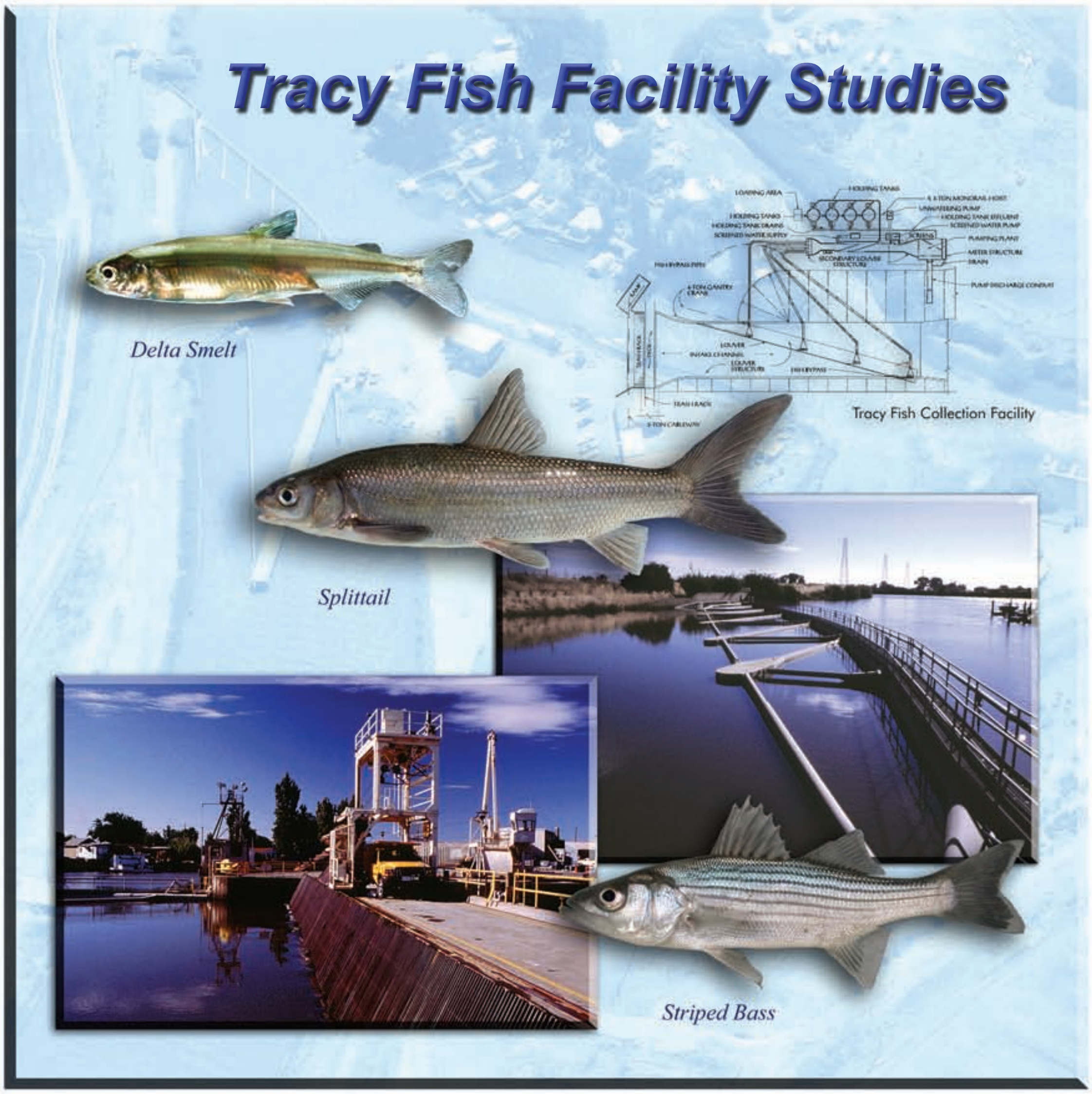
SJC-531

RECLAMATION
Managing Water in the West



Spawning, Early Life Stages, and Early Life Histories of the Osmerids Found in the Sacramento-San Joaquin Delta of California

Volume 38

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

October 2007

REPORT DOCUMENTATION PAGE	Form Approved SJC-531 OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
October 2007

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Spawning, Early Life Stages, and Early Life Histories of the Osmerids Found in the Sacramento-San Joaquin Delta of California

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 Science, Inc., Central Valley Project/Tracy Fish Collection Facility, 6725 Lindemann Road, Byron CA 94514
Bureau of Reclamation, Tracy Fish Collection Facility, TO-412, 6725 Lindemann Road, Byron CA 94514

8. PERFORMING ORGANIZATION REPORT NUMBER
Volume 38

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

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
Delta smelt, *Hypomesus transpacificus*; surf smelt, *Hypomesus pretiosus*; longfin smelt, *Spirinchus thaleicthys*; and wakasagi, *Hypomesus nipponensis* are observed in the upper Sacramento-San Joaquin River Estuary (Delta, including Suisun Bay). This report provides drawings, photographs, and information of early life stages and early life histories and updates the Interagency Ecological Program Technical Report No. 9 published in 1986 (Wang). Delta smelt is a euryhaline fish and is endemic to the Delta. Spawning occurs at the lower reaches of the Sacramento and San Joaquin Rivers and extends further upstream to the Central and South Delta during dry years. Spawning also occurs in Suisun Bay and Napa River but may descend further downstream to other tributaries during wet years. Spawning locations mainly occur above the entrapment zone and changes with Delta outflow. The delta smelt population fluctuates annually, but recruitment occurs in the estuary in all types of water years. Surf smelt, a coastal marine species, uses the estuary as an extended nursery ground. Juveniles are found in the Delta occasionally. Longfin smelt spawn mainly in Suisun Bay but they also spawn in Cache Slough, an inland spawning location. Longfin smelt is the most abundant smelt species in the study area, although its population size appears to be decreasing. Wakasagi, an introduced species from Japan, descended from the reservoirs and established a reproductive population in the Delta in the early 1990s. Their distribution is known principally in freshwater. Their spawning information is scarce and abundance trends have not been observed.

15. SUBJECT TERMS
smelt, spawning, embryology, eggs, larvae, juveniles, life history, Delta.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Doug Craft
a. REPORT	b. ABSTRACT	a. THIS PAGE		110	19b. TELEPHONE NUMBER *(Include area code)*
					303-445-2182

Tracy Fish Facility Studies California

Spawning, Early Life Stages, and Early Life Histories of the Osmerids Found in the Sacramento-San Joaquin Delta of California

Volume 38

by

Johnson C.S. Wang[1]
Illustrations and Photography by René C. Reyes

October 2007

U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region

[1] National Environmental Science, Inc.
Central Valley Project/Tracy Fish Collection Facility
6525 Lindemann Rd.
Byron CA 94514

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

SERIES EDITOR

Doug Craft
U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver CO 80225-0007

COVER

Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
Design by Doug Craft.

DISCLAIMER

Table of Contents

Table of Contents—continued

Page

Table of Contents—continued

Tables

Table of Contents—continued

Figures

Appendix Tables

Table of Contents—continued

Appendix Tables

Table *Page*

ABSTRACT

Delta smelt, *Hypomesus transpacificus*; surf smelt, *Hypomesus pretiosus*; longfin smelt, *Spirinchus thaleicthys*; and wakasagi, *Hypomesus nipponensis*, are observed in the upper Sacramento-San Joaquin River Estuary (Delta, including Suisun Bay). This report provides drawings, photographs, and information of early life stages and early life histories and updates the Interagency Ecological Program Technical Report No. 9 published in 1986 (Wang). Delta smelt is a euryhaline fish and is endemic to the Delta. Spawning occurs at the lower reaches of the Sacramento and San Joaquin Rivers and extends further upstream to the Central and South Delta during dry years. Spawning also occurs in Suisun Bay and Napa River but may descend further downstream to other tributaries during wet years. Spawning locations mainly occur above the entrapment zone and changes with Delta outflow. The delta smelt population fluctuates annually, but recruitment occurs in the estuary in all types of water years. Surf smelt, a coastal marine species, uses the estuary as an extended nursery ground. Juveniles are found in the Delta occasionally. Longfin smelt spawn mainly in Suisun Bay but they also spawn in Cache Slough, an inland spawning location. Longfin smelt is the most abundant smelt species in the study area, although its population size appears to be decreasing. Wakasagi, an introduced species from Japan, descended from the reservoirs and established a reproductive population in the Delta in the early 1990s. Their distribution is known principally in freshwater. Their spawning information is scarce and abundance trends have not been observed.

PREFACE

The author of this report, Dr. Johnson Wang, is a recognized expert on larval and juvenile fish identification for species in the Sacramento-San Joaquin Delta (Delta) and San Francisco Bay Estuary (Bay) regions of California. In 1986, Dr. Wang published *Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories*, a definitive and widely used key to the identification, distribution, and life histories of fish in the Delta and Bay. The current report represents an important update to the 1986 guide by including significant observations about smelts, family Osmeridae, to provide a more comprehensive synthesis and understanding of smelts in the Bay and Delta. Dr. Wang has made special efforts over the last 20 years to identify likely spawning locations and conditions for Osmerids using his own field investigations and larval smelt abundance data collected by many researchers and agency programs in the Bay and Delta. Through this effort, he has also identified several factors that may affect smelt spawning success.

One of the most important factors affecting spawning success in the Bay and Delta is “water year type,” a variable that combines precipitation and snowmelt runoff in the Bay-Delta watershed. During drier water years, the crucial spring spawning entrapment zone moves upstream in the tributary rivers and the entrapment zone moves downstream to Suisun Bay and even San Pablo Bay during wetter years. Wet years favor downstream locations for the entrapment zone and by making more habitat available; generally favor larger year classes of young fish. However, too much flow can flush the larval fish into San Francisco Bay where salinity can be detrimental.

We believe you will find that this report is a valuable addition to the scientific literature and a helpful guide that will benefit fishery researchers and fish facility personnel working in the Bay and Delta.

Ron Silva
Manager, Tracy Fish Facility Improvement Program

EXECUTIVE SUMMARY

Four species of smelt from the smelt family (Osmeridae) are found in the Sacramento-San Joaquin River Estuary (including San Francisco Bay, San Pablo Bay, Suisun Bay, and the Delta). They are delta smelt, *Hypomesus transpacificus*; surf smelt, *Hypomesus pretiosus*; longfin smelt, *Spirinchus thaleichthys*; and wakasagi, *Hypomesus nipponensis*. Delta smelt are mostly found between freshwater and brackish water, surf smelt are in coastal marine environments, longfin smelt tend to be in brackish water, and wakasagi inhabit primarily freshwater. Wakasagi is an introduced species from Japan and the other three species are native. In this study, the information on smelt early life stages and early life histories updates and expands the Interagency Ecological Program (IEP) Technical Report No. 9 (Wang, 1986). Discussions on spawning and embryology of delta smelt and wakasagi are included along with their distribution of early life stages by types of water year.

The delta smelt is endemic to the estuary and is considered to be euryhaline, spending most of its time in the upper Sacramento-San Joaquin River Estuary (Delta, including Suisun Bay) and less in the saltier bays. Major spawning grounds are located at the lower reaches of the Sacramento and San Joaquin Rivers and extend to the Central and South Delta in drier years. Spawning occurs further downstream in wetter years as indicated by the presence of ripe fish. Delta smelt spawn in Suisun Bay and Napa River in extremely wet years, and may descend even further downstream than sampling programs monitor. Spawning locations seem to concentrate near the entrapment zone. Judging from the small numbers of larvae collected at any one location, delta smelt are likely to be fractional spawners with many micro spawning habitats. Delta smelt utilize a combination of freshwater and brackish water environments in order to complete its life cycle. Surf smelt use the lower estuary as an extended nursery ground and arrive in the Delta on rare occasions. Surf smelt spawn along coastal beaches, including the beaches adjacent to San Francisco Bay. Longfin smelt, also a euryhaline fish, are the most abundant fish in the estuary among the four species of smelt, although its abundance in the Delta is declining. Spawning activities are concentrated in Suisun Bay, Napa River, San Pablo Bay, and Cache Slough, with the latter location probably the upper most location for this species. Spawning (location and intensity) seems to have a mixed response in regards to Delta outflow; apparently, other factors may influence their spawning. Juvenile longfin smelt are found mostly in brackish water habitat such as the Suisun Bay, but are also observed in the South Delta in dry years. The majority of adults remain in the higher saline water of San Francisco Bay and San Pablo Bay. Wakasagi have been establishing a reproductive population in the Bay and Delta since the early 1990s. Wakasagi share a similar spawning habitat with delta smelt and longfin smelt, which include the Sacramento River to Suisun Bay. However, detailed information on life history in the open water habitats of the Bay and Delta is still scarce. They are elusive and abundance trends are lacking. Wakasagi are thriving in the San Luis Reservoir, where the population was introduced from the Delta via the State and Federal water projects.

Study of early life stages and early life histories are important steps to understanding the osmerid species. The interaction of each osmerid species with other fish species determines how successful the osmerids are in the ecosystem. The population of the delta smelt and longfin smelt have been fluctuating rapidly in recent years. More basic life history studies are needed to determine the impact of water related management activities in California. After descending to the Delta from the reservoirs about a decade ago, the wakasagi's ecological status in the upper Sacramento-San Joaquin Estuary is currently not fully described.

INTRODUCTION

There are seven species of osmerids occurring in California. Four of them are marine species: whitebait smelt, *Allosmerus elongates*; surf smelt, *Hypomesus pretiosus*; and night smelt, *Spirinchus starksi*; and eulachon, *Thaleicthys pacificus*. Eulachon have been recorded in the Sonoma County (Emmett *et al.*, 1991) and may extend further south along the California coast (Moyle, 2002). Delta smelt, *Hypomesus transpacificus* is a euryhaline fish endemic to the Sacramento-San Joaquin River Estuary (including San Francisco Bay, San Pablo Bay, Suisun Bay, and the Delta) and spends most of its life in the freshwater habitats (Hearld, 1961; Moyle, 1976; Mager, 1996). The longfin smelt, *Spirinchus thaleichthys* is also a euryhaline fish that has a definite migratory pattern during the spawning season and is generally found in saltier water than delta smelt (Moyle, 1976; 2002). Wakasagi, *Hypomesus nipponensis*, a freshwater smelt from Japan, was introduced into California by the California Department of Fish and Game (Wales, 1962); however, it was not observed in the Bay and Delta by Ganssle (1966). Initially they were stocked in some of Northern California's reservoirs as forage for salmonids. Wakasagi migrated down the Feather River and American River into the lower Sacramento River. A reproductive population probably became established sometime in the early 1990s (Wang, 1995).

This report discusses four of the seven species of smelt found in the Bay and Delta regions including delta smelt, surf smelt, longfin smelt, and wakasagi. Each of their spawning areas is discussed with the exception of surf smelt. Whitebait smelt, night smelt, and eulachon are not found in the Delta and are omitted from the description in this report.

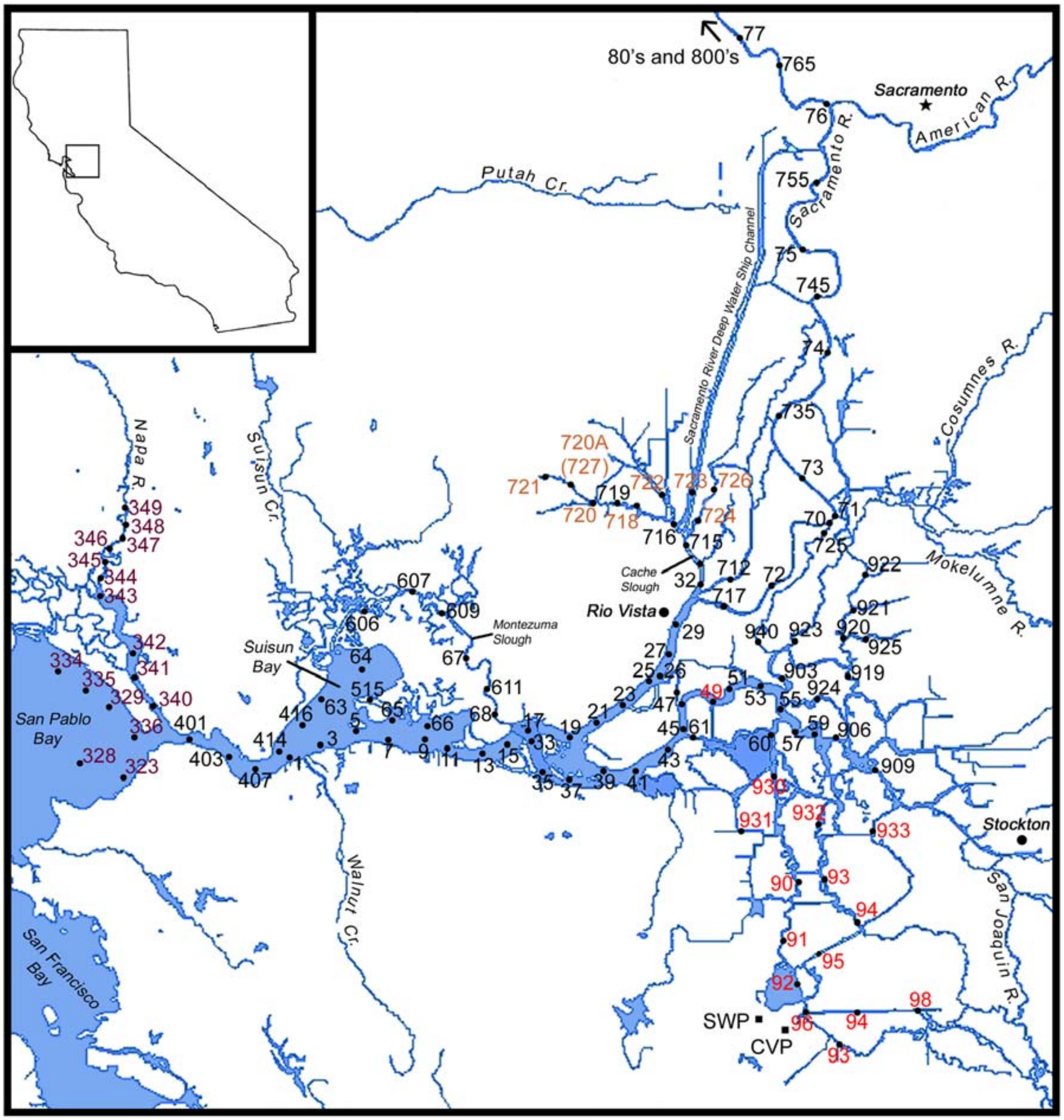
The three purposes of this report are to: (1) revise Chapter 6 of IEP Technical Report No. 9 (Wang, 1986) and update the life history of osmerids found in the upper Delta with special attention to the South Delta where water export pumping occurs; (2) describe the embryology of wakasagi and delta smelt with a discussion of hybridization between male wakasagi and female delta smelt; and (3) document the potential spawning areas by presence of their early life stages.

METHODOLOGY

Specimens Examined

Specimens were collected through four large and several smaller sampling programs, preserved in 3 – 5 percent formalin, and stained with Rose Bengal to facilitate removal from samples. The four larger eggs and larvae (E&L) sampling programs were in: (1) the Delta from 1988 to 1995 conducted by the California Department of Fish and

Game (CDFG), (2) the North Bay Aqueduct (NBA) from 1993 to 2004 conducted by CDFG and the Department of Water Resources (DWR), (3) the Central and South Delta from 1993 to 1995 conducted by DWR, and (4) Napa River from 1995–2005 conducted by CDFG. A map of the study area (figure 1) identifies all the sampling stations from these four programs.



LEGEND
CDFG Striped Bass Egg & Larvae Survey Stations
CDFG North Bay Aqueduct Fish Eggs & Larvae Sampling Stations
DWR Central and South Delta Fish Eggs & Larvae Sampling Stations
CDFG Napa River and San Pablo Sampling Stations (except 347, 348, 349)

FIGURE 1.—Map of study area.

Additional information and specimens were obtained from the following agencies and individuals:

1. Central Valley Project (CVP)/Tracy Fish Collection Facility (TFCF) Holding Tank 10-Minute Count Samples and All Special Studies, 1995–2005.

2. University of California at Davis (UC Davis) Suisun Marsh Fish Egg and Larvae Sampling Program (contracted by DWR), 1995–2002.

3. CDFG Delta Smelt and Longfin Smelt (Delta Smelt Larvae Survey or DSLS) Pilot Sampling Program, 2005.

4. CDFG Wakasagi Sampling at Lake Almanor, Lake Oroville, Lake Natoma and Folsom Lake in the 1990s.

5. Bureau of Reclamation (Reclamation) Beach Seining at San Luis Reservoir, 1995–2001.

6. Live specimens of wakasagi and delta smelt were obtained from Brent Bridges of Reclamation, Dr. Joan Lindberg, and Dr. Bradd Baskerville-Bridges from the Fish Conservation and Culture Laboratory (FCCL) located at the Skinner Delta Fish Protective Facility (SDFPF) in the late 1990s to early 2000s.

Laboratory Equipment

We used Leica Microsystems models MZ8 and MZ7 dissecting microscopes with an AcuCam® video camera or Polaroid digital camera, and Media Cybernetics Image-Pro® Plus version 4.5 image analysis software. Because the body structures of the prolarval to early juvenile stages of osmerids are transparent or translucent and low contrast, transmitted light (bright field) was used for counting myomeres and for observing internal structures and pigmentation. A magnification range of 10 – 12.5X was used to measure fish length and structures; however, for detailed observations, a higher magnification range was needed (e.g., 30 – 50X). Additional images were obtained using a Sony UP-20 Color Video Printer. Line drawings were borrowed from IEP Technical Report No. 9 (Wang, 1986) by Mark Adams and Johnson Wang and enhanced by René Reyes. Additional line drawings and color photographs of fish developmental stages were provided by René Reyes and Brent Bridges.

Species Accounts

The species accounts provide spawning information, taxonomic characteristics for each life stage, life histories, and two figures (drawing and digital photographs) illustrating the development of the species. Common and scientific names of fishes follow Nelson, *et al.* (2004). Account format and content are 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 man-made structures.
Fecundity:	Estimate based on subsamples or counts of mature eggs in ovaries.

EGGS

Shape:	Fertilized egg spherical, oval, or elongated.
Diameter:	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:	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 mass:	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 bouyant.

LARVAE

Length of 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, location from recently hatched larvae.
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 sac:	TL when the yolk appears 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 anus to the most anterior myoseptum.
Postanal myomeres:	Counted from the first completed myomere behind the perpendicular line at the anus to the most posterior myoseptum.
Last fin(s) to complete development:	Name of the fin(s) that develops 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 described.

JUVENILES

Dorsal fin:	The number of spiny rays or hardened rays in Roman numerals; soft rays in Arabic numerals (Example III-10).
Anal fin:	As for dorsal fin.
Pectoral fin:	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.

Although this author tried to be comprehensive in developing this guide, some shortcomings should be noted:

1. Spatial and temporal information on osmerids spawning and distribution of their early life stages in the Bay and Delta is limited to the CDFG sampling area from 1988–1995. Sampling frequency was not consistent from year to year; therefore, comparison was limited.

2. After 1995, the E&L sampling for osmerids are limited to two locations: NBA in 1995–2004 and Suisun Marsh in 1995–2002; spatial distribution information of the osmerids in these years was severely reduced. Outside of these areas, only the South Delta CVP/TFCF samples provided larval fish information.

3. Osmerids spawning information in the lower Estuary is available from Napa River, but it is lacking from other tributaries, which drain into San Pablo Bay and San Francisco Bay, particularly during wet years.

4. Interpretation on larval fish data trends was based on the studies between 1988 and 2005, a relative short time in historical sense.

DELTA SMELT, *Hypomesus transpacificus* (McAllister); figures 2a and 2b

SPAWNING

Location:	Dead-end sloughs (Radtke, 1966); in sloughs and hallow edge of waters in the upper Delta and in Sacramento River above Rio Vista (Moyle, 2002); between Garcia Bend and confluence of Sacramento River; specifically, it includes Cache Slough, Lindsey Slough, Miner Slough, south entrance of the Sacramento Deep Water Ship Channel, Steamboat Slough, and in the vicinity of Isleton; on San Joaquin River side, it includes Sherman Island, Bradford Island, Twitchell Island, Lower Mokelumne River, and South Delta; spawning also occurs in Suisun Bay, Montezuma Slough and its tributaries (such as Cordelia Slough, Spring Branch, and Nurse Slough), and upper Napa River in wet water-years (Wang, 1986; this study).
Season:	February-June (Wang, 1986); late January to late June or early July (this study, CDFG samples collected at NBA , 1993–2004).
Temperature:	ca. 7 – 15 °C (Wang, 1986); 14.8 – 16.5 °C in the laboratory (Mager, 1996); 7 – 22 °C (Moyle, 2002); 10 – 20 °C in the laboratory (Lindberg *et al.*, 2003); a high hatching rate in the laboratory occurs at 15 °C (Lindberg *et al.*, 2003); a high hatching rate in laboratory at 14 – 17 °C (this study).
Salinity:	Freshwater.
Substrates:	Aquatic plants (Moyle, 1976); submerged inshore plants (Wang, 1986); may use sandy, hard-surface substrates such as dead snail and clam shells, gravels (this study).
Fecundity:	1,200 – 2,600 for females ranged 59 – 70 mm SL (Moyle *et al.*, 1992); fecundity increased with body length (Mager, 1996); second year smelt may have up to 5 – 6 times as many ova as first-year smelt but more often 3 – 6 times more (Bradd Baskerville-Bridges, personal communication).

EGGS

Shape:	Spherical for mature unfertilized eggs and fertilized eggs (Wang, 1986; Mager, 1996).
Diameter:	Mature unfertilized eggs formed anchors and soaked in water, ca. 1.0 mm (Wang, 1986), freshly stripped eggs 0.75 – 0.85 mm, and fertilized eggs 0.80 – 1.00 mm (Mager, 1996); fertilized eggs 0.80 – 0.94 mm for natural spawn; 0.80 – 1.10 mm for stripped eggs (this study).
Oil globule:	Many small oil globules which consolidated into 3 – 4 large oil globules after fertilization (this study).
Chorion:	Two layers: the outer layer reverses itself and forms an adhesive anchor that attaches to hard surface substrates (Wang, 1986; this study).
Perivitelline space:	ca. 0.1 – 0.2 mm in diameter in morula stage (this study).
Egg mass:	Elliptical eggs deposited singly and in one layer on substrates (Wang, 1986; this study).
Adhesiveness:	Attached to plants (Moyle, 1976); adhesive outer layer of chorion (Wang, 1986); adhesive outer layer or chorion; also formed a center stalk attaching to inner chorion (Mager, 1996); strongly adhesive.
Buoyancy:	Negatively buoyant.

LARVAE

Length of hatching:	Field collected planktonic yolk-sac larvae that might be a few days old, were in 5.5 – 6.0 mm TL (Wang, 1986); 5.1 – 5.7 mm TL (Mager, 1996); ca. 5.4 mm TL at 10 °C, ca. 5.2 mm TL at 15 °C, and ca. 4.9 mm TL at 20 °C (Lindberg *et al.*, 2003); 4.0 – 4.7 mm TL in the laboratory at a higher temperature of 20 °C (Lindberg *et al.*, 2003; this study).
Snout to anus length:	68 – 72.5 percent and mainly 70 – 71 percent (Wang *et al.*, 2005).
Yolk sac:	Field specimens: small, spherical to oval, slightly posterior to thoracic region (Wang, 1986); laboratory specimens: large, mostly spherical, slightly behind the thoracic (this study).
Oil globule(s):	Single (Wang, 1986; Mager, 1996); single, 0.2-0.3 mm in diameter.
Gut:	Straight.
Air Bladder:	Oval to elongate, slightly posterior to thoracic or slightly above and anterior of pelvic fin. Appears when larvae are 15 – 16 mm TL for field specimens (Wang *et al.*, 2005); appears at 9 – 13 mm TL for laboratory reared stock (Mager, 1996; this study).
Teeth:	In front portion of mandible first; premaxillary and maxillary later in postlarval stage (Wang, 1986).
Size at absorption of yolk sac:	6 – 7 mm TL (Wang, 1986).
Total myomeres:	53 – 56.
Preanal myomeres:	38 – 42 (Wang, 1991); 33 – 35 (Mager, 1996); mostly 34 – 36.

