GASTEROSTEIDAE (STICKLEBACKS)

Gasterosteus aculeatus Linnaeus, 1758, threespine stickleback

Historical Distribution and Status. Largely as a matter of taxonomic convenience, two forms of threespine stickleback are recognized on the Pacific coast of California: G. a. aculeatus for the fully plated anadromous form, and G. a. microcephalus for the partially plated freshwater/resident form (Miller and Hubbs, 1969; Hopkirk, 1973; Leidy, 1984; Moyle, 2002). Collections of the two forms of threespine stickleback from the Estuary during the 19th Century were often described as separate species such as G. inopinatus, G. serratus, and G. plebeius (Girard, 1854a, b; Ayres, 1855c, d; Appendix 2). Several of the earliest records from the mid-19th Century for the collection of threespine stickleback from the Estuary include the Presidio in San Francisco (1854), Mountain Lake in San Francisco (circa 1850s), Alameda Creek (late-1850s or 1860), Coyote Creek (mid-1850s), and the Petaluma River (1855)(Appendix 2). There are archaeological records for threespine stickleback for Walnut, Temescal/Strawberry, and San Francisquito creeks (Gobalet et al., 2004). I found historical and recent records for the occurrence of threespine stickleback for 52 (76%) Estuary watersheds (Appendices 2 and 3).

Within the Estuary, threespine sticklebacks are widely distributed and often locally abundant in fresh-, brackish-, and saltwater intertidal upper marsh, riverine tidal marsh, and nontidal riverine habitats (Leidy, 1984; R. Leidy, USEPA, unpublished data; IEP, 2005). Threespine sticklebacks are also abundant in large areas of salt ponds in the southern Estuary and San Pablo Bay that were formerly tidal salt and brackish marsh (Lonzarich, 1989; Lonzarich and Smith, 1997). Leidy (1984) found threespine stickleback to be the most common species in Estuary streams, occurring in 43 percent of 457 samples between the elevations 0-123 m. During this study, threespine stickleback was also widespread and abundant, occurring at 101 (37%) of the sample sites, from 0-128 m elevation.

Ecology. The threespine stickleback is a polymorphic species. The streams and tidal waters within the Estuary support resident/freshwater and anadromous/brackish-saltwater populations that presumably behave as separate species (Snyder, 1991; Moyle, 2002). Leidy (1984) observed that resident populations of threespine stickleback were most abundant in clear, cool backwater and pool habitats, containing rooted and floating aquatic vegetation that provided structurally complex cover. Sticklebacks typically are found over sand, gravel and mud substrates, but are relatively uncommon in pools characterized by excessive fine sediment and high turbidities (Leidy, 1984; Moyle, 2002).

During this study, I found the abundance of threespine stickleback was positively correlated with conductivity and percent pool habitat, and negatively correlated with elevation, stream gradient, maximum depth, and dominant substrate size (Table 14). Resident populations of stickleback typically occurred in lower elevation, shallow pools over a mixture of silt-sand-small gravel substrates. While sticklebacks were the only species collected at several sites (i.e., lower small to large mainstem), they also occurred at sites characterized by several species of native and nonnative fishes (range 2-10 species). Sticklebacks were mostly collected with other native fishes within the anadromous fishes/small to medium, cool, tributary and mixed native fishes/middle mainstem-lower large tributary assemblages. However, occasionally stickleback was common in the lowermost reaches of streams that were the preferred habitats for nonnative fishes (i.e., mixed native-nonnative fishes/lowermost small to large mainstem and estuarine fishes/tidal riverine assemblages). The location of stickleback near the center of the CCA ordination indicates their occurrence at sites with average or intermediate environmental conditions (Figures 2 and 4). Fishes commonly collected with stickleback at lower elevation (< 50 m) sites include rainwater killifish, mosquitofish, yellowfin goby, green sunfish, striped bass, hitch, Sacramento sucker, prickly sculpin, and staghorn sculpin. At elevations > 50 m sticklebacks were typically associated with native fishes such as Pacific lamprey, California roach, Sacramento pike minnow, Sacramento sucker, rainbow trout, prickly sculpin, and tule perch.

Conservation Status and Recommendations. Threespine stickleback can be expected to occur in all Estuary watersheds. Important factors negatively influencing population numbers, especially resident freshwater populations, include excess siltation and turbidity, increased water temperatures through the removal of riparian vegetation or...
water diversions, pollution, loss of nesting, feeding, and cover habitat, the construction of migration barriers such as dams or drop structures, and the introduction of non-native piscivorous fishes (Leidy, 2000).

Moyle (2002) observes that because each resident, non-migratory population is most likely independently derived from anadromous forms, resident populations within each watershed are endemic. Because sticklebacks can readily disperse through estuarine and marine environments they are able to recolonize habitats from which they have been extirpated. Presumably, freshwater populations located above natural or man-made migration barriers may be extirpated with no opportunity for recolonization. Therefore, the status of resident/freshwater populations of stickleback, especially those above barriers, should be closely monitored. Reintroduction of sticklebacks should be considered where populations have become extirpated above barriers.

**Cottidae (Sculpins)**

*Cottus aleuticus* Gilbert, 1896, coastrange sculpin

**Historical Distribution and Status.** Coastrange sculpin occur in coastal streams from Alaska to Oso Flaco Creek, Santa Barbara County (Moyle, 2002). Historical records and more recent sampling indicate that coastrange sculpin is rare or absent in the Estuary. Hopkirk (1973) noted that in the North Coast region of California, coastrange sculpin is restricted to brackish water habitats and coastal streams. Hopkirk (1973, p. 104) observed “It [i.e., coastrange sculpin] is not present in the Central Valley, but is present in streams of the San Francisco Bay region.” There are only six historical and no recent records for coastrange sculpin from Estuary watersheds (Appendix 2). Five of these records are from 1945 for Conn and Moore creeks, tributaries to the Napa River, Napa County (Appendix 2). Apparently, the specimens were collected prior to the completion of Conn Dam (Lake Hennessey), and forwarded by Brian Curtis to Leo Shapovalov, CDFG, for identification. Presumably, Shapovalov would have been familiar with morphological distinctions between coastrange and riffle sculpins, closely related species that are often confused. Shapovalov spent much of his career studying salmonids in central and northern California coastal streams many of which contained coastrange sculpin and prickly sculpin, as well as watersheds in the southern Estuary where riffle and prickly sculpins are found. The second record for coastrange sculpin is from 1980 for a tidal reach of the lower Petaluma River, near Lakeville Highway Bridge, Sonoma County (Appendix 2).

I was unable to locate any records of coastrange sculpin subsequent to 1980. Extensive mid-water and otter trawl, and beach seine samples conducted throughout the Estuary by the CDFG from 1980-1995, recorded no coastrange sculpin.

**Ecology.** Coastrange sculpin prefer swift, shallow riffles within the lower reaches of streams with lagoons or estuaries (Moyle, 2002), conditions present historically in several Estuary watersheds. Coastrange sculpins also occur in smaller tributary streams, probably similar to conditions in Conn and Moore creeks prior to the construction of Conn Dam. Adults may make downstream spawning migrations during January-March so that larvae are in close proximity to estuarine environments where larvae develop (Shapovalov and Taft, 1954, as cited in Moyle, 2002). Hopkirk (1973, p. 104) noted, “Aleuticus is an ecological associate of *Oncorhynchus kisutch* and *Gasterosteus aculeatus aculeatus*”. Coastrange sculpin also occur in coastal pacific streams with prickly sculpin (P. Moyle, UCD, personal communication, 2004).

**Conservation Status and Recommendations.** It appears that suitable habitat for coastrange sculpin would have been present historically in the Napa River and other Estuary watersheds, so it is unclear why coastrange sculpin are not represented more in historical collections. Most of the mouths of Estuary streams have been modified from urbanization and for flood control so suitable habitat is scarce today. Interestingly, the two records for the Estuary are from watersheds with relatively intact estuarine wetlands near their mouths. It is possible that coastrange sculpin occurred in only those few watersheds with large estuaries, similar to the tidewater goby, but disappeared before these habitats were thoroughly sampled, or did not occur in the Estuary at all.

