has been used broadly for aquaculture in the warm waters of Mississippi and Alabama. Modern farming technology and fish product processing plants have made channel catfish culture into a multimillion dollar “seafood” industry. Filets are sold in major food markets in the United States. Those raised in the Sacramento Valley region are sold as live fish or as a freshly caught and eviscerated fish to local Asian fish markets such as those in San Francisco and Oakland.

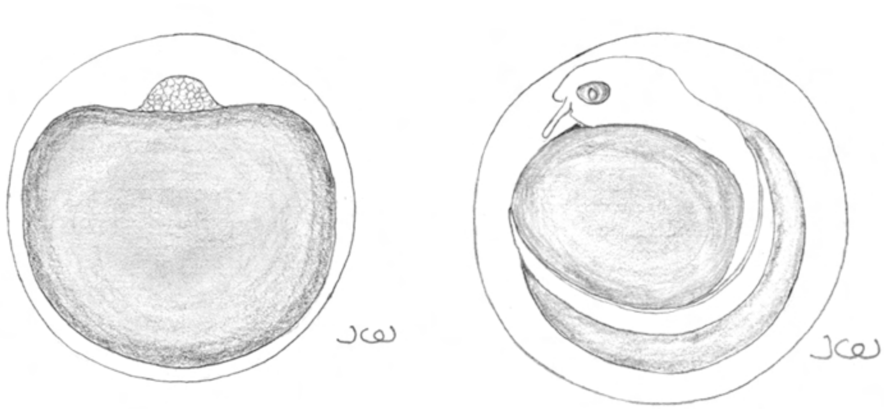


Figure 63.—*Ictalurus punctatus*, channel catfish eggs: morula 3.8 mm (left) and late embryo 4.3 mm (right; Wang 1986).

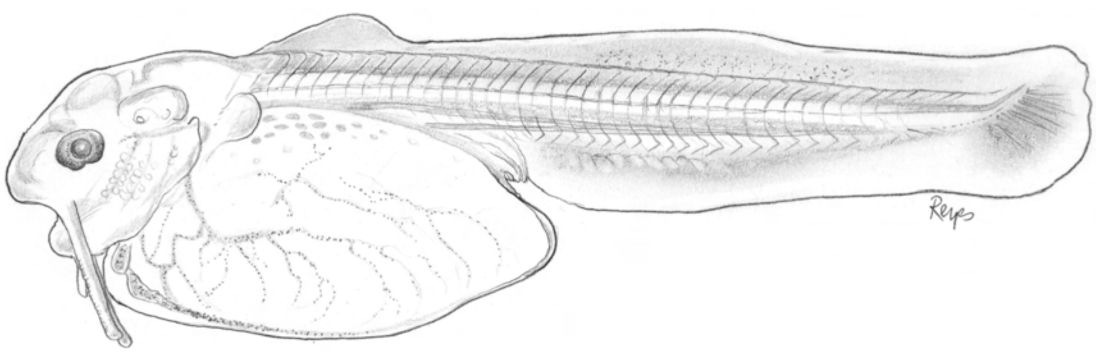


Figure 64.—*Ictalurus punctatus*, channel catfish prolarva, 11.3 mm TL.

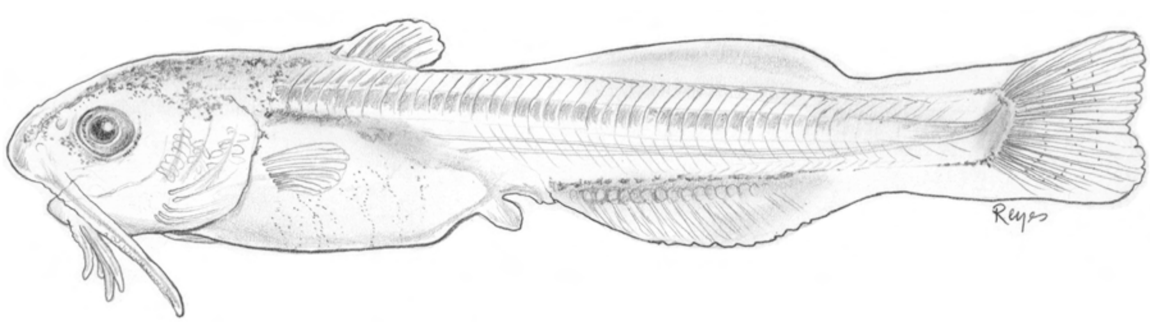


Figure 65.—*Ictalurus punctatus*, channel catfish prolarva, 14.5 mm TL.

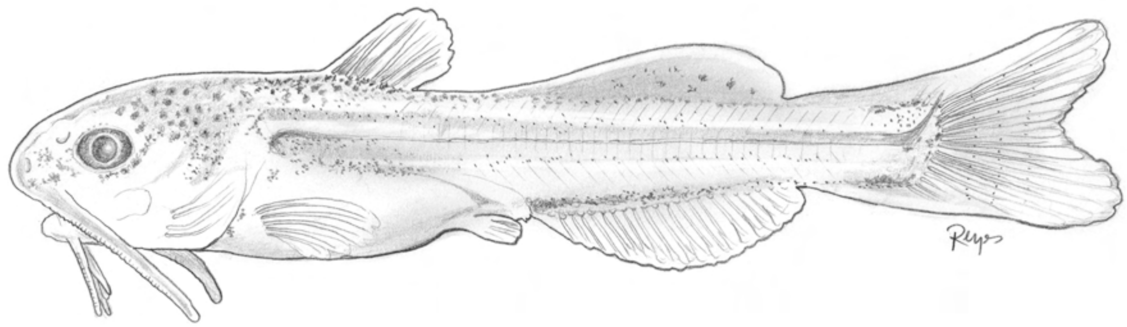


Figure 66.—*Ictalurus punctatus*, channel catfish juvenile, 16.7 mm TL.

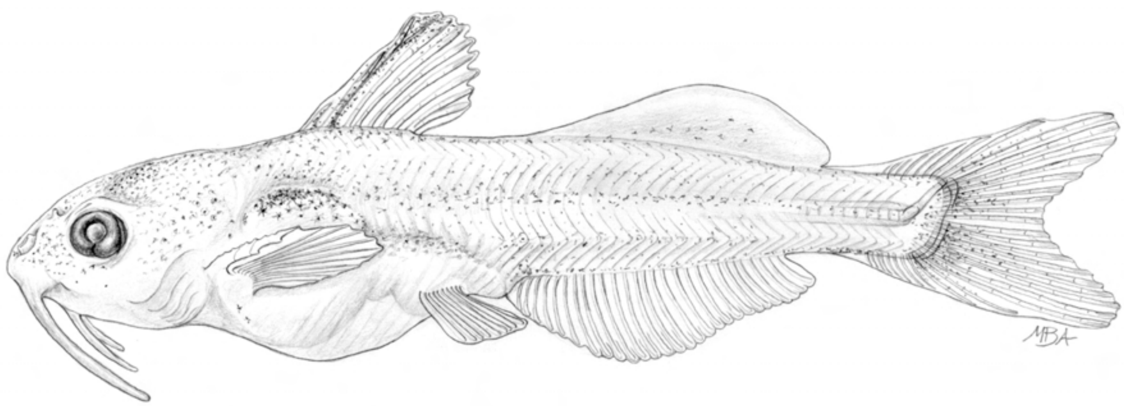


Figure 67.—*Ictalurus punctatus*, channel catfish juvenile, 19.5 mm TL (Wang 1986).

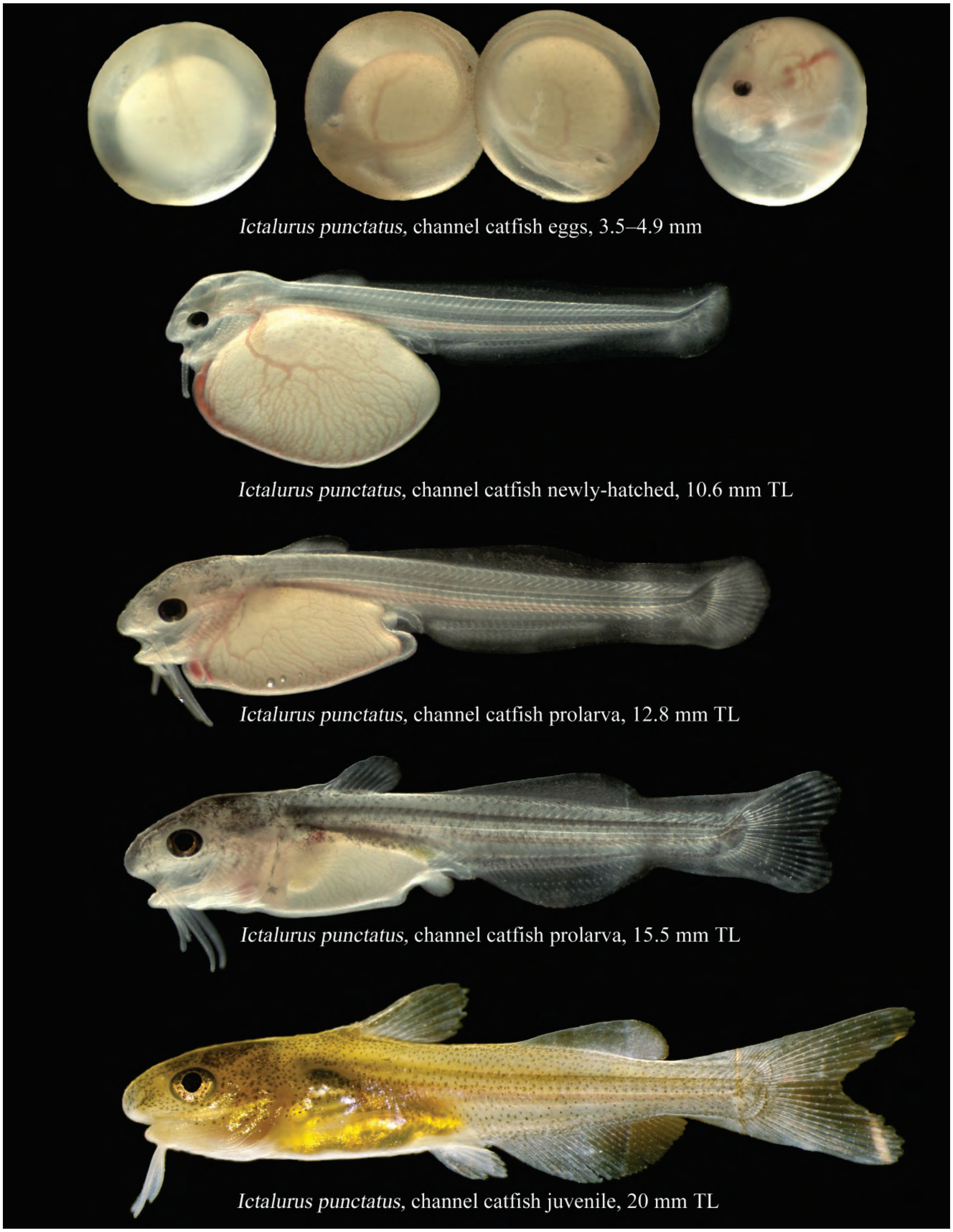


Figure 68.—*Ictalurus punctatus*, channel catfish.

Taxonomic Characteristics of Ictalurids Present in the Study Area

	White catfish	**Black bullhead**	**Brown bullhead**	**Channel catfish**
Eggs				
Size range (mm in diameter)	3.9–5.5	3.1–3.7	3.0–3.4	3.3–4.9
Color	Bright yellow	Pale yellow	Pale yellow	Pale yellow
Yolk-sac larvae				
Eye	Round	Round	Round	Oval
Nostril barbel	Short	Long	Long	Barely seen
Body pigments	None, then light	None, then very dark	None, then dark	None, then sparse
Juveniles				
Eye	Round to oval	Round	Round	Oval
Upper jaw	Slightly protruding	Slightly protruding	Slightly protruding	Protruding
Chin barbel	White	Black	Dark	white
Anal fin rays	Usually 22	15–19	18–24	Usually 26
Anal fin membrane	No pigments	Pigments	No pigments	No pigments
Caudal fin	Shallow fork	Truncate	Truncate	Deep fork

Salmonidae – Trouts and Salmon — Six species of native salmon and trout in the genus *Oncorhynchus* occur in the Sacramento-San Joaquin River system: pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), rainbow trout (*O. mykiss*), sockeye salmon (*O. nerka*), and Chinook salmon (*O. tshawytscha*) (Davidson and Hutchinson 1938, Hallock and Fry 1967). There is one species of the genus *Salmo*, brown trout (*Salmo trutta*), introduced from Scotland (Staley 1966, Moyle 1976) and one species in the genus *Salvelinus*, brook trout (*Salvelinus fontinalis*), which was introduced to California waters from the eastern United States between 1872 and 1879 (McAfee 1966, Moyle 1976).

Coho or silver salmon runs are occasionally observed at the Nimbus Hatchery (Gold River) and regular runs occur at Redwood Creek, a short coastal stream in Marin County (Wang and Keegan 1988). Most juveniles return to the ocean the same year they hatch in Redwood Creek; very few individuals return to the ocean the following year, probably due to the creek's carrying capacity and water temperature. Chum salmon has been observed in Napa River in recent years (Stillwater Sciences, Inc.). Natural runs of coho, pink, and chum salmon have been reported on rare occasions at the fish ladders located in the Sacramento River at Reclamation's RBRPP and at USFWS Coleman Hatchery (Shasta County). The San Lorenzo River is the southern limit of the ranges of pink and chum salmon (Moyle 1976) and probably also coho salmon. Recent archaeological discoveries indicate that the native southern boundary for coho salmon extended to the San Lorenzo River (Moyle 2002, Adams *et al.* 2007).

Sockeye salmon (kokanee) has been stocked by the CDFG in Lake Berryessa, Union Valley Reservoir, and Shasta Reservoir. Kokanee specimens collected in upper Sacramento River may have been flushed out from Shasta Reservoir; a natural run of kokanee in the Sacramento River (below Shasta Dam) is unlikely due to few numbers observed and the limited distance below Shasta Dam.

Brown trout and brook trout have been collected in the middle to high elevations of the Sacramento-San Joaquin River system, such as upper American River and Rubicon River (Ecological Analysts, Inc.). These two species are not found in the valley floor to foothill regions. The biology of California salmonids has been reviewed by Moyle (2002) and other federal and state biologists.

In this study, the majority of salmonids collected in the estuary and rivers were Chinook salmon and steelhead, either en route to upper freshwater rivers and tributaries to spawn or juveniles emigrating to the ocean. Species accounts for only these two species are presented in this chapter. Steelhead specimens described in this manual are from two major hatchery stocks: Nimbus Hatchery on the American River and Coleman Hatchery on Battle Creek. Wild stocks are from Pine Gulch Creek, Olema Creek, Redwood Creek, Alameda Creek, Walnut Creek, Suisun Creek, and the CVP/TFCF of the south Delta.

ANADROMOUS RAINBOW TROUT OR STEELHEAD *Oncorhynchus mykiss* (Walbaum)

SPAWNING

Location	Large to small tributaries of Sacramento-San Joaquin River system, such as the American River and Feather River (Hallock *et al.* 1961); lower reaches of American River to below Nimbus Dam and mainly in upper reach (Hannon and Deason 2005); some coastal creeks such as Waddell Creek (Hallock *et al.* 1961) and small tributaries within the estuary such as Alameda Creek and Corte Madera Creek (Wang 1986); adjacent waters to the estuary such as Olema Creek and Pine Gulch Creek (Wang 1986), Rodeo Creek, Redwood Creek, Walnut Creek, and Suisun Creek.
Season	December through April (Hallock *et al.* 1961); January through March in Nimbus Hatchery (Wang 1986); winter or spring (Moyle 2002); February to March in the American River (Hannon and Deason 2005).
Temperature	10.5°C (Wales 1941); 10–15.5°C (Scott and Crossman 1973); 10–15°C (Moyle 1976).
Salinity	Freshwater.
Substrate	Gravel and coarse gravel.
Fecundity	200–12,000 (Scott and Crossman 1973, Moyle 1976).

EGGS

Shape	Mainly spherical or slightly irregular.
Diameter	3–5 mm (Scott and Crossman 1973); 4.6–6.2 mm, Nimbus Hatchery specimens (Wang 1986).
Yolk	Pink to orange in color (Scott and Crossman 1973); pale yellow, yellow, pinkish to orange-red; granular.
Oil globule	Numerous oil globulets scattered in yolk (Knight 1963).
Chorion	Transparent to translucent, thick.
Perivitelline space	Very narrow.
Egg deposition	Deposited in loose clusters, piles, and singly.
Adhesiveness	None (Knight 1963, Breder and Rosen 1966); eggs are adhesive during water hardening process (observed at Nimbus Hatchery, Wang 1986).
Buoyancy	Negatively buoyant or demersal (Scott and Crossman 1973, Breder and Rosen 1966).

LARVAE

Length at hatching	14.0–15.5 mm TL, Nimbus Hatchery specimens (Wang 1986).
Snout to anus length	63–68% TL for prolarvae 14–18 mm TL; ~60% for larvae 23–26 mm TL (Wang 1986).
Yolk-sac	Very large, oval to elongate shape, extends from jugular to abdominal region; the posterior half of the yolk-sac overhangs free from the body.
Oil globule	One large oil globule is anteriorly placed in yolk and surrounded by many oil globulets; oil droplets also concentrate in front of yolk-sac.
Gut	Straight.
Air bladder	Oval, midway between pectorals and anus.
Teeth	None in the prolarvae; canine in postlarvae.
Size at absorption of yolk	~22–25 mm TL (Wang 1986); 26–30 mm TL at Nimbus Hatchery (R.C. Reyes 2003–2009, personal communication).
Total myomeres	59–66.
Preanal myomeres	37–42.
Postanal myomeres	20–25.
Last fin(s) to develop	Pectoral and pelvic.
Pigmentation	Pigmentation heavy on head, dorsal, and lateral areas of body; <10 parr marks which are more concentrated anterior to dorsal fin in postlarvae; abdominal region has little

	pigmentation (Wang 1986); 5–13 oval parr marks (Moyle 2002).
Distribution	Newly-hatched larvae remain in the gravel (or redd) for 2–3 weeks before emerging and moving to calm water close to shore (Moyle 2002); postlarvae live in shallow water to extremely shallow water with sand and gravel substrates.

JUVENILES

Dorsal fin rays	10–12 (Hart 1973, Miller and Lea 1972, Moyle 1976).
Anal fin rays	8–12 (Hart 1973, Moyle 2002); 8–10 (Miller and Lea 1972).
Pectoral fin rays	11–17 (Scott and Crossman 1973, Moyle 1976); about 15 (Hart 1973); mainly 14–15 (Wang 1986).
Adipose fin	Yes.
Mouth	Terminal, slightly oblique (Scott and Crossman 1973), terminal, 1arge, directed forward (Hart 1973).
Vertebrate	60–66 (Scott and Crossman 1973), 63–65 (Miller and Lea 1972).
Distribution	Remain in the cold freshwater tributaries of the Sacramento-San Joaquin River system and coastal streams for 1–3 years before entering the ocean (Moyle 1976); for the nonmigratory rainbow trout, mainly in the freshwater tributaries for few months or before stream water dries up in summer time and eventually return to lakes or reservoirs.

LIFE HISTORY

The range of steelhead covers most of the coastal waters of the Northern Hemisphere. It is native to the Pacific coast of North America from the Aleutian Islands to northwestern Mexico (Hart 1973); from Bering Sea and Japan to northern Baja California (Miller and Lea 1972); from Kuskokwim River, Alaska, to Baja California streams (Moyle 2002). The anadromous steelhead has many races and populations along the California coast (Bagley and Gall 1998). The southernmost population is *O.m. nelsoni*, a redband trout isolated in Rio Santo Domingo in the mountains of Baja California (Nielson *et al.* 1998). Also, in the Western Pacific, in southern Japan and Taiwan, there is a related species, *O. masou*, that lives in the cold mountain streams of the islands, some turning into the nonanadromous type ‘masu’ or ‘yamame’ (Oshima 1955, Chen 1956). Steelhead provides enormous academic interest due to its complex systematic and genetic characteristics, is an excellent fish farming species and is one of the most intensively studied fish by culturists (Moyle 2002), and is also a favorable sportfish sought by the fishermen.

In the Sacramento-San Joaquin River system, upstream migration of adult steelhead occurs in spring and in fall, several months before actual spawning (Hallock *et al.* 1961). Timing of migrations was documented by Moyle (2002): winter steelhead enter the river from the ocean during the winter's high water; summer steelhead (or spring run) enter streams in spring when water has receded and the adult fish remain in the deep pools in summer and fall. In hatcheries, spawning occurs from January through March. In the Sacramento-San Joaquin River system, spawning occurs from December through April (Hallock *et al.* 1961). In a recent study in the American River by Hannon and Deason (2005), peak of spawning activity occurred from mid-February to early March, slightly later than in hatcheries. Based on the presence of smolting juvenile steelhead collected at the TFCF from February to April, spawning can be traced back to winter and spring months.

Spawning habitats range from large rivers many kilometers upstream from the ocean to a few kilometers upstream in coastal streams. Spawning can be risky when sandbars form and enclose fish spawning in the upper streams of lagoons such as was observed at Rodeo Creek above Rodeo Lagoon and Redwood Creek above the Big Lagoon, both in Marin County (Wang and Keegan 1988).

The orange-red colored eggs are buried by the female in loose gravel (simply constructed redd or nest) usually at the lower end of a pool. Gravel redds are constructed in 0.5–0.8 m depth of water in moderate to fast running flow (0.5–1.0 m/s). Fish reside in redds an average of 3 d (Hannon and Deason 2005). The female releases some eggs in each batch and the process is repeated until she spawns out (Shapovalov and Taft 1954). Eggs hatch in 3–4 weeks at water temperatures of 10–15°C (Moyle 1976) or 19 d at 15°C (McAfee 1966). In Nimbus Hatchery, eggs hatched within 4 weeks at 10–12°C (Wang 1986).

Newly-hatched larvae stay in crevices of the gravel until their yolk-sac is absorbed (about 2 weeks) and then move into adjacent shallow and quiet pools located below riffles. Small juveniles (< 30 mm TL) have been collected at the CVP/TFCF after heavy storms, apparently displaced from nest sites upstream. Larvae are solitary, but a social hierarchy gradually develops within a few weeks after they emerge from the nest (Jenkins 1969), in which larger fish use deeper pools while smaller fish use the shore.

Juvenile steelhead remain in freshwater streams from 1–3 years before moving to the ocean (Moyle 1976). Downstream migration occurs in most months of the year, but peaks occur in fall and spring (Hallock *et al.* 1961). Many steelhead juveniles have been observed inshore, in sloughs, open waters of the estuary, rivers, streams, intermittent creeks, and even in some of the coastal streams behind sandbars. Small juveniles use inshore vegetation as shelter. They can also swim into extremely shallow water when disturbed or when predatory fish approach. Hatchery stocks are released by state and federal hatcheries mainly during spring at designated locations in the Sacramento-San Joaquin River system.

Little is known about the behavior and habits of juvenile steelhead after entering the ocean (Ganssle 1966). They generally return to their natal streams in 1 or 2 years (Scott and Crossman 1973) or 2 to 3 years (Moyle 1976); some immature steelhead (often called jacks) will return earlier to freshwater after staying the first summer in the ocean (Kesner and Barnhart 1972). Sexual maturity is reached by ages 3 to 5, and males often mature 1 year earlier than females. Steelhead can spawn four or more times during their lifespan (Shapovalov and Taft 1954); however, only a few accomplish multi-spawning due to the stress and high mortality of initial spawning (Moyle 2002).

Juvenile steelhead are opportunistic feeders. Major food items include terrestrial, and aquatic insects and benthic organisms. In the estuary, they also eat amphipods, other small crustaceans, snails, and even small fish (Sasaki 1966a, Moyle 2002). Migrating juvenile steelhead are preyed upon by Sacramento pikeminnow, striped bass, seagulls, and several species of aquatic birds.

Each population of steelhead will return to its natal river or stream to spawn. This well known homing behavior leads to the recognition of many local races and taxonomic variations. Sea run steelhead populations in California have been in decline due to habitat destruction. Demands for water caused by population growth, farming, and industrial activities have also added pressure on the survival of steelheads. Currently, states along the Pacific coast consider steelhead a natural resource and, therefore, provide protection for this species.

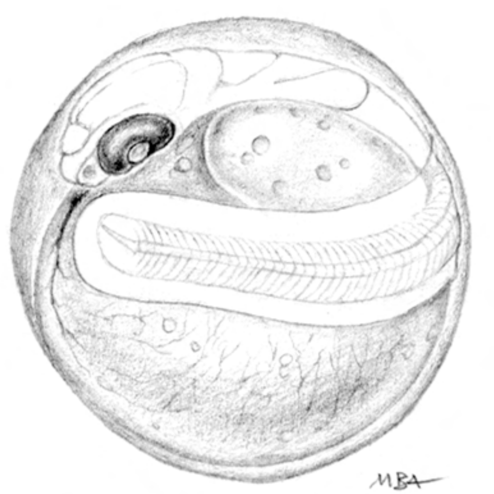


Figure 69.—*Oncorhynchus mykiss*, rainbow trout late embryo, 6 mm (Wang 1986).

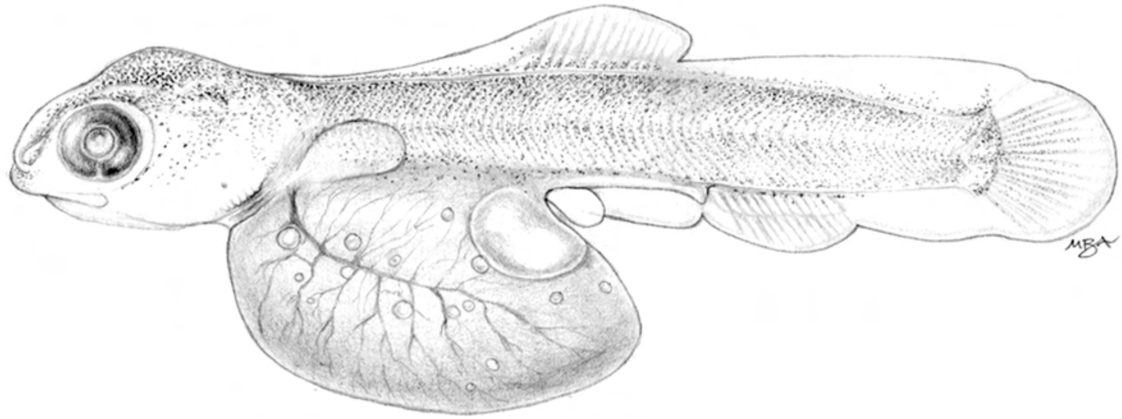


Figure 70.—*Oncorhynchus mykiss,* rainbow trout prolarva, 17 mm TL (Wang 1986).

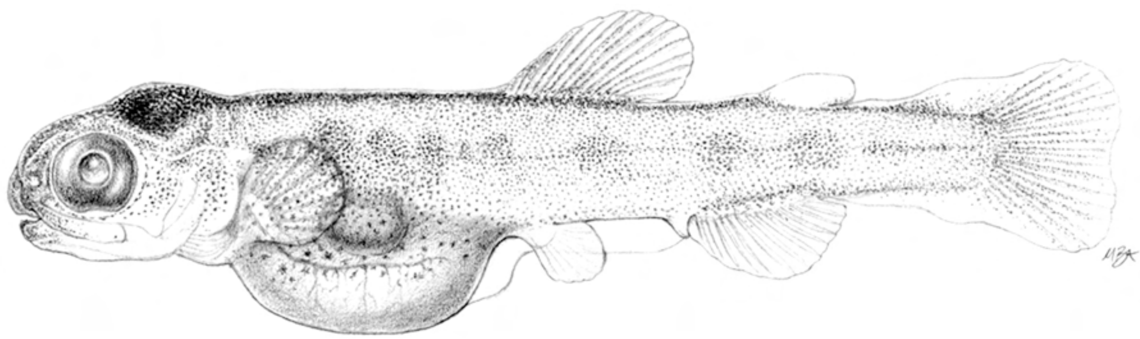


Figure 71.—*Oncorhynchus mykiss,* rainbow trout prolarva, 25 mm TL (Wang 1986).

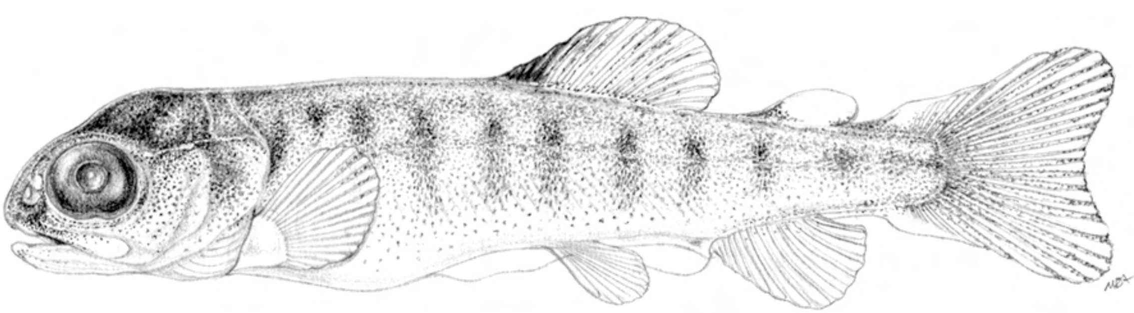


Figure 72.—*Oncorhynchus mykiss*, rainbow trout juvenile, 28 mm TL (Wang 1986).

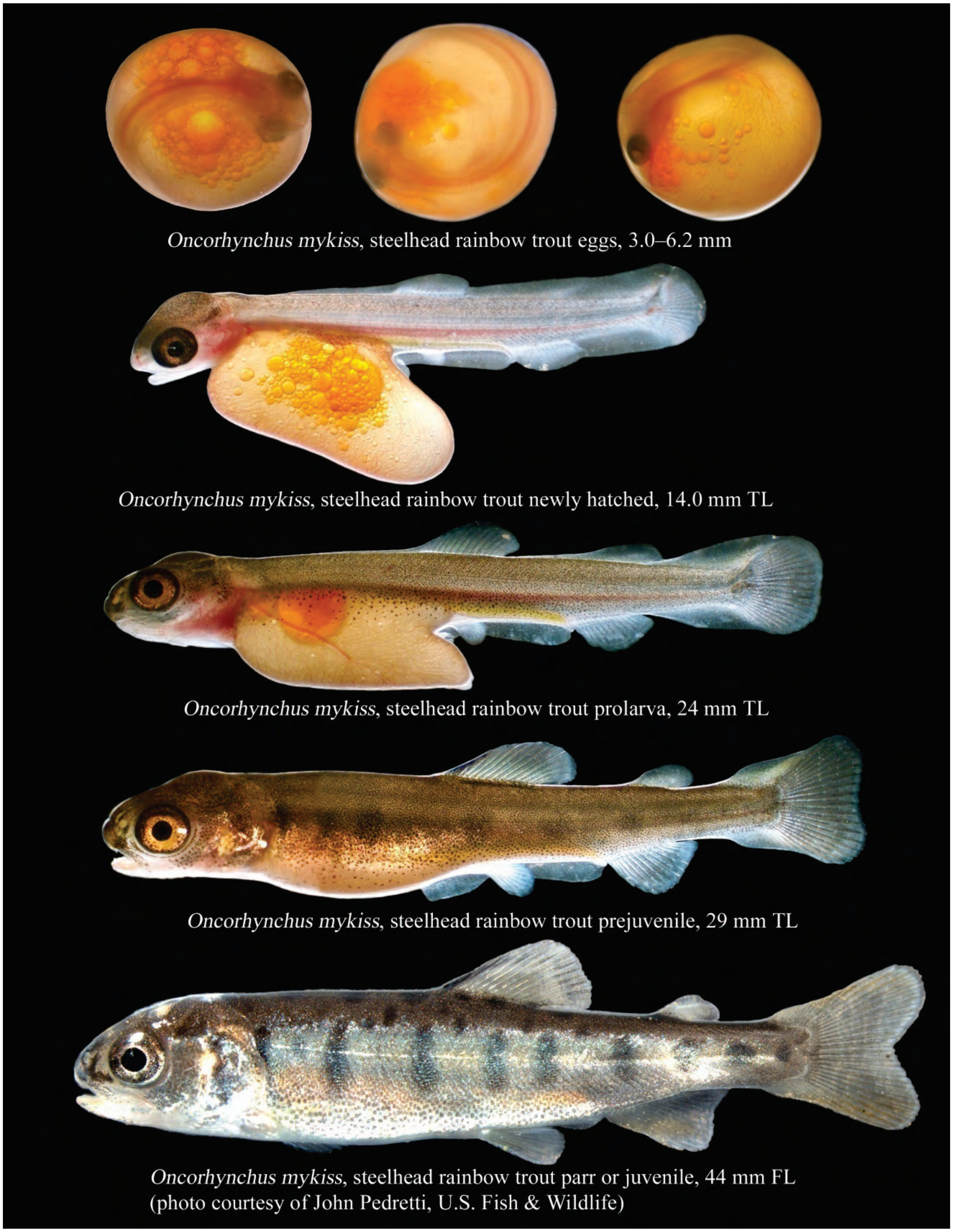


Figure 73.—*Oncorhynchus mykiss*, steelhead rainbow trout.

CHINOOK SALMON *Oncorhynchus tshawytscha* (Walbaum)

SPAWNING

Locations — In the past, spawning occurred in the upper reaches of the Sacramento River above Shasta Dam, McCloud River, Pit River, upper San Joaquin River, above Millerton Lake (Hallock and Fry 1967, Moyle 1976). At present, mostly in the upper Sacramento River from Keswick Dam southward. Some of the tributaries of the Sacramento River such as Battle Creek, Mill Creek, Feather River, Yuba River, and American River are also included. In the San Joaquin River system, spawning is reported in the Mokelumne River, Stanislaus River, and Tuolumne River (Hallock and Fry 1967). A small run in the Guadalupe River and Coyote Creek also occurred in recent years (Moyle 2002). Adult Chinook salmon were observed at the trashrack of the CVP/TFCF occasionally; apparently disoriented during migratory/spawning run.

Season — Spawning occurs all year round because many races are involved:

Race	Migratory Run	Spawning Period
Fall	July to Dec.	Oct. to Dec. (Hallock and Fry 1967)
	June to Dec.	Sept. to Dec. (Yoshiyama *et al.* 1998)
Late Fall	Oct. to Apr.	Jan. to Apr. (Hallock and Fry 1967)
	Oct. to Apr.	Jan. to Apr. (Yoshiyama *et al.* 1998)
Winter	Dec. to July	Apr. to July (Hallock and Fry 1967)
	Dec. to July	Apr. to Aug. (Yoshiyama *et al.* 1998)
Spring	Apr. to Oct.	Aug. to Oct. (Hallock and Fry 1967)
	Mar. to Sept.	Aug. to Oct. (Yoshiyama *et al.* 1998)

Temperature — 10–15°C; eggs will have maximum survival in water temperature <14°C (Moyle 1976).

Salinity — Freshwater.

Substrates — Gravel and coarse gravel in moderate to fast running water with near-saturated dissolved oxygen (Healey 1991).

Fecundity — 4,800 (Rounsefell 1957, Prakash 1958); 4,200–13,600 (Scott and Crossman 1973); 2,000–14,000 (Moyle 1976).

EGGS

Shape — Spherical, some slightly irregular.

Diameter	6.0–7.0 mm (Scott and Crossman 1973); 6.0–9.0 mm, Nimbus Hatchery stocks.
Yolk	Orange-red (Scott and Crossman 1973); bright red (Hart 1973); deep yellow to orange-red.
Oil globule	One large oil globule surrounded by many dispersed oil globulets.
Chorion	Transparent to translucent, thick and firm.
Perivitelline space	Very narrow.
Egg deposition	Deposited and buried in clusters in gravel or redd.
Adhesiveness	Non-adhesive (Breder and Rosen 1966); adhesive during water hardening.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	≥20 mm TL (Wang 1986).
Snout to anus ratio	58–61% TL for prolarvae 20–29 mm TL (Wang 1986).
Yolk-sac	Very large, oval to elongated shape extends from jugular to abdominal region; the posterior half of the yolk-sac overhangs free from the body.
Oil globule	One large oil globule surrounded by many small oil globulets; only one oil globule is present in late prolarval stages.
Gut	Straight.
Air bladder	Large, oval, midway between pectorals and anus.
Teeth	Sharp, conical, developed in late postlarval and early juvenile stages.
Size at absorption of yolk	30–40 mm TL (Wang 1986); 35–40 mm TL, Nimbus Hatchery stocks.
Total myomeres	63–69.
Preanal myomeres	41–44.
Postanal myomeres	20–25.
Last fin (s) to complete development	Pectoral and pelvic.
Pigmentation	Dense melanophores on head and dorsum; lighter melanophores in postanal area; little or no pigmentation in abdominal region. 8–10 vague parr marks and a darker horizontal stripe appear in late yolk-sac stage.
Distribution	Newly-hatched Chinook salmon larvae stay in the gravel 2–3 weeks, usually until the yolk is absorbed. Early emerging prolarvae may seek shallow water as shelter until yolk-sac is absorbed. During floods, yolk-sac larvae were

	collected in Delta and estuary localities, such as the CVP/TFCF intake and powerplant intakes (*e.g.*, Pittsburg and Contra Costa Powerplants, Ecological Analysts, Inc.). The majority of postlarvae remain in streams or move downstream (Scott and Crossman 1973, Moyle 1976).

JUVENILES

Dorsal fin rays	10 (Clothier 1950); 10–14 (Hart 1973, Moyle 1976); 10–16 (Miller and Lea 1972).
Anal fin rays	15–17 (Clothier 1950) 13–19 (Hart 1973); 13–20 (Miller and Lea 1972); 14–19 (Moyle 1976).
Pectoral fin rays	14–17 (Scott and Crossman 1973); 14–19 (Moyle 1976).
Adipose fin	Yes.
Teeth	Sharp, conical, developed in late postlarval and early juvenile stages.
Mouth	Terminal, large, slightly oblique.
Vertebrae	64–72 (Miller and Lea 1972); 62–74 (juvenile fish).
Distribution	During sea-run migration Chinook salmon are found in both shallow and open waters of the estuary and Sacramento-San Joaquin system. Some were collected from side channels such as Cache Slough (CDFG striped bass E and L survey 1988–1995; CDFG's NBA survey 1993–2004) and from tributaries such as Napa River (CDFG 20-mm fish survey); others, collected at the CVP/TFCF intake, were probably misled by 'downstream' flows.

LIFE HISTORY

Chinook salmon, also known as king salmon in California, range from San Diego to the Bering Sea and Japan (Miller and Lea 1972); however, they are now rarely found south of 40 degree north latitude due to warmer ocean temperatures occurring in recent years (Healey 1991). In Asia, this species is found in the Amur River, China, the Kamchatka Peninsula, and the Aanadr River, Russia (Hart 1973, Scott and Crossman 1973). In the Sacramento-San Joaquin River system, four races exist (Hallock and Fry 1967, Yoshiyama *et al.* 1998): fall-run, late fall-run, winter-run, and spring-run. Historically, both the Sacramento and San Joaquin River watersheds provided significant spawning grounds; however, with the construction of Friant Dam in 1946, runs in the San Joaquin became extinct. Subsequently, tributaries of the San Joaquin River such as Merced, Tuolumne, Stanislaus, and Mokelumne Rivers replaced the run in the San Joaquin River (Moyle 2002).

The following is a brief description of the four runs of the Chinook salmon in the Sacramento-San Joaquin River system. A thorough study of the runs of each race has been described by Moyle (2002). Some of the four races have been collected at the Reclamation's RBRPP and in Feather River (Seesholtz *et al.* 2004) during their downriver and sea-run migrations. A small portion of caudal fin is collected from salmon salvaged at the CVP/TFCF for further genetic identification by CDWR (S. Greene 2006–2007, personal communication).

Fall-Run The fall-run of Chinook salmon is the largest in the Sacramento River system. More fish were observed during their upward river migration in September and October. The adults were caught by gill net in Suisun Bay, near Montezuma Slough, and in the vicinity of the Pittsburg and Contra Costa Powerplants in October (Wang 1986). The spawning ground in the Sacramento River system closest to the ocean is a reach of the American River downstream of Nimbus Dam. Most of the returnees to this area are harvested and artificially spawned at the Nimbus Hatchery in October and November. Because the hatchery has limited space, fish not harvested are allowed to spawn in the American River below the hatchery. Chinook salmon propagation also has been done at Coleman National Fish Hatchery at Battle Creek for many years to mitigate the loss of spawning grounds due to Shasta Dam. Chinook salmon fall run was at one point considered as candidate for threatened status along the Pacific coast estuaries, but healthier runs have been reported in the Sacramento River in recent years.

Late Fall-Run The late fall-run is the largest run among Chinook salmon. Spawning occurs in the cold water of the upper Sacramento River in February and March. Both spawners and juveniles have been collected at the RBRPP. Larger size juveniles (≥130 mm TL) were occasionally collected at the CVP/TFCF in spring.

Winter-Run Winter-run Chinook salmon spawned in McCloud River before Shasta Dam was constructed. Currently, a small population spawns downstream of Keswick Dam in the summer months when cold hypolimnion water is released from Shasta Dam. Adults and juveniles have been observed at Reclamation's RBRPP. This unique race has been state and federally listed as endangered due to loss of habitat.

Spring-Run The upstream migration of this race of Chinook salmon starts in late spring and early summer when fish are still immature. They reach maturity in summer in the upper reaches of the Sacramento-San Joaquin River system where cold water streams and aquatic insect are available. Unfortunately, most desirable habitats for this race are blocked by dams; water temperatures below dams are also unsuitably warmer. The current run has been listed as threatened (Moyle 2002).

Ocean-going migration of all four runs occurs during the period December through May, with the occasional exception of fall and late fall-runs that start in August in some years such as 2000–2001 (S. Greene 2006–2007, personal communication).

Spawning occurs in shallow riffle areas with gravel. Females construct large redds. A dominant male joins the female in the redd and the two engage in the spawning act. The female buries the eggs in loose gravel and remains in the nest for about 2 weeks or until she dies (Scott and Crossman 1973). After spawning, dying and dead fish are observed near redds and some drift to shore (Wang 1986, Snider and Vyverberg 1996).

Chinook salmon eggs are large and incubate in cool water. Chinook salmon eggs obtained from the Nimbus Hatchery were 6.0 to 9.0 mm in diameter, bright orange-red in color, and hatched in 50–55 d at 10–12.5°C. In natural environments, incubation time varies because of temperature fluctuations; mostly between 40 and 60 d (Moyle 2002). Salmon eggs survive the best at ≤14°C (Moyle 1976); incubation temperatures must be within 5–15°C (Vogel and Marine 1991).

Newly-hatched larvae (alevins) have an oversized yolk-sac and remain in the interstitial areas of the redd for 2–3 weeks (Scott and Crossman 1973). They emerge into the water column at approximately 35 mm TL after completely absorbing their yolk. At this stage, the larvae soon migrate downstream (Moyle 1976). They were commonly found in shallow inshore waters, such as Yolo Bypass floodplains, NBA, Pittsburg and Contra Costa Powerplants, Suisun Bay, and the CVP/TFCF in winter months (Ecological Analysts, Inc., Wang and Reyes 2007; Moyle 2002; S. Greene 2006–2007, personal communication; this study). Late yolk-sac larvae (≤30 mm TL) were often collected at the CVP/TFCF after heavy rains and storms, apparently flushed from redds in the upper river. The fate of these newly emergent larvae is uncertain.

Large fish, parr-juveniles (45–75 mm TL), were collected from April to June. Sasaki (1996a) collected parr-juveniles throughout the estuary, the migration peaking in May and June. The juvenile stream residency can vary from 1–15 months depending on the race and environmental factors. Some Chinook salmon juveniles may remain in freshwater until the smolting stage (Scott and Crossman 1973, Yoshiyama *et al.* 1998).

Juvenile Chinook salmon are drift-feeders, feeding on various aquatic and terrestrial insects (such as caddisflies and chironomid larvae and pupae) and crustaceans in freshwater (Moyle 1976). Their diet changes to estuarine crustaceans such as *Neomysis* spp., *Gammarus* spp., and *Crangon* spp. when they arrive in saline water (P.B. Moyle 1982, 1987, personal communication). Juvenile salmon are preyed upon by sea gulls, cormorants, and fish such as striped bass and Sacramento pikeminnow. Downstream of Red Bluff Dam, large pikeminnows reportedly would consume 15–20 juvenile salmon (Ecological Analysts, Inc., 1982). After smolts enter the ocean, they become predators on other small fish and crustaceans (Healey 1991). Hart (1973) describes juvenile salmon moving far out into the ocean and staying well below the surface. However, immature salmon (jack) are found offshore from Half Moon Bay to Bodega Bay (information obtained from commercial and sport fishermen), their presence closely associated with the food-rich upwelling areas of the California Current (Healey 1991).

Chinook salmon are reported to mature between 2 and 9 years (Pritchard 1940), although more commonly at 4–5 years. Adults eventually return to their natal streams to spawn.

The nutritional value of Chinook salmon is outstanding making it one of the most important commercial and desirable sportfish species in California; however, their population has declined considerably in the past hundred years (Moyle 1976). The southernmost spring-run of this species in the San Joaquin River suffered the most loss. Only about 17 runs still exist between Klamath River and the Central Valley (Moyle 2002). The artificial propagation program operated through the joint efforts of federal and state agencies has compensated for some of the losses; however, the future of a fishery from this native anadromous fish is still questionable. Habitat loss due to construction of dams has been a major reason for declines in salmon populations. Pollution, introduced predatory fish, and entrainment have contributed as well as natural factors such as drought and climate changes (Moyle 2002). A ban on the commercial fishery for Chinook salmon along the California coast was posted by the Federal Advisory Board in the spring of 2008.

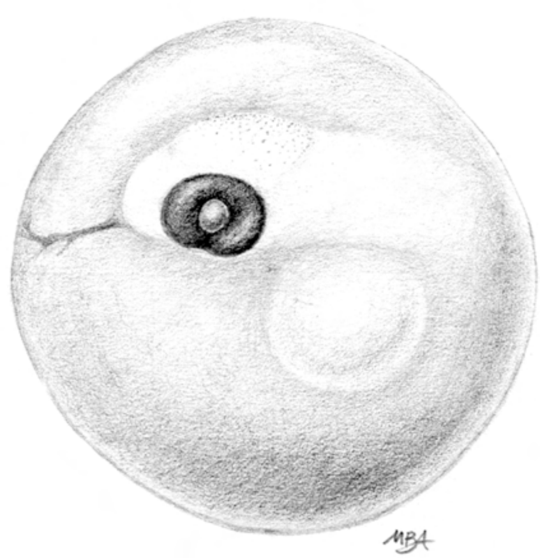


Figure 74.—*Oncorhynchus tshawytscha*, Chinook salmon late embryo, 9 mm (Wang 1986).

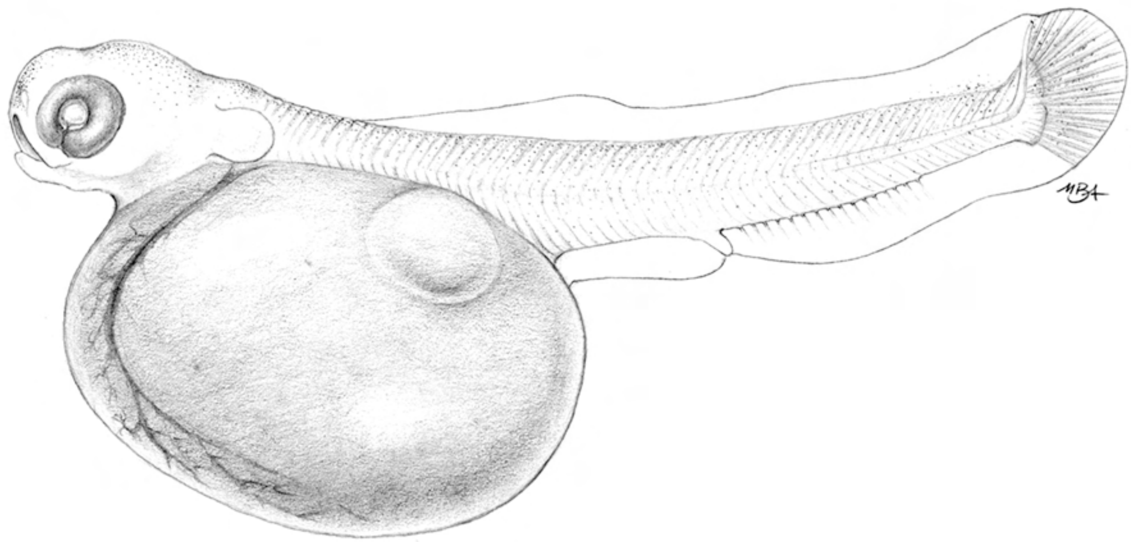


Figure 75.—*Oncorhynchus tshawytscha*, Chinook salmon prolarva, 23 mm TL (Wang 1986).

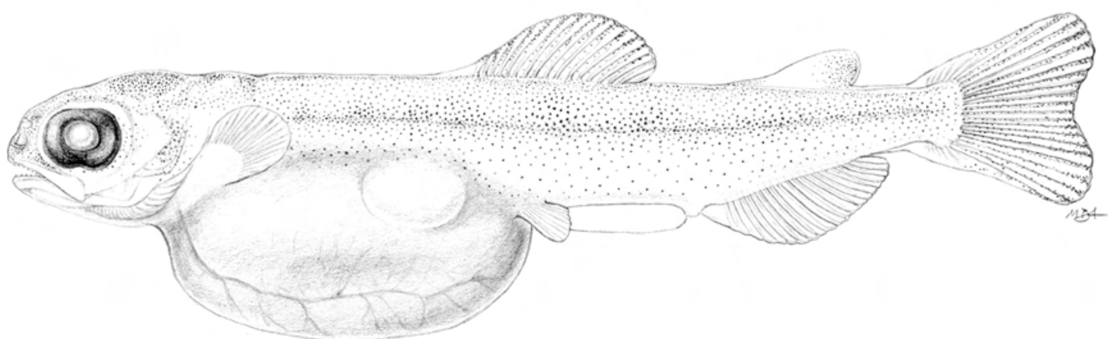


Figure 76.—*Oncorhynchus tshawytscha*, Chinook salmon prolarva, 32 mm TL (Wang 1986).

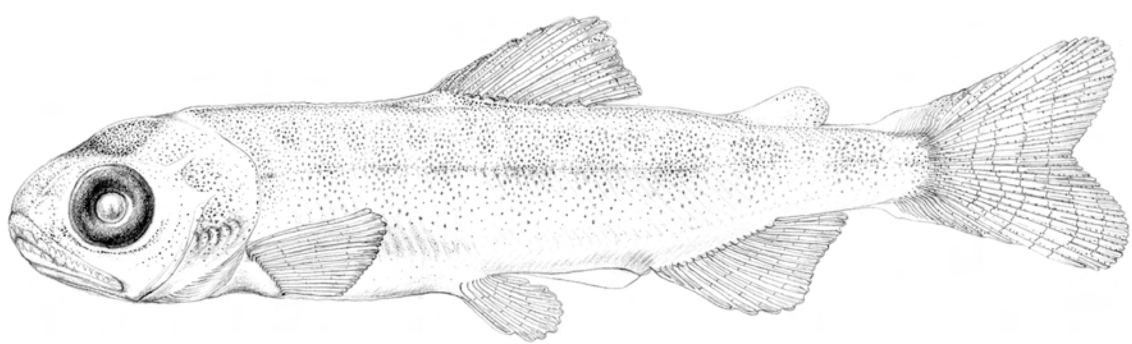


Figure 77.—*Oncorhynchus tshawytscha*, Chinook salmon juvenile, 37.5 mm TL (Wang 1986).

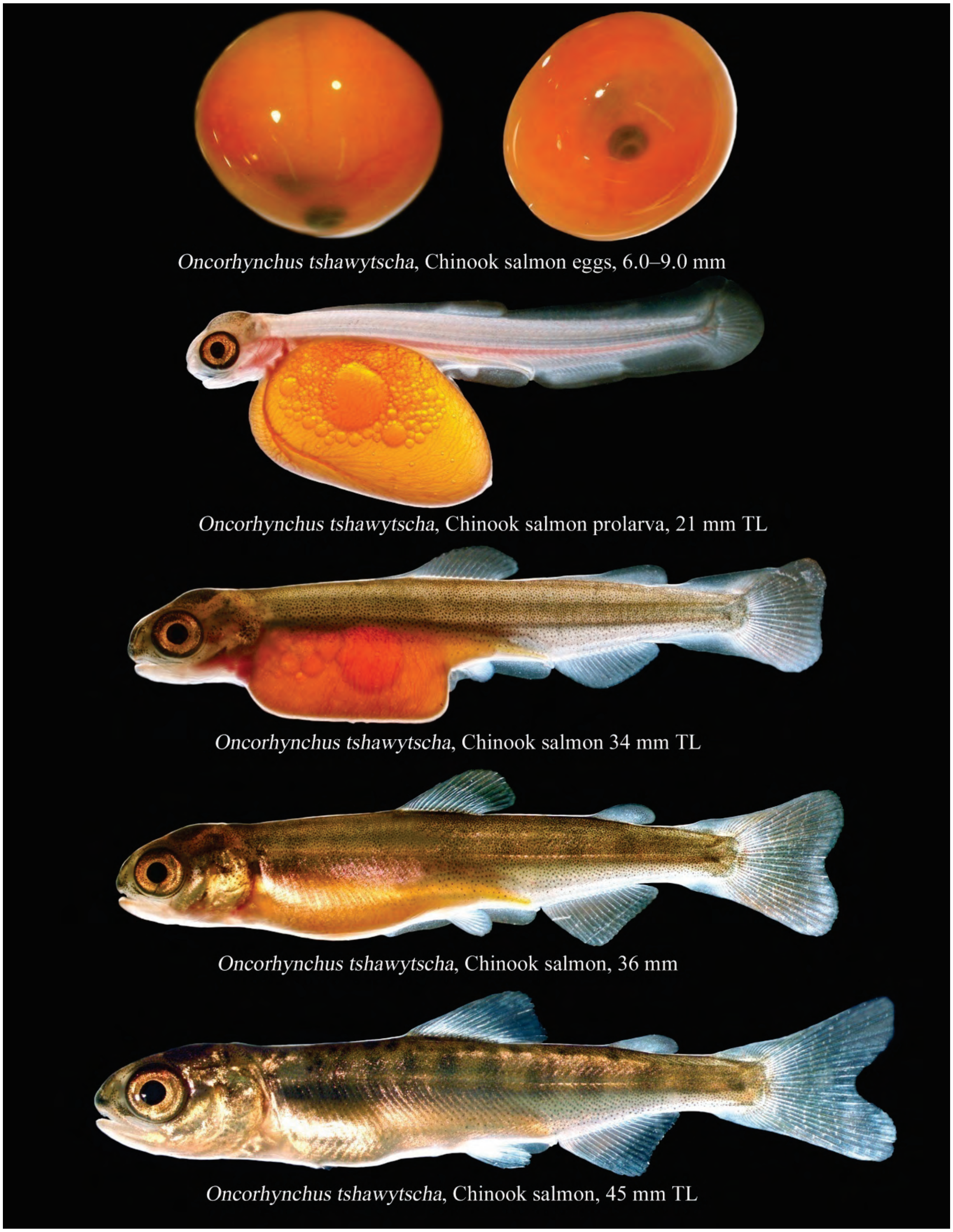


Figure 78.—*Oncorhynchus tshawytscha*, Chinook salmon.

Taxonomic Characteristics of Salmonids Present in the Study Area

	Steelhead	Chinook salmon
Eggs		
Diameter (mm)	4.6–6.2	6.0–7.0
Larvae		
Hatching size (mm TL)	~14–15	~20
Snout –Anus/TL	~60–68	~58–61
Juveniles		
Dorsal fin front pigmentation	Pigmented	Not pigmented
Dorsal and anal fin membrane pigmentation	Pigmented	Not pigmented
Anal fin rays, base	8–12, short base	14–19, long base
Anal fin, profile	High	Low
Parr mark	Bar	Bar and blotch

Batrarchoididae –Toadfishes.— In the genus *Porichthys* of the Batrachoididae family, eight species are known, one on the Atlantic coast and seven on the Pacific coast. Their habitat ranges from coastal tidal water to deep sea marine environments (Nelson *et al*. 2004). Only two species occur along the California coast, the specklefin midshipman *P. myriaster* and the plainfin midshipman *P. notatus* (Hubbs and Schultz 1939, Arora 1948, Miller and Lea 1972). Only the plainfin midshipman has been observed in the estuarine waters of the Sacramento-San Joaquin system.

PLAINFIN MIDSHIPMAN *Porichthys notatus* Girard

SPAWNING

Location	Shallow water within tidal limits (Hubbs 1920); rocky shores with tidal water (Greene 1924); shallow intertidal coastal waters (Hart 1973); spawning occurs within San Francisco Bay and in Moss Landing Harbor-Elkhorn Slough (Wang 1986).
Season	Late spring and early summer (Hubbs 1920); June–July (Greene 1924); late spring through early summer, with a peak in June (Arora 1948); in summer (Crane 1965, Hart 1973); spring and summer (Greiner *et al.* 2007); April through August and may extend to September in San Francisco Bay.
Temperature	Eggs were collected from water 18.4°C (Wang 1986).
Salinity	Seawater; may occur in polyhaline water (Wang 1986).
Substrates	Rocks, boulders (Hubbs 1920); under surface of rocks (Greene 1924).

Fecundity	20–800 (Arora 1948); ~200 (Fitch and Lavenberg 1975); 154 eggs from a single female 181 mm TL (Wang 1986).

EGGS

Shape	Spherical to subspherical (Hubbs 1920, Hart 1973).
Diameter	4.0–6.0 mm (Hubbs 1920); unfertilized eggs, 4.5–7.5 mm (Wang 1986).
Yolk	Yellow to bright yellow to pinkish, firm and hard (Arora 1948, Bane and Bane 1971, Fitch and Lavenberg 1975).
Oil globule	None.
Chorion	Transparent to opaque, firm (Arora 1948); transparent, thick, and hard.
Perivitelline space	Very narrow.
Egg deposition	Deposited singly and in single layer (Arora 1948).
Adhesiveness	Adhesive (Hubbs 1920, Arora 1948); attached to substrates.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	~7.0–8.0 mm TL (Arora 1948).
Snout to anus length	~42–44% TL for prolarvae 17.5–19.0 mm TL (Wang 1986).
Yolk-sac	Bright yellow, very large; shape of yolk-sac changes from spherical to ellipsoid to spherical to oval, until the yolk is absorbed.
Oil globule	None.
Gut	Short and thick.
Air bladder	Behind pectorals, paired and modified into a vocal organ (Greene 1924).
Teeth:	Sharp, pointed, visible in late yolk-sac larvae.
Size at absorption of yolk	Varied, ~19–23 mm TL.
Total myomeres	41–45.
Preanal myomeres	7–11.
Postanal myomeres	29–35.
Last fin(s) to complete development	Pelvic.
Pigmentation	8–9 dark vertical blotches on the upper half of the head and body. Melanophores encircle all photophores.
Distribution	Attached to the substrates in intertidal coastal waters (Hubbs 1920, Arora 1948). Some larvae (detached from

	the substrates) were collected in San Francisco Bay and Moss Landing Harbor-Elkhorn Slough.

JUVENILES

Dorsal fin rays	II, 33–38 (Miller and Lea 1972); II, 33–37 (Hart 1973).
Anal fin rays	28–34 (Miller and Lea 1972); 29–37 (Hart 1973).
Pectoral fin rays	18 (Hart 1973).
Mouth	Terminal, large, directed upward (Hart 1973).
Vertebrae	41–44 (Clothier 1950); 42–45 (Miller and Lea 1972).
Distribution	Epibenthic, mostly in bays; some may ascend to Napa River and Suisun Bay.

LIFE HISTORY

Plainfin midshipman ranges from Gorda Bank, Gulf of California, to Sitka, Alaska (Hubbs and Schultz 1939, Arora 1948, Miller and Lea 1972, Hart 1973). According to Eschmeyer *et al.* (1983), its range may extend further south from the Gulf of California. Two populations along the Pacific coast are known: one from Oregon and northward and the other from San Francisco Bay and southward. In the Sacramento-San Joaquin system, plainfin midshipman was reported in San Francisco Bay, San Pablo Bay, and up to Suisun Bay (Ganssle 1966, Messersmith 1966, Aplin 1967). This species is common in San Francisco Bay in spring and summer. CDFG's plankton netting, beach seining, and midwater trawling collected 10,766 specimens between 17–348 mm TL during the period 1981–1988 (Baxter *et al.* 1999). Collections are recorded from Tomales Bay (Bane and Bane 1971), Bodega Bay (Standing *et al.* 1975), and in Moss Landing Harbor-Elkhorn slough (Kukowski 1972, Nybakken *et al.* 1977). They are also reported from PG&E's powerplant intake screen located in the south San Francisco Bay (Wang 1986). In the upper estuary, juvenile plainfin midshipman were collected in oligohaline to freshwater on occasion (Wang 1986), in Napa River (CDFG 20-mm fish survey, 1996–1997), and in Suisun Bay (CDFG striped bass E and L survey, 1990–1994).

In San Francisco Bay, plainfin midshipman spawn mainly in Richardson Bay and south San Francisco Bay from April through August (Wang 1986). Adult fish arrive from the ocean in April (Baxter *et al.* 1999). Based on small fish collected in October and November, spawning may extend to September. During courtship, male's vocal organ (modified air bladder) produces a loud mating call, and both sexes display bioluminescence from their photophores (Crane 1965). Eggs, ~4–6 mm in diameter, attach to rocks, shells, or sand pits in the intertidal zone (Arora 1948, Hart 1973). Male fish guard the eggs during incubation and the larvae until they have completely detached from the substrate (Hubbs 1920, Arora 1948). A nest was found under a concrete block during ebb tide at Keller Ranch, San Francisco Bay on April 26, 1982. A male fish was guarding and aerating the eggs, which were attached to the underside of the concrete block in about 15 cm depth of water. Several other males were also found buried in the sand adjacent to the nesting area, apparently waiting for the tide to come in (K. Hieb 1982, 1986, personal communication).

During larval development, the large yolk-sac is initially spherical, then becomes ellipsoid, and returns to spherical and oval as the larva grows larger (Arora 1948). The swimming behavior and larval developmental process of the plainfin midshipman require habitat (shallow intertidal bays) similar to that of the oyster toadfish (*Opsanus tau*) found along the Atlantic coast of the United States (Dovel 1960, Schwartz 1974, Lowe 1975) and the gulf toadfish (*O. beta*) found along the Gulf coast and tributaries (Wang and Raney 1971). They also inhabit polyhaline waters, such as Indian River Estuary and Delaware River Estuary of the Atlantic coast (Wang and Kernehan 1979) and the Gulf coast of Florida (Wang and Raney 1971).

The male fish may continue protecting the young as free swimming larvae or fully developed juveniles or until they settle on the bottom or bury themselves in the substrate. Young plainfin midshipman are found in shallow and deep waters (Hubbs 1920, Arora 1948). Juveniles were collected in oligohaline and freshwater (Wang 1986). Juveniles start to move to the ocean in August and September (Baxter *et al.* 1999). Bay and estuaries serve as both spawning and nursery grounds for the plainfin midshipman. Juveniles were abundant in collections by otter trawl conducted by CDFG in recent years (Greiner *et al.* 2007).

Juvenile plainfin midshipman principally forage on small shrimp-like crustaceans (Bane and Bane 1971, Wang 1986). A vertical migration, coming up to feed at night, was reported for this species (Arora 1948, Fitch and Lavenberg 1971).

Age at maturity for this species is not clear. Baxter *et al.* (1999) first reported that plainfin midshipman may mature and spawn in 1 year. Ripe fish 165–181 mm TL were often captured in the powerplants' intake area at Potrero and Hunters Point in summer (Wang 1986); fish this size may belong to age 1+ class. Both sexes are believed to die after spawning (Fitch and Lavenberg 1975); however, large plainfin midshipman (as large as 348 mm TL) were captured by trawl in the San Francisco Bay, suggested some spawners may survive to spawn a second time (Baxter *et al.* 1999). The plainfin midshipman is of no commercial or sport value to humans (Bane and Bane 1971); however, it is used as bait for striped bass fishing (Baxter *et al.* 1999) and is important prey of seals and sea lions (Eschmeyer *et al.* 1983).

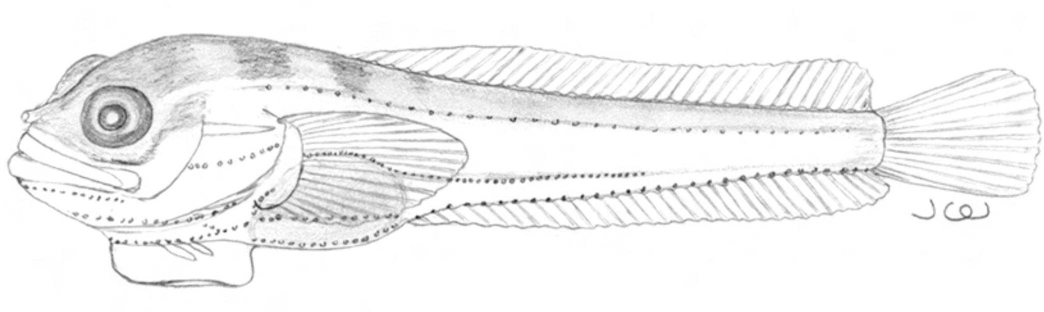


Figure 79.—*Porichthys notatus*, plainfin midshipman prolarva, 19 mm TL (Wang 1986).

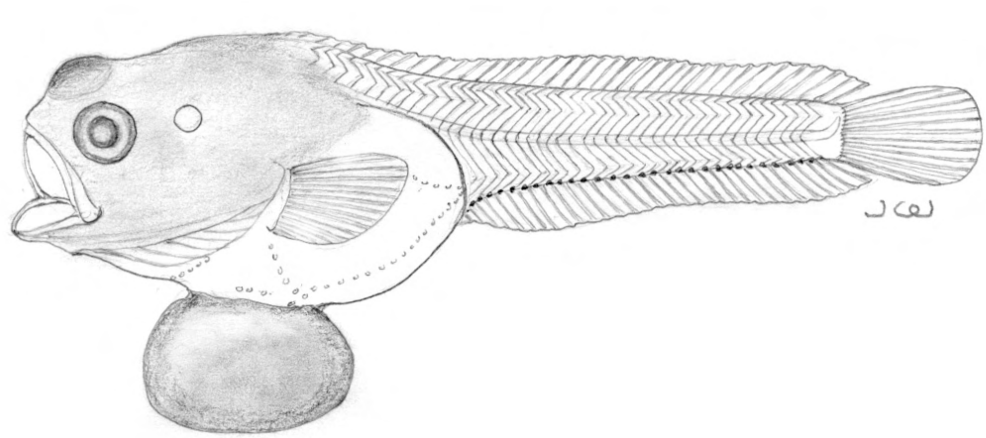


Figure 80.—*Porichthys notatus*, plainfin midshipman postlarva, 21.7 mm TL (Wang 1986

Mugilidae – Mullets — The striped mullet (*Mugil cephalus*) is the only species of mullet known to the freshwater and marine waters along the Pacific coast of California.

STRIPED MULLET *Mugil cephalus* Linnaeus

SPAWNING

Location	Warm water, worldwide; outer part of the Continental Shelf along the south Atlantic coast (Hubbs 1921b, Anderson 1958); near the coast of Taiwan in the Pacific Ocean (Tung 1961, Liao 1975); southern California coast (Sandknop and Watson 1996).
Season	All year round depending on the global location; fall months along the west coast of California (Sandknop and Watson 1996); may spawn more than once per season; usually starts from fall in the Northern Hemisphere and winter in the Gulf of Mexico (Moyle 2002); October to February on the south Atlantic coast (Anderson 1958).

Temperature	In the laboratory: 21–24.5°C (Liao 1969, 1975; Liao *et al*. 1970, 1971); 21–25°C (Tung 1970); oogenesis at 21°C (Kuo *et al.* 1974).
Salinity	Seawater but may spawn in freshwater (Johnson and McClendon 1970).
Substrate	Coastal water ~20 m in depth with fine sand bottom (T. Zhao 1987, personal communication).
Fecundity	From 760,000 (Higgins 1928) up to 7,200,000 (Nikolskii 1954); 1.2–2.8 millions of eggs (Thompson 1966).

EGGS

Shape	Spherical (Sanzo 1936, Tang 1964).
Diameter	~0.8–0.9 mm for specimens from Taiwan and Hawaii (Tang 1964, Liao 1975, Kuo *et al.* 1973); 0.74–0.82 mm for specimens from California (Sandknop and Watson 1996).
Yolk	Pale yellow to amber; homogenous (Sandknop and Watson 1996).
Oil globule	Single, ~0.3–0.4 mm for specimens from Taiwan and Hawaii (Liao 1975, Kuo *et al.* 1973); 0.28 mm for California specimens (Sandknop and Watson 1996).
Chorion	Transparent, with many fine wrinkles or fine striations (Sandknop and Watson 1996).
Perivitelline space	Very narrow.
Egg deposition	Spawned singly, pelagic.
Adhesiveness	None.
Buoyancy	Floats in seawater and brackish water; sinks in freshwater (Tang 1964).

