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Notes from the Editor

Welcome to California Fish and Game 99(3), the "Summer" issue. Over the past six months, numerous software changes occurred for Department of Fish and Wildlife e-mail users, and to the operating system and software available to those that edit and produce the journal. As Editor-in-Chief, I am a bit embarrassed by the tardiness of this issue but, suffice to say, it is finally available. Readers will likely note the extended time between date of submission of papers appearing herein, and the date (10 December 2013) this issue went to the printer ($\bar{x}$ = 5.3 ± 1.5 [*SD* = 1.5] months); in most previous issues, that period has averaged only about 3 months. Those of us involved in the production of *California Fish and Game* will do our best to get back on the regular schedule of publication now that many of the unforeseen software glitches have been worked out.

This is the first issue of *California Fish and Game* that will be published simultaneously in hard copy and electronically. We have received our ISSN for electronic publication, and it now is prominently displayed below our print ISSN. The ISSN for electronic publication will further facilitate indexing of this journal by the numerous literature search and retrieval services that now dwell on the web.

During 2014, the California Department of Fish and Wildlife will publish the 100th volume of *California Fish and Game*. Several special issues are planned to commemorate this occasion, with the plan that each special issue will follow a particular theme. We look forward to the publication of volume 100, and to continuing the fine tradition that has been the flagship of this publication over the past 100 years.

Vernon C. Bleich, *Editor-in-Chief*
California Fish and Game

California Fish and Game 99(3):115-121; 2013

Continued absence of sabellid fan worms (*Terebrasabella heterouncinata*) among intertidal gastropods at a site of eradication in California, USA

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Reaching a conclusion that a non-indigenous species is truly absent following an eradication process requires sampling at relevant spatial and temporal scales. The South African gastropod shell-dwelling sabellid polychaete *Terebrasabella heterouncinata* became locally established within abalone farms in California, USA in the mid-1990s and among turban snails *Chlorostoma* (*Tegula)* spp. in the intertidal discharge zone outside one farm. An eradication program was developed and implemented in the farm discharge zone in 1996 by reducing local host density, and sampling during 1998 detected no sabellids. We conducted nine thorough follow-up surveys annually from 2001 to 2009 (mean 1,738 shells per annum, $N = 15,647$) and found no sabellids present at the farm discharge location. It appears that the sabellid worm has been eradicated from this site despite the continued abundance of hosts. These data provide confirmation of the successful application of the host-density threshold approach to achieving eradication of a host-dependent invasive species.

Key words: abalone, eradication *Haliotis rufescens,* invasive species, sabellid, *Terebrasabella heterouncinata*

Invasive species with a high dependence on a specific host or suite of hosts have population dynamics similar to those of classic infectious disease agents, and in some cases epidemiological theory can be applied toward their management. Culver and Kuris (2000) applied such theory to eradicate a localized infestation of the South African sabellid polychaete *Terebrasabella heterouncinata* that was accidentally imported to California along with a shipment of abalone *(Haliotis)* intended for research. The worms live in tubes within shells of gastropods. They have a unique life history in which larvae crawl away from an adult brood chamber and settle on the shell margin of the same or a nearby abalone, or other susceptible gastropod, and secrete a mucus tube (Oakes and Fields 1996, Culver et al. 1997, Fitzhugh and Rouse 1999, Kuris and Culver 1999). The gastropod lays shell material over the nascent tube, creating a permanent burrow and the worm then metamorphoses into the adult form with a tentacular feeding crown. When brought to California it was inadvertently spread into production units at a large farm in Cayucos, San Luis Obispo County, California that raises native red abalone (*H. rufescens).* That farm provided seed animals for abalone farms throughout the state and the worm spread to many facilities. The worm reached such high densities that the farmed abalone exhibited brittle, distorted shells and slow growth rates, resulting in animals that had very poor market acceptance (Oakes and Fields 1996). Several farms went bankrupt and most of those that remained suffered severe hardship (J. D. Moore, California Department of Fish and Wildlife (CDFW), unpublished observations 1997–2000; Culver and Kuris 2002). The sabellid infestation was successfully managed on farms by improving hygienic practices (Culver et al. 1997, Culver and Kuris 2002, Moore et al. 2007).

Inspection of non-haliotid gastropods in production units and drains at sabellid-positive abalone farms, as well as laboratory studies, showed that numerous species are susceptible, at least under intensive exposure (Kuris and Culver 1999, Culver and Kuris 2004, Moore et al. 2007). Further, inspection of the intertidal zone near the outfall of a farm in Cayucos in 1996 indicated that the sabellid appeared to have become established in a population of susceptible gastropods (predominantly *Chlorostoma* (*Tegula)* spp.; Culver and Kuris 2000).

The concept of host density threshold maintains that a pathogen will be eliminated from a host population if the hosts reach a critical low density that reduces transmission below a sustainable level (McKendrick 1940, Stiven 1968). Therefore, the pathogen can be eliminated while some hosts are still present. Based on that concept Culver and Kuris, along with abalone farmers, resource managers and volunteers, removed 1.6 million snails from the region around the outfall of the Cayucos farm during 1996, in conjunction with reducing the release of worms from the farm and removal of infested abalone and infested shell debris. Follow-up surveys during 1998 showed an absence of sabellids, suggesting that the established population had been eradicated (Culver and Kuris 2000). However, Culver and Kuris (2000) cautioned that they termed the eradication 'apparent' and recognized the possibility that the sabellid infestation could remain at an undetectable level over their sampling period, and noted that it is extremely important to continue monitoring in subsequent years. Indeed, the potential continued presence of the worm can only be discredited by sampling at relevant temporal and spatial scales. Therefore, we began formal monitoring of the site in 2001, and concluded the eradication successful in 2009 following nine years of negative findings.

Materials and Methods

We collected gastropods from the Cayucos eradication site annually at low tides using a modification of the six transects of Culver and Kuris (2000) (Figure 1). The transect

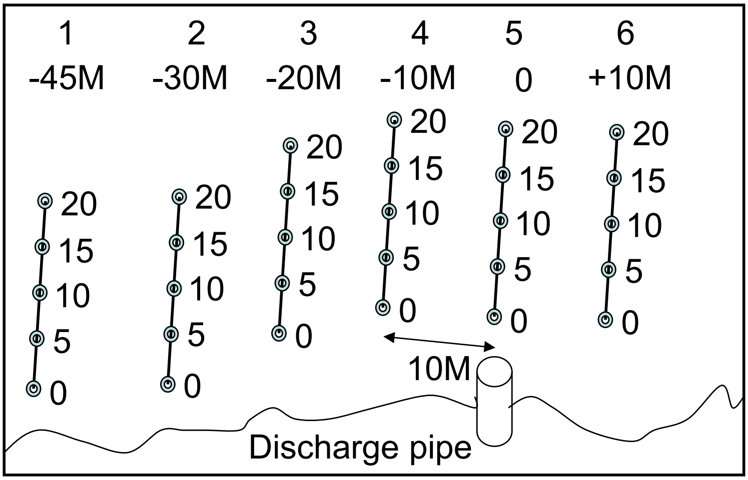

Figure 1.—Schematic diagram showing locations of transects and transect sampling points relative to the discharge pipe from a land-based abalone farm in Cayucos, San Luis Obispo County, California, USA, 2001-2009. The upper number indicates the transect number; the number below it indicates distance from the discharge point. Negative numbers are south of the discharge pipe and the positive number is north.

locations were similar to those reported by Culver and Kuris (2000), but we collected samples along each point on the transect line at 0, 5, 10, 15, and 20 m away from shore. One transect line was directly offshore from the discharge pipe, four were to the south and one was to the north. This asymmetric design was selected by Culver and Kuris (2000) due to prevailing southerly currents. Collections targeted 60 live adult snails (*Chlorostoma* spp.; minimum shell size of approximately 10 mm) per transect point. The sample size of 60 allowed for detection of a pest, pathogen or condition with 95% confidence if its prevalence in the population is at least 5% (USFWS and AFS-FHS 2003), assuming 100% efficiency of the diagnostic method (i.e., any sabellids present in the samples will be detected). The area around each transect point was searched in increasingly wide circles up to a radius of 2.5 m. When live snails were not present in sufficient quantity we collected empty *Chlorostoma* shells or shells with hermit crabs, and very small amounts of other gastropods (primarily *Nucella* sp. and various limpets). When several minutes went by without finding any new gastropods or gastropod shells, sampling of the transect point was considered complete for that sampling date. For reasons that were not recorded, the 0-m stations (i.e. the starting stations on each transect) were not surveyed in 2001-2002.

Shells from each transect point were held in separate labeled bags in a -20° C freezer and later examined for the presence of sabellid tubes, either by viewing under a dissecting microscope, or viewing without magnification that was followed by careful observation of any suspect shells under a dissecting microscope. Examiners were specifically trained in the identification of sabellids on gastropod shells.

Results

During the nine sampling events from 2001 to 2009 we collected a total of 15,647 snails with an average of 60.7 per transect point (0, 5, 10, 15, and 20 M from shore) per year for each of the six transects (Table 1, Table 2). The majority were *Chlorostoma funebralis* with the remainder being largely *C. brunnea;* these two species comprised 93.4% of the snails examined. The stations closer to shore typically had an excess of *C. funebralis*, and 60 individuals could be collected within a few minutes. The outer and, therefore, generally deeper stations had few *C. funebralis*, with *C. brunnea* being the predominant gastropod, but occurring at much lower density than *C. funebralis* closer to shore. These deeper stations required greater search efforts, often in surfgrass habitat. No sabellids were detected among any of the snails examined.

Table 1.— Total gastropod shells examined annually by transect number at Cayucos, San Luis Obispo County, California, USA, 2001–2009.

	Transect #						
Date	1	2	3	4	5	6	Totals
6/25/2001	206	185	253	197	219	195	1255
6/12/2002	300	282	316	265	240	240	1643
8/28/2003	316	321	317	318	321	327	1920
8/2/2004	300	300	301	300	300	300	1801
5/25/2005	312	310	320	309	318	321	1890
4/20/2006	314	320	335	338	332	262	1901
3/15/2007	198	251	232	282	319	312	1594
4/9/2008	188	234	277	325	320	293	1637
4/27/2009	322	337	326	363	332	326	2006
Totals	2456	2540	2677	2697	2701	2576	15647

Table 2.— Total gastropod shells examined annually by transect station (distance from transect point closest to shore, 0-m) at Cayucos, San Luis Obispo County, California, USA, 2001–2009.

	Transect Station					
Date	0	5-m	10-m	15-m	20-m	Totals
6/25/2001	n.d.	360	336	313	246	1255
6/12/2002	n.d.	387	476	387	393	1643
8/28/2003	383	383	391	386	377	1920
8/2/2004	360	360	360	360	361	1801
5/25/2005	383	380	380	379	368	1890
4/20/2006	391	399	395	394	322	1901
3/15/2007	374	363	350	279	228	1594
4/9/2008	388	386	330	296	237	1637
4/27/2009	421	406	399	387	393	2006
Totals	2700	3424	3417	3181	2925	15647

Discussion

Decisions on how to address non-native species introductions are complex and whether to devote resources toward a rapid response, and how much to invest in the response, are often controversial (Myers et al. 2000, Locke and Hanson 2009). The sabellid eradication at Cayucos has been cited as a case of successful eradication of a marine invasive species (e.g., Myers et al. 2000, Williams and Grosholz 2008, Locke and Hanson 2009), often with discussion regarding the characteristics of the system and responses that allowed success. Among these are: (1) reduction of the infestation source by installing screens in the outfall stream to catch shell and shell debris; (2) the requirement of live gastropod hosts in the life cycle; (3) the limited dispersal of the larval stage; (4) a rapid response; and (5) coordination among industry, academia and regulators. Additionally, the most abundant host in the Cayucos intertidal, *C. funebralis*, is a less susceptible host than the red abalone (Moore et al. 2007).

In their report following the density reduction of *Chlorostoma* spp. from the Cayucos site, Culver and Kuris (2000) stated that their efforts appeared to have eradicated the sabellid at the Cayucos outfall site, but emphasized the need for continued monitoring for many years following their report. The transects used by Culver and Kuris (2000) provided an appropriate spatial scale of sampling and we concluded that our annual surveys provided an appropriate temporal scale, given known sabellid life cycle and longevity (Fitzhugh and Rouse 1999), including a 165-day generation time at 15.6° C (Finley et al. 2001). Ninety-five percent of our samples contained at least 55 animals; it is worth noting, however, that at the twelve transect points with fewer animals, the risk of sabellid presence is lower than at other, higher-density transect points.