Postanal myomeres:	14 – 17 (Wang, 1991); 14 – 16 (Mager, 1996); mostly 14 – 16 (Wang *et al.*, 2005).
Last fin(s) to complete development:	Pectoral fin.
Pigmentation:	Two rows of dashed melanophores along jugular to thoracic region; then replaced by a single row of dashed melanophores on midventral region, few melanophores along postanal near caudal; pigments also appear on yolk sac (Wang, 1986); a single row of 12-15 melanophores extended on the ventral side of body, with a few melanophores posterior to anus (Wang, 1991); pigments cells were also present on the yolk sac and base of pectoral fin (Mager, 1996).
Distribution:	Off bottom (Mager, 1996); pelagic, mostly on surface of water column, from upper Napa River to Suisun Bay (including Montezuma Slough and its tributaries), to lower Sacramento-San Joaquin River Systems and Delta (Wang, 1986; this study).

JUVENILES

Dorsal fin:	9 – 10 (McAllister, 1963).
Anal fin:	15 – 17 (McAllister, 1963).
Pectoral fin:	10 – 12 (McAllister, 1963); 10 – 13.
Adipose fin:	Yes.
Mouth:	Small, flexible, maxillary does not extend past the middle of the eye (Moyle, 1976); terminal, small, oblique.
Vertebrae:	53 – 56 (McAllister, 1963).
Distribution:	West Delta, Suisun Bay, and San Pablo Bay (Baxter *et al.*, 1999); pelagic, schooling in the Delta (including South Delta in April to June), then moving to West Delta, then the brackish Suisun Bay, eastern San Pablo Bay and Lower Napa River before arriving at the vicinity of Decker Island and the confluence of the Sacramento River and San Joaquin River—the staging ground for spawning in the following year (this study; Bradd Baskerville-Bridges, personal communication).

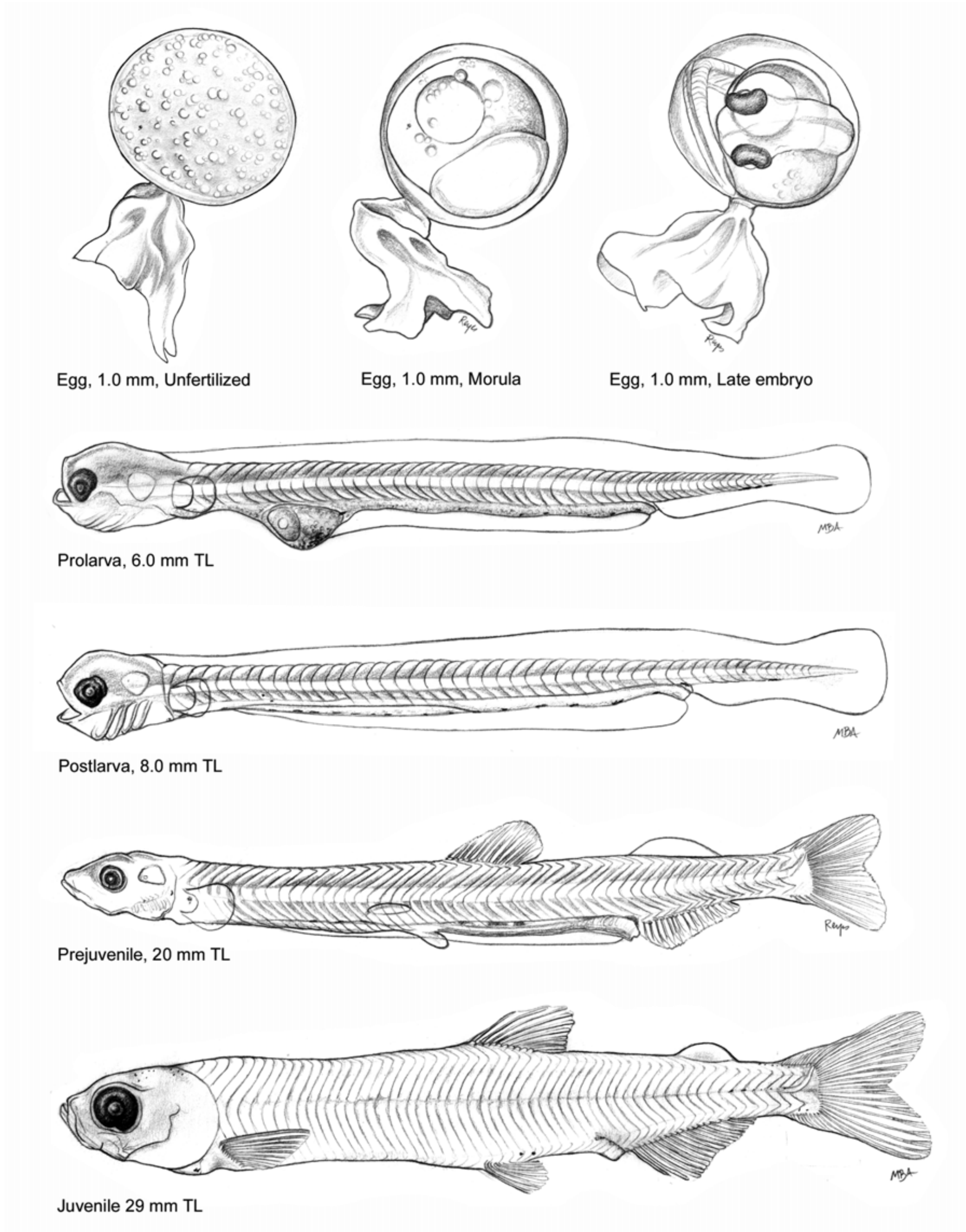


FIGURE 2a.—Early life stages of delta smelt drawings.

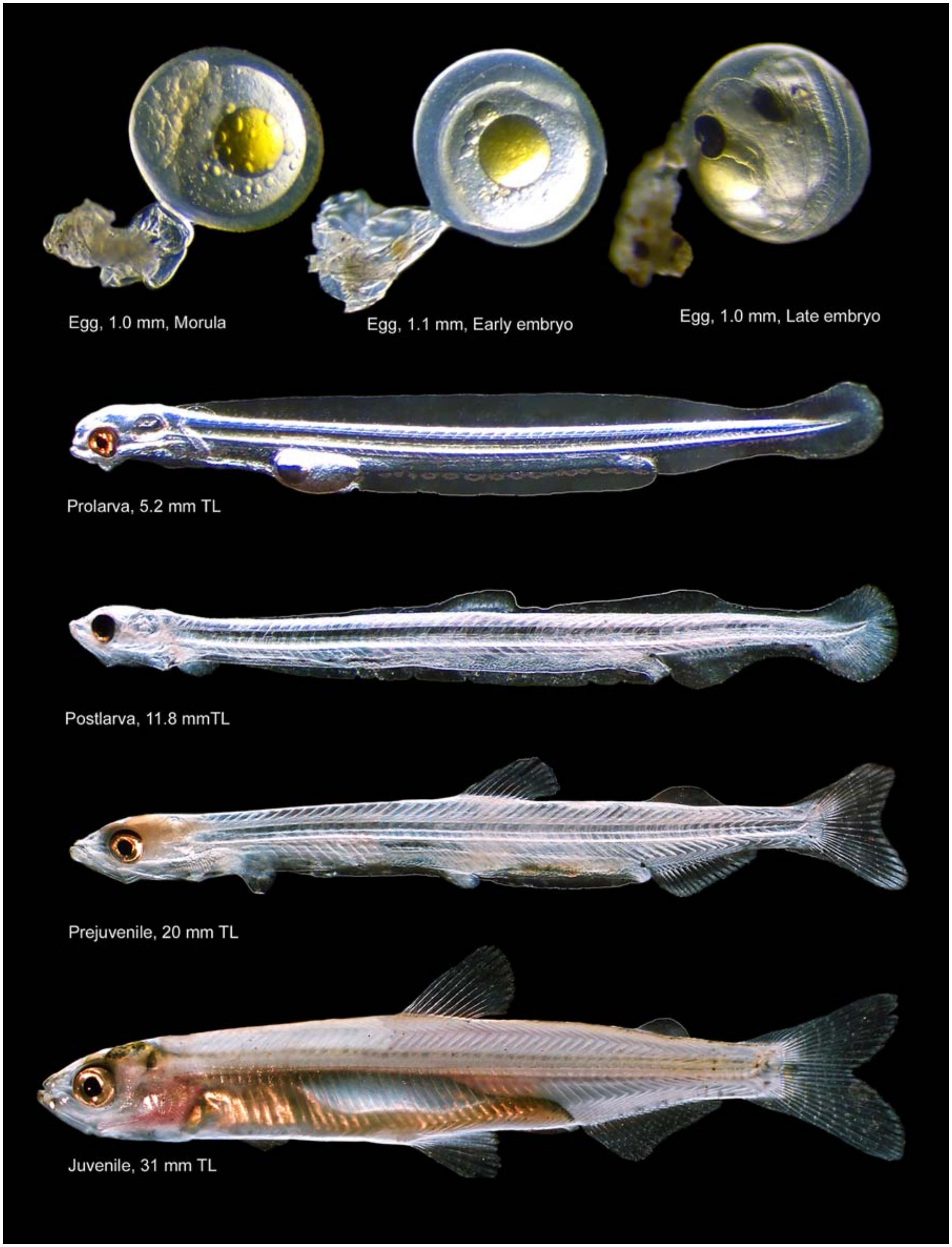


FIGURE 2b.—Early life stages of delta smelt photographs

The delta smelt is a euryhaline fish, native to the Sacramento-San Joaquin Estuary (Herald, 1961; McAllister, 1963; Moyle, 1995). It was formerly identified as the pond smelt, *Hypomesus olidus*. Revision of smelt taxonomy in 1963 separated pond smelt into several species, and making the delta smelt, *Hypomesus transpacificus*, a new species (MacAllister, 1963). Major concentrations of delta smelt population occur in the Suisun Bay and Delta (Moyle, 1976). Recent studies, conducted in the 1990s and early 2000s, indicate that delta smelt are found in the Sacramento River as far as Garcia Bend (Wang, 1991; Wang and Brown, 1993). Delta smelt may enter Yolo Bypass via the Sacramento River during winter months (Lenny Grimaldo, personal communication). Smelt are also found in the San Joaquin River and the South Delta as far south as Mossdale (Moyle, 2002). Delta smelt are found in Suisun Bay and Montezuma Slough (Meng and Matern, 2001; this study), extending further down bay (mostly in wet years with heavy run off) to San Pablo Bay and Central Bay (Baxter *et al.*, 1999). They are also found in the Napa River (CDFG 20 mm fish sampling, 1995–2005; Stillwater Sciences, Inc fish sampling, 2001–2005).

Expanded Life History – Delta Smelt

The delta smelt used to inhabit the South Delta all year round (Erkkila *et al.*, 1950). From continuous year round fish sampling at the CVP/TFCF, delta smelt are collected seasonally, particularly in dry years (tables 1 and 4). The delta smelt are using the South Delta as part of their spawning and nursery ground, mainly in winter and spring months.

TABLE 1.—Occurrence of delta smelt at the CVP/TFCF, including holding tank 10-minute count samples and all special studies, 1995–2005

Year	Adult Arrived TFCF	Estimated adult spawning	Adult left TFCF	L-J arrived TFCF	L-J left TFCF
1995	0	0	0	0	0
1996	—	—	—	04/15/96+	07/10/96
1997	03/02/97	ca. 03/07/97	03/11/97	04/23/97+	06/25/97
1998	0	0	0	06/22/98	07/06/98
1999	01/31/99	ca. 02/19/99	06/28/99	04/29/99+	08/12/99
2000	12/27/99	ca. 02/10/00	04/21/00	04/20/00+	07/16/00
2001	10/30/00	ca. 02/13/01	04/12/01	04/26/01+	06/20/01
2002	12/11/01	ca. 02/28/02	03/24/02	04/12/02+	06/20/02
2203	12/18/02	ca. 02/15/03	04/14/03	04/10/03+	07/01/03
2004	12/25/03	ca. 02/24/04	03/29/04	04/18/04+	06/27/04
2005	01/04/05	ca. 02/16/05	02/16/05	05/17/05	06/20/05

Note:
L-J: Larval to juvenile life stages.
—: No data.
+: Larvae were taken with prejuveniles and juveniles.

Sexual dimorphism

Male delta smelt

Prior to spawning: Snout, head, and dorsal of body is darker; base of anal and caudal peduncle may also be darker.

During spawning:

1. Breeding color: Darker pigments appear on snout (including upper and lower jaw) and a dark stripe below the eye. Dorsal half of the body has more pigmentation than ventral half. Darker pigments cover the entire base of anal fin. Horse-shoe shaped pigments are along the mandible and seem to be darker. Fish has a golden-glow, with silvery lateral band.

2. Breeding tubercles or breeding bumps: Secondary sexual structures are observed during the spawning period. Small, pointed breeding tubercles and less pointed breeding bumps are found on top of head (figure 3) and cover the entire body including the fins. There are two-bumps on each scale (figure 4). Scales near the front of anus and pelvic fins are highly modified into a patch of sharp serrated spines (figure 5). The bumps disappear when male fish ends the spawning activity.

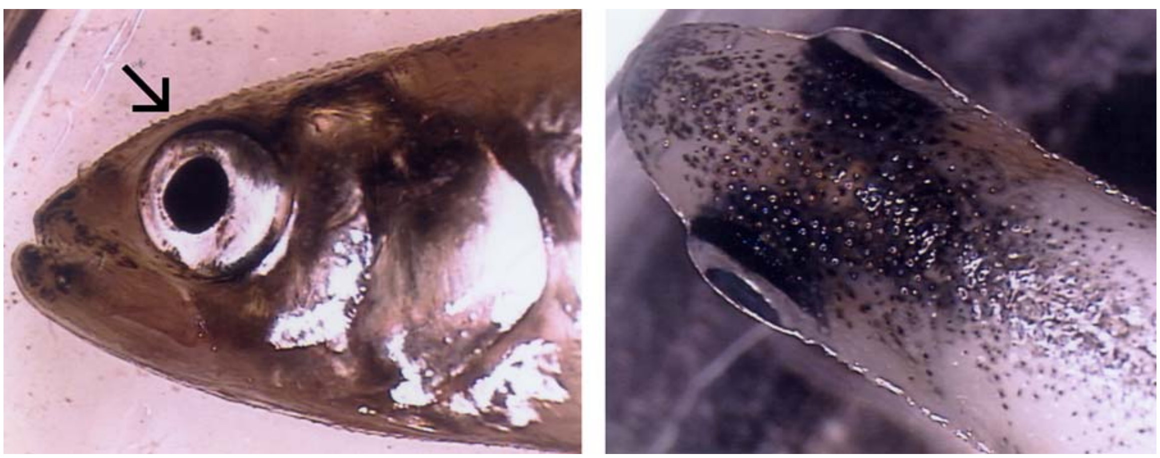


FIGURE 3.—Breeding tubercles on head of a spawning male delta smelt.

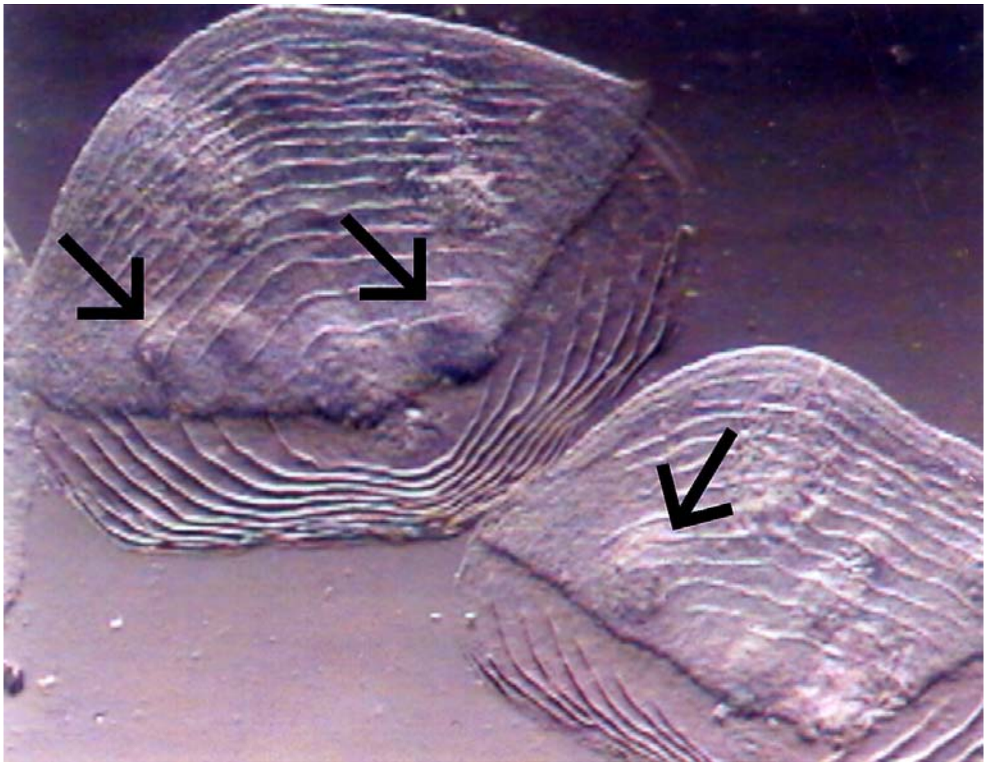


FIGURE 4.—Breading bumps located on the epidermal tissue of the scale from a spawning male delta smelt.

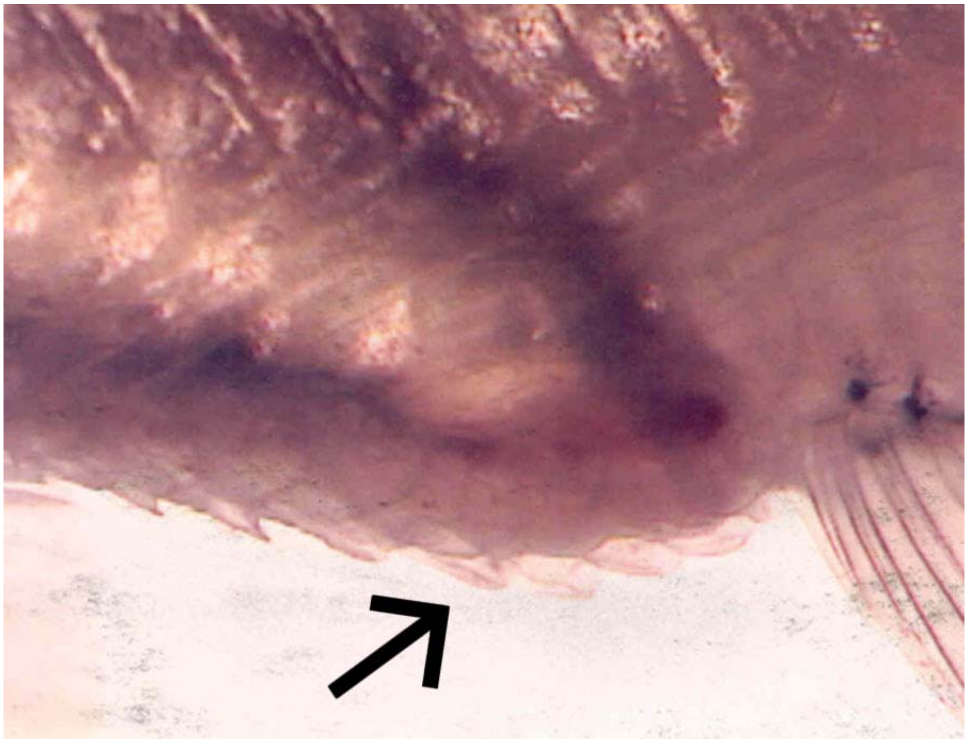


FIGURE 5.—Modified scales in front of the anal fin of delta smelt.

3. Reproductive organ: Two types of testes have been observed: paired testes are found during the developmental stage; right testes is much smaller than the left testes for some mature fish; majority of male adult delta smelt have only a functional developed left testes, whitish color; and right testes is a string barely visible.

Female delta smelt

Prior to spawning: Pigments on snout, head, dorsal half of body, and caudal peduncle become lighter. Pigments along the base of anal fin are sparse.

During spawning:

1. Breeding color: Female fish has light yellow-glow with silvery lateral band; pigmentation is similar to prespawning stage.

2. Breeding tubercles and breeding bumps: Breeding tubercles and bumps cover the entire body (rare on head) of some females, but not as noticeable as the males.

3. Reproductive organ: Paired ovary has been observed during the developmental stage. Fully developed paired ovaries are rarely observed, even in culture (Bradd Baskerville-Bridges, personal communication). The majority of female delta smelt have only one functional ovary, located on the left side of the body cavity.

Field and Laboratory Observations of Spawning

Ripe delta smelt have been collected in several freshwater sloughs of the Delta (Lindberg and Marzola, 1993). Smelt eggs were collected in the Montezuma Slough (Ecological Analysts, Inc. 316a sampling for Pacific Gas & Electric (PG&E), 1979–1982). Spawning behavior was repeatedly observed in the indoor and outdoor smelt hatching facility by Lindberg *et al.* (2003). Delta smelt eggs were harvested from the bottom of outdoor tanks in the morning, indicating smelt spawn at pre-dawn hours (Brent Bridges, personal communication). In indoor aquarium, delta smelt eggs were harvested from sand and gravel and some eggs were attached to artificial plants (this study). Lindberg *et al.* (2003) had a similar observation where eggs were observed on the horizontal surface of substrates and hardly on the vertical surface. They also detected delta smelt preferring to release eggs in strong currents over sand and gravel bottom substrates. Delta smelt have demersal eggs that drift with the current while descending; however, delta smelt were observed depositing their eggs close to the bottom substrate, which means the eggs, may not drift very far (Bradd Baskerville-Bridges, personal communication). The outer layer of chorion reverses and forms an anchor immediately as it contacts the bottom substrate. Observation made in this study would indicate that ideal incubating conditions are when the eggs contact the hard surface and bounce. This bouncing allows a short pedestal or stalk (ca. 0.2 – 0.3 mm in lengths) to form. This stalk suspends the egg off the hard substrate and provides maximum surface area for aeration.

Delta smelt yolk-sac larvae and early postlarvae taken in the late 1970s to the early 2000s indicate that the spawning period extends approximately 5 months, from February through June (Ecological Analysts, Inc.; Wang, 1986; CDFG 1988–1995). Water temperature during this period fluctuates 7 – 17 °C (Wang, 1986) or 7 – 22 °C (Moyle, 2002), although the ideal temperature is thought to be 15 °C in the laboratory (Lindberg *et al.*, 2003).

The following are general observations of spawning of the delta smelt:

1. Individual smelt completes egg discharge in a very short time (hours to few days, laboratory observation). Fish held in captivity (wild caught broodfish) have been observed to spawn multiple times (1 – 3 times per season) when suitable environmental conditions were maintained (Baskerville-Bridges and Lindberg, personal communication). The natural spawning period is generally only large enough for one clutch of eggs. Laboratory studies suggest that fish spawning early in the season may be able to spawn a second time if food and temperature levels permit. Adult smelt in the field are seldom caught in large schools of over 400 fishes in the months prior to spawning (Brent Bridges, personal communication). In addition, ripe smelt are usually caught at the CVP/TFCF in schools less than 5 fishes from 10-minute fish samples. Therefore, it is likely delta smelt may spawn in small groups and in scattered micro spawning habitats (Bradd Baskerville-Bridges, personal communication; this study). Pre-spawning smelt arrive to the staging ground (vicinity of Decker Island) about the same time each year, usually in September to October (Moyle, 2002) and through November (Bradd Baskerville-Bridges, personal communication). After the first heavy rains of the season, delta smelt disperse.

2. The gonads of most of the prespawning fish do not start to develop until sometime in November and as late as March of the following year (field samples obtained from Bradd Baskerville-Bridges and Brent Bridges from 2000–2005). Ova development of adult smelt was monitored closely at the CVP/TFCF between 2000 and 2005 (table 1). In general, it takes about 2 months (such as 2001, 2002, and 2004) to 3 months (such as 2000 and 2003) for immature ova (0.1 – 0.2 mm in diameter and no yolk present) to develop into mature ova (0.8 mm in diameter with yolk, oil globules, and anchor). Males reach maturity about 2–3 weeks ahead of females. During the warm winter in 2004–2005, the delta smelt reached maturity in less than 2 months. Gonads developed when fish reached about 60 mm TL. Large numbers of delta smelt less than 60 mm TL were collected by CDFG in mid-November 2005. The gonads of those fish were not developed (this study).

3. In the laboratory, the spawning of the delta smelt can be induced in fish less than 9 months old. This is done by alternating the photo period, water temperature, and food (laboratory spawn by mid-December 2004 and November 2005).

Delta smelt embryology

A detailed description of gametogenesis and artificial propagation of the delta smelt was reported by Mager (1996). The following is a summary of delta smelt egg incubation (both by natural spawn and artificial fertilization) and hatching in repeated observations from 1999–2001.

Spawning water temperature

At 13.7 – 15.0 °C from naturally spawned eggs and eggs fertilized in vitro.

At 15.0 – 18.5 °C incubation temperatures (increased to 19 – 21 °C caused by the eggs being viewed under the dissecting scope several times daily).

Day 0: Fertilization to early cleavage to morula stages

Cleavage starts within 2 hours (h) at the blastodisc when the blastoderm elevates into a mount and divides into 2 cells. It is at 8 – 16 cells stage in 6 h. It forms the morula stage at 12 h. The majority of the eggs are 0.9 – 1.0 mm in diameter and the perivitelline space is about 0.1 mm in width. Oil globules consolidate into 1 – 3 large oil globules surrounded by many small oil globulets in the yolk sac. A naturally deposited egg has a pedestal connecting between the inner chorion and the anchoring point. An egg fertilized in vitro has a large flat footing attached to the hard surface such as glassware. Unfertilized eggs turned white within 24 h after fertilization, and abnormally developed eggs die by the end of the morula stage.

Day 1: Blastula to gastrula stages

The germ ring starts to cover the peripheral region of the blastodisc, to the upper half of the yolk and toward the lower half. The yolk plug still can be seen as a big circle. The embryonic shield becomes visible. Tissues (or blastomeres) in the embryonic shield become thicker and forming an elongate ridge also known as the embryonic axis. This axis will develop into the central nervous system.

Day 2: Gastrula to early embryo stages

The embryonic axis grows longer. Initially, the size of the cephalic region and the caudal region are similar, and then the cephalic tissue elevates to form a head. Mesodermal somites appear on each side of the embryonic axis and eventually develop into myomeres. The spinal cord becomes more visible between the two rows of somites. The germ ring is near to close the yolk plug. The oil globules are still in the process of total consolidation.

Day 3: Early embryo to tail-bud stages

The length of embryo is approximately 1.0 – 1.5 mm TL. It lies on the top of the yolk and covers more than half of yolk hemisphere. The optic cup and lens are visible and the divisions of the brain become more defined. Tail is a bud. Yolk plug is closed and yolk sac is inside of body. Perivitelline space is less than 0.1 mm in width. The egg size is unchanged.

Day 4: Tail-free stage

The tail is free from the yolk sac. The embryo has almost made one complete circle around the yolk sac. Perivitelline space is very narrow due to the back of the embryo leaning on the inner surface of the chorion. The myomeres (ca. 40), myosepta, beating heart, auditory vesicle, and otoliths can be clearly seen. Oil globules are consolidated into one (or almost in one) and its size ranged 0.3 – 0.4 mm in diameter. Egg size remains unchanged.

Day 5: Late embryo stage

The embryo wraps around more than one full circle around the yolk sac. The total length of embryo is estimated at 2.5 mm. The yolk size is slightly reduced; long axis is 0.7 – 0.8 mm in diameter and the short axis is 0.6 mm. The oil globule is 0.3 mm in diameter. Heartbeats become more obvious and the circulatory system carries rapidly moving red blood cells. Eye and choroid fissure covered with a thin layer of melanin. The embryo moves gradually inside of chorion. Egg is firmly anchored and size of egg is unchanged.