LARVAE

Length at hatching	~2.2–2.5 mm TL (Sanzo 1936); 2.5–3.5 mm TL for laboratory hatched specimens in Taiwan (Liao 1969, 1975); 2.4–2.8 mm TL for the laboratory hatched specimens in Hawaii (Kuo *et al.* 1973); ~2.2 mm SL from southern California collection (Sandknop and Watson 1996).
Snout to anus length	~57% TL (Liao *et al.* 1970); ~55–60% TL for prolarvae (Wang and Kernehan 1979).
Yolk-sac	Large, oval extends from jugular to mid-abdominal region.
Oil globule	Single, large, used up within 2–5 d (Liao 1969, 1975); single, large, ~0.3 mm in diameter in newly-hatched larvae.
Gut	Straight.
Air bladder	Behind and above finbud.

Teeth	Uniserial, visible in late postlarvae or prejuvenile.
Size at absorption of yolk	~3.0–3.5 mm TL.
Total myomeres	24 (Sanzo 1936, Liao 1975).
Preanal myomeres	11 (Sanzo 1936, Liao 1975).
Postanal myomeres	13 (Liao 1975).
Last fin(s) to complete development	Pelvic (Sandknop and Watson 1996).
Pigmentation	Strongly pigmented (Sanzo 1936, Liao 1975); body silvery white ventrally (Liao 1975); dense stellate melanophores on head and body dorsally, less melanophores ventrally and more silvery.
Distribution	Pelagic in the warm waters of California coast; migrate toward coastal brackish water estuaries at 15–20 mm TL in early juvenile stage (Liao *et al.* 1970).

JUVENILES

Dorsal fin rays	IV–V + I, 6–8 (Miller and Lea 1972), IV, I, 8 (Moyle 2002).
Anal fin rays	III, 7–9 (Miller and Lea 1972); III, 6–8 (Sandknop and Watson 1996); III, 8–9 for adults, and II, 8–9 for juveniles (Moyle 2002).
Pectoral fin rays	14–18 (Sandknop and Watson 1996); 16–17 (Moyle 2002).
Mouth	Terminal, small (Moyle 2002).
Vertebrae	24 (Thompson 1966, Miller and Lea 1972).
Distribution	Warm waters of southern California coast; common in San Diego Bay, New Port Bay and adjacent rivers and estuaries; juveniles migrate into San Francisco Bay during El Niño years (Moyle 2002); juveniles were captured at the SWP/SDFPF and the CVP/TFCF during those El Niño years.

LIFE HISTORY

Striped mullet is a warmwater species found worldwide. In the eastern Pacific, it is known from the Galapagos Islands to Monterey, including the Gulf of California (Miller and Lea 1972). Juvenile striped mullet were first recorded at the SWP/SDFPF in the winter months of 1977 (Quelvog 1977). It is often found in the San Francisco Bay during El Niño years (Moyle 2002). Juveniles and a few subadults were also collected at the SWP/SDFPF and the CVP/TFCF during the period 1997–2000 (Morinaka 1998; J. Morinaka 2000–2007, personal communication).

Striped mullet is a catadromous species that spawns in offshore waters worldwide and year round depending on location. Striped mullet eggs and larvae are pelagic and neustonic (Zaitsev 1970), the larvae drift toward coastal waters by current. Eventually, juveniles enter brackish waters or freshwater environments, such as coastal rivers and estuaries in temperate and warm water regions. Information on the life history of striped mullet along the California coast is limited at present time (Moyle 2002). Johnson and McClendon (1970) reported a catadromous striped mullet population in the Gulf of California. Based on the collection of small juveniles (26.5–30.0 mm TL) in the Delta in winter during El Niño years (*e.g.*, 1998), offspring from this catadromous population probably hatched in fall in southern California waters and migrated northward when cold currents moved away from the California coast.

Juvenile striped mullet feed mainly on sediment particles containing high organic matters such as detritus, diatoms, bacteria, and microinvertebrates. A striped mullet's digestive system is equipped with powerful jaws (maxillary) and a gizzard stomach for grinding up hard particles and sorting out nutrients (Odum 1968).

Striped mullet fisheries are very important to Asian countries. Striped mullet roe (ovaries harvested at near mature stage) is a delicacy that carries a high price similar to sturgeon caviar. Striped mullet is also a desirable species in both freshwater and brackish water polyculture (T. Zhao 1987, personal communication). To determine ways to meet market demand, striped mullet biology (with emphasis on natural mode of migration, time of harvesting, artificial propagation, and stocking) was investigated extensively by biologists in Taiwan[2]. Most of this research was conducted between 1960 and 1975 and the consolidated results of these efforts were transferred into applicable science.

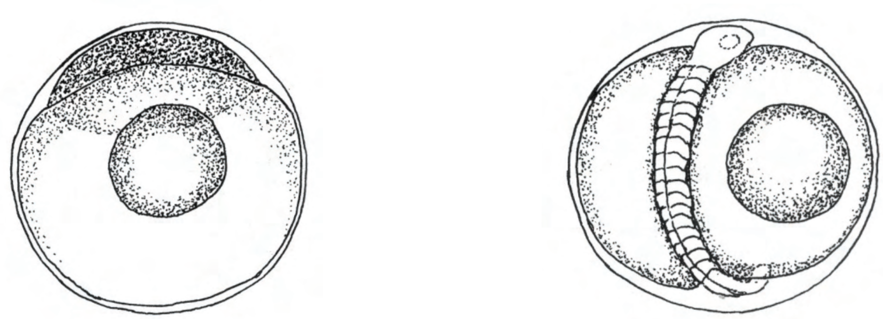


Figure 81.—*Mugil cephalus*, striped mullet embryo, morula (left) and early embryo (right) (Wang and Kernehan 1979).

[2]Tung, Ih-Hsiu (biologist, Taiwan); Tang, Yun-An (professor, Taiwan); Liao, I-Chiu (academician/professor, Taiwan); Kuo, Ching-Ming (professor, Taiwan, post-graduate worked on striped mullet biology in Hawaii).

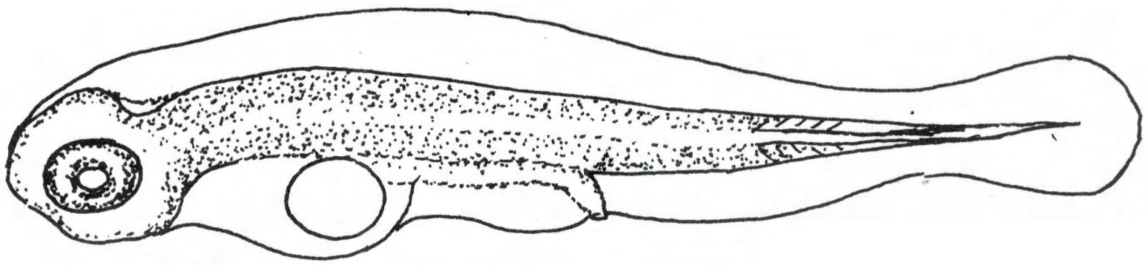


Figure 82.—*Mugil cephalus*, striped mullet prolarva, 25–30 hours after hatching (Wang and Kernehan 1979).

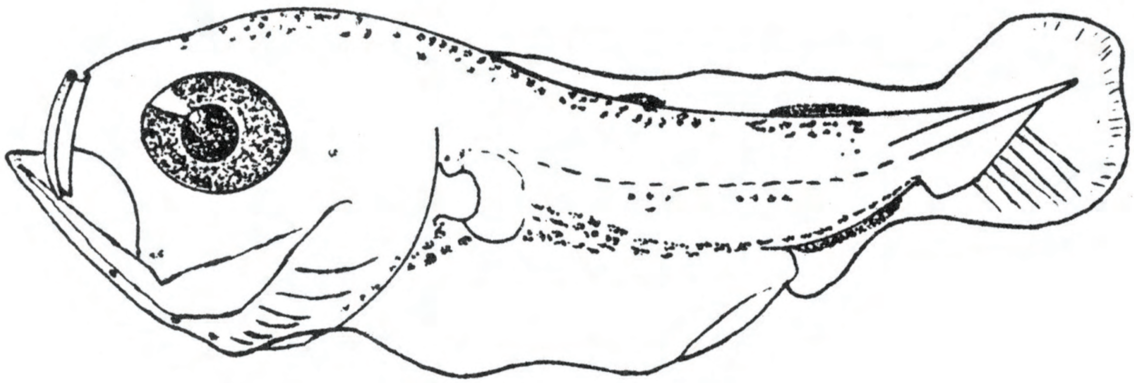


Figure 83.—*Mugil cephalus*, striped mullet postlarva, 4.0 mm TL (Anderson 1958).

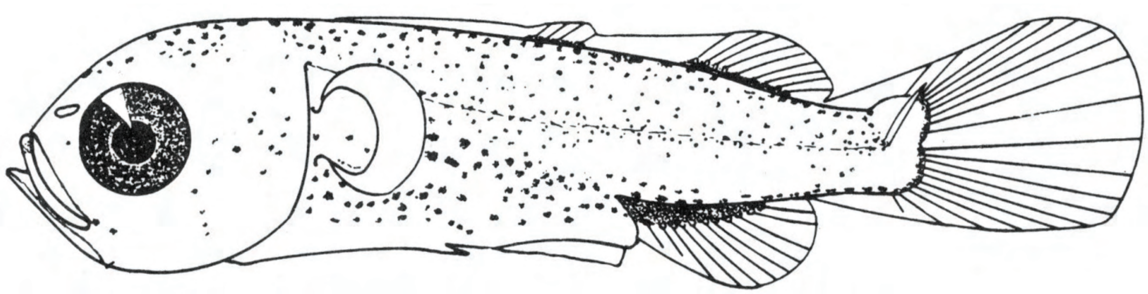


Figure 84.—*Mugil cephalus*, striped mullet prejuvenile, 6.7 mm TL (Anderson 1958).

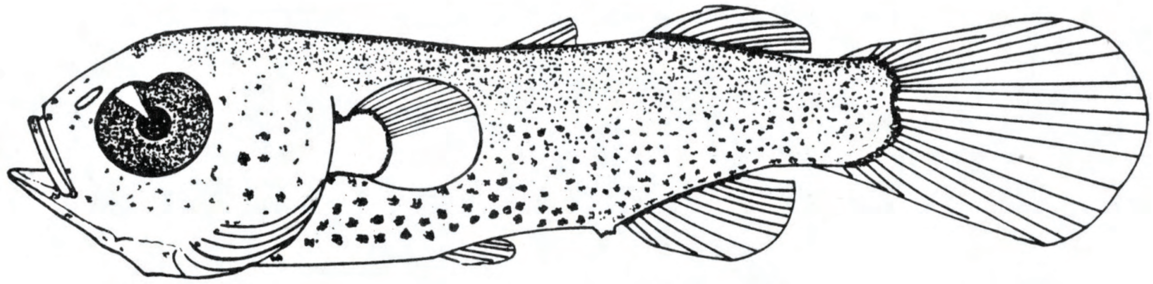


Figure 85.—*Mugil cephalus*, striped mullet prejuvenile, 7.9 mm TL (Anderson 1958).

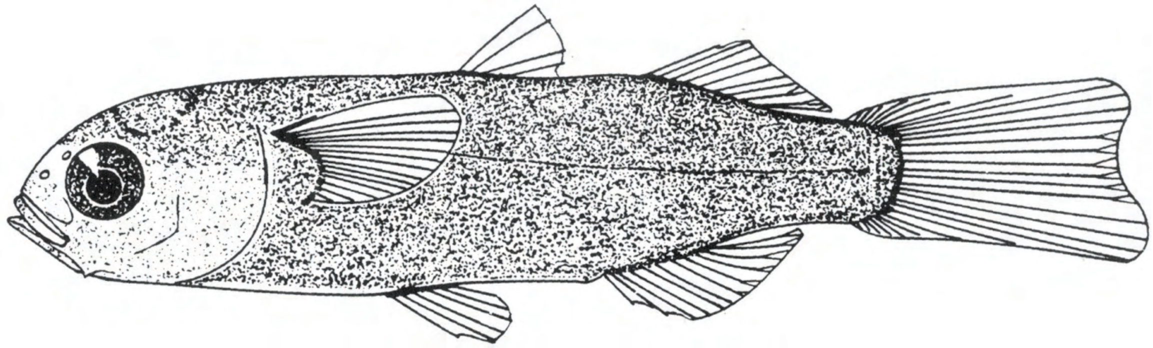


Figure 86.—*Mugil cephalus*, striped mullet prejuvenile, 12.1 mm SL (Anderson 1958).

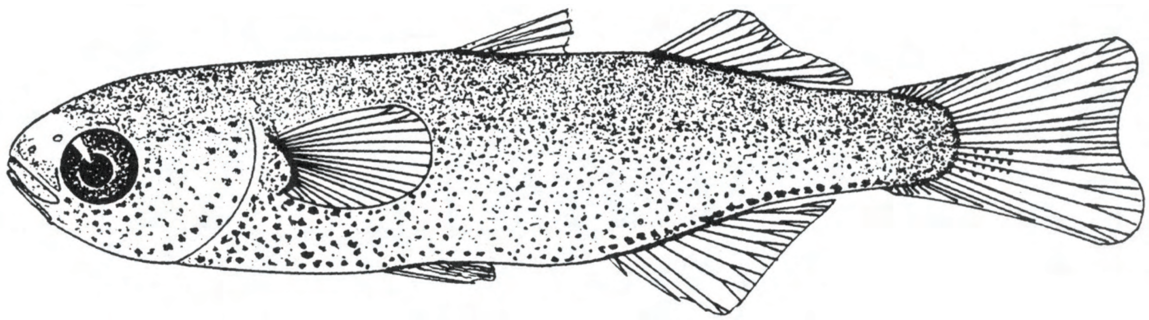


Figure 87.—*Mugil cephalus*, striped mullet prejuvenile, 19.8 mm SL (Anderson 1958).

Atherinopsidae – New World Silversides.— Four species of New World Silversides are found in the Sacramento-San Joaquin system. Three are native to the California coast: topsmelt (*Atherinops affinis*), an estuarine species; jacksmelt (*A. californiensis*), normally a coastal marine species but also collected in bays and estuaries; California grunion (*Leuresthes tenuis*), a coastal marine species. California grunion has recently returned to San Francisco Bay after a long absence (Tenera Environmental, Inc., sampling, 2005). Inland silverside (*Menidia beryllina*) is an introduced freshwater species widely distributed in California. All four species are discussed in this chapter.

TOPSMELT *Atherinops affinis* (Ayres)

SPAWNING

Location	Along the Pacific coast, in San Francisco Bay, and upstream to mesohaline portion of the estuary. Particular locations include Alviso salt pond (Carpelan 1955), Aquatic Park (Berkeley, California), vicinity of Richmond Harbor (L. Grimaldo 1998, 2003, personal communication), Oleum Powerplant of San Pablo Bay, Lake Merritt (Oakland, California), intake pond of Hunters

	Point Powerplant, San Mateo Bridge of south San Francisco Bay, and Tomales Bay.
Season	March–August (Carpelan 1955); spring–early fall (Feder *et al.* 1974); March–September (Watson 1996a); March–October (Moyle 2002); April–October.
Temperature	~20°C (Carpelan 1955); ~10–25°C in Aquatic Park (Wang 1986); 13–17°C (Middaugh and Shenker 1988, Emmett *et al.* 1991).
Salinity	Up to twice that of ocean water or up to 72 ppt (Carpelan 1955); 30 ppt (Middaugh and Shenker 1988); mainly seawater and polyhaline.
Substrate	Marine plants (Bane and Bane 1971); salty water algae and plants.
Fecundity	200–1,000/batch (Emmett *et al.* 1991).

EGGS

Shape	Spherical.
Diameter	1.5–1.7 mm.
Yolk	Amber in color, granular.
Oil globule	Usually consolidated in one, up to 0.5 mm in diameter (Watson 1996a); one single large oil globule.
Chorion	Transparent, thick, ~2–8 filaments attached to chorion in random pattern of San Francisco Bay population (Wang 1986); 5–13 filaments (Watson 1996b).
Perivitelline space	Very narrow.
Egg deposition	Deposited singly on blades or stems of vegetation, where the chorion filaments become entangled with other eggs sometimes forming a cluster.
Adhesiveness	None for egg chorion; chorion filaments entangle themselves to substrates.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	4.3–4.9 mm TL (Wang 1986); 4.3–5.4 mm SL (Watson 1996a).
Snout to anus length	30–35% TL for prolarvae, increasing to ~35– 43% TL for postlarvae.
Yolk-sac	Spherical, in thoracic region.
Oil globule	Single, small.
Gut	Very short.
Air bladder	Oval, small, behind pectorals.

Teeth	Small, pointed in postlarvae.
Size at absorption of yolk	~7.0 mm TL.
Total myomeres	42–48 in San Francisco Bay specimens (Wang 1986); 44–50 (Watson 1996a).
Preanal myomeres	13–16 (Wang 1986); 10–13 (Watson 1996a).
Postanal myomeres	27–33 (Wang 1986); 34–37 (Watson 1996a).
Last fin(s) to complete development	Spiny dorsal fin.
Pigmentation	Very large stellate melanophores are present in a single row from snout to cephalic and middorsal regions; a few melanophores present on midventral region. Large melanophores are also found on sides of gut. A series of melanophores are present along postanal region midventrally. Dashed melanophores are present along median myosepta.
Distribution	Pelagic, on surface of water column, inshore to open water in San Pablo Bay, San Francisco Bay, and along Pacific coast; rare in Napa River and Suisun Bay.

JUVENILES

Dorsal fin rays	V –IX, I, 8–14 (Miller and Lea 1972, Moyle 1976).
Anal fin rays	I, 19–25 (Miller and Lea 1972, Moyle 1976).
Pectoral fin rays	13 (Miller and Lea 1972, Moyle 1976); 13–15.
Mouth	Small, oblique (Moyle 1976); terminal, small, oblique.
Vertebrae	45–52 (Miller and Lea 1972); 45–49 in San Francisco Bay (Wang 1986); 44–52 (Watson 1996a).
Distribution	San Francisco Bay upstream to Suisun Bay (Baxter *et al.* 1999); shallow inshore waters from coast to San Francisco Bay and up to Suisun Bay and Napa River.

LIFE HISTORY

The range of topsmelt extends from the Gulf of California to Vancouver Island, British Columbia (Hart 1973, Miller and Lea 1972). Of three subspecies described by Schultz (1933) within the range, only topsmelt inhabits the estuarine waters of the Sacramento-San Joaquin system and adjacent coast. In San Francisco Bay, this species is particularly abundant in shallow waters of south San Francisco Bay (Baxter *et al.* 1999) and, in recent years, at the Crown Memorial State Beach in Alameda (D. Mayer 2008, personal communication). Locally topsmelt emigrate to Pacific coastal water in winter (Baxter *et. al* 1999); the population found in Newport Bay, however, may remain in the bay all year round (Frey 1971).

Topsmelt has a prolonged spawning period from April through October, with different peaks occurring in San Pablo Bay, central San Francisco Bay, and south San Francisco Bay (Baxter *et al.* 1999). Observations of various sized ova within individuals indicate that eggs may be deposited more than once during a single spawning season.

Spawning takes place in vegetated areas where filaments on the eggs become entangled with substrates. Hatching may occur over a wide range of salinities (Carpelan 1955). Spawning was observed in Aquatic Park (Berkeley, California) vicinity of the Richmond Harbor, and south San Francisco Bay from the Crown Memorial State Beach to Dumbarton Bridge. Topsmelt larvae are particularly abundant in land-locked basins fed by water from the bay, such as Aquatic Park and Lake Merritt (Oakland, California) basins. Collections of larvae and early juveniles in the Napa River and Suisun Bay (mainly in dry years) suggest that spawning may also occur in San Pablo Bay (CDFG striped bass E and L survey, 1988–1995; CDFG 20-mm fish survey at Napa River, 1995–2005).

Juvenile topsmelt gradually move from inshore shallow waters into open waters. Some may ascend into Suisun Bay and the lower Napa River in summer and early fall months as a salt wedge moves to the upper reaches of Suisun Bay (Wang 1986, Baxter *et al.* 1999). Juvenile topsmelt apparently can tolerate lower saline water; they were found in salinities between 0 and 10 ppt in Navarro River (Moyle 1976) and in freshwater as far upstream as Sherman Island (CDFG striped bass E and L survey, June 1989). As winter approaches, some juveniles emigrate to coastal waters and others move to higher saline waters of central and south San Francisco Bay (Baxter *et al.* 1999).

Topsmelt juveniles feed on small crustaceans (Feder *et al.* 1974), diatoms, filamentous algae, detritus, chironomid larvae, and amphipods (Moyle 1976). Topsmelt mature in their second year and may live up to 6–9 years (Schultz 1933, Feder *et al.* 1974). This species is among the most abundant of the atherinopsids in San Francisco Bay and has been used both as human food and bait fish.

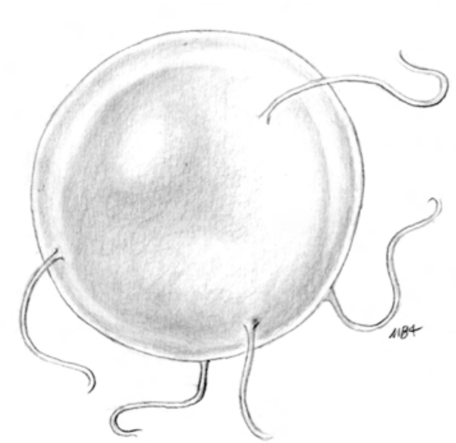


Figure 88.—*Atherinops affinis*, topsmelt egg, 1.4 mm (Wang 1986).

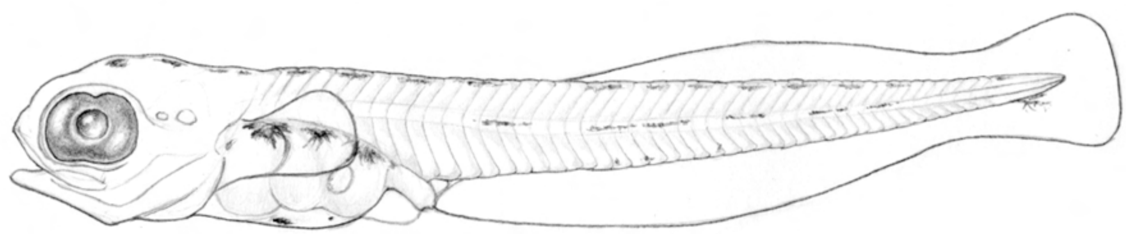


Figure 89.**—***Atherinops affinis*, topsmelt postlarva, 5 mm TL (Wang 1986).

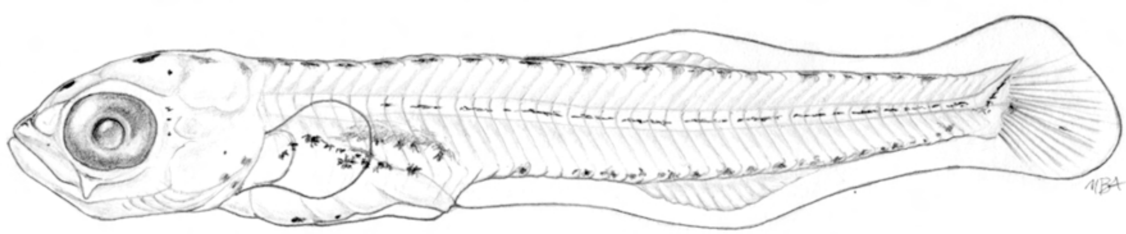


Figure 90.**—***Atherinops affinis*, topsmelt postlarva, 10 mm TL (Wang 1986).

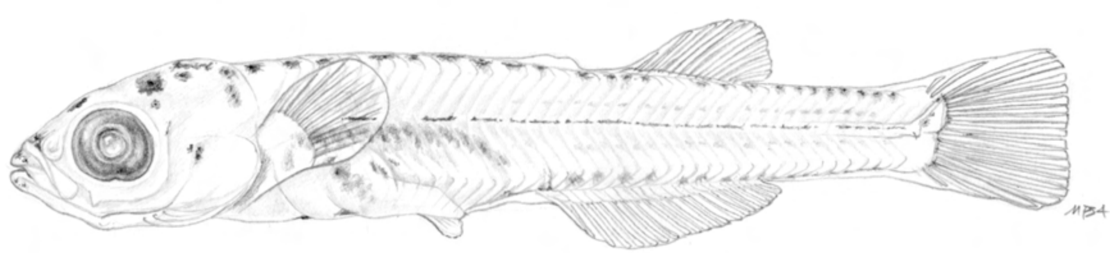


Figure 91.—*Atherinops affinis*, topsmelt prejuvenile, 14 mm TL (Wang 1986).

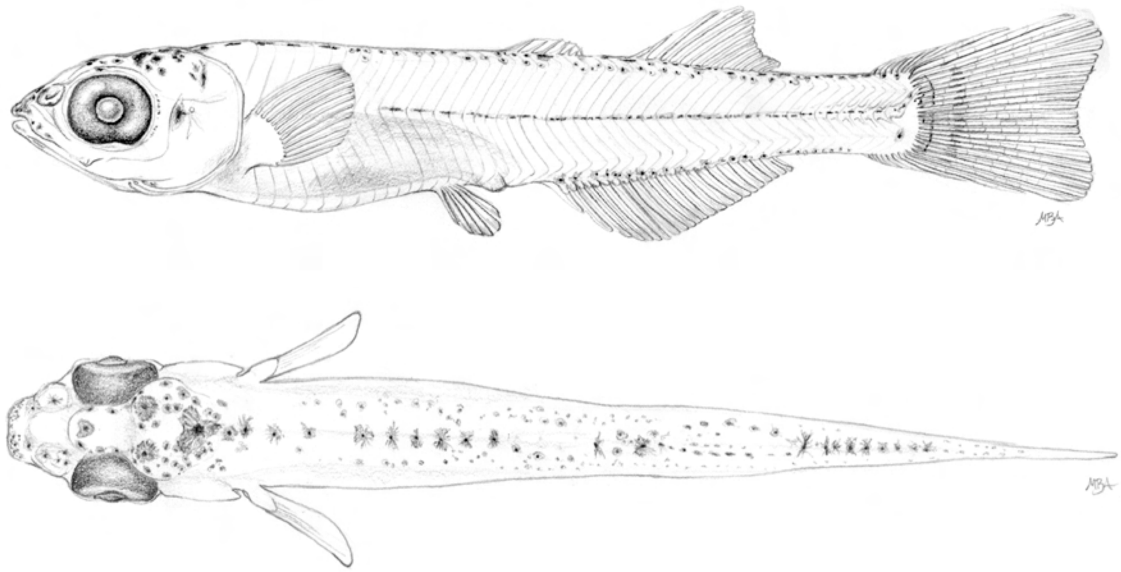


Figure 92.—*Atherinops affinis*, topsmelt juvenile, lateral and dorsal views, 18.7 mm TL (Wang 1986).

JACKSMELT *Atherinopsis californiensis* Girard

SPAWNING

Location	Shallow coastal waters in bays and estuaries such as San Pablo Bay (Ganssle 1966), San Francisco Bay (Paradise Cove and Richardson Bay), San Pablo Bay, and Tomales Bay (near Marshall).
Season	October–March (Clark 1929); October–April, primarily November through March (Watson 1996a); throughout the year in southern California (Feder *et al.* 1974); September–April (Ganssle 1966); all year round in San Francisco Bay (Baxter *et al.* 1999); mainly in October–early August.
Temperature	10°C and greater (Wang 1986); based on collections of larval jacksmelt, spawning may occur at ~6.0–8.0°C (Baxter *et al.* 1999).
Salinity	Seawater–polyhaline; may occur in mesohaline water.
Substrate	Seaweed (Baxter *et al.* 1999); algae, plants, and hydroids.

EGGS

Shape	Spherical.

Diameter	Mature eggs 0.9–2.2 mm (Clark 1929); fertilized eggs collected from San Francisco Bay and Tomales Bay were 1.9–2.5 mm.
Yolk	Yellowish orange (Bane and Bane 1971); yellowish orange to rusty brown, granular.
Oil globules	23–44 (Watson 1996a); many oil globules, tending to consolidate into one oil globule prior to hatching.
Chorion	Transparent, thick, hard; 15–16 filaments 1–2 cm long are attached to chorion in random pattern (Wang 1986); 12- to 20-cm-long filaments scattered over chorion (Watson 1996a); numbers of chorion filaments vary, <10 egg filaments observed in Richardson Bay, 2004.
Perivitelline space	Very narrow in early and late embryo stages.
Egg deposition	Released in the vicinity of aquatic vegetation and hydroids; the filaments become entangled with substrate stems and blades and form large clusters.
Adhesiveness	None from chorion; coiled filaments are not adhesive but may be tangled to plants or to each other.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	7.5–8.6 mm TL (Wang 1986); 6–9 mm SL (Watson 1996a).
Snout to anus length	30–33% TL for prolarvae, increasing to ~40% TL for postlarvae.
Yolk-sac	Spherical; at the thoracic region.
Oil globule	Single, 0.4–0.6 mm in diameter, usually located in anterior of yolk-sac.
Gut	Very short, bending in anal region.
Air bladder	Oval, small, behind the pectorals.
Teeth	Small, pointed, in postlarvae.
Size at absorption of yolk	9.5–10.0 mm TL.
Total myomeres	49–53.
Preanal myomeres	12–14.
Postanal myomeres	37–39.
Last fin(s) to complete development	Spiny dorsal fin.
Pigmentation	A few very large stellate melanophores present on snout and cephalic regions, a single row of widely-spaced melanophores present middorsally. Large melanophores on side of gut and air bladder, and dashed melanophores in lateral region.

Distribution	Larvae are pelagic and found inshore and in open waters; occupy upper strata of water column; collected from seawater and freshwater near the confluence of the Sacramento and San Joaquin Rivers (Wang and Reyes 2007; Ecological Analysts, Inc., 1978–1982).

JUVENILES

Dorsal fin rays	V–IX, I, 11–14 (Miller and Lea 1972).
Anal fin rays	I, 21–26 (Miller and Lea 1972).
Pectoral fin rays	15 (Wang 1986).
Mouth	Terminal, small, oblique.
Vertebrae	50–54 (Miller and Lea 1972).
Distribution	Shallow coastal waters (Boothe 1967); San Francisco Bay (Baxter 1960, Aplin 1967); San Pablo Bay (Ganssle 1966); Carquinez Strait (Messersmith 1966); some ascend to the Napa River (CDFG 20-mm fish survey); Suisun Bay to the vicinity of Pittsburg and Contra Costa Powerplants (Ecological Analysts, Inc., 1978–1982; Baxter *et al.* 1999; Wang and Reyes 2007).

LIFE HISTORY

Jacksmelt range from Santa Monica Bay, Baja California, to Yaquina Bay, Oregon (Miller and Lea 1972). This species is usually found within a few kilometers of shore (Boothe 1967). In the estuarine waters of the Sacramento-San Joaquin system, jacksmelt are commonly collected in salinities ranging from seawater to mesohaline (Ganssle 1966, Messersmith 1966, Aplin 1967); some larvae and juveniles ascend to oligohaline water and freshwater in the upper estuary.

Large clumps of jacksmelt eggs have been observed on the intake screens of Potrero, Hunters Point, and Oleum Powerplants (south San Francisco Bay and San Pablo Bay) mainly during winter months (Ecological Analysts, Inc., 1978–1982), indicating that bays and estuaries are important spawning grounds for this species. Egg masses were found tangled with hydroids on the ocean beach near Rodeo Lagoon, attached to eel grass along Paradise Beach of central San Francisco Bay, and near the town of Marshal by Tomales Bay. No egg masses were found in Suisun Bay. Jacksmelt eggs and Pacific herring eggs were collected from the same patch of algae growing near the high tide mark at Richardson Bay Park in January 2004. Apparently jacksmelt eggs can tolerate being out of water during low tides.

Eggs in early embryo stages hatched in the laboratory at 10–12°C in polyhaline water (Wang 1986). Jacksmelt eggs collected from Rodeo Lagoon (swept from the ocean) hatched in salinities ~5–20 ppt showing that jacksmelt can spawn successfully in mesohaline water or lower. In the laboratory, newly-hatched larvae initially remained on the bottom for 1–2 d before actively swimming near the nueston. Jacksmelt larvae were often collected from Suisun Bay to the west Delta during spring months, likely carried there from San Pablo Bay by high tide (CDFG fish E and L survey, 1988–1995; Wang and Reyes 2007).

Jacksmelt can spawn several times during a spawning season (Clark 1929). Based on collections of larval jacksmelt throughout the year from San Francisco Bay, Baxter *et al.* (1999) concluded that spawning occurs all year with two peaks, one January to February the other in September. They also noted that locations of and peaks of spawning may change from year to year. In the Moss Landing area, samples collected in the harbor and in Elkhorn Slough contained large numbers of jacksmelt larvae in winter and spring months suggesting that coastal embayment and estuaries serve as spawning grounds and as protective nursery grounds.

Jacksmelt juveniles form large schools and often mix with topsmelt (Bane and Bane 1971). They are common in the open waters of the San Pablo Bay (Ganssle 1966) and San Francisco Bay (Baxter *et al*. 1999, Aplin 1967), and seem to be more abundant in south San Francisco Bay (Baxter *et al.* 1999). Juvenile jacksmelt venture into oligohaline waters, perhaps seeking other nursery grounds. Adults, however, seldom visit these areas. Juveniles may remain in the estuary all year round, or some may move to shallow coastal waters similar to topsmelt (Boothe 1967).

Principal food items for juvenile jacksmelt include algae and small crustaceans (Bane and Bane 1971). Stomach analyses indicated that amphipods are also a common food item, suggesting that juvenile jacksmelt may feed near bottom (Wang 1986).

Jacksmelt mature in 2–3 years at about 20 cm TL, and may live for 9–10 years (Clark 1929). Commercially, the jacksmelt is harvested along with topsmelt for human consumption. Jacksmelt is also a forage species for many fish species and birds (Bane and Bane 1971) and the species is also used as food for aquatic birds and marine mammals in zoos and theme parks.

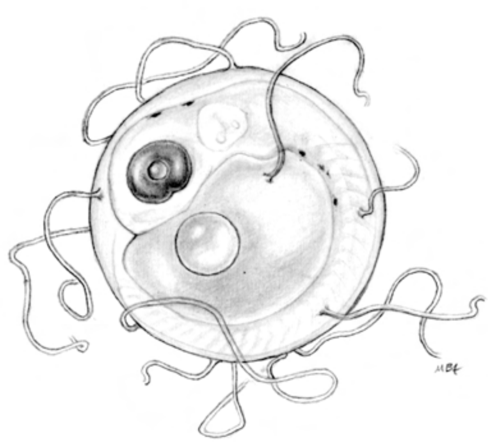


Figure 93.—*Atherinopsis californiensis*, jacksmelt late embryo, 1.8 mm (Wang 1986).

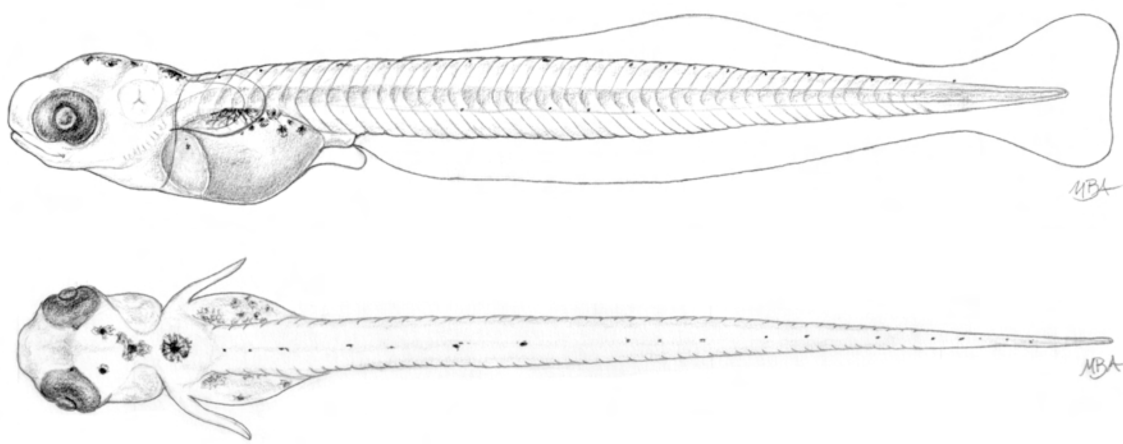


Figure 94.—*Atherinopsis californiensis*, jacksmelt prolarva, lateral and dorsal views, 9.3 mm TL (Wang 1986).

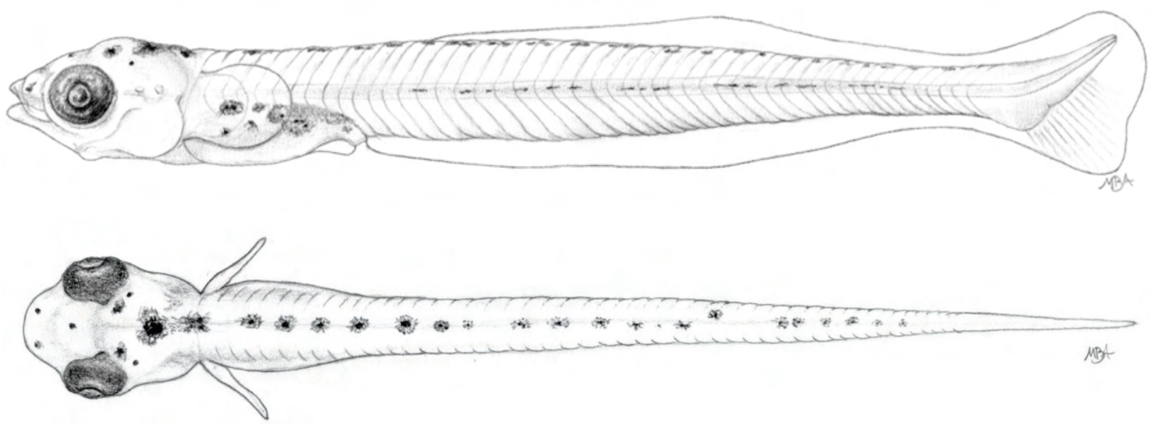


Figure 95.—*Atherinopsis californiensis*, jacksmelt postlarva, 12.8 mm TL (Wang 1986).

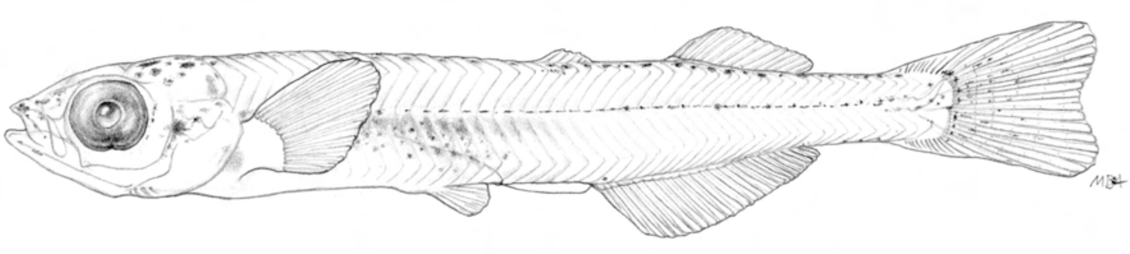


Figure 96.—*Atherinopsis californiensis*, jacksmelt juvenile, 35 mm TL (Wang 1986).

CALIFORNIA GRUNION *Leuresthes tenuis* (Ayres)

SPAWNING

Location	Sandy beaches along the southern California coast up to San Francisco Bay.
Season	March–August (Thompson and Thompson 1919); March–August, peaking in April and May (Watson 1996a).
Temperature	24.8–26.8°C (Hubbs 1965).
Salinity	Seawater; polyhaline in bays.
Substrate	Sandy beaches.
Fecundity	1,400–2,200/spawn (Thompson and Thompson 1919); ~3,000/spawn (Fitch and Levenberg 1975).

EGGS

Shape	Spherical.
Diameter	Mature eggs 1.0–1.1 mm (Clark 1925); 1.5–1.6 mm (David 1939); 1.8–2.2 mm (Moffatt and Thomson 1978); 1.6–1.9 mm (Wang 1986).
Yolk	Yellow-green, clear (David 1939).
Oil globule	23–115 small oil globules, decreasing as development proceeds and eventually consolidating into one large oil globule that is ~0.5 mm in diameter in newly-hatched yolk-sac larvae (David 1939).
Chorion	Clear, no chorion filaments (Clark 1925, David 1939, Hubbs 1965); transparent, smooth.
Perivitelline space	~0.2–0.5 mm in early developmental stages (David 1939).
Egg deposition	Deposited in clusters (David 1939).
Adhesiveness	None (Hubbs 1965).
Buoyancy	Negatively buoyant or demersal (David 1939).

LARVAE

Length at hatching	6.5–6.7 mm TL (David 1939).
Snout to anus length	30–35% TL for prolarvae and early postlarvae, increasing to 35–40% TL for postlarvae.
Yolk-sac	Spherical to oval, in thoracic region.
Oil globule	Single, usually located anteriorly in yolk-sac (David 1939).
Gut	Very short.
Air bladder	Oval, small, near and behind pectorals.
Teeth	None.

Size at absorption of yolk	~7.0 mm TL.
Total myomeres	44–45 (David 1939); 44–48.
Preanal myomeres	9–12.
Postanal myomeres	32–36.
Last fin(s) to complete development	Spiny dorsal fin.
Pigmentation	Very large stellate melanophores present on snout and cephalic region, a single row of very large stellate melanophores present middorsally, and dashed melanophores present midlaterally. Scattered melanophores are also found in postanal region and caudal region in late postlarvae. No pigmentation midventrally.
Distribution	Pelagic in southern California coastal waters and occasionally found near Point Concepcion and the vicinity of Moss Landing Harbor. Larvae have been observed in the vicinity of Crown Memorial State Beach of San Francisco Bay in recent years (A. Jahn 2004, personal communication).

JUVENILES

Dorsal fin rays	V–VII; I, 9–10 (Miller and Lea 1972); III–VII, I, 8–10 (Watson 1996a).
Anal fin rays	I, 21–24 (Miller and Lea 1972); I, 20–24 (Watson 1996a).
Pectoral fin rays	12–15 (Watson 1996a); 13–15.
Mouth	Terminal or slightly subterminal.
Vertebrae	47–50 (Miller and Lea 1972); 46–47.
Distribution	Mainly, the juvenile grunion population is concentrated along the coastal waters of southern California (Clark 1925, David 1939); postlarvae and juveniles are found in Moss Landing Harbor, Elkhorn Slough, and Morro Bay (Fitch and Lavenberg 1975); this species has returned to the San Francisco Bay in recent years.

LIFE HISTORY

There have been conflicting reports concerning the northern limits of California grunion distribution along the California coast. Miller and Lea (1972) recorded its distribution from Magdalena Bay northward to San Francisco Bay even though it had not been reported from San Francisco Bay, Tomales Bay, or Bodega Bay since the 1940s (Aplin 1967, Ganssle 1966, Bane and Bane 1971, Standing *et al.* 1975). Miller and Lea (1972) may have made an erroneous range report based on information provided to them of the sale of grunion in San Francisco fish markets; it was subsequently determined that the California grunion in question were actually shipped from Monterey Bay (L. Dampster

1985, personal communication). However, reports of California grunion along Crown Memorial State Beach (Alameda County) in recent years (A. Jahn 2004 and C. Raifsnider 2003–2008, personal communication) actually supports Miller and Lea's original claim that the species's northernmost distribution includes San Francisco Bay.

The spawning behavior and early life history of California grunion are well documented (Thompson and Thompson 1919, Clark 1925, David 1939, Hubbs 1965). Spawning occurs on sandy beaches in spring and summer, shortly after a full or new moon. The fish are carried to the high tide mark by surf, the females deposit their eggs in the sand, and the males extrude milt into the surrounding sand. The eggs incubate in warm sand and hatch approximately 15 d later during the following series of high tides. If the eggs are not exposed by those high tides, they may remain viable until the next series of high tides, up to about 22–25 d after spawning (Fitch and Lavenberg 1975). California grunion may produce four to eight batches of eggs during a single spawning period (Clark 1929). Their spawning habits, synchronization with the lunar cycle and tides and egg burying, make this species unique among marine fishes.

California grunion larvae are washed into the surf during high tide soon after hatching. The larvae immediately begin swimming on the surface along the coast (David 1939) and in bays. As juveniles, California grunion school in shallow coastal water, usually a few kilometers from the shore and feed on planktonic organisms (Fitch and Lavenberg 1975).

California grunion is a highly prolific species (~3,000 eggs/batch). Reproduction begins at age 1, and females continue to spawn for two more years (Clark 1925). This species is vulnerable during its spawning runs; therefore, take or capture by the public has been prohibited by CDFG (since 1927) during their peak spawning period (April through May) and collections are permitted during the open season only by hand.

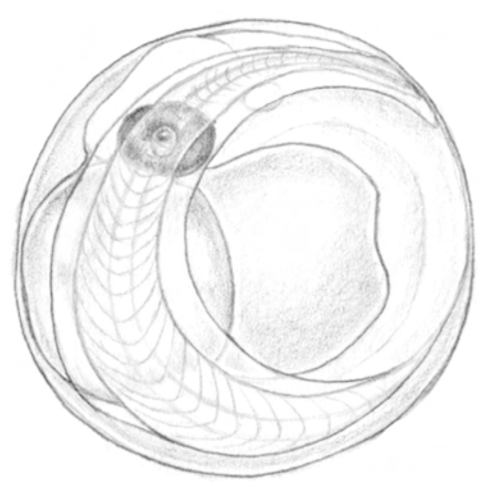


Figure 97.—*Leuresthes tenuis*, California grunion late embryo, 1.6 mm (Wang 1986).

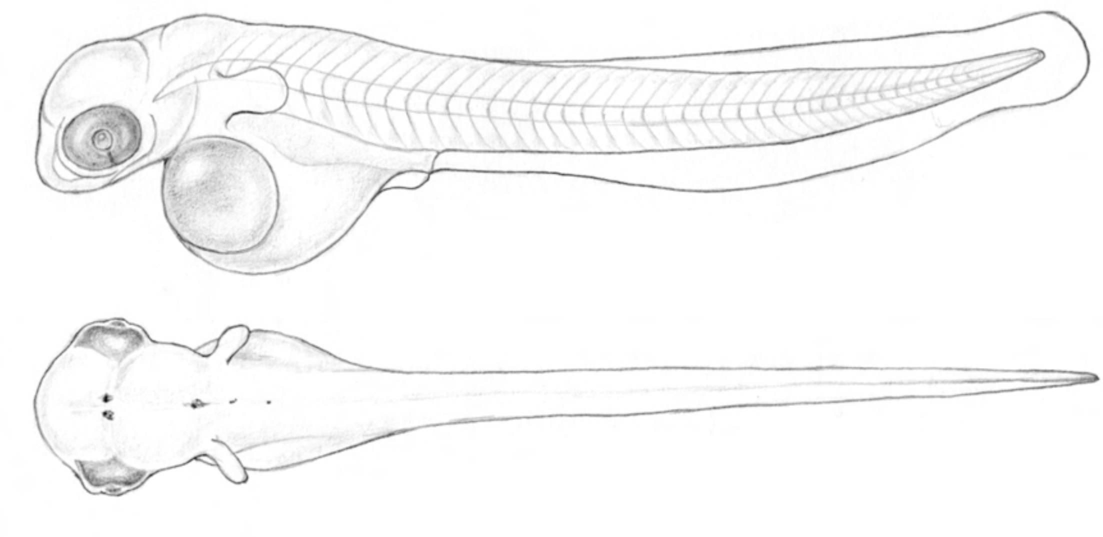


Figure 98.—*Leuresthes tenuis*, California grunion prolarva, lateral and dorsal views, 7.8 mm TL (Wang 1986).

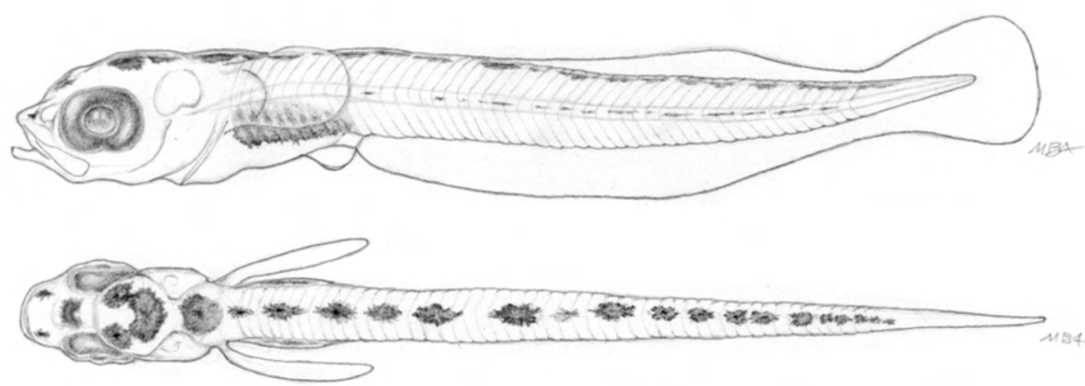


Figure 99.—*Leuresthes tenuis*, California grunion postlarva, 7.8 mm TL (Wang 1986).

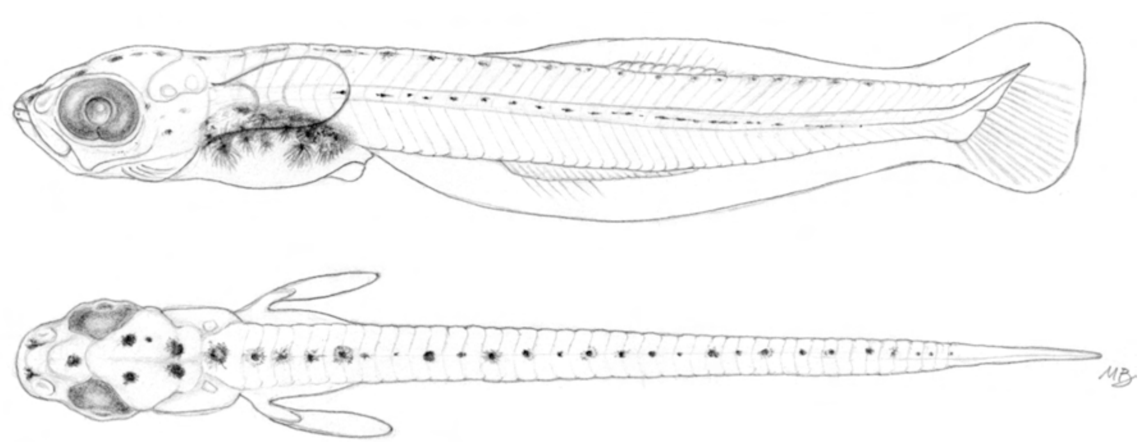


Figure 100.—*Leuresthes tenuis*, California grunion postlarva, 10 mm TL (Wang 1986).

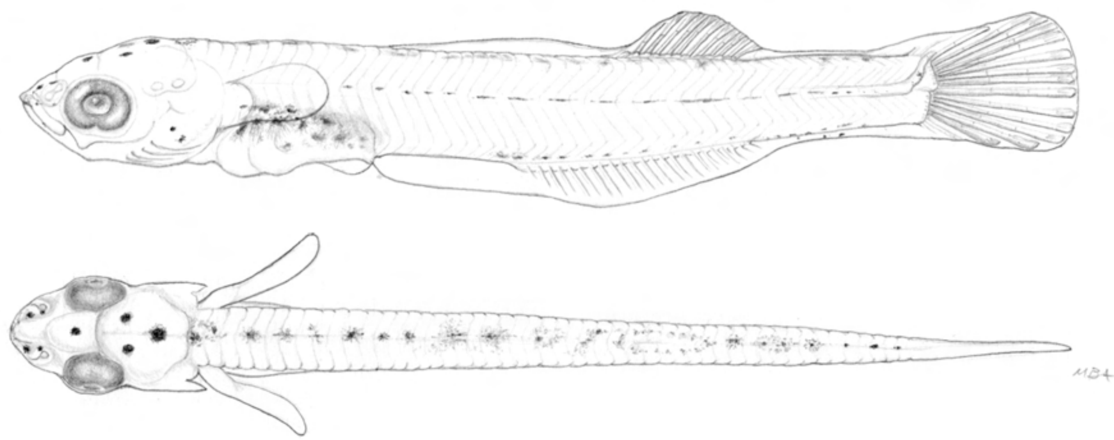


Figure 101.**—***Leuresthes tenuis*, California grunion postlarva, lateral and dorsal views, 13 mm TL (Wang 1986).

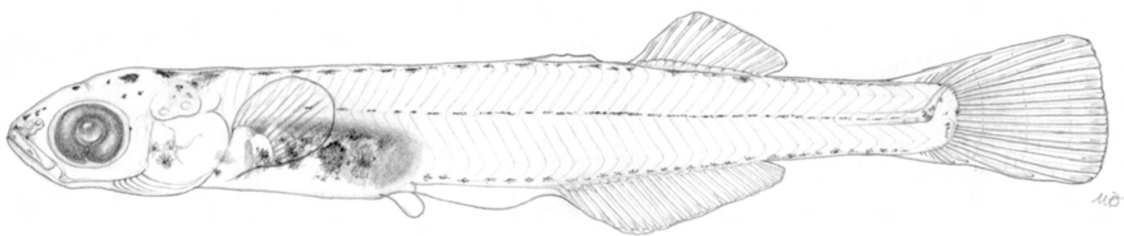


Figure 102.**—***Leuresthes tenuis*, California grunion prejuvenile, 15 mm TL (Wang 1986).

INLAND SILVERSIDE *Menidia beryllina* (Cope).

SPAWNING

Location	Tidal freshwater (Wang 1974); shallow weedy freshwaters in the Delta, tributaries, and reservoirs. Specific locations: Wilson Slough, vicinity of Contra Costa and Pittsburg Powerplants, Contra Loma Reservoir, Antioch Municipal Reservoir, North Bay Aqueduct (Barker Slough), Marsh Creek, Montezuma Slough, Putah Creek, Cosumnes River, Napa River, Sonoma Creek, Clifton Court Forebay, CVP/TFCF, and San Luis Reservoir.
Season	May–August (Moyle 1976); April–September (Wang 1986); March–August (Rockriver 1998).

Temperature	13.2–34.2°C; optimum temperature 20–25°C (Hubbs *et al.* 1971); 16–30.5°C (Wang and Kernehan 1979).
Salinity	Freshwater and oligohaline (Hubbs *et al.* 1971); mainly in freshwater.
Substrate	Aquatic vegetation, inundated terrestrial plants, and tree roots (Hubbs *et al.* 1971, Fisher 1973); cattail, tules, and dead plant stem and leaves.
Fecundity	200–2000/d for at least 3 months (Hubbs 1982).

EGGS

Shape	Spherical.
Diameter	0.8–0.9 mm (Wang and Kernehan 1979); 0.8–1.2 mm (Wang 1986).
Yolk	Pale yellow, coarse, granular.
Oil globule	1–3 oil globules, each ~0.2–0.3 mm in diameter, tend to consolidate into a single oil globule prior to hatching.
Chorion	Transparent, with 1–3 chorion filaments, ~1–2 cm long, tangled to each other (Wang 1986); 1 large and 5 or more thin filaments attached to chorion for east coast population (Wang and Kernehan 1979).
Perivitelline space	0.1–0.2 mm in width.
Egg deposition	Deposited singly, eggs become entangled on substrates by chorion filaments and form clusters.
Adhesiveness	Chorion filament adhesive.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	3.5–4.0 mm TL (Wang 1974); 3.5–4.2 mm TL.
Snout to anus length	26–30% TL for prolarvae and early postlarvae, and 28–34% TL for 8.0–11.0 mm TL postlarvae.
Yolk	Spherical, in jugular-thoracic region.
Oil globule	Mainly single, ~0.2–0.3 mm in diameter.
Gut	Extremely short (Taber 1969); very short, bending vertically in anal region.
Air bladder	Well developed (Taber 1969); very small, spherical to oval, midway between pectoral fins and anus.
Teeth	Very small, pointed, and visible in postlarvae.
Size at absorption of yolk	~4.0–5.0 mm TL.
Total myomeres	34–38.
Preanal myomeres	6–10.

Postanal myomeres	28–32.
Last fin(s) to complete development	Spiny dorsal fin.
Pigmentation	2–5 large stellate melanophores on top of head, a few or none middorsally. Pigments are found in midventral region; a series of condensed pigments along the postanal region; and dashed melanophores along lateral line region.
Distribution	Surface water column (Taber 1969); near shore zone with vegetation, surface and upper water column of freshwater and oligohaline portions of the estuary; also extremely abundant in San Luis Reservoir (Hess *et al.* 1995).

JUVENILES

Dorsal fin rays	IV–V, I, 8–9 (Moyle 1976).
Anal fin rays	I, 15–18 (Moyle 1976); I, 15–20 (Pflieger 1975); I, 15–19.
Pectoral fin rays	13–14.
Mouth	Oblique, small (Moyle 1976); terminal, small, oblique.
Vertebrae	37–42.
Distribution	Mainly in the shallow weedy areas of the freshwater-oligohaline portion of the Delta; also found in ditches, ponds, and irrigation systems associated with Delta water, including San Luis Reservoir (Hess *et al.* 1995); widely introduced to lakes and reservoirs by sport fishermen.

LIFE HISTORY

Inland silverside is native to the brackish waters along the Gulf of Mexico and into the lower Mississippi Basin and north to Oklahoma and Tennessee (Robins 1969, Pflieger 1975). It is also known from Veracruz, Mexico, along the Gulf of Mexico, to Cape Cod on the Atlantic coast (Robins 1969). In 1967, specimens of inland silverside from Texoma Reservoir, Oklahoma, were introduced into Blue Lake and Clear Lake, California (Cook and Moore 1970). The species experienced a population explosion in Clear Lake and rapidly spread into the adjacent drainages, including Cache Creek and Putah Creek, and through the irrigation network to the Delta, where they have become well established. A large silverside population also has been established in San Luis Reservoir apparently transported via the California aqueduct system. Moyle (2002) stated that the distribution of inland silverside has spread further south to the Central Valley and southern California coastal waters, mostly by unauthorized introduction. Northward, the inland silverside has not been recorded in Washington State (Wydoski and Whitney 2003).

The successful establishment of inland silverside in San Francisco Bay and Delta is probably due in part to its tolerance of various salinities and to the neustonic feeding habit of its larvae.

Moyle (1976) noted that inland silverside spawn from April through September, with peaks in May and August. In the Delta, ripe females were collected from April through September with spawning occurring in the same period. The ovaries of these females had at least two or three distinct sizes of ova present at the same time, indicating that spawning occurs more than once a season (Mense 1967, Hubbs *et al.* 1971). The eggs collected in the Delta, have one to three thin filaments, attached to the chorion, which is different from the eastern populations where the eggs have one to five filaments, one of them being much thicker (Wang and Kernehan 1979).

Inland silverside eggs hatch in 4 d at 34°C and up to 30 d at 13°C (Hubbs *et al.* 1971). Newly-hatched larvae are small, approximately between 3.5–4.2 mm TL (Wang 1986), have well-developed air bladders (Taber 1969), and become planktonic. This trait is common to all the atherinopsids on the west coast, and other silverside larvae found along the Atlantic coast (Lindsay *et al.* 1978).

Juvenile inland silverside generally inhabit vegetated inshore waters or shallow sandy waters, if there is no vegetation (such as at San Luis Reservoir). Large numbers of juveniles have been collected with beach seines indicating juvenile schooling. Their diet consists primarily of zooplankton, including large cladocerans and instars of chironomid midges and chaoborid gnats (Moyle 1976).

Inland silverside generally reach maturity at age 1, spawn, and die; although a few females are able to survive an additional year (Mense 1967, Moyle 1976). This species is used as forage by game fishes and as a biological control for reducing gnat and midge populations in Clear Lake. Their shiny, silvery bodies makes them a desirable bait fish. Fishermen are blamed for the expansion of their distribution in California waters.

Ecologically, the abundance of inland silverside in the Delta may have suppressed the delta smelt population (*e.g.*, predation on delta smelt eggs and larvae) as suggested by Bennett and Moyle (1996) and Bennett (2005). However, a similar species to the delta smelt, the wakasagi (*Hypomesus nipponensis*), has co-existed with a very large population of inland silverside in the San Luis Reservoir for over a decade (Hess *et al.* 1995, Reclamation sampling of San Luis Reservoir in 1999–2002, Wang *et al.* 2005). Certain spawning and survival strategies may have evolved in this prey and predator relationship.

Figure 103.**—***Menidia beryllina*, inland silverside eggs: from left to right, gastrula 1.1 mm, early embryo 1.1 mm, late embryo 1.1 mm (Wang 1986).

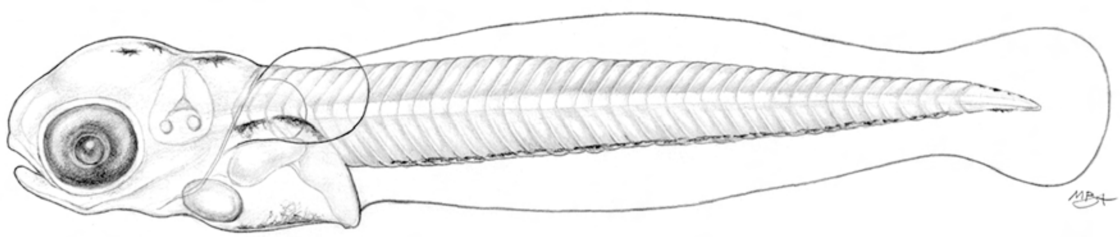


Figure 104.**—***Menidia beryllina*, inland silverside prolarva, 4.3 mm TL (Wang 1986).

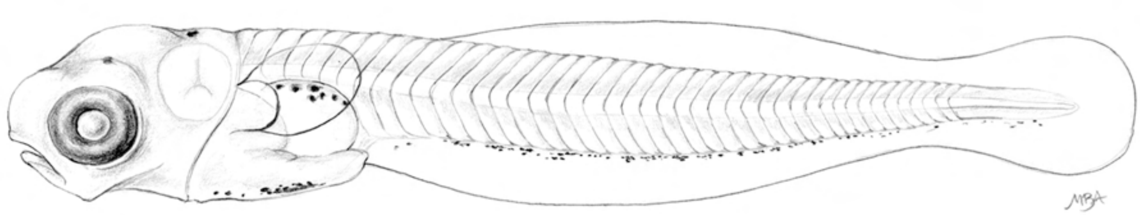


Figure 105.**—***Menidia beryllina*, inland silverside postlarva, 5.0 mm TL (Wang 1986).

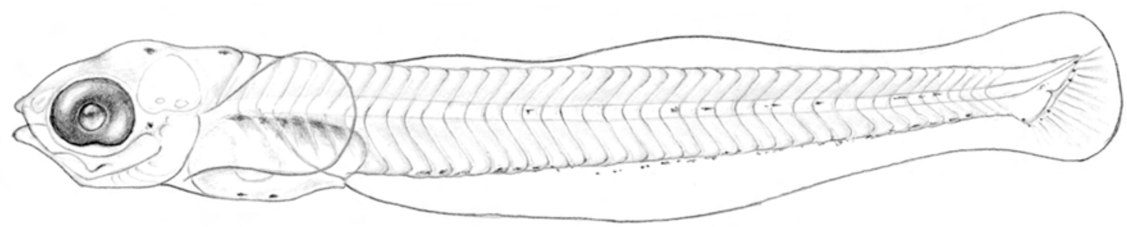


Figure 106.**—***Menidia beryllina*, inland silverside postlarva, 8.0 mm TL (Wang 1986).

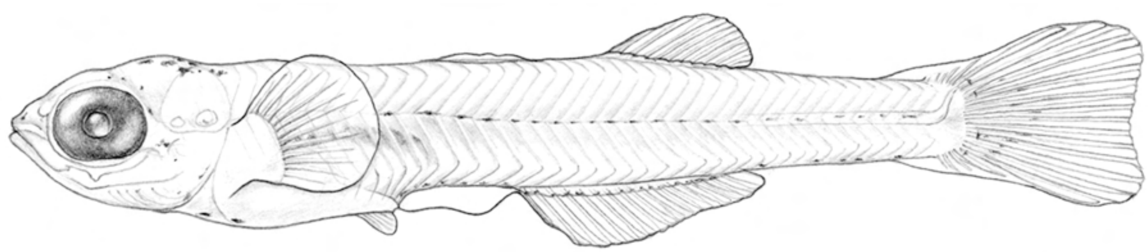


Figure 107.**—***Menidia beryllina*, inland silverside postlarva, 10.5 mm TL (Wang 1986).

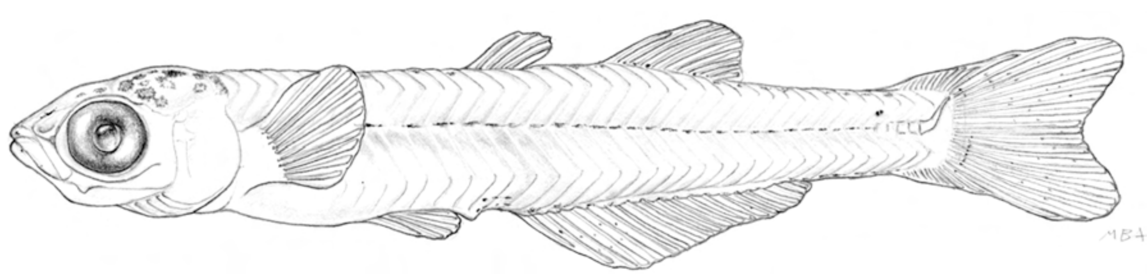


Figure 108.**—***Menidia beryllina*, inland silverside juvenile, 15.5 mm TL (Wang 1986).

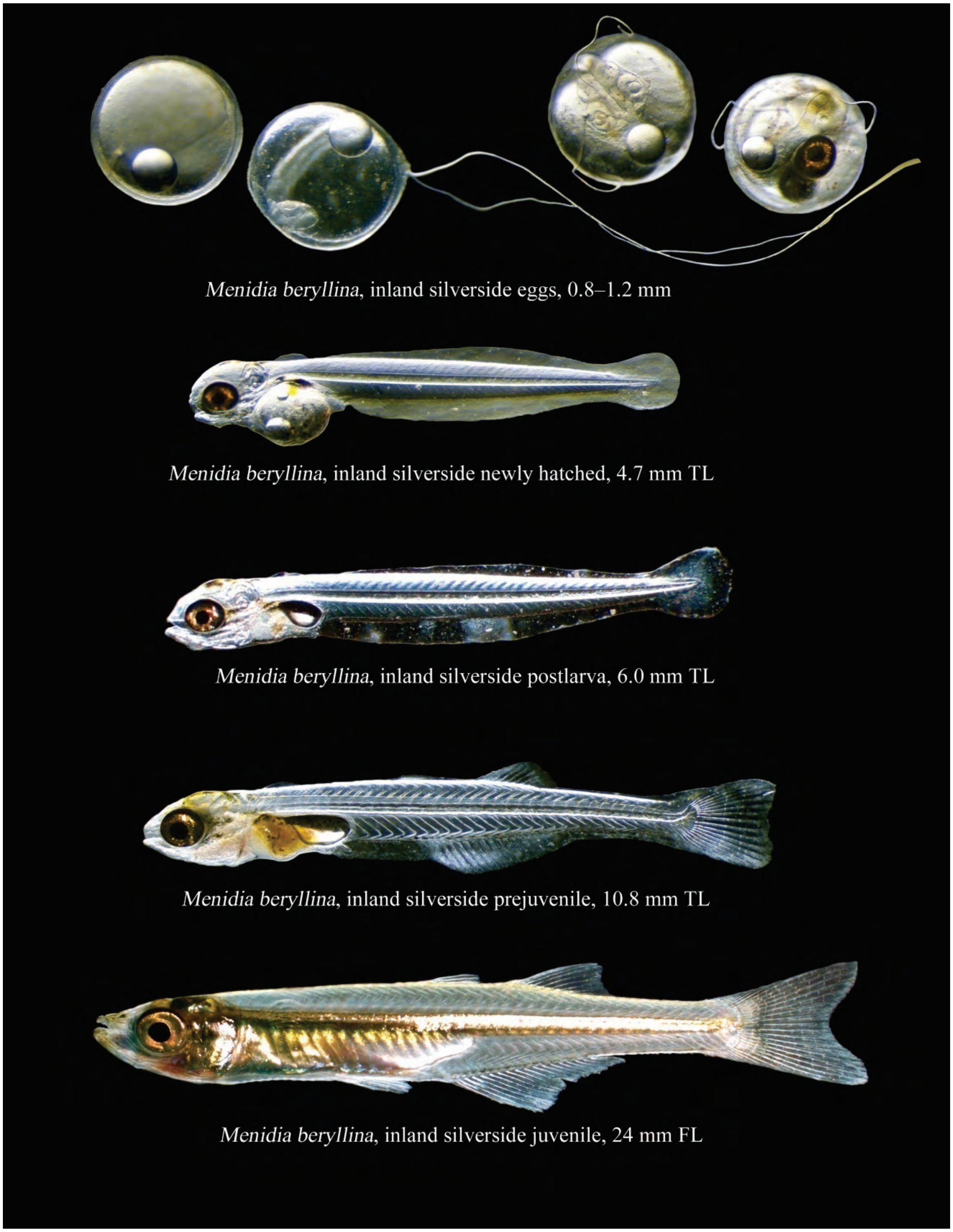


Figure 109.—*Menidia beryllina*, inland silverside.