No effort has been made to determine if there was any detrimental impact as a result of the removal of 1.6 million *Chlorostoma* in 1996, or our removal of nearly 16,000 snails in subsequent years. However, we found the snails to be extremely abundant at most transect points during our initial efforts in 2001 and noted no consistent changes in abundance in subsequent years. Recruitment of juveniles from pelagic larvae or migration of juveniles and adults from adjacent areas, or both, likely tempered the focal population reductions.

The population of sabellids on the farm at Cayucos peaked in approximately 1996 and then rapidly declined as new husbandry practices allowed for the production of sabellid-free abalone as the remaining infested groups were sold off. A few infested individuals were detected sporadically at the farm through 2004 (J. D. Moore, CDFG, 2004 unpublished data). None have been detected since then, and the farm was certified by the California Department of Fish and Game (CDFG) as sabellid-free in 2008. Thus it appears that the Cayucos intertidal site no longer has sabellids present and there is negligible chance of re-infestation. The Cayucos outfall site is the only location where sabellids are known to have become established in California. Intertidal surveys of outfall areas of onshore abalone farms in the mid-1990s (Culver and Kuris 2002) and a snapshot survey of 24 exposed sites conducted by us during 2002-2006 revealed no sabellid infestations (Moore et al. 2007).

This study confirms the success of the eradication approach taken by Culver and Kuris, based on the concept of host-density threshold (McKendrick 1940, Stiven 1968). The Cayucos eradication is an apparently unique example of the application of epidemiological theory toward eliminating a marine invasive species, although this approach is consistent with recent eradication theory and practices recognizing that localized pest extinctions can be accomplished without 100% removal. Liebhold and Bascompte (2003) provided extinction modeling and real-world data on control of gypsy moth expansion in North America. They emphasized three points: (1) extinction can be achieved with less than 100% population reduction due to stochasticity or Allee dynamics, or a combination of the two; (2) there is always a stochastic component to population extinction and, therefore, eradication should be viewed in a probabilistic framework; and (3) the proportion of the population removed is critically important, and rapid response following detection is highly desirable. These ideas, and the successful eradication of *Terebrasabella heterouncinata* at Cayucos, provide further justification for non-indigenous marine species surveillance programs and rapid-response planning efforts.

Acknowledgments

F. Wendell initiated the post-eradication sampling effort and headed the 2001 survey. We appreciate the assistance of numerous other staff and volunteers that helped collect snails, especially T. Moore. This research was supported in part by the Fisheries Branch and the Marine Region, CDFW (formerly CDFG). The views expressed are those of the authors and not necessarily those of CDFW. This publication is a contribution of the Bodega Marine Laboratory, University of California at Davis.

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Longfin smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California

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We utilized recently available sampling data (~1959-2012) from the Interagency Ecological Program and regional monitoring programs to provide a comprehensive description of the range and temporal and geographic distribution of longfin smelt (*Spirinchus thaleichthys*) by life stage within the San Francisco Estuary, California (Estuary). Within 22 sampling regions, we identified 357,538 survey events at 1,203 monitoring stations. A total of 1,035,183 longfin smelt (LFS) were observed at 643 stations (53%) in an area from Central San Francisco Bay (Tiburon) in the west, to Colusa on the Sacramento (Sacramento Valley region) in the north, Lathrop on the San Joaquin River (border of South Delta and San Joaquin River regions) to the east and South San Francisco Bay (Dumbarton Bridge) to the south, an area of approximately 137,500 ha. We found that LFS were frequently observed across a relatively large portion of their range, including East San Pablo Bay north into Suisun Marsh down through Grizzly Bay and all four regions of Suisun Bay through the Confluence to the Lower Sacramento River region. Unlike juvenile LFS, whose locations fluctuate between the bays and Suisun Marsh in relation to the low salinity zone, adults during the spawning period appeared to be not only in these locations but also in upper Delta reaches and also into San Francisco Bay, likely indicating that LFS spawning habitat may extend further upstream and downstream than LFS rearing habitat. The anadromous life stage declined in spring and mid-summer but increased throughout fall months across all areas, suggesting immigration and emigration through the Estuary. Longfin smelt appeared to migrate completely out of the lower rivers by July but some adults consistently remained in downstream Estuary areas, suggesting not all individuals demonstrate marine migration. This comprehensive data review provides managers and scientists an improved depiction of the spatial and temporal extent of LFS throughout its range within the Estuary and lends itself to future population analysis and restoration planning for this species.

Key words: Longfin smelt, San Francisco Estuary, distribution, *Spirinchus thaleichthys,* spatial analysis, life stage, observed presence

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The longfin smelt (*Spirinchus thaleichthys*) is a small (i.e., 90–110 mm standard length [SL] at maturity), semelparous, pelagic fish that has been observed in estuaries of the North American Pacific Coast, from Prince William Sound, Alaska to Monterey Bay, California with landlocked populations occurring in Lake Washington, Washington and Harrison Lake, British Columbia (McAllister 1963, Dryfoos 1965, Moulton 1979, Chigbu and Sibley 1994, Chigbu et al. 1998, Chigbu and Sibley 1998, Baxter 1999, Moyle 2002, Rosenfield and Baxter 2007). In California, the longfin smelt inhabits the San Francisco Estuary (Estuary), Humbodlt Bay, and Eel, Klamath and Smith rivers (Baxter 1999, CDFW 2009). According to Dryfoos (1965), the San Francisco Estuary (San Francisco Bay and Sacramento-San Joaquin River Delta) population has been considered the largest and southernmost self-sustaining population along the U.S. Pacific Coast, and has been considered to be genetically isolated from other populations (McAllister 1963, Moyle 2002). Once one of the most abundant species observed in Estuary surveys (Moyle et al. 2011), the Estuary longfin smelt (LFS) population has experienced dramatic declines over several decades (Rosenfield and Baxter 2007, Sommer et al. 2007, Baxter et al. 2008, Thomson et al. 2010), resulting in its March 2009 inclusion in the list of threatened pelagic fish species under the California Endangered Species Act (CDFW 2009).

A number of studies have investigated LFS distribution, habitat, and life history characteristics within the Estuary (Baxter 1999, Dege and Brown 2004, Hobbs et al. 2006, CDFW 2009, Moyle 2002, Matern et al. 2002, Rosenfield and Baxter 2007, Kimmerer et al. 2009, MacNally et al. 2010, Thomson et al. 2010). However, most of what has been learned about LFS (e.g., growth and in-river residence times) comes from other locations across its range, most often from Lake Washington (Dryfoos 1965, Eggers et al. 1978, Moulton 1979, Chigbu 1993, Chigbu and Sibley 1994a, 1994b, Chigbu and Sibley 1998, Chigbu et al. 1998, Chigbu 2000, Chigbu and Sibley 2002). Potential factors associated with abundance changes in Estuary fish species include stock-recruitment effects, increased mortality rates, reduced prey availability, overall shifts in fish assemblage composition (Feyrer et al. 2003, Sommer et al. 2007), and altered location of the 2 ppt isohaline in spring (known as "X2"; Thomson et al. 2010). Furthermore, the cascading impacts of aquatic species invasions can change food webs and make management actions for native fish more difficult (Feyrer et al. 2003).

Rosenfield and Baxter (2007) assessed the Estuary LFS population and addressed questions about distribution patterns and population dynamics. They used data from three long-term aquatic sampling programs of the California Department of Fish and Wildlife (CDFW; formerly California Department of Fish and Game) (i.e., Fall Midwater Trawl [FMWT], Bay Study Midwater Trawl [BMWT] and Otter Trawl [BOT]) and the University of California, Davis's Suisun Marsh survey that captured LFS from upstream of the Sacramento and San Joaquin River confluence to San Francisco Bay, to assess distribution and abundance, and tested for differences in abundance during pre-drought (1975–1986), drought (1987–1994) and post-drought (1995–2007) periods. Rosenfield and Baxter (2007) indicated significant declines in LFS abundance among these time periods, supporting their hypothesis that the Estuary's capacity to maintain pelagic fish species has been reduced over the past three decades. These results provide critically important information on distribution and abundance dynamics for LFS within the Estuary. However, questions remain about the full geographical extent and frequency of occurrence within the Estuary of each LFS life stage.

A full spatial depiction of where and when LFS are observed is vital to our understanding of critical management issues, including identifying important regions for each life stage, and potential opportunities for population conservation. In addition, when planning a conservation strategy for species protection and restoration, the spatial distribution of each population is required under federal and state statutes (Tracy et al. 2004, Carroll et al. 2006, Merz et al. 2011). Finally, considering data in a life stage-specific context provides for future assessment of stage-specific effects, supporting more practical and informative evaluations of specific cause–effect relationships, and will permit quantifying relationships between specific life stage transitions and environmental parameters (Merz et al. 2013). Interactive maps of some monitoring programs from CDFW have been publicly available for individually captured and monitored fish species, including LFS distribution within the Estuary (see http://www.dfg.ca.gov/delta). However, to our knowledge, no effort has been made to map LFS spatial range and distribution by life stages using available Estuary sampling data. The goal of this paper is to provide a comprehensive description of the range and temporal and geographic distribution of LFS by life stage within the Estuary.

Methods

Study area.—The San Francisco Estuary is the largest urbanized estuary (approximately 1,235 km^2) on the west coast of the United States (Lehman 2004, Oros and Ross 2005) (Figure 1). It consists of a series of basins with three distinct segments that drain an area of approximately 163,000 km^2 (40% of California's surface area): the Delta, Suisun Bay, and San Francisco Bay (van Geen and Luoma 1999, Sommer et al. 2007). The uppermost region of the Estuary is the delta of the Sacramento and San Joaquin rivers (Delta), a complex and meandering network of tidal channels around leveed islands (Moyle 2002, Kimmerer 2004). These two rivers narrow and converge before connecting with Suisun Bay, a large, shallow and highly productive expanse of brackish water that is strongly influenced by ebb and flood tides. Adjacent to Suisun Bay, Suisun Marsh, the largest contiguous brackish water wetland in the Estuary, provides a fish nursery area and habitat for migratory birds (Moyle 2002, Sommer et al. 2007). Suisun Bay is connected to San Pablo Bay — a northern extension of San Francisco Bay — through a long narrow channel called the Carquinez Strait. During high outflow years, the San Francisco Bay's salinity levels can be somewhat diluted by freshwater allowing freshwater fishes to move into tributary streams (Moyle 2002).

To qualitatively describe the spatial distribution of LFS, we delineated the Estuary into 22 regions (Figure 1, Table 1). These regions were South San Francisco Bay (1); Central San Francisco Bay (2); West San Pablo Bay (3); East San Pablo Bay (4); Lower Napa River (5); Upper Napa River (6); Carquinez Strait (7); Suisun Bay Southwest (8); Suisun Bay Northwest (9); Suisun Bay Southeast (10); Suisun Bay Northeast (11); Grizzly Bay (12); Suisun Marsh (13); Confluence (14); Lower Sacramento River (15); Upper Sacramento River (16); Cache Slough and Ship Channel (17); Lower San Joaquin River (18); East Delta (19);