Day 6: Late embryo stage (continued)

Eye is becoming more pigmented. Total length of the embryo is measured at 3 mm. The yolk sac becomes more flat, long axis is at 0.6 – 0.7 mm in diameter and short axis is at 0.5 – 0.6 mm. Oil globule is at 0.2 – 0.3 mm in diameter. The total myomeres count is 50 (measurements obtained by dissecting embryo). Live eggs are firmly anchored to the substrates, while dead eggs fall off from the pedestal.

Day 7: Late embryo stage (continued)

The eye turns completely black. The embryo is measured at ca. 3.5 mm and wraps around the yolk sac about one and a half circle. The pectoral finbud becomes visible. The yolk sac is further shrinking to a flat asymmetrical form that is 0.5 mm long and 0.5 mm wide. Oil globule stays at 0.2 – 0.3 mm in diameter with a bright yellow glow. Size of egg is unchanged.

Day 8: Late embryo stage (continued)

The embryo wraps around inside of the chorion to form two full circles (or almost two circles). The head is well defined due to the reduction in size of the yolk sac in the thoracic area. The yolk sac reshapes into spherical or slightly oval longitudinally, having a size of 0.5 – 0.7 mm in diameter. The oil globule is measured at 0.2 – 0.3 mm in diameter and all globulets have disappeared. Light-colored stellate melanophores are found on the entire surface of the yolk sac while dashed melanophores are along midventral and postanal regions. Auditory vesicle and otoliths are visible. The eyes (iris) of some embryos turn silvery color, a sign the larvae are ready to hatch.

Day 9: Prior to hatching and hatching

Smelt ready to hatch move frequently inside of the chorion. Movements are very erratic just before hatching. The tail usually emerges first (use of tail for kicking out). The ruptured chorion is still anchored to the substrate. Size of egg is not changed to slightly dilated.

Day 10 and longer: Hatching

Eggs continue hatching at day 10 and day 11 and some even longer while others are dead and never hatch. Early-hatched larvae range in size from 4.2 – 4.7 mm TL, while late-hatched larvae are slightly larger, up to 5.0 mm TL. Larvae are slightly transparent except the eye and midventral area, which are pigmented. Newly hatched larvae can swim freely by propelling itself using the tail. The pectoral finbud help balance the young larvae. Larvae use a swim/rest cycle between water column and bottom of hatching jar in short intervals. Larvae are also extremely phototactic and show swim-up behavior (Bradd Baskerville-Bridges, personal communication). Yolk-sac larval smelt reach to the water surface mostly within 2–3 days.

Fish E&L sampling in the upper Sacramento-San Joaquin Estuary, 1988–1995

CDFG surveyed the abundance of the striped bass, *Morone saxatilis*, with an E&L sampling program between 1988 and 1995. Much of early life history information on striped bass as well as other species, including delta smelt, were recorded in this 8 year study. Wang (1991) and Wang and Brown (1993) reviewed and published the first 4 years (1988–1991) of the early life history information on delta smelt from these studies. The last 4 years (1992–1995) of this database is presented in this report (appendix tables A2, A3, A4, and A5). The following is the description of temporal and spatial distributions of delta smelt larvae, with emphasis on the newly hatched larvae, which are indicative of close proximity to the spawning location (Moyle, 2002). Most of the smelt larvae collected in this study are ca. 4.0 – 8.0 mm TL.

1992 (Critically-dry year in Sacramento and San Joaquin Rivers)

1. Sacramento River: Isleton is at the center of the catch distribution, including Cache Slough, Steamboat Slough, and Sacramento River. Peak of hatching occurs in April and May.

2. San Joaquin River: Distributed mainly along the channels of Sherman, Bradford, and Twitchell Islands. Peak of hatching is March and April.

3. Distribution: Larvae more concentrated in the Lower Sacramento River (Isleton) and Lower San Joaquin River. Spawning peak was earlier in San Joaquin River than the Sacramento River. West Delta and Suisun Bay were not used much for spawning.

1993 (Average year in Sacramento River and wet year in San Joaquin River)

1. Sacramento River: No particular concentration of spawning was observed. Spawning stretched from the mouth of the Sacramento River to Elk Grove. Peak hatching occurred from February to May.

2. San Joaquin River: No concentrated spawning area was observed from the larval distribution. There were slightly higher catches at the mouth of San Joaquin River to Venice Island. Scattered hatching was observed with spawning occurring over several months from March to May.

3. Lower Mokelumne River: Scattered hatching occurred from March to May.

4. West Delta, Suisun Bay and Montezuma Slough: No real peak with hatching occurred from March to May.

5. Distribution: Larvae were observed almost in all sampling stations, from Suisun Bay to the Sacramento River, and up the San Joaquin River to the Mokelumne River. Larvae were widely distributed from river, Delta, West Delta, and Suisun Bay and spawning lasted from February to June. Many new micro-spawning habitats may have been created in this high flow water year after a period of drought conditions.

1994 (Critically-dry year in Sacramento and San Joaquin Rivers)

1. Sacramento River: Larvae were observed mainly in the vicinity of Isleton. Their distribution extended from Decker Island to Garcia Bend in the north. Peak hatching was from mid-March to early May.

2. San Joaquin River: Larvae were observed mostly from Sherman Island to Venice Island. Peak hatching occurred from late March to early May.

3. Mokelumne River: A few larvae were observed in late March and early June.

4. Distribution: More larvae were observed in the Sacramento River and San Joaquin River, and a few larvae were seen in the West Delta and Suisun Bay. The heaviest spawn occurred in the San Joaquin River in April.

1995 (Wet year in Sacramento and San Joaquin Rivers)

1. Sacramento River: A few larvae were observed at Decker Island and Cache Slough.

2. San Joaquin River: A few larvae were observed at the mouth of the San Joaquin River and in the Lower Mokelumne River.

3. Suisun Bay, Montezuma Slough, and West Delta: A few larvae were scattered at various stations.

4. Distribution: Only a few larvae were observed in the entire sampling area. No spawning peak was observed. The major spawning area may have been displaced further down bay in this very wet year with high flows.

Observations and discussions of delta smelt

1. Observations of delta smelt larvae: Young larvae collected in the field ranged in size from ca. 4 – 8 mm TL. Larger size larvae (or postlarvae) declined rapidly from the sample. Larvae have been collected in both channel and inshore sampling stations. Delta smelt larvae are mainly found in the lower reaches of the Sacramento River and San Joaquin River in spring months.

   In laboratory observations, the larvae at hatching are at rest on the tank bottom. They do not come up initially. However, larvae can swim up to the water surface when disturbed. In turbid environments shortly after hatching, larvae are spread out in a homogenous distribution in the water column. When the tank clears, larvae tend to go back to the tank bottom (Bradd Baskerville-Bridges, personal communication).

   When feeding, larvae adopt (coil) an “S”-shape configuration, orient themselves on their prey, and thrust forward (recoil) to catch their prey (rotifers) and starter food (Baskerville-Bridges *et al.*, 2004). Young larvae require turbid conditions to initiate and continue feeding. As the larvae approach 20 mm, they become less dependent on highly turbid conditions. They will feed in the open water even at lower turbidities, compared to the young larvae. Therefore, larger fish may be more vulnerable to being caught in samples. Vertical movement is influenced by light intensity, turbidity, and very likely flow (Bradd Baskerville-Bridges, personal communication).

2. Observations of delta smelt juveniles: When delta smelt reach prejuvenile life stage (ca. 15 – 16 mm TL), the air bladder becomes inflated and they turn into a pelagic swimmer. Juveniles are abundant in the South Delta, particularly in May and June (table 3). At the CVP/TFCF they arrive in many small pulses. The detailed movement patterns within the Delta are unclear. Juvenile delta smelt leave the South Delta by the end of June or early July when they reach ca. 40 – 50 mm TL (this study). Larger juveniles move to the Suisun Bay in July. Large numbers of smelt were observed at times on the intake screens at Pittsburg and Contra Costa power plants, again indicating that delta smelt swim in large schools (Wang, 1986).

   Juvenile delta smelt may move downstream (Radtke, 1966; Baxter *et al.*, 1999) as far as San Pablo Bay and Carquinez Strait (Ganssle, 1966; Messersmith, 1966; Baxter *et al.*, 1999). The seasonal movement of delta smelt between the upper Delta and San Pablo Bay can carry these small fish more than 150 kilometers. Juvenile movement downstream from the Central and South Delta is likely due to temperature tolerance and foraging. By July, much of the Central and South Delta is too hot for delta smelt to survive. Juveniles will forage on distinct food in different areas of the Delta to achieve the maximum growth in the shortest possible time. Large juvenile delta smelt moving into the brackish water may be seeking additional marine nutrients necessary to physiologically reach sexual maturity before returning to the staging area near Decker Island in the fall. A sustainable population of delta smelt has not been established in freshwater lakes such the San Luis Reservoir, but spawning occurs in the laboratory under freshwater conditions with special artificial diet containing marine nutrients (Baskerville-Bridges *et al.*, 2004). In the wild, juvenile delta smelt feed primarily on planktonic crustaceans, including their nauplii stages, and insect larvae (Moyle, 2002). Amphipods (*Gammarus spp*.) are a common diet for delta smelt prior to spawning (this study).

3. Sexual maturity and ecological status: Delta smelt reach maturity after their first year. Some adults die after spawning and some will survive a second year (Bradd Baskerville-Bridges, personal communication). Moyle (2002) stated that a small number either do not spawn in their first year or spawn a second time. One plus year-old fish with a clear annulus on their scales were collected at the CVP/TFCF in January 2, 2002. Their ovary contained two different sizes of ova: an old, cyst-like ova ca. 0.7 – 0.8 mm in diameter surrounded by a newly developed ova ca. 0.3 – 0.4 mm in diameter. Two-year-old fish were observed occasionally in the brood stock collected from Decker Island in fall 2000–2003 (Brent Bridges and Bradd Baskerville-Bridges, personal communication). Apparently some delta smelt are able to spawn at least twice (Bennett, 2005; Baskerville-Bridges and J. Lindberg, personal communication). Extreme temperature may influence and inhibit spawning behavior in adults (Bradd Baskerville-Bridges, personal communication). In contrast, sufficient food, light, and mild water temperature will induce spawning in fish as young as 9 months old in the laboratory (Brent Bridges and Bradd Baskerville-Bridges, personal communication; this study).

   Delta smelt were historically used as food fish by Native Americans. Currently, delta smelt have no value in the sport or commercial fisheries. Today their principal value is as an ecological indicator species ("the canary of the Delta") to measure the water quality in the Sacramento-San Joaquin Estuary.

Delta smelt major spawning locations

There are four known locations of delta smelt spawning: the Lower Sacramento River, Cache Slough and Lindsey Slough (vicinity of Isleton); the Lower San Joaquin River (from Sherman Island to Venice Island), Lower Mokelumne River (north and south branches) and the South Delta; the West Delta, Suisun Bay, and Suisun Marsh; and finally, the Napa River, mainly in wet years.

Lower Sacramento River, Cache Slough, and Lindsey Slough

This area is thought to be the major delta smelt spawning area since CDFG striped bass E&L sampling started in 1988. Intensive sampling at Lindsey Slough area (NBA Project) has generated additional information on spawning for the delta smelt (table 2).

TABLE 2.—Delta smelt larvae and juveniles collected at the NBA by CDFG in fish E&L sampling program, 1993–2004

Year	February	March	April	May	June	July	Total
[1]1993	0	8	11	9	2	0	**30**
1994	0	20	108	41	4	0	**173**
1995	0	9	2	2	0	0	**13**
1996	0	34	10	72	18	0	**244**
1997	0	45	234	141	12	0	**432**
1998	0	7	3	6	2	0	**18**
1999	0	0	2	34	3	0	**39**
2000	3	3	135	82	18	1	**242**
2001	86	93	231	172	11	4	**597**
2002	2,008	411	76	40	27	4	**2,566**
[2]2003	126	133	81	52	16	3	**411**
2004	7	23	30	90	9	0	**159**

[1] The delta smelt identification was performed by this author in 1993–2002.
[2] Delta smelt identification was performed by CDFG biologists in 2003 and 2004.

During the average years and wet years of 1993, 1995, and 1998, the Lower Sacramento River was seldom used for spawning by the delta smelt. During dry years, such as 1999 and 2002, spawning activity was intense in this area. In general, it demonstrates that delta smelt spawning and rearing is further downstream during wet years. Delta smelt have no regular spawning ground.

Two major factors why delta smelt may choose this area for spawning are: (1) the water moves constantly by tidal action and by river flow such as in Barker Slough, Sacramento River Deep Ship Channel, Miner Slough, Steamboat Slough (via Sutter and Elk Sloughs), and Sacramento River, and (2) these channels are located only a short distance above the entrapment zone, a known place where food organisms accumulate. Likewise the interwoven nature of those secondary waterways connecting to the main river make ideal spawning/rearing habitat.

The Lower San Joaquin River, Lower Mokelumne River, and South Delta

The Lower San Joaquin River receives freshwater from the Mokelumne River and from the Sacramento River via connectors such as the Delta Cross Channel, Georgiana Slough (with positive flow), and Three Mile Slough. It is one of the most dynamic areas for delta smelt spawning. During wet years, the delta smelt move to the Suisun Bay and the West Delta to spawn. Delta smelt retreat up the Lower San Joaquin River during dry years thus avoiding the salt wedge that moves into the confluence area. Delta smelt will move further inland to the upper Delta (or the North and South forks of the Mokelumne River) in dry years. In recent dry years, some of the spawning occurs further upstream into the South Delta. Delta smelt of all life stages have been observed at the CVP/TFCF (table 3).

TABLE 3.—Delta smelt collected at the CVP/TFCF by Reclamation, including holding tank 10-minute count sampling and all special studies, 1995–2005

Month	Life Stages	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
October	A	0	0	0	0	0	1	0	0	0	0	0
	J-L	0	0	0	0	0	0	0	0	0	0	0
November	A	0	0	0	0	0	22	1	0	0	0	0
	J-L	0	0	0	0	0	0	0	0	0	0	0
December	A	0	0	0	0	4	13	26	67	10	0	0
	J-L	0	0	0	0	0	0	0	0	0	0	0
January	A	0	0	0	0	2	32	13	95	179	101	12
	J-L	0	0	0	0	0	0	0	0	0	0	0
February	A	0	0	0	0	38	47	60	13	43	40	6
	J-L	0	0	0	0	0	0	0	0	0	0	0
March	A	0	0	36	0	0	49	0	5	38	72	0
	J-L	0	0	0	0	0	0	0	0	0	0	0
April	A	0	0	0	0	0	0	8	0	3	0	0
	J-L	0	11	272	0	3	99	17	202	216	60	0
May	A	0	0	0	0	1	0	0	0	0	0	0
	J-L	0	595	1,410	0	1,814	1,409	713	1,076	1,675	339	6
June	A	0	0	0	0	2	0	0	0	0	0	0
	J-L	0	41	52	1	1,898	693	107	329	122	53	8
July	A	0	0	0	0	0	0	0	0	0	0	0
	J-L	0	1	0	3	27	21	0	2	0	0	0
August	A	0	0	0	0	0	0	0	0	0	0	0
	J-L	0	0	0	0	1	0	0	0	0	0	0
Total	**A**	**0**	**0**	**36**	**0**	**47**	**160**	**108**	**180**	**273**	**213**	**18**
	J-L	**0**	**647**	**1,734**	**4**	**3,743**	**2,222**	**837**	**1,609**	**2,013**	**452**	**14**
20 mm less* (percent)		0	—	24.1	0	1.6	16.5	17.7	13.1	14.8	10.2	0

Note:
A: Adult.
L-J: Larvae, prejuveniles, and juveniles.
*: Size ranged: 9.5 – 19.5 mm TL.
—: No data.

Catch of delta smelt less than 20 mm TL at the CVP/TFCF sampling had a range of 0 to 24.1 percent and with 14.5 percent average in 2000–2004 (table 3). Due to the sampling methodology used by the CVP/TFCF, the delta smelt prolarvae and postlarvae were seldom collected. The smallest larva was recorded at 9.5 mm TL on May 1, 2003. However, small delta smelt larvae have been documented in the South Delta, including in the vicinity of the CVP/TFCF and SWP/SDFPF by Spaar (1990a; 1990b; 1991; 1992, 1993; Spaar and Wadsworth, 1994; Hiebert, 1995; and Siegfried *et al.*, 2000). More larvae of the delta smelt have been observed in dry years than wet years (table 4).

TABLE 4.—Comparison of early life stages of delta smelt collected at Central and South Delta by DWR in fish E&L sampling stations, 1993–1995

Station:	49	930	931	932	933	934	91	92	93	95	96	98	Total
1993: Average year/Sacramento River and wet year/San Joaquin River													
Feb.	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Mar.	0	1	4	3	0	7	0	1	0	0	1	0	**17**
Apr.	0	5	2	0	7	7	2	0	0	2	1	0	**26**
May	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Jun.	0	0	0	1	0	0	0	0	0	0	0	0	**1**
1994: Critical year/Sacramento River and San Joaquin River													
Feb.	0	1	0	0	0	1	0	0	0	0	0	0	**2**
Mar.	32	2	1	6	1	0	0	4	1	1	2	0	**50**
Apr.	67	0	0	7	2	1	0	0	1	0	0	0	**78**
May	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Jun.	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1995: Wet year/Sacramento River and San Joaquin River													
Feb.	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Mar.	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Apr.	1	1	0	0	0	0	0	0	0	0	0	0	**0**
May	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Jun.	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Comments on Lower San Joaquin and South Delta spawning habitat

1. The Lower San Joaquin and the South Delta respond to the salt wedge. When the salt wedge moves upstream from the Bay, delta smelt spawn further inland.

2. Receiving freshwater flow from the Sacramento River via the above mentioned connectors causes spawning to be more intense in some years such as 1989, 1990 (Wang and Brown, 1993), and 1994 (this study).

3. Spawning habitat shifts toward the South Delta during critically-dry years causing abundance to increase in the exported water. Delta smelt are seldom observed in the South Delta in high Delta outflow years such as 1995, 1998, and 2005 (tables 3 and 4). The South Delta is too far away from the entrapment zone and has been used in rare occasions as a spawning habitat.

4. Delta smelt were found in the vicinity of Mossdale of San Joaquin River (Erkkila *et al.*, 1950; Moyle 2002); thus, sampling for delta smelt spawning in the lower Calaveras River and French Camp Slough is recommended during dry years.

West Delta, Suisun Bay and Suisun Marsh

Of the three areas, Suisun Marsh is the principal spawning habitat for the delta smelt (table 5). The majority of the spawning activity occurs in the tributaries of the Montezuma Slough, namely the Cordelia Creek, Nurse Slough and Spring Branch (UC Davis Suisun Marsh sampling):

1. Judging from the location of delta smelt larvae collected by UC Davis, the delta smelt spawning area principally occurs in waters above the entrapment zone of the Cordelia Creek, Spring Branch, and Nurse Slough, with some spawning probably in the entrapment zone (Wang, 1991). Spawning activity can be very intense, as in 1996, or very light, as in 1997 (table 5). Both were wet years with greatly fluctuating spawning activity. Spawning activity may relate to the interactions from the flows of local tributaries as well as the Delta.

TABLE 5.—Delta smelt larvae and juveniles collected at Suisun Marsh by UC Davis in fish E&L sampling program, 1995–2002

Month	1995	1996	1997	1998	1999	2000	2001	2002
February	0	0	0	0	0	0	2	2
March	0	8	0	0	0	20	5	4
April	16	193	0	13	44	45	3	9
May	45	588	9	14	58	51	18	0
June	15	44	0	9	0	0	0	0
Total	76	825	9	36	102	116	28	15

2. Suisun Marsh creeks and sloughs can become a very unfavorable spawning habitat when high saline water intrusion rushes into these upper areas and are insufficiently buffered by the freshwater outflow from upper drainages.

3. Despite environmental variables, Suisun Marsh still is an important spawning/ nursery habitat for the delta smelt. Over 70 percent (115/163 larvae) of the delta smelt larvae were collected from the sampling stations located in the Montezuma Slough in CDFG's Delta Smelt Larvae Survey (DSLS) pilot sampling program in 2005 (Mike Dege, personal communication). This may be attributed to the proximity between the entrapment zone and the spawning ground in Suisun Marsh in a wet year when the entrapment zone moves westward from the Delta.

Napa River

The Napa River probably has been used as delta spawning ground for many years, but it was not identified until 1995 (Sweetnam, 1999). Napa River may be an alternative spawning ground for the delta smelt. The following lists the occurrence of delta smelt in the Napa River:

1. From CDFG sampling catch record, delta smelt larvae observed at Sampling Station 323 (E. San Pablo Bay) and Sampling Station 340 (Lower Napa River) on May 15, 1995.

2. Delta smelt larvae were found at Napa River Sampling Stations (340, 342, 344, 345, and 346) in March and April 1996.

3. Stillwater Sciences, Inc.[1] collected approximately 4,000 delta smelt (over 600 were in the ranges 5.7 – 23.0 mm TL) in the upper Napa River sampling stations 347, 348, and 349 in 2001).

4. CDFG 20 mm fish sampling observed delta smelt in the Napa River most of the years between 1995 and 2005 (appendix table A10), and

5. The Napa River may act as a short estuary where the delta smelt abundance shifts with yearly flow conditions, so the delta smelt use it as an alternative spawning/nursery ground.

Comments on delta smelt spawning strategy

1. Delta smelt spawning location is correlated with freshwater outflow, and spawning occurs mainly above the entrapment zone. Spawning locations change within a season and from year to year. Delta smelt, longfin smelt, wakasagi, and splittail ascend to the river and Delta to spawn in dry year of 1994, and descend to the Delta and Bay to spawn in a wet year of 1995 (Wang, 1996).

2. Delta smelt do not leave this system regardless of the water year types and flows. For example, the year of 1998 was a very wet year; a few delta smelt larvae and juveniles were observed at three known locations (table 6); delta smelt bounced back in 1999, another wet year. Delta smelt apparently spawn in a much wider area in the system during wet years, which the current sampling methodology (fixed sampling station) is unable to detect.

3. Low catches of delta smelt larvae in wet years do not represent a true picture of the delta smelt recruitment failure. Delta smelt may have more spawning habitat and larvae may disperse in a much wider rearing area in wet years than dry years. Spawning may have moved from river and Delta to Suisun Bay and

[1] U.S. Army Corps of Engineers contracted Stillwater Sciences, Inc. to conduct fisheries study in the Flood Plain area of upper Napa River in 2001–2005 (appendix table A11).

possibly further down Bay, depending on the volume of outflow during the spawning season. This author believes that delta smelt spawn in areas down Bay (and its tributaries) and that wet years may actually benefit delta smelt recruitment. This can be demonstrated by the catch of delta smelt larvae at three above mentioned locations in 1998 and 1999 (table 6). Looking at the historical CDFG's delta smelt fall abundance indices (7.4 in 1995, 47.4 in 1996, 8.5 in 1998, 47.6 in 1999) for adult delta smelt appears to be comparable. The success of delta smelt population recruitment is due to diversified spawning and rearing habitat and should not be summarized from solely using any small study area or any single year. This author suggests exploring the delta smelt spawning activity in other tributaries draining into San Pablo Bay and San Francisco Bay in very wet years.

TABLE 6.—Comparison of relative abundance of delta smelt larvae and juveniles collected at the NBA, CVP/TFCF, and Suisun Marsh in 1998 and 1999 (wet years)

Month	Location					
	NBA		CVP/TFCF		Suisun Marsh	
	1998	1999	1998	1999	1998	1999
February	0	0	0	0	0	0
March	7	0	0	0	13	0
April	3	2	0	3	14	44
May	6	34	0	1,814	9	58
June	2	3	[1]1	1,898	0	0
July	0	0	[1]3	27	—	—
Total	**18**	**39**	**4**	**3,843**	**36**	**102**

Note:
— not sampled
[1] Juvenile life stage only

4. Delta smelt are short lived fish; however, to compensate for their short lives they have the ability to extend and maximize their spawning. Although largely food and temperature limited, delta smelt can vary their timing at which they reach sexual maturity, spawn in wide ranges of water temperatures, and spawn in various micro-habitats (Lindberg *et al.*, 2003). Spawning in a wide area and in a sporadic manner may reduce egg loss from predation.

5. Wang and Brown (1993) noted that delta smelt were able to switch spawning ground (toward Sacramento River) in short notice in late April 1991 to avoid salinity intrusions occurring in the West Delta. Whenever the entrapment zone moves, the spawning location changes.

6. Some individual smelt may delay or spawn twice in their life, which may enable the species to avoid natural disaster.

7. Delta smelt may reach maturity at a smaller size (ca. 60 mm TL) in very unfavorable environments, such as during a very dry year in 1994. Their elusive behavior can be interpreted as part of the survival strategy of the species.

SURF SMELT, *Hypomesus pretiosus* (Girard); figures 6a and 6b

SPAWNING

Location: Beaches at high tide mark and surf zone of the Pacific Coast (Thompson *et al.*, 1936); at the head of sheltered bays with exposed or shaded beaches (Schaefer, 1936; Hart and McHugh, 1944); sandy and gravel beaches (Yapchiongco, 1949); beaches of Puget Sound (Penttila, 2000); coastal beaches of Sonoma County and San Mateo County (Frey, ed., 1971).

Season: May–March (Schaefer, 1936); May-October (Yapchiongco, 1949; McAllister, 1963); most months of the year (Hart and McHugh, 1944; Hart, 1973); all year round but mainly in fall and winter in Puget Sound (Penttila, 2000); fall and winter months in San Francisco Bay and Tomales Bay (Wang, 1986); all year round in Humboldt Bay, California (Ecological Analysts, Inc. fish sampling in the vicinity of Humboldt Bay PG&E nuclear power plant, 1978–1979).

Temperature: ca. 10 °C and higher (Schaefer, 1936).

Salinity: Seawater-mesohaline (Thompson *et al.*, 1936; Schaefer, 1936).

Substrates: Sand, coarse sand, shell and gravel (Thompson *et al.*, 1936; Schaefer, 1936; Yapchiongco, 1949).

Fecundity: 4,020 – 13,700 (Thompson *et al.*, 1936); 2,500 – 29,300 (Schaefer, 1936); 2,500 – 37,000 per batch (Hart and McHugh, 1944); 1,500 – 30,000 (Fitch and Lavenberg, 1971).

EGGS

Shape: Spherical (Yapchiongco, 1949).

Diameter: 1.00 – 1.12 mm (Thompson *et al.*, 1936); 1.02 mm (Schaefer, 1936); ranges 0.93 – 1.24 mm, and mostly 1.10 mm (Yapchiongco, 1949); 0.9 – 1.2 mm (from specimens collected by Dan Penttila in Puget Sound, loaned to this study).

Yolk: Paraffin-like in opaqueness (Yapchiongco, 1949); unfertilized egg yolk, granular (Wang, 1986).

Oil globule: Numerous near periphery of yolk (Yapchiongco, 1949).

Chorion: Transparent with many minute pores, with a cap-like accessory structure superimposed on the chorion (Yapchiongco, 1949); chorion has two layers, the inner layer is clear and smooth, outer layer will reverse and attach after the egg is released (Wang, 1986; Penttila, 2000).

Perivitelline space: 0.13 mm in width (Schaefer, 1936).

Egg mass: Deposited singly, but may appear clustered due to successive broadcast over a certain area of the substrate (Yapchiongco, 1949).

Adhesiveness: Adhesive (Thompson *et al.*, 1936; Schaefer, 1936; Yapchiongco, 1949); adhesive at the anchoring area and mostly no stalk between chorion and sand particles or substrates (Penttila, 2000; this study).

Buoyancy: Negatively bouyant.

LARVAE

Length of hatching: ca. 3.0 mm TL (Schaefer, 1936); ranges 4 – 6 mm TL (Yapchiongco, 1949); 4.0 – 5.2 mm TL (Puget Sound specimen).

Snout to anus length: 71 – 74 percent of TL of larvae at 6.1 – 29.5 mm TL.

Oil globule(s): One, ca. 0.1 – 0.2 mm in diameter (Puget Sound specimens).

Gut: Straight.

Air Bladder: Single, small oval to large oval, located midway between base of pectoral fin and anus, or slightly anterior and above pelvic fin bud in postlarval stage.

Teeth: Very small, apparent in postlarvae.

Size at absorption of yolk sac: 6.0 – 6.2 mm TL (Yapchiongco, 1949); ca. 6.5 – 7.0 mm TL.

Total myomeres: 63 – 67.

Preanal myomeres: 47 – 52.

Postanal myomeres: 14 – 17.