Taxonomic Characteristics of Atherinopsids Present in the Study Area

	Topsmelt	**Jacksmelt**	**California grunion**	**Inland silverside**
Spawning location	San Francisco Bay to San Pablo Bay	San Francisco Bay to San Pablo Bay	Oakland Crown Beach of San Francisco Bay	Freshwater to oligohaline waters in Sacramento-San Joaquin Delta
Eggs				
Diameter	1.5–1.7	1.9–2.5	1.5–2.2	0.8–1.2
Number of chorion filaments	5–8	~10–16	0	1–3
Larvae				
Total myomeres	42–48	49–53	44–48	34–38
Melanophores on head and middorsum	Large on head and middorsum	Large on head, small on middorsum	Very large on head and middorsum	Large on head, few or none on middorsum
Juveniles				
Type of scales	Ctenoid	Ctenoid	Ctenoid	Cycloid
Relative position of insertion of D1 and origin of A	Over/under	D1 anterior	D1 posterior	D1 anterior

Fundulidae –Topminnows.— Two species of top minnows are found along the, California coast and estuaries. The California killifish (*Fundulus parvipinnis*) is native to the California coast and is known from Almejas Bay, Baja California to Morro Bay (Miller and Lea 1972). The rainwater killifish (*Lucania parva*) is native to the Atlantic coast and was probably introduced to San Francisco Bay in 1958 (Hubbs and Miller 1965). Only rainwater killifish is discussed in this chapter.

RAINWATER KILLIFISH *Lucania parva (*Baird and Girard*)*

SPAWNING

Location	Within dense vegetation in shallow inshore waters of the Sacramento-San Joaquin sytem. In higher saline waters of Aquatic Park (Berkeley, California), Lake Merritt (Oakland, California), and Newark Slough of south San Francisco Bay. In freshwater spawning occurs in Corte Madera Creek (Wang 1986). Larvae have been collected at Suisun Marsh, Montezuma Slough, and central and south Delta which indicate that spawning may occur there.

Season	May through July in the Sacramento-San Joaquin system (Wang 1986); continuous all year round (Kilby 1955); varies upon temperature and regional environment, such as February to October in Florida and April to July in Chesapeake Bay (Hildebrand and Schroeder 1928); will spawn year round under laboratory conditions (J. Pedretti 2008, personal communication).
Temperature	17.8°C in aquaria (Nichols and Breder 1927); 25°C (Crawford and Balon 1994). Eggs collected from the Aquatic Park at 20°C hatched in the laboratory at 22–24°C (Wang 1986); 19.8°C in the TFCF laboratory (R.C. Reyes 2003–2009, personal communication).
Salinity	Mesohaline to freshwater or 0–19 ppt (Wang 1986); 2.5 ppt (Crawford and Balon 1994); 10 ppt (R.C. Reyes 2003–2009, personal communication).
Substrate	Submerged aquatic vegetation; artificial plants, and filamentous algae; some eggs were observed attached to gravel in the laboratory (R.C. Reyes 2003–2009, personal communication).
Fecundity	Maximum 104 (Hildebrand and Schroeder 1928); 7–46 ripe ova in the ovary (McLane 1955); ~15 eggs/clutch (Crawford and Balon 1994).

EGGS

Shape	Spherical (Foster 1967, 1974).
Diameter	Average 1.23 mm (Foster 1967); 1.1–1.3 mm (Foster 1974); 1.1–1.3 mm.
Yolk	Yellowish, transparent (Kuntz 1916, Hildebrand and Schroeder 1928); whitish, granular, transparent.
Oil globule	12–20 oil globules at animal pole (Kuntz 1914, Kuntz and Radcliffe 1917, Hildebrand and Schroeder 1928, Brinley 1938, Foster 1974); more than 10 oil globules, the largest, ~0.31–0.44 mm in diameter (Wang and Kernehan 1979); single large oil globule, ~0.4 mm in diameter, surrounded by ~10 small oil globules.
Chorion	Transparent, with coarse adhesive threads tangled on chorion (Kuntz 1916, Kuntz and Radcliffe 1917); transparent, with many fine filaments attached to chorion.
Perivitelline space	Very narrow (Foster 1967, 1974); ~1.0 mm in width.
Egg deposition	Deposited singly or in small clusters on substrates; deposited singly in the CVP/TFCF laboratory (R.C. Reyes 2003–2009, personal communication).

Adhesiveness	Coarse adhesive threads (Kuntz 1914); chorion filaments are adhesive (Wang 1986).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	5.0 mm TL (Kuntz 1916); 4.0 mm TL (Foster 1967, 1974), 4.0–5.5 mm (Wang and Kernehan 1979); ~4.0–4.5 mm TL for the specimens collected at Aquatic Park; 4.5–5.1 mm TL for laboratory specimens (R.C. Reyes 2003–2009, personal communication).
Snout to anus length	~37–40% of TL of both prolarvae and postlarvae.
Yolk-sac	Medium size, flat on ventral side. Yolk-sac extends from the thoracic to the abdominal region.
Oil globule	Single or several scattered in the yolk-sac.
Gut	Short and thick, bends ventrally in the abdominal region.
Air bladder	Large, behind the base of the pectoral fin.
Teeth	Small, pointed in single row, visible in postlarvae.
Size at absorption of yolk	6.0 mm TL (Foster 1974); ~6.0 mm TL.
Total myomeres	26 (Hudson and Hardy 1975); 26–27.
Preanal myomeres	8 (Hudson and Hardy 1975); 8–10.
Postanal myomeres	18 (Hudson and Hardy 1975); 17–18.
Last fin(s) to complete development	Pelvic.
Pigmentation	Darker melanophores in reticular network found from isthmus to the abdominal region; light pigmentation appears over most of the head, body, and abdominal region; caudal and pectoral fins have numerous melanophores.
Distribution	Prolarvae remain on the bottom, swimming just above bottom after yolk is absorbed; in the Sacramento-San Joaquin system and some of its tributaries, larvae remain near shallow water with vegetation.

JUVENILES

Dorsal fin rays	9–10 for San Francisco Bay population (Hubbs and Miller 1965); 9–14 (Moyle 1976, Hardy 1978a).
Anal fin rays	8–10 for San Francisco Bay population (Hubbs and Miller 1965); 8–13 (Moyle 1976, Hardy 1978a).
Pectoral fin rays	12–15 (Hubbs and Miller 1965, this study); 10–15 (Moyle 1976, Hardy 1978a).
Mouth	Terminal to superior, small and oblique.

Vertebrae	28 (Garman 1895); 25–30 (Hardy 1978a); 27–28.
Distribution	Near bottom, in shallow inshore weedy areas of the Sacramento-San Joaquin Estuary and Delta, Suisun Marsh, Montezuma Slough, and central and south Delta; entrained in irrigation ditches; found at lower end of tributaries, such as Corte Madera Creek, Napa River, and Cordelia Creek; distribution is patchy.

LIFE HISTORY

Rainwater killifish is native to the Atlantic coast from Cape Cod, Massachusetts, through Florida and from the Gulf of Mexico to the lower Rio Panuco system, Tamaulipas, Mexico (Hubbs and Miller 1965). Rainwater killifish have been introduced into several western states. Introductions to California (San Francisco Bay) were reported as early as 1958 (Hubbs and Miller 1965); later introductions occurred in the 1960s to 1970s (Ruth 1964, Brittan *et al.* 1970). In the study area, rainwater killifish have been collected in Cordelia Creek, Suisun Bay, and Montezuma Slough (Wang and Reyes 2007; UC Davis sampling Marsh Study, 1995–2004; this study), near Pittsburgh Powerplant (Wang 1986), Cache Slough (CDFG's NBA survey, 1995–2004), Sacramento River up to Red Bluff (Reclamation's RBRPP records), central Delta, and south Delta (Reclamation salvage records; L. Grimaldo 1998, 2003, personal communication). Distribution of this species is scattered and patchy. Specimens collected with plankton net and beach seine were mostly late postlarvae and juveniles.

Along the Atlantic coast, rainwater killifish migrate into freshwater to breed (Gunter 1945, 1950; Beck and Massmann 1951). A similar migration is probable in the Delta. Breeding males were collected mainly in the higher saline waters of Aquatic Park as well as in Corte Madera Creek, a small freshwater tributary of San Francisco Bay (Wang 1986). Postlarvae and early juveniles have been collected in various locations in the Delta including at the CVP/TFCF intakes. Rainwater killifish are also found in the Red Bluff area of the upper Sacramento River suggesting that some may complete their life cycle locally.

Spawning period of rainwater killifish in the Delta and estuary is similar to that reported in the Atlantic region, April through July (Kuntz 1916, Hildebrand and Schroeder 1928, Wang and Kernehan 1979). In the laboratory, fins of the male become brilliant orange-red in color prior to spawning. in the wild, males establish small territories associated with aquatic vegetation. After courtship, females deposit a few eggs at a time over vegetation near the water surface. The eggs have many fine filaments, which attach to the substrate. Eggs were found on both the surface and the inner layers of a cotton mop which was used in the laboratory in place of vegetation. Although paying little attention to the eggs themselves, the male actively guards his territory during their development. The eggs hatch in 12 d at 25°C in both mesohaline (5–18 ppt) and freshwater conditions (Wang and Kernehan 1979). Foster (1967) also reported a hatching time of 6 d at 24–25°C. Rainwater killifish eggs will also hatch at room temperature in a cork-sealed test tube in about 2 weeks or slightly longer (W. Gallager 1985, personal communication). Eggs of different developmental stages are found in the ovary and only a few are discharged during a spawning act, suggesting that females spawn more than once during the spawning season. Details of killifish reproductive behavior have been well documented by Foster (1967).

Newly-hatched larvae are lightly pigmented over most of their bodies, with large and dark melanophores in the thoracic and yolk-sac regions. Another description indicates that newly-hatched larvae have light pigmentation mostly in the ventral and lateral postanal region, with denser pigmentation on the caudal peduncle and caudal fin (R.C. Reyes 2003–2009, personal communication). Young larvae initially remain on the bottom and begin to swim into shallow inshore areas as they develop.

Juvenile rainwater killifish are solitary or stay in small schools and are usually found near aquatic vegetation. Some individuals have been found in inshore waters only a few millimeters deep, possibly an important survival strategy for avoiding predation. The diet of juvenile rainwater killifish includes copepods, mosquito larvae, amphipods, and small insects (Harrington and Harrington 1961, this study).

Rainwater killifish reach sexual maturity by ~25 mm TL (Hildebrand and Schroeder 1928) or in 3–5 months. Females are larger than the males (Foster 1967). This species is valued as a mosquito control fish (Moyle 2002), as an aquarium pet, and as a forage species for game fish.

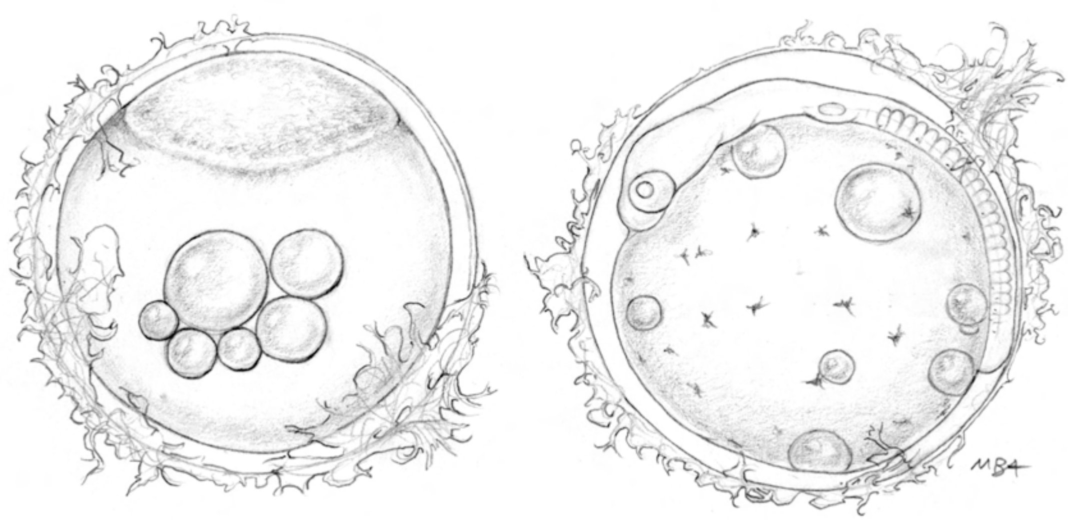


Figure 110.—*Lucania parva*, rainwater killifish eggs, morula and early embryo, 1.1 mm (Wang 1986).

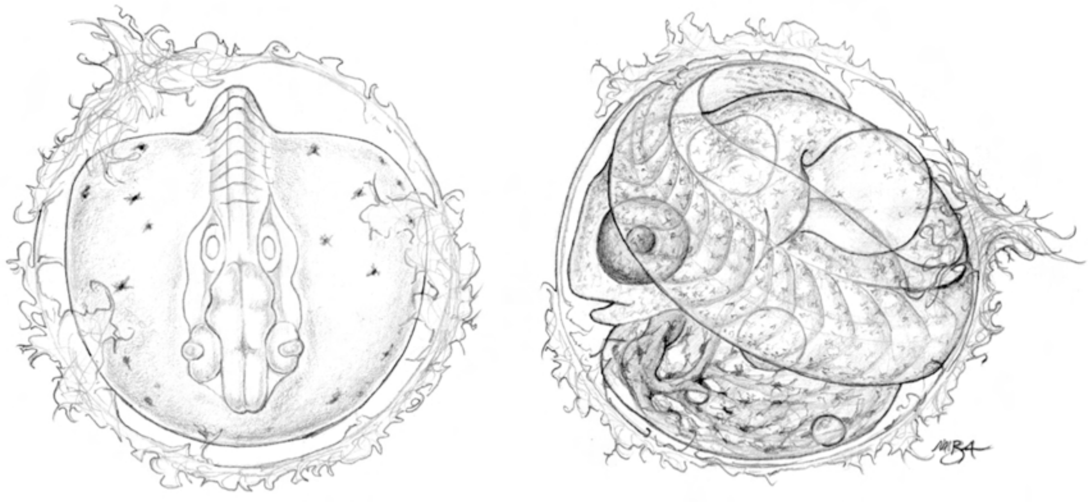


Figure 111.**—***Lucania parva*, rainwater killifish eggs, late embryo, 1.1 mm (Wang 1986).

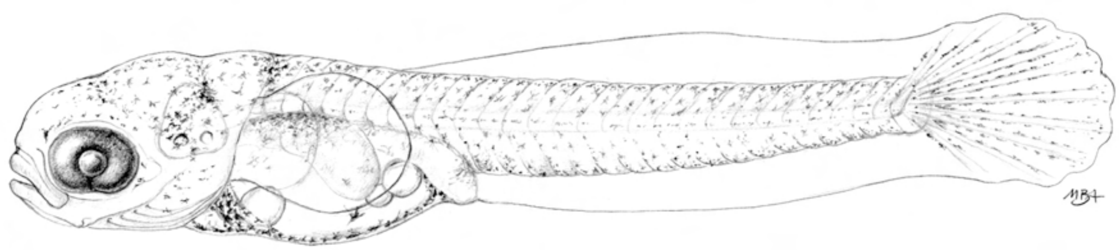


Figure 112.**—***Lucania parva*, rainwater killifish prolarva, 5 mm TL (Wang 1986).

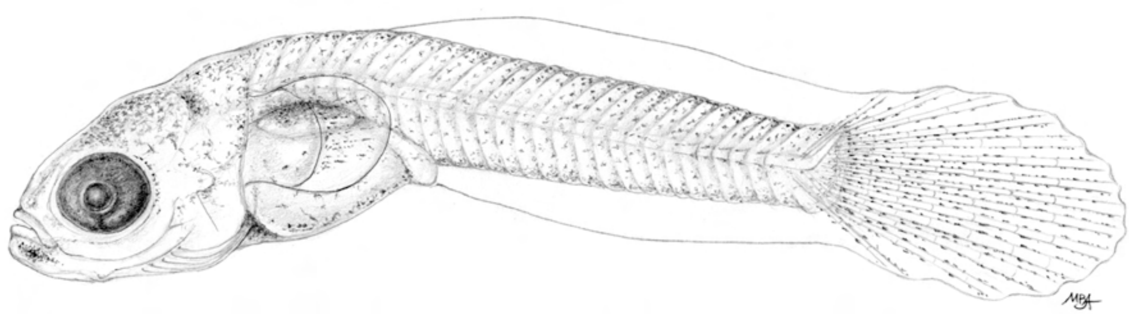


Figure 113.**—***Lucania parva,* rainwater killifish postlarva, 7 mm TL (Wang 1986).

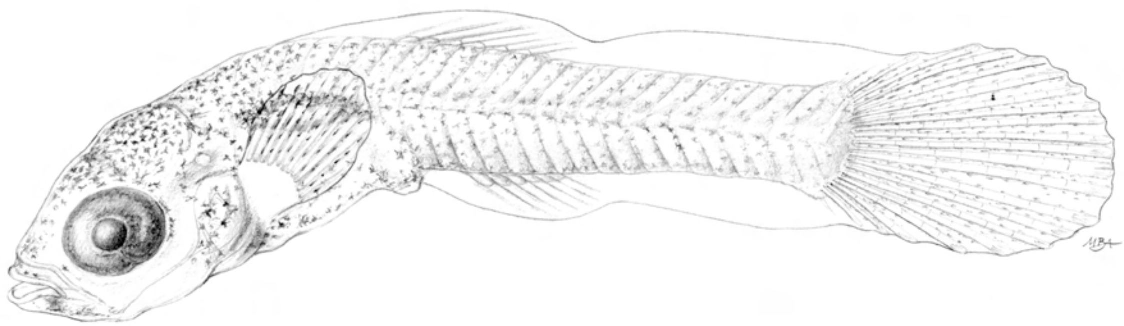


Figure 114.**—***Lucania parva*, rainwater killifish postlarva, 8.1 mm TL (Wang 1986).

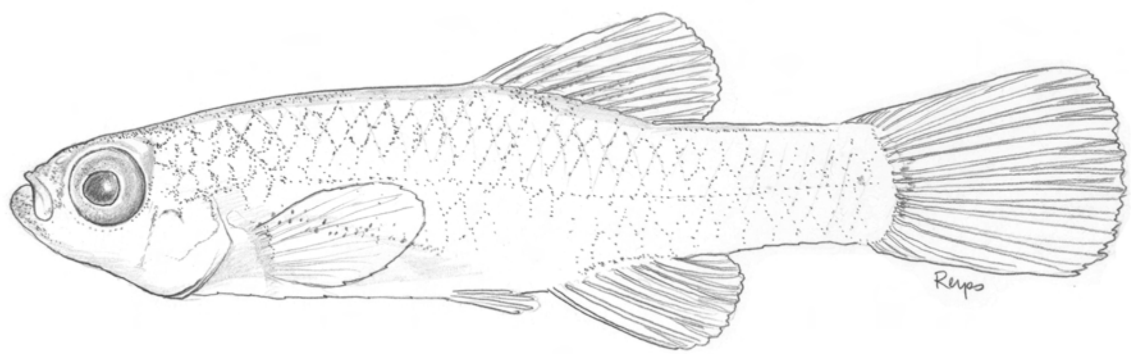


Figure 115.**—***Lucania parva*, rainwater killifish juvenile, 29 mm TL.

Figure 116.—*Lucania parva*, rainwater killifish.

Poeciliidae – Livebearers — At least four species of livebearers have been introduced into California: western mosquitofish (*Gambusia affinis*), sailfin molly (*Poecilia latipinna*), shortfin molly (*P. mexicana*), and porthole livebearer (*Poeciliopsis gracilis*). Currently, only the western mosquitofish is known in the Delta watershed. The other three species are found in warm southern California waters and in the Salton Sea (Dill and Cordone 1997, Moyle 2002). Only the western mosquitofish is discussed in this chapter.

WESTERN MOSQUITOFISH *Gambusia affinis* (Baird and Girard)

SPAWNING

Location	Low to mid-elevation, sluggish waters of the Delta and watershed, including land-locked ponds, reservoirs, irrigation ditches, rice fields, flood control ditches, creeks, streams, pools, and sloughs.
Season	April–September (Moyle 1976) or early May through October based on collections made during this study.
Temperature	15.6 (Self 1940); 15.5°C (Medlen 1952); up to 30°C (Okada 1955); 15°C up to 30°C or more in the cooling ponds of Pittsburg Powerplant (Wang 1986).
Salinity	Mainly in freshwater, but may occur in oligohaline water, such as in Suisun Marsh (Matern *et al*. 2002).
Fecundity	Highly variable (Hardy 1978a); 1–300 (La Rivers 1962); reports of brood average range from 11 (Fowler 1907) to 300 (Beckman 1952), 20–100 (Wang 1986), or around 50 (Moyle 2002).

EGGS (descriptions based on eggs obtained by caesarian removal)

Shape	Mostly spherical; may also be irregular when embryos are developing in the ovary creating a congested condition, particularly in late gestation.
Diameter	2.1 mm (Ryder 1882); 1.8 mm (Lippson and Moran 1974); 2.4–2.8 mm (Wang and Kernehan 1979); 2.0 mm in early developmental stages and 2.5–3.0 mm in late embryo stages.
Yolk	Golden yellow (Kuntz 1914); bright yellow, granular.
Oil globule	Numerous small oil globulets (Ryder 1882, 1885; Kuntz 1914).
Chorion	Thin and transparent, with filaments attaching from chorion to the center of ovarian tissue (Ryder 1885, 1887; Kuntz 1914).
Perivitelline space	Very narrow.

Egg deposition	Small clusters within ovary; individual ovum attached to the center of the ovarian tissue (Ryder 1885, 1887; Kuntz 1914). Eggs hatch internally.
Adhesiveness	Chorion filaments are adhesive.
Buoyancy	Ova embedded in the ovary during the entire gestation period.

LARVAE (embedded in female's ovary)

Length at hatching	7.4 mm (Kuntz 1914); 8–10 mm TL (Hildebrand and Schroeder 1928); 7.0 mm TL (Regan 1961); 4.5–6.6 mm TL before birth (Wang and Kernehan 1979); ~4.0–5.5 mm TL for larvae in ovary before birth and ~6–9 mm TL at the time of birth.
Snout to anus length	~40–45% TL for larvae in the ovary and newly born juveniles (Wang 1986).
Yolk-sac	Spherical, very large, extends from snout to abdominal region.
Oil globule	Numerous small oil globulets scattered in the yolk-sac.
Air bladder	Small, oval, located above and behind pectoral fins.
Teeth	Small, in one row, apparent at birth.
Size at absorption of yolk	~6.0 mm TL, prior to birth.
Total myomeres	28–32 (Wang 1986); up to 34 (R.C. Reyes 2003–2009, personal communication).
Preanal myomeres	12–14.
Postanal myomeres	16–20.
Last fin (s) to complete development	Pelvic.
Pigmentation	Stellate melanophores are heavy on the snout, head, and to the middorsal region; pigmention is light ventrally and on fin membranes. Pigmentation along the edges of scales becomes more prominent shortly after birth.

JUVENILES

Dorsal fin rays	5 (Bailey *et al.* 1954) up to 11 (Garman 1895); 6 (Moyle 2002); 6–8 (Wang 1986).
Anal fin rays	9–11 (Hildebrand and Schroeder 1928); 9 (Moyle 2002); the anterior anal fin ray of male fish modified into an intromittent organ or gonopodium (Hildebrand and Schroeder 1928, Turner 1941).
Pectoral fin rays	12–14 (Garman 1895, Moyle 2002); 12–13.

Mouth	Slightly superior, lower jaw projecting (Hildebrand and Schroeder 1928); small oblique (Moyle 1976); terminal to superior, oblique.
Vertebrae	Trunk vertebrae 13–14, caudal vertebrae 17–20 (Garman 1895, Hollister 1940); 30–33.
Distribution	Sluggish water with vegetation. Common in the Sacramento-San Joaquin River system; more common in nontidal than in tidal waters. County mosquito and vector control districts often stock mosquitofish in creeks and ponds near population centers.

LIFE HISTORY

Western mosquitofish is native to North America, from southern Illinois through the Mississippi drainage, to Texas and along the Gulf of Mexico coast to the Rio Panuco basin, Mexico. On the Atlantic coast, its range extends from New Jersey southward to Florida (Hildebrand and Schroeder 1928, Krumholz 1948, Rosen and Bailey 1963). Because western mosquitofish feed on mosquito larvae and pupae, they have been introduced into the tropical and temperate regions throughout the world. The species was introduced into California in 1922 (Moyle 1976, Dill and Cordone 1997). It is present in almost all backwaters and sluggish waters of the Sacramento-San Joaquin River system, including mid-elevation reservoirs and ponds, such as the Millerton Lake and Kerckhoff Reservoir. Moyle and Nichols (1973) also reported this species in Sierra Nevada foothill waters.

In the study area, western mosquitofish spawned continuously year round in favorable environments. The greater part of the local population gives birth from April through October (Wang 1986); although the last brood may be in September (Moyle 2002). Females can produce three to four broods at temperatures of 25–30°C (Vondracek *et al.* 1988, Moyle 2002) and give birth to free-swimming young starting at 15.5°C (Medlen 1952). Gestation period is about 21–28 d (Krumholz 1948) in the warm environments in California (Moyle 2002); much longer in cold environments (Wang 1986). Reproduction may cease in cold periods during winter (Moyle 2002).

Eggs are contained in a single ovary. Each egg is covered by a thin chorion and attaches to the central ovarian tissue by means of filaments (Kuntz 1914). Male fish use a gonopodium (modified from anal fin rays) to contact the female's genital tract and transfer sperm into the ovary. Females may store sperm and eggs fertilized from several copulations (Moyle 2002). As eggs are fertilized and embryo development proceeds, the female abdomen gradually swells.

Embryos hatch out of the chorion as larvae but remain within the ovary for several days before birth (Wang 1986). Larval development within the same brood is fairly constant, although some larvae will develop slower. When a female gives birth, both mature and premature individuals are discharged within a few minutes.

Newly-born western mosquitofish have fully developed fin rays in all but the pelvic fins, a body covered with scales, and have already developed to the juvenile life stage. Laboratory observations indicate that mature young swim immediately after birth; and that premature and abnormal individuals remain on the bottom of the aquarium. In the wild, young mosquitofish are probably preyed upon by other fish or are cannibalized (Moyle 2002). Juveniles tend to form small schools and use dense vegetation for shelter and nursery habitat. By the end of summer, juveniles and small adults outnumber large adults. Numbers of both juveniles and adults decline drastically in the late fall, perhaps from lack of food and temperature changes.

Juvenile mosquitofish are opportunistic and omnivorous feeders. Though noted for feeding on mosquito larvae and pupae, their highly varied diet also includes any item readily available such as algae, zooplankton, and insects (Harrington and Harrington 1961, Rees 1958, Swanson *et al.* 1996).

Krumholz (1948) reported that western mosquitofish reach maturity 6 weeks after birth and usually live <1 year, although same may live as long as 15 months. Western mosquitofish is a forage species for many predatory fishes. More importantly, they function as a mosquito control agent for residential areas. An albino strain has also been bred and is available to the public as an ornamental as well as a functional fish (C. Miller 2003, personal communication). In California and throughout the world, they are used for pest control in rice fields.

Western mosquitofish are successful in controlling mosquitoes due to several reasons: 1) they tolerate temperatures ranging from 4 to 37°C (Krumholz 1948, Carlander 1969), 2) they have the ability to breathe at the surface that allows them to survive in extremely eutrophic ponds, lakes, and ditches, 3) they are opportunistic feeders, feeding on zooplankton as well as on phytoplankton (Moyle 1976), 4) they do not require any particular spawning habitat since mosquitofish are livebearers, and finally, 5) they will readily breed under both natural and artificial conditions (Hardy 1978a). Because they are hardy and prolific, mosquitofish often outcompete native fish for food (Myers 1965). It is therefore necessary for natural resource agencies to carefully control introductions.

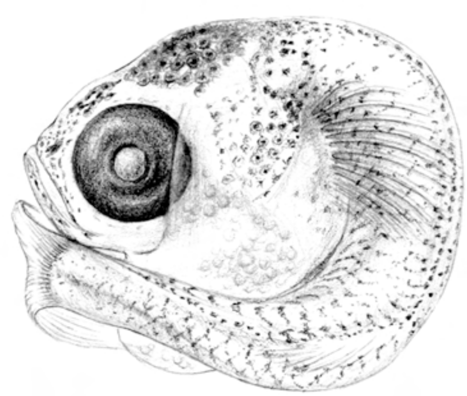


Figure 117.—*Gambusia affinis*, western mosquitofish dissected embryo, 3.2 mm (Wang 1986).

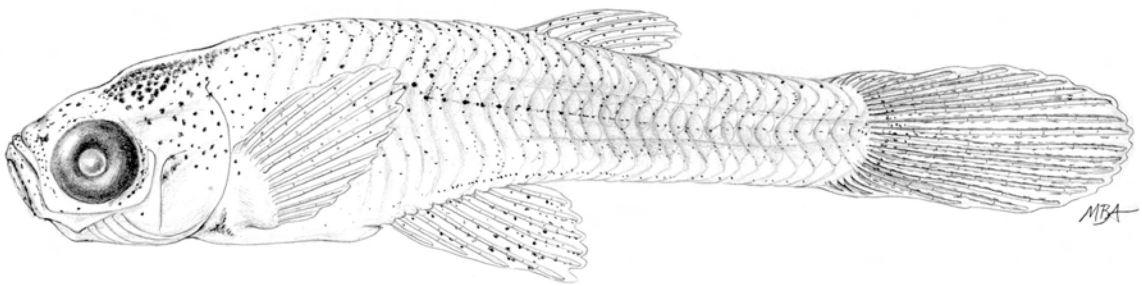


Figure 118.—*Gambusia affinis*, western mosquitofish newly born postlarva, 9.5 mm TL (Wang 1986).

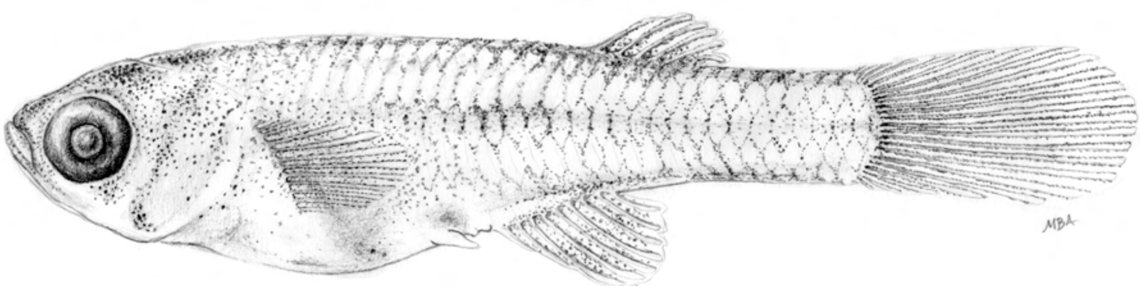


Figure 119.—*Gambusia affinis*, western mosquitofish juvenile, 11.6 mm TL (Wang 1986).

Figure 120.—*Gambusia affinis*, western mosquitofish.

Gasterosteidae – Sticklebacks — Five species of sticklebacks are recognized in North America (Nelson *et al*. 2004). Two of these are found in California: threespine stickleback (*Gasterosteus aculeatus*) and brook stickleback (*Culaea inconstans*). The fascinating social and mating behaviors of the threespine stickleback have stimulated an enormous amount of research by fishery biologists and behaviorists since the late 1880s. Both freshwater and anadromous forms of this species are found in the study area. Brook stickleback is known only from the Scott River of northern California and is not included in this chapter.

THREESPINE STICKLEBACK *Gasterosteus aculeatus* Linnaeus

SPAWNING

Location	Shallow weedy areas of the Sacramento-San Joaquin Estuary and adjacent coastal streams, bays, and sloughs. Specific locations where spawning was observed include San Ramon Creek below a spill pool (San Ramon, California); Walnut Creek near Civic Drive (Walnut Creek, California); behind Hilton Hotel (Concord, California); Pine Creek at Hill Crest Community Park (Concord, California); Wilton Slough; Suisun Creek near Lake Curry (Napa County, California); upper Napa River below Napa; Aquatic Park (Berkeley, California); Pine Gulch near Bolinas; Walker Creek of Tomales Bay; and Rodeo Lagoon at the Golden Gate National Recreation Area.
Season	May–July (Kuntz and Radcliffe 1917); February–August (Vrat 1949); April–July (Moyle 1976); March–October in the study area, will spawn year round in laboratory in temperature controlled conditions.
Temperature	15.8–18.5°C (Vrat 1949); 18–20°C (Moyle 2002); in the wild, males exhibit breeding colors at ~12°C, spawning occurs at ~15°C and larvae were collected at 18°C.
Salinity	Freshwater and brackish water (Bigelow and Schroeder 1953, Altman and Dittmer 1962); freshwater up to mesohaline.
Substrates	Twigs and debris (Scott and Crossman 1973); strands of algae and pieces of aquatic plants (Moyle 1976); fragments of aquatic plants, filamentous algae, and debris.
Fecundity	50 (Tinbergen 1952); 292 (Hagen 1967); <100 (Livingstone 1951); 100–150/batch (Bigelow and Schroeder 1953); usually <100 (Livingstone 1951); 50–300 eggs in each batch, and several batches during spawning season (Moyle 1976); varies from population to population (Hagen 1967); based on the number of larvae that hatched in an aquarium, mostly between 50–100/batch.

EGGS

Shape	Spherical (Kuntz and Radcliffe 1917, Vrat 1949).
Diameter	1.5–1.9 mm (Vrat 1949); 1.5–1.7 mm (Kuntz and Radcliffe 1917, Wang 1986).
Yolk	Yellowish to light tan, semi-opaque (Kuntz and Radcliffe 1917, Brinley 1938, Swarup 1958); yellowish, smooth.
Oil globule	Numerous oil globules (Kuntz and Radcliffe 1917). Several large oil globules ~0.3–0.4 mm in diameter and many small ones; all oil globules gradually consolidate into one oil globule as embryonic development proceeds.
Chorion	Transparent (Vrat 1949); tough (Swarup 1958); transparent, thick, and elastic.
Perivitelline space	Very narrow, ~0.05–0.1 mm in width.
Egg deposition	Deposited in clusters (Vrat 1949); each batch is in a small cluster deposited in the nest or inside a hut.
Adhesiveness	Highly adhesive to each other, but not to substrates (Vrat 1949, Bigelow and Schroeder 1953).
Buoyancy	Negatively buoyant or demersal (Brinley 1938, Battle 1944).

LARVAE

Length at hatching	4.2–4.5 mm TL (Kuntz and Radcliffe 1917); 4.7–4.9 mm SL (Vrat 1949); as small as 3.0 mm TL (Swarup 1958); ~5.0–5.5 mm TL.
Snout to anus length	~54–59% TL for both prolarvae and postlarvae.
Yolk-sac	Large, spherical to oval, extends from jugular to abdominal region.
Oil globule	Single, ~0.3 mm in diameter, located anteriorly in the yolk-sac and used up shortly after hatching.
Air bladder	Large, oval to elongate, just behind the pectoral fins.
Teeth	Small, pointed teeth in one row, visible in postlarvae.
Size at absorption of yolk	~6.5–7.0 mm TL.
Total myomeres	29–32.
Preanal myomeres	15–17.
Postanal myomeres	14–16.
Last fin(s) to complete development	Spiny dorsal fin and pelvic fin.
Pigmentation	Pigmentation is heavy in the late embryo stage prior to hatching; newly-hatched prolarvae have dense melanophores on upper part of the body, dorsally on gut,

	and in postanal regions. Heavy pigmentation covers the head and body of postlarvae and forms 7–9 dark blotches on sides of body.
Distribution	Planktonic, in pools with aquatic vegetation, or among vegetation near shoreline such as in Montezuma Slough and its tributaries (Matern *et al.* 2002).

JUVENILES

Dorsal fin rays	III, 11–12 (Hart 1973); III–VI, 10–14 (Scott and Crossman 1973); II–III, I, 10–13 (Miller and Lea 1972).
Anal fin rays	I, 8–9 (Hart 1973); I, 8–10 (Scott and Crossman 1973); I, 7–12 (Miller and Lea 1972); 6–10 (Moyle 1976).
Pectoral fin rays	10 (Hart 1973); 9–11 (Moyle 1976); 10–11.
Mouth	Terminal and slanting upward (Moyle 1976); terminal, small, oblique.
Vertebrae	29–33 (Scott and Crossman 1973); 30–33 (Miller and Lea 1972); 30–33.
Distribution	Threespine stickleback is common in the coastal streams of California (Moyle 2002) and widely distributed in the Sacramento-San Joaquin Estuary and River systems including areas that are landlocked. It is also common in coastal bays and lagoons such as Rodeo Lagoon, Tomales Bay, Moss Landing, and Elkhorn Slough, and in foothill lakes such as Millerton Lake and Kerckhoff Lake (Wang 1986, Brown and Moyle 1993).

LIFE HISTORY

Threespine stickleback is widely distributed throughout the Northern Hemisphere (Bigelow and Welsh 1925, Livingston 1951, Scott and Crossman 1973). It is most often collected in estuarine waters (Bigelow and Schroeder 1953) and in the ocean; however, spawning often occurs in freshwater. In the Pacific, the species is known from Baja California (Barraclough 1967) to the Bering Sea (Wilimovsky 1954, 1964), to Japan and Korea (Okada 1955), and as far as western China (Livingstone 1951). Threespine sticklebacks are present throughout the Sacramento-San Joaquin Estuary and River system, particularly in channelized creeks, such as Walnut Creek, where they were abundant below spill pools. They congregate in dense vegetation of Suisun Marsh and most of the irrigation ditches in the Delta. They are rarely collected by plankton tows in open water.

Spawning occurs from March through October. Males develop brilliant dark green and orange-red spawning coloration as early as March, when the water temperature reaches about 12–15°C, in both freshwater and brackish environments. Males will retain their breeding color for a month after the spawning season. At room temperature (~20–23°C) in the laboratory, male threespine sticklebacks exhibit spawning colors throughout the year. As the spawning period approaches, the male builds a nest. A nest may be irregular and cocoon-shaped, formed from aquatic plants with an opening at each end, or just a simple hut formed by placing plant material over a hollow sand pit. Nests are constructed with plant fragments and renal secretions (Greenbank and Nelson 1959). After the courtship ritual, the female deposits her eggs in the nest, the male fertilizes the eggs, and then the male drives the female away. The male loosens the top of the nest to enhance ventilation. Eggs, in small clusters, are highly adhesive to each other but not to the substrate (Vrat 1949). The male assumes a head-stand posture at one end of the nest and circulates water over the eggs by fanning his pectoral fins (Moyle 1976), and will clean the eggs with his mouth. When hatching time approaches, he tears down the nest (Bigelow and Schroeder 1953) or pushes away the pit cover. The eggs are exposed, the chorion crushed, and individual eggs scattered. This may be an important spawning strategy in that individual eggs have a better chance to hatch than clustered eggs (eggs in the center of clusters often die from suffocation). Eggs will hatch in <6 d (or 192 h) at 18–19°C (Swarup 1958), 7 d at 19°C (Breder and Rosen 1966), or 7 d at 18–20°C.

Threespine sticklebacks spawn multiple times during the breeding season (Moyle 1976). Under ideal laboratory conditions (*i.e.*, 21–23°C, proper aeration and feeding, and ample breeding space and substrates), a pair can spawn six times within an interval of 10–15 d (Wang 1986). Hatching success is dependent on the male; some males desert the nest during the incubation period

The male guards newly-hatched larvae for several days. Initially, the larvae stay near the bottom but as they achieve full swimming ability, they begin to disperse into shallow water with dense vegetation. In the laboratory, they swim near the surface or hide behind aerators to avoid predation or cannibalism. Threespine stickleback larvae school with fish of similar size and sometimes with other species.

Juvenile threespine stickleback equipped with armored plates (unarmored forms are found only in southern California) and spines, emerge from vegetation into open pools, where they form loose aggregations. In the tributaries of the study area (such as Walnut Creek) and adjacent to the study area (such as Newark Slough, Alameda Creek, Pine Gulch, and Rodeo Lagoon), threespine stickleback is the dominant species in the fish community. The number of the juveniles reaches a peak in the late summer and then drastically declines in the fall. It is unclear if this decline is due to juveniles migrating toward the sea as described in the eastern Pacific by Igarashi (1970) or due to massive mortality from overcrowding and food shortage.

Juvenile threespine sticklebacks are active feeders. Food items for the freshwater form include aquatic insects, insect larvae, fish eggs, and larval fish (Hagen 1967); the anadromous form consumes mostly free-swimming crustaceans (Barraclough and Fulton 1967, Moyle 1976). Diet is dependent on seasonal food availability; they will feed on aquatic insects and crustaceans in summer and earthworms in winter (Snyder 1984). Threespine sticklebacks are preyed upon by salmonids, other predatory fishes, and seabirds (Hart 1973, Scott and Crossman 1973, Moyle 1976).

Most threespine sticklebacks reach maturity in their second spring (Narver 1969) or complete their life cycle in 1 year (Moyle 2002). Some individuals may live up to 3 years (Moyle 1976). Spawning multiple times during the breeding season is an important survival strategy for a fish with a short lifespan. The threespine stickleback's complex social and mating behavior continuously fascinates behaviorist.

Figure 121.—*Gasterosteus aculeatus*, threespine stickleback eggs, 1.7 mm (Wang 1986).

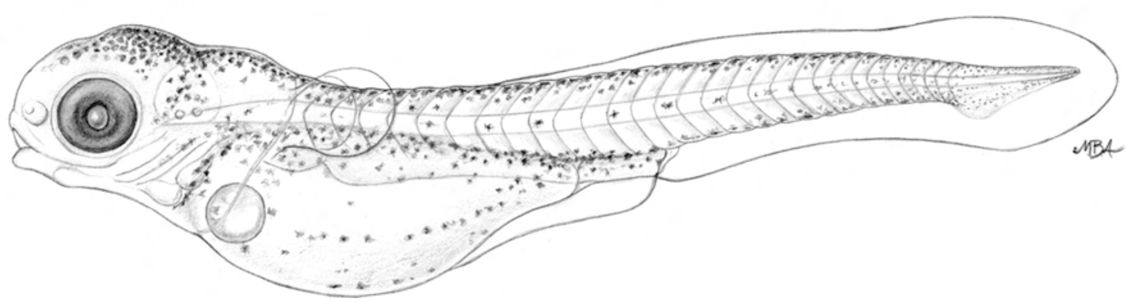


Figure 122.—*Gasterosteus aculeatus*, threespine stickleback prolarva, 6.6 mm TL (Wang 1986).

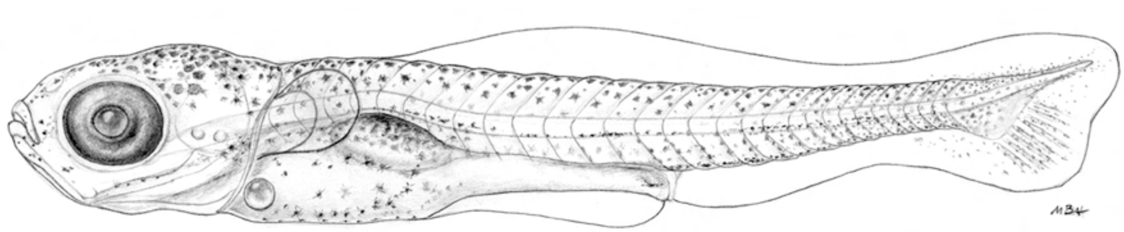


Figure 123.—*Gasterosteus aculeatus*, threespine stickleback postlarva, 6.6 mm TL (Wang 1986).

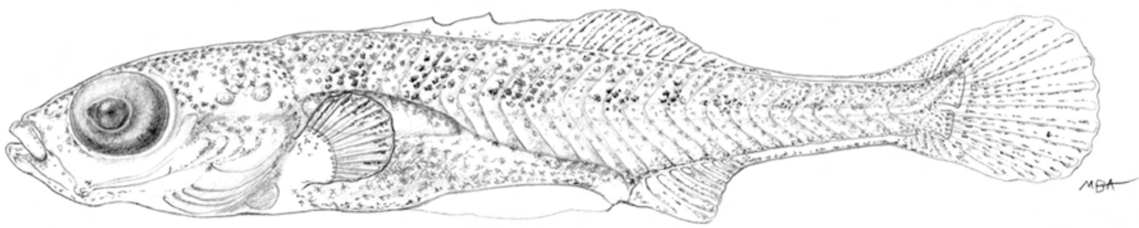


Figure 124.—*Gasterosteus aculeatus*, threespine stickleback postlarva, 9.2 mm TL (Wang 1986).

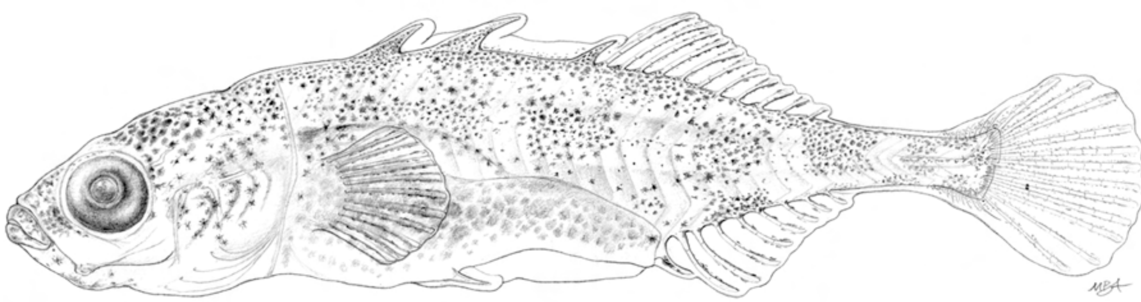


Figure 125.—*Gasterosteus aculeatus*, threespine stickleback juvenile, 14.5 mm TL (Wang 1986).

Figure 126—*Gasterosteus aculeatus*, threespine stickleback.

Syngnathidae – Pipefishes — Two species of pipefishes are known in the San Francisco Bay area, the kelp pipefish (*Syngnathus californiensis*) and the bay pipefish (*S. leptorhynchus*), but kelp pipefish was not collected during this study. Specimens collected in San Francisco Bay, San Pablo Bay, and Suisun Bay, have a vertebrae count range of 54–64 and are bay pipefish (kelp pipefish have a vertebrae count range of 65–74; Miller and Lea 1972). Only the bay pipefish is discussed in this chapter.

BAY PIPEFISH, *Syngnathus leptorhynchus* Girard

SPAWNING

Location	Shallow water with eelgrass, algae, and other types of vegetation in bays and estuaries.
Season	Males carry young in August (Clemens and Wilby 1961); males carry eggs in May and young in August (Hart 1973); mating in May and June (Moyle 1976); eggs and larvae were found in the male pouch from February through November.
Temperature	~15°C (based on the time at which male fish were found to be incubating eggs).
Salinity	Seawater to mesohaline.
Fecundity	Up to 225 eggs deposited in the male pouch (Bane and Bane 1971); 2–3 distinctive developmental stages of eggs were found in a male's pouch, which could be eggs deposited intermittently from different females.

EGGS (removed from male pouch)

Shape	Spherical to oval.
Diameter	~1.0–1.5 mm.
Yolk	Bright yellow, smooth.
Oil globule	One or a few large oil globules (0.4–0.5 mm in diameter).
Chorion	Transparent to translucent.
Perivitelline space	Very narrow in all stages.
Egg deposition	Adhesive eggs are deposited in the male's brood pouch.
Buoyancy	Embedded in male's brood pouch.

LARVAE (removed from male pouch)

Length at hatching	4.5–5.0 mm TL.
Snout to anus ratio	~35–40% TL for larvae 4.5–5.0 mm TL.
Yolk-sac	Very large, spherical, and bright, in thoracic region.
Oil globules	Many oil globules.

Gut	Straight.
Air bladder	Small and shallow, near pectorals.
Teeth	None.
Size at absorption of yolk	~10 mm TL at the time of birth.
Total myomeres (rings: body plates that encircle the body)	57–63 (Wang 1986); 53–64 (Watson and Sandknop 1996b).
Preanal myomeres (rings)	16–19 (Wang 1986); 16–21 (Watson and Sandknop 1996b).
Postanal myomeres (rings)	39–44 (Wang 1986); 36–46 (Watson and Sandknop 1996b).
Last fin(s) to complete development	Anal fin (only females have an anal fin).
Pigmentation	Newly-hatched larvae have little pigmentation. Melanophores gradually cover head and body, and form about 20+ vertical blotches.
Distribution	Eggs incubate and larvae develop in the male's pouch.

JUVENILES

Dorsal fin rays	28–37 (Herald 1941); 35–44 (Bane and Bane 1971); 28–44 (Miller and Lea 1972).
Anal fin rays	3–5 (Miller and Lea 1972); 3 in females (Hart 1973).
Pectoral fin rays	~15 (Hart 1973).
Mouth	Terminal, minute, directed somewhat upward (Hart 1973); mouth small, snout tubular (Bane and Bane 1971); mouth small protruding from snout.
Vertebrae	56–64 (Miller and Lea 1972).
Distribution	Bay pipefish juveniles inhabit shallow waters with eelgrass, kelp beds, filamentous algae, pilings, and other substrates into which they can blend. More are found in the higher saline San Francisco Bay and San Pablo Bay, some in east San Pablo Bay and Napa River, and a few in Suisun Bay, in recent years. Other known areas frequented by juvenile bay pipefish include Moss Landing Harbor-Elkhorn Slough, Tomales Bay (Wang 1986), and Morro Bay (E. Calix 1999–2005, personal communication).

LIFE HISTORY

The bay pipefish ranges from Bahia Santa Maria, Baja California to southeastern Alaska (Herald 1941, 1961; Wilimovsky 1954; Fritzsche 1980) and is known to inhabit both marine and estuarine environments. Specimens have been collected from San Francisco Bay (Ganssle 1966) to San Pablo Bay and Napa River (CDFG Bay Studies and 20-mm fish survey in Napa River, 1995–1996, 2004) to the freshwater portion of Suisun Bay

(Wang 1986). In recent years, it has been collected in the lower Napa River but not in Suisun Bay. The bay pipefish has been considered a subspecies of the kelp pipefish (Herald 1941); however, Miller and Lea (1972), Fritzsche (1980), and Nelson *et al*. (2004) consider the bay pipefish a separate species.

Clemens and Wilby (1961) reported that bay pipefish spawn from May through August. Eggs and larvae were found in the male pouches from February through November. The presence of eggs in various developmental stages in the same pouch suggests that a male may accept eggs deposited by more than one female (Wang 1986). It is also possible that a small fish, like the male bay pipefish, has a limited pouch space and that the female releases a few eggs to the male's pouch repeatedly, eventually increasing the total number of egg generations during her reproductive lifespan. As the male pouch receives newly deposited eggs, newly born juveniles are also discharged. Egg incubation and larval development are completed in the male pouch in 8–15 d (Bane and Bane 1971) or 2–3 weeks, depending upon water temperature (Moyle 1976). When the offspring are released, they are in the early juvenile stage, similar to other livebearers such as western mosquitofish and tule perch.

Juvenile and adult bay pipefish are slow swimmers and usually orient in horizontal or oblique positions when kept in an aquarium. In the wild, they are often associated with eelgrass and other vegetations in intertidal areas (K. Hieb 1982, 1986, personal communication). They are common in otter trawl collections from the San Francisco Bay and San Pablo Bay (n = 412 from 1980–1995, Baxter *et al.* 1999); however, they are seldom observed in Suisun Bay, perhaps due to the location of the sampling station and dense vegetation. Bay pipefish have small tubular mouths and feed on live crustaceans (Moyle 1976). This species has no sport value; however, dried pipefish and seahorse (*Hypocampus* spp.) are often used as a medicinal ingredient in Asian countries.

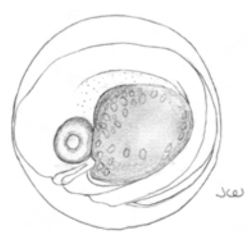


Figure 127.—*Syngnathus leptorhynchus*, bay pipefish egg (dissected from male brood pouch), 1.4 mm (Wang 1986).

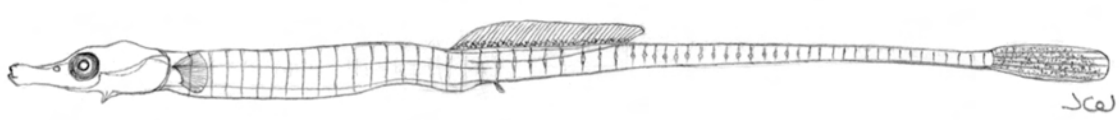


Figure 128.—*Syngnathus leptorhynchus*, bay pipefish juvenile, 47 mm TL (Wang 1986).

Cottidae – Sculpins.— The sculpin family comprises numerous species that have successfully adapted to a wide range of salinities and environments. Approximately 300 species of cottids have been reported from Northern Hemisphere waters of the Pacific and Atlantic Oceans (Bolin 1944). Most species inhabit coastal waters, while some are found only in freshwater. Others migrate between areas of high and low salinities depending on their life stage.

Twenty species of sculpins have been reported in the Sacramento-San Joaquin River sytem and adjacent waters (Miller and Lea 1972, Wang 1986): scalyhead sculpin (*Artedius harringtoni*), smoothhead sculpin (*A. lateralis*), bonyhead sculpin (*A. notospilotus*), rosylip sculpin (*Ascelichthys rhodorus*), sharpnose sculpin (*Clinocottus acuticeps*), woolly sculpin (*C. analis*), calico sculpin (*C. embryum*), mosshead sculpin (*C. globiceps*), bald sculpin (*C. recalvus*), coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*Cottus asper*), riffle sculpin (*Cottus gulosus*), buffalo sculpin (*Enophrys bison*), brown Irish lord (*Hemilepidotus spinosus*), Pacific staghorn sculpin (*Leptocottus armatus*), sailfin sculpin (*Nautichthys oculofasciatus*)[3], tidepool sculpin (*Oligocottus maculosus*), saddleback sculpin (*O. rimensis*), fluffy sculpin (*O. snyderi*), and cabezon (*Scorpaenichthys marmoratus*). Baxter *et al.* (1999) collected nine speciesof cottids from CDFG fish surveys in the San Francisco Estuary during the period 1980 and 1995: Pacific staghorn sculpin, prickly sculpin, bonyhead sculpin, brown Irish lord, red Irish lord (*H. hemilepidotus*), scalyhead sculpin, cabezon, fluffy sculpin, and tidepool sculpin. In the Sacramento-San Joaquin River system, the prickly sculpin, riffle sculpin, and Pacific staghorn sculpin were collected during this study and are discussed in this chapter.

PRICKLY SCULPIN Cottus asper Richardson

SPAWNING

Location	Prickly sculpin spawn in habitats ranging from freshwater to oligohaline in the Sacramento-San Joaquin River system. In the Sacramento River drainage, larvae were collected from the Reclamation's RBRPP, Feather River (including Oroville Reservoir), and the American River (including Folsom Lake and Lake Natoma). In the San Joaquin River drainage, larvae were collected in Kerckhoff Reservoir, Millerton Lake, Mokelumne River (including Lodi Municipal Lake), and the Consumnes River. Spawning also occurs in San Francisco Bay and Delta areas, such as Cache Slough, tributaries of Suisun Bay and Montezuma Slough, Walnut Creek, Napa River, and Sonoma Creek as

[3] Sailfin sculpin has recently been reclassified with the searaven family (Hemitripteridae; Nelson *et al.* 2004).

	well as in Lake Berryessa, Putah Creek, the south Delta, O'Neill Forebay, and San Luis Reservoir.
Season	February through June (Krejsa 1967); mainly in March and April (Moyle 1976); February through May (Millikan 1968); January through May in the Delta and San Joaquin watershed while extending to September in foothill creeks (Wang 1986).
Temperature	8–13°C (Krejsa 1967); ~9–17°C in Millerton Lake (Wang 1986).
Salinity	Brackish and freshwater (McAllister and Lindsey 1960); up to 12 ppt salinity (Millikan 1968); freshwater to intertidal (Moyle 1976); freshwater to oligohaline, such as at Rodeo Lagoon (Wang 1982, 1986).
Substrates	Large cobbles or flat rocks (Krejsa 1967); under surface of rocks, in beer cans, submerged automobile bodies, and other trash (Millikan 1968); under surfaces or crevices of rocky bottoms and banks, jetties; concrete blocks and other artificial substrates (Wang 1986); PVC pipes (R.C. Reyes 2003–2009, personal commnication).
Fecundity	336–5,652 eggs in ovaries and 700–4,000/cluster (Krejsa 1967); 584–10,980 (Bond 1963); 280–7,410, number depending on size and age of female (Patten 1971); 1,094–5,656 (Millikan 1968); ~200 eggs deposited in clusters collected at the CVP/TFCF salvage counts in winter.

EGGS

Shape	Spherical.
Diameter	<1.0 mm (Krejsa 1967); mature ova 1.1–1.3 mm (Millikan 1968); fertilized eggs 1.4–1.6 mm (Wang 1986); eggs collected from the CVP/TFCF salvage counts were 1.2–1.6 mm in diameter.
Yolk	Orange (Krejsa 1967); creamy yellow-white (Millikan 1968); yellowish, partially clear, and partially granular.
Oil globule	One large oil globule (~0.2–0.3 mm in diameter), with many small oil globulets congregating in yolk-sac.
Chorion	Transparent, thick, and hard.
Perivitelline space	~0.1–0.2 mm in width in early developmental stages.
Egg deposition	Eggs deposited in jelly-enclosed cluster (Krejsa 1967); in small clusters.
Adhesiveness	Very adhesive (Krejsa 1967); very adhesive to one another forming a ball of eggs, but less adhesive to substrates (Wang 1986).

Buoyancy	Negatively buoyant or demersal, but easily detached from substrates and then susceptible to bouncing movement with current and tide.

LARVAE

Length at hatching	5–7 mm TL (Krejsa 1967); 5.5–6.3 mm TL (Stein 1972); mainly 4.5–5.0 mm TL (Wang 1986).
Snout to anus length	~38–45% TL for prolarvae; decreasing to ~32–39% TL for postlarvae; 34-38% TL for prolarvae, 33–40% TL for postlarvae (R.C. Reyes 2003–2009, personal communication).
Yolk-sac	Large, spherical to oval, in thoracic region.
Oil globule	Single, usually located anteriorly in yolk-sac, with many small oil globulets.
Gut	Short, coiled in one loop in prolarvae; twisted 1–2 times in postlarvae.
Air bladder	None.
Teeth	Sharp, pointed.
Size at absorption of yolk	5.2–6.0 mm TL (Millikan 1968); 5.0–6.0 mm TL.
Total myomeres	32–37.
Preanal myomeres	8–12.
Postanal myomeres	22–26.
Last fin(s) to complete development	Pelvic.
Pigmentation	Large stellate melanophores at base of pectoral fins, midventrally, and on dorsal surface of gut (near anus); a series of melanophores along postanal region.
Distribution	Larvae are pelagic (Millikan 1968); planktonic, found near surface of water column in shallow inshore and deep open waters of freshwater and oligohaline regions (Broadway and Moyle 1978, Wang 1986); larvae were also collected in the higher saline waters of San Pablo Bay and San Francisco Bay (Baxter *et al.* 1999); also common in higher elevation lakes, such as Millerton Lake (Lambert 1979).

JUVENILES

Dorsal fin rays	VII–X, 19–23 (Moyle 1976); VII–XI for the first dorsal fin (McAllister and Lindsey 1960); 19–22 for the second dorsal fin (Scott and Crossman 1973).

Anal fin rays	15–18, mostly 17–18 (Moyle 1976); 14–18 (Scott and Crossman 1973); mainly 17–18 for the fish collected from the CVP/TFCF.
Pectoral fin rays	15–18 (Moyle 1976, Scott and Crossman 1973).
Mouth	Terminal.
Vertebrae	34–36 (Scott and Crossman 1973); 34–37 (Wang 1986).
Distribution	Demersal (Broadway and Moyle 1978), widely distributed in Sacramento-San Joaquin River system, including foothill areas of the San Joaquin River, such as Millerton Lake (Moyle 1976); Kerckhoff Reservoir and below Kerckhoff Dam of San Joaquin River (Wang 1986); in the Central Valley floor waters, they are common in the reservoirs via California water project systems (Moyle 2002).

LIFE HISTORY

Prickly sculpin ranges from Kenai Peninsula, Alaska, southward along the Pacific coast to Ventura River in southern California (Krejsa 1967, Moyle 2002). Locally, prickly sculpin is very common in the Sacramento and San Joaquin Rivers and Estuary (Wang 1986) and in almost every tributary adjacent to the estuary (Leidy 1984). Its present range may be much wider than its historical range because its planktonic larvae can be widely distributed via California water project systems (*e.g.*, North Bay Aqueduct, California Aqueduct, and Friant-Kern Canal), which divert water to various portions of the Central Valley, reservoirs, lakes, and ponds. There is an established population of prickly sculpin in the O'Neill Forebay of San Luis Reservoir, which served as evidence of larvae transport via the water projects (Hess *et al.* 1995).

Prior to the spawning season (late fall to early winter), males move into spawning habitats in freshwater or brackish water, later to be joined by females (Krejsa 1967, McAllister and Lindsey 1960). Nonmigratory populations of prickly sculpin exist in the Delta, rivers, creeks, and land-locked lakes and reservoirs. Krejsa (1967) reported that spawning migration is limited to coastal populations and does not occur in inland populations. Because prickly sculpin do not spawn in high saline water, coastal populations migrate upstream to spawn. Their planktonic larvae are then carried to San Pablo and San Francisco Bays from the upper estuary. The juveniles initially settle in down-bay locations but ascend to the upper estuary in summer and fall. The inland nonmigratory populations spawn in January (larvae observed in early February) and into spring in the Sacramento-San Joaquin River system and Central Valley floor. Spawning may also extend into summer in foothill creeks where water temperatures remain cool (*e.g.*, San Joaquin River downstream of Kerckhoff Dam).

Egg clusters are deposited on the ceiling of crevices of rocks or jetties, or in other hollow submerged objects. The male parent guards the nest and aerates the eggs by fanning with his large pectoral fins until the eggs hatch (Krejsa 1967). Mating occurred mostly at night or in darkened conditions. Eggs adhere strongly to one another, but less so to substrates. Clusters of eggs (usually about 200) in late developmental stages were collected at the CVP/TFCF during winter months, indicating that sculpin eggs can detach from the substrate during incubation and eventually disperse to various locations.

Although newly-hatched prickly sculpin larvae are pelagic and usually able to swim immediately (Krejsa 1967, Millikan 1968), in laboratory, they sometimes remained in the nest for a few hours until their bodies straightened and they were capable of free-swimming. Prickly sculpins do not have air bladders, and the larvae have to swim at the neuston level, possibly using surface tension to maintain position (Mason and Machidori 1976). Larvae remain planktonic and near the water surface for 30–35 d (Krejsa 1967, Mason and Machidori 1976) or 3–5 weeks (McLarney 1968). Prickly sculpin larvae were among the most abundant fish collected in plankton tows in Suisun Bay and the Delta from March through May (Wang 1986). They were also common in San Pablo Bay and were collected in San Francisco Bay (Baxter *et al.* 1999).

Juveniles become demersal at approximately 15 mm TL (Broadway and Moyle 1978) and are commonly collected in shallow water over various bottom substrates and shelters. They may remain in the upper estuary until early summer of the following year, and then ascend into tributaries and upriver. A similar behavior was reported for migratory populations in British Columbia (Krejsa 1967, Mason and Machidori 1976). This upstream and downstream migration of the prickly sculpin is most likely genetically determined rather than a learned behavior (McAllister and Lindsey 1960). Both migratory and nonmigratory populations are observed in the Sacramento-San Joaquin Estuary. However, the downstream migration as described by Shapovalov and Taft (1954) may not apply (Baxter *et al.* 1999). Small juveniles ($\leq$20 mm TL) are often collected in the spring from the salvage samples conducted at the CVP/TFCF, suggesting that young sculpin are moving around or foraging in the Delta.

Juvenile prickly sculpin feed on planktonic crustaceans, insects, different kinds of benthic invertebrates (Cook 1964, Millikan 1968, Moyle 1976), and sometimes larval fish (Herbold 1987).

Prickly sculpin mature in their second to fourth year (Millikan 1968, Patten 1971). They live and take shelter on the bottom and are seldom seen. They are important forage for salmon, trout, bass, and birds (Moyle 1976). Moyle (1976) suggested that the degree of genetic isolation of various populations of prickly sculpin should be examined in order to develop conservation strategies.

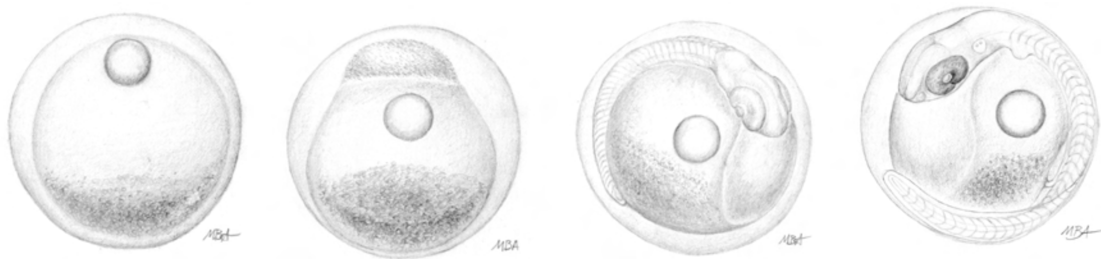


Figure 129.—*Cottus asper*, prickly sculpin eggs, (left to right): newly fertilized egg 1.4 mm, morula 1.4 mm, early embryo 1.5 mm, and late embryo 1.5 mm (Wang 1986).

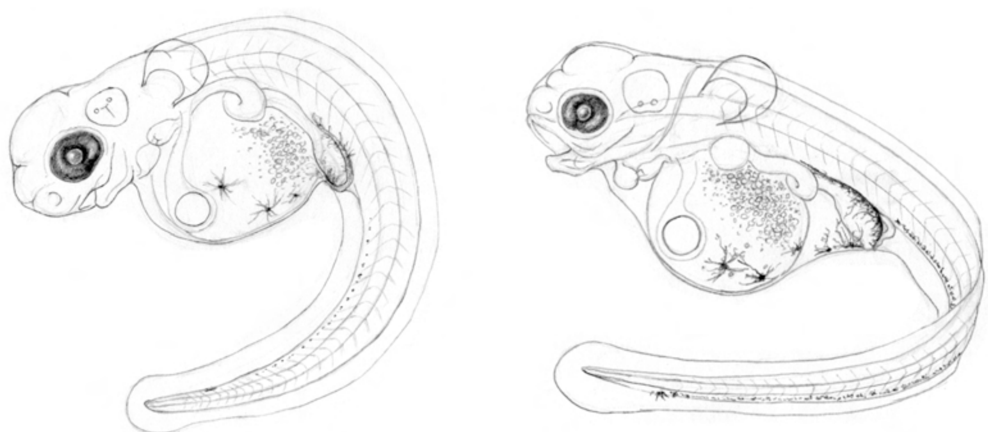


Figure 130.—*Cottus asper*, prickly sculpin newly-hatched prolarvae, 4.5 mm TL (Wang 1986).

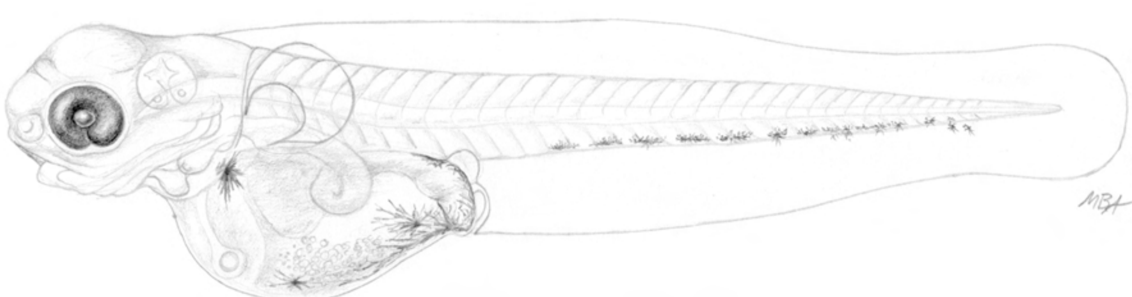


Figure 131.—*Cottus asper*, prickly sculpin prolarva, 5.5 mm TL (Wang 1986).

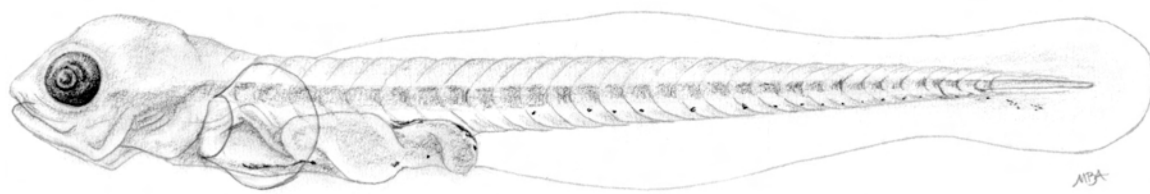


Figure 132.—*Cottus asper*, prickly sculpin postlarva, 6 mm TL (Wang 1986).