Moyle (2002) rates the coastrange sculpin in California as widespread with presumably stable populations. Coastrange sculpin is probably extirpated within the Estuary. Study of the sculpin species currently found in Conn and
Moore creeks upstream from Lake Hennessey should be undertaken to establish which species are present.

*Cottus asper* Richardson, 1836, prickly sculpin (Figure V.18)

**Historical Distribution and Status.** Prickly sculpin naturally occur in watersheds of the Pacific Coast from Alaska to the Ventura River in southern California (Moyle, 2002). They are found within tributaries of the Estuary and throughout the Central Valley. There appear to be three forms within California based on morphological differences such as the amount of prickling (Moyle, 2002). The three forms are coastal, Clear Lake, and inland, or Central Valley (Hopkirk, 1973). Hopkirk (1973) noted that in streams of the Estuary prickly sculpin appeared intermediate between coastal and inland forms, but this aspect of its morphology has not been studied in detail.

Prickly sculpin are geographically widespread and locally abundant in the Estuary. Nineteenth century records for prickly sculpin from Estuary watersheds include San Mateo Creek (1854-1860), Petaluma River (1855 or 1859), Mare Island, at the mouth of the Napa River (1881), Alameda Creek (1890s), Coyote Creek (1890s), Guadalupe Creek (1890s), Adobe Creek (1893), and the Napa River (1890s)/(Appendix 2). There are records for the occurrence of prickly sculpin from twenty-seven Estuary watersheds (Table 1, Appendices 2 and 3). Leidy (1984) collected prickly sculpin from 34 (7%) of the 457 sites sampled in 1981. Prickly sculpin were found at 75 (27%) of the sample sites during this study.

**Ecology.** Prickly sculpin tolerate a wide range of environmental conditions. Leidy (1984) and this study found that prickly sculpin occur in a variety of habitats, from low elevation (1 m), highly disturbed, channelized stream reaches to undisturbed headwater sites (293 to 320 m). During this study I found that the abundance of prickly sculpin was positively correlated with stream order, water temperature, percent open canopy, conductivity, and the total number of species (Table 14). Prickly sculpin were negatively correlated with elevation, stream gradient, dominant substrate size, and percent native species (Table 14). In the rainbow trout/upper mainstem-headwater tributary assemblage prickly sculpin occurred with rainbow trout/steelhead, California roach, and juvenile Sacramento sucker in clear, well-shaded pools with sand and gravel substrates. Species occurring with prickly sculpin at lower elevations within the mixed native fishes/middle mainstem-lower large tributary assemblage include California roach, hitch, Sacramento pikeminnow, Sacramento sucker, threespine stickleback, and tule perch. With the exception of tule perch, prickly sculpin was more often associated with nonnative fishes than any native species (Table 14). In the lowermost reaches of large streams (e.g., Walnut, Alameda, and Coyote creeks), prickly sculpin may be the most abundant native fish, often found with 3-7 nonnative species. Prickly sculpin also were found in brackish water within the tidal, estuarine portions of rivers. During this study I collected prickly sculpin and staghorn sculpin together from lowermost Alameda Creek, and prickly sculpin with riffle sculpin from the lower reaches of Corte Madera Creek and middle reaches of the Napa River.

Prickly sculpin are also found in reservoirs. It is possible that construction of Crystal Springs Reservoir on San Mateo Creek may have contributed to the spread of prickly sculpin into headwater reaches of the watershed resulting in the extirpation of riffle sculpin.

**Conservation Status and Recommendations.** Prickly sculpin appear to be stable in Estuary watersheds. Because prickly sculpin are saltwater dispersant and have pelagic larvae, they may easily colonize new habitats following extirpation of local populations (Moyle, 2002). Biochemical and taxonomic analyses of coastal Pacific, Estuary, and Central Valley populations of prickly sculpin populations could clarify taxonomic relationships within this highly variable species.

*Cottus gulosus* (Girard, 1854), riffle sculpin (Figure V.19)

**Historical Distribution and Status.** Girard (1854a) first described *Cottopsis gulosus* (= *Cottus gulosus*) within the Estuary from San Mateo Creek, San Mateo County. Leidy (1984) noted that riffle sculpin has not been collected from San Mateo Creek since Girard’s original description. San Mateo Creek currently contains prickly sculpin (*Cottus asper*) and the possibility exists that construction of Crystal Springs Reservoir in 1888 contributed to the dis-
appearance of riffle sculpin in the watershed, while favoring the spread of prickly sculpin that may occur in the reservoir. Other nineteenth century records for riffle sculpin from Estuary watersheds include the Petaluma River (mid-1800s), Alameda Creek (late-1800s), Napa River (1894, 1897), and Coyote Creek (1890s) (Table 1, Appendix 2). The current status of riffle sculpin in Alameda Creek is unknown. It has not been recorded in the Alameda Creek for approximately 70 years; however, riffle sculpin may persist in remote headwater reaches of the watershed.

There are records for the occurrence of riffle sculpin from twelve Estuary watersheds (Table 1, Appendices 2 and 3). Leidy (1984) collected riffle sculpin from 26 (6%) of 457 sites sampled in 1981. Riffle sculpin were found at 42 (16%) of the sample sites during this study. Riffle sculpin occurred in seven watersheds; including Coyote Creek, Guadalupe River, Corte Madera Creek, Miller Creek, Sonoma Creek, Napa River, and Green Valley Creek.

Freshwater cottids are often very difficult to identify because of variable and overlapping character traits within and among taxa and local populations, as well as hybridization among species. Misidentification of sculpin species is probably a common occurrence. It is interesting that there are more records for unidentified cottid species than for any other native stream fish (Appendix 2). Hopkirk (1973) noted that populations of riffle sculpin exhibit geographic variation in morphology from Central Valley populations. In addition, riffle sculpin and prickly sculpin may hybridize making clear identification of species more difficult (Moyle, 2002).

Moyle (2002) notes that there is much confusion regarding the systematics of riffle sculpin in California. Riffle sculpin currently exist as two geographically separated groups. One group occurs in streams of Central California (including streams tributary to the Estuary and the Central Valley), and another group is found in coastal streams of northern Oregon and Washington (Moyle, 2002). Riffle sculpin are poor dispersers that colonize streams exclusively through freshwater. It is unclear how these two widely separated groups of riffle sculpin colonized two such geographically disjunct regions given their poor dispersal ability. One plausible explanation is that riffle sculpin in California and Oregon/Washington are distinct taxa.

Ecology. In the Estuary, riffle sculpin occur primarily within the rainbow trout/upper mainstem-headwater tributary and mixed native fishes/middle mainstem-lower large tributary assemblages. Leidy (1984) and this study found that riffle sculpin in headwater streams utilize habitats similar to rainbow trout/steelhead. Riffle sculpin was typically found in moderately shaded, cool pools with low conductivities, high water clarity, and a substrate dominated by gravel and cobble (Table 14). Examples of such streams are the upper Coyote Creek in Henry Coe State Park, Guadalupe Creek upstream from Guadalupe Reservoir, and Bear Creek (Sonoma Creek watershed) within Sugarloaf Ridge State Park. At these sites riffle sculpin was most often associated with rainbow trout, California roach, and juvenile Sacramento sucker.

Riffle sculpin abundance was positively correlated with stream gradient, the total number of species, and percent native species (Table 14). Riffle sculpin rarely occurred in samples with nonnative fishes. That riffle sculpin are positively correlated with the number of species reflects their occurrence within middle mainstem-lower large tributary sites characterized by 4-8 native species. Native species associated with riffle sculpin included Pacific lamprey, rainbow trout, California roach, Sacramento pikeminnow, hardhead (Napa River), Sacramento sucker, threespine stickleback, tule perch, and occasionally prickly sculpin. Examples of this assemblage include the intermediate reaches of Sonoma Creek, Napa River, Coyote Creek upstream from Anderson Reservoir, and lower Corte Madera Creek.