Last fin(s) to complete development: Pectoral.

Pigmentation: In prolarvae, yolk sac is heavily pigmented with paired melanophores on the thoracic, midventral and postanal regions. In postlarvae, two rows of large melanophores on the midventral and postanal regions; a few melanophores on percales and caudal peduncle; dashed melanophores along lateral line, especially posterior portion of body.

Distribution: Pelagic along the Pacific Coast, bay and estuary; locally, up to Suisun Bay (Baxter *et al.*, 1999); Suisun Bay to the South Delta and also observed in lower Walker Creek of Tomales Bay.

JUVENILES

Dorsal fin: 8 – 11 (Miller and Lea, 1976).

Anal fin: 12 – 17 (Miller and Lea, 1976).

Pectoral fin: 14 – 17 (McAllister, 1963; Miller and Lea, 1976).

Adipose fin: Yes.

Mouth: Terminal, moderate.

Vertebrae: 62 – 70 (McAllister, 1963), mostly 65 – 66.

Distribution: Along the Pacific Coast; coastal beach near to estuarine plume; juveniles are also entering the euryhaline waters such as the Sacramento-San Joaquin Estuary and Tomales Bay.

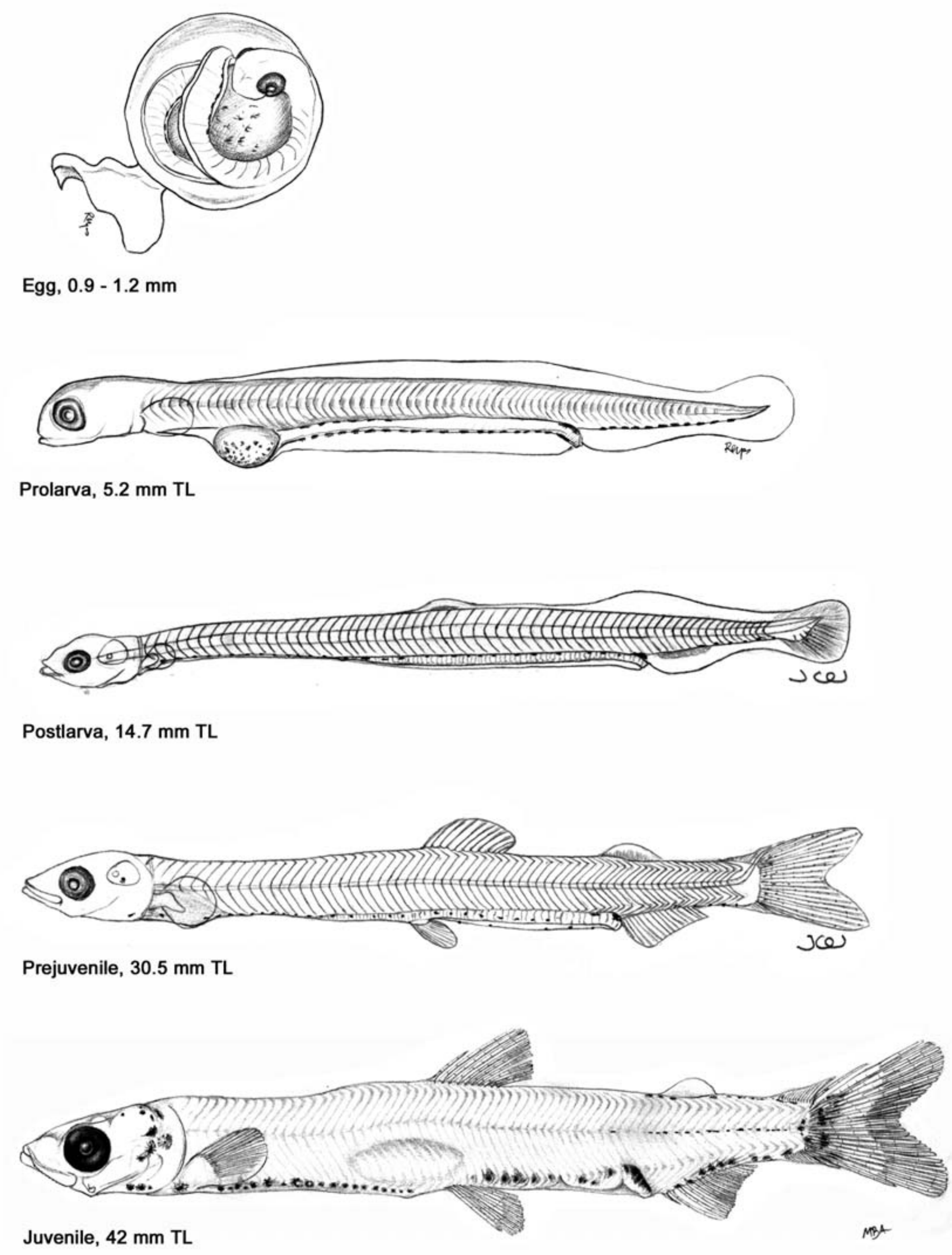


FIGURE 6a.—Early life stages of surf smelt drawings.

FIGURE 6b.—Early life stages of surf smelt photographs.

Expanded Life History – Surf Smelt

The surf smelt has been reported from Prince William Sound and Chignik Lagoon, Alaska, southward to Long Beach, California (Miller and Lea, 1976; Hart, 1973). In the Sacramento-San Joaquin Estuary, the surf smelt has been observed mostly in the San Francisco Bay, San Pablo Bay, Carquinez Strait, and Suisun Bay (Ganssle, 1966; Messersmith, 1966; Aplin, 1967; Baxter *et al.*, 1999). The larvae and juveniles can tolerate the mesohaline and freshwater, however, they are seldom observed above the Carquinez Strait (Wang, 1986; Baxter *et al.*, 1999).

Observations of spawning

Hart (1973) and Hart and McHugh (1944) noted surf smelt spawning during most months of the year. Contributing to their prolonged spawning season is the fact that females may spawn more than once in a season and that each of the many Pacific Coast surf smelt populations has its own spawning period.

Eggs are deposited in the surf zone on sandy beaches at high tide, usually at the mouth of small bays or inlets (Schaefer, 1936; Hart and McHugh, 1944; Yapchiongco, 1949; Penttila, 2000). Spawning was reported along the coastal beaches of Sonoma and San Mateo counties (Frey, 1971). Small larvae were also collected in the Moss Landing Harbor (Wang, 1986) and spawning in the harbor inlet is a possibility. A detailed account of spawning behavior has been given by Schaefer (1936). The adhesive eggs become encrusted with sand grains or anchored to pieces of gravel (Hart and McHugh, 1944; Penttila, 2000). The eggs hatch in 10 – 11 days in summer and take a longer time in the winter (Hart, 1973). In the Puget Sound, eggs hatched in 14–21 days and were dependent on the season (Penttila, 2000).

Judging from the size of the larvae collected from the Sacramento-San Joaquin Estuary, surf smelt spawn only during the fall and winter months in this area (Wang, 1986). Surf smelt larvae were only taken in Central San Francisco Bay in November and March (Baxter *et al.*, 1999). Surf smelt larvae collected year round in the vicinity of Humboldt Bay Nuclear Power Plant indicate that they spawn year round in their northern range.

Observations of surf smelt larvae and juveniles

In contrast with the longfin smelt spawning, the small numbers of surf smelt larvae collected within the Sacramento-San Joaquin Estuary indicate that most spawning occurs outside of the estuary. Surf smelt use the estuary as an extended nursery in their early life stages. Follett (1952) collected postlarval stages of surf smelt from the vicinity of the southeast Farallon Islands in 33 – 44 fathoms of water. In the San Francisco Bay, wide range surf smelt larvae and juveniles were captured in beach seine, midwater trawl, and otter trawl by CDFG between 1980 and 1995 (Baxter *et al.*, 1999). Postlarvae and juveniles (30 – 50 mm TL) have been collected in Suisun Bay and Walker Creek of Sonoma County occasionally during the winter months. Smaller larvae (< 15 mm TL) were collected in Moss Landing Harbor (Wang, 1986; this study). Larvae and juveniles were also observed at the CVP/TFCF on rare occasions (Wang, 1986), such as a small juvenile (46.5 mm TL) on February 2, 2001, (Brent Bridges, personal communication). Major food items of juvenile surf smelt included small crustaceans such as copepods, amphipods, and shrimp and crab larvae (Hart, 1973). Insect larvae are found in the stomach when they inhabit freshwater (Yapchiongco, 1949). Preserved specimens obtained from Paradise Beach and Treasure Island (Lisa Lynch, personal communication) showed orange coloration in the stomach (chitinous tissues of crustaceans).

Observations of surf smelt adults and sexual maturity

Surf smelt reach maturity in 1 to 3 years and usually do not live more than 3 years (Yapchiongco, 1949; Penttila, 1978). Surf smelt are relatively small, ranging in size from 222 to 305 mm (Hart, 1973), are considered to be a delicacy (fried smelt), and constitute one of California's important coastal fishery (Fitch and Lavenberg, 1971).

LONGFIN SMELT, *Spirinchus thaleichthys* (Ayres); figures 7a and 7b

SPAWNING

Location:	Freshwater section of the lower Delta (Moyle, 1976; Baxter, 2000); specific locations include Lower San Joaquin River, Lower Sacramento River, tributaries of Montezuma Slough, West Delta, Suisun Bay, and upper Napa River.
Season:	December-June (Wang, 1986); January-May (Baxter *et al.*, 1999); mostly in February through April (Moyle, 2002); December-February in Suisun Marsh (Schroeter and Moyle, 2004 and 2005).
Temperature:	7 – 14.5 °C (Wang, 1986; Emmett *et al.*, 1991).
Salinity:	Freshwater (Hart and McHugh, 1944; Hart, 1973; Moyle 2002); larvae were collected in San Francisco Bay in high outflow years (Baxter *et al.*, 1999) and spawn may also occur in brackish water in some years.
Substrates:	Rocks and aquatic plants (Moyle, 1976); submerged plants and hard substrates (Lindsey Slough); and sandy bottom (Cordelia Creek).
Fecundity:	9,621 – 23,624, with an average of 18,100, in Lake Washington (Dryfoos, 1965); 24,000 (Moyle, 1976).

EGGS

Shape:	Spherical.
Diameter:	1.2 mm (Dryfoos, 1965); 0.9 – 1.1 mm.
Yolk:	Yellowish, coarse granular.
Oil globule:	Many oil globules, largest ca. 0.35 mm in diameter.
Chorion:	Two layers; inner layer transparent, smooth; the outer layer will reverse and attach to the substrates.
Perivitelline space:	ca. 0.1 – 0.15 mm in width.
Egg mass:	Deposited singly and in single layer.
Adhesiveness:	Outer layer of chorion is adhesive and forms a stalk and anchor between the inner layer of chorion and substrate.
Buoyancy:	Negatively bouyant.

LARVAE

Length of hatching:	6.9 – 8.0 mm TL (Dryfoos, 1965); 5.3 – 6.8 mm TL.
Snout to anus length:	68 – 71 percent of TL of prolarvae at 5.3 – 7.5 mm TL; and 65 percent of TL of postlarvae.
Yolk sac:	Thoracic, in tear drop shape.
Oil globule(s):	One, bright, in front of yolk sac.
Gut:	Straight in prolarvae, and depressed below air bladder in postlarvae.
Teeth:	Small, sharp, pointed, and curled, on both jaws, apparent in postlarval stage.
Size at absorption of yolk sac:	8 – 10 mm TL.
Total myomeres:	51 – 60.
Preanal myomeres:	37 – 42.
Postanal myomeres:	14 – 19.
Last fin(s) to complete development:	Pectoral fins.
Pigmentation:	In prolarvae a row of dashed melanophores ca. 5 – 12 along midventral region. In postlarvae, 1 – 4 paired melanophores extend from pectoral to air bladder and a row of 6 – 10 melanophores along air bladder to anus (Simonsen, 1977; this study). 3 – 5 postanal melanophores and 1 circumanal melanophores (Simonsen, 1977).
Distribution:	Initially planktonic and turning into pelagic (air bladder inflated in postlarval stage). On surface water column from eastern San Pablo Bay, Napa River, Carquinez Strait, Suisun Bay (including the tributaries of Montezuma Slough), West Delta, lower reaches of the Sacramento River, and lower reaches of the San Joaquin River.

JUVENILES

Dorsal fin:	8 – 10 (McAllister, 1963).
Anal fin:	15 – 19 (McAllister, 1963); 15 – 22 (Moyle, 2002).
Pectoral fin:	10 – 12 (McAllister, 1963).
Mouth:	Large, slightly upward (this study). Maxillary elongate and extends to posterior margin of the eye (Moyle, 1976).

Vertebrae: 54 – 61 for entire distributional range and 55 – 58 for the California population (McAllister, 1963).

Distribution: Middle to bottom water column (McAllister, 1963; Moyle, 1976); Suisun Bay, San Pablo Bay, and San Francisco Bay (Ganssle, 1966; Messersmith, 1966; Aplin, 1967); outside of the Golden Gate Bridge to the Farallon Islands (Baxter 2000); Lower Sacramento River and Lower San Joaquin River (Wang, 1986); Napa River (CDFG sampling in Napa River 1995–2005); shallow sloughs and at the CVP/TFCF of South Delta (this study).

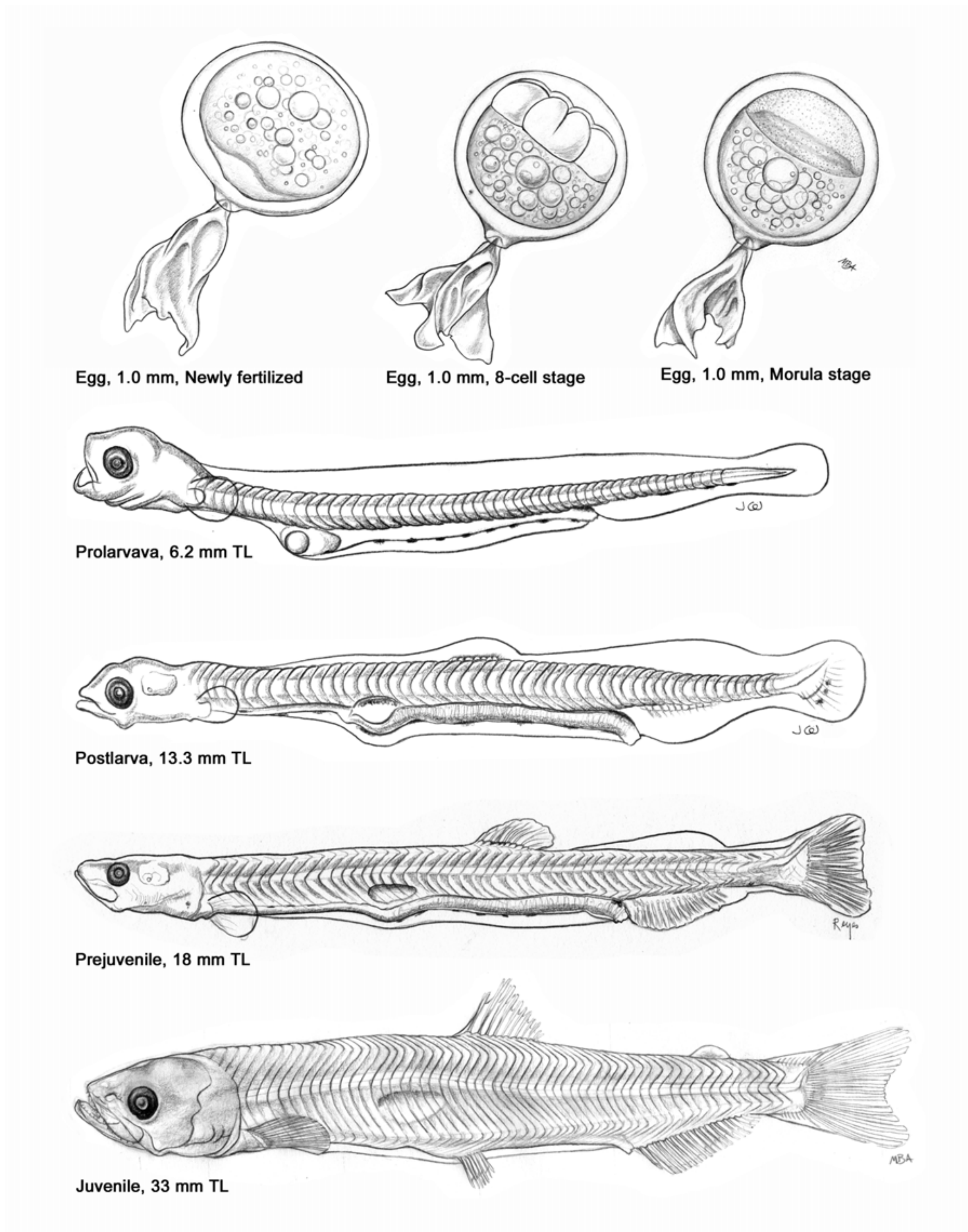


FIGURE 7a.—Early life stages of longfin smelt drawings.

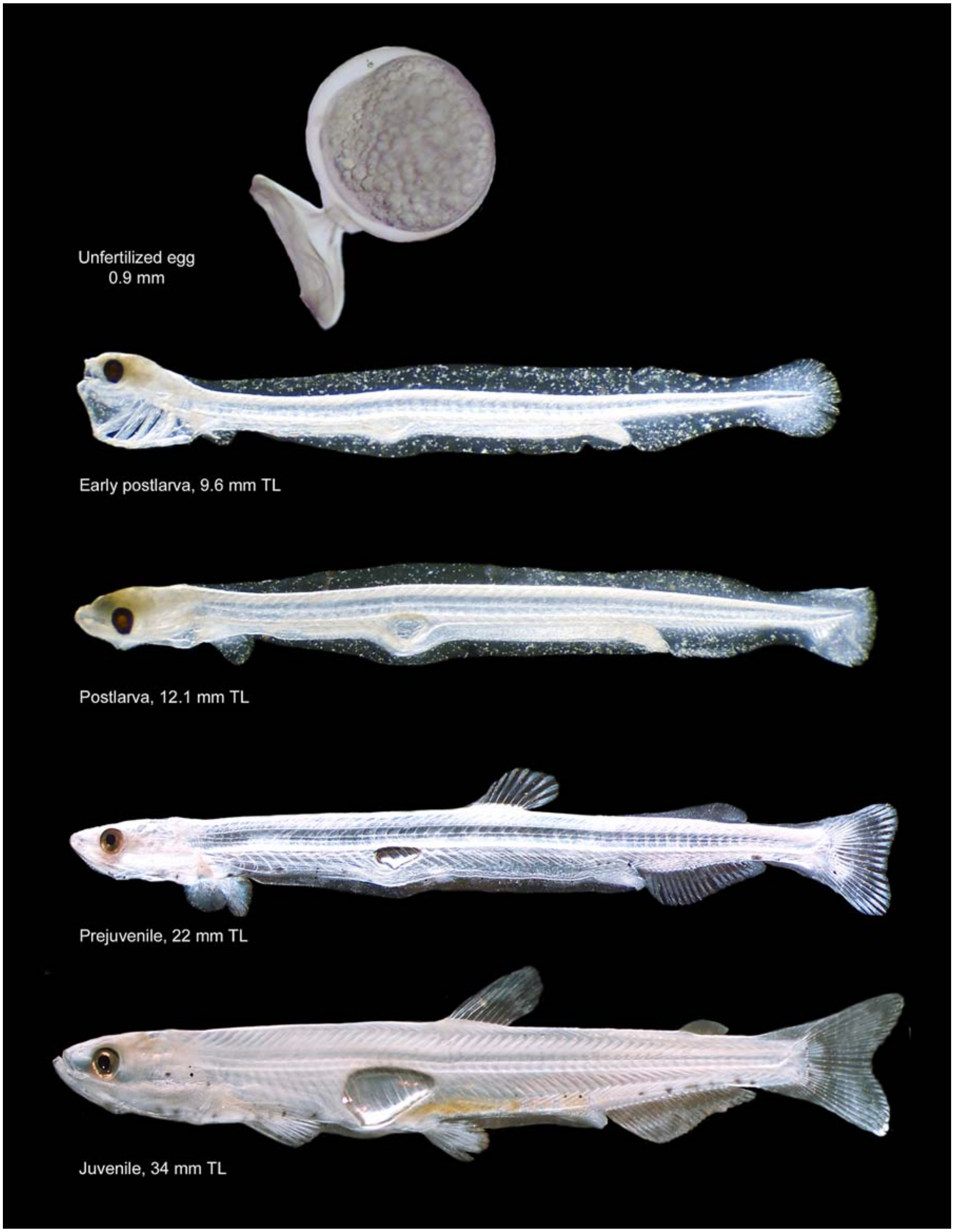


FIGURE 7b.—Early life stages of longfin smelt photographs.

Expanded Life History – Longfin Smelt

The distribution of the longfin smelt is from Prince Williams Sound, Hinchinbrook Island, Alaska, southward to the Sacramento-San Joaquin Estuary (McAllister, 1963; Miller and Lea, 1972; 1976). Locally, they are abundant in Suisun Bay, San Pablo Bay, and Central Bay. They are less abundant in the West Delta and South Bay (Baxter *et al.*, 1999). They are also found in the vicinity of the NBA Project and South Delta (this study). According to Moyle (2002), the subpopulation of longfin smelt in the San Francisco Estuary, the southernmost representative of this species has been isolated from other populations of longfin smelt for a long period of time. Stray longfin smelt have been found south of San Francisco Bay; with an adult longfin smelt recorded from Moss Landing Harbor in March 1980 (Wang, 1986). A single specimen was also recorded in Monterey Bay by Eschmeyer *et al.* (1983).

Sexual dimorphism

Male longfin smelt

During spawning, the anal fin of the male longfin smelt becomes elongated; the body becomes greenish and covered with speckled dark melanophores. The male fish looks very different.

Female longfin smelt

Female may have slightly elongated anal fin and may have light speckled pigmentation on all fins. Body of female longfin smelt is not dark or less pigmented.

Observations of longfin smelt spawning

Similar to that of the delta smelt, longfin smelt can complete their life cycle within San Francisco Bay and Delta. Adult longfin smelt prefer higher saline water. In the fall, the adults move from San Francisco Bay and San Pablo Bay to Montezuma Slough, Suisun Bay, West Delta, and the lower reaches of the Sacramento and San Joaquin Rivers. This upstream movement of adults is a sign of anadromous behavior. Gravid longfin smelt have been caught at Decker Island and Antioch Bridge in November and December 2003–2004 (Brent Bridges, personal communication). The primary spawning period appears to be from December to June (Wang, 1986). Spawning may start as early as November and extends to July (Baxter *et al.*, 1999). The majority of spawning occurs from February to April (Moyle, 2002) as documented by the CDFG striped bass E&L sampling in 1992–1995 (appendix tables A6, A7, A8, A9). Spawning in the Lower Sacramento River has a more restricted period, from February to March (this study). Spawning temperature ranged 7.0 – 14.5 °C (Emmett *et al.*, 1991). Yolk-sac larvae were observed at 15.0 °C and greater from samples collected at the NBA by CDFG.

Females with eggs were observed at the CVP/TFCF intake on December 22, 2000 and December 28, 2001. In these females the outer layer of chorion was reversed to form an anchor that adhered to glassware. The size of the mature eggs ranged from 0.9 to 1.2 mm in diameter. Eggs are deposited singly and in single layer on the substrate.

Observations of longfin smelt larvae

Newly hatched longfin smelt are planktonic but turn into a pelagic larva when the air bladder is inflated. Larvae are usually found in the upper layer of the water column, preferring inshore and offshore (in channel) locations. The longfin smelt larvae school with other longfin smelt and delta smelt. Longfin smelt and delta smelt were often collected at the same time at the CVP/TFCF; however, longfin smelt, delta smelt, and wakasagi have been collected at the same time on a rare occasion.

Observations of longfin smelt juveniles

Spring movements of juvenile longfin smelt in the South Delta at the CVP/TFCF were observed in 2001–2003 with a peak in 2002 (table 9). Longfin smelt have similar migration behavior as delta smelt, but are not observed every year in the South Delta. Apparently not all the longfin smelt move down Bay after hatching, especially in dry years. Ganssle (1966) described a downstream movement of juvenile longfin smelt in Carquinez Strait, San Pablo Bay and San Francisco Bay that increased substantially during spring and summer (Messersmith, 1966; Alpin, 1967). Large numbers of longfin smelt larvae and juveniles were captured in Suisun Bay, particular it's west side in the early 1980s (Wang, 1986). Distribution ranges of juveniles were from Suisun Bay to Central San Francisco Bay from summer to winter months (Baxter *et al.*, 1999). Juveniles are abundant in the Napa River (CDFG 20 mm fish sampling and Stillwater Sciences sampling). Juvenile longfin smelt feed on opossum shrimps, *Neomysis mercedis* and *Acanthomysis spp.*, copepods, and other small crustaceans (Moyle, 2002).

Observations of longfin smelt adult and sexual maturity

Longfin smelt reach maturity at the end of their second year (Dryfoos, 1965).

Some longfin smelt may reach sexual maturity in one year (Kathryn Hieb, personal communication). Most die after spawning, but a few females may live and spawn a second time (Moyle, 1976). Older smelt spawn earlier in the season than younger ones, which may explain the extended spawning season.

Longfin smelt are the most abundant osmerid in the Sacramento-San Joaquin Delta and San Francisco Bay. Ecologically, the longfin smelt in the San Francisco Estuary is an isolated population and is the southernmost representative of the species along the Pacific Coast (Moyle, 2002). Historically, longfin smelt have been sold commercially in the local fish market (smelt fry). Today, their long-term decline in California has prompted the CDFG to list longfin smelt as a species of special concern (Moyle, 2002).

Longfin smelt spawning (CDFG's fish E&L sampling, 1992–1995)

The CDFG striped bass E&L sampling program generated the information on longfin smelt spawning. Sampling area covered was from Carquinez Strait to the Delta and to the Sacramento River. Sampling period was from February to July each year from 1992 to 1995 (appendix tables A6, A7, A8, and A9).

1992 (Critically-dry year in Sacramento and San Joaquin Rivers)

1. Sacramento River: Selected sampling stations were sampled; few larvae were caught. Larvae were mainly observed in February and March.

2. San Joaquin River: Selective sampling stations were sampled; larvae were common toward Suisun Bay. Larvae observed in February and March.

3. Suisun Bay (south) and West Delta: Larvae were common in these areas and mainly observed in March.

4. Suisun Bay (north) and Montezuma Slough: Montezuma Slough sampling stations were not sampled in 1992; two West Delta sampling stations 65 and 66 were sampled. Larvae were common at these two stations, with most of the catch in March.

5. Comments on distribution: Spawning occurred mostly toward the Suisun Bay and West Delta. Spawning period was very short and peaking in March.

1993 (Average year in Sacramento River and wet year in San Joaquin River)

1. Sacramento River: Very few larvae were collected in the lower sampling stations in March.

2. San Joaquin River and West Delta: Most larvae were at the lower reaches of the San Joaquin River; peaking in February and March.

3. Suisun Bay (south) and West Delta: Larvae concentrated in these areas in February to May.

4. Suisun Bay (north) and Montezuma Slough: Larvae concentrated in these areas in February to May.

5. Comments on distribution: Most of the spawning occurs in Suisun Bay, Montezuma Slough, and West Delta; less in the inland Delta waters. Larvae abundant from February to May.

1994 Critically-dry year in the Sacramento and San Joaquin Rivers)

1. Sacramento River: Larvae were observed at all sampling stations located in the lower reaches of the Sacramento River. Peak abundance was from February to April.

2. San Joaquin River: Larvae were abundant over the entire sampling stations, and peak abundance was from February to April.

3. Suisun Bay (south) and West Delta: Larvae were very abundant these areas, peaking in February to early April.

4. Suisun Bay (north) and Montezuma Slough: Larvae were very abundant in these areas and peaked in February to mid April.

5. Comments on distributions: Heavy spawning occurred in Suisun Bay, Montezuma Slough, and West Delta; spawning also occurred in the lower reaches of the Sacramento and San Joaquin Rivers. Spawning occurred in February to April with a peak in March; larvae were very abundant.

1995 (Wet year in the Sacramento and San Joaquin Rivers)

1. Sacramento River: Few larvae were observed at the lower reaches of Sacramento River and no peak in abundance was observed.