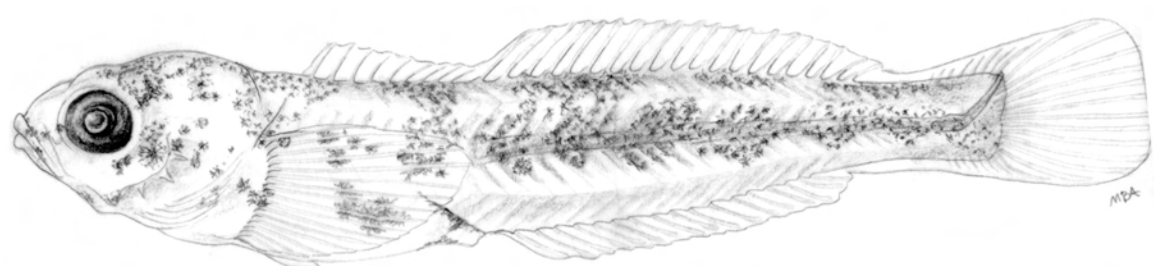


Figure 133.—*Cottus asper*, prickly sculpin 11.4 mm TL (Wang 1986).

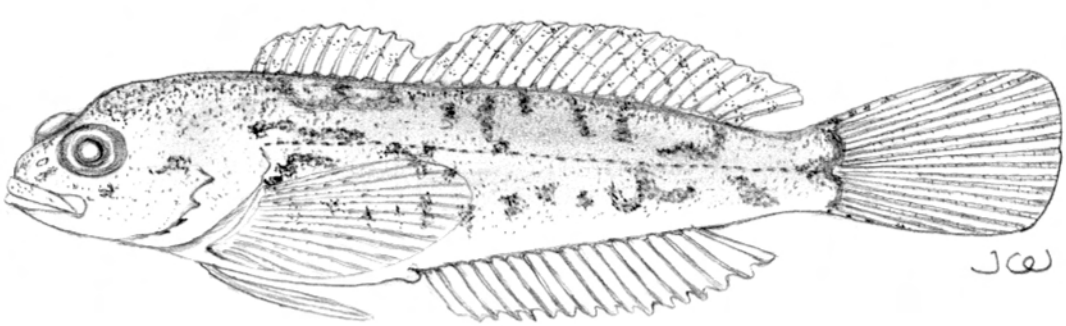


Figure 134.—*Cottus asper*, prickly sculpin juvenile, 34.5 mm TL (Wang 1986).

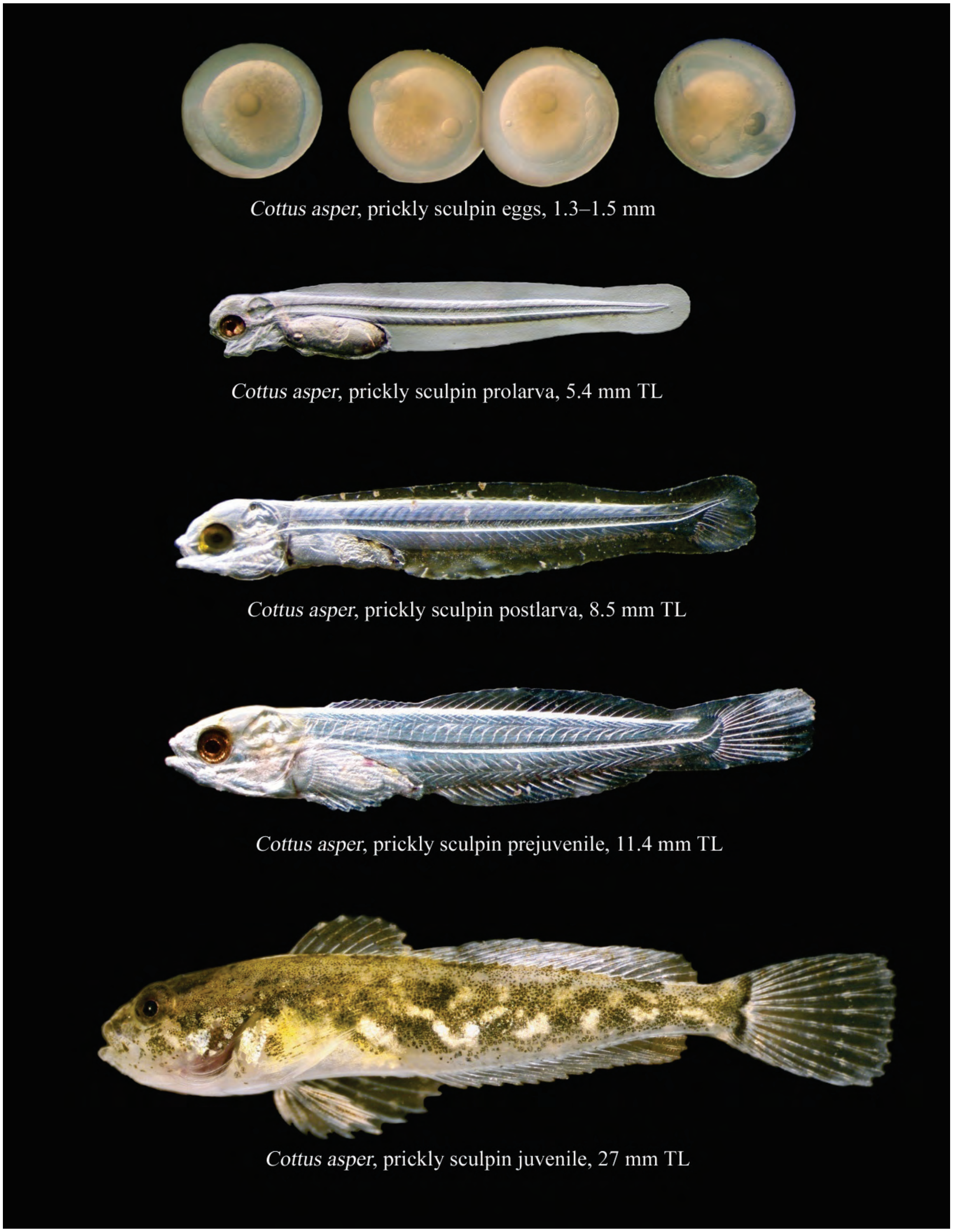


Figure 135.—*Cottus asper*, prickly sculpin.

RIFFLE SCULPIN *Cottus gulosus* (Girard)

SPAWNING

Location	Mostly in cool-water streams with sandy to rocky bottoms. Specific locations where spawning is reported include Capell Creek (a distributary of Lake Berryessa), Dry Creek (a tributary of Putah Creek; Marchetti and Moyle 2000), Olema Creek (a tributary of Tomales Bay), and Big Chico Creek and Mud Creek (tributaries of the Sacramento River).
Season	February–April (Moyle 1976); February–May (Bond 1963, Millikan 1968, Wang 1986).
Temperature	10–12°C (Millikan 1968); ~10–17.7°C recorded at Capell Creek (Wang 1986).
Salinity	Freshwater to 12 ppt (Millikan 1968); freshwater.
Substrates	Rotting logs (Millikan 1968); gravel, rocks, and undercut vegetation.
Fecundity	104 to 449 (Millikan 1968); nests can contain more than 1,000 eggs with deposits made by more than one female (Moyle 2002).

EGGS

Shape	Spherical.
Diameter	2.3–2.6 mm in diameter (Millikan 1968); mature eggs 2.0–2.2 mm.
Yolk	Pale yellow to deep orange (Millikan 1968); yellowish.
Oil globule	Single, large, 0.25–0.4 mm in diameter (Wang 1986); also there is a white spot which contains many small oil globulets (Millikan 1968).
Chorion	Thick, smooth, except the adhering spot.
Egg deposition	Deposited in small clusters (Millikan 1968).
Adhesiveness	Adhesive (Millikan 1968).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	~6.0–6.5 mm TL (Wang 1986); possibly >6.5 mm.
Snout to anus length	~42–45% TL for prolarvae and early postlarvae.
Yolk	Spherical to oval, very large, in thoracic region.
Gut	Short, forms a single loop in late prolarvae and early postlarvae.

Air bladder	None.
Teeth	Small and pointed, appear in postlarvae.
Size at absorption of yolk	~7.0 mm TL, and varied by location and water temperature.
Total myomeres	31–34.
Preanal myomeres	10–12.
Postanal myomeres	20–22.
Last fin to complete development	Pelvic.
Pigmentation	In prolarvae, a few large stellate melanophores are scattered on head, yolk-sac, and dorsum of gut, and a series of melanophores ventrally along the postanal region. In postlarvae, dark and large melanophores are scattered on the head and body. The density of pigmentation varies among individuals by time and location.
Distribution	Benthic (Millikan 1968). Found in shallow, moderate to fast running streams and pools (such as Capell Creek); in the lower end of pools (as in Dry Creek, tributary to Putah Creek); cool, well-oxygenated freshwater streams.

JUVENILES

Dorsal fin rays	VII–VIII, 16–19 (Moyle 1976); V–VIII, 17–18 from Capell Creek (Wang 1986).
Anal fin rays	12–16, and mainly 13–15 (Moyle 2002); 14–16, mainly 15.
Pectoral fin rays	15–16 (Moyle 1976); 14–17 (Bond 1973, Wang 1986).
Mouth	Large, maxillary reaches near edge of eye (Moyle 1976); large, terminal or slightly subterminal.
Vertebrae	32–34.
Distribution	On the bottom of cool streams, pool and lakes, with sand gravel, rock, or clumps of vegetation roots. Some juveniles do not take shelter, resting on rocks instead; may occur in the Delta in winter.

LIFE HISTORY

Riffle sculpin is a freshwater cottid found in the Sacramento-San Joaquin River system and in coastal streams of California from Morro Bay to the Noyo River (Moyle 1976). Riffle sculpin populations also occur further north in coastal streams from Coquille River, Oregon, to Puget Sound, Washington (Bond 1963, 1973). Populations endemic to California may be a separate species from the Oregon-Washington populations due to a long period of isolation (Moyle 2002). In the study area, riffle sculpin was collected mainly in the surrounding drainages of the Sacramento-San Joaquin River system, such as Putah Creek, Lake Berryessa, and Olema Creek. Adult riffle sculpin were observed occasionally at the CVP/TFCF fish salvage during winter months. It is uncertain whether riffle sculpins migrate during their spawning season. This species was not collected in lowland, altered creeks, and manmade ponds in the Delta (Wang 1986).

Spawning occurs from February through April (Moyle 1976). In this study, both ripe riffle sculpin and prolarvae were observed and collected in May (Capell Creek/Lake Berryessa), suggesting that the spawning period in the study area may extend later than in the colder waters of Oregon and Washington (Bond 1963, Millikan 1968). The female deposits small clusters of eggs on the undersides of rocks and in crevices of rotting logs (Bond 1963, Millikan 1968). Ova of different sizes in the ovaries, indicate that a female may deposit several batches of eggs during the spawning season. Mature ova were 2.0–2.6 mm in diameter (Millikan 1968) which is large for a small freshwater cottid. Food availability in small streams is often minimal. Therefore, possessing more stored energy in the form of larger ova and yolk-sacs is beneficial (Millikan 1968). Compared with the prickly sculpin, riffle sculpin prolarvae collected in Lake Berryessa and Putah Creek have yolk-sacs that are two to three times larger and a total length that is about 1 mm longer (riffle sculpin hatch at 6.0–6.5 mm TL, prickly sculpin at 4.5–5.0 mm TL).

Riffle sculpin larvae are planktonic and have similar dispersing mechanism similar to other cottids. Riffle sculpin larvae are initially benthic after the yolk-sac is absorbed (Millikan 1968). Although newly-hatched larvae are planktonic, Wang (1986) initially questioned this behavior because of prolarval collections from shallow waters in both Capell Creek and Olema Creek . Riffle sculpin prolarvae have also been collected in deeper water along with prickly sculpin larvae in Putah Creek (Marchetti and Moyle 2000; M.P. Marchetti 1998, personal communication).

Both riffle sculpin larvae and early juveniles were captured with fine-mesh beach seines (0.5 mm) in shallow streams. Juvenile riffle sculpins cling to gravel substrate or rest on the sandy bottom, seldom moving.

The principal food of juvenile riffle sculpins consists of amphipods and other crustaceans (Millikan 1968). Large juveniles feed on mayflies, midges, other insect larvae, and fish eggs (Baltz *et al.* 1982, Wang 1986).

Riffle sculpin reach maturity at the end of their second year (Millikan 1968). Some individuals may descend to the Delta for foraging before moving upstream to spawn and some may be flushed by winter floods and end up in the Delta. There is, however, no clear picture of migration. Riffle sculpins have no commercial value because of their small size, but they may be convenient forage for predatory stream fishes.

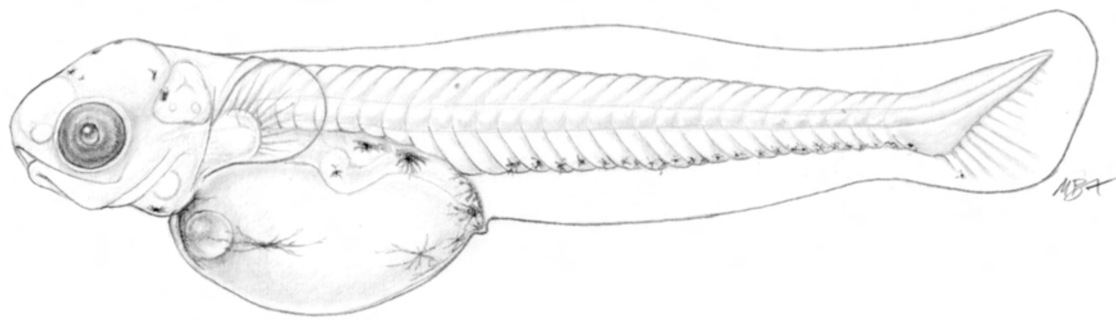


Figure 136.—*Cottus gulosus*, riffle sculpin prolarva, 6.5 mm (Wang 1986).

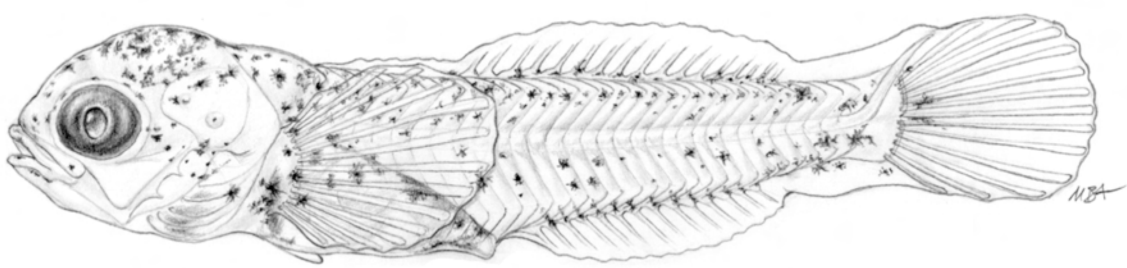


Figure 137.—*Cottus gulosus*, riffle sculpin postlarva, 7.2 mm TL (Wang 1986).

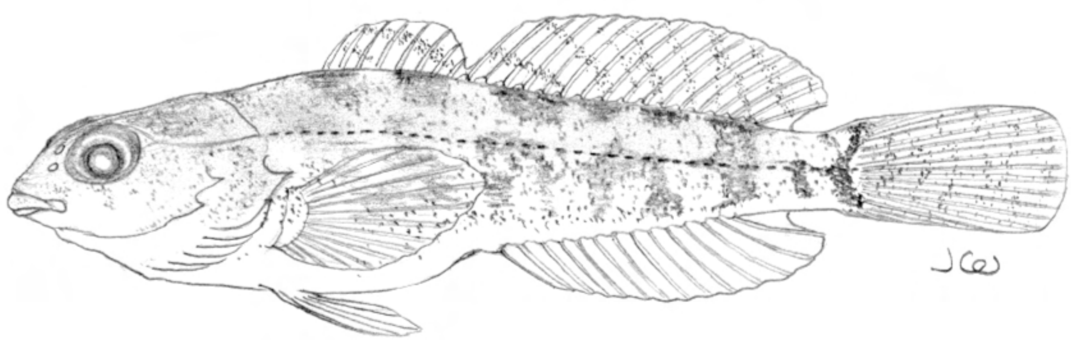


Figure 138.—*Cottus gulosus*, riffle sculpin juvenile, 22.7 mm TL (Wang 1986).

PACIFIC STAGHORN SCULPIN Leptocottus armatus Girard

SPAWNING

Location	Shallow coastal waters, bays, inlets, sounds, and sloughs (Jones 1962). Locally, they spawn in San Francisco Bay, San Pablo Bay, Tomales Bay, and lower Napa River.
Season	October–March, with a peak in January and February (Jones 1962); February (Hart 1973); October–April (Wang

	1986); based on collection of small larvae, spawning may extend from October to May (Baxter *et al.* 1999).
Temperature	~15°C (Jones 1962); ~9–15.2°C.
Salinity	Optimum 27–28.3 ppt (Sumner *et al.* 1914); oligohaline–seawater (Jones 1962); mainly in mesohaline to polyhaline.
Substrates	Various; muddy sloughs, firm substrates, rocky area of intertidal zones.
Fecundity	~2,000–11,000, with an average of 5,000/year (Jones 1962); mean fecundity 3,200 (Tasto 1975).

EGGS

Shape	Spherical, slightly flattened at adhering area (Jones 1962).
Diameter	Mature eggs, 1.36–1.5 mm (Jones 1962); fertilized eggs in late embryo stage collected from Rodeo Lagoon, usually 1.4–1.5 mm, (Wang 1986).
Yolk	Creamy white to yellow or orange to deep orange, containing a mass of flocculent material (Jones 1962); yellow and granular (Wang 1986).
Oil globule	1–7 oil globules (Jones 1962); fertilized egg with a large oil globule (~0.3 mm in diameter).
Chorion	Transparent, smooth except for the adhering area.
Perivitelline space	Prominent (Jones 1962); 0.1–0.2 mm in width.
Egg deposition	Deposited in clusters (Jones 1962); in clusters with vegetation attached.
Adhesiveness	Adhesive (Jones 1962); adhesive to one another, less so to substrates.
Buoyancy	Negatively buoyant or demersal (Jones 1962).

LARVAE

Length at hatching	3.8–4.9 mm TL (Jones 1962); usually 4.5 mm TL.
Snout to anus length	~37–40% TL for prolarvae and postlarvae (Wang 1986).
Yolk-sac	Spherical, large (Jones 1962); spherical to oval, large, in thoracic region.
Oil globule	Single, located anteriorly in yolk-sac, ~0.3 mm in diameter (Jones 1962, Wang 1986).
Gut	Short, straight in prolarvae, and coiled and twisted in late prolarvae and early postlarvae.
Air bladder	None.
Teeth	Small, less pointed in postlarvae.
Size at absorption of yolk	~5.5–6.0 mm TL (Wang 1986).

Total myomeres	32–37.
Preanal myomeres	8–12.
Postanal myomeres	23–28.
Last fin(s) to complete development	Pelvic.
Pigmentation	In prolarvae, 5–8 dark lobed bands (condensed melanophores) shade the dorsal portion of the body cavity and several large stellate melanophores are present on cephalic region. A dark horizontal bar is on snout; small melanophores in thoracic and postanal region ventrolaterally in postlarvae. At least three distinctive dark blotches on the middorsal region and may have irregular blotches on side of body.
Distribution	Swimming near the water surface (Jones 1962); planktonic, mainly in polyhaline and mesohaline; some found in oligohaline waters of Tomales Bay, Moss Landing, and Elkhorn Slough.

JUVENILES

Dorsal fin rays	VI–VII, 15–20 (Bolin 1944, Miller and Lea 1972, Hart 1973); VI–VIII, 15–20 (Moyle 1976).
Anal fin rays	15–20 (Bolin 1944, Hart 1973); 14–20 (Miller and Lea 1972); 17 (Moyle 1976); ~19 (Hart 1973).
Pectoral fin rays	17–20 (Bolin 1944, Miller and Lea 1972); ~19 (Hart 1973).
Mouth	Large, maxillary reaches to anterior or middle margin of pupil (Bolin 1944); maxillary passes the eye (Moyle 1976).
Vertebrae	35–38 (Miller and Lea 1972).
Distribution	Bottom dwelling throughout the estuary (Jones 1962); in tidal oligohaline and freshwater of the Delta, but more abundant in the higher saline waters of San Francisco Bay and San Pablo Bay.

LIFE HISTORY

Pacific staghorn sculpin is a euryhaline species (Jones 1962) found from Quintin Bay, Baja California, to Karluk (on Kodiak Island), Alaska (Bolin 1944, Jones 1962). Juveniles and early adults are common in the freshwater portions of the estuaries (Baxter *et al.* 1999). Locally, this species is abundant in San Francisco Bay and San Pablo Bay (Ganssle 1966, Aplin 1967), especially in San Pablo Bay (Baxter *et al.* 1999). It is also collected in Tomales Bay (Jones 1962), mainly in the areas between the inlet of the bay and the mouth of Walker Creek. Juveniles ascend to Suisun Bay (Baxter *et al.* 1999), and they are reported as far as the CVP/TFCF of the south Delta. This species has not been collected in Barker Slough (NBA Project) of the lower Sacramento River (CDFG fish E and L survey).

Spawning behavior of Pacific staghorn sculpin is not fully understood (Jones 1962, Marliave 1975) but its early development and early life history have been well documented by Jones (1962). Based on egg and larval collections, spawning occurs October through early April in polyhaline and mesohaline waters of the estuary (Wang 1986), and may extend to May (Baxter *et al.* 1999). The peak of spawning occurs in cool waters during winter. Clustered eggs were observed on muddy, sandy, or rocky substrates, such as in Tomales Bay. Gravid females contain eggs of similar size and development suggesting that Pacific staghorn sculpin probably spawn only once during the breeding season (Jones 1962, this study). Females may reach maturity at different times. Because eggs are clustered and are adhesive, males probably guard the nest. Live clustered eggs have been found in the lower mesohaline portions of Rodeo Lagoon during winter months, although their origin is not known. Eggs hatch in 9–14 d at 15°C in the laboratory (Jones 1962).

Although newly-hatched Pacific staghorn sculpin larvae immediately swim to the surface in the laboratory (Jones 1962), prolarvae were seldom in plankton samples in this study suggesting that prolarvae with their large yolk-sacs may remain on the bottom for a short time before becoming planktonic swimmers. The majority of Pacific staghorn sculpin larvae were collected from higher saline waters of the estuary, such as south and central San Francisco Bay (Wang 1986, Baxter *et al.* 1999). The presence of postlarvae and early juveniles in San Pablo Bay, lower Napa River, Suisun Bay, and further up the estuary may be due to tidal drift. Larvae disperse before descending to the bottom. Their planktonic stages may provide forage for other fish species.

Few juveniles larger than 10–15 mm TL were caught in plankton samples, suggesting that they have become demersal by this size. Moyle (1976) reported movement of juveniles up the estuary. Only juvenile life stages were observed at the CVP/TFCF in the south Delta. Juveniles prefer shallow inshore water and sloughs.

Principal prey includes amphipods (*Corophium* spp.), nereid worms, small anchovy (Jones 1962), and aquatic insects in freshwater (Moyle 2002). Juveniles are ambushing predators.

Pacific staghorn sculpins become sexually mature at age 1 (Jones 1962) or near the end of their first year of life (Tasto 1975). Adults leave the shallow spawning ground to inhabit deep offshore water after spawning (Tasto 1975). They are used as bait by sport fishermen.

Pacific staghorn sculpins cohabit with gobies and other sculpins. Brittan *et al*. (1970) mentioned an interspecific competition between the yellowfin goby and Pacific staghorn sculpin in Palo Alto Yacht Harbor, San Francisco Bay. There is, however, probably little or no competition because these species do not share the same habitat throughout most of their lifespan. It is only during the winter spawning season that competition for resources may occur.

Figure 139.—*Leptocottus armatus*, Pacific staghorn sculpin late embryo, 1.4 mm (Wang 1986).

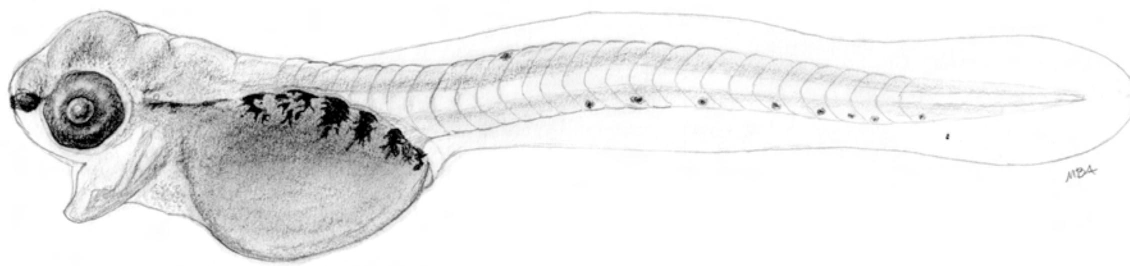


Figure 140.—*Leptocottus armatus*, Pacific staghorn sculpin prolarva, 5 mm TL (Wang 1986).

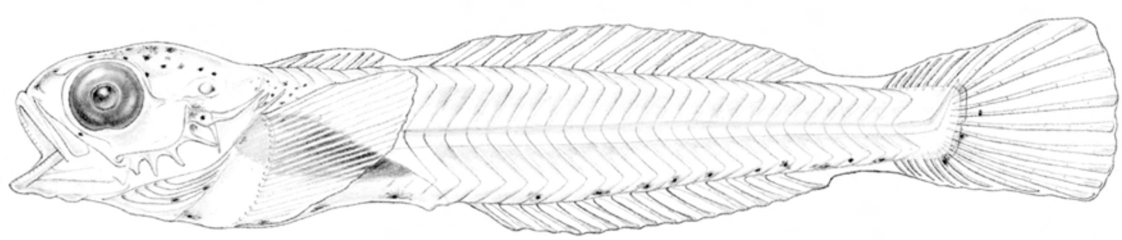


Figure 141.—*Leptocottus armatus*, Pacific staghorn sculpin postlarva, 12 mm TL (Wang 1986).

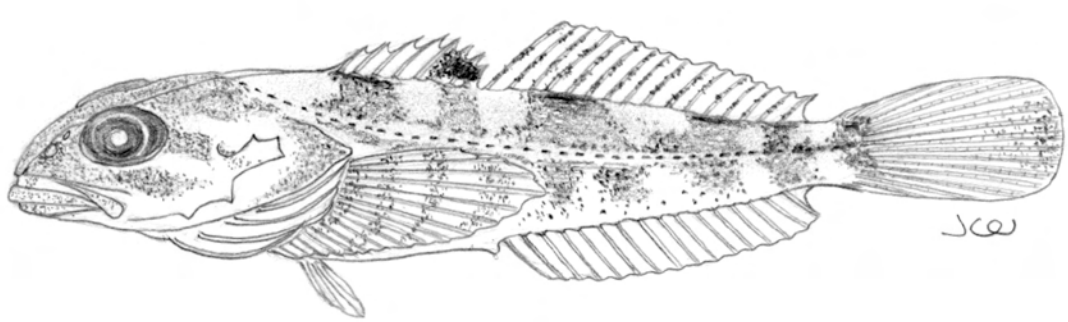


Figure 142.—*Leptocottus armatus*, Pacific staghorn sculpin juvenile, 43 mm TL (Wang 1986).

Taxonomic Characteristics of Cottids Present in the Study Area

	Prickly sculpin	Riffle sculpin	Pacific staghorn sculpin
Eggs			
Diameter (mm)	1.2–1.6	2.0–2.6	1.4–1.5
Larvae			
Yolk-sac pigmentation	Little, mid-ventral	Little, mid-ventral	~7 dark bands on side
Yolk-sac size	Usually small	Very large	Usually small
Juveniles			
Anal fin	15–18, usually 18	14–16, usually 15	14–20, usually 15–17
Mouth- specific characteristics	Small, before eye Long anal base	Small, before eye Large dark blotch on D1	Large, passing eye "Antlers" protrude from preopercle
Body pigmentation	Mottled	Spotted	Mottled

Moronidae – Temperate Basses.— Two members of the temperate bass family have been introduced into California: striped bass (*Morone saxatilis*) and white bass (*M. chrysops*). Striped bass was introduced from the east coast into the Sacramento-San Joaquin Estuary in 1879 and 1882 (Dill and Cordone 1997) and currently support one of the most popular sport fisheries in the bay, Delta, and associated water systems (Kohlhorst 1999). White bass was introduced by the CDFG into Nacimiento Reservoir, San Luis Obispo County, in 1965 (von Geldern 1966). It was also introduced by anglers to Pine Flat Reservoir of Kings River, Fresno County (Moyle 2002). This species has not been reported in the study area.

STRIPED BASS *Morone saxatilis* (Walbaum)

SPAWNING

Location

In flooded islands of the Delta (Scofield 1931), lower Sacramento and San Joaquin Rivers, Piper Slough, Three Mile Slough, Big Break, Fisherman's Cut, Middle River, lower Mokelumne River, Sacramento River in the vicinity of Marysville, San Joaquin River in the vicinity of San Joaquin City (Woodhull 1947), mouth of the Middle River, lower part of Old River, False River, Rio Vista to Verona, Suisun Slough (Chadwick 1958), Rio Vista to Butte City in the Sacramento River, Antioch to Venice Island and Stockton to Mossdale in the San Joaquin River (Farley 1966); mostly between Colusa and Feather River in the Sacramento River (Moyle 2002). Striped bass eggs were

	collected at the CVP/TFCF (Hiebert *et al.* 1995, Siegfried *et al.* 2000). Some spawning also occurred in the south Delta in the 1990s and a landlocked population occasionally spawned in Millerton Lake.
Season	April–May (Scofield 1931); April–June (Erkkila *et al.* 1950, Farley 1966, Calhoun and Woodhull 1948, Calhoun *et al.* 1950, Chadwick 1958, Moyle 1976); early April to late June or early July, depending on flow and water temperature.
Temperature	14.4–23.9°C (Scofield 1931, Calhoun *et al.* 1950); ~19.5–20.0 (Woodhull 1947); 14.4–15.6°C (Chadwick 1967); 15–20°C (Moyle 2002); majority of spawning at 15–18°C.
Salinity	Mostly in freshwater (Raney 1952); some in brackish water (Woodhull 1947); from tidal oligohaline to tidal freshwater to nontidal freshwater.
Substrates	None.
Fecundity	243,000–1,400,000 for 4–8 year old females (Stevens *et al.* 1985); wide difference of estimation because both mature and immature eggs are found in the same ova and because of a wide range of sizes for breeding females (Hardy 1978b).

EGGS

Shape	Spherical (Pearson 1938, Woodhull 1947).
Diameter	3.2 mm (Murawski 1969) to 4.6 mm (Albrecht 1964). For California population, mean diameter 3.3 mm (Woodhull 1947), with a range of 2.5 mm (collected in Suisun Bay in CDFG striped bass E and L survey) to 4.2 mm (at Bryte, Sacramento River).
Yolk	Heavily granulated (Pearson 1938); lightly granulated (Hardy 1978b); smooth to granulated.
Oil globule	0.56 mm in diameter (Pearson 1938); may have additional oil globules (Hardy 1978a, b); single and located opposite to the blastoderm and suspended on the top in the embryo.
Chorion	Transparent (Pearson 1938); smooth, transparent and elastic.
Perivitelline space	Very wide, ~65–85% of egg diameter (Mansueti 1958); ~50% and greater in early development.
Egg deposition	Eggs broadcasted singly but large numbers of eggs released in a short amount of time.
Adhesiveness	None (Pearson 1938).

Buoyancy	Slightly heavier than freshwater (Raney 1952); suspended near bottom (Woodhull 1947); suspended by current; live eggs near bottom and dead eggs close to surface.

LARVAE

Length at hatching	2.5 mm TL (Pearson 1938); 2.0–3.7 mm TL and up to 4.0 mm TL (Mansueti and Mansueti 1955, Mansueti 1958); 1.7–3.0 mm TL (Lippson and Moran 1974); 2.9–5.0 mm TL (Wang and Kernehan 1979); ~3.0–4.0 mm TL in CDFG striped bass E and L survey (newly-hatched prolarvae; eye was not pigmented).
Snout to anus length	54.7% TL for larvae at 5.5–6.0 mm TL (Mansueti and Hollis 1963); 51–59% TL for both prolarvae and postlarvae.
Yolk-sac	Protrudes forward past head or at least anterior to eye (Pearson 1938); large and oblong with cylindrical recess.
Oil globule	Large, near front of yolk-sac.
Gut	Intestine distinctly folded (Hardy 1978b); initially straight, and then becoming S-shaped with a twist.
Air bladder	Shallow, located near pectoral fin in prolarvae; shifting to midway between pectorals and anus in postlarvae.
Teeth	Sharp, conical, present in postlarvae (Mansueti 1958); pointed, sharp, formed in one row in postlarvae.
Size at absorption of yolk	5.0–6.5 mm TL (Mansueti 1958); mostly 6.0–7.0 mm TL and may vary considerably according to location and water temperature.
Total myomeres	17–25, with an average of 22 (Mansueti 1958); 22–25, usually 24 (in postlarvae when myomeres fully developed).
Preanal myomeres	8–13 (Mansueti 1958); 8–10 (Mansueti and Hollis 1963); 11–13, with a mean of 12 (Hardy 1978b); 11–13 and mostly 12 for postlarvae in the Sacramento-San Joaquin Estuary.
Postanal myomeres	9–15 (Fowler 1911); 9–13 (Mansueti 1958); 11–13 and mostly 12 for postlarvae in the Sacramento-San Joaquin Estuary.
Last fin (s) to complete development	Pelvic.
Pigmentation	In prolarvae, scattered melanophores on entire body, more along yolk-sac and ventrolaterally in postanal region. In postlarvae, large stellate melanophores are found in the lower jaw and isthmus, thoracic, on dorsum of gut, and ventrolaterally in postanal region.

Distribution	Both shallow and open waters of the lower reaches of the Sacramento and San Joaquin Rivers, the Delta, Suisun Bay, Montezuma Slough, and Carquinez Strait. Larvae were found in the Carquinez Strait and the eastern portion of San Pablo Bay during a period of flooding (CDFG striped bass E and L survey, 1988–1995).

JUVENILES

Dorsal fin rays	West coast population: IX, I–II, 12 (Miller and Lea 1972); VIII–X, I, 10–13 (Hart 1973); IX–X, I–II, 11–12 (Moyle 2002). In Chesapeake Bay: IX–X, I, 11–12 (Hildebrand and Schroeder 1928); along east coast: D 1: VIII–IX (Merriman 1940); D 2: I, 9–14 (Raney and Woolcott 1955).
Anal fin rays	West coast population: III, 9–11 (Miller and Lea 1972, Moyle 2002); III, 7–13 (Hart 1973). In Chesapeake Bay: III, 10–11 (Hildebrand and Schroeder 1928).
Pectoral fin rays	West coast population: 16–17 (Miller and Lea 1972); 13–17 (Moyle 2002); along east and southeast coasts: 13–19 (Merriman 1940, Raney and Woolcott 1955).
Mouth	Large, oblique, lower jaw projecting, maxillary extends to the middle of the eye (Hildebrand and Schroeder 1928); terminal and large (Moyle 2002); terminal for small juveniles, lower jaw is gradually projecting and mouth slightly oblique in large juveniles.
Vertebrae	24–25 (Truitt 1936, Merriman 1940); 24 (Scott and Crossman 1973); 25 (Mansueti 1958); 24 in California population (Miller and Lea 1972).
Distribution	Sacramento-San Joaquin Estuary and its large tributaries (such as Napa River and Mokelumne River), in the Delta and its irrigation ditches; O'Neill Forebay, San Luis Reservoir, and further into southern California (via California aqueduct system). They are also stocked into some large Central Valley reservoirs such as Millerton Lake by CDFG in support of a sport fishery (Moyle 2002).

LIFE HISTORY

Striped bass is an anadromous species, inhabiting marine and estuarine waters from the St. Lawrence River to the St. Johns River, Florida, and along the Gulf coast to Louisiana (Raney 1952). There are many races of this species within its southeastern distribution (Raney 1954, Raney and Woolcott 1955). Striped bass was introduced to California in 1879 and 1882 (Scofield 1931, Skinner 1962). On the west coast, it has been recorded from just south of the California-Mexico border to Barkley Sound, British Columbia (Miller and Lea 1972). It is collected in the Sacramento-San Joaquin River estuary and

Delta, Tomales Bay, Moss Landing, Elkhorn Slough, and in land-locked waters such as O'Neill Forebay, San Luis Reservoir, and the Millerton Lake.

Two breeding locations are known on the west coast: Coos Bay (Oregon) and the Sacramento-San Joaquin Estuary (Moyle 2002). Spawning in the Sacramento-San Joaquin Estuary occurs from April through June, peaking in early May in the San Joaquin River and the Delta, while peaking in late May or early June in the Sacramento River (Chadwick 1958, this study). Warmer water temperatures in the Delta and lower San Joaquin River probably promote early spawning. Time and location of spawning are closely correlated with the temperature, flow, and the salinity of the two rivers (Turner 1972, Turner and Chadwick 1972). The flows from both rivers are extremely variable and mostly controlled by an extensive series of dams and reservoirs throughout the watershed. Higher riverflows increase spawning habitat and generally yield a strong year class (Stevens 1977).

A land-locked striped bass population exists in Millerton Lake (Moyle 1976). However, no fertilized striped bass eggs have been collected there (Lambert 1979). Ripe male striped bass were collected in upper Millerton Lake with gill-nets during the period 1979–1981 (Ecological Analysts, Inc.). A few unfertilized eggs were also collected in the lake in August 1980. In the mid-1980s to late-1990s, more ripe male striped bass were collected at Fine Gold Creek, a tributary of Millerton Lake, by electrofishing. However, no ripe female striped bass were collected (PG&E sampling of the Kerckhoff 2 Hydroelectric Project) and Wang (1986) questioned the reproductive successfulness of this land-locked population of striped bass. However, after 1986, juvenile striped bass were collected by electrofishing on several occasions. At this point, CDFG's striped bass stocking program in Millerton Lake had already ceased suggesting the possibility that female striped bass can reach maturity in this land-locked environment.

Striped bass eggs are slightly heavier than freshwater (Raney 1952) and have a tendency to sink. Striped bass spawn in areas with good flow and/or tidal actions, providing increased agitation and aeration to the eggs and help keep them in suspension. A large perivitelline space in the eggs enables them to absorb the shock of bouncing. Eggs generally hatch in 2 d at 17–18°C (Pearson 1938, Raney 1954, Mansueti 1958, Doroshov 1970).

Newly-hatched larvae, with unpigmented eyes, mostly lie on the bottom (Rinaldo 1971), but may ascend into the water column when they are disturbed (Mansueti 1958). In plankton samples, opossum shrimp (*Neomysis mercedis*) devouring newly-hatched striped bass larvae suggests they are not good swimmers. Prolarvae swim into the water column within 3–4 d after hatching.

Postlarvae have been observed in the lower reaches of the Sacramento and San Joaquin Rivers, and are continuously carried into the Delta, entrapment zone, and upper bays (Calhoun and Woodhull 1948, Erkkila *et al.* 1950) where they are abundant (Chadwick 1958, Farley 1966). Apparently, the oligohaline entrapment zone serves as a very important nursery ground for postlarval and juvenile striped bass. They were very abundant in Suisun Bay in spring 1993, a moderate wet year after a long period of drought. They have been collected as far downstream as Carquinez Strait and Eastern San Pablo Bay in very wet years, such as in 1982 (Wang 1986) and 1995 (Wang and Reyes 2007).

A spawning survey of striped bass in the lower reaches of the Napa River was conducted by CDFG in 1979. No striped bass eggs or larvae were collected, although the Napa River was considered a potential spawning area for striped bass (Chadwick 1958). No striped bass larvae were collected by CDFG's 20-mm fish survey between 1995 and 2005 (M. Dege 1995–2006, personal communication), and neither eggs nor larvae were collected in the upper Napa River (Stillwater Sciences, Inc., 2000).

Historically, various life stages of striped bass have been found at the CVP/TFCF (Hiebert *et al.* 1995, Siegfried *et al.* 2000, Wang and Reyes 2007). Small striped bass have gone through the facility's louver system and ended up in O'Neill Forebay and San Luis Reservoir via the Delta Mendota Canal. However, striped bass eggs have not been collected at the CVP/TFCF, and the number of striped bass larvae has declined drastically since 2004. Scofield and Bryant (1926) reported that young striped bass occur in the shallow water of San Francisco Bay and upper bays. Collections from beach seines and bottom trawls from the Carquinez Straits and up to the Delta show that young striped bass are near the bottom in both deeper and inshore waters of Suisun Bay, Montezuma Slough, and in the vicinity of Pittsburg and Contra Costa Powerplants. Sasaki (1966b) reported young striped bass abundant in the lower San Joaquin River in summer. Ganssle (1966) reported young striped bass concentrated in the Pittsburg-Crockett-Pinole section of the estuary in summer and fall, and less frequently in San Pablo Bay during the same period. A large concentration of young striped bass was found in the vicinity of Contra Costa and Pittsburg Powerplants in fall and early winter (Wang 1986).

The distributional range and migratory patterns of striped bass, juveniles in particular, have been studied for many years (Chadwick 1964, 1967; Ganssle 1966; Turner and Chadwick 1972; Stevens 1977; Stevens *et al.* 1985). However, the complex migratory pattern of young striped bass is not completely understood. Radovich (1963) stated that Pacific coast striped bass do not appear to make extensive migration, unlike those on the Atlantic coast that move northward along the coast with the help from the warmer Gulf Stream. The cold-water barrier of the California current as it passes just outside the Golden Gate Bridge may hinder a seaward run. During El Niño years, when ocean waters are warmer, striped bass venture to the ocean (Moyle 2002). The lack of large estuaries on the west coast could be an important factor contributing to the differences in migratory behavior (Wang 1986).

Calhoun (1949) and Radtke (1966) reported the distribution of 2- to 3-year-old bass throughout the Sacramento-San Joaquin system. Several year-classes were caught in the vicinity of the Pittsburg and Contra Costa Powerplants (Wang 1986). From the CVP/TFCF salvage collections, striped bass of all ages were observed year round with juvenile bass particularly abundant in the summer and fall months. It is possible that some striped bass may remain in the estuary for a large part of their lifespan

(P. Chadwick 1986, personal communication). It is unclear if striped bass can complete their life cycle within the bay and river.

Juvenile striped bass feed on invertebrates, such as opossum shrimp, amphipods, copepods, and occasionally threadfin shad (Heubach *et al.* 1963, Thomas 1967, Moyle 1976). Feeding on *Acanthomysis* spp. has increased in recent years (Moyle 2002). Observed during predatory fish removal experiments conducted at the CVP/TFCF in 2004–2005, juvenile striped bass (~150 mm TL or 1-year-old fish) fed heavily on *Corophium* spp., *Gammarus* spp., and copepods. Few starved adults were also observed in the same period. Large numbers of juvenile common carp, splittail, Sacramento sucker, and black crappie provide potential prey for the striped bass and are present at the CVP/TFCF in June and July.

Male striped bass may reach maturity in their first year (Raney 1952), but usually in their second year (Raney 1954), or most not until they are 2–3 years old (Moyle 2002). Females mature at 3–4 years (Merriman 1938, Raney 1952). Although capable of spawning every year if conditions are right (Moyle 2002), females do not spawn every year after maturing (Raney 1952). This is particularly evident in large females with undeveloped ovaries during the spawning season.

Striped bass provides a valuable commercial fisheries along the Atlantic coast, less so in the Pacific coast, and is considered one of the most valuable game species in the study area. This species is highly valued for recreation, consumption, and fishery-related economics. Unfortunately, the striped bass population in the study area has been declining since the early 1960s (Turner 1972, Kohlhorst 1999). Striped bass were abundant during the wetter years of the 1980s and declined during the drought years of the 1990s to present. Collections of larvae and juveniles at the CVP/TFCF in May 2009 suggest a spawning pulse may have occurred in the Sacramento River.

Moyle (2002) described the reasons for and consequences of the decline of striped bass, including factors such as climate change, south Delta pumps and agricultural diversions, pollutants, reduced estuarine productivity, other non-native introductions, and overfishing. Currently, the IEP is investigating all of the potential factors causing the decline of pelagic organisms such as threadfin shad, delta smelt, and longfin smelt residing in San Francisco Bay and Delta.

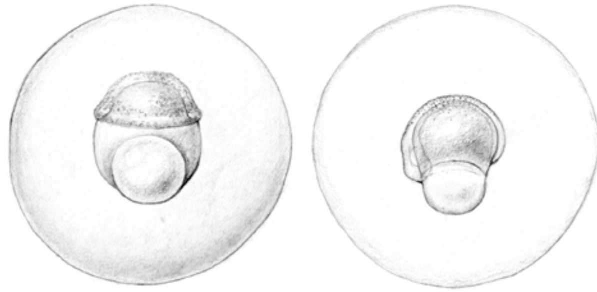


Figure 143.—*Morone saxatilis*, striped bass eggs: morula, 3.0 mm (left) and early embryo, 4.0 mm (right; Wang 1986).

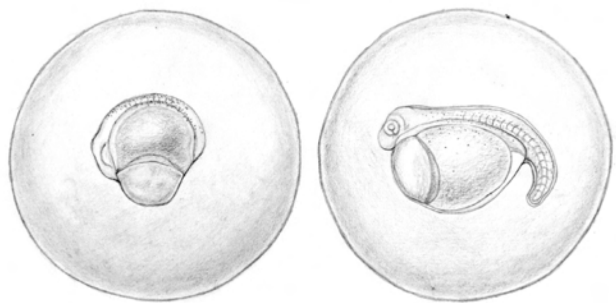


Figure 144.—*Morone saxatilis*, striped bass eggs: early embryo, 4.0 mm (left) and late embryo, 4.0 mm (right; Wang 1986).

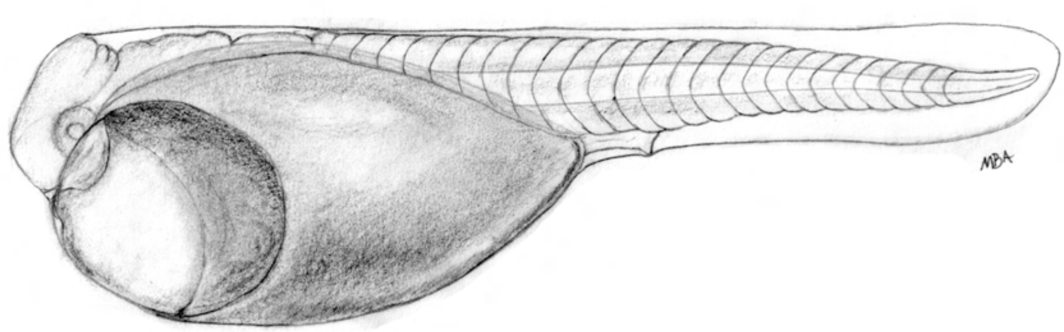


Figure 145.—*Morone saxatilis*, striped bass prolarva, 3.6 mm TL (Wang 1986).

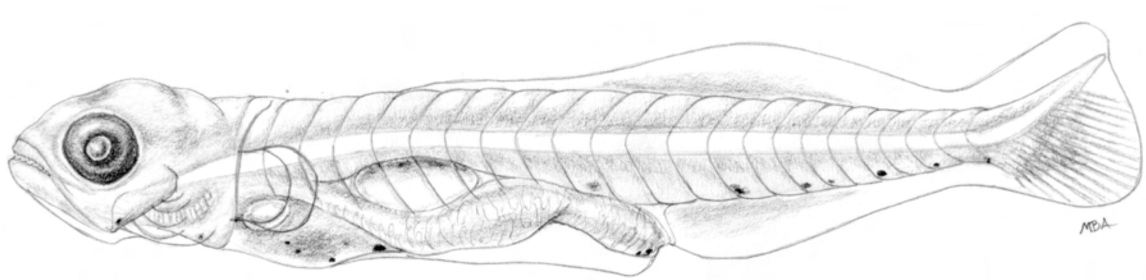


Figure 14**6**.—*Morone saxatilis*, striped bass postlarva, 9.5 mm TL (Wang 1986).

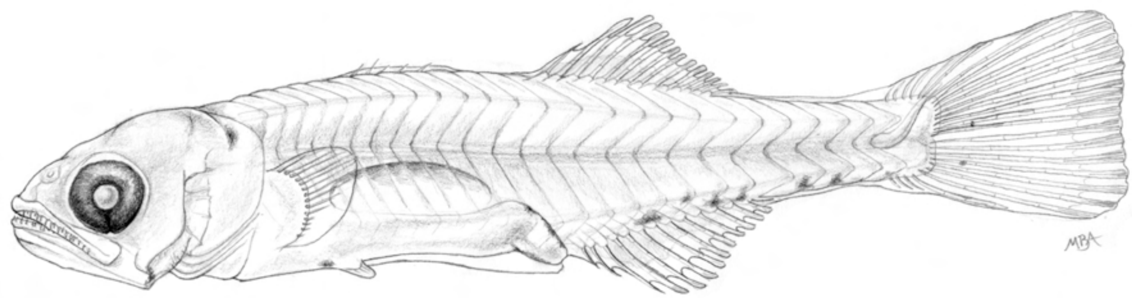


Figure 147.—*Morone saxatilis*, striped bass prejuvenile, 15.2 mm TL (Wang 1986).

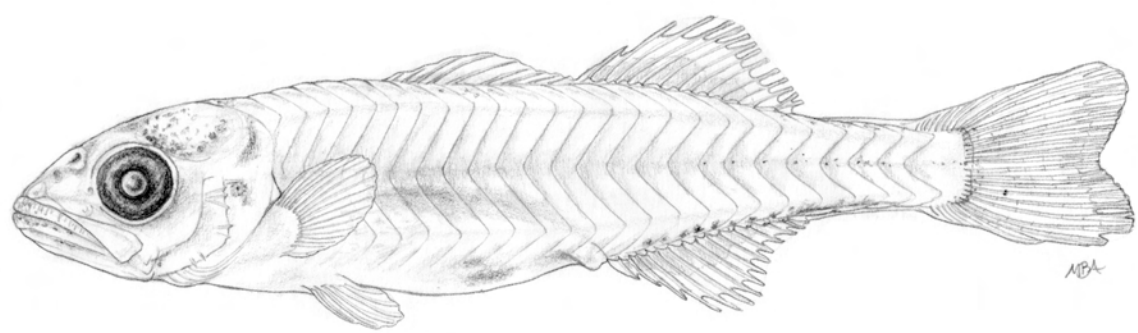


Figure 148.—*Morone saxatilis*, striped bass juvenile, 18 mm TL (Wang 1986).

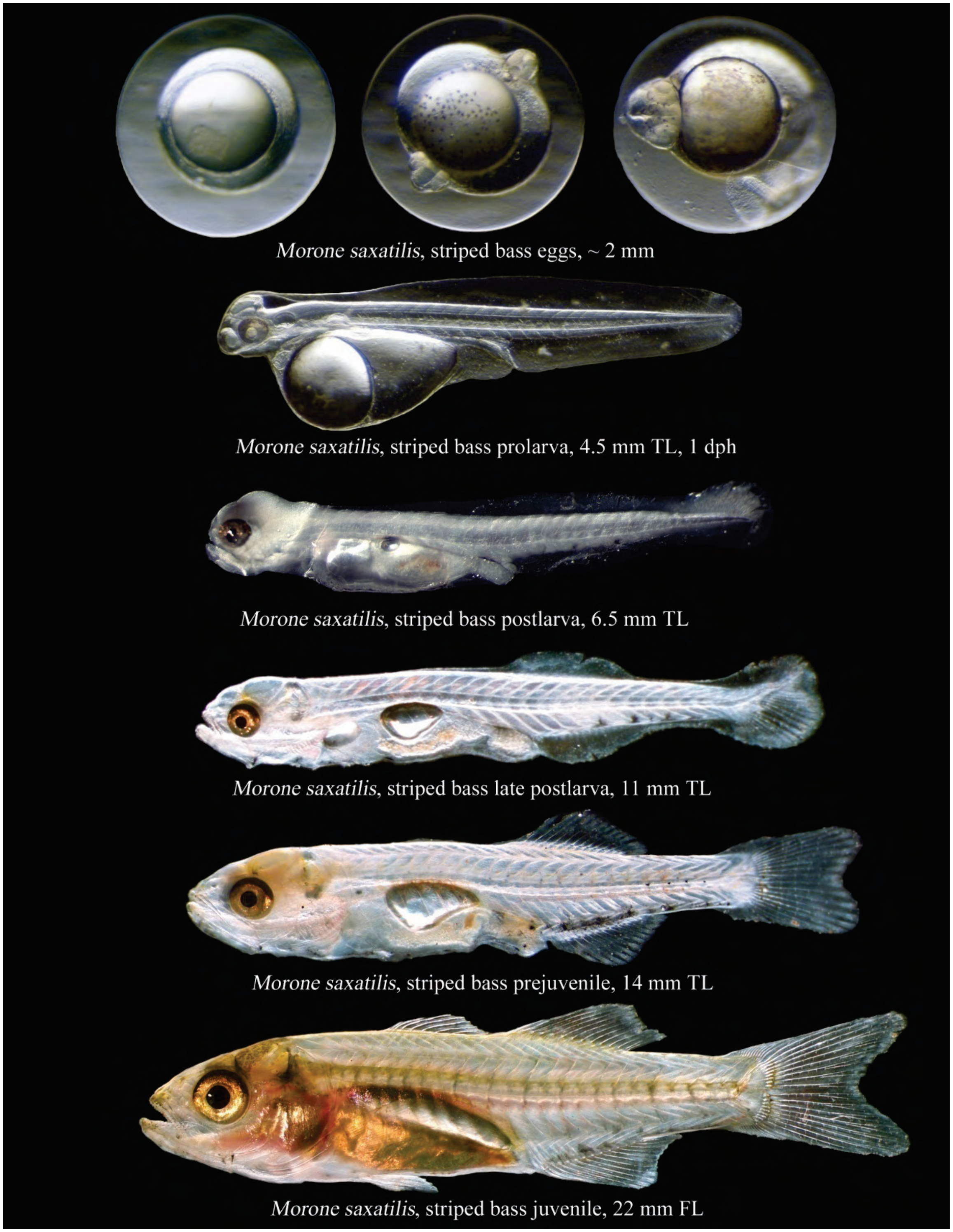


Figure 149.—*Morone saxatilis*, striped bass.

Percidae – Perches — Members of the perch family are native east of the Rocky Mountains. Three species have been introduced to California (Moyle 1976, Dill and Cordone 1997, Stevenson and Thomson 1978): are yellow perch (*Perca flavescens*), bigscale logperch (*Percina macrolepida*), and walleye (*Stizostedion vitreum*). Both yellow perch and bigscale logperch are known to the Sacramento-San Joaquin River system, but only the bigscale logperch has been collected in this study.

BIGSCALE LOGPERCH, *Percina macrolepida* Stevenson

SPAWNING

Location	Freshwater sloughs and irrigation ditches of the Delta; eggs were collected at the CVP/TFCF; larvae were collected from Montezuma Slough, Contra Costa Water District (CCWD) intakes (Mallard Slough, Rock Slough, and Old River); vicinity of Contra Costa Powerplant, Pittsburg Powerplant, NBA (including Cache Slough, Lindsey Slough, and Barker Slough), Middle River, Stone Slough, Putah Creek, Clifton Forebay, CVP/TFCF, O'Neill Forebay, and San Luis Reservoir.
Season	March–June (Wang 1986), February–July (Marchetti 1998), as early as February in Cache Slough and at the CVP/TFCF during warm winter years.
Temperature	Starting at ~12°C; peaking at 17–20°C.
Salinity	Freshwater.
Substrates	Aquatic plants (Moyle 1976, 2002); eggs observed attached to aquatic vegetation, such as *Egaria densa,* at the CVP/TFCF, and buried in sand and gravel at the CVP/TFCF laboratory (R.C. Reyes 2003–2009 and D. Hansen 2001, 2007, personal communication).
Fecundity	150–400 (Moyle 2002); 186 and 365 for females 72 mm and 83 mm TL (Hubbs 1967).

EGGS

Shape	Spherical; can be slightly flat and irregular due to adherence to substrate.
Diameter	Average 1.32–1.4 mm (Hubbs 1967); 1.3–1.5 mm (R.C. Reyes 2003–2009, personal communication); 1.1–1.6 mm (eggs in late embryo stage).
Yolk	Yellowish, clear and smooth.
Oil globule	Single, very large, ~0.3–0.4 mm in diameter, anteriorly placed in yolk.
Chorion	Transparent, clear, smooth (except at the adhering area).

Perivitelline space	Very narrow during late incubation.
Egg deposition	Deposited individually on the stems or leaves of aquatic plants (Moyle 1976, 2002; Wang 1986); also reported eggs buried in shallow sand (Moyle 2002, this study); eggs buried individually (R.C. Reyes 2003–2009, personal communication); deposited in single layer.
Adhesiveness	Adhesive (Moyle 1976); eggs adhere to the substrates and to each other.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	~4.3–5.0 mm TL (specimens collected at NBA and CVP/TFCF); 5.7–6.0 mm TL in laboratory (R.C. Reyes 2003–2009, personal communication).
Snout to anus length	54–59% TL for both prolarvae and postlarvae.
Yolk-sac	Large, elongate and cylindrical extending from thoracic to abdominal region.
Gut	Straight, large and tube-like.
Air bladder	Under-developed in prolarvae, small air bladder chamber appears in postlarvae at ~10–12 mm TL.
Teeth	Sharp, pointed, appears in postlarval stage.
Total myomeres	39–43.
Preanal myomeres	23–27.
Postanal myomeres	14–18.
Last fin(s) to complete development	Spiny dorsal fin.
Pigmentation	Small, light melanophores present midventrally and posterior to anus on ventrum; postanal melanophore count usually ≤10.
Distribution	Planktonic in prolarva and early postlarval stages; common in nontidal as well as tidal freshwater tributaries, sloughs, and ditches.

JUVENILES

Dorsal fin rays	XIII–XV, 12–15 (Stevenson 1971).
Anal fin rays	II, 7–10 (Stevenson 1971).
Pectoral fin rays	12–14 (Stevenson 1971); 13–15.
Mouth	Subtermainal to inferior, with a pointed snout.
Vertebrae	Modal number 40 (Stevenson 1971); 40–43.

Distribution — Epibenthic or on the bottom of sloughs and irrigation ditches of the Delta; introduced into lakes and reservoirs associated with the state and federal water diversion systems; others were released as bait by the fishermen to some of the lakes and reservoirs not connected to the Delta, such as Lake Berryessa (Moyle 2002).

LIFE HISTORY

Bigscale logperch, originally from the Trinity River in Texas, were accidentally introduced into Yuba County, California, by the USFWS in 1953 (McKechnie 1966). At that time, they were identified as the logperch (*P. carpodes*). Stevenson (1971) described a new species of logperch (*P. macrolepida*) living in sympatric and allopatric association with *P. carpodes* in Texas and Oklahoma, although Miller and Robison (1973) expressed reservations about this separation. Sturgess (1976) then recognized the California population as *P. macrolepida*, and J. Stevenson confirmed it (Moyle 1976).

The bigscale logperch population has expanded rapidly from the tributaries of the Yuba River into the lower Sacramento River and the Delta (Moyle 1976). Some expansion of their range to southern California has occurred through state and federal water diversion networks (Moyle 2002). Bigscale logperch were collected from Red Bluff of the Sacramento River, downstream to Suisun Bay and Montezuma Slough, and the Delta (Reclamation's RBRPP records, Moyle 2002, Matern *et al*. 2002, CDFG sampling at the NBA and Delta; CDWR sampling in central Delta, and Reclamation salvage records). However, there have been no bigscale logperch larvae or juveniles collected in the Napa River (CDFG 20-mm fish survey).

The bigscale logperch has a very prolonged breeding season. Individuals may mature at different times depending on water temperature, but maturity is usually reached in their second year (Moyle 1976). The female bigscale logperch will spawn many times with different males during the breeding season (Moyle 1976). Males exhibit aggressive behavior with other males during the breeding season. Likely searching for mates, solitary adult males with bright golden coloration are encountered at the CVP/TFCF as early as late-December (CVP/TFCF records). During warmer winters, spawning starts as early as February and usually peaks from March to June. In the cooler upper Sacramento River, spawning can be delayed to April (CDFG striped bass E and L survey). Marchetti (1998) recorded bigscale logperch spawning in the warm waters of Putah Creek in February and in the cooler waters of Dry Creek in July.

Moyle (1976) reported that bigscale logperch deposit their eggs on aquatic plants, a behavior different from other *Percina* spp. This behavior could be an adaptation to the environment. The swamp darter (*Etheostoma fusiforme*) inhabits mid-Atlantic coastal streams and swamps and also uses aquatic vegetation for its spawning substrate (Wang and Kernehan 1979). The attachment of eggs to aquatic plants suspended in the water column may enhance hatching. This strategy may also reduce predation by blending eggs into dense vegetation. In laboratory, bigscale logperch deposited their eggs in the sandy and small gravel bottom of aquariums where they were not noticed by predators. Only a small number of eggs (~10–20) were observed on leaves collected at CVP/TFCF. Eggs deposited in small amounts intermittently at different locations may also be another breeding strategy.

Bigscale logperch have no visible air bladder during the prolarval stage, but larvae engage in planktonic swimming similar to prickly sculpin. The large oil globule and large sized yolk-sac may help the larvae maintain position near the neuston during dispersion. Prolarvae have been taken with plankton nets and light traps at the North Bay Aqueduct (Wang and Reyes 2007), Putah Creek (Marchetti 1998, Rockriver 1998), and the CVP/TFCF (Siegfried *et al.* 2000). A small air bladder develops between late postlarval and early prejuvenile life stages (~10–12 mm TL).

Small juveniles (≤15 mm TL) are able to swim in the water column. Large juveniles, with visible dark bars on the side of the body, gradually descend to the bottom, swimming erratically by using the pelvic fins and the tail as a tripod, and darting forward with the aid of the pectoral fins. Occasionally, bigscale logperch swim up in the water column but usually only for short distances and short periods of time. Apparently swimming in small groups, juveniles have been captured in beach seines and in collecting buckets, such as at the CVP/TFCF. Moyle (1976) noticed that juvenile bigscale logperch show no territorial behavior; similar behavior was observed in the laboratory.

Juveniles feed on insect larvae, small crustaceans, and mysid shrimps (Moyle 1976); they also eat oligochaetes (red worm) in the laboratory. They may also be carnivorous; a small larval fish was found in the stomach of a bigscale logperch ~11 mm TL.

Bigscale logperch are used as bait by anglers. Unused bait is often released and may explain the rapid expansion of this species into reservoirs outside of the Delta (Moyle 2002).

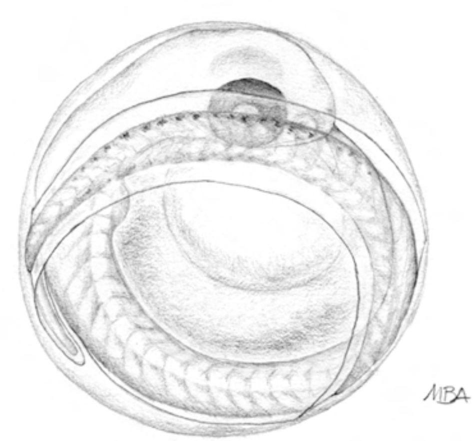


Figure 150.—*Percina macrolepida*, bigscale logperch egg, 1.3 mm (Wang 1986).

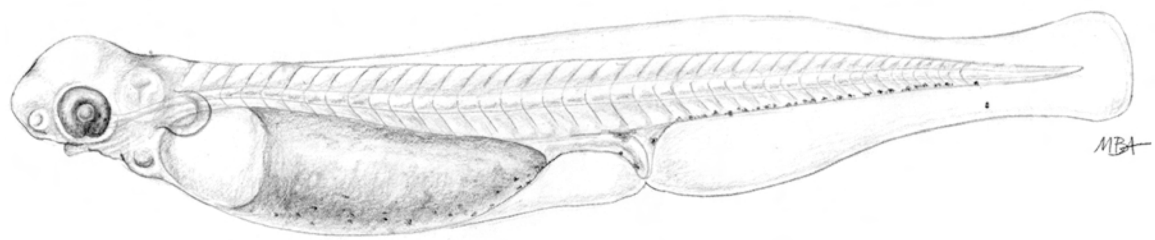


Figure 151.—*Percina macrolepida*, bigscale logperch prolarva, 5 mm TL (Wang 1986).

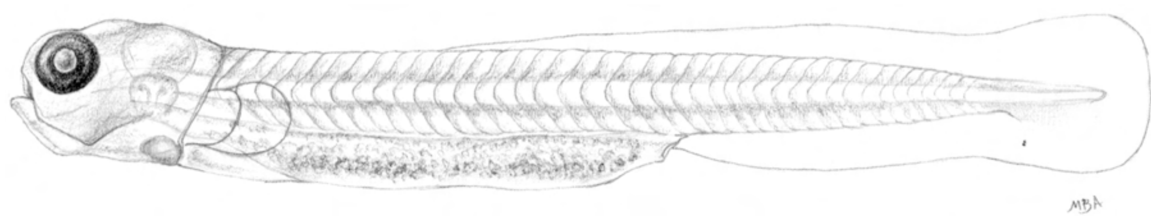


Figure 152.—*Percina macrolepida*, bigscale logperch postlarva, 8.2 mm TL (Wang 1986).

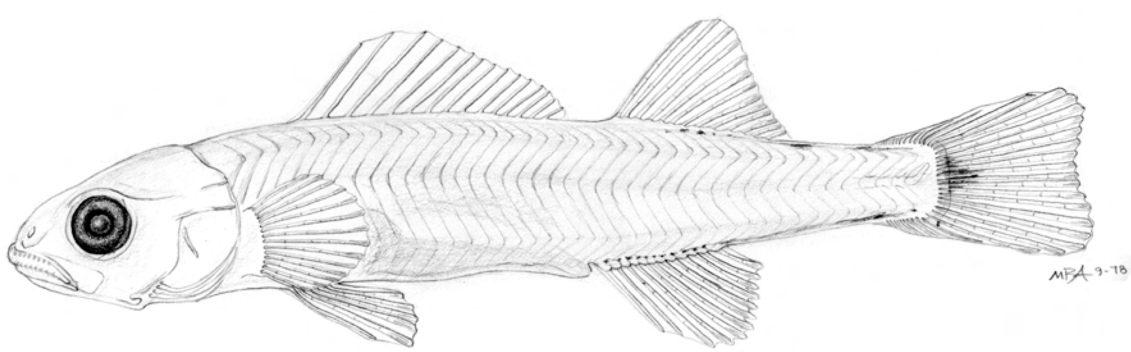


Figure 153.—*Percina macrolepida*, bigscale logperch juvenile, 22.5 mm TL (Wang 1986).

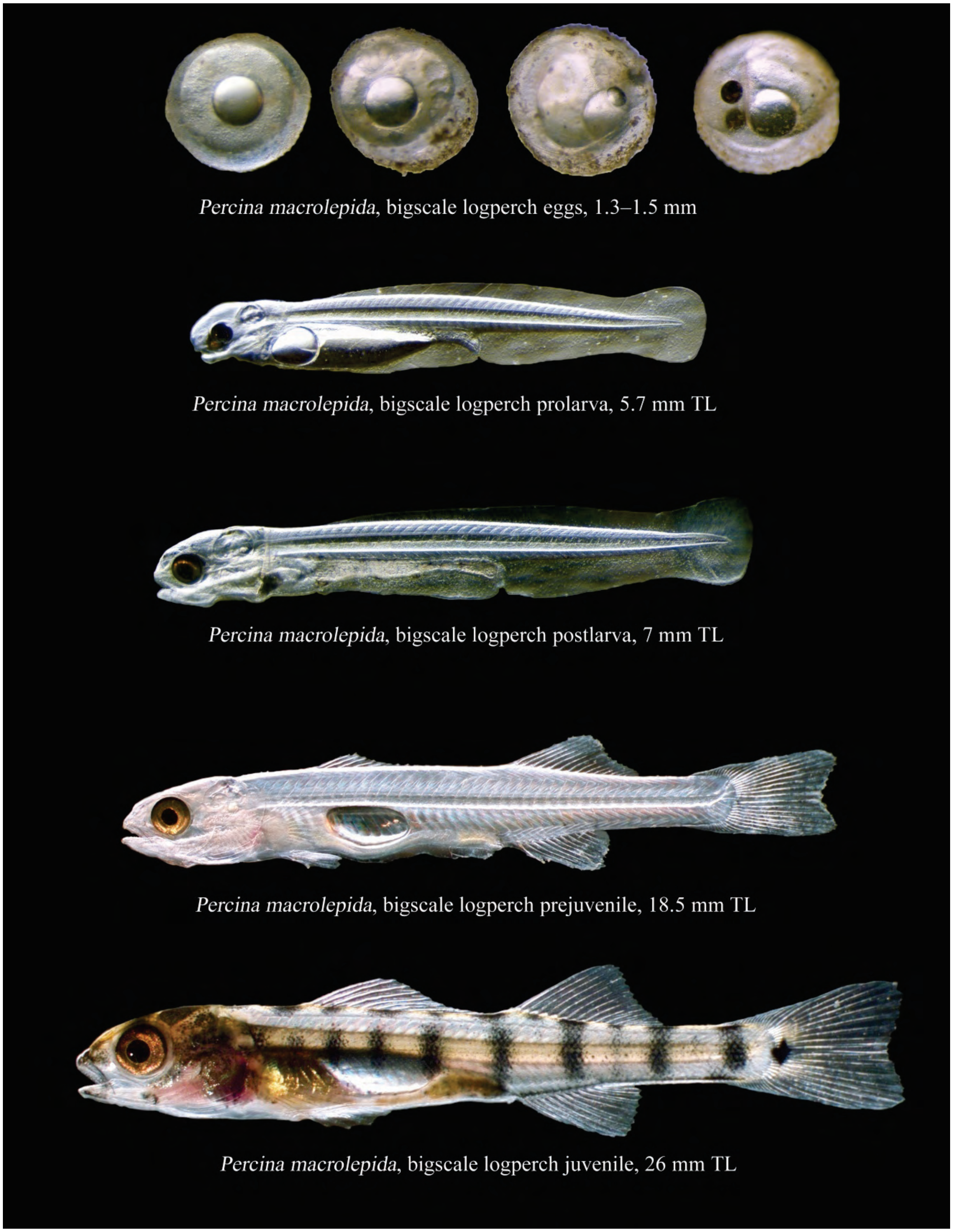


Figure 154.—*Percina macrolepida*, bigscale logperch.