Conservation Status and Recommendations. Moyle (2002) noted that riffle sculpin are widely distributed and locally abundant, but expressed concern that populations are becoming increasing isolated and subject to local extinction. Riffle sculpin populations in Estuary streams appear to be stable and secure largely because their populations occur in headwater streams that are within protected lands. However, riffle sculpin populations within middle mainstem-lower large tributary sites (e.g., Sonoma Creek, Napa River) are vulnerable to ongoing land use practices such as sedimentation and pollution (fertilizers and pesticides) from adjacent agricultural activities. These mid-elevation sites merit more protection. In addition, the systematics of riffle sculpin populations in Estuary streams and elsewhere in Central California should be examined using biochemical and morphological analyses.
**Leptocottus armatus** Girard, 1854,
Pacific staghorn sculpin

**Historical Distribution and Status.** Girard (1854a) first described Pacific staghorn sculpin from specimens collected from the vicinity of San Francisco. There are several additional records for “San Francisco” for the period 1856-1862 by T.G. Cary and A. Agassiz, and others (MCZ 13756-13759, 22695, 31482, 36019, USNM 310). The research vessel Steam er Albatross regularly collected Staghorn sculpin from various locations throughout San Francisco Bay in 1912 (CAS, fish collection and accession files).

There are records for Pacific staghorn sculpin from several archaeological sites surrounding the northern Estuary, including San Francisco, Yerba Buena Island, Emeryville Shellmound, Walnut Creek, San Antonio Creek, and an unnamed creek tributary to tidal reaches of the lower Petaluma River (Gobalet et al., 2004; Gobalet, CSUB, unpublished data, 2005). Pacific staghorn sculpin is one of the most widely distributed and abundant fishes inhabiting the Estuary, occurring within and immediately adjacent to tidal habitats at the mouths of virtually all Estuary watersheds (Baxter et al., 1999). Staghorn sculpin were found at only 4 (1%) of the sample sites during this study because I typically did not sample tidal environments.

**Ecology.** Pacific staghorn sculpin is a true estuarine species that can tolerate salinities from fresh to saltwater (CDFG, 1988; Baxter et al., 1999; Goals Project, 2000). Juvenile staghorn sculpin are commonly found in low salinity waters (0-5 ppt) and may migrate into the lower reaches of Estuary streams where they are found with assemblages of brackish to fresh water tolerant fishes (Baxter et al., 1999; Moyle, 2002).

In the Alameda and Walnut Creek watersheds, I collected exclusively juvenile staghorn sculpin (size range: 41-87 mm TL) with mixed species assemblages of native and nonnative fishes including rainwater killifish, inland silverside, striped bass, green sunfish, threespine stickleback, and prickly sculpin. Interestingly, juvenile staghorn and prickly sculpins were collected together from the same microhabitat, characterized by a silt substrate and emergent macrophytes such as *Scirpus* spp.

**Conservation Status and Recommendations.** The staghorn sculpin is one of the most widely distributed and abundant fishes and, along with threespine stickleback, can be expected to occur in the estuarine portions of all Estuary streams. Staghorn sculpin may be one of the few native fishes able to tolerate degraded aquatic habitat conditions associated with stream channelization.

**CENTRARCHIDAE (SUNFISH)**

**Archoplites interruptus** (Girard, 1854),
Sacramento perch (Figure V.20)

**Historical Distribution and Status.** Sacramento perch is the only native centrarchid found west of the Rocky Mountains (Moyle, 2002). Fossil evidence indicates that it has been isolated in California since the Miocene and this long isolation has likely contributed to the retention of ancestral morphological and behavioral characteristics (Miller, 1959; Moyle, 2002). Sacramento perch is native to the Sacramento-San Joaquin Fish province, including the Central Valley, Clear Lake, and Monterey Bay subprovinces, but with the exception of Clear Lake, Lake County, and possibly within the Alameda Creek drainage, Alameda County, Sacramento perch is thought to be extinct in its native habitats (Moyle et al., 1995; Moyle, 2002; R. Leidy, this study). Sacramento perch has been widely introduced into reservoirs and ponds in California and Nevada (Moyle, 2002).

There are several records prior to 1900 for “San Francisco” that were likely based on market fish collected from the Central Valley (Appendix 2). The earliest record that I found for San Francisco was 1853 (MNHN 0278, Appendix 2). Girard (1858, p. 10) lists *Archoplites interruptus* (= *Archoplites interruptus*) from “San Francisco” but the exact collection location of this specimen is unknown and likely also represents fish acquired from a fish market in San Francisco. Ayres (1862, p. 163, at a meeting of CANS, 3/Feb/1862) references eight species of freshwater fish, including Sacramento perch, “…caught [by fisherman] at all the various points in the bay, at which salt water fishes only have previously been found.” Presumably, these fish were transported to San Francisco Bay from rivers and streams during the great floods of 1861-1862. There are two early records (circa 1890-1910) of Sacramento perch from Mare Island, Solano County, and although the exact collection locality is not known, the specimens were presumably historically present in tidal es-
tuarine environments of the lower Napa River (USNM 67328 and Evermann and Latimer, 1910). Historical records indicate that Sacramento perch is native to at least seven watersheds within the study area: Marsh and Walnut Creeks Contra Costa County; Alameda and Strawberry/Temescal creeks, Alameda County; Coyote Creek, Santa Clara County; San Francisquito Creek, Santa Clara/San Mateo counties; and the Napa River, Napa County (Leidy, 1984; Appendices 2 and 3). Sacramento perch also has been documented from several lakes and reservoirs within the study area into which it has been introduced (Leidy, 1984).

Gobalet (1992) identified remains of Sacramento perch from archeological sites within the Marsh Creek and Walnut Creek watersheds. The site on Marsh Creek is west of Brentwood near the John Marsh Historic Park and is dated from A.D. 1000-1500. Sacramento perch from this site could have been captured by Native Americans from nearby Marsh Creek, which would have contained suitable habitat, or from Suisun Bay to the north and then transported to the village site. Gobalet (1992) also recorded Sacramento perch from an archaeological site dated from A.D. 1400-1500 adjacent to Tice Creek, a tributary to Walnut Creek. Suitable habitat for Sacramento perch would likely have been present in nearby Walnut Creek. Gobalet et al. (2004) also identified Sacramento perch from middens within the Strawberry/Temescal, and Alameda creek, and Napa River watersheds.

Aceituno et al. (1976) and Aceituno and Nicola (1976) questioned whether Sacramento perch was native to the Alameda Creek drainage. Indirect evidence supported its non-native status in Alameda Creek since it appeared in a collection from Calaveras Reservoir in 1943 (CAS 20926), following completion of the reservoir in 1925, while the first collections for Alameda Creek were not until 1953 (CAS 25736, CAS 25739). Two archaeological records however, confirm the native status of Sacramento perch in the Alameda Creek watershed. Schulz (1986) identified Sacramento perch remains from an archaeological site dated from 1 A.D. - 600 A.D. on lower Alameda Creek near the confluence of Dry Creek. Gobalet (1990b) also confirmed the native status of Sacramento perch from fish remains recovered during excavation of an archaeological site that was occupied beginning from at least 1465 B.C. This site is adjacent to Arroyo de la Laguna, a major tributary to Alameda Creek. The archeological site along Arroyo de la Laguna Creek is adjacent to Willow Marsh, historically a large lowland freshwater wetland system that has been completely drained and filled as a result of urbanization. For the period 1943-1981, I located 27 documented records of Sacramento perch for the watershed, primarily from Alameda Creek and several adjacent sand and gravel ponds near the town Niles Canyon, within Niles Canyon, and from Arroyo de la Laguna, upstream from Niles Canyon (Leidy, 1984; Appendix 2). These collections typically contained young-of-the-year (age-0), juvenile (age-1+), and adult (age-3+) specimens indicating that Sacramento perch were reproducing within the stream. Sacramento perch persisted in Alameda Creek in Niles Canyon and downstream near Niles until at least the mid-1980s (Leidy, 1984; A. Launer, SU, personal communication, 2001, MCZ 78127-78130). I recorded Sacramento perch within Alameda Creek proper in 1981 when a single juvenile was collected in a large pool immediately downstream from the spillway of the Old Spring Valley Water Company Diversification Dam (removed in 2006) in Niles Canyon (Leidy, 1984).