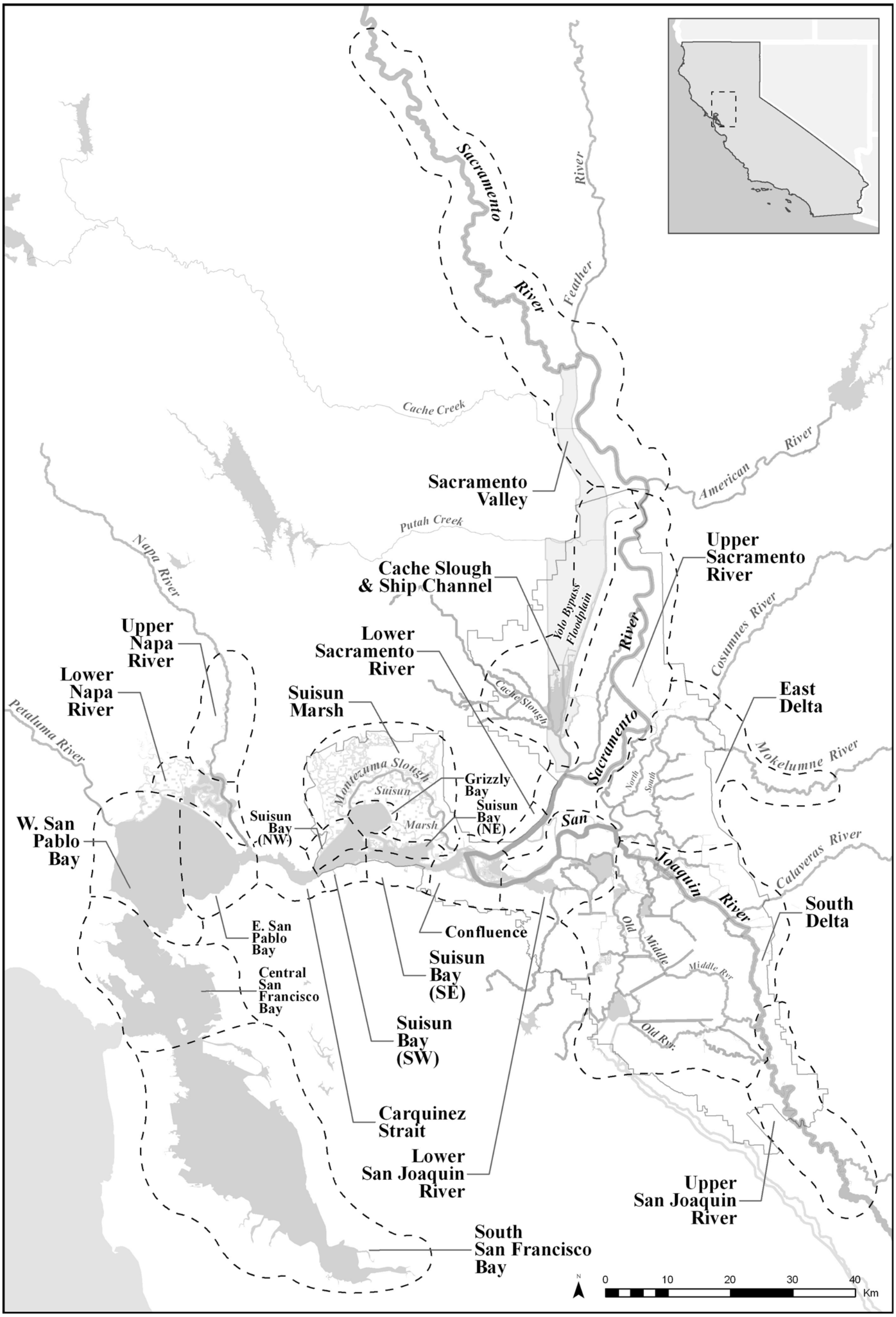

Figure 1.—A map of the San Francisco Estuary, California, and the 22 regions identified in this paper. Dashed lines indicate the estuary's regional delineations, which was based on the physical habitat and flow characteristics as well as physical landmarks (Kimmerer 2009, Merz et al. 2011).

Table 1.—Interagency Ecological Program (IEP) and Regional Monitoring Program (RMP) data that are publicly available, and were used to establish longfin smelt geographical extent range in the San Francisco Estuary, California.

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Sacramento-San Joaquin Delta, Sacramento River, Chipps Island, San Francisco Estuary, Mossdale Crossing	Chinook and POD[a] Species	Beach Seine, Midwater Trawl, Kodiak Trawl	1976 - present	USFWS[b]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta	20mm Survey	20-mm Plankton Net	1995 - present	CDFG[c]	IEP
Delta, Suisun Bay and Suisun Marsh	Smelt Larval Survey	Egg and Larval Net	2009 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Spring Kodiak Trawl	Kodiak Trawl	2002 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Fall Midwater Trawl	Midwater Trawl	1967 - present	CDFG[c]	IEP
San Pablo Bay, Suisun Bay, Sacramento-San Joaquin Delta, Sacramento Deep Water Ship Channel	Summer Tow Net Survey	Tow Net	1959 - present	CDFG[c]	IEP
San Francisco Bay, San Pablo Bay, Suisun Bay and downstream of Sacramento-San Joaquin Delta	San Francisco Bay Study	Midwater Trawl, Otter Trawl	1980 - present	CDFG[c]	IEP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
San Francisco Bay, San Pablo Bay, Suisun Bay and downstream of Sacramento-San Joaquin Delta	San Francisco Plankton Net	Larval/Plankton Net	1980 - 1989	CDFG[c]	IEP
State Water Project and Central Valley Water Project	Fish Salvage Monitoring	Sieve Net	1993-present	CDFG[c]	IEP
Northern Sacramento-San Joaquin Delta	North Bay Aqueduct Survey	Larval Net	1995-2004	CDFG[c]	IEP
Suisun Marsh	Suisun Marsh Monitoring	Beach Seine, Larval Sled, Midwater Trawl, Otter Trawl	1980 - present	DWR[d] - UC Davis	IEP
Yolo Bypass	Yolo Bypass Study	Beach Seine	1998-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Fyke Net	1998	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Fyke Trap	1999-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Purse Seine	1998	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Study	Rotary Screw Trap	1998-2005	DWR[d]	RMP
Yolo Bypass	Yolo Bypass Floodplain Study	Rotary Screw Trap	1999-2002	Sommer et al. 2004	RMP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Sacramento-San Joaquin Delta	Littoral Fish Assemblages	Electrofishing	1980-2000	Brown & Michniuk 2007	RMP
Mokelumne River	Salmon and Steelhead Monitoring	Rotary screw trap	1993-2004	EBMUD[e]	RMP
Central Delta	Distribution of native and alien ichthyoplankton	Ichthyoplankton net	1990-2000	Grimaldo et al. 2004	RMP
Suisun Marsh	Native Alien Fishes	Beach Seine, Otter Trawl	1979-1999	Matern et al. 2002	RMP
Cosumnes River	Floodplain monitoring: Native and Alien Fish	Seine, Electrofishing	1998-2005	Moyle et al. 2007	RMP
Cosumnes River	Stream Evaluation	Seining, Rotary Screw Trap	1990-2000	Snider & Titus 2000	RMP
Cosumnes River	Larval Fishes on a restored Floodplain	Light traps, Dip nets	1999 - 2001	Crain et al. 2004	RMP
Lower Mokelumne River	Fish Community Survey	Seining, Backpack and Boat Electrofishing	1997-2004	Merz & Saldate 2000, 2005	RMP
Sacramento-San Joaquin Delta	Fishes of the Delta	Otter Trawl	1963-1964	Radtke 1966	RMP

TABLE 1 (continued).

Location	Survey Name	Gear Used	Study Period	Agency/ Sources	Program
Liberty Island	Spatial and temporal patterns by native and non-native fish larvae of a recently flooded island	Light traps, larval trawls	2003-2005	Marshall et al. 2006	RMP
South-east Suisun Bay, Confluence Sacramento and San Joaquin Rivers	Delta Mirant Power Plants	Sieve Net	2006 - 2008	Pittsburg and Contra Costa Power Plants	RMP
Lower Calaveras River	Calaveras River Barrier Removal	Beach Seine	2010	T.Kennedy[f]	RMP
West Delta	West Delta Survey	Beach Seine	2005-2006	T.Kennedy[f]	RMP

[a]POD: Pelagic Organism Decline
[b]USFWS: United States Fish and Wildlife
[c]CDFG: California Department of Fish and Game
[d]DWR: Department of Water Resources
[e]EBMUD: East Bay Municipal Utility District
[f]Fishery Foundation of California, personal communication

South Delta (20); Upper San Joaquin River (21); and Sacramento Valley (22). Delineation of Estuary regions was based on physical habitat, flow characteristics, and physical landmarks described in Kimmerer (2009) and Merz et al. (2011).

Monitoring data.—We synthesized all available information on Estuary fish monitoring surveys from the 1960s through 2012. These data were obtained directly from governmental and non-governmental entities, published and unpublished papers or reports, and through publicly available online databases of different surveys (i.e., http://www.water.ca.gov/iep/products/data.cfm). All data were reviewed and classified into either the Interagency Ecological Program (IEP) or the Regional Monitoring Program (RMP).

Interagency Ecological Program (IEP).—The Interagency Ecological Program (IEP) is a consortium of federal and state agencies that conducts long-term biological and ecological monitoring for use in Estuary management (Table 1). These monitoring surveys were from the United States Fish and Wildlife Service (USFWS) for Chinook salmon and pelagic organism decline (POD) species; CDFW for 20-mm plankton-net (20mm), Smelt Larval Survey (SLS), Spring Kodiak trawl (Kodiak), Fall midwater trawl (FMWT), Summer tow net, North Bay Aqueduct, Fish Salvage, San Francisco Bay Study's midwater trawl and Bay otter trawl (BOT), and San Francisco plankton net (Bay Plankton); and,California Department of Water Resources (CDWR) and the University of California Davis (UCD) for the Suisun Marsh monitoring. The IEP monitoring program is conducted using different sampling periods (e.g., biweekly, monthly), during different seasons and sampling frequency (e.g., Fall midwater trawl, Spring Kodiak trawl, Summer Tow Net), and on some occasions at a varying number of stations (i.e., supplemental stations are sometimes added for special study, or changes occurred depending on funding). Explicit, detailed descriptions for each IEP monitoring survey are available at the IEP website (http://www.water.ca.gov/iep/products/data.cfm).

Regional Monitoring Program (RMP).—Surveys conducted on a smaller geographic scale of the Estuary, and oftentimes in a shorter time period compared to the IEP surveys were classified in this study as RMP surveys (Table 1). The RMP surveys were carried out by various research institutions and governmental entities, and for a variety of project purposes (e.g. fish community survey, distribution and abundance, fish monitoring, floodplain monitoring). We summarized the number of sampling stations within each of the 22 identified regions, and identified the percentage of regions sampled by each survey (Table 2).

Observed geographic extent.—We utilized IEP and RMP survey records to identify the geographical extent of LFS within the Estuary. Following the approach of Merz et al. (2011) in developing the extent range of delta smelt (*Hypomesus transpacificus*) we used ArcGIS version 10 (ESRI, Redlands, CA) to plot all surveyed stations from the different monitoring programs from the 1960s through 2012 (Figure 2). If LFS were detected at least once at any given monitoring station, the species was designated as present at that site; otherwise the site was designated as "not observed" (Figure 2). We then developed a boundary around the stations where LFS were detected using a 1-km buffer (Merz et al. 2011, Graham and Hijmans 2006). We also calculated the total surface area of all waters within the range where LFS were observed using the ArcGIS 10 geoprocessing calculation tool (http://www.esri.com/software/arcgis/arcgis10). Note that the LFS geographical extent developed in this study did not consider the species to be absent if LFS were not observed, because of the lack of information on detection probability and different sampling frequencies for each survey gear type (Merz et al. 2011, Pearce and Boyce 2006).

TABLE 2.—The San Francisco Estuary regions and associated number of monitoring stations by sampling gears and monitoring surveys. "NS" = not sampled and "NI" = no regional sampling identified. San Francisco Estuary, California.

	Interagency Ecological Program Surveys										
	CDFG Monitoring Surveys								USFWS	DWR-UC Davis	Regional Surveys
Region	Spring Kodiak Trawl	20mm Survey	Summer Tow Net Survey	Delta Fall Midwater Trawl	Smelt Larva Survey	Smelt Larval Survey	SF Bay Study	Fish Salvage	Chinook and POD Surveys	Suisun Marsh Surveys	
South San Francisco Bay	NS	NS	NS	1	NS	NS	48	NS	NS	NS	NI
Central San Francisco Bay	NS	NS	NS	2	NS	NS	32	NS	10	NS	NI
West San Pablo Bay	NS	NS	3	22	NS	NS	20	NS	4	NS	NI
East San Pablo Bay	NS	7	8	17	NS	7	20	NS	4	NS	NI
Lower Napa River	2	3	4	2	NS	3	NS	NS	0	NS	NI
Upper Napa River	4	7	1	NS	NS	7	NS	NS	0	NS	NI
Carquinez Strait	1	1	3	8	1	1	8	NS	6	NS	NI
Suisun Bay (SW)	1	1	1	5	1	1	4	NS	1	NS	NI
Suisun Bay (NW)	1	1	1	6	1	1	12	NS	0	NS	NI
Suisun Bay (SE)	2	2	2	8	2	2	4	NS	2	NS	1
Suisun Bay (NE)	2	2	2	5	2	2	4	NS	0	NS	NI
Grizzly Bay	1	1	1	4	1	1	4	NS	0	NS	NI
Suisun Marsh	5	3	3	5	3	3	NS	NS	9	93	10
Confluence	4	5	4	13	5	5	8	NS	11	NS	41
Lower Sacramento	4	4	3	4	4	4	6	NS	0	NS	36
Upper Sacramento	4	3	2	13	1	1	6	NS	51	NS	10
Cache Slough/Ship Channel	5	11	1	10	2	1	0	NS	11	NS	17
Lower San Joaquin River	6	6	4	13	5	6	12	NS	15	NS	34
East Delta (Mokelumne)	5	1	2	8	1	1	0	NS	26	NS	51
South Delta	6	9	7	15	6	6	0	3	50	NS	15
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	0	NS	23	NS	2
Sacramento Valley	NS	NS	NS	NS	NS	NS	0	NS	53	NS	6
Total number of stations surveyed	53	67	52	161	35	52	188	3	276	93	223
Percent of regions represented	73	77	82	86	64	77	86	5	95	5	50