2. San Joaquin River: Few larvae were observed and no peak.

3. Suisun Bay (south) and West Delta: Some larvae were observed in late February and early March.

4. Suisun Bay (north) and Montezuma Slough: Some larvae were observed mainly in February and March.

5. Comments on distribution: Spawning was light in all four areas, and larvae were present for a very short duration.

Judging from the relatively low abundance of longfin smelt larvae collected from the CDFG striped bass E&L surveys from 1992–1995, it can be stated that:

1. Longfin smelt general spawning does not always correlate with Delta outflow. During critically-dry water years, such as 1994, longfin smelt move to the Suisun Bay to spawn. In wet water years, such as 1995, longfin smelt descend to the San Pablo Bay to spawn. However, intensive spawning also occurs in the upper Estuary in dry water years (tables 7 and 9). The success of longfin smelt spawning may involve multiple environmental factors. In some years, Delta outflow may be a factor; however, longfin smelt larval abundance does not always correlate to Delta outflow (Baxter *et al.*, 1999).

2. Longfin smelt may spawn in brackish water. Longfin smelt is thought to be a freshwater spawner. However, large numbers of longfin smelt yolk-sac larvae were also observed at the west end of Suisun Bay near Carquinez Strait (oligohaline) during the dry years.

3. The majority of longfin smelt larvae and juveniles stay in the Delta between February and April (this study). The juveniles move into Suisun Bay (Ecological Analysts Inc. sampling in the vicinity of Pittsburg and Contra Costa power plants in 1978–1982) and further down to San Pablo and Central Bays (Baxter *et al.*, 1999).

4. Longfin smelt use the Delta, the Lower Sacramento River, and tributaries of Montezuma Slough as their primary spawning area. Suisun Bay is used as a nursery area, especially during dry years.

5. Some longfin smelt larvae are found in the Cache Slough area, regardless of the type of water year.

Longfin smelt spawning at three sampling locations

CDFG had conducted the striped bass E&L sampling in the Sacramento-San Joaquin Delta for 8 years (1988–1995). After 1995, sampling of fish E&L was concentrated in two areas, the NBA and the Suisun Marsh. In addition, longfin smelt (mainly juveniles) were seasonally collected at the CVP/TFCF. Spawning information for the three areas, NBA, Suisun Marsh, and CVP/TFCF, are presented below:

NBA

Larvae longfin smelt were seldom caught near Elk Grove (Sample Station # 71) on the Sacramento River. Larval fish taken at Cache and Lindsey sloughs represent the northernmost (upriver) spawning location in the Sacramento River for this species. Three points are made regarding longfin smelt use of this area:

1. The usage of this area for spawning was not intense until 2002 (table 7). In that year a spawning spike occurred in February and March, and then subsided in April. A similar pattern was observed for longfin smelt abundance in Suisun Bay and at the CVP/TFCF (tables 8 and 9).

2. Longfin smelt share the same spawning ground with delta smelt and wakasagi at this location.

TABLE 7.—Longfin smelt larvae and juveniles collected at NBA by CDFG in fish E&L sampling program, 1993–2004

Year	February	March	April	May	June	Total
[1]1993	0	5	0	0	0	5
1994	155	177	42	3	0	377
1995	27	33	2	0	0	62
1996	0	0	0	0	0	0
1997	97	352	98	4	0	551
1998	0	0	0	0	0	0
1999	12	17	0	0	0	29
2000	2	0	2	1	0	5
2201	1,219	980	81	10	0	2,290
2002	10,4945	11,687	928	58	1	23,168
[2]2003	302	572	116	7	0	997
2004	351	13	1	0	0	365

Note:
[1] Quality control on longfin smelt identification was performed by this author.
[2] Longfin smelt identification was performed by CDFG biologists in 2003 and 2004.

TABLE 8.—Longfin smelt larvae and juveniles collected at Suisun Marsh by UC Davis in fish E&L sampling program, 1995–2002

Year	February	March	April	May	June	Total
1995	18	2	3	0	0	23
1996	94	72	16	27	2	211
1997	291	481	256	24	0	1,052
1998	0	16	1	0	0	17
1999	126	37	117	3	0	283
2000	796	84	189	32	0	401
2001	1,028	1,859	234	9	0	3,130
2002	4,966	5,038	307	15	0	10,326

TABLE 9.—Longfin smelt juveniles collected at CVP/TFCF by Reclamation (including holding tank 10-minute sampling and all special studies), 1995–2005

Year	February	March	April	May	June	Total
1995	0	0	0	0	0	0
1996	0	1	2	0	0	3
1997	0	0	56	120	3	179
1998	0	0	0	0	0	0
1999	4	0	0	9	7	20
2000	0	0	21	15	1	37
2001	0	11	196	234	0	441
2002	0	34	2,835	1,124	8	4,001
2203	0	0	182	213	1	396
2004	0	2	13	14	0	29
2205	0	0	1	0	0	1

3. Cache/Lindsey Slough area receives flows from upper Sacramento River via Miner Slough and Steamboat Slough, and has a complex secondary channel network. Furthermore, flows from this area are also enhanced by the tidal movements that allow for constant aeration of eggs. This appears to be an ideal location for not only smelt spawning but many other fish species as well (Wang and Reyes, 2005. In press).

Suisun Marsh

Suisun Bay, Suisun Marsh, Montezuma Slough, and West Delta are the historical spawning grounds for longfin smelt (Moyle, 1976; Wang, 1986, 1991). Information on spawning indicates that Suisun Marsh has been used as spawning habitat by longfin smelt and delta smelt for many years, and more recently in 1995, by the wakasagi (table 11, this study). Three points are made from longfin smelt use of this area:

1. Longfin smelt spawn in the Montezuma Slough and its tributaries; the Cordelia Creek having the highest numbers of longfin smelt larvae collected in 2001 and 2002 (table 8).

2. The entrapment zone of these tributaries is limited in size (length and width), and it leads one to believe that longfin smelt may spawn in freshwater as well as in brackish water.

3. Due to the spawning habitat limitation, timing of local tributaries run-off, and water temperatures, the intensive spawning occurs mainly in February, March, eventually subsiding in April.

CVP/TFCF

Mainly juvenile longfin smelt are observed at the CVP/TFCF. Five points are made from the presence of longfin smelt at the CVP/TFCF. They are:

1. Adult longfin smelt were observed at the CVP/TFCF on rare occasions during winter months, and very few larvae were collected in the South Delta by Spaar (1990a; 1990b; 1991; 1992, and 1993) and Spaar and Wadsworth (1994).

2. Longfin smelt seldom appeared in the South Delta in the second half of the1990s with the exception of 1997. During this year longfin smelt were found to be moderately abundant at the CVP/TFCF.

3. Sampling in 2001–2003 showed the greatest number of the longfin smelt in the South Delta, with a dramatic spike in April and May, 2002 (table 9).

4. Small number of longfin smelt larvae was collected in the CVP/TFCF during 2001 and 2003. It is believed these numbers indicate that some longfin smelt may have shifted their spawning towards the South Delta.

5. Judging from the juvenile fish length distributions at the CVP/TFCF in 2002, juveniles arrived in several pulses. This behavior is similar to that of delta smelt, namely moving into the South Delta before migrating to the down bay rearing habitat.

Comments on longfin smelt spawning

1. Longfin smelt spawning behavior is elusive. Spawning requirements may involve many habitat factors.

2. Suisun Marsh is the major spawning area for longfin smelt. Some intensive spawns also occurred at the NBA and possibly in the South Delta in the early 2000s.

3. Large numbers of juvenile longfin smelt were observed in the Napa River in recent years (CDFG 20 mm fish sampling, 1995–2005; Stillwater Sciences upper Napa River sampling, 2001–2005). E&L sampling of longfin smelt in the other tributaries located in the bay may help us understand longfin smelt spawning.

4. Similar to the delta smelt, longfin smelt population has been in a downward trend in Suisun Marsh since 2003 (Schroeter and Moyle, 2004; 2005). An explanation to this downward trend is currently being investigated.

WAKASAGI, *Hypomesus nipponensis* (McAllister); figure 10a and 10b

SPAWNING

Location:	In the tidal and nontidal freshwaters of the Sacramento-San Joaquin Delta, specifically, the Lower Feather River, Sacramento River, Lower American River, NBA, Sacramento River Deep Water Ship Channel, Lower Mokelumne River (North Fork and South Fork), tributaries of Montezuma Slough, and upper Napa River (Wang *et al.*, 2005; this study). Adjacent to the Sacramento-San Joaquin Delta, wakasagi spawn in San Luis Reservoir (Hess *et al.*, 1995), Folsom Lake, Lake Natoma, Lake Oroville, and Lake Almanor (CDFG sampling).
Season:	April to May (Moyle, 2002); mostly January to April and may extend to May.
Temperature:	ca. 10 – 15 °C in the wild; wakasagi also can spawn in higher water temperature, 14 – 21 °C in the laboratory (this study); 15 – 19.5 °C in laboratory environment (Bradd Baskerville-Bridges, personal communication).
Salinity:	Freshwater.
Substrates:	Sandy, hard surface substrates, and submerged plants and tree branches (this study, observed at San Luis Reservoirs); in large outdoor tanks, eggs were found in the part of the tank where water entered and also in moss-like algae (Bradd Baskerville-Bridges, personal communication); in the laboratory, eggs attached to fiberglass holding tank and glassware.
Fecundity:	1,500 – 2,000 of fish in the 85 – 90 mm TL collected from San Luis Reservoir; ~ 5,000 – 10,000 estimated (Bradd Baskerville-Bridges, personal communication).

EGGS

Shape:	Spherical.
Diameter:	0.80 – 0.94 of natural spawn and 0.80 – 1.10 mm of artificially stripped eggs.
Yolk:	Yellowish, granular.
Oil globule:	Many small globules, and oil globules are not consolidated until prior to hatching.
Chorion:	Two layers, the outer layer reverse it and form an adhesive anchor to a common mat on substrates.
Egg mass:	Deposited singly in one layer.
Adhesiveness:	The outer layer of chorion forms an adhesive anchor, strongly adhesive.
Buoyancy:	Negatively buoyant.

LARVAE

Length of hatching:	4.0 – 4.5 mm TL at 20 – 25 °C.
Snout to anus length:	Ranged 72-76 percent; and mostly 74 percent in both prolarvae and postlarvae.
Yolk sac:	Small, spherical to oval, in thoracic.
Oil globule(s):	Single, small, mostly 0.2 mm in diameter.
Gut:	Straight.
Air Bladder:	Elongate, chamber shallow; earliest appearing at ca. 9.0 – 11.0 mm TL, located midway between pectoral fin and anus.
Teeth:	Single cusped, appearing at postlarval stages.
Size at absorption of yolk sac:	5.0 mm TL.
Total myomeres:	54 – 56 (Okiyama *ed*., 1988); 55 – 58.
Preanal myomeres:	39 (Okiyama *ed*., 1988); 39 – 41 (Shardin, 1989); 38 – 41.
Postanal myomeres:	17 (Okiyama *ed*., 1988); 17 – 19 (Shardin, 1989); 16 – 19.
Last fin(s) to complete development:	Pectoral fin.
Pigmentation:	2-3 pairs of melanophores at thoracic; at midventral, paired melanophores extend from oil globule to anus; at lateral ventral, paired melanophores extend from oil globule to anus (halfway to all the way). Postanal has little pigmentation 1 – 2 melanophores are at dorsum of caudal peduncle on occasion.
Distribution:	Pelagic, in Sacramento River, Delta, Suisun Marsh, upper Napa River, and San Luis Reservoir.

JUVENILES

Dorsal fin:	9 (Okiyama *ed*., 1988); 8 – 11 (Moyle, 2002).
Anal fin:	16 (Okiyama *ed*., 1988); 14 – 17 (Moyle, 2002).
Pectoral fin:	12-14 (Okiyama *ed*., 1988); 11 – 14 (Moyle, 2002).

Adipose fin: Yes.
Mouth: Small, flexible, terminal.
Vertebrae: 55 – 58 (Okiyama ed., 1988).
Distribution: Pelagic, in the Sacramento-San Joaquin Delta, and San Luis Reservoir.

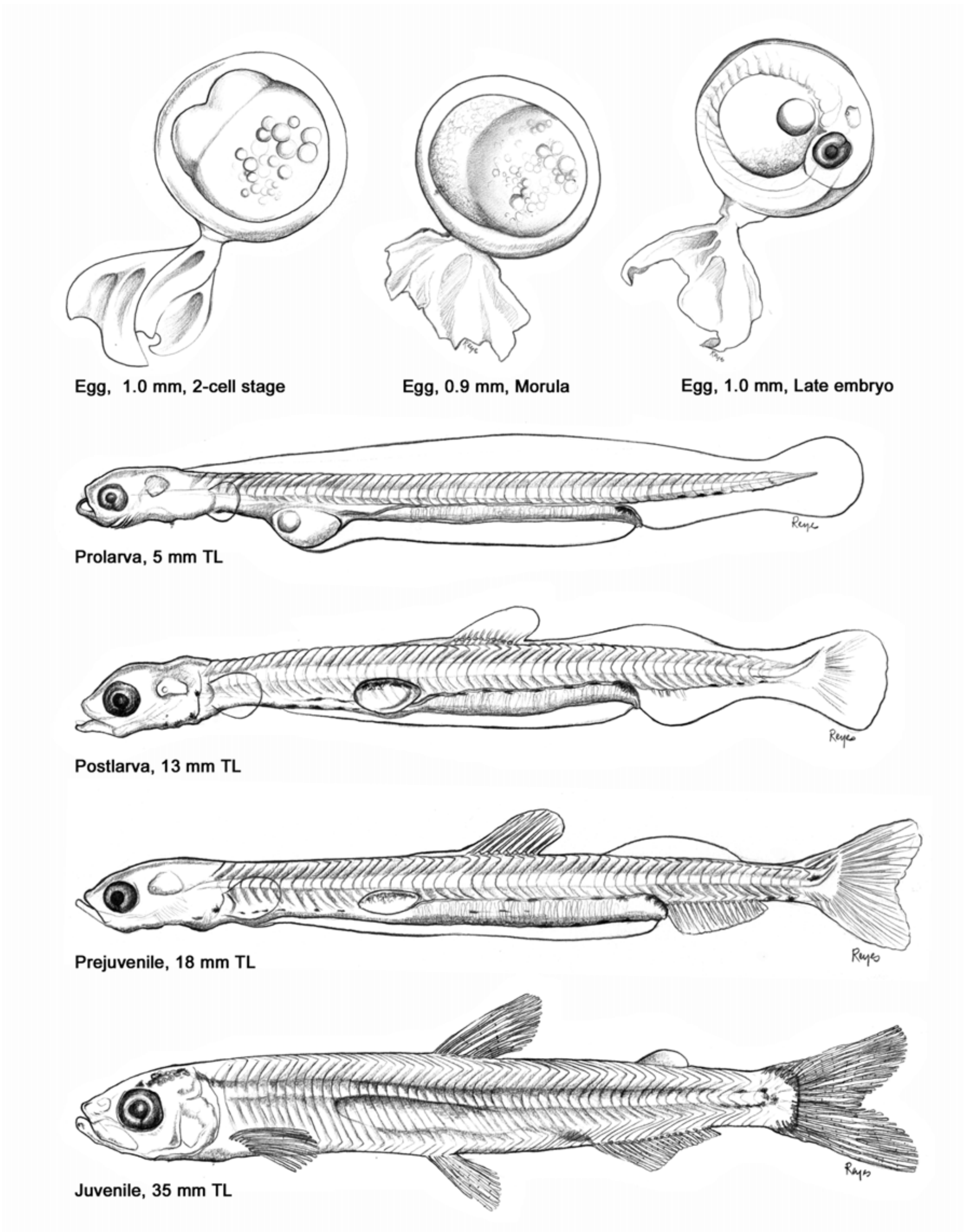


FIGURE 8a.—Early life stages of wakasagi drawings.

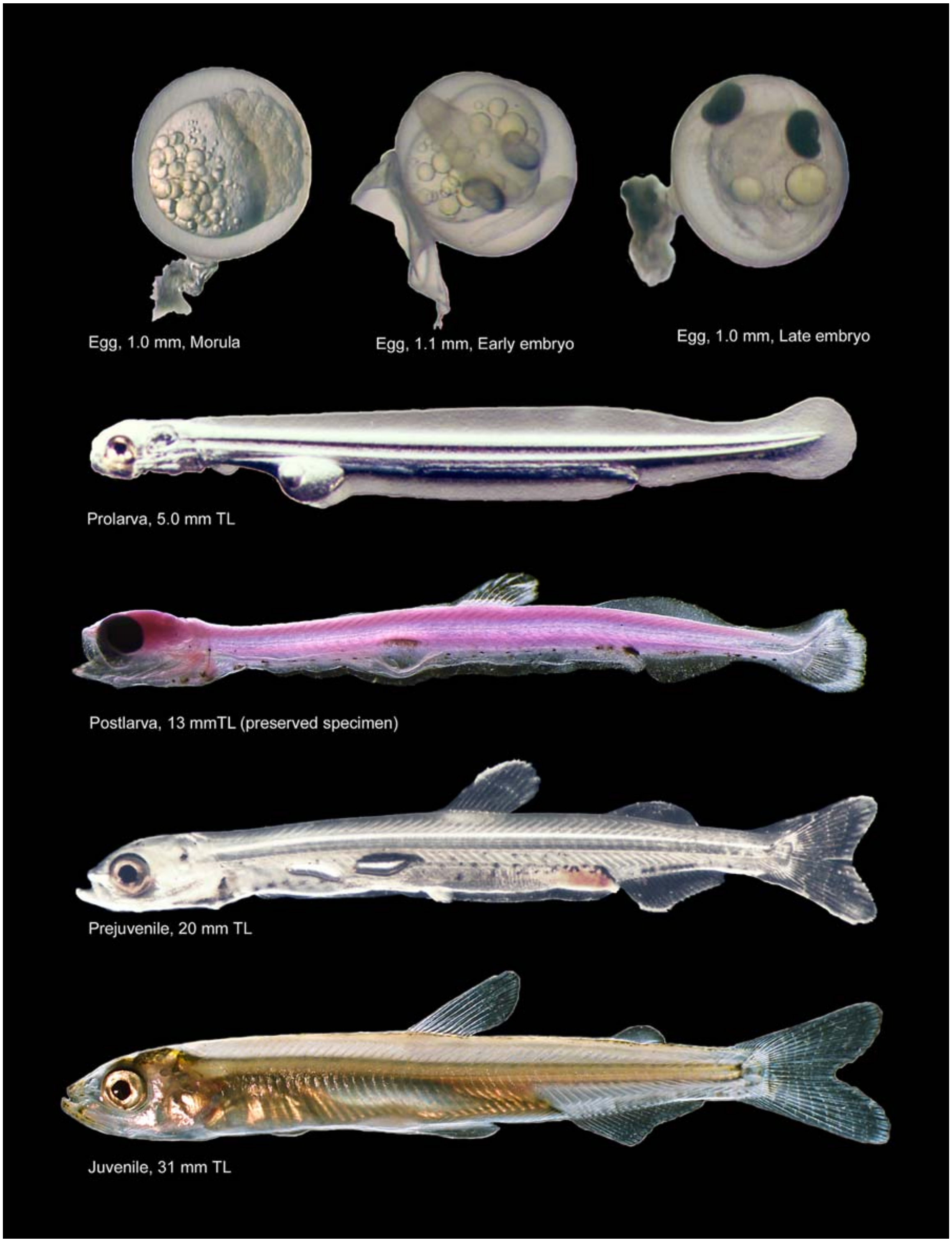


FIGURE 8b.—Early life stages of wakasagi photographs.

Expanded Life History – Wakasagi

Wakasagi are a fish native to Japan. Wakasagi were introduced to California in 1959 and used as a forage fish for salmonids by the CDFG (Wales, 1962). Initially, the egg mass were collected in Japan and stocked in the reservoirs including Freshwater Lagoon (Humboldt County), Dodge (Lassen County), Shastina (Siskiyou County), and Spaulding (Nevada County). Gradually, wakasagi escaped from some of the reservoirs and colonized other reservoirs downstream. Wakasagi has been occasionally observed in the Sacramento-San Joaquin Delta since July 1974 (Dale Sweetnam, personal communication). A small number of adult wakasagi were captured in the vicinity of Chipps Island and the confluence of Sacramento River and the San Joaquin River by the Ecological Analysts, Inc. during the 316a and 316b studies contracted by PG&E from 1978 to 1982. Explanations are unclear as to why the wakasagi were rarely seen in the Sacramento-San Joaquin Delta from the 1960s to the 1980s. In the 1990s, a rapid increase in wakasagi occurred in the Delta. It is believed that this increase in wakasagi was associated with the failure of Folsom Lake Dam gates in 1995, washing out many wakasagi into the American and Sacramento Rivers (Lloyd Hess, personal communication). Currently, wakasagi are observed in the Sacramento-San Joaquin Delta and its adjacent waters such as San Luis Reservoir and Napa River (Hess *et al.*, 1995; Aasen *et al.*, 1998; Stillwater Sciences, Inc sampling in upper Napa River, 2001–2005; CDFG 20 mm fish sampling in Lower Napa River, 1995–2005; CVP/TFCF 10-minute count sampling, 1995–2005).

Sexual dimorphism

Male wakasagi

1. Head:
    a. Snout becomes narrow dorso-ventrally, dark pigment covers both jaws.
    b. Pigment covers head in sparse pattern.
    c. Breeding bumps (whitish epidermal tissue) cover the head.
    d. Serrated tissue appears at isthmus.

2. Body:
    a. Breeding bumps are found on all scales (figure 8), front fin ray of pectoral, front fin ray of pelvic, and on adipose fin.

    b. Anal fin rays are darker and more flared (or elongated).

    c. Upper body shows darker pigmentation.

    d. Scales become more serrated near anus.

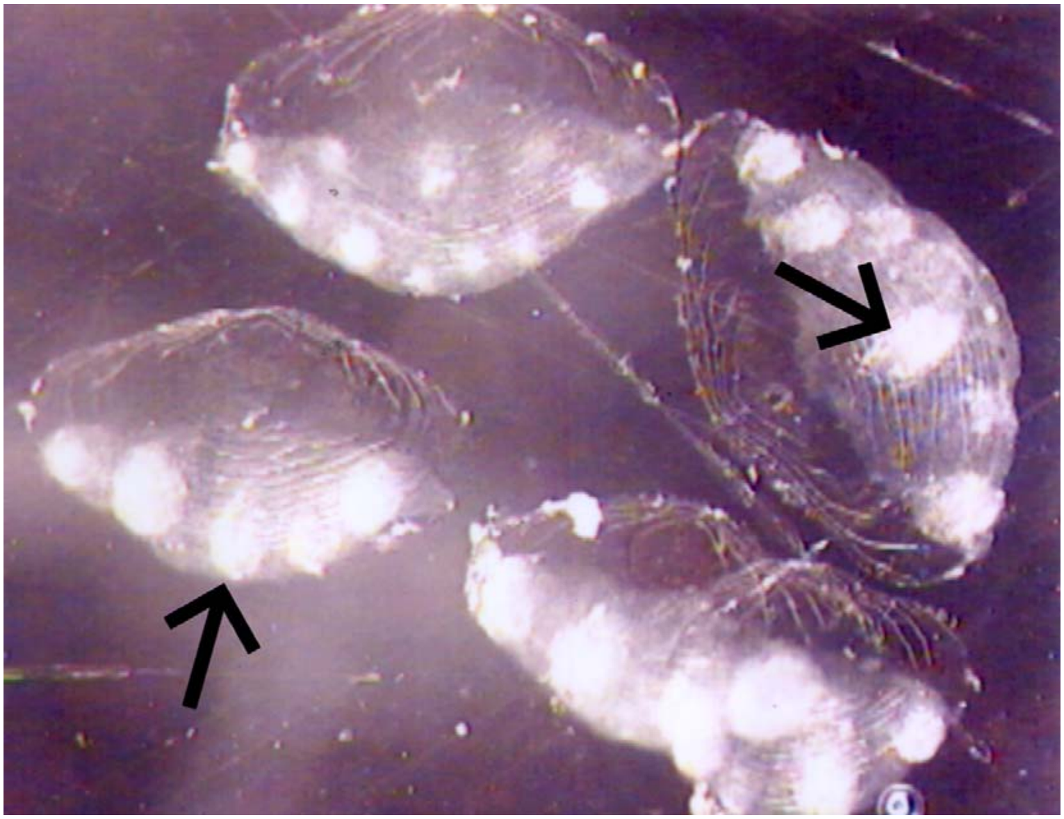


FIGURE 9.—Breeding bumps located on the epidermal tissue of scales from a spawning wakasagi

3. Overall morphology: Male fish, on average, are larger than female (80 mm TL of male and 70 mm TL of female for 1-year old fish), body is darker, and snout becomes narrow and pointed.

Female wakasagi

1. Head:
   a. Snout shows normal width and depth.

   b. Light pigmentation on upper jaw and a few pigments on lower jaw. Operculum has no pigmentation to light pigmentation.

   c. No breeding bumps on head.

   d. No serrated tissue on isthmus.

2. Body:
   a. Scale and fins have no breeding bumps.

   b. Anal fin rays normal, no flare.

c. Upper body shows light pigmentation.

d. Scales are normal and are not serrated near anus.

3. Overall morphology:
   a. Female fish are smaller than male fish, during spawning and spawning season.

Wakasagi embryology

Date:	02/02/00
Time:	09:00 – 09:30 h.
Water temperature:	At fertilization: 12 °C, kept in the laboratory room temperature fluctuating between 15 °C during the night and 20 °C during daylight h.
Number of eggs in batch:	150+ from an 80 mm TL female and several ca. 90 mm TL males (eggs were stripped).
Size of eggs:	Ranged 0.9 – 1.1 mm in diameter.
Method of spawn:	Strip spawn/dry fertilization.

Day 0: (02/02/00)

Eggs were in 2-cell to morula stage within 3 h. Outer layer of chorion formed an anchor attaching to the glass dish. Oil globules are scattered in the yolk sac.

Day 1: (02/03/00)

Eggs go through the blastula, gastrula, and to the early embryo stage. The head, body and tail of the embryo become undifferentiated to slightly differentiated. Oil globules are scattered in the yolk sac.

Day 2: (02/04/00)

Some embryos are in tail-free stage. Optic cup (lens and choroids fissure), brain, central nervous system, and portion of myomeres are observed. Heart beats and body movements are also observed. Oil globules are in the process of consolidation, some are still scattered.

Day 3: (02/05/00)

Eyes are slightly pigmented. Vascular circulation carries red blood cells. Embryo becomes elongated and constructs almost one complete circle in the chorion. Mostly 6 – 7 larger oil globules surrounded by many very small oil globulets in the yolk sac.

Day 4: (02/06/00)

Eye turns dark to black. Oil globules consolidate into 1 to 4 and surrounded by many small globulets. For some of the embryo, the consolidation of oil globules is very slow. Embryo moves more frequently.

Day 5: (02/07/00)

Eye is dark to black. The oil globules consolidate into 1 to 4; the diameter of the oil globule ranged 0.1 – 0.2 mm. Embryo moves in the chorion more frequently.

Day 6: (02/08/00)

The embryo encircles in the chorion twice. The oil globules consolidate into 1 – 3 globule. The size of the oil globule is 0.2 mm in diameter. Eye movement detected, black pupil is surrounded by silvery iris. Embryo moves actively and kicking the chorion occasionally. Thoracic, front yolk-sac, midventral, and postanal region pigmentations can be seen. First larva, measuring 4.8 mm TL, hatched out at 1300 h. It had a large yolk sac just below the head and a single oil globule.

Day 7: (02/09/00)

Eight embryos hatched out. The newly hatched larvae size ranged: 4.3 – 5.2 mm TL.

Day 8: (02/10/00)

A total 10 embryos have hatched. Size ranged between 4.1 – 4.5 mm TL. Total incubation time was 7–9 days at 15 – 21 °C.[2]

History of wakasagi larvae observed in the Sacramento-San Joaquin Delta

The wakasagi was recorded in the Delta as early as 1974 (Dale Sweetnam, personal communication). However, the wakasagi larvae were not identified until the early 1990s (Wang, 1995; Wang *et al.*, 2005). Even though they were in the samples, they went unrecognized and overlooked for the last two decades because they look nearly identical to delta smelt. The following list gives the chronological history of wakasagi samples observed by the author over the last 15 years:

1. Wakasagi larvae were first collected at the confluence between the Feather River and Sacramento River by CDFG's striped bass E&L sampling

[2] Eggs were incubated in the room temperatures between 15 and 20 °C; eggs exposed to ca. 21 °C during the examining of developmental stages under the dissecting scope with bright light.

program* in 1990 (Wang, 1995). Specimens were initially identified as the delta smelt, and later were re-identified as wakasagi.