During 1976, juvenile and adult Sacramento perch were collected from two quarry ponds (Grau and Kaiser B ponds) adjacent to lower Alameda Creek near Niles (Appendix 2). Apparently, the perch colonized the ponds from Alameda Creek during sand mining operations. In 1987, another quarry pond (Shinn pond) at the same location was sampled, but no Sacramento perch were collected. Several quarry ponds were again surveyed for fish during September 2001 and the summer of 2003, and no Sacramento perch were collected (EBRPD, fish survey data, 2001; P. Alexander, EBRPD, personal communications, 2002 and 2003). Again, in 2004 the majority of the Quarry Lakes Regional Park ponds accessible to an electrofishing boat were sampled and no Sacramento perch were collected (P. Alexander, EBRPD, personal communication, 2007). No Sacramento perch were captured during electrofishing of some of quarry ponds in 2005 and 2006 (P. Alexander, EBRPD, personal communication, 2007). It appears likely that Sacramento perch have disappeared from the quarry ponds or, if present, occur in small numbers making them difficult to detect.

Sacramento perch were also known to occur in Calaveras Reservoir in the Alameda Creek watershed (Appendix 2). Calaveras Reservoir was completed in 1938 and the first re-
cord of Sacramento perch from the reservoir is 1943 (CAS 20926). Because Sacramento perch may have become established in Calaveras Reservoir from fish residing in Calaveras Creek, any fish inhabiting the reservoir may be one of only a few remaining populations in California occurring within their native range (Leidy, 1984; Moyle, 2002). A single juvenile Sacramento perch (89 mm FL) was collected from Calaveras Reservoir during an electrofishing survey in February 1995 (B. Sak, SFPUC, personal communication, 2007). An effort to collect Sacramento perch from Calaveras Reservoir during October 2003 was unsuccessful and the population there may now be extirpated (P. Crain, UCD, personal communication, 2003), or persist in small numbers (P. Alexander, EBRPG, personal communication, 2007). A proposed study by the SFPUC (possibly as early as the summer of 2007) involving, in part, fish sampling in Calaveras Reservoir may help clarify the status of Sacramento perch (B. Sak, SFPUC, personal communication, 2007).

Subsequent sampling efforts during this study and by others during the 1990’s to the present, have been unable to confirm the presence of Sacramento perch within Alameda Creek proper, although a single juvenile was collected within Calaveras Reservoir in 1995, from which it was first recorded in 1943 (Leidy, 1984; P. Moyle, UCD, personal communication, 2002). An extensive effort to find Sacramento perch in Calaveras Reservoir in 2003 collected mainly largemouth bass and bluegill, two nonnative species known to have negative impacts on Sacramento perch populations elsewhere in California (P. Crain, UCD, personal communication, 2003). Large floods during the winter of 1994-1995 within the watershed resulted in the filling of several large, deep pool habitats with sediment that were known to support Sacramento perch. The complete filling of one such pool behind the Old Spring Valley Water Company Diver- sion Dam may have eliminated Sacramento perch from upper Niles Canyon (R. Leidy, USEPA, personal observation).

I located six historical references for the occurrence of Sacramento perch in Coyote Creek (Appendices 2 and 3). Carl Hubbs (UMMZ 63335, 63336, ANSP 85445) collected juvenile Sacramento perch in 1922 from lower Coyote Creek near the City of San Jose and between Alviso and Milpitas. Sacramento perch were collected again from lower Coyote Creek, opposite Milpitas in 1932 (Follett, 1974). There is also a reference to the collection of Sacramento perch from Coyote Creek in 1959, but a specific collecting locality for this record was not found (SJSU, CD-16). Finally, an adult Sacramento perch was collected in 1969 from Santa Teresa Pond, a small artificial water body near Coyote Creek (SJSU, 1969; Appendix 3). Presumably this Sacramento perch was the result of an introduction. Dr. L. J. Hendricks, San Jose State University observes that “None of these [i.e., Sacramento perch] have been found in the Santa Clara Valley to my knowledge since 1948” (SJSU, 1969: 3). Based on these few collection records, it appears that Sacramento perch may have disappeared from Coyote Creek sometime during the late-1950s to early-1960s.

Of particular interest are several specimens of Sacramento perch collected in 1860 from “Francisquita” [San Franciscoquito] Creek by Alexander Agassiz of Harvard University (UMMZ 87164, MCZ 9605). Although the exact location of the collection(s) is not known, the 1860 record is one of the earliest documented records for Sacramento perch in California, and suggests that Sacramento perch may have been present in other similar-sized watersheds surrounding the Estuary prior to the extensive modification of streams associated with urbanization.

Sacramento perch also occurred historically within the Napa River watershed. Gobalet et al. (2004) identified the remains of Sacramento perch from an archaeological site dated circa 2000 years ago, which lies adjacent to the Napa River on what is now the northern edge of the City of Napa. As discussed above, Sacramento perch were also known to occur near Mare Island near the mouth of the Napa River (USNM 67328 and Evermann and Latimer, 1910). Finally, twelve Sacramento perch were collected from the Napa River marshes during 1976 as part of a multi-year fish-sampling program of the marshes by the California Department of Fish and Game (CDFG, 1979; also cited in Madrone Associates, 1977).
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1957, Mathews 1962). Hopkirk (1973) notes several probable locations as sources for fish for the original introduction to Lake Anza, including Thurston Lake within the Clear Lake basin, the University of California, Hopland Field Station within the Russian River watershed, and Brickyard Pond near Sacramento. Sacramento perch was able to establish a reproducing population within Lake Anza following its introduction in 1953, and apparently remained abundant in the lake as evidenced by collections of juveniles and adults made throughout the 1950s and 1960s (Appendix 2). Wang (1986, pp. 25-1, 25-3) reports the presence of Sacramento perch in Lake Anza, as well as Jewel Lake located on Wildcat Creek several km downstream from Lake Anza. Wang (1986) collected larvae and two juvenile (10-15 mm TL) Sacramento perch from the vegetated shallows of Lake Anza 1980. Sacramento perch have not been recorded from Lake Anza since 1983, and evidence suggests that Sacramento perch populations there had been in decline since the introduction into Lake Anza of Florida strain largemouth bass in the early 1970s (P. Alexander, EBRPD, personal communication, 2007). Sacramento perch persist in Jewel Lake, but the population declined dramatically in 2006 when large quantities of silt-laden runoff reduced the lake volume significantly (P. Alexander, EBRPD, personal communication, 2007). Sacramento perch also occur in Sindicich Ponds within Briones Regional Park, into which they were introduced (P. Alexander, EBRPD, personal communication, 2007).

Hopkirk (1973, p. 83) observed that Sacramento perch was “apparently introduced” to Lake Merced, San Francisco County. There are several historical references to collections of Sacramento perch from Lake Merced beginning in 1942 and continuing through the early-1960s (Appendix 2). Prior to 19th Century settlement of San Francisco, Lake Merced was a large freshwater/brackish lagoon. There are collection records for other native fishes from Lake Merced including hitch, California roach, Sacramento blackfish, Sacramento sucker, prickly sculpin, and tule perch, suggesting the intriguing possibility that these species and Sacramento perch colonized Lake Merced during periods of lower sea level some 8,000 years ago.

Sacramento perch were not collected during this study.