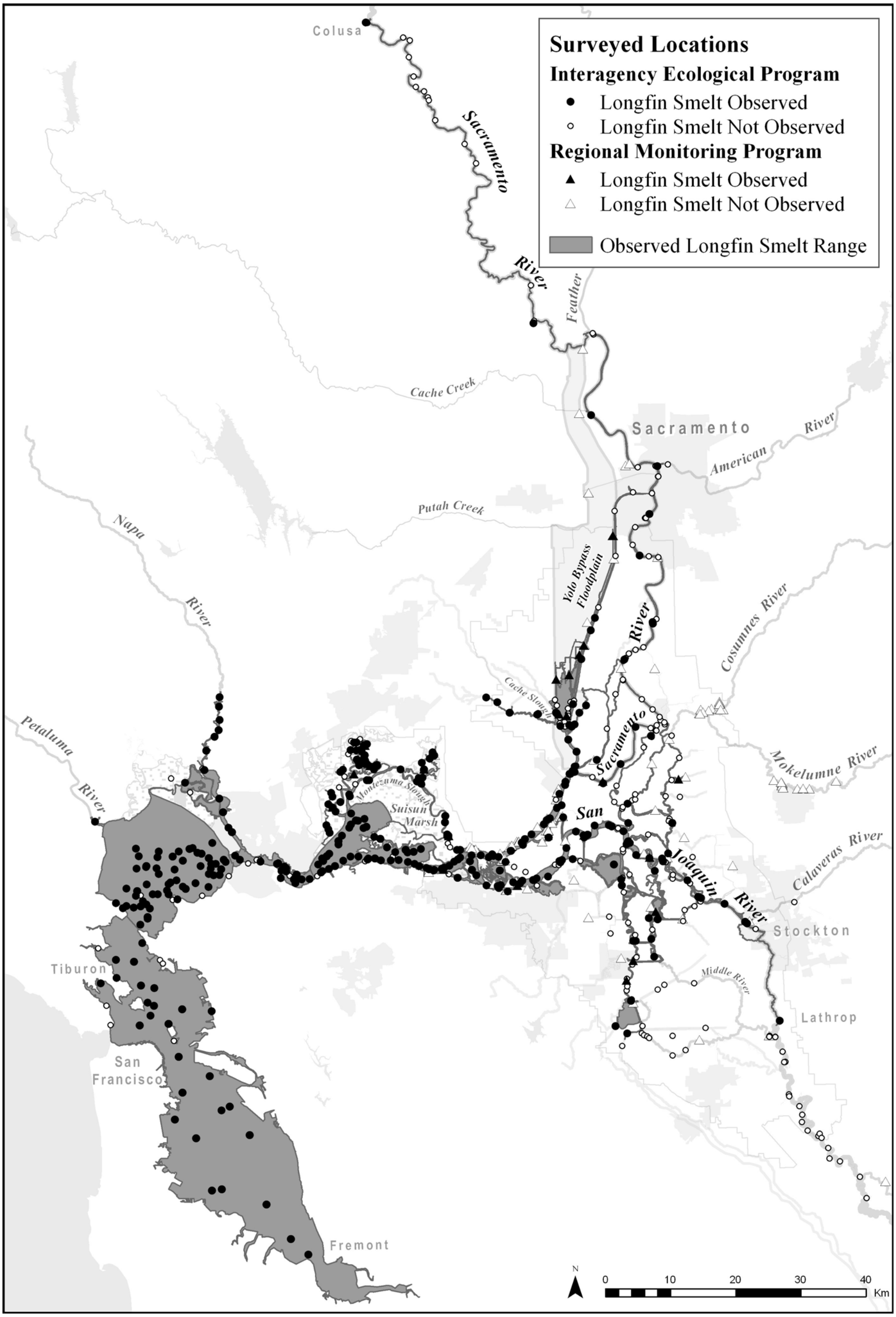

Figure 2.—The geographical extent range and observations of longfin smelt at monitoring stations of Interagency Ecological Program (IEP) survey and Regional Monitoring Program (RMP) surveys. Circles indicate IEP stations where longfin smelt were observed (closed) or not observed (open). Triangles indicate RMP stations where longfin smelt where observed (closed) or not observed (open). The dark gray represents the observed longfin smelt range in the San Francisco Estuary, California.

TABLE 3.—Delineations of longfin smelt lifestages by time-period, sizes, IEP sampling gears and sampling periods, and descriptions used for frequency of detection analysis in the San Francisco Estuary, California.

Life Stage	Time Period	Sizes	Sampling Study[1]	Sampling Years	Sampling Months	Description
Larva	Jan -June	<16 mm	Bay Plankton 20mm SLS	1980-1989 1995-2011 2009-2011	Jan-June Mar-May Jan-Mar	The larval phase begins after hatching and ends when resorption of the yolk-sac and fin formation are nearly complete (< 16mm; Wang 1991).
Juvenile	Apr-Oct	Baxter (2009) monthly cutoffs	BOT 20mm FMWT	1980-2011 1995-2011 1980-2011	Apr-Oct Apr-Jul Sep-Oct	This phase begins when fin formation is nearly complete (16mm; Wang 1991), and encompasses the first major growth period of longfin smelt (Moyle 2002).
Sub-adult	Nov-Apr	Baxter (2009) monthly cutoffs	BOT FMWT Kodiak	1980-2011 1980-2011 2002-2011	Nov-Apr Nov-Dec Jan-Apr	Period of slow-growth during winter months (Moyle 2002) prior to anadromous migration.
Anadromous	Mar-Jan	Baxter (2009) monthly cutoffs	BOT	1980-2011	Mar-Jan	Encompasses second major growth period (Moyle 2002) and period of anadromous outmigration for a portion of the population towards the ocean from March through August and immigration upstream from September through January (Rosenfield and Baxter 2007).
Adult	Dec-May	Baxter (2009) monthly cutoffs	BOT Kodiak	1980-2011 2002-2011	Dec-May Jan-May	Encompasses spawning period of adult longfin smelt (Moyle 2002). Gravid females are detected between late-fall and winter (Rosenfield 2010; Moyle 2002)

[1]Bay Plankton = San Francisco Plankton Net Survey, 20mm = 20mm survey, SLS = Smelt Larval Survey, BOT = San Francisco Bay Study Otter Trawl, FMWT = Fall Midwater Trawl, and Kodiak Trawl = Spring Kodiak Trawl.

Life stage determinations.—We delineated life stages based on month and fish-size (Table 3, Figure 3). We adapted LFS life-stage definitions and monthly cut-offs established by DRERIP (Delta Regional Ecosystem Restoration Implementation Plan; Rosenfeld 2010). LFS life stages used in this study are *larva, juvenile, sub-adult, anadromous,* and *adult* (Table 3, Figure 3). Unlike DRERIP (Rosenfield 2010), we defined an anadromous stage to highlight the LFS migratory period (Rosenfield and Baxter 2007), and defined an adult life stage instead of "sexually mature adult" due to unavailability of sexual maturation data to differentiate premature versus mature LFS. We also did not evaluate the egg life stage as there are no Bay-Delta surveys (e.g., plankton net) that monitor LFS eggs. Because the

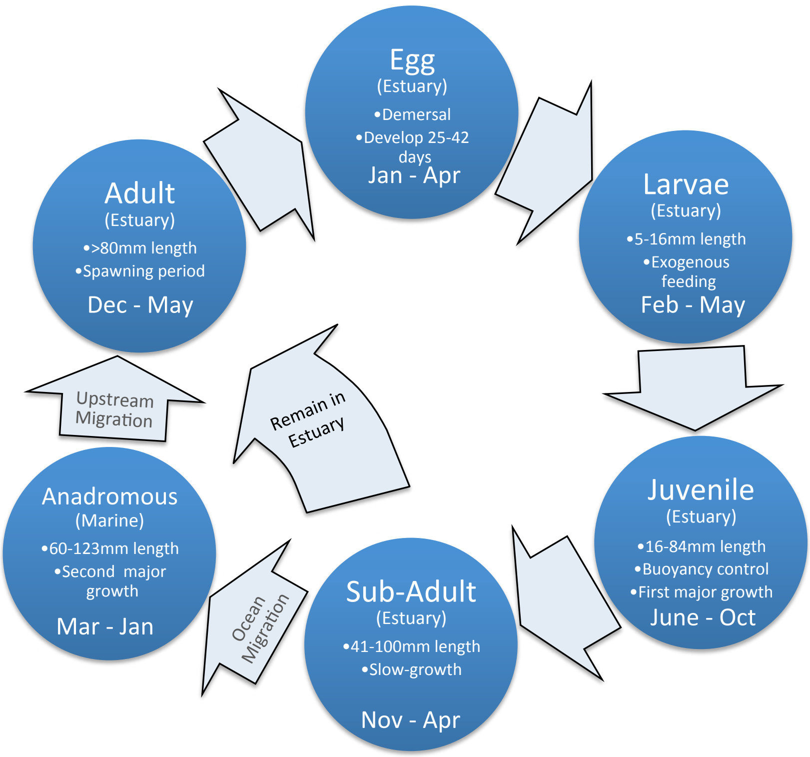

Figure 3.—Life cycle of longfin smelt, adapted from the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) Conceptual Models. Available at: http://www.dfg.ca.gov/erp/cm_list.asp

LFS life cycle spans 3 calendar years, we used the monthly fork length criteria defined by Baxter (1999) to separate LFS of each age (years 1, 2, or 3; Table 4). The only modification of Baxter's (1999) criteria is the addition of a maximum length cutoff of 15 mm for larva, which is the length at which yolk-sac resorption and fin formation are nearly complete (Wang 1991; Table 4).

Table 4.—Length (mm) delineations of longfin smelt by year, life stage, and month used in frequency of detection analyses. Monthly length cut-offs from Baxter (1999), except for 16-mm cutoff for larva used to separate larvae and juveniles. San Francisco Estuary, California.

Year 1			Year 2			Year 3		
Life Stage (s)	Month	FL (mm)[1]	Life Stage (s)	Month	FL (mm)	Life Stage (s)	Month	FL (mm)
Larva	Jan	<16	Sub-adult	Jan	40-89	Anadromous, Adult	Jan	>89a
Larva	Feb	<16	Sub-adult	Feb	42-92	Adult	Feb	>92
Larva	Mar	<16	Sub-adult, Anadromous	Mar	46-95[2]	Adult	Mar	>95
Larva, Juvenile	Apr	<16, 16-51	Sub-adult, Anadromous	Apr	52-99[2]	Adult	Apr	>99
Larva, Juvenile	May	<16, 16-58	Anadromous	May	59-104	Adult	May	>104
Larva, Juvenile	Jun	<16, 16-66	Anadromous	Jun	67-107			
Juvenile	Jul	<71	Anadromous	Jul	71-110			
Juvenile	Aug	<75	Anadromous	Aug	75-113			
Juvenile	Sep	<80	Anadromous	Sep	80-116			
Juvenile	Oct	<83	Anadromous	Oct	83-119			
Sub-adult	Nov	<85	Anadromous	Nov	85-122			
Sub-adult	Dec	<87	Anadromous, Adult	Dec	87-124[2]			

[1] FL = Fork length
[2] Length range applied to both life stages

During the first year of life, LFS transition from egg (December–April; Rosenfield 2010) to free-floating, endogenously nourished larva (January–June; Rosenfield 2010), to juvenile when the first major growth period occurs (April–October; Moyle 2002), and to sub-adult when growth slows during winter months prior to anadromous migration (November–December; Moyle 2002). Unlike DRERIP (Rosenfield 2010), which describes the juvenile stage as extending until the end of the first year of life, we cut off the life stage in October, at the end of the first major growth period as described by Moyle (2002). Additionally, instead of the sub-adult stage extending from the beginning of the second year of life to maturation (Rosenfield 2010), we defined the sub-adult period as the winter, slow-growth period between the juvenile and anadromous life stages.