Sciaenidae – Drums and Croakers — Three members of drums and croakers are native to the coastal waters adjacent to the San Francisco Bay: white seabass (*Atractoscion nobilis*), white croaker (*Genyonemus lineatus*), and queenfish (*Seriphus politus*). Only the white croaker has been collected in the San Francisco Bay and their early life stages have been collected in the Delta.

WHITE CROAKER*, Genyonemus lineatus* (Ayres)

SPAWNING

Location	Shallow water near shore (Skogsberg 1939); in San Francisco Bay, Tomales Bay, Moss Landing Harbor (Wang 1986); Morro Bay (E. Calix 1999–2005, personal communication), and along the California coast (Moser 1996).
Season	November–May (Skogsberg 1939, Hart 1973); January–March (Bane and Bane 1971); October–March (Eldridge 1977); October–April (Goldberg 1976); December to April, with a peak in March (Moser 1996); early spring (Baxter 1960); winter months (Baxter *et al.* 1999); September to May, usually in winter months.
Temperature	8–19°C (Wang 1986).
Salinity	Seawater to polyhaline.
Substrate	Most eggs are found over sand and gravel bottoms (*e.g.*, the entrance of Moss Landing Harbor and Tomales Bay).

EGGS

Shape	Spherical.
Diameter	0.5–0.9 mm (Wang 1986); 0.85 mm (Matarese *et al.* 1989); 0.79–0.92 mm (Moser 1996).
Yolk	Homogeneous (Moser 1996); whitish to yellowish, clear, smooth.
Oil globule	Single, ~0.1–0.2 mm in diameter (Wang 1986); 0.23 mm (Matarese *et al.* 1989); 0.19–0.26 mm (Moser 1996).
Chorion	Transparent, smooth (Wang 1986, Matarese *et al.* 1989, Moser 1996).
Perivitelline space	Very narrow, all stages.
Adhesiveness	None.
Buoyancy	Pelagic.

LARVAE

Length at hatching	<2.2–2.8 mm TL based on wild caught larvae specimens (Wang 1986); 1.5–2.0 mm SL (Matarese *et al.* 1989); 1.2–1.8 mm SL (Moser 1996).
Snout to anus length	~33–35% TL for prolarvae 2.2–2.8 mm TL; ~36–39% TL for postlarvae 3.8–8.9 mm TL (Wang 1986); 38–53% SL (Matarese *et al.* 1989); 36–56% SL for yolk-sac larvae (Moser 1996).
Yolk-sac	Spherical to oval, very large, extending from jugular to abdominal region, yolk sac protrudes anteriorly that the head appears situated above the yolk-sac in newly-hatched larvae.
Oil globule	Single, usually bright yellow, located in central or anterior portion of the yolk-sac.
Gut	Short, coiled in one loop, bends ventrally in a sharp angle at anus.
Air bladder	Spherical to oval, near base of pectoral fins, becoming enlarged in postlarvae.
Teeth	Conical, sharp, appears in postlarval stage.
Total myomeres	24–26.
Preanal myomeres	7–11.
Postanal myomeres	14–17.
Last fin(s) to complete development	Pectoral.
Pigmentation	In prolarvae, there is a series of large stellate melanophores in the postanal region, forming 2–3 broken bars or blotches; scattered melanophores are present on thorax, scapula, and anus; a single melanophore on nape and suborbital. In postlarvae, there is a series of melanophores along postanal region and scattered melanophores are found on head, thoracic, and anus areas.
Distribution	In open coastal waters, San Francisco Bay; some ascend to lower saline waters and freshwater of San Pablo Bay, Napa River, Suisun Bay, and west Delta.

JUVENILES

Dorsal fin rays	XII–XV, I, 21–24 (Skogsberg 1939); XII–XV, I, 18–25 (Miller and Lea 1972).
Anal fin rays	II, 11–12 (Skogsberg 1939, Hart 1973); II, 10–12 (Miller and Lea 1972).

Pectoral fin rays	I, 17 (Miller and Lea 1972); 16–19 (Hart 1973); 17–18 (Moser 1996).
Mouth	Snout round, lower jaw included, maxillary usually extends to middle or posterior edge of pupil (Skogsberg 1939, Hart 1973); mouth moderate (Bane and Bane 1971); terminal to subterminal, large; tiny barbels in lower chin.
Vertebrae	25 (Hart 1973); 26 (Miller and Lea 1972, Moser 1996).
Distribution	Mostly near bottom. Early juveniles remain in the bay and estuary while most large juveniles descend from the estuary into the ocean.

LIFE HISTORY

White croaker ranges from Todos Santos Bay, Baja California, northward to Barkley Sound, Vancouver Island, British Columbia (Skogsberg 1939, Miller and Lea 1972, Hart 1973), inhabiting both inshore and offshore waters up to 100 m in depth (Skogsberg 1939, Frey 1971). All life stages of white croaker have been found in San Francisco Bay, Tomales Bay, and Moss Landing-Elkhorn Slough (Wang 1986). In the study area, the postlarvae and early juveniles were occasionally collected in eastern San Pablo Bay, Napa River, Suisun Bay, and in west Delta. In dry years, such as 1992, white croaker larvae were found at the confluence of the Sacramento and San Joaquin Rivers (Wang and Reyes 2007).

White croakers mature in 2–3 years and spawn from November through May (Skogsberg 1939) and possibly from October to April (Goldberg 1976). In San Francisco Bay, based on collections of eggs and small larvae, spawning occurs from September through May with a peak in the winter months (Wang 1986). Gravid females were collected from the intake screens of Potrero and Hunters Point Powerplants in San Francisco Bay and from the Moss Landing Powerplant in Moss Landing Harbor (Wang 1986). Eggs were collected from Horseshoe Cove, just below the northern base of the Golden Gate Bridge, up to Paradise Beach County Park and Hunters Point in San Francisco Bay, and in Moss Landing Harbor. This indicates that spawning may occur in both open and shallow waters of bays.

White croaker eggs range in size from 0.5–0.9 mm in diameter, have a single oil globule (~0.1–0.2 mm) and a very narrow perivitelline space. The egg size of the white croaker is also similar to that of the starry flounder which is found in the same location and season. However, the starry flounder egg can be separated from the white croaker egg by its fine irregular ridges on the surface of the chorion and the lack of an oil globule in the yolk.

Newly-hatched white croaker larvae are pelagic with a large head, yolk-sac, and a high finfold. A few larvae are thought to drift into bay waters with incoming tides. Bays and estuaries are also used as extended spawning and nursery grounds. As larval flexion develops, they become epibenthic (Moser 1996). Some larvae and early juvenile white croakers move further up into the lower saline waters of San Pablo Bay, Napa River, and

Suisun Bay (Ganssle 1966, Messersmith 1966, CDFG 20-mm fish survey, CDFG striped bass E and L survey, Greiner *et al.* 2007). It is assumed that white croaker exhibits migratory behavior similar to that of some of the east coast sciaenids, in that early life stages of both east and west coast sciaenids use the upper estuaries and rivers as nurseries (Smith 1971, Thomas 1971). Principal food items of juvenile white croaker include small invertebrates, crabs, shrimps, mollusks, and detritus (Bane and Bane 1971).

White croakers are used as a baitfish and they support a small local commercial fishery appearing in Asian fish markets where they are labeled as "white-flower fish." Some white croakers may live as long as 15 years (Frey 1971). This species is also reported to be host to some parasites (Baxter 1960, Bane and Bane 1971, Hart 1973).

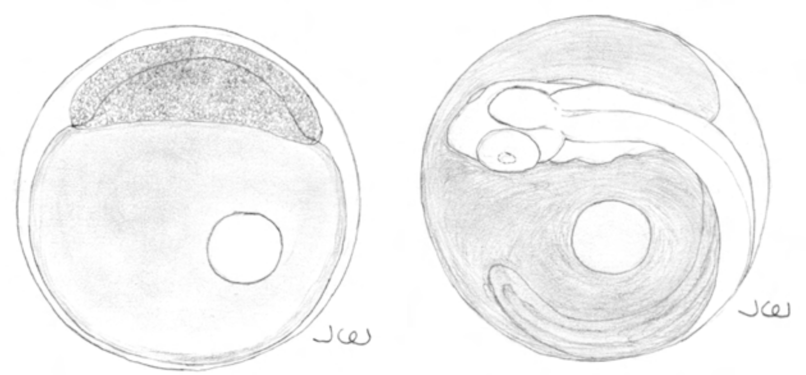


Figure 155.—*Genyonemus lineatus*, white croaker eggs: gastrula, 0.7 mm (left) and late embryo, 0.8 mm (right; Wang 1986).

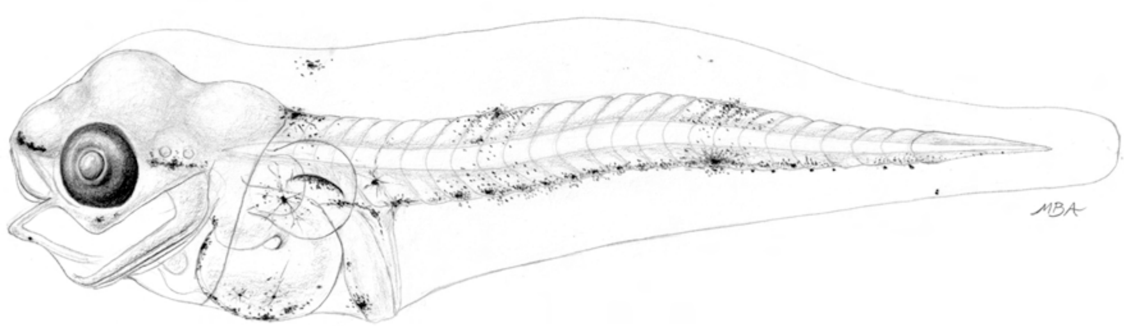


Figure 156.—*Genyonemus lineatus*, white croaker prolarva, 3.3 mm TL (Wang 1986).

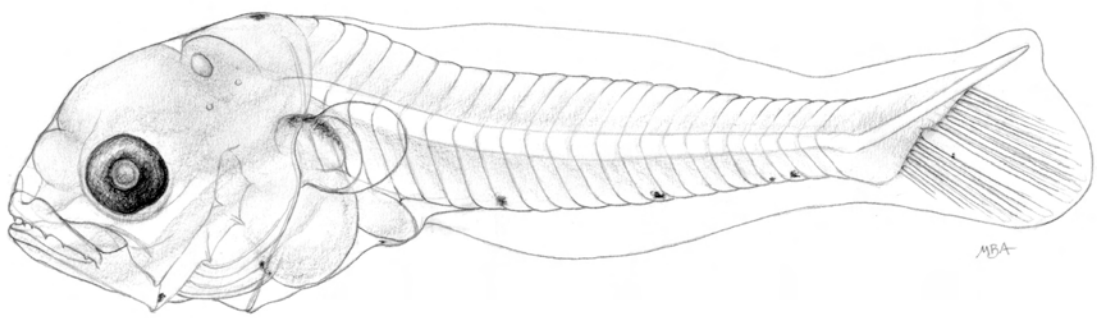


Figure 157.—*Genyonemus lineatus*, white croaker postlarva, 6.5 mm TL (Wang 1986).

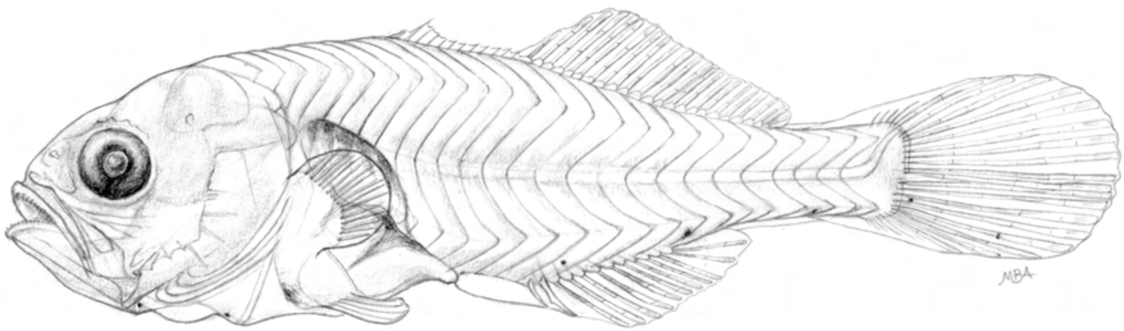


Figure 158.—*Genyonemus lineatus* white croaker juvenile, 13 mm TL (Wang 1986).

Embiotocidae – Surfperches — This family of viviparous (livebearer) species is native to the Pacific coast. At least 17 species of surfperches have been reported in the estuarine waters of Sacramento-San Joaquin system (Miller and Lea 1972, Wang 1986). The tule perch (*Hysterocarpus traskii*) is the only surfperch found in freshwater. The other 16 species are coastal in origin and include: barred surfperch (*Amphistichus argenteus*), calico surfperch (*A. koelzi*), redtail surfperch (*A. rhodoterus*), kelp perch (*Brachyistius frenatus*), shiner perch (*Cymatogaster aggregata*), black perch (*Embiotoca jacksoni*), striped seaperch (*E. lateralis*), spotfin surfperch (*Hyperprosopon anale*), walleye surfperch (*H. argenteum*), silver surfperch (*H. ellipticum*), rainbow seaperch (*Hypsurus caryi*), dwarf perch (*Micrometrus minimus*), white seaperch (*Phanerodon furcatus*), rubberlip seaperch (*Rhacochilus toxotes*), pile perch (*R. vacca*), and pink seaperch (*Zalembius rosaceus*). Baxter *et al.* (1999) reported 14 species of surfperch from the San Francisco Bay (CDFG Bay Studies, 1982–1995). Kelp perch, striped seaperch, and pink seaperch were not collected. Walleye perch and shiner perch were common species in otter trawl surveys conducted by the CDFG during the period 1996–2005 (Greiner *et al*. 2006). Pile perch were not reported in the San Francisco Bay fishery study conducted from 2003 to 2006 (Greiner *et al.* 2007). Only the shiner perch and the tule perch are discussed in this chapter.

SHINER PERCH *Cymatogaster aggregata* Gibbons

SPAWNING

Location	California coastal waters, San Francisco Bay, San Pablo Bay, Tomales Bay, and Moss Landing Harbor-Elkhorn Slough.
Season	*Mating:* Throughout the year (Feder *et al.* 1974); in summer (Shaw 1971); from April through July in British Columbia, Canada (Hart 1973).
	Birth: Females become gravid in December (Eigemann 1892); young are born from May through August (Hart 1973, Moyle 2002); young are observed throughout the year (Feder *et al.* 1974); young are born in spring and summer (Shaw 1971); newly born young are abundant in May and June in San Francisco Bay (Baxter *et al.* 1999).
Salinity	Seawater, polyhaline, and may occur in mesohaline.
Fecundity (number of embryos)	5–17 (Gordon 1965); 8–36 (Clemens and Wilby 1961); 8 (Bane and Bane 1971); 15–20 (Baltz 1984).

EGGS (Embedded in the ovarian chamber)

Shape	Spherical.
Diameter	~0.25 mm in diameter in early developmental stage (Eigenmann 1892, Wang 1986).
Oil globule	None.
Chorion	Enclosed in the follicle and covered with thick layer of granulous tissue and cells; chorion is thick after it is free from ovarian tissue.

LARVAE (Obtained from ovarian chamber)

Length at hatching	Newly-developed embryo in the modified ovarian chamber; ~0.45 mm in sagittal section; 34 mm TL at birth (Eigenmann 1892).
Snout to anus length	~43–44% TL for embryo 1.6 mm TL.
Yolk-sac	Flat to oval, in thoracic region (Eigenmann 1892).
Oil globule	None.
Gut	Twisted, then coiled (Eigenmann 1892); large, thick, particularly the hind gut near the anus (Wang 1986).
Air bladder	Shallow, elongated.
Teeth	None at this stage.
Total myomeres	33–35, San Francisco Bay specimens (Wang 1986).
Last fin(s) to complete development	Pelvic.
Pigmentation	No pigmentation (except the eyes) in embryonic stage; light melanophores cover head and body of juveniles prior to birth.

JUVENILES (After birth)

Dorsal fin rays	IX, 20 (Clothier 1950); VIII–XI, 19–22 (Tarp 1952); VIII–XI, 19–22 (Hart 1973); VIII–XI, 18–23 (Miller and Lea 1972); XIII–IX, 18–23 (Moyle 2002).
Anal fin rays	III, 23 (Clothier 1950); III, 22–25 (Tarp 1952, Moyle 2002); III, 22–25 (Hart 1973); III, 22–26 (Miller and Lea 1972).
Pectoral fin rays	19–21 (Tarp 1952, Miller and Lea 1972, Moyle 2002); 19–20 (Hart 1973).
Mouth	Terminal, small, directed slightly upward (Hart 1973).
Vertebrae	33–37 (Clothier 1950); 34–38 (Miller and Lea 1972).

Distribution	Euryhaline in San Francisco Bay and San Pablo Bay; occasionally found in Suisun Bay (Wang 1986); common in south San Francisco Bay (Baxter *et al.* 1999) and Tomales Bay (Bane and Bane 1971); Moss Landing Harbor-Elkhorn Slough (Nybakken *et al.* 1977).

LIFE HISTORY

Shiner perch has one of the broadest distributions of all the embiotocids found along the Pacific coast. It is known from San Quintin Bay, Baja California, to Port Wrangell, Alaska (Roedel 1953, Miller and Lea 1972). Shiner perch has been reported in San Francisco Bay (Aplin 1967), Richardson Bay (Green 1975, Eldridge 1977), San Pablo Bay (Ganssle 1966), and Carquinez Strait (Messersmith 1966). In the study area, shiner perch was collected throughout the San Francisco Bay (CDFG Bay Studies, 1981–1995) and was also found in Suisun Bay (Baxter *et al.* 1999) and lower Napa River (CDFG 20-mm fish survey). It often moves from San Francisco Bay to eastern San Pablo Bay, Napa River, and Suisun Bay (Moyle 1976, Baxter *et al.* 1999). During the period 1979–1982 young shiner perch were collected from Suisun Bay to the west Delta near Pittsburg Powerplant(Wang 1986). They were also common in Tomales Bay (Bane and Bane 1971) and Bodega Bay (Standing *et al.* 1975). Shiner perch, particularly YOY, can tolerate lower salinities (Moyle 1976).

The reproductive behavior of the shiner perch has been described by Hubbs (1917), Wiebe (1968), and Shaw (1971). Males reach sexual maturity shortly after birth. Females can be inseminated soon after birth and carry the sperm in their ovaries until eggs mature in December when fertilization can occur (Turner 1938, Shaw 1971). However, Gordon (1965) reported that no yearling (age-0) female shiner perch carried embryos; only 2-year-old females had embryos. Sperm from several males are stored inactively in the ovary of the female for a period of about 5–6 months (Eigenmann 1892, Gorden 1965, Wiebe 1968). When the ova become mature, usually between November and December, stored sperm becomes active and fertilization takes place while the ova are still in ovarian tissue (Turner 1938). The total time between mating and giving birth of young is approximately 1 year (Hubbs 1917, 1921a). Prior to giving birth, shiner perch females enter coastal bays for parturition (Bane and Robinson 1970). Pregnant females search for shallow and protected waters to give birth. Smaller females give birth to 6–10 young (Wiebe 1968) and larger females may produce 15–20 young (Baltz 1984).

Newly-born shiner perch (born as juveniles) display longer dorsal and anal fin rays that gradually recede. Juvenile females are slightly larger than males (Wiebe 1968). Bane and Robinson (1970) observed that most of juveniles and 1-year adults remain in the bay for their first year and emigrate to coastal waters when they are 2 years old. During their first year, shiner perch will move from shallow water to deeper water for over-wintering (Bane and Robinson 1970, Baxter *et al.* 1999). Ganssle (1966) and Aplin (1967) found that young shiner perch are common in San Francisco Bay and San Pablo Bay in the summer and fall months. Baxter *et al.* (1999) found age-0 shiner perch in Suisun Bay during summer months. Apparently, this species uses the bay and estuary as a nursery ground more extensively than other marine-origin embiotocids.

Juveniles are omnivorous, feeding on zooplankton, small crustaceans, algae, and detritus (Gordon 1965; Bane and Robinson 1970; Odenweller 1975a, b) and also on polychaetes, mollusks, and benthic organisms (Boothe 1967, Nybakken *et al.* 1977). Unlike adults that feed mainly during the day, juvenile shiner perch feed both day and night (Moyle 2002). Male shiner perch have a lifespan of 3 years, while females live 5 years (Anderson and Bryan 1970).

Shiner perch is not of great importance commercially, although it is commonly caught by sport fishermen along the ocean shore and in bays (Odenweller 1975a, b). It is sometimes used as bait fish (Bane and Bane 1971). Predators of shiner perch include striped bass, sturgeon, salmon, and harbor seals (Thomas 1967, Feder *et al.* 1974). This species was once common in San Francisco Bay but recent declines in abundance are probably the result of various environmental changes including shallow-water nursery habitat degradation (Baxter *et al.* 1999, Moyle 2002).

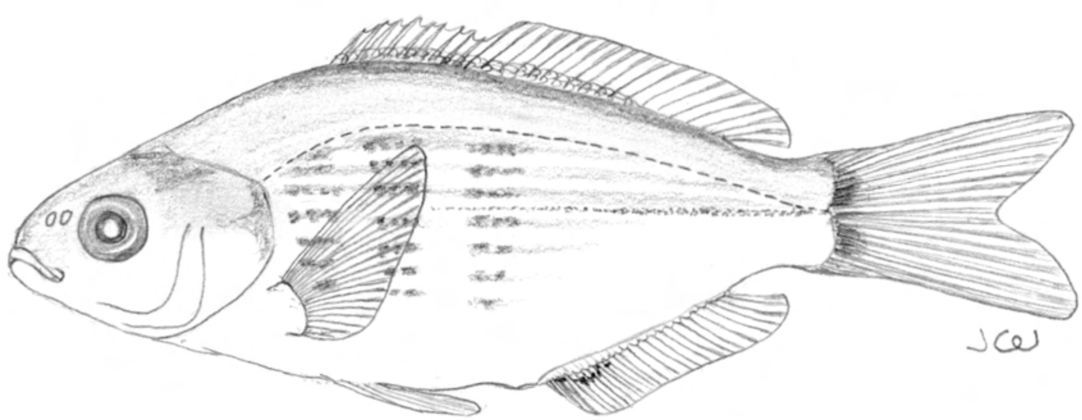


Figure 159.—*Cymatogaster aggregata,* shiner perch 51 mm TL (Wang 1986).

TULE PERCH *Hysterocarpus traskii* Gibbons

SPAWNING

Location	In the tule marshes and other types of vegetation in Napa River, Suisun Bay, Suisun Marsh, Montezuma Slough and most sloughs in the Delta, the Sacramento River upstream to Red Bluff, south Delta, and O’Neill Forebay.
Season	*Mating*: Based on testicular development, mating begins in July and continues through September (Bundy 1970).
	Birth: May (Bundy 1970, Bryant 1977); May and June.

Temperature	Females give birth at 18–20°C in the laboratory (Wang 1986).
Salinity	Freshwater.
Fecundity (number of embryos)	22–83 (Bundy 1970); 5–93 (Byrant 1977); 12–45 (Moyle and Baltz 1985); 26–75 from 53 females examined (Wang 1986). An additional 15 females were examined at the CVP/TFCF where the number of embryos ranged 26–75.

EGGS (Embedded in the ovarian chamber)

Shape	Spherical.
Diameter	0.3–0.5 mm in diameter (Wang 1986).
Yolk	Yellowish, granular.
Oil globule	None, or occasionally has small oil globulets.
Chorion	Clear, smooth.
Perivitelline space	Fairly wide.

LARVAE (Obtained from ovarian chamber)

Length at hatching	Early embryo, 0.25 mm dropped into the modified ovarian chamber in January (Bryant 1977); slightly large embryos, 0.3–0.5 mm were observed by Wang (1986); juveniles born at 29 mm SL (Bryant 1977); 33–44 mm TL (Bundy 1970).
Snout to anus length	~60% TL for embryo 2.5 mm; decreasing to ~45% TL for embryo 14.0 mm TL.
Yolk-sac	Small amount of yolk in the thoracic region (Bundy 1970, Bryant 1977); yellowish, small in the thoracic region.
Gut	Coiled at 5.0 mm long (Wang 1986); hind gut protrudes from the body (Bundy 1970); hind gut extends beyond the yolk-sac (Bryant 1977); large and thick, particularly the protruding portion of the hind gut.
Teeth	None at this stage.
Size at absorption of yolk	~5.0 mm long (Brandy 1970); 5.8 mm TL (Bryant 1977).
Total myomeres	33–35 (Wang 1986).
Last fin(s) to complete development	Pelvic.
Pigmentation	No pigments during early development, except for the eyes; sparse covering of melanophores over head and body of embryo prior to birth.

JUVENILES (After birth)

Dorsal fin rays	XII, 11 (Rutter 1907); XV–XVIII, 9–13 (Tarp 1952); XVI–XIX, 10–14 (Hopkirk 1973); XV–XIX, 9–15 (Moyle 1976).
Anal fin rays	III, 23 (Rutter 1907); III, 19–23 (Tarp 1952); III, 21–26 (Hopkirk 1973); III, 20–26 (Moyle 1976).
Pectoral fin rays	17–19 (Tarp 1952, Moyle 1976).
Mouth	Terminal, small (Rutter 1907, Moyle 1976); terminal, small, and oblique.
Vertebrae	33–35 (Wang 1986).
Distribution	Found in sluggish waters with vegetation of the Sacramento-San Joaquin River system and upper estuary and in some associated irrigation waterways including the O'Neill Forebay.

LIFE HISTORY

Tule perch is the only freshwater embiotocid in California (Rutter 1907; Tarp 1952; Hopkirk 1962, 1973). It is found in the Sacramento-San Joaquin River system, including the major tributaries which drain into the bay and Delta. It is also reported from the lower saline waters of Suisun Bay (Baxter *et al.* 1999, Moyle 2002). Distribution has been expanded to south of the Central Valley via state and federal water projects, from O'Neill Forebay (Wang 1986) and into southern California's Pyramid Reservoir (Swift *et al.* 1993). Currently, the distribution of tule perch in the Central Valley is known from Pit Falls (on the Pit River) in the north to Kings River in the south (Moyle 2002). Adjacent to the bay and Delta water systems, Moyle (2002) also reported the existence of tule perch in the Russian River, Clear Lake, and Blue Lake, but populations once known in Pajaro and Salinas Rivers have disappeared.

Long-term separation and isolation have resulted in morphological differences for tule perch from different drainages, and three subspecies have been recognized (Hopkirk 1962, 1973) and validated by Baltz and Moyle (1981, 1982). The three subspecies are Sacramento tule perch, Clear Lake tule perch, and Russian River tule perch. In the study area, Sacramento tule perch is found in the Delta, Suisun Marsh, Napa River, Sonoma Creek, and Petaluma River, and is particularly abundant in the main body of the Sacramento River (Wang 1986, RBRPP records). Tule perch requires the cool, well-oxygenated water, with good flow which the Sacramento River provides (Moyle 2002). A tule perch population reported in Alameda Creek and Coyote Creek by Snyder (1905), disappeared in the 1930s (Moyle 1976, Aceituno *et al.* 1976), but was recently rediscovered (Moyle 2002).

The tule perch mating season is from July through September (Bundy 1970). After mating, sperm is stored in the ovary until the ova become mature. Fertilization takes place in January (Bryant 1977), when the ova is still embedded in ovarian tissue. Before the eggs become segmented (cleavage), they fall into the ovarian cavity (Amoroso 1960, Bryant 1977). Numerous ova were found in the ovarian tissue during November and December. Eggs and early embryos were present in the heavily wrinkled ovarian cavity in January. Ova and eggs or early developed embryos were 0.3–0.5 mm in diameter (Wang 1986). Bundy (1970) observed early embryos that were 3.0 mm TL in March, while Bryant (1977) measured embryos from the ovarian cavity at 0.25 mm TL in mid-February. Fecundity is highly variable and related to fish age, size, location, feeding, and other environmental factors. For example, a range of 22–83 embryos/female was recorded by Bundy (1970), 5–93 by Bryant (1977), 12–45 by Moyle and Baltz (1985), and 26–75, from 53 specimens by Wang (1986).

Tule perch embryos have a small yolk-sac in the thoracic region and a large tubular hind gut. The hind gut functions as a nutrient-absorbing organ (Hubbs 1921a; Turner 1941, 1952). Epithelial cells lining the folded ovarian cavity create an internal fluid reservoir. This reservoir provides both nutrient and oxygen to the embryo (Wiebe 1968). Nitrogenous wastes are absorbed through the ovarian wall (Turner 1952). As fins develop in the embryo, the highly vascularized ovarian wall can also exchange gas with the vertical fin dermal flaps or spatula-like appendages of the embryo (Turner 1938, Bundy 1970, Bryant 1977). After the gill slit is formed, the gut becomes functional (Turner 1952, Amoroso 1960). Embryos grow rapidly in seven to eight ovarian compartments. When they reach 30–40 mm SL, they are juveniles and soon will be born (Bryant 1977). Bryant (1977) and Wang (1986) stated that most tule perch are born head first, although a few were observed tail-first and sideways. Moyle (2002) stated that most are born tail first.

Juvenile tule perch swim freely immediately after birth. They are found among vegetation or in protected areas such as rocky jetties, submerged logs, and old tires (Wang 1986). They have been collected in near-shore zones with plankton nets (L. Grimaldo 1998, 2003, personal communication). In the laboratory, juveniles swim together but not with the parent fish (Wang 1986).

Juvenile tule perch feed on zooplankton, aquatic insects, and benthic invertebrates when they are in rivers and lakes (Moyle 1976). They feed mainly on benthic amphipods and mysid shrimp in the Delta and upper Sacramento-San Joaquin Estuary (Turner 1966).

Tule perch reach sexual maturity within a few months of birth. Spermatozoa are found in the juvenile males. Females can be inseminated prior to August (Bryant 1977), but sperm is stored in the ovary until the ova become mature in about 1–2 years (Baltz and Moyle 1982). Most tule perch live up to 3 years (Bundy 1970), but lifespan ranges from 2–8 years depending on environmental conditions (such as water quality and introduced predator fish species, particular centrarchids) and food availability (Moyle 2002). The three subspecies of tule perch have patchy distributions and their future is uncertain (Moyle 2002). This species has little commercial or sport value due to its small size; however, it is an ecological indicator species.

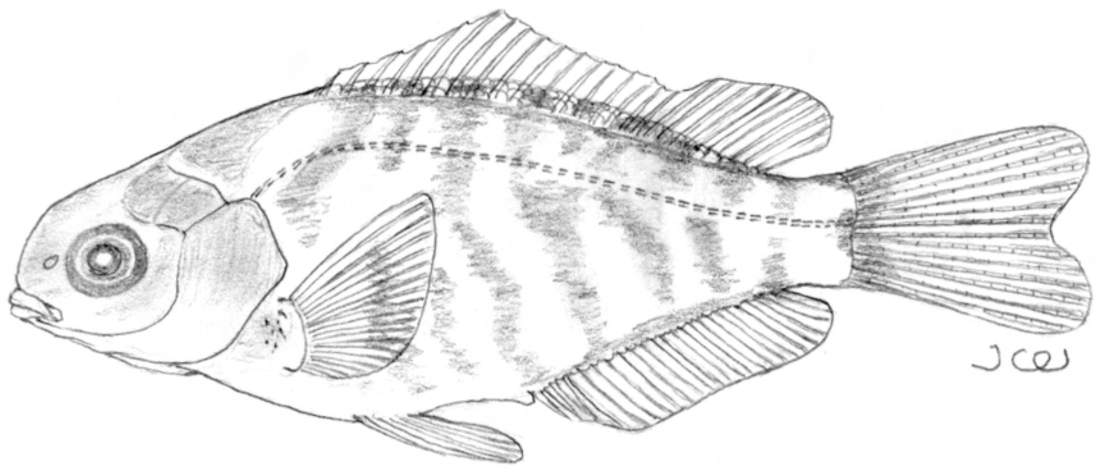


Figure 160.—*Hysterocarpus traskii*, tule perch juvenile, 36 mm TL (Wang 1986).

Taxonomic Characteristics of Embiotocids

	Shiner surfperch	**Tule perch**
Dorsal fin	VIII–XI,18–23	XV–XIX, 9–15
Pectoral fin rays	19–21	17–19
Pigmentation	Body has 3 yellow bars	Body has dark, oblique, irregular bars or no bars
Habitat	Mainly found in seawater and polyhaline waters, may enter freshwater	Mainly in freshwater, may enter oligohaline waters

Gobiidae – Gobies — Miller and Lea (1972) reported eight species of gobies inhabiting the estuarine waters of the Sacramento-San Joaquin system: yellowfin goby (*Acanthogobius flavimanus*), arrow goby (*Clevelandia ios*), tidewater goby (*Eucyclogobius newberryi*), longjaw mudsucker (*Gillichthys mirabilis*), cheekspot goby (*Ilypnus gilberti*), bay goby (*Lepidogobius lepidus*), blackeye goby (*Rhinogobiops nicholsii*), and chameleon goby (*Tridentiger trigonocephalus*). Only the yellowfin goby and chameleon goby are not native to the estuary. Recently, two more species were introduced, shimofuri goby (*T. bifasciatus*) and Shokihaze goby (*T. barbatus*). In this chapter, yellowfin goby, arrow goby, tidewater goby, longjaw mudsucker, cheekspot goby, bay goby, blackeye goby, chameleon goby, shimofuri goby, and Shokihaze goby are discussed.

Though all gobies have a short lifespan, they are able to produce many clutches of eggs during the spawning season, which ensures the continuity of the species. The larvae are generally pelagic or planktonic, and usually are able to drift with the tide thereby dispersing themselves into various salinity gradients in the estuary. Larvae drift near the surface during incoming tide and remain near the bottom during ebb tide. With light body pigmentation, which deters detection by predators, larval gobies usually have successful planktonic lives. Juvenile gobies descend to the bottom and have various mottled pigmentation patterns that allow them to blend in with the substrate. The body pigmentation can change quickly to blend with the surrounding environment when disturbed. Also, the pelvic fins fuse into a suction cup enabling the fish to conceal themselves by clinging to vegetations and the underside of rocks. Adults mostly burrow or are camouflaged with the surrounding environment.

YELLOWFIN GOBY *Acanthogobius flavimanus* (Temminck and Schlegel)

SPAWNING

Location	Tidal mudflats of coast and estuary (Miyazaki 1940, Dotsu and Mito 1955); tidal flats of south and central San Francisco Bays, San Pablo Bay, Moss Landing Harbor, and Elkhorn Slough (Wang 1986); Suisun Bay and Montezuma Slough on occasion.
Season	February through May in Japan (Miyazaki 1940); January through March in Kyushu, Japan (Dotsu and Mito 1955); larvae collected from December through July in San Francisco Bay and San Pablo Bay (Wang 1986); winter and early spring in Suisun Bay during dry-water years.
Temperature	7.5–13°C (Dotsu and Mito 1955); ~10–15 °C when prolarvae collected.
Salinity	Seawater to mesohaline.
Substrate	Hollow bamboo segments (Miyazaki 1940); sand, mud, and ceramic tube (Dotsu and Mito 1955); mostly in sand and mud bottoms in burrows.
Fecundity	6,000–32,000 (Myazaki 1940); 18,000 for a female 156 mm TL, and 22,252 for a female 197 mm TL.

EGGS

Shape	Tear-drop to club-shaped for fertilized eggs (Dotsu and Mito 1955); mature unfertilized eggs soaked in water, turned teardrop-shaped to club-shaped (B. Baskerville-Bridges 2007 and R.C. Reyes 2003–2009, personal communication).
Diameter	5.0–5.8 mm in long axis; 0.9–1.0 mm(average of 0.96 mm) in short axis (Dotsu and Mito 1955); mature unfertilized egg, long axis 1.2–2.5, short axis 1.0–1.5 mm in diameter, mainly 2.5 x 1.1.

Yolk	Yellowish, granular (Wang 1986); pale yellowish and granular.
Oil globule	Many oil globules in early embryo stage, consolidated into one in late embryo stage (Dotsu and Mito 1955).
Chorion	Transparent, smooth, thick, and elastic (Dotsu and Mito 1955).
Perivitelline space	Very wide in the long axis and narrow in short axis in early developmental stage (Dotsu and Mito 1955).
Egg deposition	Deposited in single layer on roof or wall of breeding chamber, may be very dense per unit area (Dotsu and Mito 1955).
Adhesiveness	Adhesive at anchoring point with short filaments (Dotsu and Mito 1955).
Buoyancy	Negatively bouyant or demersal; attached to substrate (Dotsu and Mito 1955).

LARVAE

Length at hatching:	4.6–5.0 mm TL (Dotsu and Mito 1955); 4.4–5.2 mm TL wild caught (Wang 1986).
Snout to anus length	46–48% TL for both prolarvae and postlarvae.
Yolk-sac	Toward thoracic.
Oil globule	Single oil globule in thoracic (Dotsu and Mito 1955).
Gut	Straight in prolarvae, rectum slanted in postlarvae.
Air bladder	Small, oval, just to rear of pectorals in prolarvae; large, oval, midway between pectorals and anus in postlarvae.
Teeth	Small and pointed in postlarvae.
Size at absorption of yolk	≥5.5 mm TL.
Total myomeres	32 (Dotsu and Mito 1955); 31–33.
Preanal myomeres	14 (Dotsu and Mito 1955); 13–14.
Postanal myomeres	18 (Dotsu and Mito 1955); 18–19.
Last fin(s) to complete development	Pectoral and pelvic (Watson 1996b); fused pelvic fin.
Pigmentation	In prolarvae, a large stellate melanophore is located midway between anus and caudal fin on the ventrum plus a small melanophore on the dorsum. In postlarvae, stellate melanophores are located on thoracic, postanal, caudal, and dorsally on anus.
Distribution	Prolarvae and postlarvae are pelagic, found in polyhaline to mesohaline waters in San Francisco Bay, San Pablo Bay, Napa River, and a few in Suisun Bay. Most larvae drift by

	tide via Carquinez Strait and end up in the Delta and its lower section of tributaries.

JUVENILES

Dorsal fin rays	VIII, 14 (Dotsu and Mito 1955); VIII, 14 (Miller and Lea 1972); VII–VIII, 14.
Anal fin rays	12–13 (Dotsu and Mito 1955); 11–12 (Miller and Lea 1972); I, 11–12 (Wang 1986); 12–14 (Okiyama 1988).
Pectoral fin rays	21 (Dotsu and Mito 1955); 20–22.
Mouth	Maxillary does not extend beyond the center of eye (Moyle 1976); large, terminal to subterminal.
Vertebrae	33 (Dotsu and Mito 1955); 33–35.
Distribution	Benthic (burrowed) and epibenthic in Napa River, passing through Carquinez Strait to Suisun Bay, Delta, and tidally influenced portions of Delta tributaries; juveniles also found in Rodeo Lagoon, upper Tomales Bay, lower Walker Creek, Moss Landing Harbor, and Elkhorn Slough.

LIFE HISTORY

Yellowfin goby was accidentally introduced into San Francisco Bay in the 1950s from the ballast of ships coming from East Asian countries (Brittan *et al.* 1963). It has been very successful in expanding its range in the euryhaline estuary and coastal waters. It spread rapidly in the Sacramento-San Joaquin Estuary soon after its introduction (Brittan *et al.* 1970). Currently, major populations are known to the coast of California. Their northern range is from Tomales Bay to Elkhorn Slough (Miller and Lea 1972). Their southern range is from Los Angeles Harbor to Newport Beach (Haaker 1979). They are also found in Moss Landing Harbor, Elkhorn Slough, and Morro Bay (E. Calix 1999–2005, personal communication). More recently, their range has expanded to include Estero Americano in northern California and Baja California (Watson 1996b). No yellowfin goby was collected from O'Neill Forebay and San Luis Reservoir during the periods 1979–1981 and 1994–1995 (Hess *et al*. 1995), although it was previously reported from these locations.

Prespawning colors of yellowfin goby males and females were observed during their catadromous runs at the CVP/TFCF. For males, the color on the head and dorsum ranged from light to dark. Approximately seven dark blotches across the dorsum and on both sides of the body, irregular mottled blotches along the lateral line region, and a dark spot at the base of caudal fin were observed. The color of isthmus varied from light to dark. The fused pelvic fin has around nine radiated dark bands or no pigmentation. Pectoral fin has yellowish hue and no pigments except at the base. Anal fin is yellowish and with a dark band across all the fin rays. A dark band was also observed at the ventral edge of the caudal fin. Dorsal fins and caudal fin were very spotty with black pigments arranged in mosaic pattern similar to pheasant feathers. The abdominal region is whitish (fully developed testes are milky-white in color and occupy most of the abdominal cavity). The pigmentation of mature females is almost identical to that of males, with abdominal region whitish to yellowish but more bulging.

Yellowfin goby apparently cannot complete its life cycle in freshwater to oligohaline waters (Wang 1986). Based on collection of prolarval specimens in the study area, spawning is estimated to occur from December through early July in higher saline waters of San Francisco Bay, San Pablo Bay, and occasionally, Suisun Bay. Wang (1982, 1986) reported prolarvae on sandbar of Rodeo Lagoon when salinities were ≥5 ppt. When the National Park Service prevented the natural breaching of the sandbar, saltwater was prevented from entering the lagoon, and kept the lagoon's salinity at ≤5 ppt. At this salinity, yellowfin goby ceased spawning in the lagoon. Yellowfin goby prolarvae were never observed from samples taken from freshwater and reproductive populations of yellowfin goby have not been found outside of the Delta freshwater systems, such as O'Neill Forebay and San Luis Reservoir (Hess *et al.* 1995), suggesting that yellowfin goby do not spawn in freshwater.

Spawning and nesting behaviors of yellowfin goby were reported by Dotsu and Mito (1955) in its native waters of Japan. Newly-hatched larvae initially stay in the Y-shaped burrow and become planktonic as they exit their burrow (Dotsu and Mito 1955). Some larvae that hatch in San Francisco Bay ascend to Carquinez Strait and Suisun Bay as early as late February (Wang 1986). This upstream movement is similar to that of the naked goby (*Gobiosoma bosc*) which uses tidal changes to move into the upper estuaries from the mid-Atlantic coast. The larvae float near the surface of the water column during flood tide and descend near the bottom while the tide ebbs (Massman *et al.* 1963). This strategy is also known to be used by white croaker and starry flounder in the estuary (Wang 1986).

Juveniles settle on the bottom at about 13 mm TL (Miyazaki 1940), their body begins to exhibit mottled pigmentation, and their pelvic fins fuse into a sucking disc. They are able to cling to substrate or tunnel into burrows. Juvenile yellowfin goby prefer tidal sloughs with muddy bottoms and peat moss banks, such as the environments of Montezuma Slough and Suisun Marsh (Matern *et al*. 2002). They often hide in burrows to avoid predators while at the same time ambushing small prey. Juveniles occasionally venture into the lower portions of the Delta tributaries such as Pacheco Creek in Contra Costa County. They are abundant in various sloughs and irrigation channels of the Delta in summer months (T. Woods 1994–1995, personal communication).

Major food items for small juvenile yellowfin goby include various copepods (Dotsu and Mito 1955). Large juveniles eat amphipods (such as *Gammarus* spp.), mysid shrimp, and smaller fish. In the laboratory, juveniles are adaptable feeders and can be trained to eat chopped fish fillet, trout pellet, and Tetramin® flake.

In Japan, some yellowfin goby reach maturity after 1 year (Miyazaki 1940, Dotsu and Mito 1955). In the California population, maturity is reached in 2–3 years (Brittan *et al.* 1963). Mature, 1-year-old yellowfin goby generally ranged from 85 to 220 mm TL.

During their catadromous run, male yellowfin goby initially appear at CVP/TFCF, followed by females (Table 1). Males appeared in larger numbers than females beginning September; the numbers of females increased at the beginning of the following year. The ratio between males and females was close to 1:1 until the run ceased at the end of March 2003. The catadromous run may be associated with Delta outflow and water temperature. In 2004, yellowfin goby males started their catadromous movement in late September. Winter storms started earlier in the season and the water was warmer. The bulk of the run was completed by the end of December, earlier compared to 2002–2003. Towards the end of the run, more individuals with undeveloped gonads were observed (5 out of 12 seen in February 2003; 1 in March 2003). Whether they reach maturity after arriving in the San Francisco Bay, die without reproducing, or delay spawning is unclear, although it is likely that the majority die after spawning (Fish *et al.* 2008). The anadromous run of the adult yellow fin goby has not been observed in this study.

Table 1.—Proportion of male to female yellowfin goby during catadromous run, Central Valley Project's Tracy Fish Collection Facility, 2000–2003.

Month/Year	**Total Fish**	**Male**	**Female**	**Sex Ratio(M:F)**
Sept.–Nov. 2002	47	43	4	~10:1
Dec. 2002 (1st half)	73	33	40	~1:1
Dec. 2002 (2nd half)	19	10	9	~1:1
Jan. 2003 (Early month)	30	11	19	~1:2
Jan. 2003 (Late month)	17	2	15	~1:7
Feb. 2003 (Late month)	7	0	7	~0:7
Total	**193**	**99**	**94**	**~1:1**

The yellowfin goby population in the Sacramento-San Joaquin Estuary seems to be declining. During the period 1990–2007, there were only two large catadromous runs: 1993 (~600,000), 2000 (~400,000). Low numbers were recorded in the spawning runs of 2006 (~6,000) and 2007 (~16,000) (Reclamation salvage records). Juvenile collections were also low in 2005 and lower still in 2006. In 2008, as late as May, there were large numbers of small (~100 mm) but mature females collected from the CVP/TFCF. Finally, in 2009, very few juveniles were observed at the CVP/TFCF larval sampling.

Yellowfin goby is considered a game fish and an expensive delicacy in Japan, having a fine texture when filleted (Miyazaki 1940, Dotsu 1978). In Japan, cut bamboo tubes, which yellowfin gobies use for shelter, are inserted into mudflats during ebb tide and are harvested at the next low tide. Yellowfin goby from the study area is sold as food fish in Asian fish markets mostly during the winter months. Commonly called mudsucker or bullhead, this species is also a highly valued bait fish (both in live and frozen forms) and sold in tackle shops. It may expand its territory along the California coastal lagoons and estuaries through the release of live bait by fishermen.

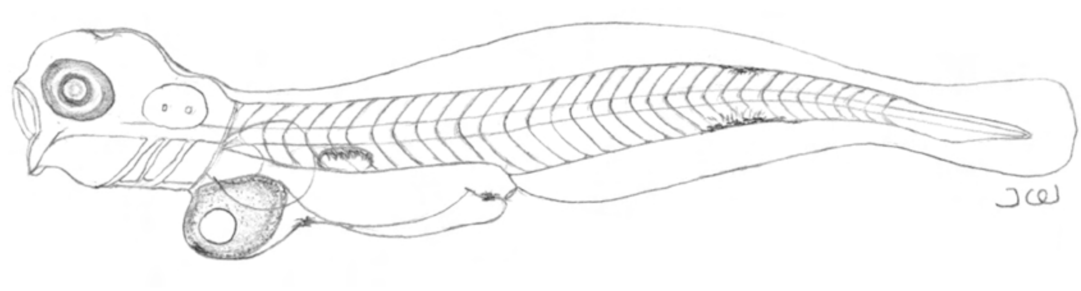


Figure 161.—*Acanthogobius flavimanus*, yellowfin goby prolarva, 5.5 mm TL (Wang 1986).

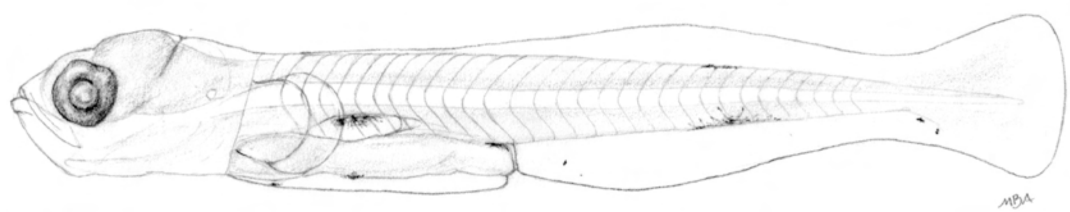


Figure 162.—*Acanthogobius flavimanus*, yellowfin goby postlarva, 6.8 mm TL (Wang 1986).

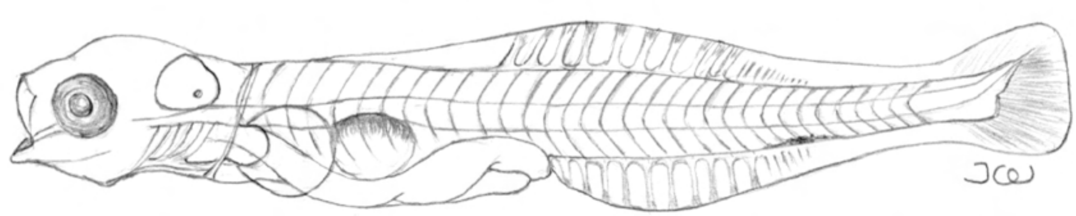


Figure 163.—*Acanthogobius flavimanus*, yellowfin goby postlarva, 8 mm TL (Wang 1986).

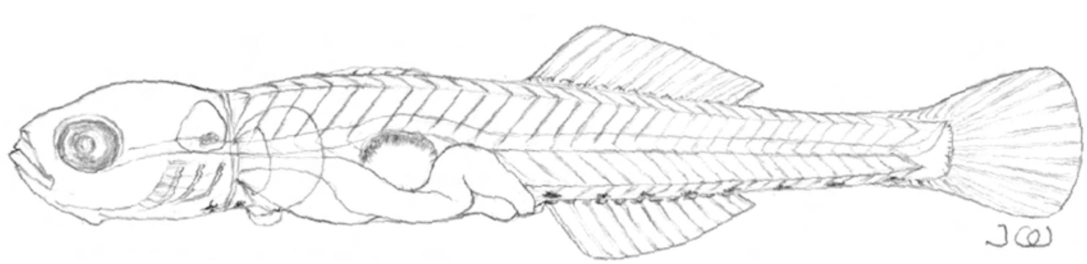


Figure 164.—*Acanthogobius flavimanus*, yellowfin goby prejuvenile, 13.2 mm TL (Wang 1986).

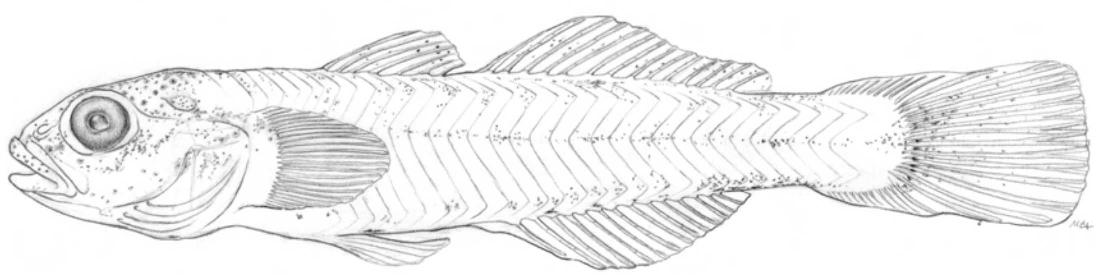
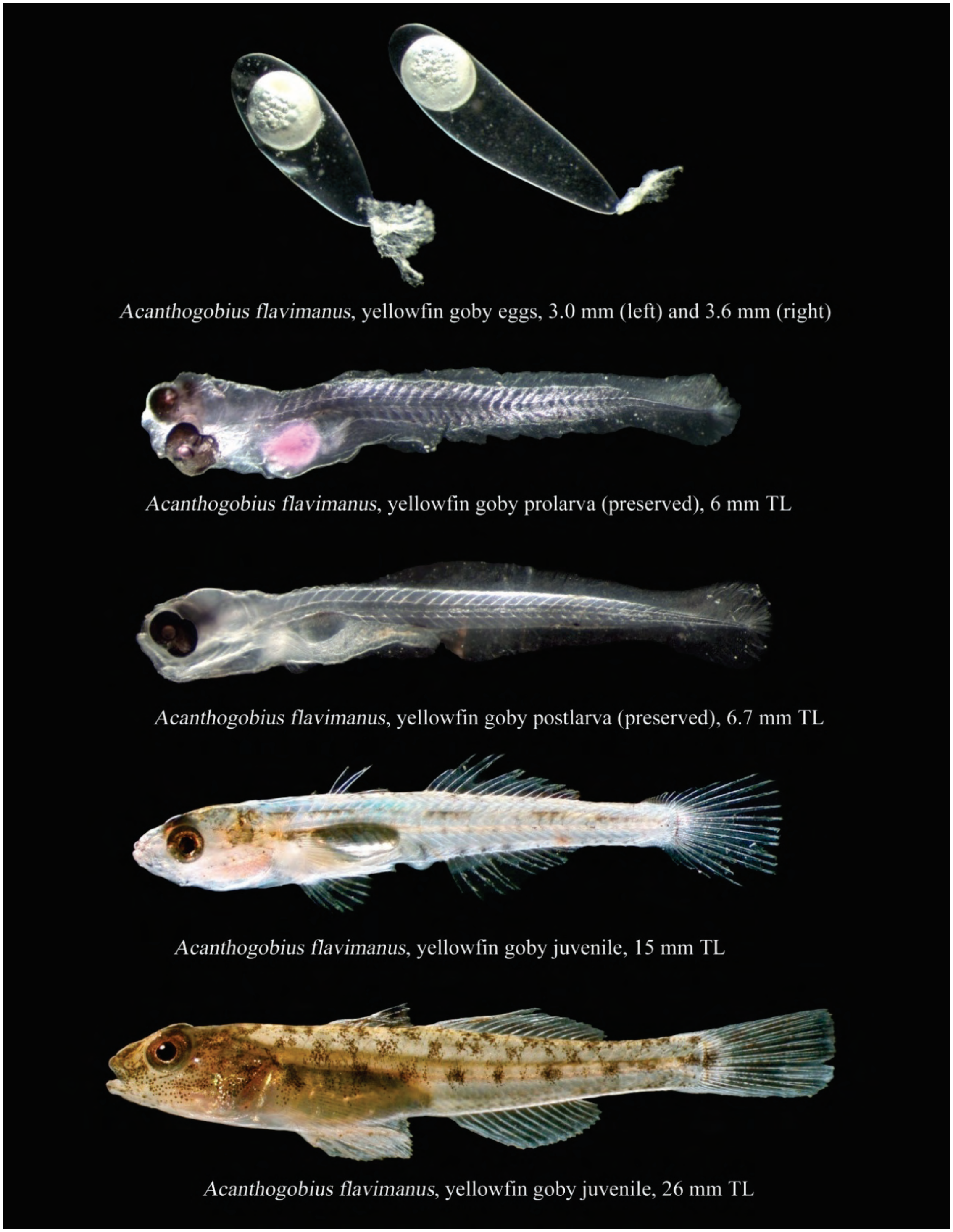


Figure 165.—*Acanthogobius flavimanus*, yellowfin goby juvenile, 22.3 mm TL (Wang 1986).



Acanthogobius flavimanus, yellowfin goby eggs, 3.0 mm (left) and 3.6 mm (right)

Acanthogobius flavimanus, yellowfin goby prolarva (preserved), 6 mm TL

Acanthogobius flavimanus, yellowfin goby postlarva (preserved), 6.7 mm TL

Acanthogobius flavimanus, yellowfin goby juvenile, 15 mm TL

Acanthogobius flavimanus, yellowfin goby juvenile, 26 mm TL

Figure 166.—*Acanthogobius flavimanus*, yellowfin goby.

ARROW GOBY *Clevelandia ios* (Jordan and Gilbert)

SPAWNING

Location	Lagoons, estuaries, and tidal sloughs (MacDonald 1972); intertidal mud or sand flats, and coastal waters. Specific locations: Moss Landing Harbor, Elkhorn Slough, and Tomales Bay, San Francisco Bay, San Pablo Bay, and Lake Merritt. Morro Bay also has arrow goby spawning population (E. Calix 1999–2005, personal communication).
Season	December through August, with peak spawning in March to June (Prasad 1959); December through September (MacDonald 1972); year round.
Temperature	~15°C (Prasad 1959); ≥10°C.
Salinity	Seawater to polyhaline.
Substrate	Mud or sand (MacDonald 1972); mud, sand, and gravel.
Fecundity	750–1,000 eggs at one time; actual count of ripe ova 800–1,200 (Prasad 1959); 15–25 at one laying (MacGinitie 1935); ~425–450 mature ova in females 50.0–53.0 mm TL.

EGGS

Shape	Elliptical, club-shaped (Prasad 1959, Brothers 1975).
Diameter	Mature eggs, long axis 0.735 mm and short axis 0.645 mm (MacGinitie 1935); unfertilized eggs spherical, 0.735 mm, fertilized eggs nearly elliptical, long axis 1.17–1.30 mm and short axis 0.715–0.790 mm (Prasad 1959); ripe eggs 0.62–0.65 mm (Brothers 1975); fertilized eggs 2.5 mm long (Watson 1996b).
Yolk	Honey color, translucent (Prasad 1959), yellowish, granular.
Oil globule	Many small oil globules in early incubating stages consolidate into one globule prior to hatching (Prasad 1959); ~0.2 mm in diameter (Watson 1996b).
Chorion	Transparent and smooth except at the proximal end of long axis.
Perivitelline space	Prior to early embryo stages, the space is wide through long axis and narrow through the short axis (Prasad 1959).
Egg deposition	Deposited in single layer, but threads of adjacent eggs may join together as in a bunch of grapes (Prasad 1959).
Adhesiveness	Restricted to anchoring point, with a bundle of filaments at the basal end of long axis.

Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	2.75–3.20 mm TL (Prasad 1959); 3.0 mm TL (Brothers 1975).
Snout to anus length	~46–59% TL for prolarvae and postlarvae.
Yolk	Almost round (Prasad 1959); spherical and thoracic.
Oil globule	Single (Prasad 1959); ~0.2–0.3 mm in diameter and located anteriorly or in center of yolk-sac.
Gut	Straight and thick.
Air bladder	Small, oval, near pectorals in prolarvae; midway between pectorals and anus or near anus in postlarvae.
Teeth	Small, pointed, developed in postlarvae.
Size at absorption of yolk	~3.5–4.5 mm TL.
Total myomeres	34–36.
Preanal myomeres	16–19.
Postanal myomeres	16–19.
Last fin(s) to complete development	Fused pelvic fin (Wang 1986); spiny dorsal fin (Watson 1996b).
Pigmentation	In prolarvae, a few melanophores on dorsal surface of gut and postanal region ventrally; in postlarvae, a few melanophores dorsally on gut near anus; dashed melanophores midventrally; a few melanophores in postanal region midventrally; two large stellate melanophores midway between anus and caudal fin, one on dorsum and one on ventrum, the dorsal one is diminished in late postlarvae.
Distribution	Pelagic along the Pacific coast (Prasad 1959); common in Richardson Bay (Eldridge 1977); most remain in more saline central and south San Francisco Bay, and San Pablo Bay; few are found in Suisun Bay and Napa River; larvae are common in Tomales Bay, Moss Landing Harbor, and Elkhorn Slough (Prasad 1969, Nybakken *et al.* 1977, Wang 1986).

JUVENILES

Dorsal fin rays	IV–VI; 0–I, 14–17 (Miller and Lea 1972).
Anal fin rays	0–I, 14–17 (Miller and Lea 1972).
Pectoral fin rays	18–21 (Wang 1986).
Mouth	Terminal, large, maxillary extending beyond posterior margin of the eye.

Vertebrae	36–37 (Miller and Lea 1972); 35–37 (Matarese *et al*. 1989); mostly 36.
Distribution	Richardson Bay (Eldridge 1977); mostly lower bays and along the coast; some in San Pablo Bay, Napa River, and Suisun Bay; abundant in Lake Merritt (Oakland, California); abundant in Tomales Bay (Wang 1986); abundant in Moss Landing Harbor and Elkhorn Slough (Prasad 1959, Nybakken *et al.* 1977, Wang 1986); Morro Bay (E. Calix 1999–2005, personal communication).

LIFE HISTORY

Arrow goby ranges from the Gulf of California to the Straits of Georgia, British Columbia, inhabiting coastal lagoons, estuaries, and tidal sloughs (Miller and Lea 1972, MacDonald 1972, Hart 1973). It has been reported as the most abundant goby in Richardson Bay (Eldridge 1977), Moss Landing Harbor, and Elkhorn Slough (Prasad 1959, Nybakken *et al.* 1977). Juveniles of arrow goby have been collected in the lower Napa River, eastern San Pablo Bay, and Suisun Bay occasionally during dry years. Larvae were common in the higher saline waters of San Francisco Bay.

Arrow goby appear to spawn year round—larvae were captured monthly in the San Francisco Bay, Tomales Bay, Moss Landing Harbor, and Elkhorn Slough (Wang 1986). Spawning activity is high all year except for autumn (Prasad 1959). In aquaria, arrow gobies lay their eggs on bottom where they adhered to sand granules (MacGinitie 1935, Prasad 1959). Arrow goby spawn in burrows excavated by ghost shrimp or other invertebrates, depositing eggs approximately 10 cm deep on the walls of the burrow (MacDonald 1972, Wang 1986). Different sizes of ova found in the ovaries indicate that arrow gobies have a lengthy breeding period and produce more than one clutch of eggs. Eggs hatch in 10–12 d at 15°C (Prasad 1959).

Newly-hatched arrow goby larvae are pelagic (Prasad 1959). Large numbers of yolk-sac larvae were collected near the Moss Landing Powerplant intake areas in winter and spring months, indicating that they swim out of burrows soon after hatching (Wang 1986). A similar situation had occurred at Morro Bay Powerplant (E. Calix 1999–2005, personal communication). In the Sacramento-San Joaquin Estuary, the bulk of the larval population remains in the San Francisco Bay, south San Francisco Bay, and San Pablo Bay (Wang 1986). They have also been observed in lower Napa River, but not in Carquinez Strait, and Suisun Bay (CDFG fish E and L survey, 1988–1995). MacDonald (1972) reported that arrow goby can tolerate salinity changes, may migrate upstream, but can not spawn in low salinity.

Juvenile arrow goby begin to settle on the bottom and burrow at approximately 10–14 mm TL (MacDonald 1972). Prefered habitats include tidal sloughs, lagoons, and coves with sand and mud bottoms where tidal action is slight (Prasad 1959). Large numbers of juveniles were collected in such locations as Hunters Point in the south San Francisco Bay, Lake Merritt, Marconi Cove in Tomales Bay, and the upper portion of

Elkhorn Slough (Wang 1986). As Prasad (1959) has reported, juvenile arrow goby do not move into deeper water during the ebbing tide; rather, they hide in burrows or beneath rocks and cobbles. More juvenile arrow goby were collected in the shallow slough during ebb tide than during flood tide. They also moved into lower saline waters such as Napa River and Suisun Bay probably to feed (CDFG striped bass E and L survey, 1988–1995; CDFG 20-mm fish survey in Napa River, 1995–2005; Stillwater Sciences, Inc., sampling in upper Napa River, 2000–2001). They may also occasionally swim into freshwater at the head of the estuaries (Moyle 2002).

Principal food items of juvenile arrow goby are copepods, ostracods, nematodes, and other small invertebrates (Prasad 1959, MacDonald 1972).

Arrow goby become sexually mature after 1 year and their lifespan is estimated to be 3 years (Brothers 1975). This species has no commercial or sport value because of its small size (most <50 mm TL). It may have some importance as forage for predatory fishes and seabirds.

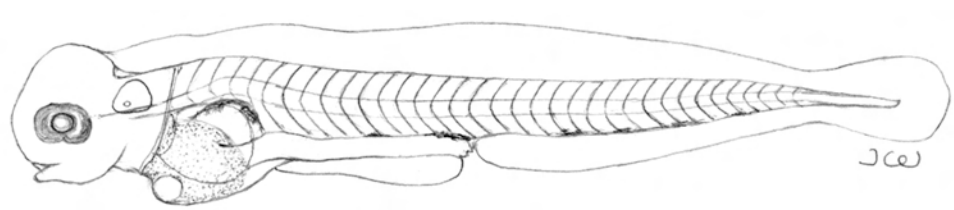


Figure 167.—*Clevelandia ios*, arrow goby prolarva, 3.1 mm TL (Wang 1986).

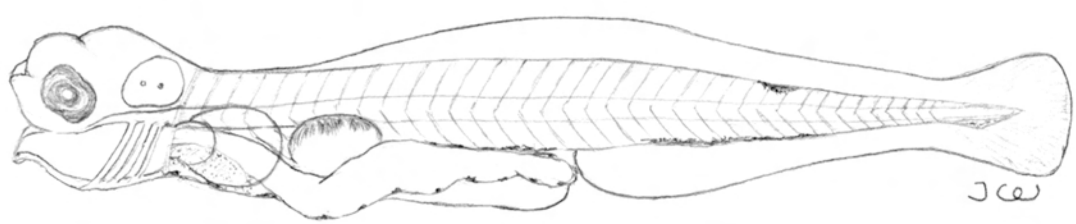


Figure 168.—*Clevelandia ios*, arrow goby postlarva, 4.8 mm TL (Wang 1986).

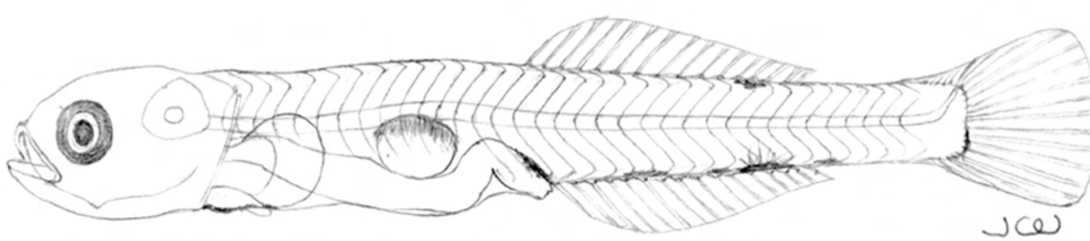


Figure 169.—*Clevelandia ios*, arrow goby prejuvenile, 11.5 mm TL (Wang 1986).

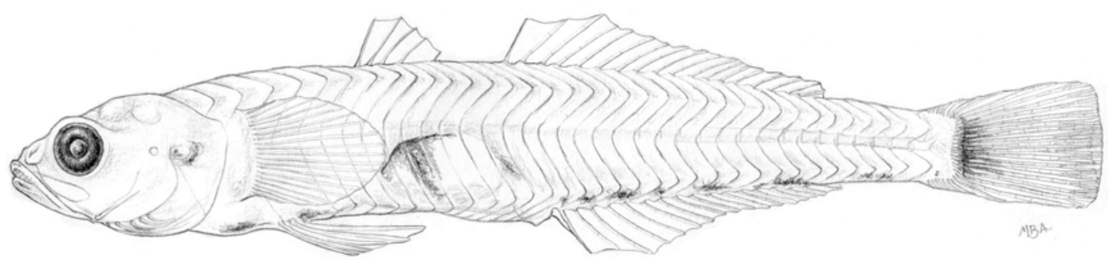


Figure 170.—*Clevelandia ios*, arrow goby juvenile, 21.5 mm TL (Wang 1986).

TIDEWATER GOBY *Eucyclogobius newberryi* (Girard)

SPAWNING

Location	Shallow water of Pacific coastal streams (Swift 1980, Swift *et al.* 1989). Locally, in Rodeo Lagoon, Estero de San Antonio, and Estero Americano (Wang 1982, 1984).
Season	Almost all year round (Goldberg 1977); peaking April through June in southern California (Goldberg 1977); spawns all year round and peaks in spring months in Rodeo Lagoon (Wang 1984).
Temperature	In Rodeo Lagoon, 8.0–21.0°C (Wang 1982, 1984).
Salinity	Mesohaline to freshwater (Wang 1982); freshwater with access to saline water.
Substrate	Sandy burrows (Swift 1980); shallow weedy inshore areas or ditches with gravel, sand or clay mud bottom in Rodeo Lagoon (Wang 1982, 1984).
Fecundity	640–800/batch for ripe females 43–47 mm TL (Wang 1982); 150–1,100/clutch and up to 2,400–4,800 for females that survived two spawning seasons, number or eggs increasing linearly with female size (Swenson 1999).