Ecology. Within the Estuary, Sacramento perch occurred in lower-elevation pools, sluggish stream reaches, and floodplain lakes, often characterized by emergent wetlands. These conditions are currently found in stream reaches supporting the mixed native-nonnative fishes/lower small to large mainstem assemblage. This is consistent with other habitats in which it historically occurred in the Central Valley (Moyle, 2002). Sacramento perch were known to occur in the tidal waters of Mare Island near the mouth of the Napa River (i.e., estuarine fishes/tidal riverine assemblage), that undergoes large diurnal and seasonal fluctuations in water salinities. Presumably, the ability of Sacramento perch to tolerate moderately high salinities, as well as large fluctuations in salinity levels on a daily and annual basis, allowed Sacramento perch to occur in sloughs with fresh-to-brackish water conditions (Moyle, 2002). Sacramento perch apparently also inhabited large floodplain lakes and marshes within the Estuary. One of the few such wetland environments in the Estuary known to support Sacramento perch was Willow Marsh, historically a large, inland, lowland freshwater marsh environment adjacent to Arroyo de la Laguna Creek in the Livermore Valley (Thompson and West, 1878; Gobalet, 1990b). Another large, alkaline permanent pond-wetland complex that no longer exists, Laguna Seca adjacent to Coyote Creek, likely also supported Sacramento perch historically (Grossinger et al., 2006).

Historical records provide an indication of what other native fishes occurred with Sacramento perch in Estuary streams. A single specimen of Sacramento perch was identified from remains at an archaeological site on the lower Napa River that likely was an estuarine environment similar to present conditions (Gobalet et al., 2004). Sacramento perch was identified with the remains of nine other native fish species at the archaeological site on the Napa River, including sturgeon, thicktail chub, hitch, hardhead, Sacramento pikeminnow, Sacramento splittail, Sacramento blackfish, and Sacramento sucker (Gobalet et al., 2004). Sacramento perch was also known to occur in the low-elevation reaches of Alameda Creek and near the mouth of Coyote Creek, where in addition to the other species listed above; Sacramento perch would have occurred with prickly sculpin and tule perch (Appendix 2).

Conservation Status and Recommendations. Moyle (2002) identified habitat alteration and interspecific competition with nonnative fishes for food and space as important
reasons for the dramatic decline of Sacramento perch within their native habitats. The decline of Sacramento perch in the Estuary is correlated with extensive modification of the lowland habitats of many streams, the construction of reservoirs, and the concomitant spread of nonnative fishes, especially other centrarchids. Interspecific competition with nonnative centrarchids has been postulated as a primary mechanism contributing to the decline of Sacramento perch throughout its native range (Aceituno and Nicola, 1976; Marchetti, 1999). For example, the repeated intentional introduction of nonnative game fishes into Coyote and Anderson reservoirs following their completion in 1936 and 1950, respectively, contributed to their spread throughout the lower Coyote Creek watershed into habitats occupied by Sacramento perch. Prior to 1950, nonnative fishes were still infrequent in collections made in the Coyote Creek watershed. However, during the 25-year period from 1953-1978 fourteen nonnative fish species, including at least five centrarchid species, were first recorded from the lower Coyote Creek (Buchan et al., 1999). Three nonnative species, bluegill, green sunfish, and largemouth bass became widespread and abundant throughout the lower watershed following their initial introductions. In addition, Anderson and Coyote reservoirs altered streamflow patterns in much of lower Coyote Creek, and along with other channelization contributed to urbanization of much of the floodplain.

The apparent rapid decline of Sacramento perch in the 1970s-1980s within the Alameda Creek watershed is of significant conservation concern. In addition to Clear Lake, Alameda Creek may have supported until relatively recently the only other remaining naturally occurring population of Sacramento perch within their native range (Leidy, 1984; Moyle, 2002). However, the current status of Sacramento perch in the Alameda Creek watershed is unclear. Surveys focused within Niles Canyon and Calaveras Reservoir should be conducted to ascertain the status of Sacramento perch in the watershed, and if present, specimens obtained to determine the genetic makeup and probable origin (native or introduced) of the population(s). If Sacramento perch within the Alameda Creek watershed are native, then a management plan aimed at protecting the remaining fish should developed.

The practicability of reintroducing Sacramento perch into suitable historical habitats within the Estuary should be explored. Recently, the Contra Costa Mosquito and Vector Control District has been evaluating the potential of Sacramento perch for mosquito control (C. Miller, CCMVCD, personal communication, 2006). Sacramento perch have been spawned, reared, and released by the District into various ponds, lakes, sloughs, and tidal marshes within the Estuary and elsewhere with mixed success (Miller, 2005; C. Miller, CCMVCD, personal communication, 2006). Continued research and monitoring focused on the reintroduction of Sacramento perch should target stream reaches where other centrarchids are not abundant (i.e., mixed native fishes/middle mainstream-lower large tributary assemblage).

**EMBIOTOCIDAE (SURFPERCH)**

*Hysterocarpus traskii* Gibbons, 1854, tule perch (Figure V.21)

**Historical Distribution and Status.** Dr. William P. Gibbons (1854) first described *Hysterocarpus traskii* from specimens obtained by Dr. L.B. Trask, CANS, presumably from the Sacramento River. Hopkirk (1962, p. 1) provided a review of the somewhat confusing chronology of early descriptions of the tule perch:

The original description of the genus and species was published on May 18, 1854, in a San Francisco newspaper, “The Daily Placer Times and Transcript.” A formal publication of the description appeared twice (Gibbons, 1856a: 105; 1856b: 124) in the “1854” volume of the “Proceedings of the Philadelphia Academy of Natural Sciences.” The first of the two 1856 descriptions is slightly modified from the original, while the second is an accurate reprinting. Troschel (1855: 336) translated the original description into German.

Gobalet (1990b) confirmed the prehistoric presence of tule perch from near Willow Marsh within the Alameda Creek drainage, Alameda County, from fish remains excavated from archeological sites dated beginning at least B.C. 1465. Tule perch remains have also been identified from midden sites adjacent to Walnut Creek (Gobalet et al., 2004). There are several records of tule perch from collections by J.O. Snyder and his associates during the 1890s for the study area including Alameda Creek, near Sunol (CNHM 2597, FMNH 2597, 2600, CAS 105003, 105929, Snyder 1905), lower Coyote Creek, Santa Clara County (CAS 105004, 105007, MNHN 1901 0241-0242, Snyder 1905),
and the Napa River (Snyder, 1908)(Appendix 3). There are several records for tule perch in Coyote Creek from 1922-1925 by C.L. Hubbs and others (UMMZ 63287, 63288, 63392, ANSP 92464, SJSU, CD-21).

Within Alameda Creek, tule perch has been collected irregularly from 1898 until the early 1980s within and downstream of Niles Canyon (Appendix 2; Leidy, 1984). In 1977, tule perch were abundant in Alameda Creek near Niles (J. Smith, SJSU, personal communication, 1981). Sampling during the 1970s-1980s confirmed the presence of tule perch in Shinn and Kaiser B ponds, two abandoned gravel quarry pits immediately adjacent Alameda Creek near Niles within Quarry Lakes Regional Park (Anderson, 1976b; Gray, 1987). However, no tule perch were collected from several of the ponds surveyed during the fall of 2001 and summer of 2003 (P. Alexander, personal communications, 2002 and 2003). However, in 2005 and 2006 several tule perch were collected in Horseshoe Lake (P. Alexander, EBRPD, personal communication, 2007). Efforts to collect tule perch within Alameda Creek during this study were unsuccessful. It is interesting to note that tule perch historically occurred in collections with Sacramento perch in Alameda Creek immediately above and below the Old Spring Valley Water Company Diversion Dam in Niles Canyon until large floods during the winter of 1994-1995 resulted in the filling with sediment of the large, deep pool habitats upstream of the diversion dam (Leidy, 1984).