The second and third years of life begin with the slow-growth period of sub-adults continuing into spring (January–April; Moyle 2002). Next, a portion of the LFS population undertakes an anadromous migration (emigration) towards the ocean, followed by return upstream migration (immigration) during March–January (Rosenfield and Baxter 2007), while remaining LFS continue to rear in the Estuary. This summer and fall period encompasses the second major LFS growth period (Moyle 2002). Finally, the LFS adult life stage encompasses the spawning period during December–May (Rosenfield 2010; Moyle 2002).

Frequency of detection. —Because each type of gear selectively captures different LFS life stages and is deployed in different seasons, we used data from six IEP monitoring surveys (Bay Plankton, 20mm, SLS, BOT, Kodiak trawl, and FMWT) to examine LFS spatial distribution across life stages within the Estuary (Table 3). For each life stage, only data from each gear type that fell within delineated months for that life stage were used (Table 3). We used LFS catch data for years 1980 to 2011 for all surveys except for 20mm, SLS and Kodiak, where sampling started in 1995, 2009 and 2002 respectively (Table 3). We included only sampling stations that were consistently surveyed, as determined by identifying stations that were sampled ≥90% of the time across all years (Merz et al. 2011).

The average annual LFS detection frequency at consistently surveyed stations for each life stage (except anadromous stage) in each region was calculated as

$$P_{lrpy} = (S_{lrpy} / N_{rpy}) * 100$$

where P_{lrpy} represents the percent of unique numbers of sampling events in which the life stage *l* LFS were captured in each region *r* during time period *p* and year *y*; S_{lrpy} represents the number of sampling events in a region *r* when the life stage *l* LFS were captured during time period *p* and year *y*; and, N_{rpy} represents the total number of sampling events from region *r* during time period *p* and year *y*. Next, the average annual frequency of observation for LFS by life stage and region was calculated as a simple average over all years. Results from LFS detection frequencies by life stage (except anadromous stage) and region were mapped using ArcGIS 10.

Because a portion of the Estuary LFS population migrates during the anadromous life stage, detection frequency was calculated monthly within regions to better depict LFS migratory movements. Similar methods employed for the other life stages were used to calculate detection frequency for the anadromous life stage, except time period *p* was monthly, and regions *r* were grouped into four areas (Lower Rivers, Suisun, East Bay, and West Bay) to better visualize anadromous behavior. Lower Rivers covers all regions from Sacramento Valley downstream to the Lower Sacramento River and San Joaquin River regions, Suisun covers the Confluence and all Suisun Bay regions, East Bay covers Carquinez Straight downstream to East San Pablo Bay, and West Bay covers the West San Pablo Bay and San Francisco Bay regions.

Results

Within the 22 Estuary regions, we identified 357,538 survey events (a sampling event at a given location and time) at 1,203 monitoring stations. Of these, 343,482 (96%) were from IEP and 14,056 (4%) were from regional monitoring programs (Table 1). The program or survey with the single greatest number of monitoring stations was the Chinook and POD (276), followed by the SF Bay Study (188), FMWT (161), Suisun Marsh surveys (93), 20mm Survey (67), and Spring Kodiak Trawl (53) (Table 2). A total of 1,035,183 LFS were observed at 620 of the 980 (63%) IEP monitoring stations and at 23 of the 223 (10%) regional monitoring stations identified in this study.

Observed geographic extent.—LFS were observed in all 22 regions covering an area of about 137,500 ha (Figure 2). Observations occurred as far west as Tiburon in Central San Francisco Bay, north as far as the town of Colusa on the Sacramento River (Sacramento Valley region), east as far as Lathrop on the San Joaquin River (border of South Delta and San Joaquin River regions), and south as far as the Dumbarton Bridge in South San Francisco Bay. Tributary observations included the Napa and Petaluma rivers, Cache Slough, and the Mokelumne River to the east. LFS were also observed in seasonally-inundated habitat of the Yolo Bypass.

No single IEP monitoring program sampled all 22 regions (Table 2) that make up the observed extent of LFS range, and three regions had no IEP sampling. The Chinook and POD surveys had the highest coverage (95% of regions each). The FMWT and SF Bay surveys covered 86% of the regions each, while coverage among the other IEP surveys ranged from 5 to 82%. Each RMP survey typically covered less than 4% of the observed extended range.

Distribution by life stage.— For all life stages, LFS were observed most frequently throughout a relatively large portion of their range – from East San Pablo Bay north into Suisun Marsh down through Grizzly Bay, and all four regions of Suisun Bay through the Confluence (Figure 4, Figure 5). In addition to being frequently detected in the central

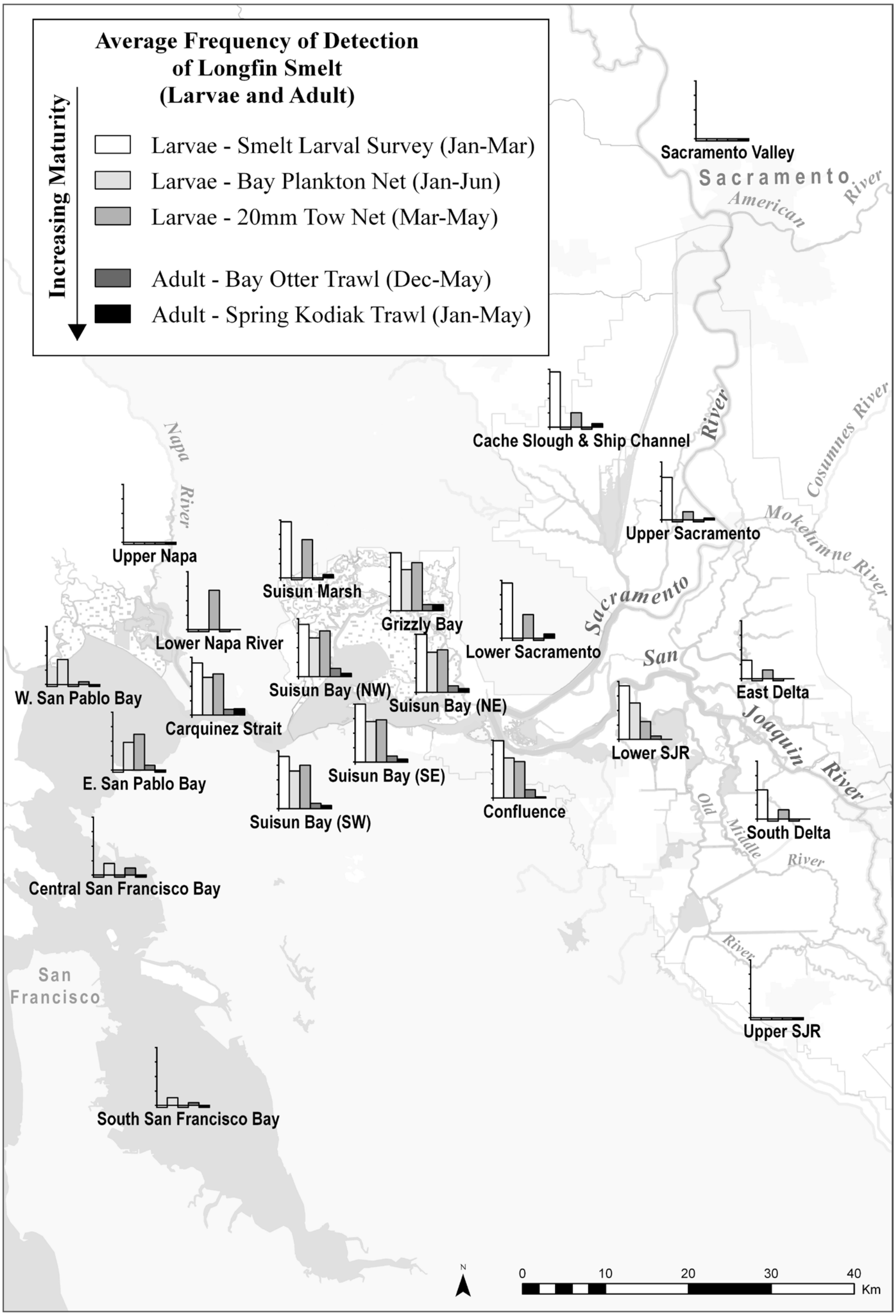

FIGURE 4.—Average annual frequency of longfin smelt detection (%) for larvae and adult lifestages by region and Interagency Ecological Program survey type. The percent of sampling events where longfin smelt was observed over the total number of sampling events within a region. Regions where the percent frequency of detection for a given life stage was zero is indicated by no data column/bar being present in the bar graph. Regions that were not sampled for a given life stage are indicated by a data column/bar suspended slightly below the x-axis. Y-axis ticks indicate percent frequencies of 0, 25, 50, 75 and 100 percent.

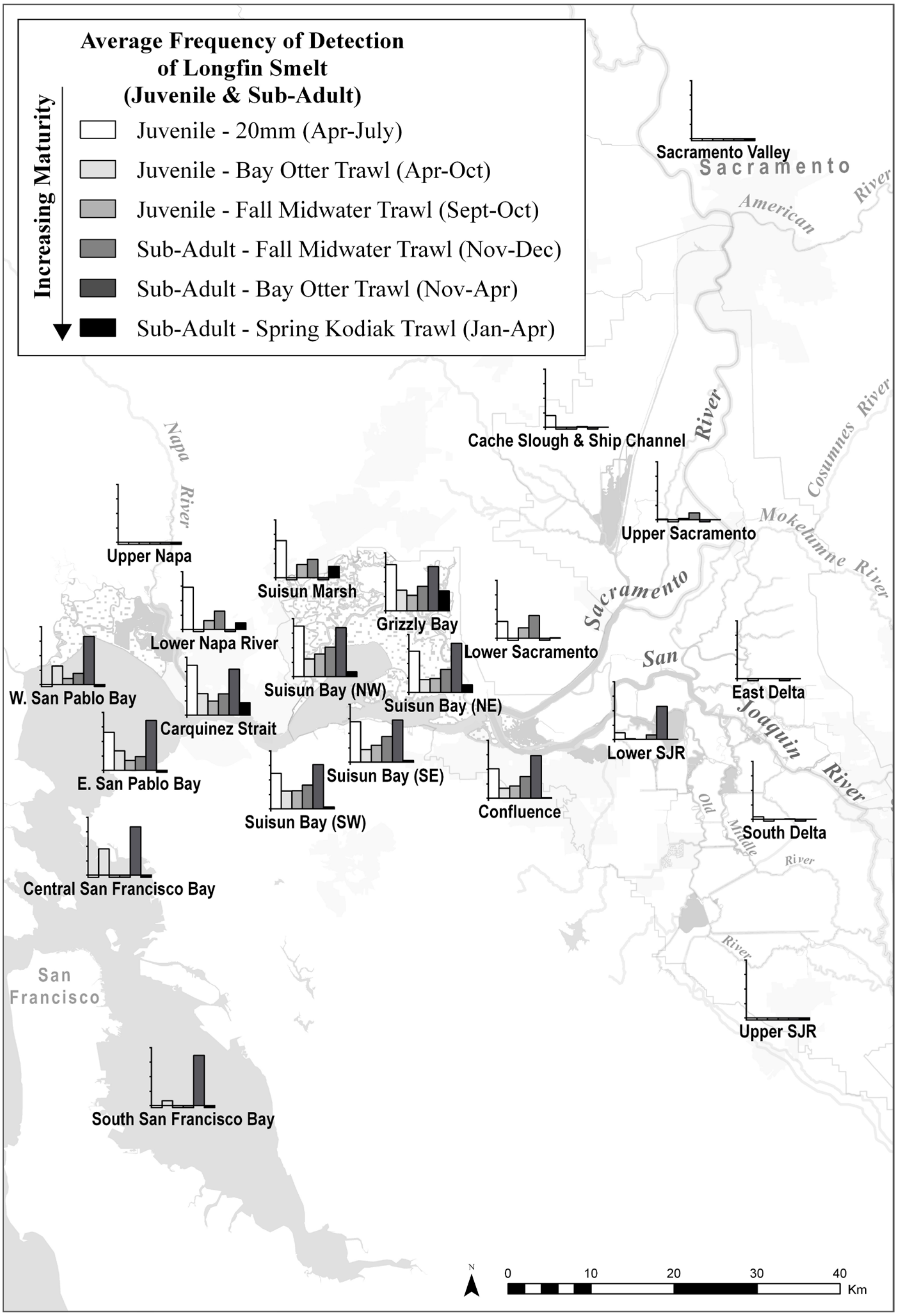

Figure 5.—Average annual frequency of longfin smelt detection (%) for juvenile and sub-adult life stages by region and Interagency Ecological Program survey type. The percent of sampling events where longfin smelt was observed over the total number of sampling events within a region. Regions where the percent frequency of detection for a given life stage was zero is indicated by no data column/bar being present in the bar graph. Regions that were not sampled for a given life stage are indicated by a data column/bar suspended slightly below the x-axis. Y-axis ticks indicate percent frequencies of 0, 25, 50, 75 and 100 percent.

regions (from Carquinez Straight upstream to the Confluence), adult and larvae were both detected relatively frequently upstream of the Confluence (Figure 4, Table 5). Larvae were detected greater than 73% of the time in the Lower Sacramento, Upper Sacramento, Cache Slough and Ship Channel, and Lower San Joaquin regions, and greater than 31% of the time in the East Delta and South Delta regions during the SLS (Figure 4, Table 5). Although detected at a much lower frequency across all regions than larvae, adults were also detected in South San Francisco Bay, upstream in Cache Slough and Ship Channel, and Upper Sacramento regions.