2. Additional wakasagi larvae were found near Fair Oaks at the American River by Hanson Environmental, Inc. in 1991 (Wang, 1995).

3. Wakasagi larvae were found just below the confluence between American River and Sacramento River in 1991 (Wang, 1995).

4. One wakasagi larva was collected in the Sacramento River just above Walnut Grove in 1991 (Wang, 1995).

5. Wakasagi larvae, prejuvenile and juvenile, were collected by Steve Hiebert (personal communication) at the U.S. Air Force docking site (Bryte, California) of the Sacramento River in 1991–1994 (Wang, 1995).

6. In 1993 and 1994, approximately 110 plus specimens of wakasagi larvae were observed in the Sacramento River below American River, Cache Slough, Miner Slough, Sacramento Deep Water Ship Channel, Barker Slough, and Lower Mokelumne River. The specimens collected in the Mokelumne River likely came from the Sacramento River via the Delta Cross Channel. Moyle (2002) stated that they may also descend from Jenkinson Reservoir to Cosumnes River. A large number of juvenile wakasagi were also collected at the CVP/TFCF in the South Delta in 1993. Some of these identifications are questionable due to the similarity of phenotypes between wakasagi and delta smelt (this study) and the lack of an appropriate taxonomic key to separate the early life stages of the two species. Apparently, wakasagi was introduced to San Luis Reservoir via the Delta Mendota Canal and California Aqueduct sometime around 1993–1994. Hess *et al.* (1995) collected larval wakasagi near Portuguese Cove of San Luis Reservoir in 1995. Further spread of wakasagi to Southern California is a possibility (Moyle, 2002).

7. Probably between 1993 and 1995, wakasagi moved from the Sacramento-San Joaquin Delta further westward to Suisun Bay, Montezuma Slough, and its tributaries (UC Davis sampling, 1995–2002; Wang *et al.*, 2005), eastern edge of San Pablo Bay, and upper Napa River (CDFG sampling in 1995–2005; Stillwater Sciences, Inc. sampling in 2001–2005).

8. Currently, the wakasagi is a reproductive resident fish in the Sacramento-San Joaquin Delta; the detailed life history and distributional pattern are still not completely known.[3]

[3] CDFG striped bass (or fish) E&L sampling of Sacramento-San Joaquin Delta started in 1988; samples were taken up to Garcia Bend of Sacramento River in 1989, and further up to Feather River confluence in 1990 (Wang and Brown, 1993).

Observations of different life stages and hybrid smelt

1. Observations of wakasagi spawning (in wild and laboratory): The life history of wakasagi was studied in the impoundment environment of Shastina Reservoir by Wiggleworth (1975) and Rogers (1984). In this study, the life history of the wakasagi in the open water of the Delta as well as the impoundment of San Luis Reservoir was examined. Over 200 adult wakasagi were collected at San Luis Reservoir by Reclamation biologists between January and March in 2000–2001. Spawning of 1 year old fish started in early February. Two year old fish may spawn at the same time as 1 year old fish, but most of them spawn in later months. Spawning may last to early May in temperature controlled conditions in the laboratory (Bradd Baskerville-Bridges, personal communication). In the mid-1990s to early 2000s, CDFG collected wakasagi larvae and juveniles in Lake Almanor, Lake Oroville, and Folsom Lake in late winter and early spring. Collections of larvae were sporadic; indicating that they probably spawn earlier than delta smelt or that they change spawning locations. The reservoir-caught larvae and juveniles had morphological characteristics, particularly the pigmentation patterns, different from the Delta specimens. Until these characteristics of lake populations were recognized as different from the Delta/river populations, some confusion resulted in incorrect identifications.

   Similar to most of the osmerids found in the Northern Hemisphere, wakasagi spawn in winter and spring months. In the Sacramento-San Joaquin Delta, the wakasagi larvae are observed in Cache Slough, Lindsey Slough, Miner Slough, Sacramento Deep Water Ship Channel, Lower Mokelumne River, Montezuma Slough and its tributaries, and Napa River. Wakasagi larvae are typically mixed with delta smelt and longfin smelt larvae in temporal and spatial distributions. A morphological key to separate the early life stages between delta smelt and longfin smelt was written by Wang (1991), and a key to separate the wakasagi from delta smelt was recently completed by Wang *et al.* (2005).

   In San Luis Reservoir, wakasagi spawning is known to occur in shallow inshore water near Portuguese Cove. San Luis Reservoir has a reproducing population of wakasagi, since 1 to 2 year old fish and all their life stages have been collected. It is interesting to note that even though both wakasagi and delta smelt have been transported to the San Luis Reservoir for several years, only the wakasagi have established itself there. Delta smelt have not been observed in any reservoirs and ponds. It is postulated that delta smelt require a certain level of flow, salinity, and nutrients to complete their reproductive cycle, levels that may not be present in San Luis Reservoir. In addition, because San Luis Reservoir is clear, turbidity may also be a factor. Delta smelt may require sufficient amounts of sediment and algae in the water column to elicit a feeding response (Bradd Baskerville-Bridges, personal communication).

2. Observations of wakasagi larvae: Judging by the larval fish taken by plankton tows and observations of newly hatched larvae in the laboratory, wakasagi larvae are planktonic and swim near the surface of the water column. This is similar to what is observed with delta smelt larvae. Wakasagi air bladder becomes apparent at 9 – 11 mm TL. Wakasagi larvae turn into a pelagic swimmer shortly after the air bladder is inflated. This is much earlier than air bladder formation in delta smelt (i.e. 16 mm TL, this study). Wakasagi larvae seem to scatter in the Sacramento-San Joaquin Delta; the information on abundance is limited due to the difficulty in differentiating from delta smelt larvae.

3. Observations of wakasagi juveniles: Juveniles were observed more in freshwater, less frequently in oligohaline water, and seldom in the mesohaline (such as in the eastern San Pablo Bay and Lower Napa River). It is believed that California wakasagi are probably from a freshwater-resident type of population when it was introduced from Japan. The anadromous type (migrating from saltwater to freshwater to spawn) is also known to Japan (Moyle, 2002). Diets of small juveniles are mainly cladocerans while large juveniles eat mostly chironomid pupae, cladocerans, and copepods (Wiggleworth, 1975). Formalin-preserved juvenile wakasagi showed orange-colored gut contents indicating they were feeding on crustaceans (this study).

4. Adult wakasagi and sexual maturity: Wakasagi reach sexual maturity after their first year and they can repeat spawn in their second year (Wiggleworth, 1975). Wakasagi collected from San Luis Reservoir contained both 1 and 2 year-old fish. Moyle (2002) is concerned that competition and hybridization between the wakasagi and delta smelt could impact the native delta smelt species. Hybrid crosses between wakasagi and delta smelt have been detected in the wild by using of electrophoretic analysis (Stanley *et al.*, 1995; May, 1996; Trenham *et al.*, 1998).

5. Hybrid (male wakasagi x female delta smelt) embryology: In the CVP/TFCF laboratory, a male wakasagi and female delta smelt were crossed by artificial fertilization. As a control, half of the female eggs were fertilized with a male delta smelt and nearly all of these eggs survived and started feeding normally. The following is a brief chronological description of hybridized embryology and larval hatching

Day 0: (02/24/00)

1. Artificial fertilization started at 1730 h.

2. Male wakasagi: ca. 90 – 95 mm TL and female delta smelt: ca. 75 mm TL

3. Delta smelt eggs: 0.9 – 1.1 mm in diameter stripped from the ovary.

4. Total eggs removed from the ovary: 250+.

5. Water temperature: Fertilized at 14 °C and eggs incubated at room temperatures (14 – 21 °C[4]) in static bath of Alhambra drinking water.

Day 1: (02/25/00)

1. Fertilized eggs were in morula stage.

2. Some eggs fertilized and developed abnormally (not normal blastomere formation), and many were not fertilized and eventually perished.

3. Perivitelline space was not well-defined for abnormal eggs.

4. Fertilized eggs had 3 – 7 large oil globules and surrounded by many small oil globulets. In abnormal eggs oil globules failed to consolidate.

Day 2: (02/26/00)

1. Ten percent of eggs developed into morula stage, with a well-defined perivitelline space. Healthy to abnormal egg proportion of 1:10.

2. Abnormal eggs died and tissue became discolored.

Day 3: (02/27/00)

1. Eggs developed into gastrula stage.

2. Oil globules consolidated into 2 – 6.

Day 4: (02/28/00)

1. Eggs were into early embryo stage; head and tail were differentiated.

2. Oil globules are still not completely consolidated.

Day 5: (02/29/00)

1. Eggs developed into early embryo stage; some advanced into tail-free stage.

2. Oil globules consolidated into 2 – 3 in some eggs; others were not consolidated.

Day 6: (03/01/00)

1. Eggs developed into late embryo stage.

2. In normal embryos, eyes are pigmented. In abnormal embryos, eyes are partially or not pigmented.

[4] Eggs were examined under dissecting scope with a bright light, water temperature in the glass container rose from 19 °C to 21 °C momentarily.

3. Oil globules consolidated into 1 – 2.

Day 7: (03/02/00)

1. Eye became heavily pigmented.

2. Abnormal eggs: Eye not pigmented, less pigmented to one eye pigmented, some with only one eye developing. Some eggs are stalled at this late embryo stage and start degenerating (figure 9). Yolk sac was less pigmented.

3. Lengths of late embryos were in different sizes.

Days 8 and 9: (03/03/00–03/04/00)

1. Embryo moved frequently in the chorion.

2. Iris of eye has more silvery pigments; embryo is ready to hatch out.

3. Some embryos were stalled in late embryo stages of development (appeared to be a problem of organological development).

Day 10: (03/05/00)

1. First hybrid larva hatch.

2. Size of larva: 4.4 mm TL with a large oil globule.

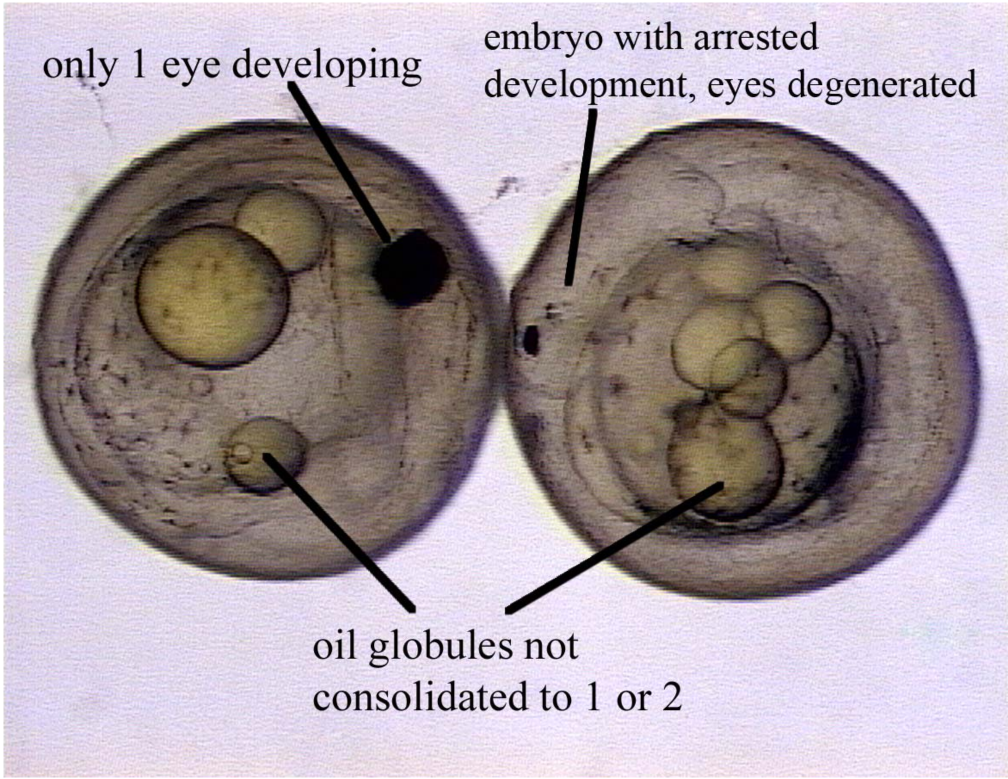
3. Four more hybrids hatched on day 11 (03/06/00).

4. Total myomeres ranged: 38 – 39/16 – 17 (N = 5).

5. Pigmentations: Melanophores extend from thoracic (in front of pectoral girdle) to anus (the midventral region), postanal, and lateral ventral. Additional melanophores are observed on the yolk sac and few on dorsum (above anus and above caudal peduncle).

6. Morphology: Egg development and oil globule consolidation resemble that of a wakasagi egg. The pigmentation pattern is intermediate between the two species: pigmentation found in front of pectoral girdle of the thoracic looks like the delta smelt, melanophores found on the dorsum look like the wakasagi. Height of the dorsal finfold is similar to that of delta smelt.

7. For those eggs stalled in the late embryo stage, eyes lose their coloration and degenerate. Those eggs were preserved in 10 percent formalin on 03/23/00 (day 28).



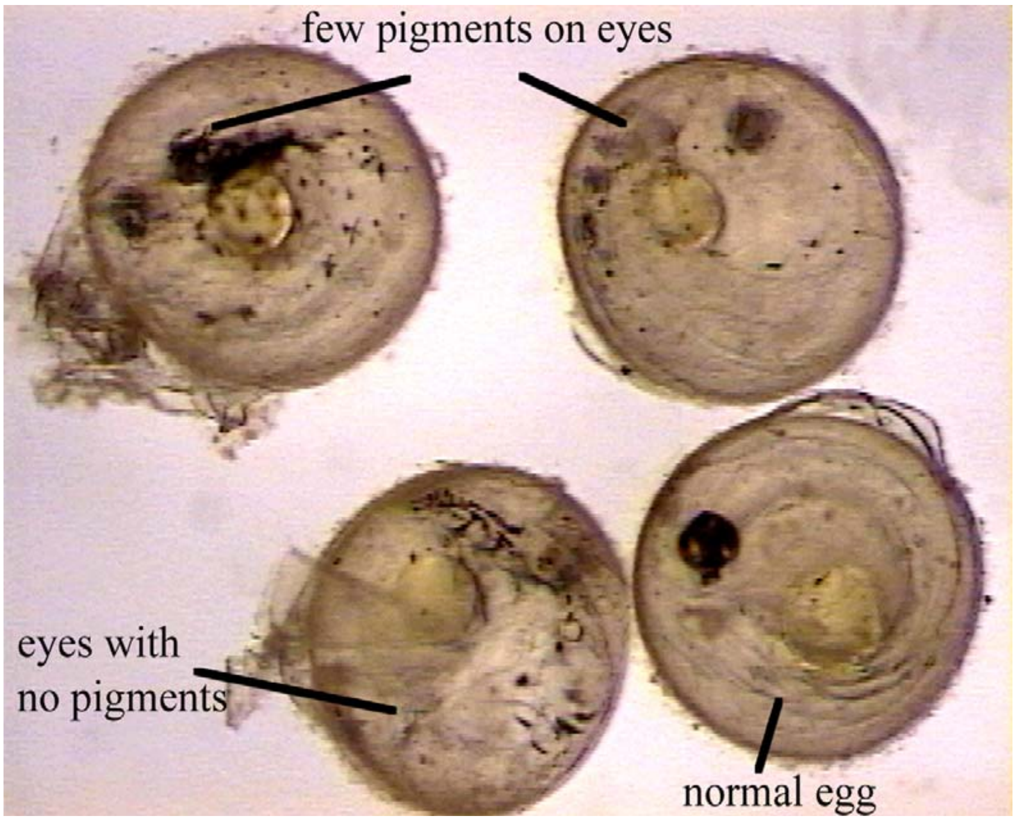


FIGURE 10.—Hybrid delta smelt-wakasagi embryos exhibiting deformities.

8. A second batch of eggs was incubated at a constant 14 °C (temperature controlled refrigerator) and it took 14–16 days for hatching to occur. This second batch also had a very high mortality and low hatching success (ca. 1.6 percent).

9. Heavy mortality occurred at the morula stage (quick death). Many eggs developed abnormally at the late embryo stage (slow death).

10. Hybridized larvae carry morphological characteristics of both species. However, all larvae showed a morphological deformity (e.g., incomplete finfolds, sometimes with two heads). Deformities prevented larvae from eating and swimming normally. All larvae died before reaching first feeding stage.

Wakasagi spawning locations

CDFG striped bass E&L sampling program (started in 1988 and terminated in 1995) was the sampling program used to delineate spawning locations. After the program's termination, sampling continued at three locations: NBA, Suisun Marsh, and CVP/TFCF. This discussion is based on a historical generalized area where the smaller smelt larvae are found in the proximity of a spawning location, then applying that information to the three specific locations that have been sampled in recent years. The spawning information generated for wakasagi at these locations is as follows:

NBA

The NBA probably is one of the initial spawning locations for wakasagi after descending from the upper Sacramento River (estimated in 1993). The wakasagi population explosion has not been observed after being introduced into the Delta more than a decade ago, although the wakasagi are known to be a larger and stronger fish than the native delta smelt (Swanson *et al.*, 2000). It does not appear that wakasagi are replacing the delta smelt at this location. This scenario is quite different from what occurred with another fish introduced from Japan, the shimofuri goby, *Tridentiger bifasciatus*. It was introduced in the mid-1980s (Matern and Fleming, 1995; Matern, 1999) and the population quickly exploded. There is no observable pattern within the larval wakasagi sampling/distribution records that would indicate they had higher reproductive success in certain types of water-year. By far the highest numbers of wakasagi larvae were collected in the NBA in the year 2000 (table 10), an above normal water-year. Information about wakasagi spawning in this area is still lacking.

TABLE 10.—Wakasagi larvae and juveniles collected from the NBA by CDFG in fish E&L sampling program, 1995–2004

Month	[1]1995	1996	1997	1998	1999	2000	2001	2002	[2]2003	2004
February	0	17	0	0	0	3	0	0	0	0
March	2	0	18	0	3	1	0	2	0	3
April	3	4	6	7	2	108	17	12	0	0
May	4	4	0	24	8	18	2	0	1	9
June	0	0	1	0	0	1	0	4	0	0
July	0	0	0	1	0	0	0	8	0	0
Total	**9**	**25**	**25**	**32**	**13**	**131**	**19**	**26**	**1**	**12**

Note:
[1] Quality control on wakasagi identification was performed by this author in 1995–2002.
[2] Wakasagi identification was performed by CDFG biologists in 2003 and 2004.

Wakasagi, delta smelt, and long fin smelt are using similar habitat for spawning and have overlapping spawning seasons. This makes the native delta smelt vulnerable to hybridization with the introduced wakasagi (Stanley *et al.*, 1995; May, 1996; Trenham *et al.*, 1998). The hybrid delta smelt has been discovered in the wild, but it is likely these hybrids are sterile (Trenham *et al.*, 1998; Moyle, 2002). However, more research is recommended to verify the statement.

Spawning at Suisun Marsh

Wakasagi descended from upper Sacramento River to Suisun Marsh sometime between 1993 and 1995. After 6 years of drought, 1993 was the first average water year (critical to dry water years, DWR/Division of Flood Management/Database). It is typical in wetter years for many fish species to descend from upper river into the Delta and Suisun Bay to spawn, including wakasagi (Wang, 1996). Wakasagi were observed spawning in the freshwater tributaries of the Montezuma Slough, a similar behavior with delta smelt. In some years, wakasagi seem to be using Suisun Marsh more often in the wet years than the dry years. This might be attributed to certain favorable habitat from the marsh tributary drainages. In other years, spawning may not occur at all in the Suisun Marsh tributaries regardless of water year type, such as in 1997, a wet year, and 2002 a dry year (table 11). The reasons and explanations behind wakasagi spawning in an on/off manner in this area are not well-understood.

TABLE 11.—Wakasagi larvae and juveniles collected at Suisun Marsh by UC Davis in fish E&L sampling program, 1995–2002

Month	1995	1996	1997	1998	1999	2000	2001	2002
February	0	0	0	0	0	0	2	0
March	1	3	0	0	0	20	5	0
April	6	1	0	13	44	45	3	0
May	2	20	0	14	58	51	18	0
June	0	0	0	9	0	0	0	0
Total	9	24	0	36	102	116	28	0

CVP/TFCF

The catch of wakasagi adult and juveniles at the CVP/TFCF was sparse. Only a few juveniles and adults were observed in the last decade. Judging from the daily sampling at the CVP/TFCF between 1995 and 2005, no distinctive abundance trend could be recognized (table 12). While juveniles and adult life stages were collected at the CVP/TFCF, no larval stages were collected which might indicate a lack of wakasagi spawning habitat in the South Delta. The Federal and State water diversion systems have transported wakasagi from the Delta to San Luis Reservoir since the mid-1990s (Hess *et al.*, 1995). Since the wakasagi have established in San Luis this may also indicate that wakasagi may survive better in lentic (freshwater impoundment) than lotic (flowing estuarine) environments. Since the wakasagi were introduced from Japan to California reservoirs in 1959 (Wales, 1962) and substantially found their way to the Delta in the mid-1970s, there is still quite a bit of missing information on where they have been for the last three decades. One hypothesis is that a few individuals may have existed in the upper Sacramento River and were never noticed until the gates of Folsom Dam broke in 1995 when a large number of wakasagi escaped and established a reproductive population in the Delta (Lloyd Hess, personal communication). Another explanation may have derived from the misidentification of the wakasagi. Their elusive behavior may have also contributed to the lack of information.

Summary: Wakasagi has established a reproductive population in the upper Sacramento-San Joaquin Estuary since the early 1990s. Wakasagi larvae and adults were collected mainly from the freshwater in many locations of the upper Estuary. However, distribution patterns are not clearly known. Even though Wakasagi use the same spawning locations as delta smelt and longfin smelt, it seems that wakasagi survive better in lentic environments such as San Luis Reservoir and other known reservoirs in Northern California. The lotic estuarine environments may not be the best habitat for wakasagi, but currently the ecological status of wakasagi in the upper Estuary is poorly understood.

TABLE 12.—Wakasagi juvenile and adult collected at CVP/TFCF by Reclamation (including holding tank 10-minute sampling and all special studies), 1995–2005

Month		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
January	Ad.	0	0	0	0	0	0	0	0	0	1	0
	J.	0	0	0	0	0	0	0	0	0	0	0
February	Ad.	0	0	0	0	1	0	3	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
Mach	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
April	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	0	1	0	0	1	0	1	1	0	0
May	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	18	21	0	9	58	3	15	3	6	0
June	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	5	7	0	25	10	1	13	0	1	0
July	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	0	0	5	0	2	0	1	0	0	0
August	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
September	Ad.	0	0	0	0	0	1	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
October	Ad.	0	0	0	0	0	0	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
November	Ad.	0	0	0	0	0	3	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
December	Ad.	0	0	0	0	1	1	0	0	0	0	0
	J.	0	0	0	0	0	0	0	0	0	0	0
Total	**Ad.**	**0**	**0**	**0**	**0**	**2**	**5**	**3**	**0**	**0**	**1**	**0**
	J.	**0**	**23**	**29**	**5**	**24**	**71**	**4**	**30**	**4**	**9**	**0**

ACKNOWLEDGMENTS

I would like to thank the following people and institutions for their help in making this study and document possible. Financial support was received from the U.S. Department of Interior, Bureau of Reclamation, Tracy Fish Collection Facility Improvement Program. In addition, the following institutions and people provided valuable assistance in letting me view specimens and helping edit this report

California Department of Water Resources for sampling and supporting a quality control program on fish identification. Field specimens from CDFG, UC Davis (Scott Matern and Robert Schroeter), DWR. Laboratory specimens from Drs. Joan Lindberg and Bradd Baskerville-Bridges; laboratory egg incubation assistance from Brent Bridges; and the Napa River fishery database obtained from Mike Dege (CDFG) and Lauren Dusek (Stillwater Sciences, Inc.).

Lloyd Hess, Bradd Baskerville-Bridges, Brent Bridges, and the late Randy Brown for technical reviews.

Jean Temple for word processing. René Reyes for the illustrations and photography, reformatting the manuscript, and editing to comply with Tracy Series publication standards.

Ron Silva, Steve Hiebert, and Randy Brown for additional funding.

REFERENCES

Aasen, G.A., D.A. Sweetnam, and L.M. Lynch, 1998. *Establishment of the Wakasagi, Hypomesus nipponensis, in the Sacramento San Joaquin Estuary.* California Department of Fish and Game 84 (1): pp. 31–35.

Aplin, J.A., 1967. *Biological Survey of San Francisco Bay, 1963–1966*. California Department of Fish and Game, Mar. Resour. Oper., MRO Ref. 67–4, 131 pp.

Baskerville-Bridges, B., J. Lindberg, and S. Doroshov, 2004. *Effect of Light Intensity, Alga Concentration, and Prey Density on Feeding Behavior of Delta Smelt Larvae*. American Fisheries Society Symposium 39: 219–227.

Baskerville-Bridges, B., 2000–2005. Personal communications.

Baskerville-Bridges, B., and J. Lindberg, 2007. Personal communications.

Baxter, R.D., 2000. *Splittail and Longfin Smelt.* IEP Newsletter. Spring: 19–21 pp.

Baxter, R.D., K. Hieb, S. Deleon, K. Fleming, and J. Orsi, 1999. *Report on 1980–1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary, California.* IEP Sacramento-San Joaquin Estuary Tech. Rpt. 63, 503 pp.

Bennett, W.A., 2005. *Critical Assessment of the Delta Smelt Population in the San Francisco Estuary, California.* San Francisco Estuary and Watershed Sciences. Vol. 3, Iss. 2 (September 2005), Art 1, 71pp.

Bridges, B., 1999–2005. Personal communications.

Dege, M., 2003–2005. Personal communications.

Dryfoos, R.L., 1965. *The Life History and Ecology of the Longfin Smelt in Lake Washington.* PhD. Dissertation, Univ. Wash., 229 pp.

Emmett, R.L., S.A. Hinton, S.L. Stone, and M.E. Monaco, 1991. *Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries. Vol. 2: Species Life History Summaries.* Rockville, Md. NOAA/NOS Strategic Env. Asses. Div. ELMR Rpt. 8, 329 pp.

Erkkila, L.F., J.W. Moffett, O.B. Cope, B.R. Smith, and R.S. Nelson, 1950. *Sacramento-San Joaquin Delta Fishery Resources; Effects of Tracy Pumping Plant and Delta Cross Channel.* USFWS Spec. Sci. Rpt Fish 56, 109 pp.

Eschmeyer, W.N., E.S. Herald, and H. Harmann, 1983. *A Field Guide to Pacific Coast Fishes of North America.* Houghton Mifflin Co. Boston, 336 pp.

Fitch, J. S., and R.J. Lavenberg, 1971. *Marine Food and Game Gishes of California.* University of California Press, Berkley, California, 179 pp.

Follett, W.I., 1952. *Annotated List of Fishes Obtained by California Academy of Sciences During Six Cruises of the USS Mulberry Conducted by the United States Navy of Central California in 1949–1950.* Proc. California Acad. Sci. 27 (16): 399–432.

Frey, H.W., ed., 1971. *California's Living Marine Resources and Their Utilization*. California Department of Fish and Game, 148 pp.

Ganssle, D., 1966. *Fishes and Decapods of San Pablo and Suisun Bay. In: D. W. Kelley, ed., Ecological Studies of the Sacramento-San Joaquin Estuary. Part I.* California Department of Fish and Game, Fish. Bull. 33: 64–94.

Grimaldo, L., 2004. Personal communication.

Hart, J.L., 1973. *Pacific Fishes of Canada*. Canada Fish. Res. Board Can. Bull. 180, 740 pp.

Hart, J.L., and J.L. McHugh, 1944. *The Smelt (Osmeridae) of British Columbia.* Fish. Res. Board Can. Bull. 54, 27 pp.