Tule perch were recorded from the lower Coyote Creek watershed on several occasions from 1895-1925 (Appendix 2). There were no records for the occurrence of tule perch in Coyote Creek for a period of 74 years and it was presumed extirpated from the watershed (Leidy, 1984). However, in 1999 reproducing populations of tule perch, as evidenced by the presence of juvenile and adult fish, were found downstream from Anderson Reservoir (Buchan et al., 1999; Demgen and Dorsey, 2000). The presence of tule perch within this reach of Coyote Creek was reconfirmed as recently as June 2003 (D. Salsbery, SCVWD, personal communication, 2003).

In June 2003 tule perch were recorded for the first time from the Guadalupe River in the southern Estuary (D. Salsbery, SCVWD, personal communication, 2003). That tule perch have gone undetected in the Guadalupe River, as they did in adjacent Coyote Creek for over half a century, suggests that populations may persist at low abundances going undetected in fish surveys for many years. Another possibility is that tule perch were able to recolonize the Guadalupe River through the Bay during periods when the surface waters of the Bay are brackish or fresh as a result of high total Estuary outflow. Alternatively, it has been suggested that tule perch in Coyote Creek and the Guadalupe River may have been reintroduced through water transfers from the Central Valley (J. Smith, SJSU, personal communication, 2003).

Tule perch are also known from streams draining into San Pablo Bay. Tule perch have historically been collected from the lower Napa River (Appendix 2), where they remain locally common in the middle-to-lower reaches of the Napa River, particularly within the tidal marshes and sloughs (CDFG, 1979; Feyrer, 2003; Hieb, 2003; USACE, 2006; Leidy, this study). I also collected tule perch from the middle-to-lower reaches of Sonoma Creek. Tule perch also persist in the lower Petaluma River and marshes (Caywood, 1974; Levy, 1993). While historically known from lower Corte Madera Creek, tule perch apparently disappeared from this stream following the channelization of its lower reaches for flood control in the 1960s.

There are historical and recent records confirming the presence of tule perch in streams and wetlands contiguous with the Carquinez Strait, Suisun Bay and Suisun Marsh (Leidy, 1984). During the 1960s, tule perch were known to occur in Hastings Slough near Port Chicago and in wetlands bordering the Carquinez Strait at Benicia (Appendix 2). Tule perch were present in lower Green Valley Creek in 1981, and their presence there was reconfirmed during this study in 1996 and 1998 (Leidy, 1984; Appendix 2). Tule perch were recorded from near the tidal reaches of lower Suisun Creek in 1980 (Appendix 2). Tule perch are known to be common in Suisun Marsh so their presence in the lower reaches of these streams is not surprising (Baxter et al., 1999; Matern et al., 2002).

There is a 1953 record for the occurrence of tule perch in Crystal Springs Reservoir, San Mateo County, on upper San Mateo Creek (Appendix 2). Hopkirk (1973, p. 84) suggests that these specimens are “apparently introduced”; however, Crystal Springs Reservoir was completed in 1888, and
the fact that San Mateo Creek supported other native fishes suggests that tule perch may be native to the watershed and became trapped in the reservoir following its construction. Similarly, the origin of tule perch in Calaveras Reservoir on Alameda Creek is likely also the result of stream populations being trapped behind the newly constructed reservoir.

Tule perch were found at only 9 (3%) sites during this study (Table 14). Within the Napa River watershed tule perch were locally common in tidal sloughs and channels fringed by emergent wetlands dominated by bulrushes (*Scirpus* spp.). Tule perch were also found within the non-tidal, valley floor, reaches of the mainstem Napa River and Sonoma Creek. I also collected tule perch from the non-tidal reaches of the mainstem of Sonoma Creek, as well as from lower Green Valley Creek.

**Ecology.** During this study, I found the abundance of tule perch positively correlated with stream order, average and maximum depth, wetted channel width, water temperature, percent open canopy, percent pool habitat, conductivity, and the total number of species (Table 14). Tule perch was negatively correlated with elevation and dominant substrate size. Tule perch were typically found in two habitat types along an elevation gradient. In the lower Napa River Marsh complex, tule perch were associated with relatively deep, wide tidal channels and sloughs, with little or no canopy cover and warm water temperatures. Salinities ranged from 30-42 ppt and water clarity was low. Associated fish species included striped bass, staghorn sculpin, longjaw mudsucker, yellowfin goby, chameleon goby, and starry flounder. In addition, tule perch have also been collected from Napa River marshes with other euryhaline species such as threadfin shad, Delta smelt, longfin smelt, Sacramento splittail, Sacramento sucker, inland silverside, and shishofuri goby (Hopkirk, 1962; CDFG, 1979; Feyrer, 2003; Hieb, 2003).

Tule perch were typically found within the low gradient, low elevation, non-tidal reaches of the mainstem Napa River and Sonoma Creek, where they were associated with warm, deep pools with moderate-to-high water clarity (as part of the mixed native fishes/middle mainstem-lower large tributary assemblage). Conductivities ranged from 500-600 mho and substrates were typically dominated by sand and small gravel. Ninety-seven percent of the fish species collected with tule perch were native, including California roach, Sacramento pikeminnow, hardhead, rainbow trout, Sacramento sucker, threespine stickleback, prickly sculpin, and rifle sculpin. The only non-native species collected was smallmouth bass.

Tule perch typically do not exceed 160 mm SL or 5 years of age, but a few may grow to over 200 mm and live for seven to eight years (Moyle, 2002). In 1994, I collected adult tule perch (n = 6) from Napa Slough ranging in size from 145-238 mm FL (mean = 170 mm FL). While I did not determine their age, these fish likely range from age-three to age-six, or more (Moyle, 2002). The specimen measuring 238 mm FL is likely the largest specimen of tule perch on record (Moyle, 2002).

**Conservation Status and Recommendations.** Moyle (2002) recommends that populations of tule perch be regularly monitored to determine if protective status is needed in the future. In the Estuary, Moyle (2002) suggests that tule perch may be in long-term decline, possibly in response to increasing abundances of nonnative centrarchids. My research indicates that tule perch were probably more common in Estuary streams in the past than at present. However, tule perch remain geographically widespread in the Estuary. Tule perch apparently are most abundant in the Napa River and Sonoma Creek watersheds that flow into San Pablo Bay. The status of tule perch should be closely monitored, especially in streams of the southern Estuary (i.e., Alameda Creek and adjacent quarry ponds, Coyote Creek, and the Guadalupe River). The persistence of tule perch in small numbers in some Estuary streams suggests that populations may persist and go undetected for many years. The possibility of reintroduction of tule perch into suitable historical habitats should be explored.

**Cymatogaster aggregata** Gibbons, 1854, shiner perch

**Historical Distribution and Status.** The shiner perch is common in subtidal and intertidal habitats throughout the Estuary (Goals Project, 2000). Shiner perch can be expected to occur in the tidal reaches of most Estuary streams, especially near the mouths of larger watersheds characterized by tidal sloughs and marshes. Between 1981 and 1986, shiner perch were consistently rated as one of
the most abundant fishes in otter trawl catches from tidal sloughs near the mouths of Coyote Creek and the Guadalupe River, especially during late-fall and early winter (Stevenson et al., 1987). Also in the southern Estuary, shiner perch is known to occur at the mouth of Alameda Creek (Appendix 2). In San Pablo Bay, it is common in the lower Petaluma River and marshes, the Sonoma-Napa wetlands complex, and tidal creek channels of Corte Madera and Gallinas Creeks, especially during summer months (CDFG, river and stream files, 1973-1979, Yountville; Green, 1975; Levy, 1993; CHM Hill, 1982). I did not collect any shiner perch during this study because we did not sample tidal environments where it is expected to occur.