Unlike adult and larval life stages, juvenile and sub-adult life stages were not frequently detected upstream of the Confluence, and instead were more frequently detected in the most downstream Bay regions (Figure 5, Table 5). During BOT sampling, juveniles and sub-adults were detected in greater than 32% of sampling events in both San Pablo Bay regions and Central San Francisco Bay. Sub-adults were also detected at a relatively high frequency (86.6%) in the South San Francisco Bay during BOT sampling (Figure 5, Table 5).

During the anadromous life stage, LFS exhibited declining average frequency of detection during the spring months and into mid-summer, followed by increasing average detection frequency throughout the fall months across all Estuary areas during BOT sampling (Figure 6). The lowest average detection frequencies for each area occurred at successively

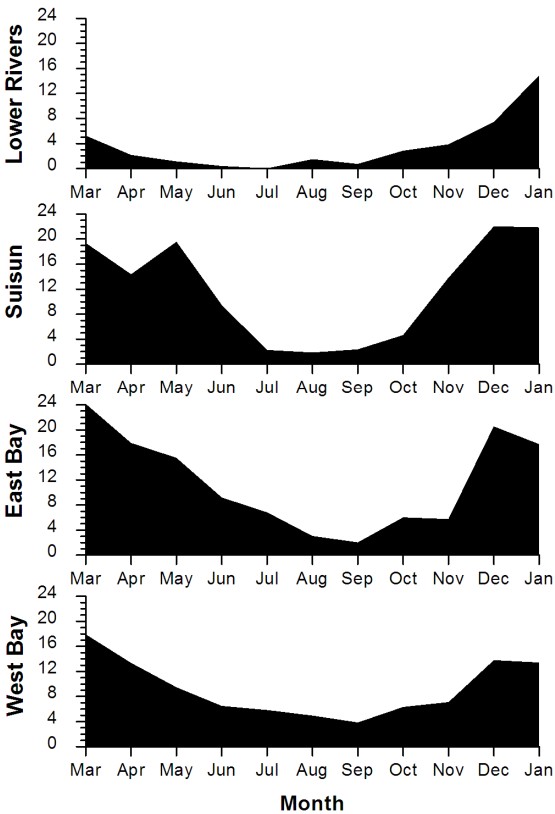

FIGURE 6.—Average annual frequency of longfin smelt detection (%) for the anadromous life stage by month and area for the years 1980–2011. Frequency of detection was calculated as the percent of sampling events where longfin smelt were observed over the total number of sampling events within an area. Lower Rivers covers all regions from Sacramento Valley downstream to the Lower Sacramento and San Joaquin River regions, Suisun covers the Confluence and all Suisun Bay regions, East Bay covers Carquinez Straight downstream to East San Pablo Bay, and West Bay covers West San Pablo Bay and San Francisco Bay regions.

Table 5.—Average frequency (%) of longfin smelt detection by life-stage across all years, Interagency Ecological Program monitoring program, and region in the San Francisco Estuary, California.

	Life-Stage										
	Larvae			Juvenile				Sub-Adult		Adult	
Monitoring Program[1]	BP	20mm	SLS	BOT	20mm	FMWT	BOT	FMWT	Kodiak	BOT	Kodiak
Years of data used	80-89	95-11	09-11	80-11	95-11	80-11	80-11	80-11	02-11	80-11	02-11
Time Period	Jan-Jun	Mar-Jun	Jan-Mar	Apr-Oct	Apr-Jul	Sep-Oct	Nov-Apr	Nov-Dec	Jan-Apr	Dec-May	Jan-May
Region											
South San Francisco Bay	13.0	ns[2]	ns	8.2	ns	ns	86.6	ns	ns	4.7	ns
Central San Francisco Bay	20.0	ns	ns	45.6	ns	ns	83.6	ns	ns	12.1	ns
West San Pablo Bay	43.0	ns	ns	32.1	ns	10.4	82.6	19.1	ns	4.7	ns
East San Pablo Bay	48.0	62.0	ns	33.5	65.4	17.0	85.9	23.4	ns	8.7	ns
Lower Napa River	ns	68.0	ns	ns	73.0	15.6	ns	31.8	11.7	ns	0.0
Upper Napa River	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Carquinez Strait	65.0	71.0	90.0	37.0	86.1	24.2	79.2	36.6	21.7	9.7	11.0
Suisun Bay (SW)	65.0	75.0	90.0	30.7	61.0	31.1	76.0	40.9	3.3	9.4	5.8
Suisun Bay (NW)	67.0	79.0	90.0	30.7	87.1	39.1	84.6	50.9	8.3	14.1	5.8
Suisun Bay (SE)	70.0	73.0	100.0	21.8	69.9	29.3	72.6	44.2	2.9	10.3	5.3
Suisun Bay (NE)	69.0	73.0	100.0	21.8	70.9	23.8	84.4	39.5	12.9	11.1	6.3
Grizzly Bay	71.0	83.0	100.0	35.1	79.3	26.3	76.2	42.1	34.2	10.7	10.7
Suisun Marsh	ns	66.0	96.7	ns	64.4	22.9	ns	31.8	19.7	ns	5.8
Confluence	69.0	63.0	99.0	16.8	50.7	21.0	73.3	37.3	0.8	14.4	2.2
Lower Sacramento	ns	41.0	95.4	ns	29.2	18.0	ns	39.5	0.8	ns	7.7
Upper Sacramento	ns	14.0	73.3	ns	0.9	2.0	ns	11.9	0.0	ns	3.3
Cache Slough & Ship Channel	ns	25.0	95.4	ns	19.8	ns	ns	0.8	0.0	ns	6.4
Lower San Joaquin River	63.0	31.0	92.3	1.0	11.5	0.2	57.1	8.0	0.0	5.9	0.0
East Delta (Mokelumne)	ns	15.0	31.7	ns	0.0	0.0	ns	0.0	0.0	ns	0.0
South Delta	ns	16.0	50.6	ns	4.0	0.0	ns	0.5	0.0	ns	0.0
Upper San Joaquin River	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sacramento Valley	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] BP = San Francisco Bay Plankton Net Survey, 20mm = 20mm survey, SLS = Smelt Larval Survey, BOT = San Francisco Bay Study Otter Trawl, FMWT = Fall Midwater Trawl, and Kodiak Trawl = Spring Kodiak Trawl.

[2] "ns" indicates no survey conducted or regions which had inconsistently surveyed stations across all years, hence, excluded in calculating frequency of detection

later months moving downstream (Lower Rivers = July, Suisun = August, East and West Bay = September), possibly indicating downstream emigration through each Estuary area. Although LFS appeared to migrate completely out of the Lower Rivers area with an average detection frequency of zero being observed in July, monthly average detection frequencies did not drop below 2% for any Estuary area downstream.

Discussion

Observed geographic extent.—Effective conservation programs typically require a description of a species' geographical distribution or use of habitats (Pearce and Boyce 2006). Examples include reserve design (Araujo & Williams 2000), population viability analysis (Boyce et al. 1994; Akcakaya et al. 2004) and species or resource management (Johnson et al. 2004). Techniques characterizing geographical distributions by relating observed occurrence localities to environmental data have been widely applied across a range of biogeographical analyses (Guisan and Thuiller 2005). A general description of LFS distribution by occurrence was described by Moyle (2002), Rosenfield and Baxter (2007), and Rosenfield (2010); all indicated that during the LFS life cycle, it used the entire Estuary from the freshwater Sacramento-San Joaquin Delta downstream to South San Francisco Bay, and out into coastal marine waters. Regarding the extent of LFS range, those fish have been observed in a considerable portion of the western Delta, and upstream of the Feather River confluence with the Sacramento River, and the San Joaquin River to its confluence with the Tuolumne River.

Similar to the treatment of delta smelt by Merz et al. (2011), we utilized recently available data from the 20-mm and Kodiak, and Chinook and POD surveys together with other IEP and regional monitoring programs to provide information on areas of the Estuary where identified LFS life stages have been observed. While our study found similar extent of LFS distribution within the Estuary when compared with Moyle (2002), Rosenfield and Baxter (2007), and Rosenfield (2010), we observed the range of LFS extending further north on the Sacramento River, in the Petaluma River to the west, and extensions upstream on the Napa River and northern Suisun Marsh, covering an estimated area of 137,500 ha. Observations at the most upstream sampling stations in the Napa and Petaluma rivers indicated that the extent of LFS distribution in these locations remains unknown. Expanding research into these watersheds may provide insight into habitat management and future restoration for native estuarine fish assemblages including LFS (Gewant and Bollens 2012).

Distribution by life stage.— We found that LFS were frequently observed across a relatively large portion of their range, including East San Pablo Bay north into Suisun Marsh down through Grizzly Bay, and all four regions of Suisun Bay through the Confluence to the Lower Sacramento River region. Furthermore, we were able to identify regions such as Suisun Marsh and San Pablo Bay where the frequency of occurrence was relatively high in each life stage, suggesting a continuous Estuary presence. As with other anadromous species, it is likely that the mosaic of Estuary habitats provides benefits to LFS at various stages during their life history and development (Simenstad et al. 2000, Able 2005).

Identifying nursery habitats is important to conservation, as these habitats disproportionately contribute individuals to adult populations of a species (Hobbs et al. 2010). Longfin smelt are anadromous, and are known to spawn in freshwater and then move seaward for rearing. Longfin smelt have been collected in the Gulf of Farallones (Baxter

1999, CDFW 2009) and spawning has been documented in freshwater Estuary tributaries (USFWS 1996). Previous research has indicated a specific "low salinity zone" of the Estuary that serves as nursery habitat for various species (Jassby et al. 1995); in particular, the Suisun Bay has been identified as critical nursery habitat providing ideal LFS feeding and growing conditons (Hobbs et al. 2006). By utilizing all available survey data at once, we developed maps that provide evidence of a widespread rearing zone extending across the Estuary and spanning San Pablo and San Francisco bays as far upstream as the Lower Sacramento River and Lower San Joaquin River regions.

We found that both adult and larval LFS were detected relatively frequently in the uppermost regions of the Estuary (upstream of Confluence), unlike the juvenile and sub-adult life stages, likely indicating that LFS spawning habitat extends further upstream into freshwater areas than LFS rearing habitat. Unlike juvenile LFS, whose locations fluctuate between the bays and Suisun Marsh in relation to the low salinity zone (Dege and Brown 2004; Bennett et al. 2002), spawning adults appear to be not only in these locations but also to disperse into upper Delta reaches and into San Francisco Bay as well. However, adult presence in the San Francisco Bay during the spawning period likely relates to years with high Delta inflows, when low salinity habitat shifted westward. Spawning of LFS in high salinity habitat is unlikely, as such an occurrence would be maladaptive due to the low tolerance of LFS larvae to high salinity (Baxter 2009). Kimmerer et al. (2009) found larvae and juveniles most abundant at 2 ppt, and declined rapidly as salinity increased to 15 ppt.

Similar to findings of Rosenfield and Baxter (2007), we found evidence of LFS exhibiting anadromous behavior during their second year of life. The relative detection frequency of sub-adult LFS declined throughout the spring and summer months, possibly indicating a marine migration outside of the sampling area. A subsequent increase in LFS detection frequency during their second fall and winter indicates a migration back into the sampling area prior to the spring spawning season. This is consistent with an observation by Moyle (2002) that LFS gradually migrate upstream during fall and winter, as yearlings prepare for spawning. Rosenfield and Baxter (2007) also observed a decrease in LFS detection frequency and distribution after their first winter (sub-adults), followed by an increase during the second winter (adults). Although these results indicate that the marine residency of LFS is relatively brief (up to 6 to 8 months), annual variability in the duration of marine migrations remains unknown, as do the factors affecting timing of immigration and emigration (Rosenfield and Baxter 2007). There also appears to be a portion of sub-adults that do not fully leave the Estuary, suggesting a diversity in life-history strategies. A better understanding of the potential benefits of anadromy verses Estuary residency, interaction of Estuary LFS with other populations, and environmental mechanisms behind LFS anadromy appears relevant to the long-term management of this population.