EGGS

Shape	Elliptical and elongate; club-shaped with blunt distal end, slender, and pointed at proximal end (fertilized eggs specimen from R. Swenson, UC Davis).
Diameter	Mature unfertilized eggs oval, long axis 1.1–1.3 mm; short axis 0.8–1.1 mm (Wang 1982); fertilized eggs, long axis

	~4.0–4.2 mm; short axis ~1.0–1.3 mm (fertilized eggs specimen from R. Swenson, UC Davis).
Yolk	Yellowish, granular (Wang 1982).
Oil globule	Mature egg has one large oil globule, ~0.2–0.3 mm in diameter, and many small oil globulets (Wang 1982); fertilized egg has one consolidated oil globule, ~0.3–0.35 mm in diameter.
Chorion	Transparent, smooth, except at the long axis (proximal end), with anchoring filaments.
Egg deposition	Deposited in burrows (Swift 1980); deposited in burrow in single layer and attached to a common mat (Swenson 1999).
Adhesiveness	Restricted to the adhesive filaments at the proximal end of the egg.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	Larvae were ~4.0 mm TL when collected from a burrow.
Snout to anus length	~51–52% TL for prolarvae 4.2–5.2 mm TL; ~49–51% TL for postlarvae 8.6–12.3 mm TL (Wang 1986).
Yolk-sac	Spherical, small, and in thoracic.
Oil globule	Single, usually located in anterior portion of yolk-sac (Wang 1982); ~0.1–0.2 mm in diameter.
Gut	Straight in prolarvae and early postlarvae, twisted in postlarvae.
Air bladder	Oval in prolarvae; elongate and midway between pectoral fin and anus in postlarvae.
Size at absorption of yolk	~4.8 mm TL.
Teeth	Sharp, pointed in postlarvae.
Total myomeres	32–34.
Preanal myomeres	16–17.
Postanal myomeres	15–17.
Last fin(s) to complete development	Fused pelvic (pelvic disc).
Pigmentation	In prolarvae, stellate melanophores along dorsal surface of gut at postanal region ventrally and dorsally, and dashed to dotted melanophores along the midventral region. In postlarvae, large stellate melanophores on snout, head, and middorsal regions (some specimens collected in fall lacked this pigmentation). Scattered melanophores along body, both dorsally and ventrally. A single black spot at distal

	end of mandible. Some large postlarvae (≥11.0 mm TL) may have pigmentation "network" wrapping around the vertebral column (Wang 1982).
Distribution	Newly-hatched larvae remain in the burrow, with development eventually becomes planktonic. They can be found near the sandbar at Rodeo Lagoon and in Estero Americano (below Valley Ford on Franklin School Road, Marin County).

JUVENILES

Dorsal fin rays	VI–VII; I, 9–12 (Miller and Lea 1972); 6–7 slender spines in first dorsal fin and 9–13 in second dorsal fin (Moyle 2002).
Anal fin rays	I, 8–11 (Miller and Lea 1972); I, 9–12.
Pectoral fin rays	18–22 (Wang 1986); 19–21 (Watson 1996b).
Mouth:	Terminal and large, maxillary extends to posterior margin of the eye (Moyle 1976); middle of the eye to posterior margin of the eye.
Vertebrae	33–35 (Miller and Lea 1972, Watson 1996b).
Distribution	On bottom or existing on submerged plants in shallow weedy areas of California coastal lagoons, rivers, and streams where freshwater meets saline water.

LIFE HISTORY

Tidewater goby is a small native species (usually <50 mm TL) found along the Pacific coast of California from the Smith River, Del Norte County, south to Agua Hedioonda Lagoon, San Diego County (Swift 1980, Swenson 1999). Local records from the California Academy of Sciences show it inhabitating Paper Mill (or Lagunitas) Creek and Rodeo Lagoon in Golden Gate National Recreation Area (GGNRA). It was also found at the mouth of Corte Madera Creek at Corte Madera (Hubbs and Miller 1965), Lake Merced in San Francisco, the Aquatic Park of Berkeley, Lake Merritt in Oakland, and at the mouth of Novato Creek of San Pablo Bay (Swift 1980). It was not found within San Francisco Bay in this study (Wang 1986, Moyle 2002).

Tidewater goby was collected in Waddell Creek (Shapovalov and Taft 1954), Elkhorn Slough (Nybakken *et al.* 1977, this study) and Salmon Creek near Bodega Bay (P.B. Moyle 1982, 1987, personal communication). It is reported from Rodeo Lagoon, Estero de San Antonio, and Estero Americano, but not at Big Lagoon of Muir Woods Creek (Wang 1984, Wang and Keegan 1988). It was also collected in Morro Bay (E. Calix 1999–2005, personal communication). Currently, there are ≤40 existing tidewater goby habitat locations left from the 87 original locations that Swift *et al.* 1989 described.

Goldberg (1977) observed that the tidewater goby has an asynchronous ovarian cycle; individuals are in different stages of reproductive development throughout the year. Although larvae were collected year round (Wang 1984), the spawning peak in Rodeo Lagoon can be separated into two major periods: from late March to July on sandbars near the ocean and from late August to November below the road bridge in the distal end of the lagoon where cooler water from Rodeo Creek flows. The tidewater goby may slow down or delay spawning at water temperatures exceeding 20°C (Wang 1982, 1984). Unlike shimofuri goby, tidewater goby spawn in cooler water; however, like the shimofuri goby, tidewater goby can produce multiple clutches of eggs during a spawning season (Swenson 1995, Matern 1999, this study). Tidewater goby has a short lifespan, therefore, producing many eggs in different seasons may be an important survival strategy.

During a study of the tidewater goby in Rodeo Lagoon during the period 1980–1986 (Wang 1982, 1984; Wang and Keegan 1988), gravid females were observed at two different sites. The first site is near a concrete bridge built in 1982 which replaced an old wooden bridge but left only gravel and mud. The tidewater goby may have used gravel crevices for spawning in this location. The other location is near a sandbar on the ocean side of the lagoon. At this location, sand is used for spawning. Gravid females (with deep yellowish yolk) were collected from both sites.

Female tidewater goby are colorful and take a leading role by competing with other females in order to mate with males (Swenson 1999), a behavior different from other gobies in the study area. Spawning females, with much darker fin coloration, were often found in the shallow ditches and inshore areas of lower Rodeo Lagoon (Wang 1986). Females deposit eggs in a single layer; the proximal end of the egg bears a bundle of adhesive filaments attached to a common mat which in turn is attached to spawning substrate, the wall of a burrow. The male parent guards the nest after the female finishes depositing eggs.

Tidewater goby larvae initially remain in burrows after hatching; however, it is unclear how long the larvae remain in the burrows because male tidewater goby plug the entrance (Swenson 1999). Yolk-sac planktonic larvae, measuring approximately 4 mm TL, were captured with an ichthyoplankton net from 1 m deep, open waters of the Rodeo Lagoon (Wang 1986). Late yolk-sac larvae >5.0 mm TL, found inshore with vegetation, had dense pigmentation covering both dorsal and ventral body surfaces.

Juvenile and adult tidewater gobies are benthic inhabitants (Swift 1980). In the laboratory, juveniles were observed resting on the aquarium bottom or in submerged vegetation. Their swimming patterns are fluid, without the jerky movement common to other goby species. Schools of juveniles were observed spring and summer months in dense inshore bushes near sandbars in the mid-section of Rodeo Lagoon (Wang 1984, Wang and Keegan 1988).

Swift (1980) reported mollusks, insects, and crustaceans as food for the tidewater goby. Other principal food items include benthic invertebrates such as ostracods, chironomid larvae, and a gammarid amphipod (*Corophium spinicorne*; Swenson and McCray 1996). In the Rodeo Lagoon, small crustaceans such as copepods, amphipods, and mysid shrimps were often consumed by juvenile tidewater goby (Wang 1986). Swenson and McCray (1996) found that juveniles fed at all hours whereas adults fed mainly at night. They also found that fish from the marsh were substantially larger than those from other habitats, suggesting that marshes provide better opportunities for growth.

Most of the tidewater gobies collected Rodeo Lagoon were YOY to 1+ year-old fish; no 2-year-old fish were collected (Wang 1986, Swenson 1999). Swift (1980) noted that some tidewater goby in the northern portion of their range live as long as their third summer. Factors that may limit the lifespan of tidewater goby include the lack of year-round food sources and predation by other fish and seabirds.

The tidewater goby has been listed as an endangered fish species by the U.S. Fish and Wildlife Service (USFW) since 1994. It is morphologically unique among the gobies because it has cycloid scales (most gobies have ctenoid scales). Their sexual behavior is also unique among the gobies as mentioned above. This species has a short lifespan and needs specific brackish-freshwater habitats. It cannot complete its life cycle in a total freshwater environment, such as at the Rodeo Lake in Marin County, a lake separated by a small manmade dam from the lagoon since World War II (J. Howell 1982, personal communication).

Tidewater goby has no sport or commercial value for humans; however, it is an important ecological indicator species similar to delta smelt, serving as a measure for environmental condition of its habitat. For example, when a short-term oil spill occurred near the sandbar area of Rodeo Lagoon in February 1986, the tidewater goby retreated but gradually returned to their historically preferred sandbar areas after 2–3 months (Wang and Keegan 1988). Protective management is crucial for the survival of the remaining tidewater goby populations known to the Pacific coast of California.

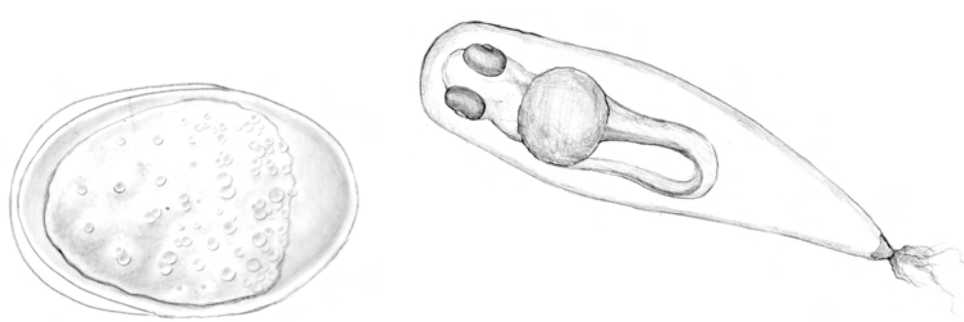


Figure 171.—*Eucyclogobius newberryi*, tidewater goby unfertilized egg (left), 1.8-mm-long axis, 0.8-mm-short axis (Wang 1986); advanced embryo (right).

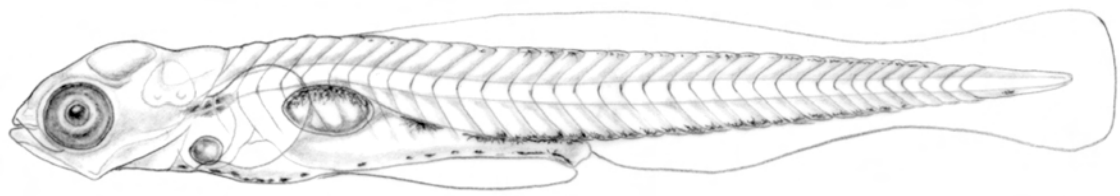


Figure 172.—*Eucyclogobius newberryi*, tidewater goby prolarva, 5.1 mm TL (Wang 1986).

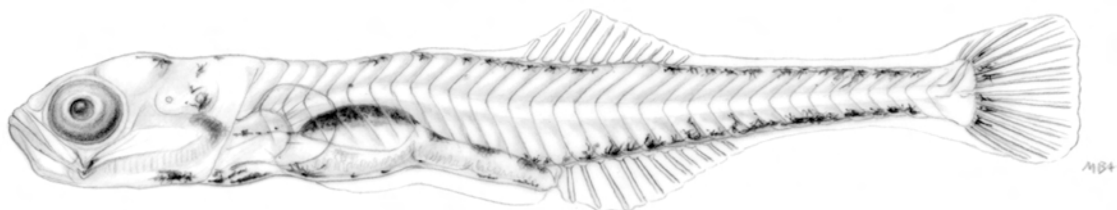


Figure 173.—*Eucyclogobius newberryi*, tidewater goby postlarva, 8.6 mm TL (Wang 1986).

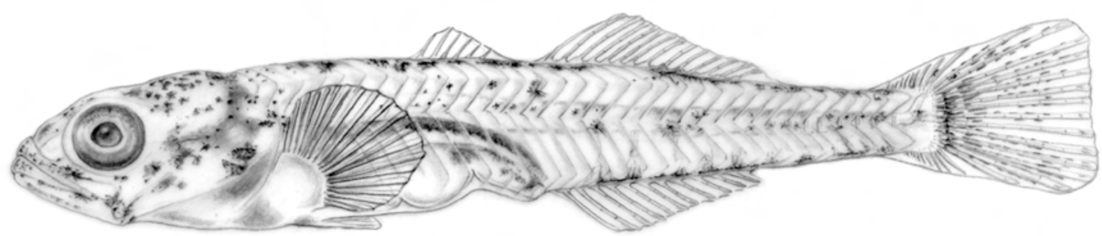


Figure 174. —*Eucyclogobius newberryi*, tidewater goby juvenile, 15 mm TL (Wang 1986).

LONGJAW MUDSUCKER *Gillichthys mirabilis* Cooper

SPAWNING

Location	Saltwater ponds and tidal water sloughs such as Alviso Salt Pond of south San Francisco Bay (De Vlaming 1972); Elkhorn Slough (Nybakken *et al.* 1977); south Tomales Bay, San Pablo Bay, lower Napa River, Suisun Bay, and Montezuma Slough.
Season	January through July (Weisel 1947); January through September (De Vlaming 1972); January through June typical for the northern half of its range along California coast (Barlow and De Vlaming 1972); all seasons in Elkhorn Slough (Nybakken *et al.* 1977); November through June in San Francisco Bay and Tomales Bay (Wang 1986); September–January and May–July in southern California

	(Watson 1996b); January through June in Napa River and Suisun Bay.
Temperature	18°C (Weisel 1947); ≥10°C.
Salinity	Hypersaline (Barlow 1961, 1963; Barlow and De Vlaming 1972); hypersaline to mesohaline in Napa River and lower mesohaline in Suisun Bay and Montezuma Slough.
Fecundity	4,000–9,000 (Weisel 1947); 8,000–27,000 (Barlow 1961, Barlow and De Vlaming 1972).

EGGS

Shape	Unfertilized eggs are spherical, fertilized eggs are club-shaped (Weisel 1947).
Diameter	2.27–3.37 mm in long axis; 1.06–1.13 mm in short axis (Weisel 1947).
Oil globule	Many small oil globules in early development stages; number reduced as embryo develops (Weisel 1947).
Chorion	Transparent at 24-h stage, many fine gelatinous threads start to cover the surface of chorion (Weisel 1947).
Perivitelline space	Very wide in long axis and short in short axis after fertilization (Weisel 1947).
Egg deposition	Clusters of eggs attached to center stalks (Weisel 1947).
Adhesiveness	Numerous adhesive threads at proximal end (long axis) of the egg (Weisel 1947).
Buoyancy	Negatively buoyant or demersal (Weisel 1947).

LARVAE

Length at hatching	<3.5 mm TL (Weisel 1947); ~3.0–4.0 mm TL, for specimens collected at Elkhorn Slough.
Snout to anus length	48–53% TL for prolarvae and postlarvae.
Yolk-sac	Yellowish, spherical, thoracic.
Oil globule	Single oil globule located anteriorly or in central region of yolk-sac.
Gut	Straight in prolarvae; twisted in postlarvae.
Air bladder	Oval, small, behind pectoral fin in prolarvae and early postlarvae; more posterior in postlarvae.
Teeth	Sharp and pointed in postlarvae.
Size at absorption of yolk	~4.4–5.0 mm TL.
Total myomeres	29–32.
Preanal myomeres	14–17.
Postanal myomeres	14–16.

Last fin(s) to complete and development	Pectoral and first dorsal (Wang 1986); first dorsal, pelvic, pectoral (Watson 1996b).
Pigmentation	Single series of very large satellite melanophores (ranges 6–10; mainly 8–9) along head, and middorsal to caudal region; large melanophores midventrally, on dorsal surface of gut, and postanal region ventrally; a few melanophores on upper and lower jaws; and a few dotted and dashed melanophores along lateral line near caudal peduncle in late postlarvae.
Distribution	Pelagic (Barlow 1961); in shallow inshore waters of south San Francisco Bay (Barlow 1961); Moss Landing Harbor-Elkhorn Slough (Nybakken *et al.* 1977, Wang 1986); San Pablo Bay, Tomales Bay, Napa River, Suisun Bay, Montezuma Slough, Honker Bay, west Delta, and lower Sacramento and San Joaquin Rivers in dry years (Wang and Reyes 2007).

JUVENILES

Dorsal fin rays	IV –VIII; I–III, 9–14 (Barlow 1961, Miller and Lea 1972); 4–8 spines and 10–17 soft rays (Moyle 2002)
Anal fin rays	I–II, 8–14 (Barlow 1961); I–III, 8–14 (Miller and Lea 1972); 10–17 elements (usually 10–11 rays) (Moyle 2002).
Pectoral fin rays	18–23 (Barlow 1961); 15–23 (Moyle 2002).
Mouth	Terminal, large, maxillary extends beyond posterior margin of the eye, but the distal end of maxillary does not become extremely elongate in early juveniles.
Vertebrae	31–33 (Barlow 1961).
Distribution	Settle into burrow or on the bottom in late postlarval stage (Wang 1986); found in south San Francisco Bay, San Pablo Bay, Moss Landing Harbor-Elkhorn Slough, and Tomales Bay (Wang 1986); Napa River, Suisun Bay, Honker Bay, and extending to lower Sacramento and San Joaquin Rivers (Wang and Reyes 2007).

LIFE HISTORY

The longjaw mudsucker has been reported from Bahia Magdalena, Baja California to Tomales Bay (Roedel 1953); it was reported as far north as Puget Sound in another record (Jordan and Starks 1896). A relict population also exists in the upper part of the Gulf of California (Hubbs 1948, 1960; Barlow 1961, 1963). Longjaw mudsucker was introduced into the Salton Sea by CDFG in 1930 (Barlow 1961) and has thrived. Along the Pacific coast, San Francisco Bay probably contains the northernmost reproducing populations of this species (Barlow 1961). A spawning population of longjaw mudsucker is present in the Tomales Bay; larvae have been collected at the south end of Tomales

Bay near the mouth of Grand Canyon Creek. Based on collections of prolarvae and early postlarvae, a spawning population may move into the Suisun Bay and the west entrance of the Montezuma Slough during dry-water years (CDFG fish E and L survey 1991–1992, 1994).

Spawning begins in December and lasts through June at the Alviso salt ponds of south San Francisco Bay (De Vlaming 1972). A typical spawning period for northern populations of longjaw mudsucker is from January to June (Barlow and De Vlaming 1972). Based on larval collections, the spawning period occurs from January through June in San Francisco Bay and up to Suisun Bay. Weisel (1947) also reported that longjaw mudsucker spawn only once and rarely twice in a single season. However, Walker *et al.* (1961) found that this species breeds two to three times a year at an interval of 2–3 months in the Salton Sea. Individuals spawn more than once in the Alviso ponds in south San Francisco Bay (De Vlaming 1972). Many adults were excavated from burrows in upper Elkhorn Slough. Ova of different sizes found in the ovaries of the females and the presence of larvae and juveniles in the same sample indicate that longjaw mudsucker have an asynchronous ovarian cycle and that they are multiple spawners with a lengthy breeding season.

Weisel (1947) described egg clusters attached to the wall of burrows with adhesive threads. The male parent guards the nest until hatching. Incubation takes 10–12 d at 18°C.

Longjaw mudsucker larvae are pelagic (Barlow 1963). Nybakken *et al.* (1977) took large numbers of larvae in surface tows in Elkhorn Slough and larvae were abundant in similar habitats at Morro Bay (E. Calix 1999–2005, personal communication). The pelagic stage is very short. Large stellate melanophores appear on the dorsum and ventrally at the postanal region in early postlarval stage (5–6 mm TL), just prior to descension to the bottom. Different sizes of longjaw mudsucker larvae were collected using a vertical pump sampler (Wang 1986). Most larvae were collected in shallow (<1.5-m) ditches of upper Elkhorn Slough during flood tide and densely concentrated in shallow channels during ebb tides (Wang 1986). Larvae move only short distances in Moss Landing Harbor and Elkhorn Slough, but in the estuary, larvae ascend by tide drift from the lower bay to Napa River and to the confluence of the Sacramento-San Joaquin Rivers.

Longjaw mudsucker late postlarvae and early juveniles (8–12 mm TL) descend to the bottom (Barlow 1963). Based on pigmentation pattern and larval behavior, Barlow (1963) suggested that longjaw mudsucker larvae are not as well adapted for the pelagic life. The related genera, *Clevelandia* and *Ilypnus* (such as arrow goby and cheekspot goby), have sparse melanophores and a transparent body that helps elude predator detection. Longjaw mudsucker at this similar life stage and size, however, are gradually covered with dense pigmentation. This dense pigmentation may explain why the longjaw mudsucker is doing well in south San Francisco Bay and Elkhorn Slough where the current and tide are less strong and water more turbid.

Principal food items for juveniles are copepods, nematodes, fry larvae, small invertebrates, and small fish (Walker *et al.* 1961). Juveniles feed actively during night hours (Weisel 1947).

Longjaw mudsucker becomes sexually mature at <1 year and the maximum life expectancy is about 2 years (Walker *et al.* 1961). The largest specimen was 14.7 cm TL, taken from Elkhorn Slough (Wang 1986). This species is commonly used as bait fish. They are very hardy (they can breathe air when they are out of the water; Todd and Ebeling 1966, Courtois 1976) and can live in water of various salinities (Weisel 1947, Courtois 1976). “Mudsucker” is a trade name which applies to longjaw mudsucker as well as several other goby species used for bait. Longjaw mudsucker also serves as food for seabirds and predatory fishes (Fitch and Levenberg 1975).

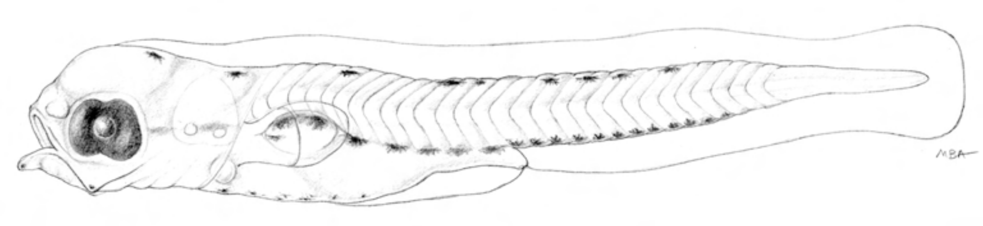


Figure 175.—*Gillichthys mirabilis*, longjaw mudsucker prolarva, 3.5 mm TL (Wang 1986).

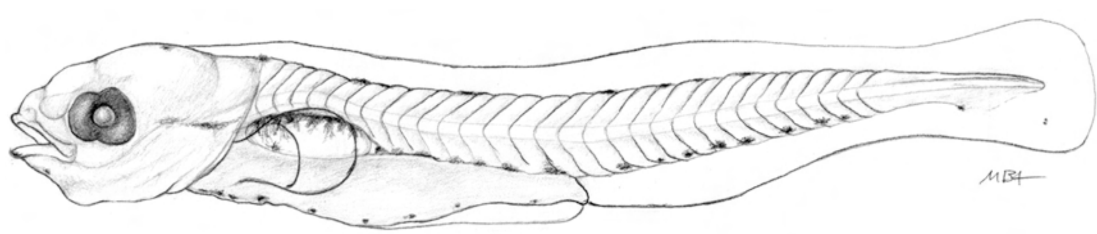


Figure 176.—*Gillichthys mirabilis*, longjaw mudsucker postlarva, 5.2 mm TL (Wang 1986).

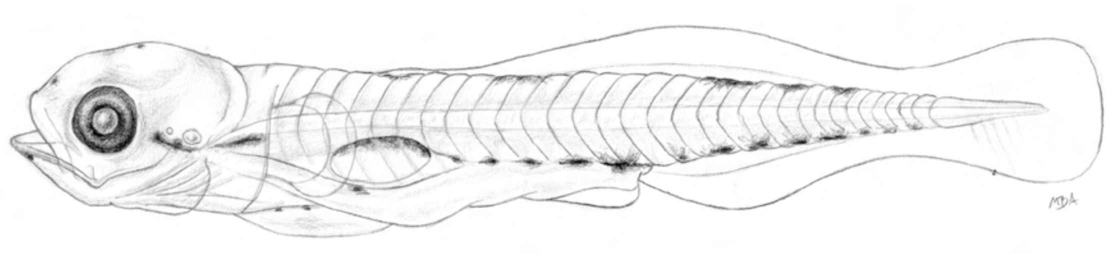


Figure 177.—*Gillichthys mirabilis*, longjaw mudsucker postlarva, 6.2 mm TL (Wang 1986).

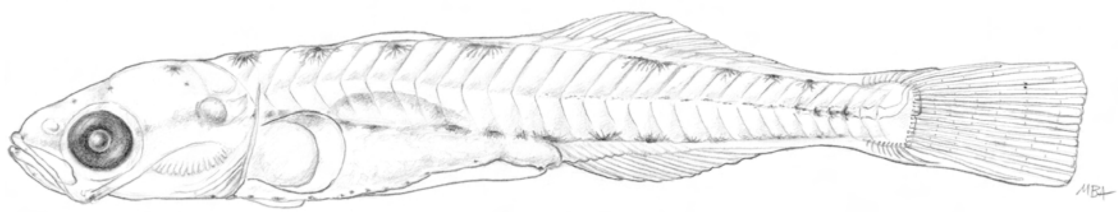


Figure 178.—*Gillichthys mirabilis*, longjaw mudsucker prejuvenile, 10.5 mm TL (Wang 1986).

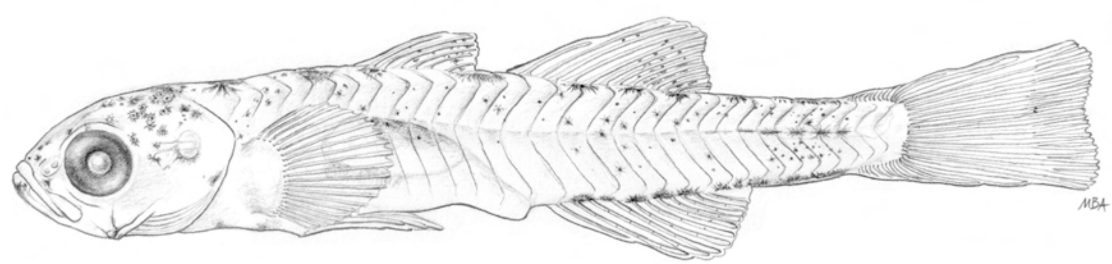


Figure 179.—*Gillichthys mirabilis*, longjaw mudsucker juvenile, 15 mm TL (Wang 1986).

CHEEKSPOT GOBY *Ilypnus gilberti* (Eigenmann and Eigenmann)

SPAWNING

Location	Shallow coastal waters and estuaries; Richardson Bay (Eldridge 1977); San Francisco Bay, south San Francisco Bay; San Pablo Bay (Wang 1986); lower reaches of Napa River and Suisun Bay (near the mouth of Cordelia Creek and west entrance of Montezuma Slough).
Season	Mature ova found in all seasons (Brothers 1975); larvae were taken from September through December (Eldridge 1977); throughout the year but more in winter months in San Pablo Bay and spring months in Suisun Bay (UC Davis Suisun Marsh Study, 1995–2002).
Salinity	Seawater to lower mesohaline (Wang 1986; UC Davis Suisun Marsh Study, 1995–2002); also may occur in oligohaline.
Substrate	Sandy areas or mud flats with little vegetation (Brothers 1975).
Fecundity	~250–1,800 and 150–300/burrow by one female (Brothers 1975).

EGGS

Shape	Unfertilized eggs are spherical; fertilized eggs are club-shaped (Brothers 1975).
Diameter	Ripe eggs are 0.62–0.65 mm. Fertilized eggs are 3.3 mm measuring the length of the egg capsule or the long axis (Brothers 1975).
Yolk	Yellowish in mature eggs.
Chorion	Mature eggs, transparent.
Perivitelline space	Wide in long axis and narrow in short axis in early embryonic development.
Egg deposition	Deposited in single layer in burrows, packed closely to each other (Brothers 1975).
Adhesiveness	Adhesive at proximal end of eggs, with filaments for anchoring to substrates (Brothers 1975).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	3.1 mm TL (Brothers 1975).
Snout to anus length	~47–50 % TL for prolarvae and postlarvae.
Yolk-sac	Spherical, small, in thoracic (Brothers 1975).
Oil globule	Single.
Gut	Straight (Brothers 1975); straight, thick, and tapers toward anus.
Air bladder	Oval and small, behind pectoral fin in late prolarvae and early postlarvae, midway between pectoral fin and anus in postlarvae.
Teeth	Sharp, pointed appearing in late postlarvae.
Total myomeres	32–34.
Preanal myomeres	16–18.
Postanal myomeres	15–17.
Last fin (s) to complete development	Pectoral and pelvic (Wang 1986); pelvic and spiny dorsal (Watson 1996b).
Pigmentation	Stellate melanophores midventrally and dorsal surface of gut. Usually 4–6 large stellate melanophores evenly spaced ventrally at the postanal region (Brothers 1975). A single stellate melanophore on dorsum midway between anus and caudal peduncle, series of stellate melanophores along the ventrum of postanal regions, some fused.
Distribution	Pelagic (Barlow 1963); found mostly on high tide in Richardson Bay (Eldridge 1977); planktonic in San

	Francisco Bay, San Pablo Bay, Napa River, Suisun Bay, and west Delta during dry-water years; also known from Tomales Bay, Moss Landing Harbor, and Elkhorn Slough (Wang 1986).

JUVENILES

Dorsal fin rays	V+0–I, 13–17 (Miller and Lea 1972).
Anal fin rays	0–I, 12–16 (Miller and Lea 1972).
Pectoral fin rays	21–22 (Wang 1986).
Mouth	Terminal, large, maxillary extends to between posterior margin of pupil and posterior margin of the eye.
Vertebrae	32–34 (Miller and Lea 1972).
Distribution	Benthic or burrowing in intertidal mud flats (Brothers 1975); common in south San Francisco Bay; sparse in San Francisco Bay, San Pablo Bay, Moss Landing and Elkhorn Slough. Some collected by Tetra Tech, Inc., in Suisun Bay in 1976. There is a resident population in Suisun Bay near the mouth of Cordelia Creek and west entrance of Montezuma Slough (UC Davis Suisun Marsh Study, 1995–2002); common in Napa River (CDFG 20-mm fish survey, 1995–2005).

LIFE HISTORY

The cheekspot goby ranges from the Gulf of California to Walker Creek in Tomales Bay (Miller and Lea 1972). Various life stages of this species were collected in the Sacramento-San Joaquin Estuary, Tomales Bay, Moss Landing Harbor, and Elkhorn Slough (Wang 1986).

Cheekspot goby spawn in intertidal mud flats in southern California throughout the year, although some years there may be short respite during the fall (Brothers 1975). Larvae were mostly collected during winter in San Francisco Bay and during spring in Napa River and Suisun Bay. The cheekspot goby deposits eggs in a single layer in a slightly enlarged chamber on burrow, which is approximately 15 mm deep (Brothers 1975). The walls of this sandy burrow are coated with a layer of mucopolysaccharide, probably secreted from the mouth or body. Males guard the nest. Similar to other gobies, cheekspot goby females often deposit more than one batch of eggs with one or more males during a season.

The larvae are pelagic (Barlow 1963, Brothers 1975). They seem to be common in south San Francisco Bay but patchy in San Francisco Bay, San Pablo Bay, and Napa River. Cheekspot goby larvae were collected from Suisun Bay during the period 1988–1994 (CDFG fish E and L) and in the early 2000s (UC Davis). Few larvae were observed at CVP/TFCF during the dry-water year of 1994.

Cheekspot goby juveniles are usually found over sandy and muddy bottoms and assume benthic or burrowing habits. They are rarely collected by conventional (such as beach seine) methods (Brothers 1975); however, they were commonly caught in Napa River by CDFG 20-mm fish survey using rigid-opening net constructed of 1,600-µm mesh.

Juvenile cheekspot goby feed on copepods, amphipods, ostracods, and sand grains (Brothers 1975).

Cheekspot goby matures in 1–3 years and individuals may live up to 5 or more years (Brothers 1975). It is not abundant in the estuary, but it is one of the few native gobies able to coexist with introduced gobies such as yellowfin goby, shimofuri goby, and Shokihaze goby in lower saline upper estuarine habitat. It was extremely abundant in the otter trawl survey in the estuary conducted by CDFG in 2007 (Fish *et al.* 2008). Cheekspot goby is prey for various fishes and seabirds.

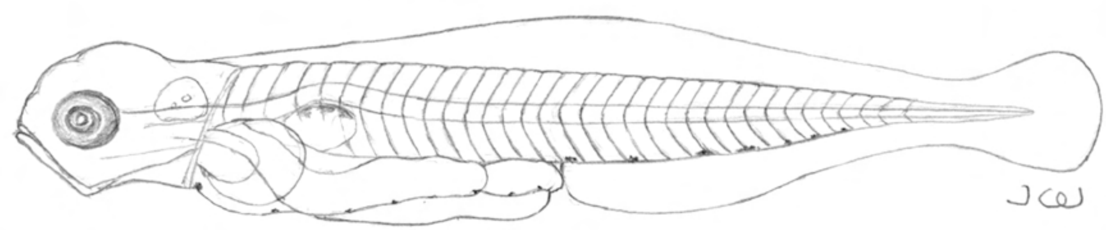


Figure 180.—*Ilypnus gilberti,* cheekspot goby postlarva, 4.9 mm TL (Wang 1986).

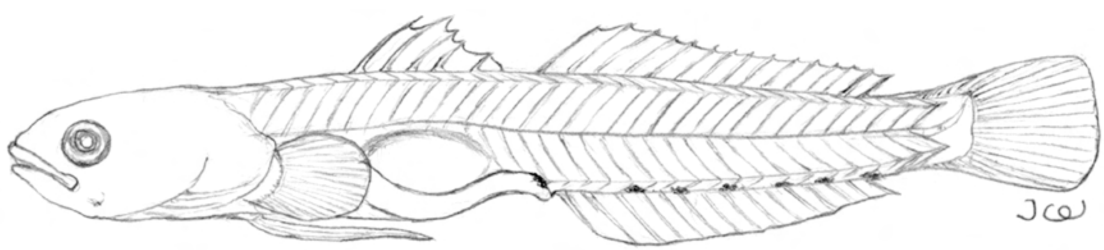


Figure 181.—*Ilypnus gilberti*, cheekspot goby juvenile, 14.8 mm TL (Wang 1986).

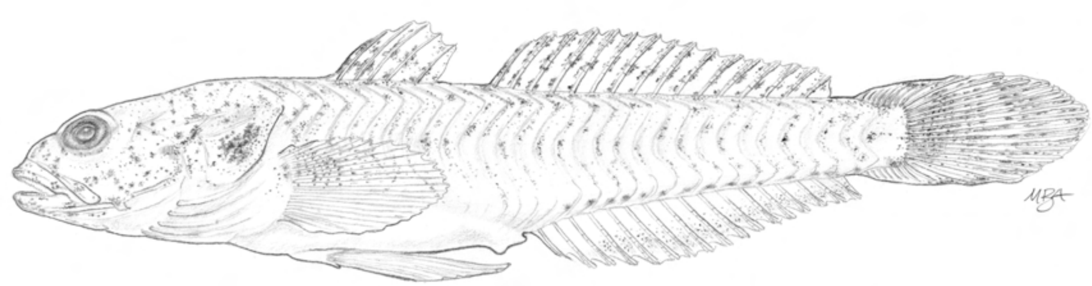


Figure 182.—*Ilypnus gilberti*, cheekspot goby juvenile, 32 mm TL (Wang 1986).

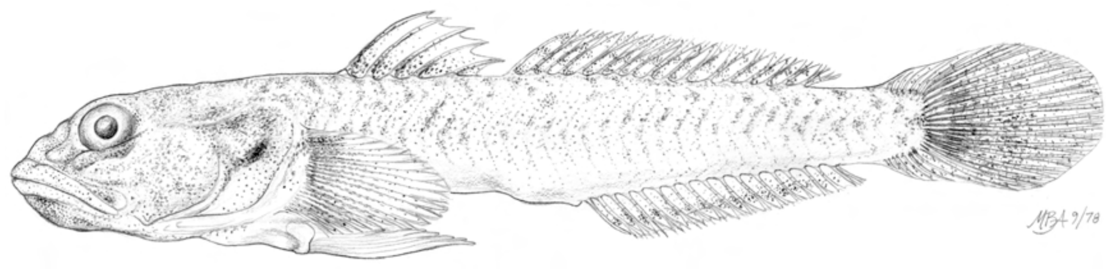


Figure 183.—*Ilypnus gilberti*, cheekspot goby juvenile, 45 mm TL (Wang 1986).

BAY GOBY *Lepidogobius lepidus* (Girard)

SPAWNING

Location	Intertidal mudflats (Grossman 1979a, b); in south and central San Francisco Bay, San Pablo Bay; Moss Landing Harbor and Elkhorn Slough; Tomales Bay, and along the Pacific coast intertidal areas.
Season	Large yolk-filled eggs were found from September to March and spawning peaked from January to March (Grossman 1979a, b); larvae were taken from April through September in Humboldt Bay (Eldridge and Bryan 1972); probably all year round (Wang 1986); mainly October through June (Watson 1996b); based on larval collections, spawning occurs mainly in spring.
Temperature	~10°C based on larval collections from the San Francisco Bay.
Salinity	Seawater to polyhaline.
Substrate	Mud (Grossman 1979a, b); mud and sand.

EGGS

Shape	Spherical initially; mature unfertilized eggs become elliptical when soaked in water.
Diameter	Mature eggs ~1.3–1.8 mm in long axis and ~0.8–1.0 mm in short axis (Wang 1986).
Yolk	Yellowish, granular, and round.
Oil globules	Mature eggs have many globulets scattered in the yolk.
Chorion	Mature eggs, transparent and smooth, except at anchoring point (proximal tip of egg).

Perivitelline space	Wide in long axis and narrow in short axis in mature eggs soaked in water.
Egg deposition	Fertilized eggs form small clusters that are anchored to substrate, but do not adhere to one another.
Adhesiveness	Adhesive only at anchoring point (a patch of filaments at the basal end of long axis).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	Wild-caught specimens were as small as ~2.5–3.0 mm TL (Wang 1986); ~3.0–3.2 mm SL (Watson 1996b).
Snout to anus length	~50–57% TL for prolarvae and early postlarvae 3.2–3.8 mm TL; ~44–50% for postlarvae 11.8–14.8 mm TL (Wang 1986).
Yolk-sac	Yellowish, spherical, thoracic.
Oil globule	Single, in anterior yolk-sac.
Gut	Straight or slightly wavy in appearance, thick.
Air bladder	Small, behind pectoral fin in prolarvae and early postlarvae; midway between pectoral fin and anus or close to anus in postlarvae.
Teeth	Pointed, very small, appear in late postlarvae.
Size at absorption of yolk	~3.5–3.8 mm TL.
Total myomeres	36–38 and mostly 37.
Preanal myomeres	17–19.
Postanal myomeres	18–20.
Last fin (s) to complete development	Fused pelvic fin (Wang 1986); pectoral fin (Watson 1996b).
Pigmentation	In prolarvae and early postlarvae, three groups of stellate melanophores appear on middorsum: midway between pectoral fin and anus, above gut, and above anus; a series of melanophores midventrally, on dorsal surfaces of gut, and on postanal region ventrally. In postlarvae, most of the pigmentation disappears except ventrally on the postanal region. In juveniles, large blotches of melanophores and leopard-like spots gradually develops dorsolaterally.
Distribution	Larvae (Grossman 1979a, b) and early juveniles are pelagic. Larvae were commonly collected in the polyhaline waters of San Francisco Bay, south San Francisco Bay, and San Pablo Bay. Other collection locations include Moss Landing Harbor, Elkhorn Slough, and Tomales Bay.

JUVENILES

Dorsal fin rays	VII-VIII; 0–I, 14–18 (Miller and Lea 1972); VII, 16–18 (Hart 1973); VI–IX; 0–I, 14–18 (Watson 1996b).
Pectoral fin rays	~20 (Hart 1973); 20–22 (Wang 1986); 20–24 (Watson 1996b).
Anal fin rays	0–I, 13–16 (Miller and Lea 1972); 0–I, 12–16 (Watson 1996b).
Mouth	Terminal, moderate in size (Hart 1973); terminal to subterminal, maxillary extends to mid-eye.
Vertebrae	37–38 (Miller and Lea 1972).
Distribution:	Large juveniles are benthic (Grossman 1979a, b); early juveniles are pelagic and benthic or in burrows (~20–25 mm TL); juveniles have been collected in San Francisco Bay, south San Francisco Bay, San Pablo Bay, Napa River, Suisun Bay, and west Delta during dry-water years. Other known locations include Tomales Bay, Moss Landing Harbor, and Elkhorn Slough (Wang 1986), and Morro Bay (E. Calix 1999–2005, personal communication).

LIFE HISTORY

Bay goby ranges from Cedros Islands, Baja California, to Vancouver Island, including the Strait of Georgia and Denman Island, British Columbia (Miller and Lea 1972, Hart 1973, Matarese *et al.* 1989). In the studay area, it occasionally ascends to the upper estuary, above Carquinez Strait (Ganssle 1966, Messersmith 1966). Juvenile and adult bay gobies were collected in San Francisco Bay, south San Francisco Bay, San Pablo Bay, and Napa River. Similar to arrow goby, all life stages of bay goby are carried by tides to Suisun Bay. Both species are unlikely to spawn above the Carquinez Strait. Overall, bay goby has been increasing in abundance in San Francisco Bay since 2001 (Greiner *et al.* 2007).

Grossman (1979a, b) observed ripe bay goby in Morro Bay area from September through March, and estimated spawning peaks from January to March. The majority of larval bay goby were collected in higher saline waters of San Francisco Bay from November through May, with a peak in April and May (Wang 1986). The spawning behavior of the bay goby is unknown. Grossman (1979a, b) found juvenile and adult bay goby using burrows as shelter from predators and dehydration during ebb tides. It is possible that bay goby reproduce in burrows, as do most other gobies found along the California coast (De Vlaming 1972, Wiley 1973, Brothers 1975). Females have ova of different sizes and stages of development in the ovaries (Wang 1986), suggesting an asynchronous, multiple spawning reproductive strategy.

Newly-hatched bay goby larvae are small (≤3.0 mm TL) and have a 3–4 month plankton life (Grossman 1979a, b). Both postlarvae and early juveniles have little body pigmentation. The young occur sympatrically with arrow goby, cheekspot goby, and yellowfin goby in San Francisco Bay. Most larval collections have been concentrated near the Golden Gate Bridge and Angel Island (Wang 1986). During spring months of the period 1998–1991, some bay goby larvae drifted by tides to Suisun Bay, Montezuma Slough, and west Delta; however, this was seldom observed between 1992 and 1995 (CDFG striped bass E and L survey).

Bay goby juveniles descend to the bottom when they reach ~25 mm TL (Wang 1986) where they often occupy the burrows of blue mud shrimp (*Upogebia pugettensis*), geoduck clams (*Panopea abrupta*), and other burrowing animals (Grossman 1979a, b). Juveniles are common in Napa River and Suisun Bay during dry-water years (CDFG 20-mm fish survey). Juveniles often venture to San Pablo Bay in November and December when water temperatures are cooler (Greiner *et al.* 2006).

Juveniles feed on copepods, amphipods, and other small crustaceans.
Few bay goby reach sexual maturity at the end of their first year, but most do in their second year. Their lifespan is about 7 years (Grossman 1979a, b). Bay goby has no value as human food because of its small size (~90 mm TL). Lengthy planktonic larval and early juvenile life stages make them important forage species.

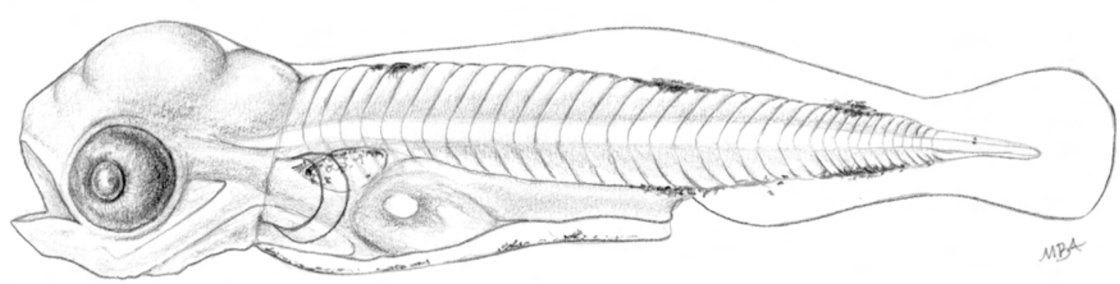


Figure 184.—*Lepidogobius lepidus*, bay goby prolarva, 3.7 mm TL (Wang 1986).

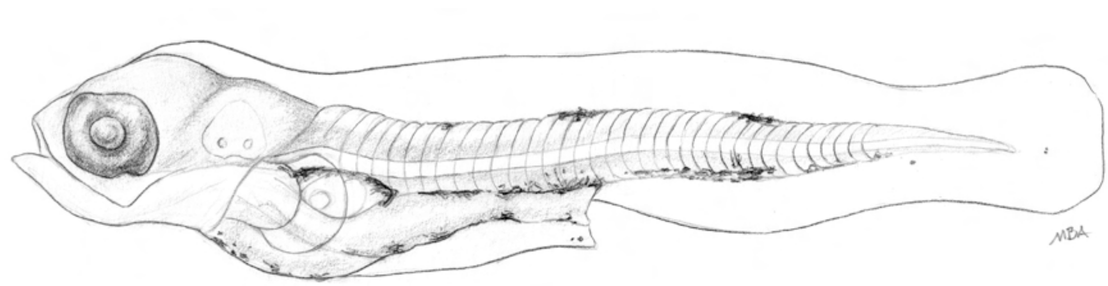


Figure 185.—*Lepidogobius lepidus*, bay goby prolarva, 3.7 mm TL (Wang 1986).

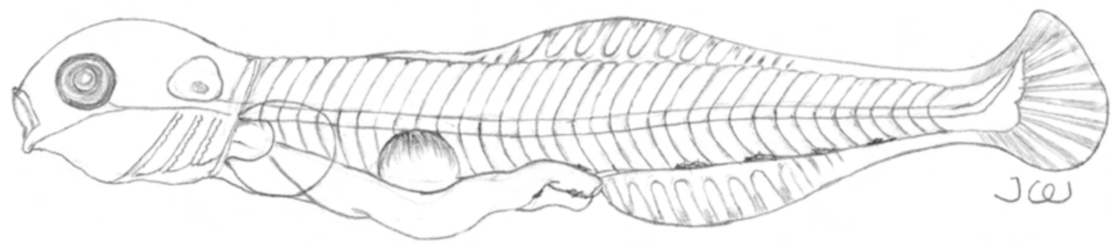


Figure 186.—*Lepidogobius lepidus*, bay goby postlarva, 6.9 mm TL (Wang 1986).

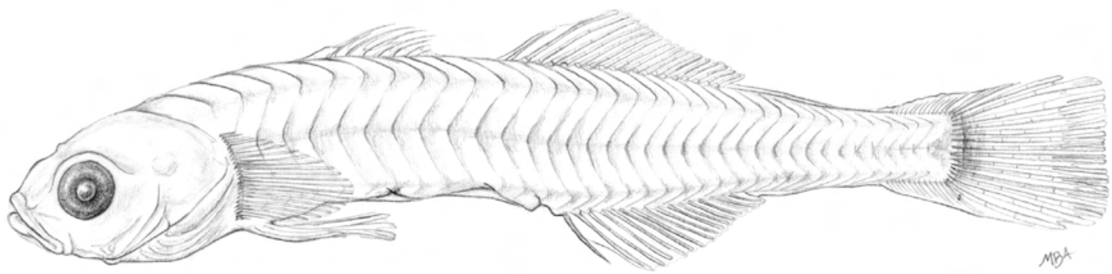


Figure 187.—*Lepidogobius lepidus*, bay goby juvenile, 28 mm TL (Wang 1986).

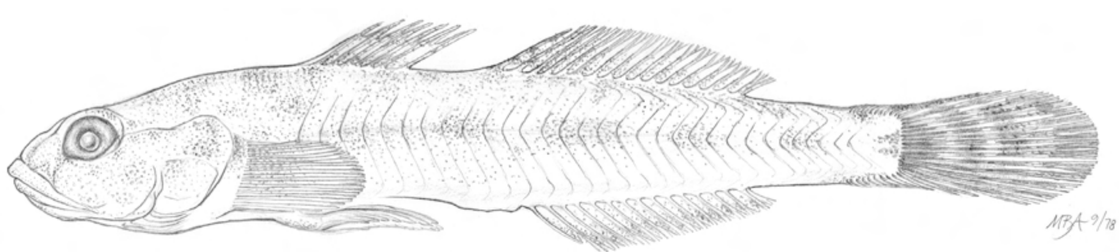


Figure 188.—*Lepidogobius lepidus*, bay goby juvenile, 57 mm TL (Wang 1986).

BLACKEYE GOBY *Rhinogobiops nicholsii* (Bean)

SPAWNING

Location	Subtidal and intertidal coastal waters (Ebert and Turner 1962); may occur in bays such as south San Francisco Bay and Moss Landing Harbor (Wang 1986).

Season	Nests found from April through October (Ebert and Turner 1962); ripe ovaries observed from February through August (Wiley 1973); year round and mainly in February through October (Watson 1996b); January through August.
Temperature	12.9–16.0°C (Ebert and Turner 1962).
Salinity	Seawater and may occur in polyhaline water.
Substrates	Rocky areas with sandy bottom; small holes in reefs (Ebert and Turner 1962, Wiley 1973).
Fecundity	1,700 eggs on a nest from one female (Ebert and Turner 1962); 3,274–4,788 (Wiley 1973).

EGGS

Shape	Ovarian ripe eggs are spherical, 0.4–0.7 mm, fertilized eggs are elongate, pointed, spindle-shaped, long axis 2.2 mm and short axis 0.5 mm (Ebert and Turner 1962, Wiley 1973); long axis 2.2 mm, short axis 0.5 mm (late embryo stage) collected at the Moss Landing Powerplant intake in Moss Landing Harbor (Wang 1986).
Yolk	Ripe eggs orange (Wiley 1973); preserved eggs from field collection were yellow.
Oil globule	Many (Watson 1996b).
Chorion	Transparent, smooth, with exception at anchoring point.
Perivitelline space	Wide in long axis and narrow in short axis (Ebert and Turner 1962, Wiley 1973).
Egg deposition	Deposited on substrates in single layer (Ebert and Turner 1962).
Adhesiveness	Adhesive at the anchoring point, but without threads (Ebert and Turner 1962, Wiley 1973).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	2.97 mm TL (Ebert and Turner 1962); individuals ~2.5–2.8 mm were collected in Moss Landing Harbor and south San Francisco Bay (Wang 1986); 2.8–3.0 mm SL (Watson 1996b).
Snout to anus length	~43–49% TL for larvae 2.8–7.1 mm TL (Wang 1986).
Yolk-sac	Yellowish, spherical, thoracic.
Gut	Straight, thick in prolarvae. Gut is depressed by air bladder in postlarvae.

Air bladder	Small, oval, and near pectoral fins for prolarvae and postlarvae; toward midpoint between pectoral fins and anus in late postlarvae.
Size at absorption of yolk	~3.0 mm TL wild-caught specimens from Moss Landing Harbor (Wang 1986).
Total myomeres	25–26.
Preanal myomeres	9–10.
Postanal myomeres	14–17.
Last fin(s) to complete development	Fused pelvic fin (Wang 1986, Watson 1996b).
Pigmentation	A few stellate melanophores on dorsal surface of gut and mid-ventrally; a short series of melanophores (11–15) along postanal region; a short series of small melanophores dorsally in front of caudal peduncle.
Distribution	Pelagic in coastal and oceanic waters (Wiley 1973); mostly in coastal waters, some enter high saline estuaries and bays, such as San Francisco Bay and Moss Landing Harbor (Wang 1986) and Morro Bay (E. Calix 1999–2005, personal communication).

JUVENILES

Dorsal fin rays	V–VI; I–II, 9–14 (Miller and Lea 1972); first dorsal spines IV–VI, second dorsal rays 12–15 (Wiley 1973); V–VII, 12–14 (Hart 1973); IV–VIII; I–II, 9–15 (Watson 1996b).
Anal fin rays	0–I, 11–12 (Miller and Lea 1972); I, 11–14 (Wiley 1973); 11–12 rays (Hart 1973); 0–I, 11–13 (Watson 1996b).
Pectoral fin rays	21–24 (Wiley 1973); ~22 (Hart 1973); 16–24 (Watson 1996b).
Mouth	Terminal, moderate in size, directed forward (Hart 1973).
Vertebrate	26 (Miller and Lea 1972, Matarese *et al.* 1989).
Distribution	Early juveniles are pelagic, larger juveniles found along coastal rocky reefs (Wiley 1973); in bays, such as San Francisco Bay, south San Francisco Bay, and Moss Landing Harbor (Wang 1986); in Moss Landing Harbor and Morro Bay (E. Calix 1999–2005, personal communication).

LIFE HISTORY

Blackeye goby has been reported from Point Rompiente, Baja California, to Queen Charlotte Islands, British Columbia (Hart 1973, Miller and Lea 1972). It was commonly collected in Moss Landing Powerplant intake samples in Moss Landing Harbor (Wang 1986), but less commonly found in San Francisco Bay. It was also collected near the entrance of Morro Bay, just south of Moss Landing Harbor (E. Calix 1999–2005, personal communication).

Ebert and Turner (1962) found nests of blackeye goby off Hermosa Beach, in southern California, from April through October. Wiley (1973) observed mature eggs near Laguna Beach, southern California, from February through August. Based on collections of eggs and larvae in Moss Landing Harbor, blackeye goby apparently spawn from January through August (Wang 1986). During spawning, the male goby exhibits a protruding urogenital papilla, a dark pelvic fin, and aggressive territorial behavior (Wiley 1973). The female deposits eggs on the undersides of rocks. The male takes over the nest, guarding and aerating the eggs until hatching. Spawning temperature at Hermosa Beach was between 12.9–14.6°C (Ebert and Turner 1962). Ova have been collected in two distinctive sizes, indicating that blackeye goby spawn more than once during the breeding season (Wiley 1973). Larvae are present for a long period. Newly hatched larvae through the early juvenile stages of blackeye goby are pelagic swimmers and can be found far from the shore line (Wiley 1973). Hart (1973) reported blackeye goby larvae from south San Francisco Bay to Suisun Bay, indicating that larvae can survive low salinities. However, larvae were not observed in the striped bass E and L samples (CDFG in 1988–1995), UC Davis Suisun Marsh Study, or in Napa River (CDFG 20-mm fish survey, 1995–2005).

Large juveniles (~21–28 mm TL) gradually settle into demersal habitats such as sandy bottoms near rocky reefs and crevices (Watson 1996b).

Principal food items for juveniles include small crustaceans such as copepods and amphipods. They also feed on mollusk larvae, echinoderms, and bryozoans (Hart 1973, Wiley 1973).

Females are sexually mature at 2–5 years; males at 3–5 years (Wiley 1973). Fitch and Lavenberg (1975) reported maturity after the first winter. This species has no commercial value. It serves as a forage fish for other predatory fishes and seabirds.

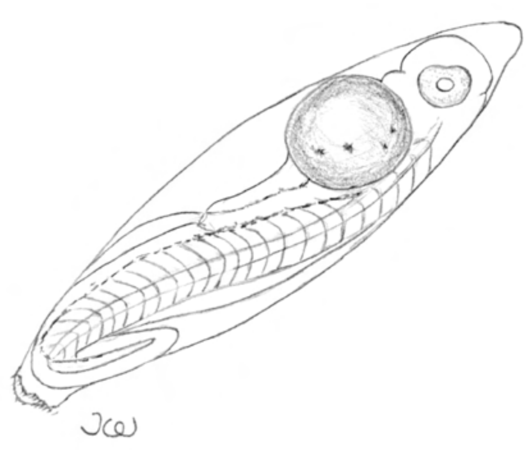


Figure 189.—*Rhinogobiops nicholsii*, blackeye goby egg, 2.2 mm long axis, 1.2 mm short axis (Wang 1986).

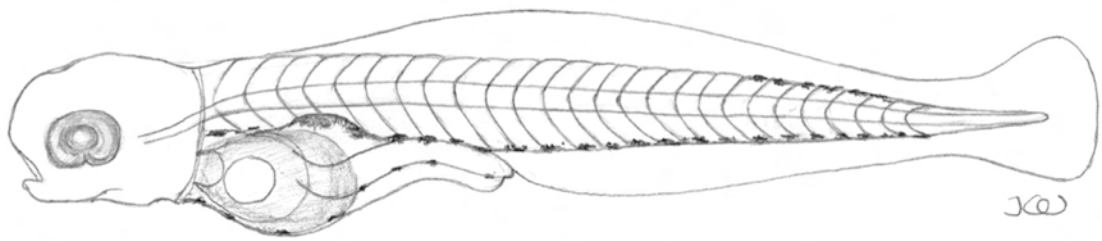


Figure 190.—*Rhinogobiops nicholsii*, blackeye goby prolarva, 2.2 mm TL (Wang 1986).

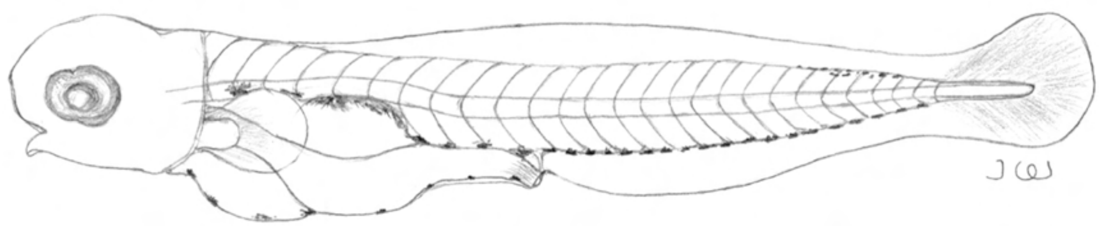


Figure 191.—*Rhinogobiops nicholsii*, blackeye goby postlarva, 3.4 mm TL (Wang 1986).

CHAMELEON GOBY *Tridentiger trigonocephalus* (Gill)

SPAWNING

Location	Intertidal mudflats, oyster beds (Dotsu 1958); south San Francisco Bay (vicinity of Hunters Point, San Mateo, and Dumbarton Bridge); Aquatic Park near Berkeley; central San Francisco Bay; western San Pablo Bay (Wang 1986).
Season	May through September in Kyushu, Japan (Dotsu 1958); well developed eggs were collected at Los Angeles Harbor in May, and egg masses were found in September (Haaker 1979); larvae were observed in higher saline waters of south San Francisco Bay and Aquatic Park from June through October, spawning estimated from May through September (CDFG fish E and L survey, 1980–1987; Wang 1986).
Temperature	~20°C (Dotsu 1958).
Salinity	Seawater to mesohaline (Haaker 1979); mainly in seawater, may occur in mesohaline (Matern and Fleming 1995).

Substrate	Clam shells, oyster shells (Dotsu 1958); beer cans, bottles (Haaker 1979); probably in the crevices of jetties, in plastic and glass containers.
Fecundity	1,248–9,700 for females 29–47 mm TL (Dotsu 1958).

EGGS

Shape	Mature eggs and newly fertilized eggs are initially spherical; later become pyriform with pointed tip at distal end (Dotsu 1958).
Diameter	Mature eggs, spherical, 0.50–0.60 mm in diameter; fertilized eggs, elliptical, 1.4-mm-inch long axis and 0.6-mm-inch short axis (Dotsu 1958).
Yolk	Yellowish, translucent (Dotsu 1958).
Oil globule	More than 10 oil globulets in early development stages that consolidate into one oil globule prior to hatching (Dotsu 1958).
Chorion	Transparent, smooth (Dotsu 1958).
Perivitelline space	Very wide at long axis and narrower at short axis in early developmental stages (Dotsu 1958).
Egg deposition	Deposited in single layer, and can be very dense per unit area (Dotsu 1958).
Adhesiveness	Adhesive at proximal end, where a bundle of filaments attaches to substrates (Dotsu 1958).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	2.4 mm TL (Dotsu 1958); 2.2 mm TL specimen collection from Aquatic Park of Berkeley (Wang 1986).
Snout to anus length	44–51% TL for prolarvae and postlarvae 2.4–9.7 mm TL.
Yolk-sac	Spherical, thoracic (Dotsu 1958).
Oil globule	Single, large (Dotsu 1958); single, anteriorly in yolk-sac, ca 0.1–0.2 mm in diameter (Wang 1986).
Gut	Straight in prolarvae and early postlarvae (Dotsu 1958); twisted into one loop near posterior portion of intestine in postlarvae (Wang 1986).
Air bladder	Oval, small, near pectoral fins in prolarvae; midway between pectoral fins and anus in postlarvae (Dotsu 1958).
Teeth	Pointed, sharp in postlarvae; tri-cusped teeth developed in juvenile.
Size at absorption of yolk	~2.6–2.9 mm TL.
Total myomeres	24–26.

Preanal myomeres	10–14 (Wang 1986); usually 10–11.
Postanal myomeres	13–15.
Last fin(s) to complete development	Fused pelvic fin.
Pigmentation	A few melanophores along postanal and caudal regions (Dotsu 1958); in postlarvae, large stellate melanophores midventrally and on dorsal surface of gut; a single, large melanophore on dorsum in front of caudal peduncle and one in postanal region ventrally; in late postlarvae, most pigmentation disappears except for ~6 melanophores scattered ventrally along the postanal region (Wang 1986); 2 horizontal stripes developed on upper side of body in prejuvenile stages.
Distribution	Pelagic (Dotsu 1958); found mostly in the South Francisco Bay

JUVENILES

Dorsal fin rays	VI, 13 (Dotsu 1958); VI + I, 11–12 (Miller and Lea 1972); VI–I, 12 (Okiyama 1988).
Anal fin rays	11 (Dotsu 1958); I, 10–11 (Miller and Lea 1972); I , 11 (Wang 1986); I–10 (Okiyama 1988).
Pectoral fin rays	21 (Dotsu 1958); 20–22 (Wang 1986); 20 (Okiyama 1988).
Mouth	Terminal or subterminal, maxillary extends to mid-eye.
Vertebrae	26 (Miller and Lea 1972); 26 (Okiyama 1988); 26–27 (Watson 1996b)
Distribution	Juveniles become benthic at ≥15 mm TL (Dotsu 1958); benthic or epibenthic in clam shells, cans, bottles, polychaete tubes, crevices of jetties, and on vegetation.

LIFE HISTORY

Chameleon goby is native to China, Korea, eastern Siberia, and Japan (Tomiyama 1936, Chen 1956, Fowler 1961). It was introduced into California during the 1950s, probably through ship ballast water. Currently, there are two isolated chameleon goby populations known to the west coast of the United States: one in San Francisco Bay, including Lake Merritt (Ruth 1964, Brittan *et al.* 1970, Miller and Lea 1972, Moyle 1976) and the other in Los Angeles Harbor (Hubbs and Miller 1965, Miller and Lea 1972, Haaker 1979). Wang (1986) reported the chameleon goby in south San Francisco Bay and Aquatic Park and near Oleum Power of San Pablo Bay. This species has not been reported in California's freshwater systems (Shapovalov *et al.* 1981). However, Matern and Fleming (1995) have noticed two groups of "chameleon goby" residing in the Sacramento-San Joaquin Estuary since the mid-1980s; one group is in the polyhaline water of San Francisco Bay and south San Francisco Bay and other is in the mesohaline to oligohaline eastern San Pablo Bay and Suisun Bay. Specimens of these two groups were shipped to

Japan for identification by Akihito and Sakamoto (1989). The group residing in the lower saline waters of the Sacramento-San Joaquin Estuary were identified as shimofuri goby. Shimofuri goby was formerly included with chameleon goby as a single species (Okiyama 1988, Akihito and Sakamoto 1989). Currently, the geographic range of the two species overlaps in the vicinity of Pinole Point of San Pablo Bay and south of Dumbarton Bridge (T.A. Greiner 2002, personal communication). Matern and Fleming (1995) estimated that shimofuri goby was introduced to the estuary in 1985, but is possible that shimofuri goby may have arrived earlier than 1985 since the "chameleon goby" was reported from 1978 to 1982 at San Pablo Bay at Rodeo, California, located west of Carquinez Strait where salinity is mostly mesohaline (Wang 1986).

In Japan, chameleon goby spawns from April through September in oyster beds or on clam shells (Dotsu 1958). In the Los Angeles Harbor area, mature eggs of this species were found in May and September (Haaker 1979). In the San Francisco Bay area, based on larval collections, the spawning period is from May through September. Eggs are deposited on the inner surface of shells in a single layer by one or more female fish. The male guards the nest. Eggs hatch in ~8 d at 20°C (Dotsu 1958). Dotsu also noticed two different sizes of eggs in the ovary suggesting that females may spawn more than once in a season. Chameleon goby is found mainly in south San Francisco Bay even though there are few, if any, oyster beds in the south San Francisco Bay. Beer bottles and drink have been used as spawning habitat by chameleon goby in southern California (Haaker 1979). They may also use crevices of rocks and jetties and other hard surfaces such as glass, hollow containers, and ceramic tiles.

Chameleon goby larvae are planktonic (Dotsu 1958). Small numbers were found in entrainment samples at Hunters Point Powerplant (Wang 1986) and in fine-meshed beach seine samples from Aquatic Park (Wang 1986). Most larvae are found in the open waters of south San Francisco Bay, particularly in the vicinity of the San Mateo and Dumbarton Bridges (Wang 1986). Similar to the shimofuri goby, newly-hatched larvae of the chameleon goby are approximately 2.2–2.4 mm TL. The two species are separated by habitat preference (*e.g.*, salinity); however, a clear taxonomic separation of their larvae is yet to be completed. Species identification is further complicated by the Shokihaze goby, a recently introduced goby from Eastern Asia to the Sacramento-San Joaquin Estuary (Greiner 2002, Moyle 2002).

Chameleon goby juveniles gradually descend to the bottom at about 15 mm TL (Dotsu 1958). At Aquatic Park near Berkeley, juveniles were observed perching on the algae or near the entrances of crevices and tunnels (Wang 1986). Their stomachs contained copepods, small amphipods, benthic organisms, and detritus. The population fluctuated due to environmental changes such as the availability of starter food.

Chameleon goby mature at 1 year; some individuals may live to 3 years (Dotsu 1958). This species has no commercial or sport value because of its small size (usually < 50 mm TL) but may have forage value for other predatory fishes and seabirds.

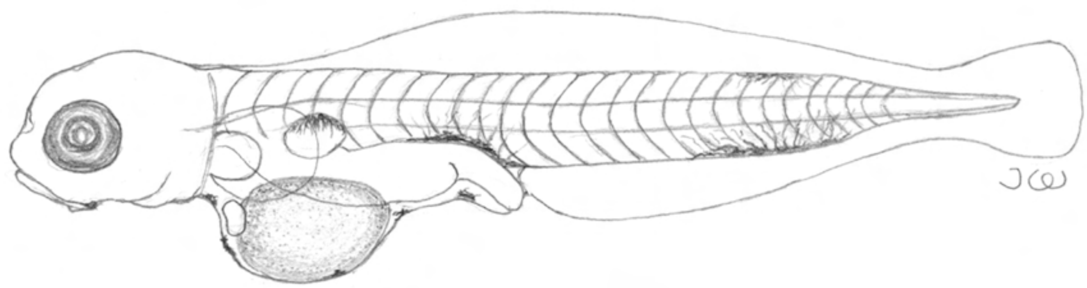


Figure 192.—*Tridentiger trigonocephalus*, chameleon goby prolarva, 2.5 mm TL (Wang 1986).

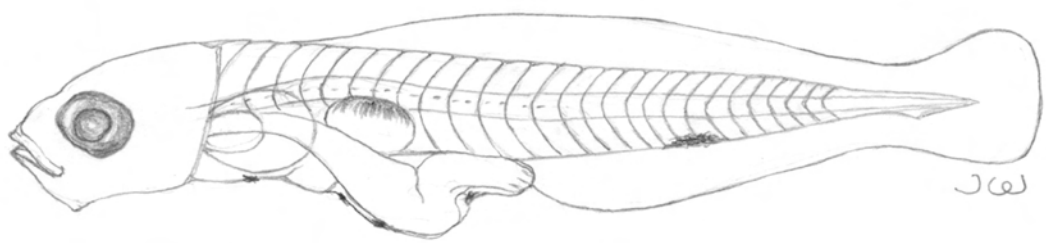


Figure 193.—*Tridentiger trigonocephalus*, chameleon goby postlarva, 4.3 mm TL (Wang 1986).