Ecology. The life history and environmental requirements of shiner perch within the California and the Estuary are reviewed by Baxter et al. (1999) and Moyle (2002). Shiner perch occur within the tidal estuarine portions of streams. Although shiner perch are often found in euryhaline (1-3 ppt) environments, they are more abundant in waters with salinities between 18 and >30 ppt (Baxter et al., 1999). In open water otter trawl and beach seine sampling in the Estuary by the CDFG between 1980 and 1995, age-1+ shiner perch were collected at salinities from ranging from 0.1 to 34.3 ppt (mean = 25 ppt) and 0.6 to 33.3 ppt (mean = 23.1 ppt), with relatively few fish collected at salinities < 5 ppt. (Baxter et al., 1999). In the South Bay, the median salinity relative to catch per unit effort for shiner perch was 23.4 ppt (first and second quartile range = 15.4-26.6 ppt) (Stevenson et al., 1987). Peak occurrence within the Estuary occurs from May through October, and fish may emigrate from estuaries and tidal stream reaches during winter and spring should salinities become too low (Herbold et al., 1992; Baxter, et al. 1999; Moyle, 2002). Because of a broad salinity tolerance, shiner perch within the Estuary may be most commonly associated with other euryhaline fishes such as Chinook salmon, steelhead, longfin smelt, Sacramento splittail, white sturgeon, inland silverside, American shad, yellowfin goby, starry flounder, striped bass, and Delta smelt (CDFG, river and stream files, 1973-1979; Baxter et al., 1999; Goals Project, 2000).

Conservation Status. Moyle (2002) rates shiner perch populations as stable throughout California. Shiner perch remains widespread and often locally abundant in the Estuary; however, their abundance declined beginning in 1987, and remained low through 1995 (Baxter et al., 1999). Because shiner perch occur in estuarine habitats that have been adversely affected by activities such as dredging, construction of flood control projects, and poor water quality, and because of low fecundity, their abundance in the Estuary should continue to be monitored. Should shiner perch abundance remain low or continue to decline special management measures may become necessary.

Gobiidae (Gobies)

Eucyclogobius newberryi (Girard, 1856), tidewater goby

Historical Distribution and Status. The California endemic tidewater goby is distributed in coastal drainages from Del Norte County, northern California to northern San Diego County (Eschmeyer et al., 1983; Moyle, 2002). There is confusion regarding the type locality for tidewater goby. The type locality for specimens collected by E. Samuels in 1856 and used by Charles Girard to describe tidewater goby is presumed, based on museum ledger entries, to be Tomales Bay, Marin County, California (Girard, 1856b, USNM 360). However, data tags on these type specimens, including an additional 39 specimens not accounted for in the ledger entry; note “Petaluma” as the locality of E. Samuel’s collection. It is therefore possible that the Petaluma River is the type locality for tidewater goby. This is plausible also because E. Samuels collected other fishes from the Petaluma River between 1855 and 1859, and tidewater goby was known to historically occur in watersheds proximate to the Petaluma River (Appendix 2). For now however, the tidewater goby specimens from “Petaluma” collected by E. Samuels have been listed as possible syntypes.

Tidewater goby has been collected from lower Novato and Corte Madera creeks, Marin County (Leidy, 1984; Swift, 1980; Swift et al., 1989; Appendix 2). This goby was recorded from Corte Madera Creek near Kentville in 1959 and 1961 (CAS 26690, 23685), a tidal lagoon near the mouth of Corte Madera Creek in 1958 (CAS 31772), and from Novato Creek at the Highway 101 Bridge in 1945 (CAS 12995). There is also a record from 1895 for tidewater goby from Lake Merced in San Francisco (CAS 12483). In Alameda County, there are records for Berkeley Aquatic Park in 1950
likely contributing to the decline of the tidewater goby. Native species, and the alteration of tidal wetlands as toxic and organic pollutants), the competition from nonnative fishes contribute to the local decline from coastal lagoons used by tidewater goby in that seasonal sand bars do not block their mouths, and therefore their lower reaches are subject to twice daily tidal fluctuations. Historically the lower tidal reaches of Novato and Corte Madera creeks may have had perched tidal pond and channel backwater habitats that would retain water during outgoing tides and provide suitable habitat for tidewater goby.

Species associated with tidewater goby in 1959 in lower Corte Madera Creek included native fishes such as threespine stickleback, longjaw mudsucker, and arrow goby, and the nonnative rainwater killifish (Hubbs and Miller, 1965). Collections made in 1994 near this same location on Corte Madera Creek, however, included nonnative chameleon and yellowfin gobies, which became established in the Estuary circa 1964 and 1966, respectively (Ruth, 1964; Brittan et al., 1970; R. Swenson, TNC, personal communication, 2000). Tidal reaches of Corte Madera Creek and Novato creeks also support populations of carp, rainwater killifish, and mosquitofish (Appendix 3). Moyle (2002) suggested that competition from nonnative fishes contribute to the local decline and extirpation of tidewater goby populations.

 Conservation Status and Recommendations. Moyle (2002) identified poor water quality (i.e., sedimentation, toxic and organic pollutants), the competition from nonnative species, and the alteration of tidal wetlands as likely contributing to the decline of the tidewater goby. These factors have no doubt adversely affected historically suitable habitat for tidewater goby in the Estuary and contributed to its extirpation in the Estuary.

Sampling for tidewater goby should be conducted in lower Novato and Corte Madera creeks, and several other small streams in Marin County that are tributary to the Estuary. Because habitats used by tidewater goby are not often or easily sampled, and because their abundance often fluctuates widely and they are also able to recolonize suitable habitats, it is possible that this species may persist in small numbers in the Estuary.

*Gillichthys mirabilis* Cooper, 1864, longjaw mudsucker

**Historical Distribution and Status.** There are records for the occurrence of longjaw mudsucker from only seven Estuary watersheds (Appendices 2 and 3); however, it likely is common within tidal riverine and other brackish water habitats near the mouths of most Estuary streams. For example, it is commonly collected within the tidal portions of the Napa River (IEP, 2005). Gobalet et al. (2004) documented the occurrence of longjaw mudsucker from archaeological sites adjacent to the lower reaches of several geographically widespread Estuary streams. Leidy (1984) and this study collected longjaw mudsucker from one site each, a reflection of its preference for tidal habitats not sampled during this study.

**Ecology.** Longjaw mudsucker is a salt to brackish water species that occurs in shallow subtidal and intertidal habitats near the mouths of streams (Moyle 2002). It occasionally occurs with other stream fishes of the estuarine fishes/tidal riverine assemblage, including threespine stickleback, Pacific staghorn sculpin, striped bass, yellowfin goby, and starry flounder.

**Conservation Status.** Longjaw mudsucker appears to be widespread within the tidal portions of the Estuary (Moyle 2002); however open water and beach seine sampling in the Estuary by the CDFG between 1980 and 1995 rarely recorded longjaw mudsucker (Baxter et al., 1999). The potential adverse affects of other nonnative goby species and introduced marine organisms are not known. Moyle (2002) rates the population status of longjaw mudsucker in California as stable.
**PLEURONECTIDAE**  
**(RIGHTEYE FLOUNDERS)**

*Platichthys stellatus* (Pallas, 1788),  
**starry flounder**

**Historical Distribution and Status.** Gobalet et al. (2004) recorded starry flounder from several archaeological sites surrounding San Francisco and San Pablo bays. The starry flounder is widely distributed within shallow to deep, subtidal sand and mud flat habitats throughout the Estuary (Baxter et al., 1999; Goals Project, 2000). It can be expected to occur in the tidal reaches of most of the larger Estuary streams, characterized by well-developed tidal channels, sloughs and marshes. Between 1981 and 1986, starry flounder were consistently rated as one of the most abundant fishes in otter trawl catches from tidal sloughs in the southern Estuary near the mouths of Coyote Creek and the Guadalupe River, especially during late-fall and early winter (Stevenson et al., 1987). In San Pablo Bay, starry flounder is common in the lower Petaluma River and wetlands, the Sonoma-Napa wetland complex, and tidal creek channels of Corte Madera and Gallinas Creeks, (CDFG, 1979; Caywood, 1974; CHJ M Hill, 1982; IEP, 2005). Juvenile starry founder are common within Suisun Marsh (P. Moyle, personal communication, 2004). Starry flounder has been collected from Del Valle Reservoir in the Alameda Creek watershed where it presumably was transported from the Delta via California Water Project aqueducts (EBRPD, 1997). During this study, starry flounder was collected from a single site in the Napa River marsh complex.