Although each of the current Estuary sampling protocols suffered from one or more notable shortcomings (Bennett 2005), existing data can be explored to offer groundwork for understanding Estuary fisheries resources and specifically LFS geographic range by life stage. A better understanding of LFS spatial distribution informs conservation efforts by serving as an illustration of habitat use. Restoration strategies must include an understanding of habitat functions to effectively contribute to LFS recovery within the Estuary. There is a specific need for strategic planning in rehabilitation efforts. Some researchers have approached the question of relative influence of biological and physical factors on population abundance and the impact to conservation, and suggested mechanisms of population recovery (Mace et al. 2010). Researchers interested in developing a self-sustaining system have argued for the recovery of key processes that maintain habitat conditions (Beechie et al. 2010).

Understanding that critical differences exist in Estuary habitat value for each life stage among sites and time periods supports the use of spatial analysis in Estuary conservation and restoration planning. Exploring existing LFS data from various studies and databases, and making additional investigations into population demographics (i.e., timing or location of declines), environmental factors demonstrating the greatest influence on population abundance (e.g., temperature, water quality, prey density, etc.), and affinity analyses to assess habitat preference would provide a solid basis to address key issues. Longfin smelt are vulnerable to a large number of environmental stressors within the Estuary (Moyle 2002; Baxter et al. 2008; Healey et al. 2008) and individual stressors may have more or less significance for a species or population based on the manifestation of the stressor and proximity to that species (Tong 2001, Armor et al. 2005). Therefore, further investigations using an affinity analysis are warranted to understand more about life stage-specific key habitat attributes.

In this study, we have demonstrated the extent of LFS range is greater than previously reported (Rosenfield and Baxter 2007). We have provided additional information on distribution and detection frequencies of the Estuary population of LFS by life stage and season to support conservation planning by identifying areas to focus further study. While this analysis documents Estuary areas utilized by LFS, more work is needed to better understand the relationship between mapped spatial distribution and habitat use and productivity.

Long-term average distributional patterns are affected by inter-annual population shifts (e.g., eggs and larvae as per Dege and Brown 2004). Sampling program duration may further affect the percentage of detections at specific sites. Additionally, if the population range has shifted over time, then sampling that occurred only in recent years (e.g. in the northern Delta as the Bay Study sampling program expanded) might reveal a different pattern than if all the sampling localities in this study had been monitored over 50 years. This suggests further investigation into LFS population abundance by life stage and season is warranted, in particular investigations of the relationship between abundance and environmental factors within the Estuary.

According to Merz et al (2013), difficulty in assessing management effectiveness for anadromous fishes arises from several factors. First, anadromous life cycles are often complex and encompass both freshwater and marine ecosystems. Second, from a monitoring perspective, time series of counts at any one life stage reflect cumulative effects of freshwater, estuarine, and marine factors over the full life cycle, thereby complicating the ability to measure population responses to specific factors. Third, complex interactions of factors, which range from stream flow and temperature to large-scale and long-term shifts in marine conditions, occur. Because of these confounding factors, resource managers have not been successful in evaluating the effectiveness of managment actions that use the traditional method of quantifying abundance at single life stages in isolation. An alternative is to consider survival rates, life history variability, and the health (e.g., size, fecundity, disease) of a species that transitions between each life stage within the habitats that they occupy. Providing a spatial context for each life-stage of LFS, as we have done here, may facilitate our understanding of how Estuary habitats contribute to different life cycle stages and, thus, the effectiveness of management actions in improving population performance in the face of extrinsic constraints. Continued LFS investigations that focus on identifying, protecting, and enhancing aquatic habitats of the highest value contribute to Estuary science and management, and provide a basis for future conservation and restoration.

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Angler catch-per-unit-effort in restored and reference sections of the Merced River, California: a preliminary analysis

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The headwaters of the Merced River originate in the western Sierra Nevada, California. The river then flows 217 km westward through Yosemite National Park (YNP) and into the San Joaquin Valley, where it flows into the San Joaquin River south of Modesto, California. Due to its proximity to large population centers and its path through the popular YNP, the Merced River gets extensive recreational pressure from rafters, photographers, swimmers, and fishermen. Recreation, through fishing license sales, equipment sales, and area hotel and camping fees produces high revenue for state and local economies. From 2003–2011, the State of California generated an average of $58,347,000 in sport fishing license sales, with a high of $65,174,000 in 2009 (CDFG 2012). A portion of the revenue generated by fishing is allocated for fish stocking and habitat restoration efforts.

Land use and river management practices such as agriculture, flood control, water supply, and mining have resulted in severe habitat degradation to portions of the Merced River (CDWR 2001). For example, the lower Merced River has shown signs of fragmentation and pooling during periods of low water. River fragmentation and pooling resulted in decreased dissolved oxygen and increased water temperatures (CDWR 2001). Past research has shown that a change in water characteristics can result in assemblage shifts from a coldwater fishery to one that supports large, warmwater-tolerant predators, such as largemouth bass (*Micropterus salmoides*) and spotted bass (*Micropterus punctulatus*), piscivorous cyprinids such as pikeminnow (*Ptychocheilus grandis*) and hardhead minnows (*Mylopharodon conocephalus*), and other larger predators such as striped bass (*Morone saxatilis*) and white catfish (*Ameiurus catus*) (Brown 2000, CDWR 2001).

The Merced River historically has been an important river for spawning by anadromous salmonids, particularly for Chinook salmon (*Oncorhynchus tshawytscha*) (CDWR 2001). In addition to warming water temperatures and a shift in predator species, suitable spawning habitat was lacking due to a high rate of sedimentation and diminished rates of sediment flushing (USFWS 2001). The lack of cover and suitable spawning habitat has been demonstrated to limit spawning success of native salmonids and result in higher rates of predation on young by avian predators (Grand and Dill 1997), native aquatic predators such as hardhead minnows and pikeminnows (Bettelheim 2001, Peterson and Barfoot 2003), and non-native warmwater predators such as largemouth bass (Rieman et al. 1991).

In order to protect and restore salmonid populations, multiple agencies supported restoration of several sections of the lower Merced River. This included a 2-km section of river upstream from the Highway 59 bridge (37° 28' 14.4" N, 120° 30' 2.3" W) known as the Robinson Reach, a project that began in July of 2001 and was completed in February of 2002 (CDWR 2010). During that project a new channel was constructed and the floodplain was restored to eliminate fragmentation. This helped to create a defined corridor for fish movement while eliminating most of the ponded areas within or near the reach. Gravel and cobble substrate was added to the river to create spawning and rearing habitat. The floodplain and river banks were planted in native riparian species to provide habitat for fish, provide cover from predators, and establish a riparian buffer. However, due to the dry, rocky nature of the floodplain, a majority of the newly planted vegetation died, and the floodplain and riparian area remained quite bare (M. C. Wilberding, personal observation).

We designed a study to examine the fish density in the 2-km restored section of the Merced River (Robinson Reach) and compare it to a non-restored, more natural section of similar length immediately upstream of the Robinson Reach. The upstream reference section flows through hardwood forests and farmland, and included a riffle, run, and pool composition that served as a control for comparison with the restored section.

We designed our investigation to estimate the relative abundance of potential predators of Chinook salmon in each section by conducting an angling catch-per-unit-effort study (CPUE; fish/hr). We used lightweight tackle (light-action rods with 1.8-2.7 kg test line) and small spinners or small Rapala lures (<7.62 cm) thought to mimic age-0 salmonids. Barbless hooks were used in accordance with current fishing regulations. CPUE was analyzed based on (1) fish hooked and lost, and (2) fish landed. To get a better idea of relative abundance, those two categories were pooled into a single category as total hooked, with the assumptions that a hooked, but missed, fish did not bite again, possibly the result of stress or experience.

Angling was conducted from 21 March to 15 April 2012 in the Merced River between the Highway 59 and Snelling Road bridges. This reach was broken into two smaller sections: a 2-km restored section of the Robinson Reach (RR; downstream end 37°28' 23.9" N, 120° 29' 49.2" W) and a 2 km non-restored reference section just upstream of the restored reach (US; downstream end 37° 29' 8.5" N, 120° 28' 52.3" W). Two anglers participated in this study and each angler fished a total of 25 hours in each of the two sections. Angling occurred between 0630 and 1930 and the sections fished both were alternated between outings and anglers. All angling was conducted while wading in the upstream direction. Each angler recorded the date, river section, time fished (start and stop), fish strikes (caught or missed) and time, species, length (mm), and other potentially relevant observations (e.g., weather or water conditions).

To determine if CPUE was similar between anglers we used a Wilcoxon rank-sum test (Hollander and Wolf 1999) in program R (R Core Team 2011). To help ensure samples were independent we made comparisons using the number of fish caught during each hour instead of the cumulative CPUE. We also tested for a significant difference in CPUE between RR and US sections using the Wilcoxon rank-sum test.

CPUE for Angler A (1.40) and B (1.14) did not differ ($W = 372.5$, $P = 0.24$); thus, we pooled data for further analysis. A total of 127 fish were hooked, resulting in an overall CPUE of 1.27 fish/hr. Overall, CPUE was significantly greater ($W = 1785$, $P < 0.001$) in the US reference section (1.84 fish/hr) than it was in the RR restored section (0.70 fish/hr).

Of the 127 fish hooked, 92 were salmonids (*Oncorhynchus spp.*), with a CPUE of 0.92 fish/hr; 32 were non-salmonid piscivorous fish with a CPUE of 0.32 fish/hr. Due to their similar morphologies rainbow trout, cutthroat trout, and hybrids were grouped as *Oncorhynchus* spp. Fish species caught in order of decreasing occurrence were: *Oncorhynchus* spp., pikeminnow ($n = 21$), hardhead minnow ($n = 5$), largemouth bass ($n = 3$), spotted bass ($n = 3$), and unidentified fish that were lost ($n = 3$). Of the 92 salmonids, 68 (73.9%) were in the US reference section (1.36 fish/hr) compared with 24 (26.1%) in the RR restored section (0.48 fish/hr). Of the non-salmonid fish hooked, 23 (71.9%) were in the US (0.46 fish/hr) and 9 (21.1%) were in the RR (0.18 fish/hr).

This preliminary study was conducted to assess the results of large-scale restoration and reconstruction efforts on the Robinson Reach. Those restoration efforts were in large part to provide a defined corridor for movements and suitable spawning and rearing habitat for Chinook salmon. Our study was conducted to estimate relative abundance of piscivorous fish, which may prey on juvenile Chinook.

Greater CPUE in the US reference section than in the restored RR section (1.84 and 0.70 fish/hr, respectively) could be due to the abundant streamside vegetative cover, instream woody debris, and riffle, run, pool make-up of the US reference section, which contained far more streamside cover than did the RR section (~2-5%; personal observations). The lack of cover in the RR section likely provided limited habitat and protection for fish, created a potential for warming stream temperatures (Beschta 1997), and increased vulnerability of fish to terrestrial predators (Harvey and Stewart 1991). Instream habitat complexity and cover are essential for viable salmonid populations, and often yield increased salmonid abundance and average fish size (Boussu 1954). Additionally, salmonid populations and production typically are higher in streams that contain woody debris in comparison with sections where woody debris has been removed or is absent (Dolloff 1986). Riparian vegetation and large, instream woody debris are essential habitat components, and the limited amount of this habitat available in the RR section is likely a limiting factor for salmonid populations.

In addition to the lower CPUE in the RR section, the paucity of cover likely presented a problem for both adult and juvenile fish. Vegetative cover (both in water and overhanging) is very important, not only for carbon input, but also for maintaining cooler water temperatures and providing cover for young fish, while simultaneously providing access to food (plankton and aquatic invertebrates) for those juveniles. Indeed, Jones et al. (1999) reported a decline in fish abundance in southern Appalachian streams lacking forested riparian buffers. Murphy et al. (1986) also reported that vegetative buffer strips on streams provided woody debris and habitat, resulting in increased primary production and abundance of parr and fry salmonids.