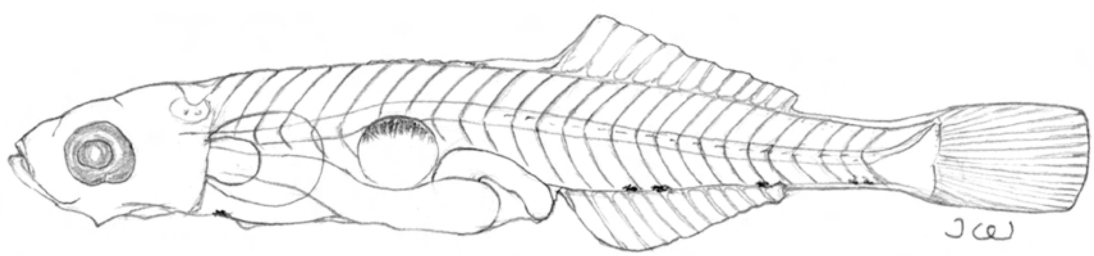


Figure 194.—*Tridentiger trigonocephalus*, chameleon goby prejuvenile, 6.8 mm TL (Wang 1986).

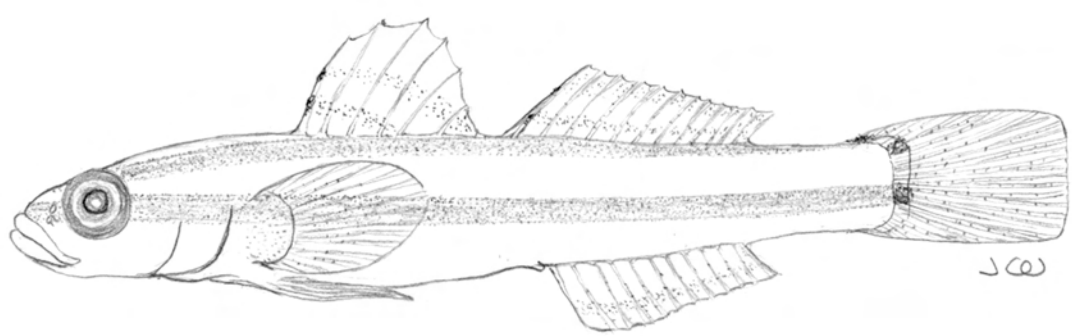


Figure 195.—*Tridentiger trigonocephalus*, chameleon goby juvenile, 23.2 mm TL (Wang 1986).

SHIMOFURI GOBY *Tridentiger bifasciatus* Steindachner

SPAWNING

Location	Rocks, logs, tule root masses (Matern 1999, Moyle 2002); hard hollow cavities, such as cans, bottles, and cups in Suisun Marsh (Matern and Fleming 1995, Matern 1999); Pyramid Reservoir, Piru Creek (Matern 1999); O'Neill Forebay (Hess *et al.* 1995); Walker Creek, a tributary of Tomales Bay (Wang 1986); Mallard Slough of CCWD (C. Raifsnider 2003–2008, personal communication); Napa River (Stillwater Sciences, Inc., 2001–2005; Wang 2007) and the Delta (Moyle 2002, Wang and Reyes 2007).
Season	Based on larval collections, spawning season lasts from late April to September (Matern and Fleming 1995, Wang 2007); March to August (Matern 1999, Moyle 2002). Judging by the spawning color exhibited by the males after maturity, spawning is almost all year round when feeding and water temperature conditions are optimal. In field collections, spawning starts in March and finishes in June (Wang 2007).
Temperature	20°C (Matern and Fleming 1995), ~16–25°C (field data collected by CDFG); 20–25°C in the laboratory.
Salinity	Up to 19 ppt (Matern 1999); mesohaline to freshwater, mainly in oligohaline.
Substrates	Hard surfaces (such as ceramic, glass, and metal) in dark environments.
Fecundity	Estimated 2,000–5,000/batch and varies greatly by size of females.

EGGS

Shape	Mature eggs are oval; fertilized eggs are elliptical and pyriform with a pointed tip at the distal end (opposite end of the anchored base) angled at 10 and 2 o'clock.
Diameter	Fertilized eggs are 1.2–1.3 mm at the long axis and 0.5 mm at the short axis.
Yolk	Yellowish, granular, translucent.
Oil globule	A cluster of more than 10 globulets in newly fertilized eggs consolidates into one globule in early embryo or early prolarval life stage.
Chorion	Transparent and smooth except in the basal area along long axis.

Perivitelline space	Very wide at both ends of long axis and narrow at short axis in the early development, fully occupied during the late embryo stage.
Egg deposition	Males secrete a coating (mat) on the wall of burrow. Eggs deposited by females on a mat in a compact, single layer, some eggs deposited on small mat, and less deposited singly or with no mat.
Adhesiveness	Limited to the basal end of the egg where a bundle of fine filaments are attached to a common mat. The common mat is also attached to a hard surfaced substrate.
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	2.2–2.6 mm TL (L. Lynch 2002, personal communication), 2.0–2.2 mm TL.
Snout to anus length	39–45% TL for prolarvae and postlarvae.
Yolk-sac	Spherical, large, and in thoracic.
Oil globule	Single, large, 0.1–0.15 mm in diameter
Gut	Straight in prolarvae, twisted in one tight loop in postlarvae.
Air bladder	Oval with a heavy pigmented ceiling near the pectoral fins in prolarvae; midway between pectoral fins and anus in postlarvae.
Teeth	Sharp, and pointed (single cusp in the early life stage; tricuspid in juvenile).
Size at absorption of yolk	~3.0–3.5 mm TL.
Total myomeres	24 (L. Lynch 2002, personal communication); 24–26.
Preanal myomere	8 (L. Lynch 2002, personal communication); 8–10.
Postanal myomere	16 (L. Lynch 2002, personal communication); 14–16.
Last fins(s) to complete development	Pelvic fins fused into a sucking disc.
Pigmentation	In prolarvae, there are two large stellate melanophores ventrally, one midway of the postanal region and another above the anus. Dashed melanophores along the midventral region to thoracic; few scattered melanophores both on dorsum and postanal regions.
Distribution	Newly-hatched prolarvae initially stay on the bottom, but become planktonic, dispersing through tidal drift. Larvae were collected mostly in oligohaline and tidal freshwaters of the Delta. Some were found in the mesohaline ranges such as Carquinez Strait, the eastern part of San Pablo Bay, and the tidally influenced region of the Napa River.

JUVENILES

Dorsal fin rays	VI, 12 (Akihito and Sakamoto 1989); VI –VII, I, 11–14 (Moyle 2002); V–VI, I, 11–13.
Anal fin rays	I, 10 (Akihito and Sakamoto 1989); I, 9–12 (Moyle 2002); I, 9–11.
Pectoral fin rays	19–20 (Akihito and Sakamoto 1989); 19–23 (Moyle 2002); 20–21.
Mouth	Maxillary extends nearly to the back of the eye (Moyle 2002); terminal, maxillary extends over the mid-eye.
Vertebrae	26 (Akihito and Sakamoto 1989); 26.
Distribution	By ~14–15 mm in TL, juveniles become epibenthic or rest on the substrate. Their pelvic fins are completely fused and function like a suction cup. Juveniles are collected from mesohaline to freshwaters in the Delta and its adjacent waters.

LIFE HISTORY

Shimofuri goby was not recorded by Tomiyama (1936) and was not described in "An Atlas of the Early Stages of Fishes in Japan" by Okiyama 1988. It was finally taxonomically separated from sympatric species, the chameleon goby, by Akihito and Sakamoto (1989). Shimofuri goby was not described in the IEP Technical Report No. 9 (Wang 1986).

Descriptions of the life history of shimofuri goby from the study area mainly come from information collected since 1988 by the following state and federal agencies, institutions, and consulting firms since 1988:

- CDFG striped bass E and L sampling from Suisun Bay, Delta, and Sacramento River.
- CDFG 20-mm fish sampling in Delta, Suisun Bay, eastern San Pablo Bay, and Napa River.
- CDFG fish E and L survey at the NBA Project and adjacent sloughs.
- UC Davis fish E and L surveys in Suisun Marsh.
- CVP/TFCF fish salvage in the south Delta.
- Stillwater Sciences, Inc., fish E and L survey in upper Napa River.
- Tenera Environmental, Inc., fish E and L survey at CCWD water intakes.
- Hanson Environmental fish E and L survey at Pittsburg and Contra Costa Powerplants.
- CDFG Delta Smelt Larvae Survey (DSLS) and fish E and L survey in Suisun Bay and Delta.
- CDWR fish E and L survey in the Delta.
- Tenera Environmental, Inc., fish E and L survey at the Pittsburg and Contra Costa Powerplants.

Shimofuri goby is native to China, Korea, and Japan (Akihito and Sakamoto 1989). It was introduced into San Francisco Bay in 1985 (Matern and Fleming 1995), decades after the introduction of chameleon goby. Initially, two populations of chameleon goby were recognized: one inhabiting the high saline waters of the south San Francisco Bay and another living in the brackish and freshwaters of Suisun Bay. Specimens from the two groups were shipped to Japan and were verified by the Japanese Emperor Akihito and his co-worker Sakamoto as two different species, chameleon goby and shimofuri goby (Matern and Fleming 1995, Matern 1999). After introduction, shimofuri goby quickly established a sizable population, becoming an explosive invader (Moyle 2002). Initially distributed in the Suisun Marsh (Matern and Fleming 1995), shimofuri goby has since spread into the Delta and its associated lakes and reservoirs via California water diversion systems (Matern 1999).

Moyle (2002) described some factors that have made the shimofuri goby so successful in the estuary including significant larval dispersal, a tolerance for a wide range of environmental conditions, and aggressive behavior. However, the shimofuri goby population has fluctuated widely from year to year (Meng *et al.* 1994), a phenomenon not completely understood. It is possible that the availability of minute starter food may be a pertinent factor because of the small size of newly-hatched prolarvae (~2.0 mm TL). In recent years, shimofuri goby numbers have fluctuated in the south Delta (Reclamation salvage records) but this species is still abundant in the Napa River (Wang 2007; Stillwater Sciences, Inc., survey, 2001–2005).

Shimofuri goby spawn in late spring and summer months. In laboratory conditions, it will spawn year round. One female goby can produce multiple clutches of eggs and may mate with more than one male. The male parent guards the nest and engages in spawning activity continuously until he dies. See Appendix 4 for observations of social and spawning behaviors.

Shimofuri goby (and chameleon goby prior to 1989) courtship and mating behaviors were observed in shallow tidal flats in Japan. Females deposit eggs in cavities with hard surfaces such as old oyster shells. They will also dig short tunnels and deposit eggs in burrows (Okiyama 1988; Y. Dotsu 1986, personal communication). Matern (1999) was the first to document the shimofuri goby life history and spawning behavior outside of its native Japan. Spawning migration of the species is similar to that of the yellowfin goby. Spawning adults are collected at the CVP/TFCF in winter months, possibly intercepted from their catadromous run. Shimofuri goby spawn mostly in oligohaline waters, although some are known to spawn in freshwater (Matern 1999).

Fertilized eggs, elliptical or pyriform in shape and rarely deposited singly, are deposited in a single-layer on a common mat (a male-secreted substance) attached to hard substrates, such as rock crevices, clam shells, and ceramic cups. During mating, both sexes exhibit genital papilla with the male papilla protruding further. Females deposit eggs in linear formation using the female papilla which helps avoid the formation of clusters; the male fertilizes the eggs immediately. The male attends the nest, aerating the eggs by fanning constantly, and picking out dead eggs by mouth. Eggs hatch within

7–11 d at water temperatures of 20–25°C. The male parent may use his body and fins to press the egg mass gently to aid hatching.

Newly-hatched larvae are slightly >2.0 mm TL with fully pigmented eyes. Initially on the bottom, they become planktonic within 1–2 d. The large pectoral fin bud and large oil globule (~0.1–0.2 mm in diameter) may enhance floating. Large numbers of larvae are found in the oligohaline to freshwater regions of the Napa River, Suisun Marsh, and Montezuma Slough (Stillwater Sciences, Inc., survey, 2001–2005; Wang 2007; UC Davis Suisun Marsh Study; Meng and Matern 2001). They are also common in the vicinity of Cache Slough (Wang and Reyes 2007) but are rarely observed in the Sacramento River above Garcia Bend. Postlarvae are widely dispersed in the Delta by tidal influence. Postlarvae and early juveniles are often collected at the CVP/TFCF salvage collections during summer months, but few were collected during wet years of 1998, 2005, and 2006.

Shimofuri goby juveniles, at about 15 mm TL, have brownish pigments covering the body and have completely fused pelvic fins that form a suction cup. They descend to the benthic level or rest on vegetation, such as Brazilian elodea (*Egaria densa*), avoiding predation by blending with the surrounding environment. From juvenile stage to adulthood, the swimming behavior becomes less fluid and erratic.

Shimofuri goby juvenile stomach contents include hydroids, cirri of barnacles, and amphipods (Matern 1999). Stomach contents of juveniles collected at the CVP/TFCF include copepods, amphipods, and bloodworms (oliogochaeta). In the laboratory, they have been trained to feed on diced fish fillets and commercial made fish flakes. In the wild, they are ambush predators, hiding in the substrate.

Shimofuri goby reach maturity in about 1 year and can live up to 2 years (Matern 1999). In laboratory conditions, male shimofuri goby can reach maturity in 6 months but can delay maturity up to 1 year. Females reach maturity in <1 year and can reproduce another clutch of eggs in about 2–3 weeks. Both sexes live about 1–2 years. Shimofuri goby is not valued for human consumption because of its small size. It is used often as bait for striped bass fishing.

Matern (1999) believed that the presence of shimofuri goby is harmful to the coastal tidewater goby population because the former can outcompete the latter for food and breeding sites. Shimofuri goby can reproduce in both brackish and freshwater and their larvae can easily be transported to southern California estuaries (tidewater goby habitat) via the aqueduct system. The release of shimofuri goby as baitfish in coastal lagoons is also a threat to tidewater goby.

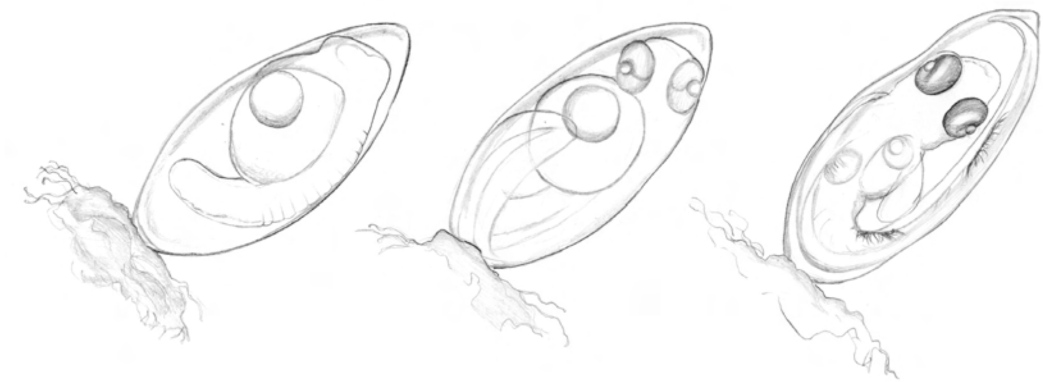


Figure 196.—*Tridentiger bifasciatus*, shimofuri goby eggs.

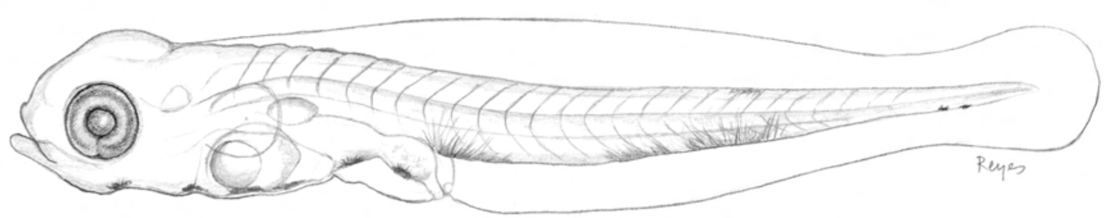


Figure 197.—*Tridentiger bifasciatus*, shimofuri goby prolarva, 2.7 mm TL.

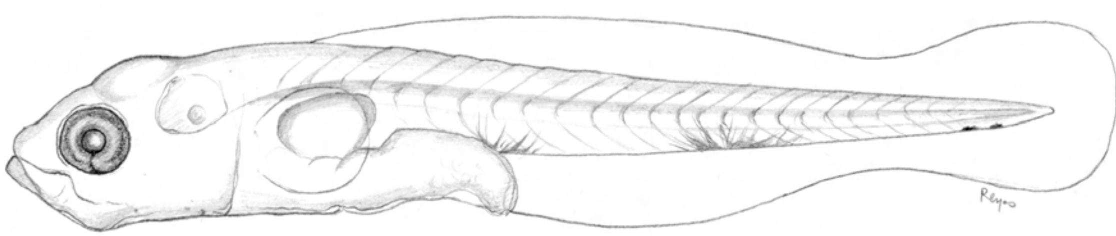


Figure 198.—*Tridentiger bifasciatus*, shimofuri goby postlarva, 3.5 mm TL.

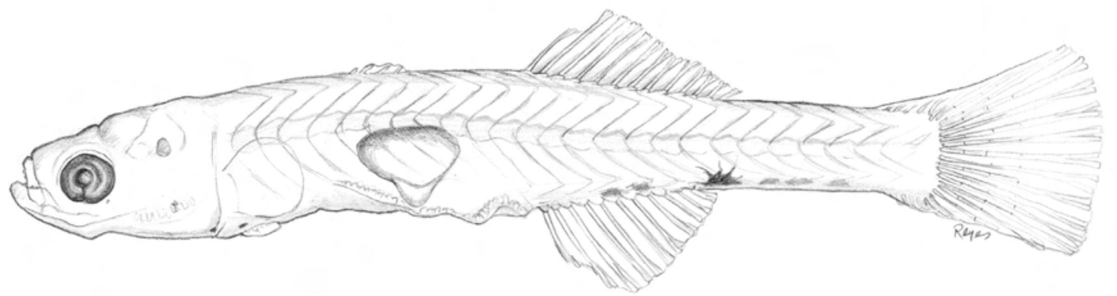


Figure 199.—*Tridentiger bifasciatus*, shimofuri goby prejuvenile, 11 mm TL.

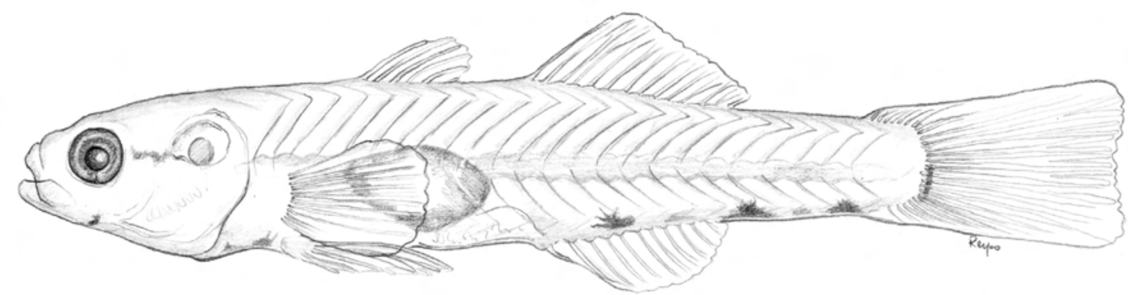


Figure 200.—*Tridentiger bifasciatus*, shimofuri goby juvenile, 15 mm TL.

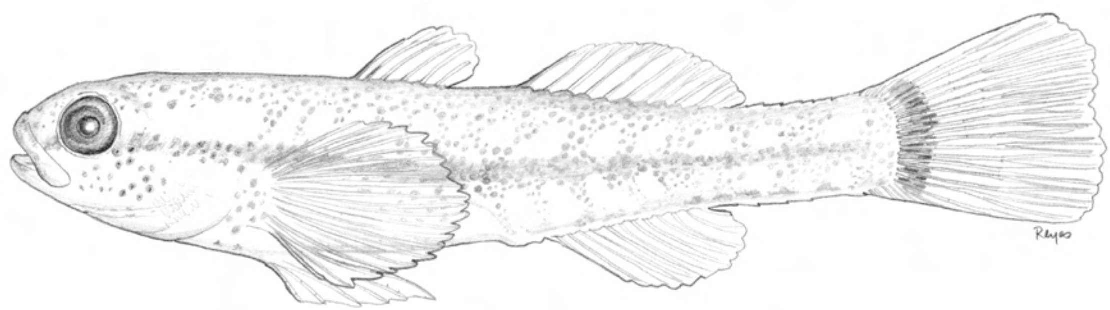


Figure 201.—*Tridentiger bifasciatus*, shimofuri goby juvenile, 18 mm TL.

Figure 202.—*Tridentiger bifasciatus*, shimofuri goby.

SHOKIHAZE GOBY *Tridentiger barbatus* (Günther)

SPAWNING

Location	Probably most often in Suisun Bay and may also occur in eastern San Pablo Bay, lower Napa River, and near Dumbarton Bridge of south San Francisco Bay based on collection of small juveniles (T.A. Greiner 2002, personal communication; Greiner 2002; Slater and Greiner 2003); may occur in lower Sacramento River and lower San Joaquin River in dry years.
Season	May to September, peaking in July (Dotsu 1957); in June and July (Slater and Greiner 2003); spawning will occur most months in laboratory environment (Slater and Greiner 2003, Slater 2005); from early April to late May in the laboratory (R.C. Reyes 2003–2009, personal communication).
Temperature	25°C (Dotsu 1957); 21–25°C (L. Lynch 2002, personal communication); 17–22°C (Slater and Greiner 2003); 23–25°C in the laboratory (R.C. Reyes 2003–2009, personal communication).
Salinity	Oligohaline (5 ppt) in the laboratory (L. Lynch 2002, personal communication, CDFG); 3–9 ppt in the laboratory (Slater and Greiner 2003); 2–9 ppt (Slater 2005); 0–5 ppt in the laboratory (R.C. Reyes 2003–2009, personal communication).
Substrate	Dead oyster shells (Dotsu 1957); cavities, empty containers, pipes, crevices of rocks, and jetties may be used as spawning substrates in the Sacramento-San Joaquin Estuary; PVC pipe (L. Lynch 2002, personal communication; Slater and Greiner 2003); open-ended 2-inch PVC tubes, capped 2-inch PVC tubes, and ceramic cups (R.C. Reyes 2003–2009, personal communication).
Fecundity	7,791–19,841/clutch by same female fish (Dotsu 1957); 8662–16,028/batch (Slater and Greiner 2003).

EGGS

Shape	Elliptical (Dotsu 1957); elliptical, club-shape, distal end is mainly round, although some are slightly pointed (specimens obtained from L. Lynch, CDFG).
Diameter	1.46–1.60 mm in long axis; 0.52–0.58 mm in short axis (Dotsu 1957); long axis 1.0–1.2 mm and short axis 0.4–0.5 mm (specimens obtained from L. Lynch, CDFG); 1.0 mm long and 0.5 mm wide (Slater and Greiner 2003).

Yolk	Yellowish, granular.
Oil globule	Many (for unfertilized eggs), consolidated into one in late embryo stage (Dotsu 1957, this study); ~0.1 mm in diameter.
Chorion	Transparent, smooth, except at basal area where there is a bundle of adhesive filaments (Dotsu 1957); smooth except the anchoring spot at basal end of long axis.
Perivitelline space	Narrow at short axis, wide at long axis.
Egg deposition	Elliptical, deposited in single layer, and attached to a common mat (male secreted coating or substance on the wall of burrow) at proximal end of the long axis.
Adhesiveness	Adhesive at anchoring spot (anchored to a common mat shared by other eggs).
Buoyancy	Negatively buoyant (demersal).

LARVAE

Length at hatching	2.50–2.55 mm TL (Dotsu 1957), 2.0–2.2 mm TL (L. Lynch 2002, personal communication); 2.0–2.5 mm TL (Slater and Greiner 2003).
Snout to anus length	~40–43% TL for newly-hatched larvae.
Yolk-sac	Spherical, large, and thoracic.
Oil globule	Single, ~0.1 mm in diameter.
Gut	Straight during prolarval stage.
Air bladder	Has thick wall (Dotsu 1957); small with pigmented ceiling and near pectoral at prolarval stage.
Teeth	Tiny on both jaws, no tri-cusped teeth at this stage.
Total myomeres	25–26 (Dotsu 1957); 24–26 (L. Lynch 2002, personal communication).
Preanal myomeres	8–10 (Dotsu 1957); 6–8 (L. Lynch 2002, personal communication).
Postanal myomeres	15–16 (Dotsu 1957); 17–19 (L. Lynch 2002, personal communication).
Last fin(s) to complete development	Fused pelvic fins (estimated).
Pigmentation	A few black dots (melanophores) and yellow dots (chromatophores) are seen at abdominal and postanal regions ventrally (Dotsu 1957); newly-hatched larvae have light dashed and stellate melanophores mid-ventrally and in postanal regions. In the postanal, ~2–4 small melanophores near the anus, one large melanophore midway between anus and tail, and ~4 near caudal (specimens obtained from

	L. Lynch, CDFG; R.C. Reyes 2003–2009, personal communication).
Distribution	Information on distribution is limited due to difficulty in distinguishing between Shokihaze goby and shimofuri goby larvae; probably from Suisun Bay to the lower Sacramento River, San Joaquin River;

JUVENILES

Dorsal fin rays	VI, I, 10 (Chen 1956, Okiyama 1988).
Anal fin rays	I, 10 (Chen 1956); I, 9–10 (Okiyama 1988).
Pectoral fin rays	22 (Dotsu 1957); 21–23 (Okiyama 1988).
Mouth	Terminal, in horizontal position (Dotsu 1957).
Vertebrae	26 (Dotsu 1957).
Distribution	From the Rio Vista of Sacramento River and lower San Joaquin River to Suisun Bay, San Pablo Bay, Napa River, and there have been isolated collections at the tip of south San Francisco Bay (Greiner 2002, Slater and Greiner 2003); collections have been made recently at the south Delta at SWP/SDFPF (J. Morinaka 2000–2007, personal communication) and at CVP/TFCF (R.C. Reyes 2003–2009, personal communication).

LIFE HISTORY

Spawning male and female Shokihaze gonbies share similar patterns of body pigmentation (six vertical blotches on side of body). However, males are larger than females and have a larger flat head. Overall, the male is slightly darker than the female. Both sexes have three distinctive dark spots, one on first dorsal fin and two at the base of caudal fin. During the spawning season, males have long and protruding genitalia and females have shorter genitalia with truncated tips (Dotsu 1957).

Shokihaze goby is a brackish water species native to Taiwan, China, southern Japan (Ariake Sound of Kyushu), and Korea (Jordan and Evermann 1902, Chen 1956, Dotsu 1957). It was first collected in the lower San Joaquin River by CDFG on November 3, 1997 (Fleming 1998). Currently, its distribution is divided into four areas: San Pablo Bay, Napa River, Suisun Bay to lower Sacramento and San Joaquin Rivers (including south Delta), and the tip of south San Francisco Bay (Greiner 2002; L. Lynch 2002, personal communication; this study). Spawning and nursery habitats of Shokihaze goby appear to overlap those of shimofuri goby and nursery habitat for yellowfin goby is also similar. Shokihaze goby populations are patchy and this species is generally far less abundant than shimofuri goby. However, Slater and Greiner (2003) reported the catch of Shokihaze goby exceeded that of chameleon goby in San Francisco Bay in 2002 and collections of Shokihaze goby seem to have increased rapidly in south San Francisco Bay in recent years (Greiner *et al.* 2006, Greiner *et al.* 2007).

Based on collections of small juveniles (16–20 mm TL) by the CDFG, Shokihaze goby appear to spawn mainly in Suisun Bay (including Montezuma Slough) in summer months. Adult males exhibit polygamous behavior. Incubation is approximately 4 d at water temperatures of 25°C and yolk-sac is absorbed in about 3 d (Dotsu 1957). Successful spawning and hatching of Shokihaze goby larvae in laboratory were recorded by L. Lynch (CDFG's Stockton laboratory, July 1999) and by R.C. Reyes (CVP/TFCF laboratory, 2007), where paired gobies were kept at water temperatures ranging 21–25°C and salinities at 0–5 ppt. At the CVP/TFCF laboratory, Shokihaze goby spawned in freshwater but the larvae did not survive in freshwater. Larvae also did not do well in 10 ppt water, surviving best in 5 ppt water. Eggs hatched in 4–7 d and larvae become planktonic within hours of hatching (R.C. Reyes 2003–2009, personal communication) or 1–2 d after hatching (L. Lynch 2002, personal communication). Larvae that incubated for 6–7 d often hatched with little remaining yolk and began feeding soon after hatching; however, most larvae begin to feed a day or two after hatching. Larvae have been observed feeding on plankton smaller than 100 microns such as rotifers and ciliates (R.C. Reyes 2003–2009, personal communication). Most large adults have been collected from Suisun Bay and early juveniles primarily from lower Sacramento River (Greiner 2002) suggesting that Shokihaze goby larvae may migrate upriver. However, migratory patterns are yet to be confirmed. Shokihaze goby descend to the bottom at ~16–17 mm TL when all the fin rays are developed and the body exhibits mottling (Dotsu 1957). Juvenile Shokihaze goby have small barbels below the mouth (at pre-orbital, sub-orbital, operculum, and lower jaw) by ~18 mm TL.

Currently, Shokihaze goby is found at depths ranging from 2.2 to 25.9 m. More adults are captured in deeper channels of Suisun Bay (Fish *et al.* 2008) and juveniles have been found mainly in shallow water at the confluence of the Sacramento and San Joaquin Rivers and slightly above the confluence, such as at Decker Island area in the Sacramento River (Greiner 2002).

Juveniles mainly feed on small crustaceans along with fish eggs and larvae of their own and other species (Dotsu 1957), detritus, and rotifers. Larger juveniles are carnivorous, consuming crustaceans and chopped fish parts in the laboratory environment (R.C. Reyes 2003–2009, personal communication).

Shokihaze goby reach maturity at 85–115 mm TL. The smallest mature female observed was 53 mm TL and male 56 mm TL; some live more than 3 years. This species can generate several clutches of eggs per spawning season (Dotsu 1957). One female spawned six times at CDFG/Stockton from March to June, 2002 (Slater and Greiner 2003). Competing males have been observed feeding on eggs of other males. Similar to shimofuri goby, the body of aging Shokihaze goby turns pale before dying. Lifespan is about 2–3 years in the laboratory environment.

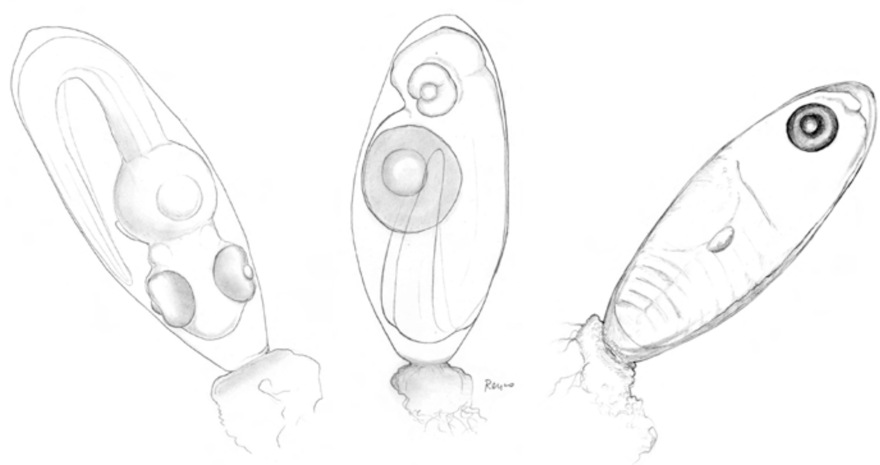


Figure 203.—*Tridentiger barbatus*, Shokihaze goby egg, 1.5 mm long axis, 0.5 short axis.

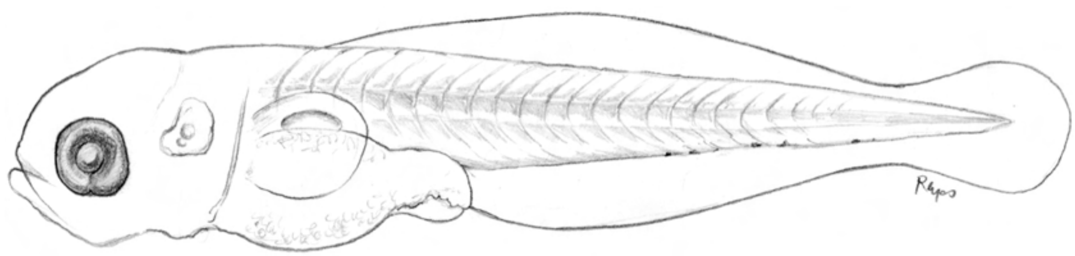


Figure 204.—*Tridentiger barbatus*, Shokihaze goby prolarva, 2.3 mm TL.

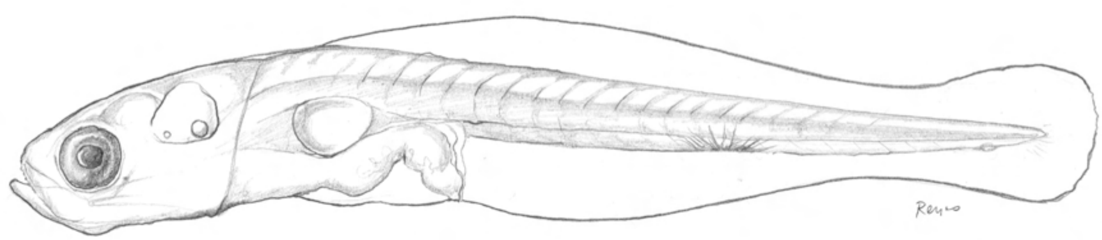


Figure 205.—*Tridentiger barbatus*, Shokihaze goby postlarva, 3.7 mm TL.

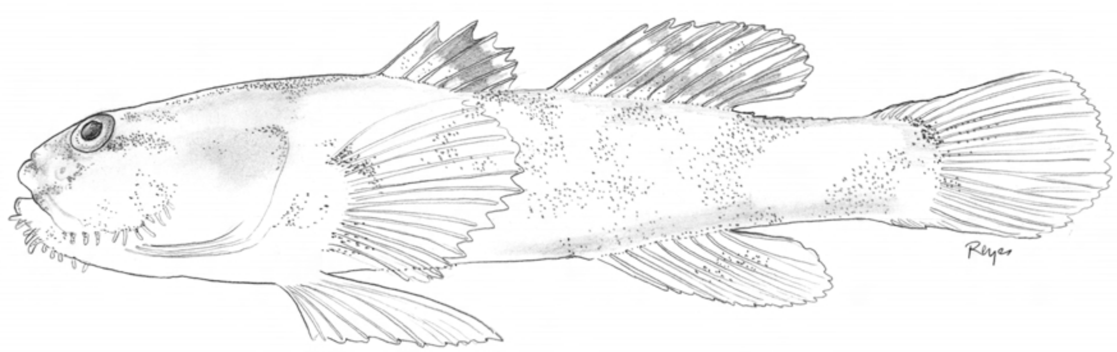


Figure 206.—*Tridentiger barbatus*, Shokihaze goby juvenile, 40 mm TL.

Figure 207.— *Tridentiger barbatus*, Shokihaze goby.

Dichotomous Key for 10 species of gobiid larvae found in the Sacramento-San Joaquin Estuary[4]

Size range: ~2.2–10.0 mm TL

1a. Total myomeres ≤ 26 2
1a. Total myomeres ≥ 29 5

2a. Total myomere count 25–26; a series (~1–10) of melanophores present middorsally and near caudal .... **Blackeye goby**
2b. Total myomere count 24–26; usually 1–2 melanophores present on middorsally and near caudal 3

3a. One large stellate melanophore located in the postanal region ventrally; additional small melanophores may or may not be present along the postanal region ventrally in late postlarvae; larvae from high saline water from lower San Pablo Bay to south San Francisco Bay .... **Chameleon goby**
3b. One large stellate melanophore in postanal region ventrally, more melanophores along the postanal region ventrally in postlarvae; larvae from lower saline waters.. 4

4a. Two groups of melanophores ventrally: 1–5 large stellate melanophores near anus; other ~2 very small melanophores at the end of caudal peduncle .... **Shimofuri goby**
4b. One group of melanophores ventrally: ~6–10 small stellate melanophores distribute along the postanal region (one in the middle may be slightly larger than others)..… .... **Shokihaze goby**

5a. Body pigment with more large melanophores on dorsum.. 6
5b. Only 0–1 melanophore on middorsum, most pigment midventral and in postanal regions ventrally 8

6a. Small speckle-typed pigmentation interwoven in postanal region ventrally; scattered pigmentation along dorsum.. **Tidewater goby**
6b. Large stellate melanophores along dorsum and ventrum of body.. 7

7a. ~5 or more large melanophores along dorsum and ~14 and greater melanophores midventrally and in postanal region ventrally ....**Longjaw mudsucker**
7b. ~3 large melanophores middorsally; ~10 or more midventrally and in postanal region ventrally ....**Bay goby**

8a. Single melanophore in the postanal region ventrally and one on the middorsum (both melanophores are symmetrically opposite each other).. **Yellowfin goby**
8b. Several melanophores along the postanal region ventrally **9**

9a. Rectum slanted toward anus; body slender and tapering toward the tail; one middorsal melanophore; myomeres 35–37.. **Arrow goby**
9b. Rectum mostly flat; body high and compressed, blade-like toward the tail; no middorsal melanophore; myomeres 32–36..**Cheekspot goby**

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[4] Tidewater goby is not included in this key. It has not been reported in the Sacramento-San Joaquin Estuary since the mid-1960s (Messersmith 1966); it has been extirpated from San Francisco Bay (Moyle 2002). It can be found in some lagoons along the California coast and streams adjacent to the study area, such as Rodeo Lagoon, Estero de San Antonio, and Estero Americano (Wang 1982, 1984).

Paralichthyidae –Sand Flounders — Three species of sand flounders inhabit the estuarine waters of the Sacramento-San Joaquin system (Ganssle 1966, Aplin 1967, Ruth 1969, Green 1975): Pacific sanddab (*Citharichthys sordidus*), speckled sanddab (*C. stigmaeus*), and California halibut (*Paralichthys californicus*). One 2-year-old California halibut was collected at Carquinez Strait in a trawl survey in 2006 (Greiner *et al.* 2007). The larvae of California halibut and Pacific sanddab have not been taken this far up the strait. Early life stages of speckled sanddab have been found in the Delta and this species is discussed in this chapter.

SPECKLED SANDDAB *Citharichthys stigmaeus* Jordan and Gilbert

SPAWNING

Location	Probably in coastal waters since females in spawning condition were collected from oceanic waters 5–45 m deep (Ford 1965); in shallow coastal waters (<90 m deep with sandy bottom), bays, and estuaries (Moser and Sumida 1996, Greiner *et al.* 2007).
Season	April–September (Ford 1965). Based on larval collections, spawning occurs in December (Eldridge and Bryan 1972); March–September (Fitch and Lavenberg 1975); larvae are collected all months, with large numbers in June and July, spawning is estimated to occur in spring and summer (Ahlstrom and Moser 1975); larvae are captured all year round along the southern California coast with the highest abundance in August and December (Moser and Sumida 1996); based on larval collections from San Francisco Bay and Moss Landing Harbor (Wang 1986), spawning occurs in these areas from November through April.
Temperature	10.5–14.0°C (Ford 1965).
Salinity	Seawater.
Fecundity	1,000–6,200 mature eggs/batch (Ford 1965).

EGGS

Diameter	Mature eggs are 0.60–0.77 mm in diameter (Ford 1965); 0.62–0.66 (Moser and Sumida 1996).
Yolk	Homogeneous (Moser and Sumida 1996).
Oil globule	One, 0.06–0.08 mm in diameter (Moser and Sumida 1996).
Chorion	Smooth (Moser and Sumida 1996).
Buoyancy	Planktonic (Moser and Sumida 1996).

LARVAE

Length at hatching	~2.0 mm TL, estimated from the smallest specimens collected at Moss Landing Harbor and San Francisco Bay (Wang 1986); ~1.3 mm SL (Moser and Sumida 1996).
Snout to anus length	36–38% TL for larvae 2.1–3.4 mm TL (Wang 1986).
Yolk-sac	Spherical, large in thoracic region.
Oil globule	Small, <0.1 mm in diameter (Moser and Sumida 1996).
Gut	Short and straight, bends vertically in anal region; forms a loop in postlarvae ~3.0 mm TL.
Air bladder	Small, spherical or oval, toward anus, arch-like pigmention covering the top; appears in postlarvae ~6.0 mm TL.
Size at absorption of yolk	~3.0 mm.
Total myomeres	36–39.
Preanal myomeres	11–14.
Postanal myomeres	24–27.
Last fin(s) to complete development	Pectoral (Wang 1986, Moser and Sumida 1996).
Pigmentation	A series of melanophores in thoracic region and dorsal portion of gut region with a single melanophore located in infraorbital region. A cluster of melanophores located around the tip of notochord. Two dark blotches encircle the body between the anus and tail.
Distribution	Pelagic in coastal waters and offshore (Fitch and Lavenberg 1975, Ahlstrom and Moser 1975); bays and estuaries (Eldridge and Bryan 1972, Wang 1986).

JUVENILES

Dorsal fin rays	79–82 (Hart 1973); 75–97 (Miller and Lea 1972); mostly 88 –90 along southern California coast (Moser and Sumida 1996).
Anal fin rays	59–72 (Hart 1973); 58–77 (Miller and Lea 1972); mostly 70 (Moser and Sumida 1996).
Pectoral fin rays	12 (Miller and Lea 1972); 10–12 (Moser and Sumida 1996).
Mouth	Terminal, moderate in size and gape (Hart 1973); mouth terminal and oblique.
Vertebrae	~37 (Clothier 1950); 34–39 (Miller and Lea 1972); 36–39 (Matarese *et al.* 1989); 36–38 along southern California coast (Moser and Sumida 1996).
Distribution	Found along shores and in open waters of bays and estuaries, such as San Francisco Bay; up to San Pablo Bay

and Suisun Bay during dry years (Baxter *et al.* 1999), and Moss Landing Harbor (Nybakken *et al.* 1977, Wang 1986).

LIFE HISTORY

Speckled sanddab is known from Magdalena Bay, Baja California, to Montague Island, Alaska (Townsend 1935, Wilimovsky 1954, Miller and Lea 1972). In San Francisco Bay, it was one of the abundant species collected by Aplin (1967), and the second most abundant flatfish in recent years (Baxter *et al.* 1999). This species has also been reported in Tomales Bay (Bane and Bane 1971) and Moss Landing Harbor-Elkhorn Slough (Nybakken *et al.* 1977, Wang 1986). In the study area, most of the speckled sanddab collected by trawl were juveniles and were collected as far upstream as Suisun Bay in spring months (Baxter *et al.* 1999). There have been a few collected from Napa River in recent years (CDFG 20-mm survey; Stillwater Sciences, Inc., survey). Some juveniles apparently ascend to the upper estuary to forage during drought years (Baxter *et al.* 1999).

Speckled sanddab spawn in coastal waters. Although adults are abundant in San Francisco Bay, their larvae have not been collected (Baxter *et al.* 1999). Richardson and Pearcy (1977) collected larvae of this species within 28 km of the Oregon coast. Anglers have caught gravid speckled sanddab females from a jetty at Moss Landing Harbor during fall and winter (Wang 1986). Larvae collected at the entrance to Moss Landing Harbor were mainly carried by the ocean tides. Larvae were collected year round along the southern California coast (Ahlstrom and Moser 1975), with the highest abundance occurring during the period August to December with peaks in October (Moser and Sumida 1996).

Speckled sanddab eggs and larvae are easily confused with those of other sanddabs species and other fish species (*e.g.*, white croaker). Egg size of the speckled sanddab is slightly larger than 0.5 mm in diameter with one oil globule. Eggs of white croaker are similar and are collected during winter months when speckled sanddab eggs are also present. Eldridge (1977) observed the larvae of an unidentified sanddab *Citharichthys* spp. in Richardson Bay, and Nybakken *et al.* (1977) collected them in Moss Landing Harbor. *Citharichthys* spp. larvae were also collected in both San Francisco Bay and Moss Landing Harbor (Wang 1986) but not above Carquinez Strait (CDFG striped bass E and L survey, 1988–1995). These *Citharichthys* spp. larvae were identified as speckled sanddab because their vertebral counts fell within the range (36–38) reported for speckled sanddab (Pacific sanddab have 38–40 vertebrae). The Pacific sanddab is known to occur in San Francisco Bay but it is uncommon (Baxter *et al.* 1999).

Speckled sanddab larvae and early juveniles are bilaterally symmetrical. As they grow, the right eye migrates to the left side of the head. Juveniles are often collected from the intake screens of Potrero, Hunters Point, and Moss Landing Powerplants mainly in winter months (Wang 1986).

In La Jolla Bay, the smallest speckled sanddab juveniles were found in waters 15–25 m, while the larger juveniles were distributed at all depths (Ford 1965). Ehrlich *et al.* (1979) reported that speckled sanddab in King Harbor were more abundant during winter and early summer months than in summer through fall months. They believed that this distribution was probably related to water temperature, since higher abundance was observed in cooler waters (8–13°C). Baxter *et al.* (1999) also found speckled sanddab in the cooler temperatures of central San Francisco Bay during the summer months, but also cited salinity as a factor for distribution in the estuary. The range of juveniles extends to San Pablo Bay and Suisun Bay during dry years.

Juvenile speckled sanddab feed primarily on small crustaceans such as copepods, isopods, amphipods, and mysid shrimps, and on annelids, such as polychaete worms (Ford 1965, Bane and Bane 1971, Ambrose 1976, Nybakken *et al.* 1977).

Speckled sanddab mature after the first year of life, and maximum age is approximately 4 years (Fitch and Lavenberg 1975). Because of its small size, it has little commercial value, although it is sold in Asian fish markets often prepared steamed or fried.

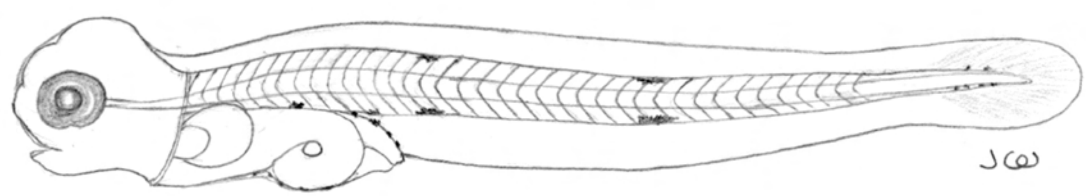

Figure 208.—*Citharichthys stigmaeus*, speckled sanddab prolarva, 3.5 mm TL (Wang 1986).

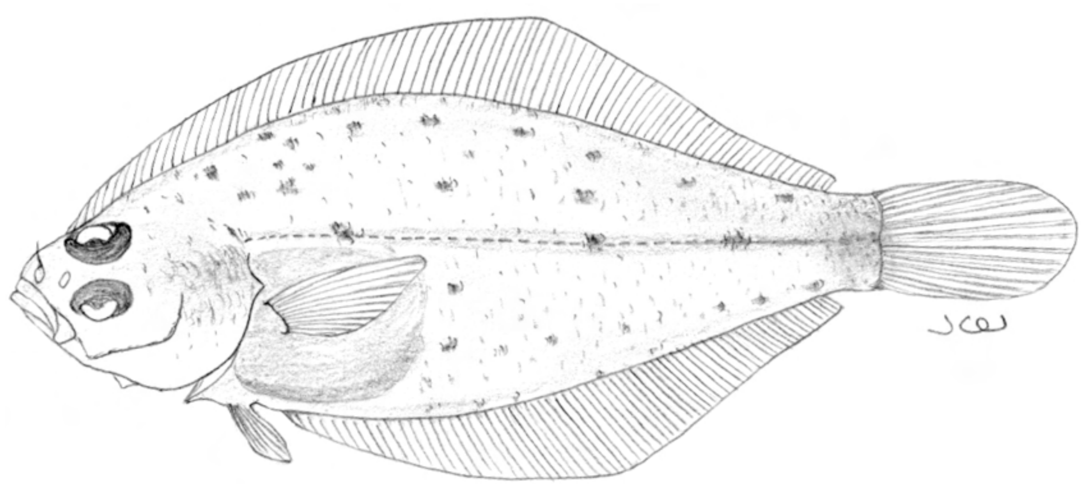

Figure 209.—*Citharichthys stigmaeus*, speckled sanddab juvenile, 52 mm TL (Wang 1986).

Pleuronectidae – Righteye Flounders — At least 11 species of righteye flounders have been reported in the Delta and estuarine waters of Sacramento-San Joaquin system (Miller and Lea 1972). Eight species collected during the period 1980–1995 (Baxter *et al.* 1999) include: English sole (*Parophrys vetulus*); starry flounder (*Platichthys stellatus*); diamond turbot (*Pleuronichthys guttulatus*); sand sole (*Psettichthys melanostictus*); curlfin turbot (*Pleuronichthys decurrens*); C-O sole (*Pleuronichthys coenosus*); hybrid sole (*Inopsetta ischyra*); and honeyhead turbot (*Pleuronichthys verticalis*). The English sole and the starry flounder are found in the Delta (above San Pablo Bay), and are discussed in this chapter.

ENGLISH SOLE Parophrys vetulus (Girard)

SPAWNING

Location	Coastal waters near San Francisco Bay (Eldridge 1977, Wang 1986); southern part of Monterey Bay (Budd 1940); south of Point Concepcion (Ahlstrom and Moser 1975); offshore of Yaquina Bay, Oregon (Pearcy and Myers 1974); sheltered water, channels or bights, and banks in Hecate Strait, Canada (Ketchen 1956); in bays of south British Columbia (Taylor 1940); may spawn in the San Francisco Bay.
Season	October to May on California coast and mainly in January and February (Jow 1969); January–May (Bane and Bane 1971); larvae were collected from San Francisco Bay upstream to Suisun Bay from January through May (Wang 1986; CDFG's DSLS, 2006); October–May in southern California (Charter and Moser 1996); November–May, peaking in late March and early April (Budd 1940); December–early April in British Columbia (Ketchen 1956); peaking in January and February in British Columbia (Frey 1971).
Temperature	13°C (Budd 1940); optimal temperature 8–9°C (Alderdice and Forrester 1968); 10.0–11.0°C (Orsi 1968); 7–9°C (Hickman 1959); 8–13°C (Frey 1971); larvae were collected in San Francisco Bay and Moss Landing Harbor at temperatures of 4.0–13.0°C (Wang 1986).
Salinity	10–40 ppt in the laboratory (Alderdice and Forrester 1968); seawater.
Fecundity	150,000–1,950,000 (Ketchen 1947, Harry 1959).

EGGS

Shape	Spherical (Budd 1940, Orsi 1968).
Diameter	0.89–0.93 mm, with an average of 0.9 mm (Budd 1940); 0.93–1.05 mm with an average of 0.99 mm (Orsi 1968); 0.80–1.1 mm (Charter and Moser 1996)
Yolk	Transparent, homogeneous (Budd 1940); homogeneous, 0.83 mm in diameter (Charter and Moser 1996).
Oil globule	None (Budd 1940); none, but may have oil droplets linked in chains (Orsi 1968).
Chorion	Transparent, thin, finely wrinkled or with striations (Budd 1940, Orsi 1968); smooth to fine striations (Charter and Moser 1996).
Perivitelline space	Very narrow or small (Orsi 1968).
Egg deposition	Broadcasted into water column.
Adhesiveness	None (Budd 1940).
Buoyancy	Pelagic, very buoyant, sinks slowly several hours before hatching (Budd 1940).

LARVAE

Length at hatching	2.8 mm SL (Budd 1940); 2.85 TL (Orsi 1968); 2.3–2.9 mm SL (Charter and Moser 1996).
Snout to anus length	33–40% TL for larvae 2.83–3.2 mm TL; ~33–40% TL for larvae 3.3–6.3 mm TL (Wang 1986); 43–45% SL (Matarese *et al.* 1989).
Yolk-sac	Colorless, newly-hatched larvae have a large yolk-sac extending from the head to the abdominal region.
Gut	Short, straight, and bends ventrally in a 90° angle to the anus in the prolarval stage; coiled in single loop in postlarvae.
Air bladder	None.
Teeth	Small and pointed in postlarvae.
Size of absorption of yolk-sac stage	~4.0–4.6 mm TL.
Total myomeres	40–44 for larvae collected in San Francisco Bay.
Preanal myomeres	10–12.
Postanal myomeres	29–34.
Last fin(s) to complete development	Pectoral (Charter and Moser 1996).
Pigmentation	Melanophores scattered on head, middorsum, thoracic, and postanal region ventrally; ~1–3 dark blotches not quite

	encircling the body between anus and tail; in the prolarval stage, stellate melanophores scattered on dorsal and ventral finfolds; in the postlarval stage, blotches diminished and are replaced by scattered melanophores on dorsum and a series of small melanophores on postanal region ventrally; ventral finfold has fine melanophores; dorsal finfold is almost pigmentation-free.
Distribution	Pelagic, mostly in shallow coastal waters of southern California (Ahlstrom and Moser 1975); some are carried into bays and estuaries by currents (Eldridge and Bryan 1972, Eldridge 1977, Wang 1986); common offshore of Yaquina Bay, Oregon, but absent or rare inside of Yaquina Bay (Pearcy and Myers 1974); transforming larvae enter Humboldt Bay (Misitano 1976); prolarvae and postlarvae were collected at Horseshoe Cove, near the northern base of the Golden Gate Bridge (Wang 1986); larvae were collected in San Pablo Bay and Napa River (CDFG's DSLS, 2006).

JUVENILES

Dorsal fin rays	71–86 (Clothier 1950); 71–93 (Miller and Lea 1972); 72–93 (Hart 1973).
Anal fin rays	54–68 (Clothier 1950); 52–70 (Miller and Lea 1972); 54–70 (Hart 1973).
Pectoral fin rays	10–12 (Miller and Lea 1972).
Mouth	Terminal, small, with narrow gape (Hart 1973); small, oblique.
Vertebrae	42–45 (Clothier 1950); 41–44 (Hart 1973); 41–47 (Miller and Lea 1972); 42–47 (Matarese *et al.* 1989).
Distribution	Early transforming stages are pelagic, but gradually settle on the bottom after metamorphosis is completed; most juveniles are collected along the coast and some enter bays (Misitano 1976, Eldridge 1977, Toole 1978, Wang 1986); juveniles were abundant in Yaquina Bay (Pearcy and Myers 1974, Westrheim 1955); ages 0–1 juveniles move from San Francisco Bay up to Suisun Bay and west Delta in small numbers (Wang 1986, Baxter *et al.* 1999); juveniles use the mesohaline San Pablo Bay for nursery in spring with high outflow (Greiner *et al.* 2007).

LIFE HISTORY

English sole, formerly known as lemon sole, ranges from San Cristobal Bay, Baja California, to Unimak Island, Alaska (Forrester 1969) and to northwest Alaska (Miller and Lea 1972). Frey (1971) identified four different stocks of this species along the Pacific coast. English sole are common in San Pablo Bay (Ganssle 1966) and San Francisco Bay (Aplin 1967). All life stages of English sole (larvae to >age-1) were some of the most abundant flatfishes in the estuarine waters of the Sacramento-San Joaquin system collected by the CDFG during the period 1980–1995 (Baxter *et al.* 1999). This species is most abundant in the central San Francisco Bay and San Pablo Bay.

The reproductive biology of English sole has been investigated by Budd (1940) and its development embryology was described by Orsi (1968). Based on larval collections by CDFG in the San Francisco Bay during the period 1980–1989, English sole spawn mainly in winter months (Baxter *et al.* 1999). The incubation period at 12°C is 3.5 d, at 4°C it is 11.8 d (Budd 1940), and at 7–9°C it is 5 d (Hickman 1959). Incubation at lower temperatures may enhance the development and survival of the larvae, so that their chance of reaching the estuarine nursery ground is greater (Ketchen 1956). However, a temperature of 2.0°C is lethal to eggs (Alderdice and Forrester 1968).

Newly-hatched English sole larvae have a large yolk-sac and are found near the surface in an upside-down position (Budd 1940). They are bilaterally symmetrical and are found swimming in coastal waters (Richardson and Pearcy 1977). Misitano (1976) sampled Humboldt Bay for English sole larvae during the peak of their spawning and found only a small number of larvae. Eldridge (1977) reported a few larvae in Richardson bay (an arm of San Francisco Bay), and proposed that English sole spawn outside of San Francisco Bay. English sole larvae have seldom been collected in San Francisco Bay. However, a large number of larvae were observed in San Pablo Bay and some have been collected in Suisun Bay in March and April 1982 (San Francisco Bay fish E and L survey, 1982; Wang 1986). They were again observed in San Pablo Bay and Napa River in January and February 2006 (CDFG's DSLS). Both occasions were in high-flow water years.

As English sole reach late postlarvae and transform into juveniles, their bodies become deeper but still remain bilaterally symmetrical. When they are about 15–20 mm TL, the left eye starts to migrate to the right side and they begin to assume an epibenthic lifestyle. Transforming larvae and early juveniles may descend into deeper water near the mouth of estuaries, where two-layered transport (freshwater on top, saltwater on bottom) can move them into the estuary. Within the estuary they can ascend to the upper layers and disperse (Westrheim 1955, Kulm and Byrne 1967, Olson and Pratt 1973, Pearcy and Myers 1974, Misitano 1976). In the study area, some age-0 English sole ascend to San Pablo Bay and Suisun Bay and have been caught by otter trawl (Baxter *et al.* 1999).

Bays and estuaries are important nursery grounds for English sole, particularly during their first year of life (Olson and Pratt 1973). In the San Francisco Bay, English sole enter the bay and estuary at age-0 and stay there for 6–18 months, then move out to the coast for maturity (Baxter *et al.* 1999). They move with changes in salinity and temperature during their time in the estuary and complete their ontogenetic changes at the same time. The estuary also serves as a sanctuary during transformation. Juvenile English sole feed on small crustaceans such as copepods, amphipods, and polychaete worms (Nybakken *et al.* 1977, Toole 1978).

English sole females reach sexual maturity at 3 years and about 300 mm TL. Males become mature between 250–270 mm (Ketchen 1947). Smith (1936) reported female English sole to mature at 3–4 years and males in 2 years. English sole support one of the most important commercial fisheries along the California coast (Frey 1971).

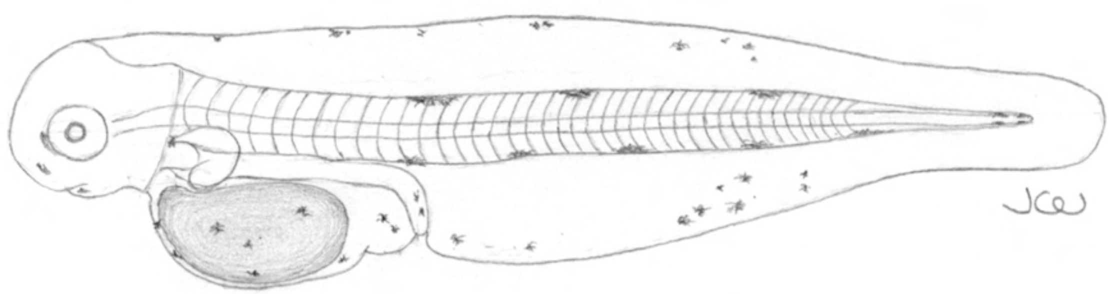

Figure 210.—*Parophrys vetulus*, English sole prolarva, 3 mm TL (Wang 1986).

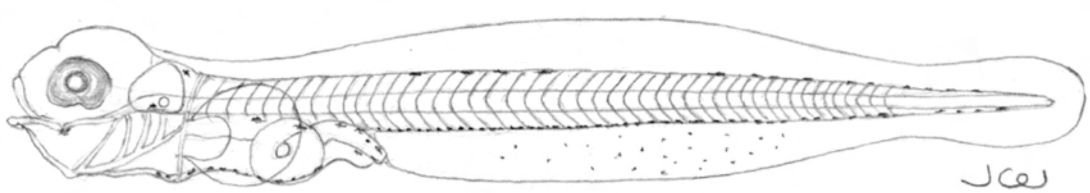

Figure 211.—*Parophrys vetulus*, English sole postlarva, 8.8 mm TL (Wang 1986).

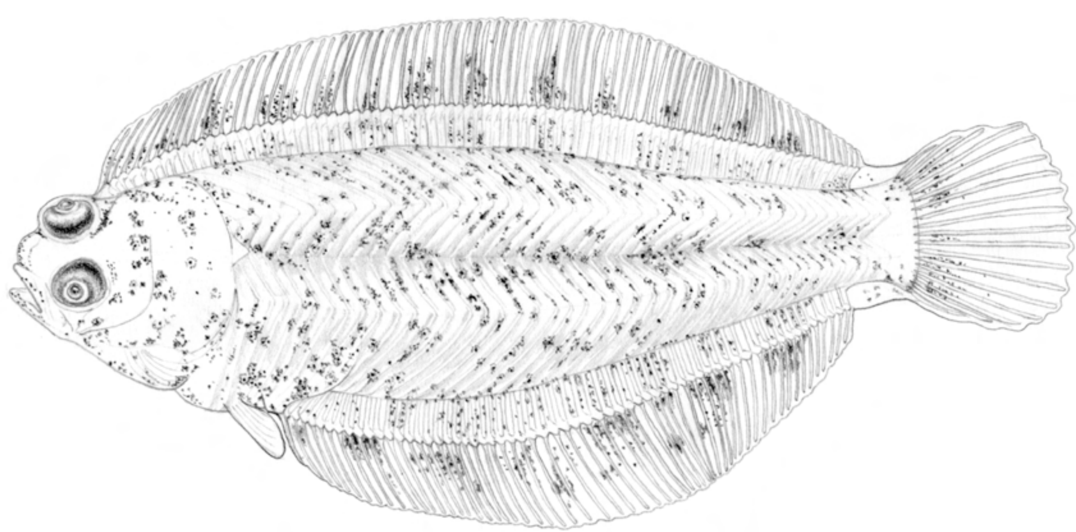

Figure 212.—*Parophrys vetulus*, English sole juvenile, 23.3 mm TL (Wang 1986).

STARRY FLOUNDER *Platichthys stellatus* (Pallas)

SPAWNING

Location	Shallow water near the mouths of rivers and sloughs (Orcutt 1950); may occur in the lower portion of San Joaquin River (Radtke 1966); outside of San Francisco Bay (Eldridge 1977); mostly in coastal waters but some spawning occurs in San Francisco Bay, further up the estuary during dry years.
Season	November–February in Elkhorn Slough (Orcutt 1950); November–February on southern California coast (Charter and Moser 1996); February–April in Puget Sound (Smith 1936); December–January in British Columbia (Hart 1973); based on size of larvae and small juveniles collected in San Francisco Bay, spawning occurs during fall and winter months.
Temperature	10.5–12.5°C (Orcutt 1950); based on water temperatures at locations where small larvae were collected, ~11–13°C (Wang 1986).
Salinity	Seawater to polyhaline.
Substrate	None.
Fecundity	Estimated at 11,000,000 for 254-mm TL specimen (Orcutt 1950).

EGGS

Shape	Spherical (Orcutt 1950).
Diameter	0.89–0.94 mm (Orcutt 1950); 0.88–1.28 (Matarese *et al.* 1989); 0.88–1.3 mm (Charter and Moser 1996).
Yolk	Colorless, smooth (Orcutt 1950); homogeneous (Charter and Moser 1996).
Oil globule	None (Orcutt 1950, Charter and Moser 1996).
Chorion	Transparent, thin, finely wrinkled (Orcutt 1950); irregular reticulations (Charter and Moser 1996).
Egg deposition	Broadcasted in water column.
Buoyancy	Pelagic (Orcutt 1950); planktonic (Charter and Moser 1996); eggs may be present at neuston level due to their wrinkled nature (increases surface tension).

LARVAE

Length at hatching	1.93–2.08 mm TL (Orcutt 1950); 1.9–2.1 mm SL (Charter and Moser 1996).
Snout to anus length	~35–40% TL for larvae 4.9–6.6 mm TL, decreasing to ~28–29% TL for larvae 7.7 to 8.4 mm TL (Wang 1986); <50% of SL (Matarese *et al.* 1989).
Yolk-sac	Colorless, very large in newly-hatched larvae, extends from the snout to the abdominal region; size of yolk-sac decreases and becomes restricted to thoracic region as larva grows larger.
Oil globule	None.
Gut	Coiled in single loop, short, bends ventrally (45–90 degrees) to anus.
Air bladder	None.
Teeth	Pointed (some embedded in the tissue) in postlarvae.
Size at absorption of yolk	~3.4 mm TL.
Total myomeres	34–38.
Preanal myomeres	8–12.
Postanal myomeres	26–28.
Last fin (s) to complete development	Pectoral (Matarese *et al.* 1989, Charter and Moser 1996).
Pigmentation	Stellate melanophores scattered on the dorsal and ventral finfolds, head, trunk, tail, gut, and yolk-sac regions; two dark blotches of more concentrated melanophores on finfold between anus and tail (Orcutt 1950, this study).
Distribution	Pelagic (Matarese *et al.* 1989); planktonic (Charter and Moser 1996); Richardson Bay of San Francisco Bay (Eldridge 1977); Elkhorn Slough (Nybakken *et al.* 1977); pelagic in coastal waters, San Francisco Bay, San Pablo Bay, and Moss Landing Harbor.

JUVENILES

Dorsal fin rays	56–62 (Clothier 1950); 52–64 (Miller and Lea 1972, Moyle 2002); 55–66 (Hart 1973).
Anal fin rays	40–46 (Clothier 1950); 38–47 (Miller and Lea 1972, Hart 1973, Moyle 2002).
Pectoral fin rays	9–10 (Charter and Moser 1996); 12 (Wang 1986); 10 (Moyle 2002).
Mouth	Terminal, small with narrow gape, asymmetrical (Hart 1973).

Vertebrae	34–37 (Clothier 1950, Miller and Lea 1972); 35–38 (Matarese *et al.* 1989, Charter and Moser 1996).
Distribution	Coastal waters up to the Delta sloughs (Radtke 1966); some have been recorded in San Luis Reservoir and O'Neill Forebay (Moyle 1976, 2002); in Napa River, Suisun Bay up to North Bay Aqueduct and Delta (CDFG striped bass E and L survey, 1988–2004); SWP/SDFPF and the CVP/TFCF.

LIFE HISTORY

Starry flounder is a member of the righteye flounder family although it can have eyes on either left or right side of the fish. It is found along the Pacific coast from Santa Ynez River (Santa Barbara County, California) northward to the Alaskan Peninsula and to the Aleutian Island chain, the Kamchatka Peninsula, the Kurile Islands, and southward to Japan (Orcutt 1950). This species is also known in Korea (Okada 1955). In San Francisco Bay and the Delta, starry flounder is one of the most common flatfish (Ganssle 1966, Radtke 1966, Alpin 1967, Baxter *et al.* 1999). Juveniles are commonly reported in the lower Sacramento River (such as NBA) and the Delta (such as the SWP/SDFPF and CVP/TFCF) all year round and are common in the spring and early summer months. Some are transported via the California Aqueduct and Delta Mendota canal to the O'Neill Forebay and San Luis Reservoir (Moyle 1976, 2002).

Starry flounder spawns in shallow waters or tidal sloughs such as Elkhorn Slough (Orcutt 1950, Nybakken *et al.* 1977, Wang 1981). Gravid females are often caught by anglers at the jetty of Moss Landing Harbor in winter months (Wang 1986). Eldridge (1977) collected starry flounder larvae in Richardson Bay in March and August. Larvae were also collected in the Sacramento-San Joaquin Estuary from September through March (CDFG striped bass fish E and L survey, 1988–2004; Wang 1986). The smallest specimen taken at the upper estuary at Cache Slough was 7.8 mm TL on April 18, 1997. Based on the various sizes of small flounders collected in the Delta in the 1990s and 2000s, most spawning is projected to occur during winter months, with peak spawning in December and January in San Francisco Bay and adjacent coastal waters (Orcutt 1950).

Radtke (1966) collected many 8- to 15-mm TL starry flounder larvae and juveniles in the lower reaches of the San Joaquin River and assumed that this species spawned in Suisun Bay and the lower San Joaquin River. However, neither mature starry flounder nor their eggs or prolarvae have been collected in those areas from 1978 to present time (UC Davis Suisun Marsh fish eggs and larval sampling, CDFG's fall midwater trawl survey, striped bass E and L survey, and North Bay Aquaduct fish E and L survey). It is suggested that all spawning occurs in the coastal waters or the higher-salinity portions of the estuaries since adults and larvae are commonly found in those areas (Gunter 1942, Westrheim 1955, Pearcy and Myers 1974). Larvae found in the upper estuaries are probably transported by the two-layered currents, freshwater on the top and salty water on the bottom. This transport mechanism has been reported for larvae of hogchoker (*Trinectes maculates*) and winter flounder (*Pseudopleuronectes americanus*) in the Atlantic estuaries (Wang and Kernehan 1979) and yellowfin goby in San Francisco Bay and Delta (Wang 1986).