Hearld. E.S., 1961. *Living Fishes of the World.* Doubleday and Co., New York, 304 pp.

Hess, L., 1996. Personal communication.

Hess, L., C. Karp, and J. Wang, 1995. *Sacramento Perch, Wakasagi, Splittail, Sacramento Blackfish, and Shimofuri Goby In San Luis Reservoir, and O'Neil Forebay*. IEP Newsletter, Autumn 1995: 18–20.

Hieb, K., 1994. Personal communication.

Hiebert, S., 1995. *Continuous Monitoring of Fish Eggs and Larvae During 1991 and 1992 Tracy Fish Collection Facility Studies, Vol. 2.* Bureau of Reclamation, Mid-Pacific Region and Denver Technical Services Center, 46 pp.

Hiebert, S., 1995. Personal communication.

Lindberg, J.C., and C. Marzola, 1993. *Delta Smelt in a Newly-Created Flooded Island in the Sacramento-San Joaquin Estuary.* Report to California Dept Water Resources, Sacramento.

Lindberg, J.C., B. Baskerville-Bridges, and S.I. Doroshov, 2003. *Two Reproductive Concerns Tested in Captive Delta Smelt, Hypomesus transpacificus, 2002: I. Effects of Substrates and Water Velocity on Spawning Behavior, and II. Effects of Temperature on Embryo/Larval Survival.* Annual report to IEP, 12 pp.

Lynch, L.M., 1998–2001. Personal communication.

Mager, R.C., 1996. *Gametogenesis , Reproduction, and Artificial Propagation of Delta Smelt, Hypomesus transpacificus*, Ph.D. Dissertation. University of California Davis, 125 pp.

Matern, S.A., 1999. *The Invasion of the Shimofuri Goby (Tridentiger bifasciatus) Into California: Establishment, Potential for Spread, and Likely Effects*. Ph.D. Dissertation. University of California Davis, 167 pp.

Matern, S.A., and K.J. Fleming, 1995. *Invasion of a Third Asian Goby, Tridentiger bifasciatus, Into California.* California Department of Fish and Game 81: 71–76.

May, B., 1996. *Identification of Smelt Species and Their Interspecific Hybrids in the Sacramento-San Joaquin Estuary by Allozyme Analysis.* IEP Newsletter. Summer 1996: 9–10.

McAllister, D.E., 1963. *A Revision of the Smelt Family,* Osmeridae. National Museum Of Canada Bull. 191, 53 pp.

Messersmith, J.D., 1966. *Fishes Collected in Carquinez Strait in 1961–1962. In: D.W. Kelley, ed., Ecological Studies of the Sacramento-San Joaquin Estuary: Part II. Fishes of the Delta.* California Department of Fish and Game, Fish Bull. 136: 57–63.

Miller, D.J., and R.N. Lea, 1976. *Guide to the Coastal Marine Fishes of California.* California Department of Fish and Game, Fish Bull. 157, 249 pp.

Moyle, P.B., 1976. *Inland Fishes of California.* University of California Press, Berkeley, 405 pp.

Moyle, P.B., 1995. *Searching Origin of the Delta Smelt.* IEP Newsletter. Spring: pp. 9–10.

Moyle, P.B., 2002. *Inland Fishes of California.* Revised and Expended. University of California Press, 502 pp.

Moyle, P.B., B. Herbold, D.E. Stevens, and L.W. Miller, 1992. L*ife History and Status Of Delta Smelt in the Sacramento-San Joaquin Estuary, California*. Trans. Am. Fish Soci. 121: 67–77.

Nelson, J.S., E.J. Crossman, H. Espinosa-Perez, L.T. Findley, C.R. Gilbert, R.N. Lea, and J.D. Williams, 2004. *Common and Scientific Names of Fishes From the United States, Canada, and Mexico*. Sixth edition. Am. Fish. Spec.Publ. 29, 386 pp.

Okiyama M., ed., 1988. *An Atlas of the Early Life Stages in Japan.* Tokai University Press. 1145 pp.

Penttila, D., 1978. *Studies of the Surf Smelt (Hypomesus pretiosus) in Puget Sound.* State of Washington Department of Fisheries, Tech. Rpt. 42.

Penttila, D., 2000. *Documented Spawning Seasons of populations of the Surf Smelt, Hypomesus, in the Puget Sound Basin.* State of Washington Department of Fish and Wildlife, Briefing Report, 32 pp.

Radtke, L.D., 1966. *Distribution of Smelt, Juvenile Sturgeon, and Starry Flounder in the Sacramento-San Joaquin Delta with Observations on Food of Sturgeon,* In J.L Turner and D.W. Kelley, ed., Ecological Studies of the Sacramento-San Joaquin Delta, Part II. California Department of Fish and Game, Fish Bull. 136, pp.115–129.

Rogers, D.A., 1984. *Seasonal Variation in Freshwater Smelt Abundance and Size and There Use as a Forage by Other Fish in Lake Shastina, Siskiyou County, 1972–1973*. California Department of Fish and Game Inland Fish Admin. Rpt. 84–2. 8 pp.

Schaefer, M.B., 1936. *Contribution of the Life History of the Surf Smelt Hypomesus pretiosus–in Puget Sound*. Wash. Dep. Fish. Biol. Rep. 35B: 1–45.

Schroeter, R.E., and P.B. Moyle, 2004. *Trend in Fish Populations of Suisun Marsh: January 2003–December 2003.* Annual Report to California Department of Water Resources. University of California at Davis, 45 pp.

Schroeter, R.E., and P.B. Moyle, 2005. *Trend in Fish Populations if Suisun Marsh: January 2004–December 2004.* Annual Report to California Department of Water Resources. University of California at Davis, 45 pp.

Shardin, A.M., 1989. *Embryonic and Larval Development of Smelt (Osmeridae) of the Far East IV.* Journal of Ichthyology, 29 (6): pp. 960–972.

Siegfried, S., D. Craft, S. Hiebert, and M. Bowen, 2000. *Continuous Monitoring of Fish Eggs and Larvae at the Tracy Fish Collection Facility, Tracy, California. February-June 1994. Tracy Fish Collection Facility Studies, California. Volume 6.* Bureau of Reclamation, Mid-Pacific Region, South Central California Area Office and Denver Technical Services Center, 30 pp. Plus appendix.

Simonsen, M., 1977. *The Use of Discrimination Function Analysis in the Identification of Two Species of Larval Smelt, Spirinchus thaleichthys and Hypomesus transpacificus, in the Sacramento-San Joaquin Estuary, California*. MS thesis. University of Pacific, Stockton, California, 53 pp.

Spaar, S., 1990a. *Results of the 1988 Striped Bass Egg and Larva Study Near the State Water Project and Central Valley Project Facilities in the Sacramento-San Joaquin Estuary*. IEP Technical Report 25 (FF/BIO-IATR/90–25).

Spaar, S., 1990b. *Losses of Striped Bass Eggs and Larvae at SWP and CVP Intakes. pp. 36-49 in 1989 Annual Report: Interagency Studies Program for the Sacramento-San Joaquin Estuary.* California Water Resources, 42 pp.

Spaar, S., 1991. *1990 Entrainment of Striped Bass Eggs and Larvae to the State Water Project and Central Valley Project Facilities in the Sacramento-San Joaquin Delta*. California Water Resources, 20 pp.

Spaar, S., 1992. *1991 Entrainment of Striped Bass E&L to the State Water Project and Central Valley Project Intakes in the Sacramento-San Joaquin Delta.* California Water Resources Memo. May 28, 1992, Sacramento, California, 17 pp.

Spaar, S., 1993. *1992 Entrainment of Striped Bass E&L to the State Water Project and Central Valley Project Intakes in the Sacramento-San Joaquin Delta.* California Water Resources Memo, January 20, 1993. Sacramento, California, 20 pp.

Spaar, S., and K. Wadsworth, 1994. *1993 Entrainment of Striped Bass E&L to the State Water Project and Central Valley Project Intakes in the Sacramento-San Joaquin Delta, California.* California Water Resources Memo. May 1993. Sacramento, California, 20 pp.

Stanley, S.E., P.B. Moyle, and H.B. Shaffer, 1995. *Allozyme Analysis of Delta Smelt, Hypomesus transpacificus and Longfin Smelt, Spirinchus thaleichthys in the Sacramento-San Joaquin Estuar*y, California. Copeia 1995: pp. 390–396.

Swanson, C., T. Reid, P.S. Young, and J.J. Cech Jr., 2000. *Comparative Environmental Tolerances of Threatened Delta Smelt (Hypomesus transpacificus) and Introduced Wakasagi (Hypomesus nipponensis) in an Altered California Estuary*. Oecologia (2000) 123: pp. 384–390.

Sweetnam, D., 1999. Personal communication.

Sweetnam, D.A., 1999. *Status of Delta Smelt in Sacramento-San Joaquin Estuary*. California Fish and Game 85: 22–7.

Thompson, W.F., F.H. Bell, H.A. Dunlop, L.P. Schultz, and R. Van Cleve, 1936. *The Spawning of the Silver Smelt, Hypomesus pretiosus.* Ecology 17(1): 158–68.

Trenham, P.C., H.B. Shaffer, and P.B. Moyle, 1998. *Biochemical Identification and Assessment of Population Subdivision in Morphologically Similar Native and Invading Smelt Species (Hypomesus) in Sacramento-San Joaquin Estuary, California*. Trans. Am. Fish. Soc. 127: 417–24.

U.S. Army Corps of Engineers, 2002. *Napa River Fisheries Monitoring Program Annual Report 2001.* Prepared by Stillwater Sciences, Berkley and Jones & Stokes Associates, Sacramento for U.S. Army Corps of Engineers. Sacramento District, California and Napa County Flood Control District.

U.S. Army Corps of Engineers, 2003a. *Napa River Fisheries Monitoring Program Final Report 2002.* Prepared by Stillwater Sciences, Berkley and Jones & Stokes Associates, Sacramento for U.S. Army Corps of Engineers, Sacramento District, California.

U.S. Army Corps of Engineers, 2003b. *Napa River Fisheries Monitoring Program Final Report 2003*. Prepared by Stillwater Sciences, Davis and Jones & Stokes Associates, Sacramento for U.S. Army Corps of Engineers, Sacramento District, California.

U.S. Army Corps of Engineers, 2004–2005. *Napa River Fisheries Monitoring Program Final Report of 2004 and 2005.* Prepared by Stillwater Sciences, Davis for U.S. Army Corps of Engineers, Sacramento District, California.

U.S. Army Corps of Engineers, 2005. *Napa River Fisheries Monitoring Program Final Report 2005*. Prepared by Stillwater Sciences for U.S. Army Corps of Engineers, Sacramento District, California.

Wales, J.H., 1962. *Introduction of Pond Smelt from Japan to California*. California Fish Game 48: pp.141–42.

Wang, J.C.S., 1986. *Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters*, California*: A Guide to The Early Histories.* IEP Tech. Rpt. 9. 612 pp.

Wang, J.C.S., 1991. *Early Life Stages and Early Life History of the Delta Smelt, Hypomesus transpacificus, in the Sacramento-San Joaquin Estuary, with Comparison of Early Life Stages of the Longfin Smelt, Spirinchus thaleichthys.* IEP Tech. Rpt. 28. 52 pp.

Wang, J.C.S., 1995. *Observation of Possible Larval and Prejuvenile and Delta/Wakasagi Hybrids in the Delta ad Tributary Streams*. IEP Newsletter. Summer 1955: pp. 18–19.

Wang, J.C.S., 1996. *Notes on Spawning of Smelt and Splittail in Sacramento-San Joaquin Estuary in Dry Year 1994 and Wet Year 1995*. IEP Newsletter. Summer 1996: pp. 31–5.

Wang, J.C.S., and R.L. Brown, 1993. *Observation of Early Life Stages if Delta Smelt, Hypomesus transpacificus, in the Sacramento-San Joaquin Estuary in 1991, With A Review of the Ecological Status in 188–1990.* IEP Tech. Rpt. 35. 18 pp. Plus appendix.

Wang, J.C.S., L.Lynch, B. Bridges, and L. Grimaldo, 2005. *Using Morphometric Characteristics to Identify the Early Life Stages of Two Sympatric Osmerids (Delta Smelt and Wakasagi-Hypomesus transpacificus and H. nipponensis) in the Sacramento-San Joaquin Delta, California. Tracy Fish Collection Facility Studies, California. Volume 30.* Bureau of Reclamation, Mid-Pacific Region and Denver Technical Services Center, 34 pp. Plus appendix.

Wang, J.C.S., and R.C. Reyes, 2005. *Early Life Stages and Early Life Histories of Cyprinids in Sacramento-San Joaquin Delta, California: With Emphasis on Splittail, Pogonichthys macrolepidotus, Spawning in the Suisun Bay and Delta.* Reclamation/Tracy Fish Collection Facility, 114 pp. Plus appendix (in Press).

Wiggleworth, K.A., 1975. *Some Life History Aspects of the Smelt (Hypomesus nipponensis) in Lake Shastina, California.* MS thesis. California State Univ., Sacramento, 22 pp.

Yapchiongco, J.V., 1949. *Hypomesus pretiosus*: *Its Development and Early Life* History. Nat. Appl.. Sci. Bull. 9(1): 3–08.

ABBREVIATIONS

ca.	circa
CDFG	California Department of Fish and Game
CVP/TFCF	Central Valley Project/Tracy Fish Collection Facility
DSLS	Delta smelt larvae survey, a CDFG delta smelt and longfin smelt pilot program
DWR	California Department of water Resources
E&L	Eggs and larvae
FCCL	Fish Culture and Conservation Laboratory
IEP	Interagency Ecological Program
NBA	North Bay Aqueduct
PG&E	Pacific Gas and Electric Company
Reclamation	Bureau of Reclamation
Sacramento-San Joaquin Delta	upper Sacramento-San Joaquin River Estuary (including Suisun Bay and Delta).
Sacramento-San Joaquin Estuary	Bay and Delta (including San Francisco Bay, San Pablo Bay, Suisun Bay, and Delta).
SDFPF	Skinner Delta Fish Protective Facility
SWP	State Water Project
TL	Total Length
UC Davis	University of California at Davis
U.S. Army Corps of Engineers	U.S. Army Corps of Engineers

APPENDIX TABLES

Table A1.—California Department of Water Resources, Division of Flood Management Database, WSIHIST, 1988–2005

Year	Sacramento River	San Joaquin River
	Million acre-feet (Oct-Mar/Apr-July)/Water year	**Million acre-feet (Oct-Mar/Apr-Jul)/Water year**
1988	5.78/2.90/Critical	0.86/1.55/Critical
1989	9.03/5.07/Dry	1.07/2.42/Critical
1990	4.94/3.72/Critical	0.83/1.59/Critical
1991	3.90/4.01/Critical	0.56/2.57/Critical
1992	5.41/2.93/Critical	0.86/1.66/Critical
1993	12.44/8.98/Average	2.49/5.65/Wet
1994	4.55/2.73/Critical	0.66/1.80/Critical
1995	19.83/13.60/Wet	3.67/8.01/Wet
1996	13.05/8.07/Wet	2.57/4.01/Wet
1997	20.22/4.39/Wet	5.75/3.59/Wet
1998	17.65/12.54/Wet	2.82/7.11/Wet
1999	12.97/7.26/Wet	1.90/3.85/Average
2000	12.06/5.96/Average	1.98/3.78/Average
2001	5.64/3.46/Dry	0.92/2.23/Dry
2002	9.32/4.57/Dry	1.27/2.75/Dry
2003	10.71/7.66.Average	1.26/3.49/Below average
2004	10.95/4.40/Below average	1.50/2.25/Dry
2005	8.3/9.29/Average	2.73/6.30/wet

Table A2.—Spatial and temporal distribution of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1992.
Area I: Upper Suisun Bay/West Delta/Lower and Upper Sacramento River

	Station Number																											
Date	**65**	**66**	**15**	**17**	**19**	**21**	**23**	**25**	**27**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**72**	**725**	**73**	**735**	**74**	**745**	**75**	**755**		**Total**
02/16/92						2										3												5
03/03/92														1		1												2
03/06/92				5		5		2		2																		14
03/07/92														1		1												2
03/13/92																		1										1
03/15/92								1																				1
03/19/92						5		1								4												10
03/23/92						1		2		1																		4
03/27/92						1		1		1				1		4												8
03/31/92				1				1		1				2								3		1	1			10
04/04/92				3		1										2												6
04/06/92															1	2	8	1										12
04/08/92														3		1		2		3		3						12
04/10/92														3	10	3	8	1		5	2	3						35
04/12/92																1						3						4
04/14/92										1		4		7	1		1		1	1	4	1	1					22
04/16/92								7		1				2		2		5				5						22
04/18/92															7		2			3		3	1					16
04/20/92								2		3				1						2		3						11
04/22/92												1		2		1	3		2	4								13
04/24/92														3				1		1					1			6
04/26/92												3						1		1				1				6
04/28/92														1		1								1				3
04/30/92												1				1		2	1	1	1	2	1	1				11
05/02/92																1				1								2
05/04/92												2	1	2	1		2	1	17	2	1		1					30
05/08/92														2	1	1		3										7
05/10/92														1		3												4
05/12/92														9				3										12
05/14/92								14						2		1		4										21
05/16/92																1	1									1		3
05/18/92										1						1		2										4
05/20/92																2	4	2										8
05/24/92																1												1
05/28/92																1												1
05/30/92																		3										3
06/01/92																1												1
06/03/92																		1										1
06/05/92															1													1
06/11/92						1																						1
06/15/92				1																								1
06/19/92								1																				1
Total				**10**		**16**		**32**		**11**		**11**	**1**	**43**	**22**	**40**	**29**	**33**	**21**	**24**	**8**	**26**	**4**	**4**	**2**	**1**		**338**

Table A2.—Spatial and temporal distributions of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1992.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River/ Lower Mokelumne River – continued

	Station Number																																
Date	**3**	**5**	**7**	**9**	**11**	**13**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**46**	**47**	**51**	**53**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**919**	**920**	**921**	**923**	**924**	**925**	**926**		**Total**
02/16/92																						1											1
02/28/92																4																	4
03/03/92															1	1					1	4											7
03/04/92														2																			2
03/06/92				1																													1
03/07/92								1	9	6		2				2					1												21
03/11/92										1		3			3					1													8
03/19/92												3			2	1		2															8
03/20/92																													2				2
03/23/92								3												2													5
03/27/92								2				2			1																		5
03/31/92												3				1		2				2											8
04/03/92														4											1	1			2	3			11
04/04/92															1	1						4											6
04/06/92												4					1	1	2	1	3			1									13
04/08/92																				1	1	1											3
04/10/92													2		1	3	2	2		1	2	1		3									17
04/12/92												4								1													5
04/14/92											1				2			1				1											5
04/16/92								1		3						1				1													6
04/20/92												1				1					1	1		2									6
04/21/92																							1				1	3			7		12
04/22/92										2	3								1	1													7
04/24/92												1			1																		2
04/26/92									4		2	1					1																8
04/28/92												1			3																		4
04/30/92							2				2	2	1																				7
05/02/92								1				1																					2
05/04/92												2	1					1															4
05/12/92												1																					1
05/16/92													1																				1
05/18/92										1																							1
05/20/92												1				1	1																3
05/26/92										2																							2
05/30/92												1																					1
06/03/92									1			1	1		1																		4
06/07/92								1																									1
06/15/92																			1														1
Total				**1**			**2**	**9**	**14**	**15**	**8**	**34**	**6**	**6**	**16**	**16**	**5**	**9**	**4**	**9**	**9**	**15**	**1**	**6**	**1**	**1**	**1**	**3**	**4**	**3**	**7**		**205**

Table A3.—Spatial and temporal distribution of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower and Upper Sacramento River

	Station Number																																					
Date	**515**	**416**	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**718**	**72**	**720**	**725**	**73**	**735**	**74**	**745**	**75**	**Total**
02/11/93																	1			1																		2
02/16/93																	1																					1
02/19/93														1	1	3			2						1	1												9
02/23/93																	1							2														3
02/27/93																			1																			1
03/03/93													1				1															1						3
03/07/93													3	1	1	3	7		3	3	4	2			1				3									31
03/08/93					4	1												1																				6
03/11/93																								3	1	1			2									7
03/12/93												1					4		2																			7
03/15/93																			1	2			1		2	2			1		1	1						11
03/16/93																		2																				2
03/19/93																			2	1		2					4						1	5				15
03/23/93												2			1	1	2		2	2					1	2												13
03/24/93																		2									1											3
03/27/93												1				1								1				1	1				1					6
03/31/93												3																			1		1			1		6
04/01/93			3																						1	1			1									6
04/04/93	3												2		2	1			1						2				1					1				13
04/08/93												1		1					1								1		1				3					8
04/09/93																		1																				1
04/12/93																								1			1											2
04/16/93																						1																1
04/17/93			4	3	5	4	5	1	1									1																				24
04/18/93																										1	1											2
04/20/93													1		1		1							2		5							1				1	12
04/24/93												5	3				3			1	1	1			2	1							1		1			19
04/25/93				2			3	7	3	2								5																				22
04/28/93														2	1		2			2			1	6				1								5	2	22
05/02/93													1	1					2	1	2	3	1	1		1								1		1		15
05/03/93	2	2			7		4	2	3	21	1																											42
05/04/93																											2											2
05/06/93																							1	8						1				1				11
05/07/93																1	2			2	5																	10
05/08/93																											4											4
05/10/93												5	1	1					1	1	2	1		7	9	5				1		3			2	2		41
05/11/93			1		8	3	1	7	9	7	9							1				10			3		1											60
05/12/93												1															4											5
05/14/93													3		3				3	1	2	5		1	5			1								2		26
05/16/93																											1											1
05/18/93													1		1	1	3										2			1								9
05/19/93																		1																				1
05/22/93												1					1		1	1		1			3		1			1								10
05/24/93																											2											2

Table A3.—Spatial and temporal distribution of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower and Upper Sacramento River – continued

	Station Number																																					
Date	**515**	**416**	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**718**	**72**	**720**	**725**	**73**	**735**	**74**	**745**	**75**	**Total**
05/26/93																									1	1	4		1	1		1			2			11
05/27/93							1		1	1																												3
05/29/93																					1					2	2		2									7
06/01/93																											1											1
06/03/93																										1												1
06/04/93				1						3	1																											5
06/07/93												1	1	1												2												5
06/11/93																1										1												2
06/12/93	5	1		1					1																													8
06/15/93												1								1																		2
06/20/93	1				8	4	2	1																														16
06/21/93																											1											1
06/23/93																			1																			1
06/25/93																										1												1
06/28/93	2	1		1		3	1				1																											9
07/01/93																											1	1										2
07/06/93														4		1																						5
07/07/93					1	1					1																											3
07/09/93												1			2		5																					8
07/13/93												1		1	1																							3
07/14/93			1				1				1																											3
Total	**13**	**4**	**9**	**8**	**33**	**16**	**18**	**18**	**18**	**34**	**14**	**24**	**17**	**13**	**14**	**13**	**34**	**14**	**23**	**19**	**17**	**26**	**4**	**32**	**32**	**28**	**34**	**4**	**13**	**5**	**2**	**6**	**8**	**8**	**5**	**11**	**3**	**594**

Table A3.—Spatial and temporal distribution of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River/Lower Mokelumne River

	Station Number																																		
Date	1	3	5	7	9	11	13	33	35	36	37	39	41	43	45	46	47	49	51	53	55	57	59	60	61	903	906	919	920	921	923	924	925	926	940	Total
02/11/93									3																											3
02/12/93																2		1								2										5
02/19/93												1																								1
02/20/93									1							1																				2
02/23/93									5					2		1																				8
03/03/93							2												1						1											4
03/07/93				5	5	2	5	1		4		1	1		2		3	4	1						1											35
03/08/93																4																				4
03/11/93									2			1																								3
03/15/93		1																																		1
03/16/93																										1										1
03/19/93			1			1					1							2																		5
03/23/93		1	2		5	1									6				1			1	1				1									19
03/24/93																6										2		1	3	1	1	1		4		19
03/27/93	1		3	2	2	1									1			3	2			6	1	1	2		3									28
03/31/93	1		1			2	1		1				2	1	1					1	4		1	1	1		2									20
04/04/93	3		1				1	1					1		3		1	3	1		1	2	2	3												23

Table A3.—Spatial and temporal distribution of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River/Lower Mokelumne River – continued

	Station Number																																			
Date	1	3	5	7	9	11	13	33	35	36	37	39	41	43	45	46	47	49	51	53	55	57	59	60	61	903	906	919	920	921	923	924	925	926	940	Total
04/07/93												1	2					1	1	1	2	2	3	1												14
04/08/93	4		3	2	1																			3												13
04/09/93																1															1					2
04/12/93								1	5				3	1			1	1		1	1															14
04/15/93				1											1																					2
04/16/93		3	1			1		4	1			1					2	1	1		1	1	1	1	2											21
04/17/93																1													2						1	4
04/20/93	1		1	2	1			1	2					1					1	1		1					1									13
04/24/93				1		3		5			1	2	1					1		2	2	2		1												21
04/25/93			6													1										1		1			3			2		14
04/28/93	1	1						2	1		1	1		2			2	1			2				1		1								1	17
05/02/93		1		4			1	3			1				3		1		1		2	4			5							1				27
05/03/93																										5	1	1		1	8			1		17
05/04/93												2																								2
05/06/93				1				3	1			1							1		3															10
05/07/93							1																													1
05/10/93												1					1	6							2											10
05/11/93																1										5			1	1	2	5		1		16
05/14/93	2						1		1					1																						5
05/18/93					1				1																										1	3
05/19/93												1			2													2						1		6
05/22/93									3		3	1					2		5						3											17
05/27/93																	7		5												3					15
05/29/93											3																						1			4
06/04/93																																		1		1
06/07/93	1				3		1	4			1																									10
06/08/93								1					1	3								1														6
06/11/93			2	1	1	2			1		1							2																		10
06/15/93					1																															1
06/18/93									1			1																								2
06/27/93						1	1				1																									3
06/28/93																																	1			1
07/01/93	1						1				1																									3
07/06/93							5	2					1																							8
07/09/93		1							1		1			2		2		2																		9
07/13/93	1	1	1		1	1																														5
Total	**16**	**9**	**22**	**19**	**21**	**15**	**20**	**28**	**30**	**4**	**15**	**15**	**12**	**13**	**19**	**20**	**20**	**28**	**21**	**6**	**18**	**20**	**9**	**11**	**18**	**16**	**9**	**5**	**6**	**3**	**18**	**7**	**2**	**10**	**3**	**508**

Table A4.—Spatial and temporal distributions of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1994.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower and Upper Sacramento River

	Station Number																																						
Date	**515**	**414**	**416**	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**28**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**72**	**725**	**73**	**735**	**74**	**745**	**75**	**755**	**Total**
02/15/94																		1																					1
02/23/94																								1				2											3
02/27/94																1		2		2							4												9
02/28/94								1													1																		2
03/03/94																											2												2
03/08/94																			1																				1
03/11/94																	3					2					3												8
03/15/94														3						5		3	9			6				1	3								30
03/16/94																			1																				1
03/19/94																		1				3	10	2		4	26	9	10	5	5	8	3		2			1	89
03/23/94																								6								3		5	1				15
03/24/94												5							10																				15
03/25/94																															5			1					6
03/27/94																5		1		17			6	1	3	7		15	46	4					1				106
03/31/94																	1	3					16		3						1	4		1		1			30
04/01/94							1	4				1							1																				7
04/04/94																				4		4	9	2		55	6	24	27		2	1					1		135
04/05/94																																1							1
04/08/94							2											6		6		6	7	2	2		8	7	14	3	3		1	1					68
04/09/94						1		4											4							4													13
04/12/94															1		4	6		12		3		1			13	18	14	11	5	1					1		90
04/16/94																1		3					4	4	1	2	3	9		6				2					35
04/17/94								2											119																				121
04/20/94														1	2	2		17					10	1	1	51	3			7			1						96
04/24/94															8		10	4					2	2	1	2			1			1							31
04/25/94											1								1							2					1								5
04/28/94																		3				1					1		6	3			1						15
05/02/94														1		1		2		7		3	1	1		15		2		1									34
05/06/94															2	5		2		1					2	4		1	1	1		1		3					23
05/11/94									1	1									6																				8
05/14/94																				1																			1
05/19/94												1																											1
05/22/94																						1														1			2
05/27/94											1																												1
05/31/94																		1				1				1													3
06/03/94													4	6	8	5	1																						24
06/07/94													4		6																								10
06/11/94														1	31	17	4			1																			54
06/12/94																			2																				2
06/15/94																	6	10		7		1	1																25
06/19/94													1		9		1	1																					12
06/20/94							2					2							1																				5
06/23/94														11	6	5	9																						31
06/27/94																1		2		4																			7
06/28/94																			2																				2
07/01/94															2	5	7																						14
07/05/94															1																								1
07/09/94													2	1	4																								7
07/14/94	3										1																												4
Total	**3**					**1**	**5**	**11**	**1**	**1**	**3**	**9**	**11**	**24**	**80**	**48**	**46**	**65**	**148**	**67**	**1**	**28**	**75**	**23**	**13**	**153**	**69**	**87**	**119**	**42**	**25**	**20**	**6**	**13**	**4**	**2**	**2**	**1**	**1206**

Table A4.—Spatial and temporal distributions of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1994.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River/Lower Mokelumne River

	Station Number																																		
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**46**	**47**	**49**	**51**	**53**	**54**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**919**	**920**	**921**	**923**	**924**	**926**	**940**	**Total**
02/11/94								1			1																								2
02/27/94									2																										2
03/07/94																			1																1
03/08/94															1															1					2
03/11/94																1	1																		2
03/15/94																		1									2								3
03/16/94																										1					1			11	13
03/19/94																	4				1	4	3	1	5										18
03/23/94																1	4	4																	9
03/24/94															28																				28
03/25/94														5																					5
03/27/94								3																											3
03/31/94												23	26					10	5		4	3		6	5										82
04/01/94															70									16	18	11			2	1	2	11	3	1	135
04/04/94							1	2		16	27	2	3	7		81	15	3	16		3	8	3				6								193
04/08/94										2		59				8	3	5		4	7		1	2	8		1	1							101
04/09/94															36											2					4	3		1	46
04/12/94			6					1		4		5	20	19		2	3	1	5		1	4	3	1	6										81
04/16/94											5	7	4	14		17	37	9	4		5	2	2	6	3		2								117
04/17/94															1													1			4	2		2	10
04/20/94									11	6	6	17	27	4		3	2	4	1			4			17										102
04/21/94																								2											2
04/24/94									2	4	12	21	11	11		3	8					1	1		10									1	85
04/25/94												4			9																				13
04/28/94													3	1		14	9	10	6																43
05/02/94								3	1	1							13	4	1		1														24
05/03/94																										1		1							2
05/06/94								1	8	3		11	3			3	2																		31
05/10/94										1	2	7	8	2								1			1										22
05/11/94															10																				10
05/14/94												1	10	2																					13
05/18/94											2														4										6
05/19/94																								1											1
05/26/94													1																						1
06/03/94								1		2	1								1						1										6
06/11/94								1						4											2										7
06/15/94										1	4	2	1				1	1	1																11
06/19/94							5	2																											7
06/23/94								1	1		1																								3
06/28/94															1																1				2
07/01/94					2	1	1																												4
07/05/94				1																															1
07/09/94				2						1																									3
07/13/94								1																											1
Total			**6**	**3**	**2**	**1**	**7**	**17**	**25**	**41**	**61**	**159**	**117**	**69**	**156**	**133**	**102**	**52**	**41**	**4**	**22**	**27**	**13**	**35**	**80**	**15**	**11**	**3**	**2**	**2**	**12**	**16**	**3**	**16**	**1253**

Table A5.—Spatial and temporal distributions of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1995.

Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower Sacramento River

	Station Number																																			
Date	**515**	**414**	**416**	**63**	**64**	**65**	**66**	**605**	**606**	**607**	**609**	**611**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**27**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**722**	**723**	**724**	**725**	**726**	**Total**
02/11/95																				1															1
03/03/95																																			2	2
03/11/95																															5				5
03/15/95																				1															1
03/16/95	3		1																																4
03/24/95					1																														1
03/31/95							2								1		1		2												1				7
04/01/95	1																																		1
05/02/95							1													1															2
05/03/95	1																																		1
05/18/95																																			1	1
05/19/95	2				1																														3
05/22/95				1																															1
05/26/95																1																			1
05/27/95								3		1																									4
06/02/95																		1																	1
06/03/95																															1				1
06/04/95	1			2	1					2		1																							7
06/11/95							1																							1		1			3
06/12/95				11					1	1	4			1																					18
06/15/95																															1				1
06/19/95																														1					1
06/20/95				1					7	3																									11
06/23/95																														2					2
06/28/95									1																										1
07/05/95																				1															1
07/06/95				1	2																														3
07/09/95																														1	1				2
Total	**8**		**1**	**16**	**5**		**4**	**3**	**9**	**7**	**4**	**1**		**1**		**2**		**2**		**6**												**5**	**9**	**1**		**3**	**87**

Table A5.—Spatial and temporal distributions of delta smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1995.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River/Lower Mokelumne River

	Station Number																																		
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**33**	**35**	**36**	**37**	**39**	**41**	**43**	**45**	**47**	**49**	**51**	**53**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**919**	**920**	**921**	**923**	**924**	**925**	**926**	**927**	**Total**
02/11/95					1							4																							5
02/27/95									1			1																							2
02/28/95																												1							1
03/15/95									2																										2
05/02/95					3																														3
05/03/95																											1			2		1			4
05/18/95					1				2																										3
05/19/95																												1		1			1	1	4
05/26/95			1				1		1					1																					4
06/02/95							1																												1
06/19/95					2																														2
06/20/95																											1								1
06/29/95												1																							1
07/05/95							1																												1
07/06/95				1																															1
Total			**1**	**1**	**7**		**3**		**6**			**6**		**1**													**2**	**2**		**3**		**1**	**1**	**1**	**35**

Table A6.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1992.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower Sacramento River.

	Station Number																										
Date	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**69**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**28**	**29**	**32**	**70**	**712**	**713**	**715**	**716**	**Total**
02/12/92												19		10		37				22							88
02/16/92												5		16		5				3							29
02/20/92												9		3						4							16
02/24/92												2								1					2		5
02/25/92				5																							5
02/28/92			6									6															12
03/03/92			19	12								5								1							37
03/06/92			38	10								5															53
03/07/92																									1		1
03/12/92			42	7								2		1						1							53
03/15/92			8	4								8		1													21
03/19/92			4	8																							12
03/23/92			13	2								4															19
03/27/92			2	8																							10
03/31/92			5	2								3															10
04/04/92			4	1								3		1													9
04/08/92				1								1															2
04/24/92			1																								1
05/02/92				1								1															2
05/06/92			1																								1
05/07/92																	1										1
05/10/92														1		1											2
05/18/92			1	1										3													5
05/22/92														1													1
05/30/92				1										1													2
Total			**144**	**63**								**73**		**38**		**43**	**1**			**32**					**3**		**397**

Table A6.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1992.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River

	Station Number																												
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**31**	**33**	**35**	**36**	**37**	**39**	**41**	**43**	**45**	**47**	**49**	**51**	**53**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**924**	**Total**
02/12/92							42			19			6		60		11		14		2			3	10		1		168
02/16/92							12			23			18		12		4		1				2						72
02/20/92							7						10		1		2							1	6				27
02/24/92							1																						1
02/25/92										3			2						2										7
02/28/92			132				1			2			6		2		3		1		1				4				152
03/03/92			39		45		8						4																96
03/04/92																												1	1
03/06/92			44		29																								73
03/07/92										1			2																3
03/11/92										2			1																3
03/12/92			4		9		48																						61
03/15/92			13		6		2			1			1		1				4		1		2		3				34
03/19/92			10		8					4			3																25
03/23/92			5		5		3			3											1		1				2		20
03/27/92			2		1		1																						4
03/31/92			1		1		1			1			1																5
04/04/92					1		1																						2
04/06/92										1			5	10															16
04/08/92			2		1		1																						4
04/10/92										1				1															2
04/12/92			2																										2
04/22/92										1					3		1												5
04/24/92					1					1																			2
04/30/92									2																				2
05/02/92			1																										1
05/06/92			1																										1
05/24/92										1																			1
05/30/92			1																										1
Total			**257**		**107**		**128**		**2**	**64**			**59**	**11**	**79**		**21**		**22**		**5**		**5**	**4**	**23**		**3**	**1**	**791**

Table A7.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower Sacramento River.

	Station Number																													
Date	**515**	**414**	**416**	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**69**	**15**	**17**	**19**	**21**	**23**	**25**	**27**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**718**	**Total**
02/11/93														1	1													1			3
02/12/93	21	24	15	13	10	12	2	67		7	2	2																			175
02/15/93														1	6																7
02/19/93														1	2	3															6
02/20/93		42	59	14	8			18	24		4		8																		177
02/23/93																							1								1
02/27/93														1																	1
02/28/93	2	6	4	1				5	2	3																					23
03/03/93														2		3		3		1											9
03/08/93	28		4	1	18	1		11	6			9																			78
03/12/93															4		1														5
03/15/93														4	5	9	2	6	3		2							2			33
03/16/93	22	6	1	3	9	18	5	11	20		2	3																			100
03/19/93														2				1													3
03/24/93									27	1																					28
04/01/93	3		1																												4
04/04/93																														1	1
04/12/93															3																3
04/17/93	2	25	9		2			2		1																					41
04/24/93														1																	1
04/25/93	32	6	2	10		49			1																						100
05/03/93	1	16	12	4	5	1		1																							40
05/07/93											2			1																	3
05/10/93														10																	10
05/11/93	2		2	7	2	21	8					9																			51
05/27/93		1									1																				2
07/14/93	2		1					1																							4
Total	**115**	**126**	**110**	**53**	**54**	**102**	**15**	**116**	**80**	**12**	**11**	**23**	**8**	**24**	**21**	**15**	**3**	**10**	**3**	**1**	**2**		**1**					**3**		**1**	**909**

Table A7.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1993.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River

	Station Number																												
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**31**	**33**	**35**	**36**	**37**	**39**	**41**	**43**	**45**	**46**	**47**	**49**	**51**	**53**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**Total**
02/11/93	17	7	7	12	4		3		22	1			22	3	10	3						5	1						124
02/15/93		13	6	4	6	2																							31
02/16/93		1					3		7	20			10	3	6	2	7	4	3	5	5					3			72
02/19/93	34	9	42	10		6	2		2	3		2	8	11	5	3		1	3	1									142
02/20/93										1																			1
02/23/93	2	2	3	2	7								4						1	1									22
02/27/93	1	8	5	3	1	1	2		1	55		3	3	3	1	1									1	1			90
03/03/93	7	1	5	4					4	1			3	2	1			1	1										30
03/07/93	4	9	13															1											27
03/11/93				19		1							1	2	1						1			2					27
03/12/93	48	28	8		12		1		12								1												110
03/15/93	19	16	7	9	5	9	3			2	7		3	2	3	1		5								2			93
03/16/93																	2												2
03/19/93	27	1	5	7	10				3	2			1	1	2	1		1	2	2		1	1		1	1			69
03/24/93		1																											1
04/12/93	1	1	3		9		1																						15
04/15/93			1																										1
04/16/93	1	1	3																										5
04/20/93	27	63		11				1	2																				104
04/24/93	9	13	42	7	9	1			1				1																83
04/28/93	19	18	30		2																								69
05/02/93	5	11	9	2									3																30
05/07/93	2	6		4	8	2																							22
05/10/93	3	2	1	3	1	1																							11
05/14/93	2	6	6	1																									15
05/18/93		1	2	3																									6
05/22/93		1		1		1																							3
05/26/93	48																												48
06/07/93				2																									2
06/11/93	1																												1
06/15/93			1																										1
06/18/93			1																										1
06/23/93			1																										1
07/09/93		1	1		1																								3
07/13/93		2																											2
Total	**277**	**222**	**202**	**104**	**75**	**24**	**15**	**1**	**54**	**85**	**7**	**5**	**59**	**27**	**29**	**11**	**3**	**20**	**10**	**9**	**6**	**6**	**2**	**2**	**2**	**7**			**1264**

Table A8.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1994.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower Sacramento River

	Station Number																														
Date	**515**	**414**	**416**	**63**	**64**	**65**	**66**	**606**	**607**	**609**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**28**	**29**	**32**	**70**	**71**	**712**	**713**	**715**	**716**	**717**	**Total**
02/11/94													27	14		3	3	5				2	2		1	2	8				67
02/12/94	202		204	223	426	57	117	49	7	7		12							4	10											1318
02/15/94													11	83	1	3		2		2						2			3		107
02/19/94													96		7	12	2			1		1	2					1	3	1	126
02/20/94	265	14	17	180	143	368	194	239	10	12	7	1							7												1457
02/23/94													5	9	2	1		1				1		1					4		24
02/27/94														13	5		7			2			5				1	2			35
02/28/94	163	51	5	62	23	171	62	7	6	1	5	94																			650
02/29/94																			2												2
03/02/94																												5			5
03/03/94													141	59		4	5	5				4	6	1				2	5		232
03/07/94													99	15	5	3	2	3		2			3								132
03/08/94	129	29	31	76		156	154	28	95	12	4	7																			721
03/11/94													4	9	3	6				2			4						5	1	34
03/15/94													21	13		1	5			5					2			15	3		65
03/16/94	207	92	129	218		236	136	21	15	5	4	12																			1075
03/19/94													201	71	8	5	3			7		10						33	6		344
03/24/94	369	27	19		112	89	118	150	5	10	2	17	21						7												946
03/25/94																		21													21
03/27/94														42	5			1				18	1			1			7		75
03/31/94													96	45	14	4		4		2		2						1			168
04/01/94	49	12	32	71	68	81	45	3	8			7							12												388
04/04/94														17	5	9	5														36
04/08/94															7	1															8
04/09/94	13	15	23	21		19	13	42	19	5									2												172
04/12/94													13	14	13	9	3	3					7								62
04/16/94													6	5	6	7	4	2		2		1					3				36
04/17/94		4	2	24	8	1	3	7		6	4	8							4												71
04/20/94													7		25	9	10					1	1						1		54
04/24/94													2	2	8	23															35
04/25/94			1	1			2	3	2	1	1	8							8												27
04/28/94														1			1	8		3											13
05/02/94																7		6		3											16
05/03/94									3																						3
05/06/94															8	5															13
05/11/94	1		1	2		1			1	2																					8
05/18/94																		1													1
05/19/94	1	3																													4
05/22/94																											1				1
05/26/94													1																		1
05/31/94														2																	2
06/04/94			2																												2
06/11/94														1	2																3
06/15/94															1	1															2
06/23/94														1																	1
Total	**1399**	**247**	**466**	**878**	**780**	**1179**	**844**	**549**	**171**	**61**	**27**	**166**	**751**	**416**	**125**	**113**	**50**	**62**	**46**	**41**		**40**	**31**	**2**	**3**	**5**	**13**	**59**	**37**	**2**	**8563**

Table A8.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1994.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River

	Station Number																												
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**31**	**33**	**35**	**36**	**37**	**39**	**41**	**43**	**45**	**46**	**47**	**49**	**51**	**53**	**55**	**57**	**59**	**60**	**61**	**903**	**906**	**923**	**Total**
02/11/94			201			45			54	32		14	21	11	6	19		3	7	2	3	3				8		1		430
02/12/94	334																1													335
02/15/94	132	142	138	170	185	219	132																							1118
02/19/94	68	129	117		412	368	55			35		24	16	22	13	3		3	3	4	4									1276
02/20/94																	1													1
02/23/94	199		130	69	51	19	3		9			8	3	2	3	5		6	1	2										510
02/25/94							121																					1		122
02/27/94	54	160	151	134	131	99	16		9	12		24	6	5	2	3	1	2	1		1			1	2	4				818
02/29/94				139					48																					187
03/03/94	68	79	66	100		187	92																							592
03/04/94							92		32	26		18	7	7	3	2			5	1	2	2	2	1		1				201
03/07/94	182	160	73	86	185	31	17	8	14	9		4	4	6	2	1		1	3	1	1	1								789
03/11/94		183	135	118	113				6	18		5	8	4		1			3		1	175	2			1				773
03/15/94	70	80	90	103		170	140		50	37		16		4	10				3	3			1		1	5				783
03/16/94																	2													2
03/19/94	62	54	72	64	153	155	103		124				16	14		5		7	1	2	1			1		3				837
03/23/94		132							13	6		5	2		1			1	2						30	2				194
03/24/94			112	150	194		101																							557
03/27/94	45	39	105	72	120	117	31		8	12																				549
03/31/94	10	6	17	15	49	61	57		75			21	12	25	10	14		2	1		2	1				1		6		385
04/01/94																	13													13
04/04/94	30	77	30	45	27	18	3		8	13		18		8	5					3						2				287
04/08/94	11					11			24	8		24				4		1							1					84
04/09/94																	1	18												19
04/12/94	2	2	3	4	8	3	4		15			7	10	13	5	7						1								84
04/16/94			5	1	2	3	6		22	19		14	24	18	3	3		7	1											128
04/17/94																	7													7
04/20/94				1	1	2	5		6	3		2	1		1				1											23
04/24/94	1		2	1			2			10		8	10	4	1	2		1												42
04/25/94																											1		2	3
04/28/94				1		1						3		1	1	2		5		5	2									21
05/02/94				1						2		5																		8
05/06/94										3																				3
05/10/94	1												1																	2
05/14/94																2														2
05/18/94													2																	2
05/26/94						1																								1
06/03/94							1																							1
06/07/94			1																											1
06/15/94	1																													1
06/27/94												1																		1
Total	**1270**	**1243**	**1448**	**1274**	**1631**	**1510**	**981**	**8**	**517**	**245**	**0**	**221**	**143**	**144**	**66**	**73**	**26**	**57**	**32**	**23**	**17**	**183**	**5**	**3**	**34**	**27**	**1**	**8**	**2**	**11192**

Table A9.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1995.
Area I: Upper Suisun Bay/Montezuma Slough/West Delta/Lower Sacramento River

	Station Number																														
Date	**515**	**414**	**416**	**63**	**64**	**65**	**605**	**66**	**606**	**607**	**609**	**610**	**611**	**67**	**68**	**15**	**17**	**19**	**21**	**23**	**25**	**26**	**27**	**28**	**29**	**32**	**722**	**723**	**724**	**726**	**Total**
02/11/95					7			7									3		1												18
02/12/95	17		2	9					178			4	10	1	1																222
02/15/95																												1	1		2
02/19/95					14																							10			24
02/21/95	29		31	6					4	1	3		1														2	2			79
02/27/95								32									9											10		1	52
02/28/95	51		79	153	68				11				23		24																409
03/03/95								34								5			37		8										84
03/07/95																											5	10			15
03/08/95	67		51		26				18	4	4	79		6																	255
03/15/95								2																							2
03/16/95			1		2								1																		4
03/24/95			8	2							2		1																		13
03/31/95																	2		2												4
04/01/95			2	1																											3
04/02/95			9	3																											12
04/25/95												3																			3
06/04/95			30																												30
06/06/95				2																											2
07/13/95			1																												1
Total	**164**		**214**	**176**	**117**			**75**	**211**	**5**	**9**	**86**	**36**	**7**	**25**	**5**	**14**		**40**		**8**						**7**	**33**	**1**	**1**	**1234**

Table A9.—Spatial and temporal distributions of longfin smelt early life stages in the Upper Sacramento-San Joaquin Estuary, 1995.
Area II: Lower Suisun Bay/West Delta/Lower San Joaquin River

	Station Number																									
Date	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**47**	**49**	**51**	**53**	**54**	**55**	**57**	**59**	**60**	**31**	**919**	**920**	**Total**
02/11/95			1		3		4		5																		13
02/12/95																									1		1
02/27/95			127		92				7		14					9											249
02/28/95																									1		1
03/07/95				46	109		26		15		14		4														214
03/15/95							1																				1
03/23/95			1						1		1		1														4
03/31/95			4		1		2		2																		9
05/02/95			1																								1
07/05/95			2																								2
07/13/95			1																								1
Total			**137**	**46**	**205**		**33**		**30**		**29**		**5**			**9**									**2**		**496**

Table A10.—Napa River fish species composition (CDFG 20mm fish survey), 1995–2005

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Family Petromyzontidae–lampreys											
River lamprey							+				
Lampetra ayresii											
Pacific lamprey		+									
Lampetra tridentata											
Family Acipenseridae–sturgeons											
White sturgeon		+									
Acipenser transmontanus											
Family Engraulidae–anchovies											
Northern anchovy	+	+	+	+		+	+	+	+	+	+
Engraulis mordax											
Family Clupeidae–herrings											
American shad		+		+	+	+			+		
Alosa sapidissima											
Pacific herring	+	+	+	+	+	+	+	+	+	+	+
Clupea pallasii											
Threadfin shad		+		+	+		+	+	+	+	+
Dorosoma petenense											
Family Cyprinidae–carps and minnows											
Common carp						+					
Cyprinus carpio											
Splittail	+	+		+	+	+	+			+	+
Pogonichthys macrolepidotus											
Cyprinids (UNID)						+					
Family Catostomidae–suckers											
Sacramento sucker		+	+	+	+	+					+
Catostomus occidentalis											
Family Ictaluridae–North American catfishes											
White catfish					+						
Ameiurus catus											
Channel catfish					+						
Ictalurus punctatus											
Family Osmeridae–smelts											
Wakasagi		+									
Hypomesus nipponensis											
Surf smelt					+						
Hypomesus pretiosus											
Delta smelt	+	+		+	+	+	+		+		+
Hypomesus transpacificus											
Longfin smelt	+	+		+	+	+	+		+	+	+
Spirinchus thaleichthys											

Table A10.—Napa River fish species composition (CDFG 20mm fish survey), 1995–2005 – continued

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Family Salmonidae–trouts and salmons											
			+	+		+		+		+	+
Chinook salmon *Oncorhynchus tshawytscha*											
Family Batrachoididae–toadfishes											
		+	+								
Plainfin midshipman *Porichthys notatus*											
Family Atherinopsidae–New World silversides											
Topsmelt	+	+	+		+	+	+	+	+	+	
Atherinops affinis											
Jacksmelt		+	+		+	+	+	+	+	+	
Atherinopsis californiensis											
Inland silverside		+	+			+	+		+		
Menidia beryllina											
Family Fundulidae–topminnows											
Rainwater killifish				+				+			
Lucania parva **Family Gasterosteidae–sticklebacks**											
Threespine stickleback	+	+		+	+	+	+	+	+	+	+
Gasterosteus aculeatus **Family Syngnathidae–pipefishes**											
Bay pipefish	+	+								+	
Syngnathus leptorhynchus											
Family Cottidae– sculpins											
Prickly sculpin	+	+	+	+	+	+	+	+	+		+
Cottus asper											
	+	+	+	+	+	+	+	+			+
Pacific staghorn sculpin *Leptocottus armatus*											
Family Moronidae–temperate basses											
	+	+	+	+	+	+	+	+	+	+	+
Striped bass *Morone saxatilis*											
Family Centrarchidae, sunfishes											
					+	+					+
Largemouth bass *Micropterus salmoides*											
		+		+							
Black crappie *Pomoxis nigromaculatus*											
Centrarchids (UNID)							+		+		+
Family Sciaenidae–drums and croakers											
White croaker		+	+	+		+	+		+		
Genyonemus lineatus **Family Embiotocidae–surfperches**											
Tule perch		+									

Hysterocarpus traskii

Table A10.—Napa River fish species composition (CDFG 20mm fish survey), 1995–2005 – continued

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Family Gobiidae, gobies											
Yellowfin goby	+	+	+	+	+	+	+	+	+	+	+
Acanthogobius flavimanus											
Arrow goby	+		+	+	+	+	+	+	+	+	+
Clevelandia ios											
Longjaw mudsucker	+	+	+	+	+	+	+	+	+	+	+
Gillichthys mirabilis											
Cheekspot goby	+	+	+	+	+	+	+		+	+	+
Ilypnus gilberti											
Bay goby		+	+	+	+	+	+	+	+	+	
Lepidogobius lepidus											
Shokihaze goby							+			+	+
Tridentiger barbatus											
Shimofuri goby	+	+	+	+	+	+	+	+	+	+	+
Tridentiger bifasciatus											
Tridentiger spp.			+	+	+	+	+	+	+	+	+
Family Paralichthyidae–sand flounders											
Speckled sanddab			+								
Citharichthys stigmaeus											
Family Pleuronectidae–righteye flounders											
Starry flounder	+	+	+	+	+	+	+			+	+
Platichthys stellatus											
Total species	**17**	**28**	**21+**	**23+**	**24+**	**25+**	**23+**	**16+**	**20+**	**19+**	**21+**

Grand Total species: 40+

SJC-531

Table A11.—Napa River fish species composition (Stillwater Sciences, Inc. fishery survey), 2001–2005

	2001		2002		2003		2004		2005	
	JA*	L**	JA	L	JA	L	JA	L	JA	L
Family Engraulidae–anchovies										
Northern anchovy *Engraulis mordax*	+	+		+						
Family Clupeidae–herrings										
American shad *Alosa sapidissima*	+		+		+		+		+	
Pacific herring *Clupea pallasii*		+	+	+	+	+	+	+	+	
Threadfin shad *Dorosoma petenense*	+	+	+		+		+		+	+
Family Cyprinidae–carps and minnows										
Common carp *Cyprinus carpio*	+		+		+		+		+	
Golden shiner *Notemigonus crysoleucas*			+				+			
Splittail *Pogonichthys macrolepidotus*	+	+	+		+		+		+	
Sacramento pikeminnow *Ptychocheilus grandis*							+			
Family Catostomidae–suckers										
Sacramento sucker *Catostomus occidentalis*		+			+		+		+	
Family Ictaluridae–catfishes										
White catfish *Ameiurus catus*					+					
Channel catfish *Ictalurus punctatus*			+							
Family Osmeridae–smelts										
Wakasagi *Hypomesus nipponensis*	+		+							
Delta smelt *Hypomesus transpacificus*		+		+						
Longfin smelt *Spirinchus thaleichthys*	+	+		+		+		+		+
Family Salmonidae–trouts and salmons										
Chum salmon *Oncorhynchus keta*							+		+	
Chinook salmon *Oncorhynchus tshawytscha*			+		+		+			
Rainbow trout or steelhead *Oncorhynchus mykiss*			+				+		+	
Family Antheriopsidae–New World silversides										
Jack smelt *Antherinopsis californiensis*		+								
Inland silverside *Menidia beryllina*	+	+	+		+	+	+		+	

Table A11.—Napa River fish species composition (Stillwater Sciences, Inc. fishery survey), 2001–2005 - continued

	2001		2002		2003		2004		2005	
	JA*	**L****	**JA**	**L**	**JA**	**L**	**JA**	**L**	**JA**	**L**
Family Fundulidae–topminnows										
Rainwater killifish *Lucania parva*					+		+		+	
Family Poeciliidae–Livebearers										
Western mosquitofish *Gambusia affinis*	+		+		+					
Family Gasterosteidae–Sticklebacks										
Threespine stickleback *Gasterosteus aculeatus*		+	+		+		+		+	
Family Cottidae– sculpins										
Prickly sculpin *Cottus asper*	+	+	+		+	+	+		+	
Pacific staghorn sculpin *Leptocottus armatus*	+		+		+		+		+	
Family Moronidae–temperate basses										
Striped bass *Morone saxatilis*	+	+	+		+	+	+		+	+
Family Centrarchidae–sunfishes										
Bluegill *Lepomis macrochirus*					+				+	
White crappie *Pomoxis annularis*									+	
Black crappie *Pomoxis nigromaculatus*			+		+		+			
Largemouth bass *Micropterus salmoides*					+		+			
Family Embiotocidae–surfperches										
Tule perch *Hysterocarpus traskii*	+		+		+		+	+	+	
Family Gobiidae–gobies										
Arrow goby *Clevelandia ios*		+								
Bay goby *Lepidogobius lepidus*		+								
Longjaw mudsucker *Gillichthys mirabili*	+	+	+						+	
Shimofuri goby *Tridentiger bifasciatus*	+	+	+	+	+	+	+	+	+	+
Family Paralichthyidae–sand flounders										
Speckled sanddab *Citharichthys stigmaeus*			+							
Family Pleuronectidae–righteye flounders										
Starry flounder *Platichthys stellatus*	+				+	+	+		+	

Grand Total species: 36
Note:

*: JA–Juvenile and adult
**: L–Larvae