We observed rafts of common mergansers (*Mergus merganser*) swimming and feeding on juvenile fish in the RR section on multiple occasions, whereas we did not observe those piscivorous birds in the US reference section. The presence of those predators could have an adverse effect on survival of juvenile salmonids as well as increasing mortality rates during times of out-migration. Collis et al. (2002) reported that juvenile salmonids accounted for up to 74% of the diet of avian predators (California gulls [*Larus californicus*] and ringbilled gulls [*Larus delawarensis*]) feeding in a freshwater environment. Wood (1987a) reported that juvenile salmonids formed a large portion of the diets of common mergansers in freshwater environments. Wood (1987b) also demonstrated that daily consumption of fish by merganser ducklings was up to 80% of their body weight, and that mergansers were capable of consuming up to 65% of the wild smolt production in freshwater ecosystems. These studies suggest that avian predation can have a substantial negative influence on juvenile salmonid survival rates and recruitment. Juvenile salmonids present in the RR section are probably more susceptible to avian predation than juvenile salmonids in the US section, likely a result of the near absence of riparian vegetation and limited instream cover in the RR section.

In addition to the lack of cover in the RR section, another area of potential concern was a connected warmwater backwater area (37° 28' 29.7" N, 120° 29' 25.8" W), an area that provided habitat for predators with the ability to move from the warmwater refuge into the river to prey on juvenile salmonids. A large proportion of the non-salmonid piscivorous fish hooked in this study were at the confluence of the mouth of the backwater and the Merced River. Additionally, in the floodplain across from the confluence there was a second warmwater pond (37° 28' 40.7" N, 120° 29' 35.1" W) that could become connected when flows inundate the flood plain. This raises the potential for recurring introductions of large warmwater predators that likely inhabit that pond.

The results of this study and the observations made while spending a substantial amount of time on the river indicate that the restored RR section of the Merced River had a lower CPUE of salmonids, higher presence of avian predators, a near absence of riparian cover and suitable aquatic habitat, and greater connectivity to a warmwater areas in comparison to the US reference section. Based on these preliminary results and observations, we suggest that riparian re-vegetation efforts be conducted and that instream woody debris be increased so that the RR section more closely resembles the US reference section. Such habitat improvements could reduce predation from both fishes and birds, and also establish a more suitable hydrologic environment, specifically reducing water temperatures. We also suggest that connectivity of warmwater areas to the RR section be managed to minimize the potential influence of non-native warmwater predators on juvenile salmonids, and that additional studies continue to monitor abundance, reproduction, and recruitment of salmonids, thereby allowing researchers to further evaluate the effectiveness of reconstruction and rehabilitation efforts, and inform adaptive management decisions.

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First record of endangered southern California steelhead (*Oncorhynchus mykiss*) in Conejo Creek, Ventura County, California

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Southern California steelhead (*Oncorhynchus mykiss*), referred to as southern steelhead, historically occurred from Santa Maria River, Santa Barbara County, to Santo Domingo River in northern Baja California. Major streams within this geographic region (Santa Ynez River, Ventura River, Santa Clara River, Malibu Creek, Arroyo Trabuco Creek, Santa Margarita River, and San Mateo Creek) supported runs of southern steelhead in the beginning of the twentieth century (Titus et al. 2010). Steelhead sightings dropped off in the 1940s and 1950s, and consistent abundance of trout has not been present in the southern portion of their range in the last 60 years (USFWS 1995, Titus et al. 2010, Capelli 2011). The decline in quality steelhead habitat, and the overall absence of steelhead in southern California, prompted the National Marine Fisheries Service (NMFS) to list southern California's Distinct Population Segment (DPS) of steelhead as endangered from the Santa Maria River south to the Malibu Coast in 1997 (Federal Register 62 FR 43937). In 2001, the range of the listing was extended to include all of the watersheds south to the Tijuana River at the U.S.-Mexico Border (Federal Register 67 FR 2002); this listing was reconfirmed in 2005 (Federal Register 70 FR 37204).

Southern steelhead are highly adaptable, able to survive in variable habitat conditions, and withstand higher stream temperatures and lower dissolved oxygen concentrations than their northern counterparts (USFWS 1995, Hovey 2004, Boughton et al. 2007, Spina 2007, Sloat and Osterback 2013). Despite this plasticity, steelhead populations have been greatly diminished in the Southern California Steelhead (SCS) DPS.

On 26 April 2013, while collecting flow rate data in Conejo Creek, Ventura County, California, we observed and collected a dead adult southern steelhead (Figure 1). The fish was observed at 34° 12' 30" N, 118° 59' 43" W, approximately 100 meters below the

Figure 1.—An adult, female southern California steelhead (*Oncorhynchus mykiss*) discovered in Conejo Creek, Ventura County, California, 26 April 2013. Photograph by T. E. Hovey.

Highway 101 freeway overpass, and was collected at 1045. The air temperature and water temperatures at time of collection were 25° C and 19° C, respectively. The steelhead was 57.5 cm total length and weighed 1.66 kg. A small ventral incision was made after collection and the fish was determined to be a female. A small sample of hydrated eggs was collected and preserved in 90% ETOH. Tissue was excised (1 cm x 1 cm) from the upper lobe of the caudal fin for genetic analysis, cut into two equal halves, and preserved dry on filter paper. Scales were collected from the dorsal area mid-body and stored in a dry, empty vial. Scaled photographs were taken of the specimen shortly after collection. After data processing, the steelhead was put on ice and transported to the regional office of the California Department of Fish and Wildlife (CDFW), Los Alamitos, for storage.

Based on carcass characteristics, it was our professional judgment that the fish had been dead ≤2 days. The gills were still red and blood filled, and body coloration at time of collection indicated that the fish had expired only recently. No external injuries were observed.

A cursory upstream and downstream search on the day of discovery revealed marginal spawning habitat a short distance upstream, but no other steelhead were observed. An additional focused survey was conducted by CDFW staff on 3 June 2013. Field assessment began downstream at the confluence of Calleguas and Conejo creeks (34° 10' 46" N, 119° 02' 22" W), and continued upstream on Conejo Creek to the 101 Highway overpass (34° 12' 32" N, 118° 59' 39" W). Suitable holding habitat for steelhead was discovered on Conejo Creek, and additional spawning habitat was observed near the area from which the specimen had been obtained. No additional steelhead were observed.

Conejo Creek is a tributary to Calleguas Creek, and discharges to the Pacific Ocean through Mugu Lagoon. Calleguas Creek extends upstream approximately 10.9 km to the confluence with Conejo Creek. We discovered the carcass of the steelhead approximately 4.3 km upstream of that confluence. The creek continues upstream, and terminates in the foothills above Thousand Oaks, Ventura County, California. Conejo Creek winds through agricultural fields, and receives consistent flow from field water runoff and waste-water treatment plants. Without this artificial flow, the lower portions of the drainage would be dry part of the year.

Regular steelhead runs have been reported in recent decades north and south of the discovery area, and occasional sightings of individual adult and smolt steelhead in coastal drainages within the SCS DPS previously have been reported from San Mateo Creek (Hovey 2004), San Luis Rey River (Kajtaniak 2007), San Juan Creek (O'Brien 2007), Santa Margarita River (Dickinson 2009), Santa Clara River (Southwick 2006, Howard 2009), and the Ventura River (Capelli 2007). A comprehensive overview of the status and distribution of southern California freshwater fishes (Swift et al. 1993) listed drainages north and south of Calleguas Creek as historically supporting steelhead trout. However, no mention is made of steelhead being observed previously in Calleguas or Conejo creeks. To the best of our knowledge, this is the first documented presence of southern steelhead trout in this drainage.

The area of the discovery is heavily developed with agricultural fields and vast residential areas, and associated flood control facilities. Historical records indicate that Conejo Creek did not maintain a defined channel on the lower Oxnard Plain, and did not regularly discharge directly to the Pacific Ocean; flows were naturally dispersed onto the Oxnard Plain and either percolated into the ground before reaching the ocean, or terminated in a lagoon and distributary channels north of Round Mountain, near the current location of California State University, Channel Islands. Calleguas Creek itself did not maintain a defined channel to Mugu Lagoon across the Oxnard Plain prior to its channelization in the late 19th and early 20th centuries, and was hydrologically connected to the Pacific Ocean on an irregular basis until a series of jetties constructed at the east end of the lagoon created a permanent, year-round opening to the watershed. Although this has been widely recognized by researchers, there is little evidence establishing the exact date of the aforementioned channelization; the date most often suggested is 1884, (Steffen 1982, Onuf 1987, Swanson 1994, Beller 2011). The Calleguas Creek Watershed Management Plan indicates that Calleguas Creek was connected to Conejo Creek by 1889, although no firm evidence is provided (Calleguas Watershed District 2004, 2005).

The marginal steelhead spawning and holding habitat in Conejo Creek is sustained only by manmade flows. The potential for a successful steelhead spawn and fry development is extremely low due to the diverse number of exotic aquatic species (common carp, channel catfish, green sunfish and largemouth bass) that likely would prey on eggs, fry, or smolts. Despite the physical challenges in Conejo Creek, our discovery illustrates the opportunistic and resilient character of southern steelhead.

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Observation of mating behavior of the Santa Ana speckled dace

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The speckled dace (*Rhinichthys osculus)* is one of the most widely distributed native fish in the western United States (Girard 1856, Moyle 2002). There are numerous forms of speckled dace and Moyle (2002) lists 7 undescribed subspecies in California. The Santa Ana speckled dace (*R. osculus* ssp.) is a small, rare, stream-dwelling cyprinid endemic to the mountains and foothills of coastal southern California. Mueller (1984) described the spawning activity of speckled dace in a small stream in New Mexico and Kaya (1991) described reproduction of the species in captivity. Little is known, however, of the life history of the Santa Ana speckled dace, and spawning activity has not been described.

On 8 May 2012, while conducting snorkel surveys in Bear Creek, tributary to the West Fork San Gabriel River (34° 16' N, 117° 53' W), Los Angeles County, California, I observed a small group of Santa Ana speckled dace congregated at the head of a lateral scour pool. Approximately 12 males, as characterized by their red snouts, were pursuing several females around the base of a small boulder in 0.5 m of water. The males repeatedly swam over, under and adjacent to the females while occasionally coming into contact with one another and forming a small tightly spaced group. This activity appeared to be communal and not territorial, although occasionally a male would give a brief chase to another male. Although gamete release was not noted, the females had distended bellies, and were observed coming into contact with a crevice near the base of the boulder and presumably releasing ova.

This behavior was observed for approximately 45 minutes beginning at 1430 and was confined to an area of 1 m^2 at the head of the pool where water velocity was greatest. The substrate at the site was primarily gravel and boulder with a near absence of fines or algae, and no aquatic vegetation. Ambient temperature was 29° C, and surface water characteristics at the site were as follows: temperature 19° C; dissolved oxygen 8.3 mg/L; pH 8.5; specific conductance 0.3 µS/cm; turbidity 1.5 NTU. The water was clear with a velocity of 0.8 m/s and a flow of 0.3 m^3/s (CMS). Rainbow trout (*Oncorhynchus mykiss*), the only other fish species detected in Bear Creek, were also present in the pool and were more abundant than dace.

I returned to the site after seven days and, although dace and trout were still present in the pool, mating or spawning activity was not observed. Flow had decreased to 0.2 CMS and dace were dispersed throughout the pool. Ova were attached to the base of the upstream face of the boulder where the mating behavior was centered during the week prior. The boulder was exposed to sunlight, and canopy closure was estimated at 50% for the entire pool.

Spawning of speckled dace has been associated with rising water temperatures (John 1963, Mueller 1984) and high flow events (John 1963). Water temperatures were slightly higher and flows were decreasing on the subsequent visit. A late-season rain event occurred in late April, which likely increased the flow in Bear Creek and may have triggered the observed mating behavior.

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Books Received and Available for Review

Copies of the following books have been received, and are available for review by interested parties. Individuals interested in preparing a formal review that will be published in *California Fish and Game* should contact the editor (Vern.Bleich@wildlife.ca.gov) with their request to do so.

Gotshall, D. W. 2012. Pacific Coast inshore fishes. Fifth edition. Sea Challengers, Monterey, California, USA. 363 pp. $9.99 (E-Book).

Kirkwood, S., and E. Meyers. 2012. America's national parks: an insider's guide to unforgettable places and experiences. Time Home Entertainment, Inc., New York, New York, USA. 208 pp. $24.95 (hard cover).

Love, M. S. 2011. Certainly more than you want to know about the fishes of the Pacific coast: a postmodern experience. Really Big Press, Santa Barbara, California, USA. 650 pp. $29.95 (soft cover).

Taylor, T. 2013. Fishing the river of time. Greystone Books, Vancouver, British Columbia, Canada. 206 pp. $19.95 (soft cover).

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