The early life development of starry flounder was detailed by Orcutt (1950). Newly-hatched starry flounder larvae initially float with their yolk-sac facing up in the water. As the larvae develop, they eventually turn over so the yolk-sac is facing down (Orcutt 1950). The larvae, with high finfolds, are pelagic and have been observed in Richardson Bay (Eldridge 1977). Small larvae were taken from Horseshoe Cove (near the north end of Golden Gate Bridge) and in the vicinity of the Potrero and Hunters Point Powerplants of south San Francisco Bay. Newly-hatched yolk-sac larvae have been collected near the jetty of Moss Landing Harbor (Wang 1981, 1986).

There is an upstream movement of YOY starry flounder from the bay to the less saline waters of the Delta (Ganssle 1966) and Napa River (CDFG 20-mm fish survey). Juvenile starry flounder can tolerate lower salinities and warmer temperatures than English sole and speckled sanddab in the estuary (Baxter *et al.* 1999). This tolerance enables them to live in Delta sloughs and remain in the Delta longer than one year. Juveniles are observed almost every year and their dependence on the estuary becomes more obvious during high flow years (Hieb and Baxter 1993). Juveniles may also be active swimmers because they have been collected by trawl and plankton net. Starry flounder return to higher saline water before reaching sexual maturity. Therefore, few adults were observed in the Delta.

Juvenile starry flounder forage a wide area including the sloughs and ditches of the Delta and adjacent waters, with the exception of the upper Sacramento River where they have not been collected. Older starry flounder (YOY up to age 2) forage in freshwater; they have been collected at the CVP/TFCF on a few occasions. Juveniles gradually settle on the bottom by the end of April. Prior to metamorphosis (left eye migrates to right side), they initially feed on planktonic algae and then planktonic crustaceans (Moyle 2002). As they grow larger, juveniles bury their bodies in the sand or bottom substrates, keeping their eyes uncovered, where they ambush live food (McCall 1992). Diet varies from small crustaceans (Orcutt 1950), barnacle larvae and cladocerans (Barraclough 1967), soft-shell clams and dipteran larvae (Porter 1964), and to a more diverse diet when crustaceans are low in availability (Feyrer 1999). They also take tubeflex worms and *Artemia* in the aquarium (R.C. Reyes 2003–2009, personal communication).

Male starry flounder reach maturity in 2 years (Orcutt 1950), females in 3 years (Orcutt 1950, Smith 1936). This species is valued for both commercial and sport fisheries (Orcutt 1950, Haugen 1992). The species is sold in Asian markets where it is renamed as “Lon-Li,” it makes an excellent seafood platter.

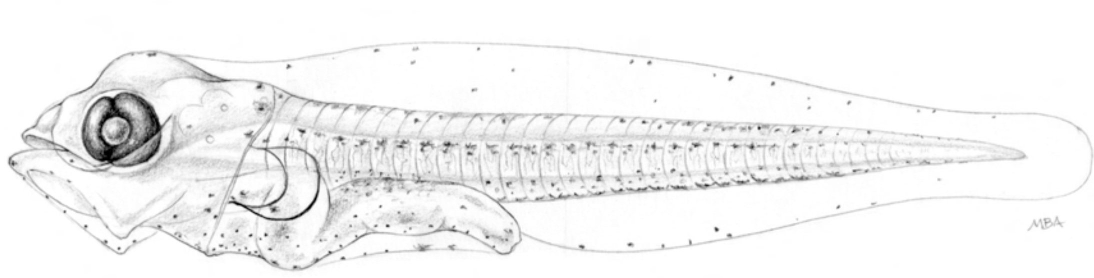

Figure 213.—*Platichthys stellatus*, starry flounder postlarva, 3.7 mm TL (Wang 1986)

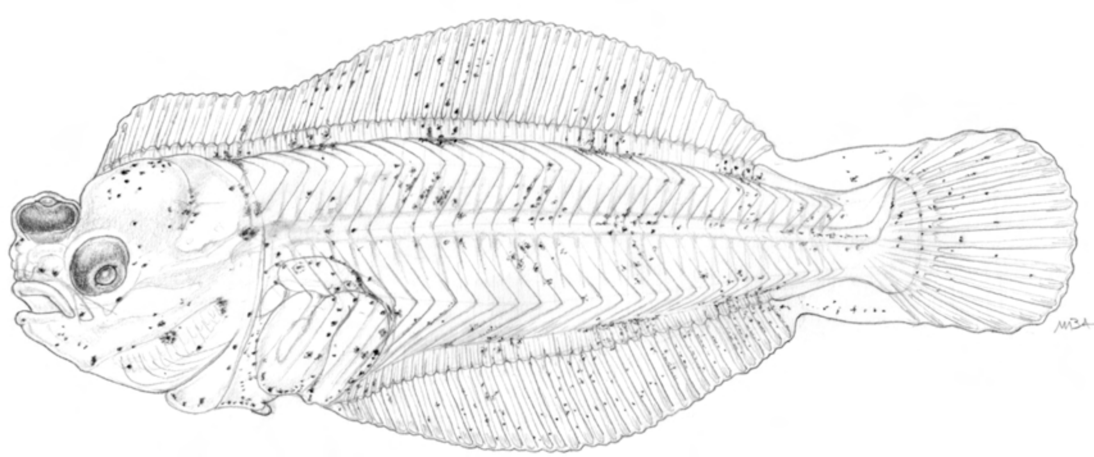

Figure 214.—*Platichthys stellatus*, starry flounder juvenile, 8.5 mm TL (Wang 1986).

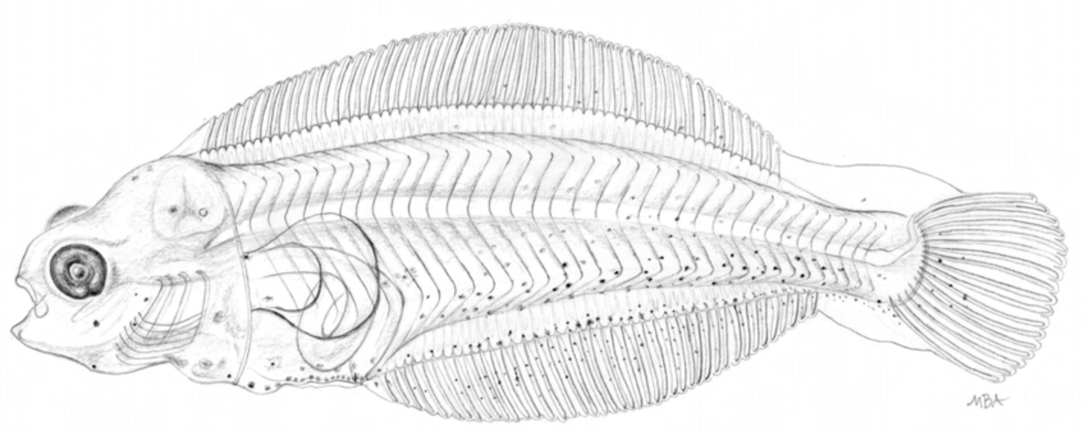

Figure 215.—*Platichthys stellatus*, starry flounder juvenile, 8.5 mm TL (Wang 1986).

Taxonomic Characteristics of English Sole and Starry Flounder

	English sole	**Starry flounder**
Eggs		
Diameter in mm	0.80–1.1	0.88–1.3
Chorion	Smooth to fine striations	Fine striations
Larvae		
Prolarvae (finfold pigmentation)	Dorsal and ventral, scattered	Dorsal and ventral, concentrated
Postlarvae (body pigmentation)	Dorsal and ventral, large melanophores	Dorsal and ventral, small melanophores
Transformation length (mm TL)	≥ ~15.0	≤ ~10.0
Total myomeres	41–44	34–37
Juveniles		
Vertebrae	41–47	34–38
Dorsal fin rays	71–93	52–64
Anal fin rays	52–70	38–47

ACKNOWLEDGMENTS

I would like to thank the following institutions and people for making this study and report possible:

- U.S. Department of Interior, Reclamation, TFCF Improvement Program for financial support. Collections of fish samples used for this report were mainly from the CVP/TFCF and RBRPP.

- CDWR (for additional samples and supporting a larval fish identification and quality control program), CDFG, UC Davis, GGNRA, PG&E, Tenera Environmental, Inc., Stillwater Sciences, Inc., Hanson Environmental, California State University (CSU) Sacramento, and CSU Chico.

- Individual contributors of specimens for the revision include: Lenny Grimaldo, Stephani Spaar, and Tracy Woods (CDWR); Lisa Lynch, Dorothy Platz, Michael Dege, and Kari Ambrosini-Martinelli (CDFG); René C. Reyes, Brent Bridges, Scott Siegfried, Zak Sutphin, Sandy Borthwick, Catherine Karp, and Brandon Wu (Reclamation); Scott Matern, Michael Marchetti, Robert Schroeter, Joan Lindberg, and Bradd Baskerville-Bridges (UC Davis); Andy Rockriver and Steve Slater (CSU Sacramento); Alicia Seesholtz, Gabriel Kopp, and Becky Walther (CSU Chico); Carol Raifsnider and Ernesto Calix (Tenera Environmental, Inc.); Judd Howell (GGNRA); Tom Lambert and Steve Ahern (PG&E); Susan Goodwin and Chris Toole (Ecological Analysts, Inc.); John Pedretti (USFW); Ramona Swenson (UC Berkeley), and Lauren Dusek (Stillwater Sciences, Inc). Diversion workers from the CVP/TFCF aided in specimen collection; scientific publications and other obscure dissertations were provided by Alba Scott, Mid-Pacific Region Librarian (Reclamation); Jean Temple (Reclamation) for word processing.

- Special thanks to René C. Reyes (Reclamation) for much original information on the early life stages and life histories of fishes, for the preparation of illustrations and photographs, and for editing/formatting; Mark Adams, René C. Reyes, and Zak Sutphin for original illustrations; Lloyd Hess, Bradd Baskerville-Bridges, Brent Bridges, Kathleen Baker, Donald E. Portz, and Robert Wallus for technical comments. The author conveys his deepest respect and indebtedness to the late Randy Brown for initiating the project in the early 1980s and for many valuable recommendations on the report's early draft.

- Ron Silva, Joe Pennino, Tony Buelna, Steve Hiebert, Charles Liston, Diana Weigmann, Herb Ng, and Jim Arthur provided funding for research, laboratory facilities, and report reproduction (1986–2009).

GLOSSARY

Abdominal On or pertaining to the belly or abdomen.

Adhesive egg An egg that adheres to a substrate or to another egg.

Adipose fin A fleshy, rayless fin usually located middorsally between the dorsal and caudal fins.

Air bladder A membranous gas-filled sac present in the dorsal portion of the body cavity.

Ammocoete The larval stage of lampreys.

Anadromous species Fishes that inhabit marine waters during juvenile and adult life stages but migrate into freshwater for spawning.

Anterior Situated at or near the front of body.

Anus (vent) The posterior opening of the digestive tract.

Barbel A fleshy, elongated sensory structure located at the corner of the jaws or adjacent to the mouth.

Benthic Living beneath or on the surface of the bottom substrate.

Blastoderm The single-layered germinal cells that lie on top of the yolk in the early developmental stage of an egg and later form an embryo.

Blastula An early embryonic stage of active cleavage characterized by the presence of a blastoderm and a blastocoele.

Catadromous Running downstream. Catadromous fishes aspend most of their lives in freshwater and migrate to the sea to reproduce.

Caudal peduncle The slender portion of the body that is between the anal and caudal fins.

Central Valley The fertile, flat valley dominating the central part of California where the Sacramento-San Joaquin River Delta is located.

Centrarchids Any member of the family Centrarchidae that includes the Sacramento perch and several species of sunfish, black bass, and crappie.

Cephalic Pertaining to the head.

Chorion The outermost semipermeable layer of an egg; also known as egg capsule.

Chorion filament A filamentous structure that grows from the chorion for buoyancy and attachment to other eggs or the substrate.

Chromatophore A pigment cell.

Cleavage Division of the entire egg or the blastomeres during the initial stages of embryonic development.

Clustered eggs Eggs which adhere to one another with the chorion or chorion filaments.

Compressed Laterally constructed or flattened lengthwise.

Ctenoid scale Scales having spines or serrae along the exposed portion.

Cycloid scale Nearly spherical scales having no spines or serrae.

Cyprinid Any member of the carp and minnow family, Cyprinidae.

Delta A tidally influenced body of water comprised of the Sacramento and the San Joaquin Rivers and their tributaries.

Demersal Negatively buoyant or living on or close to the bottom substrate; usually relates to fish species.

Depressed Dorsoventally flattened.

Depth Pertaining to fish, usually indicates the vertical measurement of head, nape, body, or the caudal peduncle areas excluding finfolds.

Detritus Decomposing organic material and debris that include small pieces of dead and decomposing plants and animals.

Dorsal Pertaining to the back or the upper part of the body. Opposite of ventral.

Dorsal finfold The median fold of integument that extends along the middorsum from the cephalic to the caudal regions from which the dorsal fin develops.

Dorsum The back side of a structure (the back).

Dry-water year A year when unimpaired runoff (measured in million acre feet) is low (CDWR's standard and measurement). In the Sacramento River, >5.4 and ≤6.5 million acre feet; in the San Joaquin River, >2.1 and ≤2.5 million acre feet.

E and L sampling Fish eggs and larvae sampling.

Early embryo The embryonic stage in which the embryonic axis and somites are evident.

Early postlarva Stage of larval development when yolk-sac is absorbed and notochord flexion is has occurred.

Epibenthic Living on the surface of the bottom substrate; usually relates to invertebrate species.

Euryhaline Capable of tolerating a wide range of salinities.

Fecundity The number of eggs produced on average by a female of a given size or age.

Fin bud or finbud An undifferentiated fin.

Finfold Median fold of integument that extends middorsally or midventrally from which the median fins develop.

Fin ray The supporting bony elements of fins, including spines and soft rays; can be segmented, unsegmented, or spinous.

Flexion The posterior end of the notochord or later developed vertebral column that bends upwards signaling the initial development of the caudal fin and fin rays.

Fresh water or freshwater Salinities less than 0.3 ppt.

Gastrula An embryonic stage which begins when the caudal edge of the embryonic shield begins to turn inward under the blastoderm and ends when the embryonic axis is evident; the yolk is partially or completely enveloped by the germinal ring during this stage.

Gill rakers Slender rodlike structures projecting into the mouth cavity from the gill arch.

Gill slits Gill openings.

Gonopodium A modified structure of the anterior anal rays of male poeciliid fishes used as an intromittent copulatory organ.

Gravid Having ripe eggs or pregnant.

Gut Digestive tract from the mouth to anus.

Holoblastic cleavage The stage at which the entire egg undergoes division (such as in lampreys).

Incubation period The elapsed time between fertilization and hatching of an egg.

Inferior mouth A mouth located on the ventral side of the snout; upper jaw extends over lower jaw.

Insertion of fin The point at which the last (most posterior) fin ray attaches to the body.

Isthmus The narrow area between the sets of branchiostegal rays across the jugular.

Jugular Related to the throat or throat area.

Juvenile Stage of fish development when median finfold has been completely absorbed, fin development is completed (an adult complement of fin rays and spines is present in all fins), and scales may or may not be completely developed.

Lamella (*pl.* lamellae) A layer or a thin plate.

Late embryo The final phase of embryonic development, characterized by a free tail and a resemblance to yolk-sac larvae.

Late postlarva Stage of larval fish development when flexion and finbuds are almost fully developed.

Lateral line Part of the sensory system extending in two major branches from the cranial nerves to the lateral sides of the body; several small branches extend to the head region.

Lateral plates Thickened, hardened scales located laterally along the body.

Lentic A reference to water, standing or slow moving water such as a pond or a lake.

Major axis of egg or long axis of egg The longest axis of a nonspherical egg.

Mandible Lower jaw.

Maxillary Lateral part of upper jaw or a dermal bone of the upper jaw which lies posterior to the premaxillary. Used interchangeably with maxilla or upper jaw.

Melanophore A black pigment cell.

Meroblastic cleavage Egg cleavage which is restricted to the blastodisc and only the blastoderm forms the embryo.

Mesohaline Salinities ranging from 5.0 to 18.00 ppt.

Micropyle A differentiated area on the surface of the chorion where spermatozoa enter an egg.

Middorsal Pertaining to the middle of the dorsum or back.

Middorsum The area running along the middle of the dorsum or back.

Midventral Pertaining to the middle of the ventral side of a fish's body from anus (vent) to jugular.

Midventrum The area running along the middle of the ventrum or belly.

Minor axis of egg or short axis of egg The shortest diameter of a nonspherical egg.

Morula Embryonic stage which has raspberry-like clusters of blastomeres on top of yolk.

Myomere A single lateral muscular segment on a fish's body, separated from each other by a connective tissue called myoseptum.

Myoseptum (*pl.* myosepta) Partition made of connective tissue separating adjacent myomeres.

Myotomes Blocks of muscles joined together by myosepta.

Nape The area along the middorsum just behind the cephalic region.

Neuston Water column just below the surface.

Newly-hatched prolarvae Fish larvae at 0 dph.

Notochord The longitudinal cartilaginous rod that is eventually replaced by the vertebral column in the body of teleostean fishes.

Oblique Slanted.

Oil globule A clear lipid droplet in the yolk of an egg or fish larva; it is an additional food source and aids in buoyancy of the egg or larva.

Oil globulet Tiny droplets of residual oil in the yolk; may consolidate into an oil globule.

Oligohaline Water with salinity range of 0.3 to 5.0 ppt.

Operculum or opercle A bony flap covering the gills.

Opportunistic spawner A fish that can adapt and spawn on any suitable habitat.

Optical vesicles Embryonic structures that give rise to the eyes.

Origin of the fin The anterior-most point of attachment of a median fin.

Osmerid Any member of the smelt family Osmeridae that includes the delta smelt.

Papillae Fleshy tissue on the lips.

Pelagic In the water column (not necessarily near the surface).

Perivitelline space Vitreous space between the chorion and the yolk.

Pharyngeal teeth Teeth attached to the pharyngeal bone of the throat.

Planktonic Floating or drifting in the water column.

Polyhaline Salinity levels ranging from 18.0 to 30.0 ppt.

Postanal myomeres Myomeres between the posterior margin of the anus (first complete myomere behind the vent) and the most posterior true myoseptum.

Posterior Situated at or behind the body.

Postlarva (larva) The stage of fish development between complete absorption of the yolk and complete differentiation of the fin rays; finfolds retreat or disappear in the same period.

Potamodromous Migrating within lentic and lotic environment of the same salinity.

Preanal myomeres The myomeres between the most anterior myoseptum and the last complete myomere before the center of anus.

Prejuvenile The early life stage of development when most fins and fin rays are fully developed.

Premaxillary The most anterior bone forming the upper jaw.

Prolarva (yolk-sac larva) The stage of fish development in which a larva has not yet absorbed the yolk.

Reclamation Term used for U.S. Bureau of Reclamation.

Ripe fish Fishes with free-flowing milt or eggs evident upon gentle abdominal squeezing.

Sea water Salinity levels greater than 30.0 ppt.

Snout The region of head measured from the anterior margin of eye to most anterior margin of head.

Snout to anus length Distance from the tip of the snout to the posterior margin of the anus. Also called preanal length.

South Delta The southern region of the Sacramento-San Joaquin Delta where the state (SWP) and federal (CVP) water diversion projects are located.

Spawning Release or deposition of spermatozoa or ova. Also, a fish reproduction process characterized by females and males depositing eggs and sperm into the water simultaneously or in succession in order to fertilize the eggs.

Spine An unsegmented, unbranched, uniserial rigid ray in a fish fin.

Stellate Pertaining to an expanded star-shape of a melanophore.

Subterminal mouth Mouth position located ventrally, is near but not at the end of the snout.

Superior mouth Mouth position located on the dorsal side of the snout; lower jaw extends beyond upper jaw.

Terminal mouth Jaws meet at the tip of the snout.

Thoracic Posterior to the throat area.

Trunk The body between the nape (behind the head) and anus.

Tubercles Temporary epidermal projections on head, body, or fins of male fish (and some females) that facilitate contact with females (or each other) during spawning or also used for defense of territories.

Upriver The upper portion of the Sacramento River starting from the City of Sacramento and upstream.

Urogenital opening The common opening of both excretory and reproductive systems; always posterior to the anus.

Urostyle Rod like bone consisting of a number of fused vertebrae at the posterior tip of the notochord, usually bending upward.

Ventral Pertaining to the underside or lower part of the fish. Opposite of dorsal.

Ventral finfold The median finfold on the ventral side of the body; separated by the anus into the preanal finfold and postanal finfold.

Viviparous (live-bearing) Eggs are fertilized internally, and embryos are nourished through a placenta or placenta-like structure within the female's oviduct; young hatch internally and are released as juveniles.

Water hardening A process after fertilization of an egg in which the chorion expands because of absorption of water into the perivitelline space.

Water year A hydrologic classification of a year based on unimpaired runoffs and used as an index. A water year begins on October 1 and ends on September 30 of the following year (*source*: CDWR).

Weberian ossicles Modified anterior vertebrae joining the ear with the air bladder.

Wet-water year A year when unimpaired runoff (measured in million acre-feet) is high. In the Sacramento River, ≥9.2 million acre-feet; in the San Joaquin River, ≥3.8 million acre-feet. Unimpaired runoff represents the natural water production of a river basin, unaltered by diversions, storage, or water exports (*source*: CDWR).

Width of the perivitelline space The distance between the yolk and the chorion.

Yolk Nutritive material of an ovum stored for the nutrition of an embryo; it is the source of basic nutrients for the egg and larva prior to the development of digestive tract and the ability to ingest food.

Yolk-sac larva See Prolarva.

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Appendix 1

List of Reference Specimens for Information of Species Accounts

The following is a list of major studies on fish early life histories and identification/ quality control (ID/QC) programs conducted by the author during the period 1986 and 2009. Other individuals, public agencies, and private institutions that contributed information or data to the study are also listed.

1986

1. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
2. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E) on upper Millerton Lake.

1987

1. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
2. Reclamation (Jim Arthur), ID/QC of fish eggs and larvae collected from Bryte to Delta Cross Channel, Sacramento River.
3. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E).

1988

1. CDFG, ID/QC of fish eggs and larvae (E and L program for striped bass) sampling program in the Delta.
2. Tenera Environmental, Inc, ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
3. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E).

1989

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. CDFG, ID/QC of San Francisco Bay fish eggs and larvae sampling program. Final year of fish egg and larvae sampling San Pablo Bay or San Francisco Bay (central and south).
3. Reclamation's CVP/TFCF, ID/QC of all osmerid specimens from the 10-minute fish collection (conducted every 2 hours to estimate fish salvage).
4. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
5. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E).

1990

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.

3. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
4. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E).

1991

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. Reclamation (Steve Hiebert), ID/QC of fish eggs and larvae collected from CVP/TFCF intake.
3. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.
4. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.
5. National Environmental Services, ID/QC of fish eggs and larvae collected at tail race of Kerckhoff 2 Hydroelectric Powerplant (PG&E). Final year of sampling.
6. CDWR (Stephani Spaar), sorting and ID/QC of fish eggs and larvae from central and south Delta.

1992

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. CDWR (Stephani Spaar), sorting and ID/QC of fish eggs and larvae from central and south Delta.
3. Reclamation (Steve Hiebert), ID/QC of fish eggs and larvae collected from CVP/TFCF intake.
4. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.
5. CDWR (Tracy Woods), sorting and ID/QC of Delta agriculture drainage fishery sampling program.
6. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants.

1993

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. CDWR (Stephani Spaar), sorting and ID/QC of fish eggs and larvae collected in the central and south Delta.
3. CDWR, sorting and ID/QC of North Bay Aqueduct (NBA) egg and larval survey.
4. CVP/TFCF, ID/QC of all osmerid specimens from 10-min fish collection.
5. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from entrainment samples at the intakes of Pittsburg and Contra Costa Powerplants. Final year of sampling.

1994

1. CDFG, ID/QC of fish E and L sampling program in the Delta.
2. CDWR (Stephani Spaar), ID/QC of fish eggs and larvae collected from central and south Delta.
3. CDWR, sorting and ID/QC of NBA egg and larval survey.

4. UC Davis (Scott Matern), ID/QC (mainly on cyprinids and osmerids) of fish eggs and larvae from Suisun Marsh Study.
5. CDWR (Tracy Woods), sorting and ID/QC of fish eggs, larvae, and juveniles from Delta agricultural drain sampling program.
6. Reclamation (Scott Siegfried), ID/QC of fish eggs and larvae collected from CVP/TFCF intake.
7. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.
8. CDWR (Katey Wadsworth), sorting and ID/QC of Clifton Court Forebay special study on fishery program.
9. CDFG (Lisa Lynch), ID/QC of eggs and larvae from Folsom Lake.
10. Hanson Environmental, ID/QC of delta smelt special townet survey in the Delta and Sacramento River.

1995

1. CDFG, ID/QC of fish E and L sampling program in the Delta. Final year of sampling for striped bass E and L.
2. CDWR (Stephani Spaar), sorting and ID/QC of fish eggs and larvae from central and south Delta.
3. CDFG, ID/QC of NBA egg and larval survey. Fish and Game took over the program from CDWR.
4. CDFG (Michael Dege), ID/QC of a portion of the specimens collected from Napa River Fish survey and 20-mm delta smelt survey.
5. CDWR (Tracy Woods), sorting and ID/QC of Delta agricultural drain fishery sampling program.
6. CDFG (Randy Baxter), ID/QC of a portion of splittail specimens collected from Sacramento River.
7. UC Davis (Ramona Swenson), tidewater goby eggs.
8. UC Davis (Scott Matern), ID/QC of a portion of egg and larval specimens from Suisun Marsh Study.
9. Reclamation (Lloyd Hess and Cathy Karp), sorting and ID/QC of San Luis Reservoir fishery collections.
10. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.
11. Reclamation (Scott Siegfried), ID/QC of fish larvae collected from Arroyo Mocho Creek.

1996

1. CDFG, ID/QC of NBA egg and larval survey.
2. UC Davis (Scott Matern), ID/QC of a portion of egg and larval samples from Suisun Marsh.
3. CDFG, ID/QC of light trap samples from Sutter Bypass.
4. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier.
5. CDFG (Michael Dege), ID/QC of a portion of sample from Napa River 20-mm fish survey.
6. Reclamation (Sandy Borthwick), ID/QC of Red Bluff Research Pumping Plant fish entrainment sampling program.

7. CDFG (Andy Rockriver), ID/QC of fish eggs and larvae collected at Lodi Municipal Lake, Cosumnes River, and Putah Creek.
8. CDFG (Lisa Lynch), ID/QC of wakasagi eggs and larvae from Folsom Lake.
9. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.
10. Reclamation (Scott Siegfried), ID/QC of fish larvae from Arroyo Mocho Creek.
11. Reclamation (Scott Siegfried and Don Faris), ID/QC of specimens from Cottonwood Creek.

1997

1. CDFG, ID/QC of NBA egg and larval survey.
2. UC Davis (Scott Matern), ID/QC of a portion of egg and larval samples from Suisun Marsh Study.
3. CDWR (Lenny Grimaldo), ID/QC of specimens from Shallow Water Survey (SWS).
4. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier.
5. UC Davis (Michael Marchetti), ID/QC of fish eggs and larvae from Putah Creek and Lagoon Valley State Park.
6. CDFG (Lisa Lynch), ID/QC of wakasagi eggs and larvae from Folsom Lake.
7. CDFG (Andy Rockriver), ID/QC of fish eggs and larvae from Lodi Municipal Lake, Cosumnes River, and Putah Creek.
8. CDFG (Michael Dege), ID/QC of a portion of sample from Napa River 20-mm fish survey.
9. CVP/TFCF, ID/QC of all osmerid specimens from 10-minute fish collection.

1998

1. CDFG, ID/QC of NBA egg and larval survey.
2. UC Davis (Scott Matern), ID/QC of a portion of fish egg and larval samples from Suisun Marsh Study.
3. CDFG (Andy Rockriver), ID/QC of fish eggs and larvae collected from Lodi Municipal Lake, Cosumnes River, and Putah Creek.
4. UC Davis (Michael Marchetti), ID/QC of fish eggs and larvae from Putah Creek.
5. UC Davis (Bill Bennett), ID/QC of fish eggs and larvae from the Sacramento-San Joaquin estuary entrapment zone.
6. CDFG, ID/QC of fish eggs and larvae from Sutter Bypass.
7. CDWR (Lenny Grimaldo), ID/QC of fish larvae from Yolo Bypass zooplankton sampling program.
8. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier. Reclamation (Sandy Borthwick), ID/QC of eggs and larvae from Red Bluff Research Pumping Plant.
9. CDFG (Michael Dege), ID/QC of a portion of samples from Napa River 20-mm fish survey.
10. CDWR (Lenny Grimaldo), ID/QC of SWS, Liberty Island, Prospect Island fishery sampling.
11. CVP/TFCF, ID/QC of all fish species from 10-minute fish collection. Author stationed full-time at the CVP/TFCF.
12. Reclamation (Brent Bridges), ID/QC of samples from Lagoon Valley Regional Park.

1999

1. CDFG, ID/QC of NBA egg and larval survey.
2. UC Davis (Robert Schroeter), ID/QC of fish egg and larval samples from Suisun Marsh Study.
3. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier.
4. CDFG, ID/QC of a portion of light trap sample from real-time-monitoring (RTM) program.
5. CDFG, ID/QC of fish eggs and larvae from Sutter Bypass.
6. CDWR (Lenny Grimaldo), ID/QC of beach seine and light trap samples from SWS. CDWR (Lenny Grimaldo), ID/QC of fish larvae from Yolo Bypass zooplankton sampling program.
7. CDFG (Lisa Lynch), ID/QC of wakasagi eggs and larvae from Folsom Lake.
8. CDWR (Katie Wadsworth), ID/QC of fish eggs and larvae from Clifton Court Forebay.
9. CVP/TFCF, ID/QC of all fish species from 10-minute fish collection.
10. Reclamation (Sandy Borthwick), ID/QC of fish eggs and larvae from Red Bluff Research Pumping Plant.
11. CDFG (Michael Dege), ID/QC (mostly cyprinids and centrarchids) of Napa River 20-mm fish survey.
12. Reclamation (Brent Bridges), delta smelt artificial fertilization experiments.
13. CVP/TFCF, laboratory observations of reproductive behavior and early life stages of shimofuri goby.
14. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae from Clifton Court Forebay.

2000

1. CDFG, ID/QC of NBA egg and larval survey.
2. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier.
3. UC Davis (Robert Schroeter), ID/QC of fish eggs and larvae from Suisun Marsh.
4. CDWR, ID/QC of fyke net samples from Sherman Island and Horseshoe Cove.
5. CDFG, ID/QC of a portion of samples from Napa River 20-mm fish survey.
6. CDWR/SWP, ID/QC of all osmerids (a portion of the sample) from 10-minute fish collection.
7. Reclamation (Brent Bridges), ID/QC of wakasagi specimens from San Luis Reservoir.
8. Reclamation (Brent Bridges), artificial fertilization of wakasagi (brood stock collected from San Luis Reservoir) and monitoring of their early development and behavior.
9. CVP/TFCF, ID/QC of all fish species from 10-minute fish collection with special attention to osmerid early life stages.
10. Stillwater Sciences, Inc., ID/QC of osmerid larval and juvenile specimens collected from upper Napa River.
11. CVP/TFCF, laboratory observations of shimofuri goby reproductive behavior.
12. Reclamation (Brent Bridges), ID/QC of fish specimens from Lagoon Valley Regional Park.

2001

1. CDFG, ID/QC of NBA egg and larval survey.
2. CDFG (Mike Healey), ID/QC of fish eggs and larvae from Old River barrier.
3. CDFG (Michael Dege), ID/QC of osmerids and gobiids from 20-mm delta smelt survey.
4. CDFG (Lisa Lynch), ID/QC of fish larvae from east San Pablo Bay.
5. UC Davis (Robert Schroeter), ID/QC of fish eggs and larvae from Suisun Marsh.
6. Reclamation (Brent Bridges), ID/QC of wakasagi specimens from San Luis Reservoir.
7. Reclamation (Brent Bridges), experiments on artificial fertilization of wakasagi (brood stock from San Luis Reservoir).
8. CVP/TFCF, ID/QC of all fishes from 10-minute fish collection, with special attention to osmerid sexual maturity.
9. CVP/TFCF, laboratory observations of reproductive behavior of shimofuri goby.
10. Stillwater Sciences, Inc., ID/QC of osmerid larvae and juveniles collected in the upper Napa River. Final year of fish eggs and larvae sampling.
11. Reclamation (with Brent Bridges), ID/QC of fish specimens from Lagoon Valley Regional Park.
12. UC Davis (Patrick Crain), ID verification of fish larvae collected from Cosumnes River Preserve.

2002

1. CDFG, ID/QC of NBA egg and larval survey.
2. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae from Clifton Court Forebay.
3. CSU Chico (Michael Marchetti and Gabriel Kopp), ID/QC of fish larvae from Mud Creek.
4. CVP/TFCF, ID/QC of all fishes from 10-minute fish collection, with special attention to sexual maturity of delta smelt collected in winter months prior to spawning.
5. Reclamation and Fish Conservation and Culture Laboratory (FCCL), hormone-induced artificial fertilization of splittail (eggs obtained from Brent Bridges), observations of their early life stage development and behavior.
6. CVP/TFCF, laboratory observations of shimofuri goby social and reproductive behavior in crowded conditions.
7. UC Davis (Robert Schroeter), ID/QC of fish eggs and larvae from Suisun Marsh. Final year of sampling.
8. CDFG (Michael Dege), ID/QC of a portion of sample from Napa River 20-mm fish survey.
9. Reclamation (Brent Bridges), ID/QC of specimens from Lagoon Valley Regional Park.
10. Reclamation (René C. Reyes), observations of early life stage development of western mosquitofish and common carp, light trap collections from the CVP/TFCF's abandoned intake canal (lagoon) and vicinity of the TFCF,.

2003

1. CVP/TFCF, ID/QC of fishes from 10-minute collection, monitoring of sexual maturity of delta smelt and splittail.
2. CDFG, ID/QC of osmerids and cyprinids from NBA egg and larval survey.
3. Reclamation and FCCL (Brent Bridges and Bradd Baskerville-Bridges) observations of splittail egg and larval development and behavior (eggs from hormone-induced fertilization of splittail).
4. Reclamation (René C. Reyes and Zak Sutphin), fish eggs and larvae sampling at Lagoon Valley Regional Park.
5. CVP/TFCF, laboratory observations of shimofuri goby social and reproductive behavior. Shimofuri observations terminated in February.
6. Reclamation (Cathy Karp), light trap sampling at CVP/TFCF intake canal.
7. Reclamation (René C. Reyes and Zak Sutphin), ID/QC of fish eggs and larvae from New Melones Reservoir, Cosumnes River Preserve, and Stony Creek.
8. Tenera Environmental, Inc., fish eggs, larvae, and juveniles sampling at Contra Costa Water District (CCWD) intakes.
9. CSU Chico (Michael Marchetti and Gabriel Kopp), ID/QC of larval fish from Mud Creek.
10. Reclamation (René C. Reyes) and CDFG (Nick Cuevas), ID/QC of fishes from Walnut Creek and its tributaries.
11. Reclamation (René C. Reyes), laboratory spawning of threespine stickleback and observations of its early life stages.
12. Reclamation (René C. Reyes), laboratory observations of Chinook salmon and steelhead early life stages (eggs provided by CDFG's Nimbus Hatchery).
13. Reclamation (René C. Reyes and Zak Sutphin), laboratory observations of inland silverside, bluegill, redear sunfish, largemouth bass, and threadfin shad early life stages (eggs obtained from Contra Loma Reservoir and the CVP/TFCF's abandoned intake canal).
14. Reclamation (René C. Reyes), laboratory spawning of California roach, Sacramento perch, prickly sculpin, Sacramento blackfish, red shiner, and fathead minnow and observations of their early life stages.
15. Reclamation (René C. Reyes and Richard Corwin), sampling of hardhead and hitch from Stony Creek.
16. Reclamation (René C. Reyes and Zak Sutphin), hormone-induced spawning of golden shiner and observations of its early life stages.

2004

1. CVP/TFCF, ID/QC of all fish species collected from 10-minute collection, with special attention to relative abundance of larval and juvenile fishes.
2. Reclamation and FCCL, artificial fertilization of splittail (brood stock from Bradd Baskerville-Bridges and Brent Bridges) and observations of early development with emphasis on larval behavior after hatching.
3. CDWR (Alicia Seesholtz), ID/QC of fish larvae from Feather River.
4. CDFG, ID/QC of osmerids and cyprinids from NBA egg and larval survey. Final year of fish eggs and larvae sampling.

5. Reclamation (René C. Reyes), ID/QC of fish eggs and larvae from American River.
6. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae collected in the Delta.
7. Reclamation (René C. Reyes and Zak Sutphin), fish eggs and larvae sampling at Lagoon Valley Regional Park.
8. Reclamation (René C. Reyes and Zak Sutphin), fish eggs and larvae sampling at Marsh Creek.
9. Reclamation (René C. Reyes), ID/QC of light trap collections from the CVP/TFCF's abandoned intake canal (lagoon) and the intake canal.
10. Reclamation (René C. Reyes and Zak Sutphin), ID/QC of fish eggs and larvae from Clear Lake (Lake County) and its tributaries and Cosumnes River Preserve.
11. CSU Chico (Gabriel Kopp, Master thesis work), ID/QC of larvae from Big Chico Creek, Little Chico Creek, and Mud Creek.
12. Reclamation (René C. Reyes and Zak Sutphin), American shad eggs and larvae sampling of Feather River by Shanghai Bend.
13. Tenera Environmental, Inc., fish eggs, larvae and juveniles sampling at CCWD intakes.
14. Reclamation (René C. Reyes) and CDFG (Nick Cuevas), ID/QC of specimens from Walnut Creek.
15. Reclamation (René C. Reyes and Zak Sutphin), ID/QC of specimens from Putah Creek.
16. Reclamation (René C. Reyes), laboratory spawning of red shiner and fathead minnow and observations of their early life stages.
17. Reclamation (René C. Reyes), observations of Sacramento sucker, Sacramento blackfish, and Sacramento pikeminnow early life stages.
18. Reclamation (René C. Reyes), observations of green sturgeon egg and larval development (eggs obtained from UC Davis Animal Sciences Department's Joel VanEeenennam).
19. Reclamation (René C. Reyes), observations of white sturgeon egg and larval development (eggs obtained from Stolts Sea Farm, Galt, California).
20. Reclamation (René C. Reyes and Zak Sutphin), ID/QC of jacksmelt and Pacific herring eggs and larvae from Blackie's Point, Marin County.
21. Reclamation (René C. Reyes), laboratory spawning of shokihaze goby.

2005

1. CVP/TFCF, ID/QC of all fish species from 10-minute collection.
2. CDFG, ID/QC of Delta Smelt Larvae Survey (DSLS), a pilot study for determining distribution of delta smelt larvae.
3. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae collected in the Delta.
4. Reclamation (René C. Reyes), ID/QC of fish eggs and larvae of Clear Creek, Tehama County.
5. Reclamation (René C. Reyes), observations of bluegill, largemouth bass, and redear sunfish early life stages collected from the CVP/TFCF's abandoned intake canal (lagoon).
6. Tenera Environmental, Inc., ID/QC of fish eggs and larvae sampling program at CCWD intake canal.

7. CVP/TFCF, identifying sexual maturity of delta smelt at CVP/TFCF as part of pelagic organism decline (POD) monitoring in the Delta.
8. Reclamation (René C. Reyes), observations of early development and feeding of Sacramento perch larvae (larval fish obtained from Chris Miller/Contra Costa Mosquito and Vector Division).
9. Reclamation (René C. Reyes), observations of warmouth and green sunfish laboratory spawning and their early life stages.
10. Reclamation (René C. Reyes), observations of Pacific lamprey egg development and early life stages (eggs from American River provided by Reclamation's John Hannon and Brian Deason).
11. Reclamation (René C. Reyes), observations of inland silverside egg and larval development (eggs provided by FCCL's Andy Sutphin).
12. Reclamation (René C. Reyes and Brandon Wu), ID/QC of specimens from Walnut Creek and its tributaries.
13. Reclamation (René C. Reyes and Zak Sutphin), threadfin shad egg collection from Contra Loma Reservoir.

2006

1. CVP/TFCF, ID/QC of all fish species from 10-minute collection.
2. CDFG, ID/QC of osmerids from DSLS.
3. Hanson Environmental, ID/QC of larval fish from the vicinity of Pittsburg and Contra Costa Power Plant intakes.
4. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from CCWD intakes.
5. Reclamation (René C. Reyes), observations of white sturgeon eggs and larvae (eggs provided by Stolts Sea Farm, Galt, California).
6. Reclamation (René C. Reyes), ID/QC of fish eggs and larvae from CVP/TFCF's intake canal and abandoned intake canal (lagoon).
7. Reclamation (René C. Reyes), Sacramento perch feeding experiment.
8. Reclamation (Bradd Baskerville-Bridges), ID/QC of eggs from yellowfin goby breeding experiment.
9. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae in the Delta.
10. CDFG, Napa River 20-mm fish survey (information obtained from Michael Dege).
11. Reclamation (René C. Reyes), laboratory spawning of green sunfish and observations of its early life stages.
12. Reclamation (René C. Reyes and Brandon Wu), observations of white catfish eggs and larvae from Discovery Bay, California.
13. Reclamation (René C. Reyes), observations of golden trout eggs and larvae (eggs provided by Vern Carr of Hot Creek Fish Hatchery, Mammoth Lakes, California).

2007

1. CVP/TFCF, ID/QC of all fish species from 10-minute collection.
2. CDWR (Lenny Grimaldo), ID/QC of fish eggs and larvae from Sacramento River Deep Water Ship Channel.
3. Tenera Environmental, Inc., ID/QC of fish eggs and larvae from CCWD intakes.

4. Reclamation (René C. Reyes), Shokihaze goby breeding and feeding experiments at CVP/TFCF laboratory.
5. Reclamation (René C. Reyes), observations of bigscale logperch spawning and its early life stages.
6. Reclamation (René C. Reyes), observations of striped bass eggs and larvae (eggs provided by Dr. David Ostrach of UC Davis' Pathobiology, Conservation and Population Biology Laboratory, John Muir Institute of the Environment).
7. Reclamation (René C. Reyes), observations of goldfish eggs and larvae.
8. Reclamation (René C. Reyes), spawning observation of rainwater killifish in laboratory environment.
9. Reclamation (René C. Reyes), observations of kokanee salmon and cutthroat trout eggs and larvae (eggs provided by Don Ward and Michael Harris of the American River Hatchery).
10. CSU Chico (Rebecca Walther), ID/QC of fish eggs and larvae from Mud Creek, Chico.
11. CDFG, ID/QC of osmerids from DSLS collection (with René C. Reyes).

2008

1. CVP/TFCF, ID/QC of all fish species from 10-minute collection.
2. CSU Chico (Rebecca Walther) and Reclamation (René C. Reyes), ID/QC of fish eggs and larvae from Mud Creek, Chico.
3. ID/QC of osmerid larvae at the CVP/TFCF and SWP as part of POD monitoring (with René C. Reyes).
4. Tenera Environmental, Inc., ID/QC of fish entrainment and impingement projects in the Delta.
5. Reclamation (René C. Reyes), observations of rainwater killifish, yellowfin goby, white catfish, and black bullhead eggs and larvae.
6. Hanson Environmental, ID/QC of fish larvae and juveniles collected from Mayberry Confluence in the Delta.
7. ID/QC of fish eggs and larvae collected by USFWS from upper Sacramento River (with René C. Reyes).

2009

1. FCCL (Luke Ellison and Galen Tigan), observations of longfin smelt eggs and larvae.
2. ID/QC of osmerid larvae at the CVP/TFCF and SWP as part of POD monitoring (with René C. Reyes).
3. CDFG (Jerry Morinaka), ID/QC of delta smelt and longfin smelt larvae and juveniles from SWP.
4. Tenera Environmental, Inc., ID/QC of fish entrainment and impingement projects in the Delta.
5. Reclamation (René C. Reyes and Brandon Wu), American shad egg collection from the American River below Nimbus Dam.
6. CDWR, ID/QC of fish eggs and larvae collected in lower Sacramento River from Sutter Bypass to Sherman Island.

Appendix 2

List of Acronyms and Abbreviations

List of Acronyms and Abbreviations

A Anal fin.

CCWD Contra Costa Water District.

CDFG California Department of Fish and Game.

CVP/TFCF Central Valley Project/Tracy Fish Collection Facility.

D Dorsal fin.

D Day.

dph Days post hatch or the number of days after the egg hatched. The day of hatching is counted as 0 dph.

DSLS Delta Smelt Larvae Survey (conducted by the California Department of Fish and Game).

CCMVCD Contra Costa Mosquito and Vector Control District.

CDWR California Department of Water Resources.

FCCL Fish Conservation and Culture Laboratory (associated with UC Davis and located at the Skinner Delta Fish Protective Facility in Byron, California).

GGNRA. Golden Gate National Recreation Area.

IEP Interagency Ecological Program. The program is comprised of several resource agencies that provide information on the factors that affect ecological resources in the Sacramento-San Joaquin Estuary for better management of the estuary.

NBA North Bay Aqueduct Project or North Bay fish E and L Survey.

PAL Preanal length. The distance from the tip of snout to the anus.

PG&E Pacific Gas and Electric.

POD Pelagic Organism Decline.

Ppt Parts per thousand (in reference to water salinity).

RBRPP Red Bluff Research Pumping Plant (operated by Reclamation located at Red Bluff, California).

SDFPF Skinner Delta Fish Protective Facility (operated by the State Water Project).

SL Standard length. The distance from the tip of the snout to the base of the urostyle.

SWP State Water Project.

SWS Shallow Water Survey.

TFCF Tracy Fish Collection Facility (operated by the Central Valley Project).

TL Total length. The distance from the tip of the snout to the tip of the caudal fin.

UC Davis University of California, Davis.

USFWS U.S. Fish and Wildlife Service.

YOY Young-of-the-year.

Appendix 3

List of Fish Species with Early Life Stage Images

List of fish species with early life stage images.

Common name	Genus and species	Family
Pacific lamprey	*Entosphenus tridentatus*	Petromyzontidae
Green sturgeon	*Acipenser medirostris*	Acipenseridae
White sturgeon	*Acipenser transmontanus*	Acipenseridae
American shad	*Alosa sapidissima*	Clupeidae
Pacific herring	*Clupea pallasii*	Clupeidae
Threadfin shad	*Dorosoma petenense*	Clupeidae
Goldfish	*Carassius auratus*[1]	Cyprinidae
Red shiner	*Cyprinella lutrensis*[1]	Cyprinidae
Common carp	*Cyprinus carpio*[1]	Cyprinidae
California roach	*Hesperoleucus symmetricus*[1]	Cyprinidae
Hitch	*Lavinia exilicauda*[1]	Cyprinidae
Hardhead	*Mylophardon conocephalus*[1]	Cyprinidae
Golden shiner	*Notemigonus crysoleucas*[1]	Cyprinidae
Sacramento blackfish	*Orthodon microlepidus*[1]	Cyprinidae
Fathead minnow	*Pimephales promelas*[1]	Cyprinidae
Splittail	*Pogonichthys macrolepidotus*[1]	Cyprinidae
Sacramento pikeminnow	*Ptychocheilus grandis*[1]	Cyprinidae
Sacramento sucker	*Catostomus occidentalis*	Catostomidae
White catfish	*Ameiurus catus*	Ictaluridae
Black bullhead	*Ameiurus melas*	Ictaluridae
Channel catfish	*Ictalurus punctatus*	Ictaluridae
Wakasagi	*Hypomesus nipponensis*[2]	Osmeridae
Surf smelt	*Hypomesus pretiosus*[2]	Osmeridae
Delta smelt	*Hypomesus transpacificus*[2]	Osmeridae
Longfin smelt	*Spirinchus thaleichthys*[2]	Osmeridae
Rainbow trout/Steelhead	*Oncorhynchus mykiss*	Salmonidae
Chinook salmon	*Oncorhynchus tshawytscha*	Salmonidae
Inland silverside	*Menidia beryllina*	Atherinopsidae
Rainwater killifish	*Lucania parva*	Fundulidae
Western mosquitofish	*Gambusia affinis*	Poecilidae
Threespine stickleback	*Gasterosteus aculeatus*	Gasterosteidae
Prickly sculpin	*Cottus asper*	Cottidae
Striped bass	*Morone saxatilis*	Moronidae
Sacramento perch	*Archoplites interruptus*[3]	Centrarchidae
Green sunfish	*Lepomis cyanellus*[3]	Centrarchidae
Pumpkinseed	*Lepomis gibbosus*[3]	Centrarchidae
Warmouth	*Lepomis gulosus*[3]	Centrarchidae
Bluegill	*Lepomis macrochirus*[3]	Centrarchidae
Redear sunfish	*Lepomis microlophus*[3]	Centrarchidae
Largemouth bass	*Micropterus salmoides*[3]	Centrarchidae
Black crappie	*Pomoxis nigromaculatus*[3]	Centrarchidae
Bigscale logperch	*Percina macrolepida*	Percidae
Yellowfin goby	*Acanthogobius flavimanus*	Gobiidae
Shimofuri goby	*Tridentiger bifasciatus*	Gobiidae
Shokihaze goby	*Tridentiger barbatus*	Gobiidae

[1]**Tracy Fish Facility Studies, Volume 32**–Early Life Stages and Life Histories of Cyprinid Fish in the Sacramento-San Joaquin Delta, California: with Emphasis on Spawning by Splittail, *Pogonichthys macrolepidotus.*

[2]**Tracy Fish Facility Studies, Volume 38**–Spawning, Early Life Stages, and Early Life Histories of the Osmerids Found in the Sacramento-San Joaquin Delta of California.

[3]**Tracy Fish Facility Studies, Volume 42**–Early Life Stages and Life Histories of Centrarchids in the Sacramento-San Joaquin River Delta System, California.

Appendix 4

Shimofuri Goby Social and Spawning Behaviors

OBSERVATIONS OF SOCIAL BEHAVIOR DURING SPAWNING SEASON

Gobies exhibit many aspects of social behavior related to reproduction (Brothers 1975). Spawning characteristics and behavior of shimofuri goby in the laboratory were observed and evaluated at the CVP/TFCF. Their spawning behavior is intricate, therefore, detailed notes and observations were gathered from 1999–2003 and are reported below. The information is divided into three sections: A) Sexual Dimorphism, B) Summary of Laboratory Notes and Observations (1999–2003), and C) Conclusion and Comments.

A. Sexual Dimorphism

Males

Shimofuri goby can reach maturity at 60 mm TL. Males exhibit very colorful bodies and fins. The head is flat and triangular (rattlesnake-like head shape), the eye is almost on the top of the head, and the operculum is widely expanded. Viewed from the front, the male looks falsely larger than its real size. The head region is dark gray with many tiny white spots. The body is also dark with a series of large white spots just below the lateral line region. The body's horizontal stripes can change to vertical bars to having no bars or stripes in just a few seconds. The pectoral fin has three distinguished colors, a vertical black band at the base, then a white band, and then the gray fin rays. Edge of the pectoral fin (on fin membranes) can also be white. The dorsal fins have orange-red color at the top and a darker horizontal band below. The anal fin is usually similarly colored although some individuals have anal fins with a yellow border (R.C. Reyes 2003–2009, personal communication). Two large dark spots are located at the base of caudal fin. Color of the round caudal fin is deep dark. The abdominal region can be whitish in color. Overall, males during the spawning season are dark and colorful with red and white mixture but can turn pale when disturbed. Males can reach maturity in a laboratory environment in about 6–7 months. Some males may delay their maturity until the following year. These males achieve lengths of about 100 mm TL, resemble oversized females, and have smaller heads. Larger, active males exhibit brilliant colors and often mate first.

Females

Shimofuri goby females can reach maturity at 45–50 mm TL. They have a small blunt head with body color ranging from pale gray to pale-green and a whitish abdomen. Two distinctive dark bands are horizontally laid out along the light gray colored body: one midlaterally and another near the dorsum. Two dark spots are located at the base of the caudal fin. All fins are pale gray in color. Females can change colors quickly during mating. Typically, when mating, they are dark, reverting back to pale gray seconds after mating.

B. Summary of Laboratory Notes and Observations (1999–2003)

1999–2000

In 1999, four adult shimofuri goby (two males, two females), collected from the CVP/TFCF in February and April, were placed in a 20-gal freshwater aquarium. Water temperature was set at 23°C, but fluctuated between 20–25°C. Gobies are cavity nesters (Moyle and Cech 1996); therefore, two ceramic coffee cups were set on the bottom. One large male (~90 mm TL) immediately chose one of the cups. Subsequently, the smaller male occupied the other cup. The females stayed on the sand-gravel bottom or adhered to the glass aquarium wall. When the cups were replaced with transparent glass cups, none of the gobies showed interest. When both males were removed and the ceramic cups replaced, both females used the cups periodically. When both males were released back to the aquarium, they exhibited dark coloration with white and red colorful patterns. Similar to observations by Matern (1999), the males frequently cleaned the inner surface of the cup. When a male passes by another male's occupied cup, the male in the cup chases the intruding male a short distance and then quickly returns to his cup. However, when a female passes by, the male remains at the rim of the cup and makes several jerky movements without leaving the cup. With mouth wide open and operculum flared, the male seems to be making a mating call. When the female is ready to spawn, she swims into the cup directly. Initially during courtship, no eggs are deposited in the cup.

Spawning was divided into several sessions. Paired fishes exhibit a very complex body language and interaction, the most common side-by-side position, an upside-down position (eggs deposited on the ceiling of the cup), a pressing and squeezing position (eggs deposited at the bottom of the cup), and a tail to head position. During each quivering movement of the body, the female deposits a small number of eggs that the male immediately fertilizes. One or both fish use their pelvic fins (suction cup) to guide the eggs' deposition in a single line into a single layer in the cup. Depending on the fecundity of the individual female, egg mass is attached as a single layer on one side or on the entire surface area of the cup. Individual eggs are attached to a common mat secreted by the male. Some eggs form small groups attached to a common mat. On rare occasions, a single egg is attached directly to the substrate. Once a female discharges all her eggs, she leaves the cup and is not allowed to return. The male tends the nest and guards the eggs until they hatch. He constantly fans the egg mass, turning circles inside the cup, taking short rests while facing towards the open side of the cup. During hatching, the male presses on the egg mass, liberating the larvae from the eggs and expelling the larvae from the nest. The male remains in the cup after the eggs hatch, and waits for the next gravid female.

In 2000, two males and one female were collected in March. The first clutch of eggs hatched in 7 d (April 18–April 24) at water temperature of 23–24°C. Some eggs removed from the nest, hatched in 9–11 d at 20–24°C; however, without the attending male, most of these eggs developed fungus. Males function as guardians of the eggs: protecting, aerating, and cleaning.

Embryogenesis was observed several times in 1999. The following is a brief description:

Day 1: Fertilized eggs started from 2-cell stage to morula, blastula, gastrula, and early embryo stages. Neural groove appeared. Oil globules scattered in the yolk.
Day 2: Early embryo stage: head enlarged, body somites appeared, tail was not free, and oil globules were different sizes (consolidating).
Day 3: Early embryo stage: tail freed, optical vesicles were visible and no lens; oil globules consolidated into one.
Day 4: Late embryo stage: eyes, eye lens, and otoliths were more defined; tail elongated and embryo occupied most of the previtelline space. Embryo often moved around inside of the chorion.
Day 5: Late embryo stage: eye was light pigmented; brain compartment became visibly more defined; light pigmentation observed along midventral and postanal regions.
Day 6: Late embryo stage: eye was darkly pigmented, with slivery iris. Head was free from yolk-sac. Body pigments became dark and embryo moved frequently inside of chorion.
Day 7: Late embryo stage to hatching: larvae broke through the chorion at the distal end or side of the chorion. Some hatched in 8–10 d; some were stillborn. Newly-hatched larvae swam from nesting area and descended to the bottom for 1–2 d before becoming planktonic.

2001–2003

In February and March of 2001, six adult and subadult shimofuri goby were collected from the CVP/TFCF. The largest one, a male, was approximately 100 mm TL and the others were between 45–55 mm TL. They were placed in a freshwater aquarium with a temperature range of 22–23°C. Spawning occurred on April 12 with the first batch hatching on April 17–18. From April through August, 1 male and 2 females had 13 clutches of eggs. The interval between each clutch for a single female is estimated to be between 2–3 weeks; however, depending on how well the female fed, the interval can be as short as 7 d. Aside from the large male and the two spawning females, the remaining three gobies showed no interest in spawning. These three gobies reached 80–85 mm TL by the end of October 2001, living well into 2002. By early September, the large spawning male looked very tired and exhausted. He was emaciated, moved out from the cup, and stayed at the corner of the aquarium. He had a layer of whitish tissue superimposed on his dark body. His breathing appeared labored with mouth open and he finally died. At death, he measured 126 mm TL. The two females eventually died also, one from natural causes while the other became over-gravid, was unable to discharge her eggs, and subsequently died.

Efforts to start shimofuri goby larvae on exogenous food were generally unsuccessful. Because of the small size of the larvae (exogenous feeding begins around 3 mm TL), small food items such as cultured ciliates and dried chicken egg yolk were attempted, but with little success (R.C. Reyes 2003–2009, personal communication). Larvae often died within 1–5 d after hatching. Starved larvae exhibited oversized melanophores on the body. The preferred starter food for newly-hatched shimofuri goby in freshwater regions of the Delta is still unknown.

In July and August 2001, 11 live shimofuri goby juveniles (~10.0–15.0 mm TL) were collected from the CVP/TFCF 10-min collection. Eight survived and grew to 35–50 mm TL by December. In early January 2002, these eight gobies were transferred to a 20-gal aquarium with the three remaining large gobies carried over from 2001. Another male (70 mm in TL) in spawning color, was collected from the 10-min collection in January 2002 and added to the tank. In all, 12 gobies resided in this 20-gal aquarium. Shortly after the 70-mm-TL male was introduced, the three large gobies started showing male spawning colors. Each of them occupied a cup except for the 70-mm-TL male. Cup-cleaning acts followed and spawning occurred on January 29, 2002. The first clutches of eggs hatched on February 4, 2002, after 7 d at 23–24°C. The age of the female parent was estimated to be only 7–8 months, the males were estimated to be <2 years old. The largest male seemed to be more attractive to the females and judging by the size of egg mass deposited in his cup, more than one female may have spawned with him. By the end of February 2002, among the 12 gobies, 6 were identified as active males, 4 were active female spawners, and 2 were possibly late-matured males.

C. Conclusion and Comments

A single female shimofuri goby can produce several clutches of eggs during the spawning season and the species spawns year round at temperatures of 20–25°C. Once spawning is initiated, they spawn continuously until death.

Males guard and aerate the eggs which hatch within 7–11 d. This species is a cavity (with hard surface) breeder but can also spawn in open areas with hard surface substrates. Eggs are not adhesive to each other; rather they are deposited in a single layer and adhere to a mat secreted by the male. Number of eggs deposited is controlled by the female's urogenital papilla. During egg deposition, the female's body is balanced by pectoral fins and pelvic suction cup, and eggs are always deposited in a single line. Total mating time ranged from approximately 4–24 h, depending on size of female and numbers of females engaged in spawning. A female would occasionally stop spawning for a while, then would return to the cup to finish.

Females usually spawned with the largest and darkest males. Young males would exhibit brilliant contrasting body color to attract females, would take less desirable spawning sites, and would wait outside a spawning cup. If a cup is occupied by a larger but weak male, the young male will force himself in and push the other from the cup. A young male, often aggressive, will contest a larger male. In serious confrontations, both may experience mortality. Combative rituals may last a matter of hours or up to a couple of days.

Young males exhibit a very complex social and mating behavior with large males. An egg-guarding male can be attacked easily and his eggs eaten, especially when he is weak. Competing males often suffer injuries and younger males often receive additional attacks by other gobies. Larger, older males receive none or little harassment. Large males have more potency and approximately 6 more months of reproductive life compared to young males who have only 3 months. Every male dies by the end of the spawning season. Having short lifespans, the ability to spawn at 6–7 months of age or delaying until they are 1+ years old enhances the survival of the species.

Males eat very little during the spawning season and almost stop eating while the eggs are incubating. As parents, males are steadfast and place all their energy into reproduction until he dies. Females eat a lot during the spawning season and can generate a clutch of eggs every 2–3 weeks in the laboratory where food availability is not an issue.

In 2002 and 2003, 7 to 12 shimofuri gobies were maintained in a 20-gal freshwater aquarium at ambient temperature (~24°C). Three ceramic coffee cups were set side by side on the bottom of the aquarium and a year long observation was conducted. The following is a decription of the interactions and behavior of shimofuri goby in this enclosed environment:

1. Three large males occupied cups; no small males and females occupied cups.

2. One small male with brilliant spawning colors had spawned with a female on the aquarium glass wall. This site was very close to a cup occupied by a large male. The small male fanned the eggs diligently in front of the large male’s nesting area. Small males can attract females although they are unlikely to secure a desirable nesting site (Matern 1999).

3. Two large males fought on February 26, 2002. One male suffered multiple bite wounds on the mouth, left operculum, left side of body and tail, with loss of fin rays and scale. During the confrontation, the operculum of both males turned bright red. With jaws locked, both fish attempted to flip the other over. When dominance was secured by a male, other males in the tank began attacking the fallen. Defeated, he abandoned the nest and died the following day.

4. Larger males can be very aggressive during nesting, attacking any other fish close to their nests. They also visit neighboring nests, and sometimes evict neighboring males from their nests (Matern 1999). Such evictions, however, are not permanent as the evicted male goby soon returns to his nest. Smaller males often lure females and are able to mate when large males are occupied with their eggs.

5. All males seem to be very hostile toward late-matured gobies (late-matured males are smaller males and resemble females, reaching sexual maturity at 1+ year old). The late-matured gobies ate more food than females and other smaller males, and were often chased by other gobies. They often hid behind the aquarium’s air pump. A late-matured male died of bite wounds on March 28.

6. A large male goby (110 mm TL) collected from CVP/TFCF 10-min fish collection on March 1 was placed in the aquarium with the others. He became dominant within 10 d and spawned on March 11, 2002, further demonstrating that females prefer the largest male.

7. Some males do not aerate or clean their eggs. As a result, their eggs die during incubation.

8. On one occasion, when the tank was being cleaned, a small male took shelter in larger male's cup. A courtship act ensued between the two males until the larger male recognized the other was also a male and drove him out of the cup. A similar incident occurred when a small white catfish, *Ameiurus catus*, took shelter in a male goby's cup.

9. Polygamous behavior was first observed on April 5 when the largest male in the tank mated with two females simultaneously. The mating lasted about 24 h, resulting in a massive egg mass covering the inner surface of the cup. The eggs hatched in about 6 d in water temperature of 24°C. The male was observed pressing his body repeatedly on eggs that were ready to hatch, dispersing newly-hatched larvae in a large area of the aquarium.

10. The largest male repeatedly used the same cup for spawning. He occasionally surveyed or visited the two other cups, thereby expressing his dominance. On such occasions, the other males opened their mouths but did not engage the larger male; a smaller male hid behind the pump or in the corner of the aquarium to avoid physical contact with the large male.

11. On May 10, a small male goby began to occupy the cup of a fatigued, pale-colored large male. The smaller male occupied the right side of the cup while the large male occupied the left. Four days later, the smaller male had become darker and more aggressive and mated with a female. The eggs were deposited on the right side of the cup. The smaller male tended and defended the eggs, briefly leaving the cup when other gobies approached. The large male did not harm the eggs and would lightly bite (a type of greeting gesture) the returning smaller male. Eventually, the large male became more exhausted and was driven out (May 22); he died the next day in the corner of the aquarium.

12. Cannibalism was first observed May 17–21 after a male was badly injured from a fight. Swimming abnormally, he was attacked and killed by other males and his flesh partially eaten.

13. A fight between a large male and a smaller male occurred on May 21. The small male was badly wounded, losing his right eye ball and receiving a tear in his right cheek muscle; he died that same day. The large male suffered a torn muscle on his right cheek. He returned to his cup and became idle. The eggs he was tending turned

yellowish and perished. Another male, taking advantage of the situation, pushed him further and deeper into the cup. The large male subsequently died on May 31.

14. The largest male from cup 1 died on May 28 after fertilizing seven clutches of eggs. Possible cause of death may be spawning stress (constant fanning and egg cleaning), starvation, and old age. By May 28, most of the large males had died and empty cups were available.

15. During one weekend (June 8–9), the 1-year-old male mated with more than two females; the eggs completely covered the inner surface of the cup. Eggs were likely deposited over an extended period because different stages of embryonic development were observed. Males seem to exhibit optimum sexual potency at a young age.

16. A young male was observed caring for two cups on June 12. He attended eggs in the hatching stage in one cup and eggs in earlier stages of development in the other cup. Both cups were fully coated with eggs and were vigorously defended by this male as he moved from one cup to another fending off other approaching males. He eventually gave up one of the cups on June 14. It is likely that guarding and tending two cups of eggs became too exhausting and ineffective. Surrendering a batch of eggs was more beneficial than losing both.

17. A form of commensalism was observed between two males: a 1-year-old male with red and white coloration and a 2-year-old male with hatching eggs. The two males had engaged in mouth-to-mouth fights but never engaged in serious duel. Although the younger male constantly challenged the older male, the younger male positioned himself in front of the older male's cup and drove away other males that approached. It seems that the smaller male shared the responsibility of guarding the older male's eggs. Interestingly, smaller males never tried to steal eggs from larger males guarding two cups of eggs simultaneously.

    Two males were observed spawning jointly in the same cup with the same female on June 17. The young male chased intruders but tolerated the larger, older male with him in the cup. After the female finished spawning with the two males, she left the cup on June 18, leaving the two males to fight each other aggressively over the responsibility of guarding the eggs. The eggs started hatching on June 21. The younger male showed dominance over the older male (fatigued with a grayish slender body) by positioning himself on top of the older male periodically.

18. A gravid female (92 mm TL) died on June 25. There were at least four males in the tank with her, oddly however, she did not mate with any of them. After she died, more gobies were added (totaling 12, half males) along with 4 more cups (7 total).

19. Quarreling males may miss spawning opportunities as observed on June 26, 2002. Two males, occupying cup 3, fought repeatedly with each other over a female until

she was excluded from the cup. She went to the adjacent cup 4 occupied by a young male and spawned soon after.

20. On June 27, the two males in cup 3 were still fighting and their physical condition was deteriorating. Their jaws were torn at the corners of the mouth. No eggs had been deposited in this cup since June 17 (see observation 17).

21. Cup 3 was eventually abandoned on the morning of June 28. The larger 2-year-old male suffered an infected, broken snout and died at noon. The younger male suffering a broken jaw, hid in the corner of the tank, and was subsequently attacked by other gobies. He died between June 28 and 29. No other 2-year-old gobies remained.

    In cup 1, a young male mated with a large female from morning to noon, covering the entire cup with eggs. At 1500 h, a smaller male appearing to be female (*i.e.*, no male coloration or aggressiveness) entered the cup with the original male. This small male was actually eating the eggs and was eventually driven out. After being driven out, his coloration turned dark, revealing his male characteristics. Appearing as a female again, he re-entered the cup a few moments later.

22. Summary of observations between July 2–29: eggs deposited in cup 1 (see observation 21) were examined under a dissecting scope. A few eggs developed into the late embryo stage (eye pigmented); most eggs were in early embryo stage (eye unpigmented). This indicated that the second batch of eggs was deposited on the same common mat where some of the first batch of eggs was eaten by the young male.

    One of the young males that attended several clutches of incubating eggs died while attending his most recent clutch. This male was less than 1 year old. It seems that once spawning is initiated, a male will spawn continuously until death.

    When an exhausted young male abandoned a nest of incubating eggs, female entered the nest and ate all the eggs.

    A young male after mating, left the female in the cup. The female chased intruders away but did not aerate the eggs by fanning. All eggs died.

    A young male spawning with two females was observed on several occasions.

23. Summary of observations between August 7–27: a total of seven gobies were still alive: three exhibited male coloration periodically and occasionally occupied cups; four that resembled mature females or late-matured males ate more food, stayed outside the cups, and showed no interest in spawning.

24. Summary of observations between September 4–20: on September 4, a male was observed tending a clutch of hatching eggs in cup 1, estimated to have been fertilized

on August 28–29. The water temperature was 24°C. This male mated two more times in September (September 9 and 20). Two other males were in and out of cups, but did not spawn.

25. Summary of observations made during October: the same male that had spawned once in August and twice in September (see observation 24), had spawned once more in October. Among the three male gobies, one was an obvious male and two were males with "off-and-on" spawning colors (see section 23). The other four gobies were females and late-matured males/females.

26. Summary of observations made during November: two more gobies died on November 7, leaving five. The same male that spawned in late-August, September, and October, spawned again on November 23; however, he was unable to fertilize all the eggs deposited by the female because of his weak physical condition. His nest was taken over by other gobies, he was attacked, and his eggs eaten. Suffering severe wounds, he abandoned the nest and died. He fertilized five clutches of eggs in a span of 3 months.

27. Observations from December: two more gobies died; two large gobies (late-matured males or females) were still alive and carried into January 2003. Shimofuri goby mature in about 6–7 months (<1 year) or delay spawning until they are >1 but <2 years old.