**Ecology.** Adult starry flounder spawn in shallow coastal marine environments (Wang, 1986; Goals Project, 2000). Juveniles migrate into the Estuary where they rear in waters with fresh to brackish salinities (Baxter et al., 1999). Age-0 flounder prefer lower salinity environments, and higher salinities as they grow (age 1+) (Baxter et al., 1999). Because they rear in brackish and freshwater environments starry flounder are commonly found in the lowermost, tidal, estuarine reaches of streams. In Napa Marsh and the lower Petaluma River starry flounder were most frequently collected with other native stream fishes that utilize estuarine environments, most notably Sacramento splittail, Delta smelt, longfin smelt, Pacific staghorn sculpin, shiner perch, tule perch, and Sacramento sucker (Caywood, 1974; CDFG, 1979; Leidy, this study).

**Conservation Status and Recommendations.** Moyle (2002) rates starry founder populations as widespread and relatively stable, even though there has been a long-term decline in commercial catches. Moyle (2002) recommends that starry flounder populations be monitored in coastal and estuarine habitats.
Nonnative Species Accounts

ANGUILLIDAE (FRESHWATER EELS)

Anguilla rostrata (Lesueur, 1817), American eel

Historical Distribution and Status. The American eel is native to rivers, streams, and coastal waters of the Atlantic Ocean from Cape Cod to Columbia, South America (Dill and Cordone, 1997). Several attempts to introduce the American eel into Alameda Creek, Alameda County and San Francisco Bay were apparently unsuccessful (Dill and Cordone, 1997). Smith (1896, p. 438) discusses an attempt in 1874 to introduce “salt-water” eels to California: “The eels from New York Harbor, about 1,500 in number, were deposited in an inlet of San Francisco Bay, near Oakland.” The location referred to by Smith (1896) may have been Lake Merritt. Stone (1882) discusses an overland trip in 1879 requested by the California Fish Commission to bring fishes to California from the eastern United States. Stone (1882, p. 439) notes “… the others [eels from the Navesink River, New Jersey](about 500 in number) reached Sacramento on June 18 in good condition and were deposited in the Sacramento River and Alameda Creek.” McCosker (1989) presents six and two records of specimens of Anguilla rostrata taken between 1978-1984 from lakes within Golden Gate Park, San Francisco, and the two records from the Sacramento-San Joaquin Delta. McCosker (1989) also reports on an additional specimen identified as A. anguilla (European eel) that was captured near Byron, Contra Costa County, in 1964 (CAS 27136, 925 mm). Apparently, attempts to establish the American eel in California have been unsuccessful.
CLUPEIDAE (HERRINGS)

Dorosoma petenense (Günther, 1867),
threadfin shad

Historical Distribution and Current Status. Threadfin shad are native to the Atlantic and Gulf watersheds of Florida south to Guatemala, and the Mississippi River drainage (Page and Burr, 1991). Threadfin shad were first brought to California from Tennessee in 1953 by the CDFG as a potential forage fish, and in 1954 they were first introduced into San Vicente Reservoir in San Diego County (Dill and Cordone, 1997). Threadfin shad were first introduced into the Central Valley in 1959 and by the early 1960s had spread throughout the tidal waters of the Estuary (Alpin, 1967; Turner and Kelley, 1966; Wild, 1969).

Threadfin shad is now one of the most geographically widespread and abundant fishes in the brackish-to-fresh tidal waters and reservoirs of the Estuary (Armor and Hergesell, 1985; Wang, 1986; Baxter et al., 1999; Matern et al., 2002; Moyle, 2002). It is common in the tidal channels, sloughs, and wetlands of lower Petaluma and Napa Rivers bordering San Pablo Bay, as well as the tidal reaches of lower Coyote Creek and the Guadalupe River in the southern Estuary (Caywood, 1974; CDFG, 1979; Stevenson et al., 1987; Feyrer, 2003, IEP, 2005).

Threadfin shad are abundant in several Estuary reservoirs, especially those in the southern Estuary (e.g., Don Castro, Del Valle, Quarry Lakes, Anderson, Cottonwood, Lexington, and Stevens Creek reservoirs) where they began to appear in abundance in fish collections beginning in the late-1960s to the 1970s (Johnson, 1967; Wood, 1970; CDWR, 1974; Anderson, 1975b, 1976a; Hendricks, 1979). Threadfin shad have subsequently spread from reservoirs into downstream stream reaches. For example, there are records for threadfin shad in lower Coyote Creek beginning around 1978, several years following their introduction into Anderson Reservoir (Pitt and Bozeman, 1982). Similarly, in lower Alameda Creek threadfin shad began appearing in collections during the mid-1970s, also following their apparent introduction into Del Valle Reservoir sometime following its completion in late-1968 (CDWR, 1974; Anderson, 1976b).

There are records for threadfin shad from only six Estuary watersheds, mostly from reservoirs and tidal riverine environments (Appendix 3). I did not collect any threadfin shad during this study or in 1981 (Leidy, 1984).

Ecology. Within the Estuary, threadfin shad are most abundant in reservoirs, large permanent ponds, and the freshwater portions of tidal riverine sloughs and backwaters (Moyle, 2002). Within the Delta and Suisun Bay, threadfin shad are found at salinities between 0-18 ppt. (Baxter et al., 1999). Threadfin shad increases during years of high total river outflow and lower salinities (Baxter et al., 1999). Threadfin shad are found at water temperatures in excess of 20° C and therefore, can be expected to occur within the warm, lowermost reaches of large Estuary watersheds, especially channelized reaches in urbanized areas (mixed native-nonnative fishes/lower small to large mainstem assemblage).

Status. Threadfin shad are absent or uncommon within most small Estuary streams because of the lack of suitable habitat. Within larger watersheds they occur almost entirely in tidal riverine environments and/or in reservoirs. Threadfin shad have experienced dramatic recent population declines in open waters of the upper San Francisco Estuary (Sommer, et al, in review; Feyrer, et al., in press). Moyle (2002) noted that the potential adverse effects of threadfin shad on native fishes are poorly understood.

Alosa sapidissima (Wilson, 1811),
American shad

Historical Distribution and Status. American shad are native to large rivers along the Atlantic Coast from Labrador, Canada, to Florida (Page and Burr, 1991). The Sacramento River received the first introduction of American shad to California in 1871, and with additional plants through 1881 the species became successfully established (Evermann and Clark, 1931; Dill and Cordone, 1997; Moyle, 2002). Nidever (1916), as referenced in Skinner (1962), notes that shad first became abundant in the fish markets of San Francisco beginning in 1879, and presumably these market fish were caught primarily in the Estuary.

American shad are now one of the most abundant and widespread nonnative in fishes in the tidal waters of the Estuary (Baxter et al., 1999; Moyle, 2002). American shad
are known to occur in the tidal reaches of larger watersheds tributary to northern San Pablo Bay, including the Petaluma and Napa rivers and (Caywood, 1974; CDFG, 1979; Levy, 1993; Feyrer, 2003; Hieb, 2003; USACE, 2006). Shad also occur in the southern Estuary, where they apparently occur regularly at low abundances near the mouths of Coyote Creek and the Guadalupe River (Stevenson et al., 1987). American shad was not collected during this study because I did not sample its preferred habitats.

**Ecology.** The ecology of American shad in California is reviewed by Moyle (2002). Shad in California likely spend 3-5 years in the ocean before returning to spawn (Moyle, 2002). Shad spawn upstream from the Estuary between March and July, primarily in the Sacramento River above Rio Vista, and its larger tributaries, as well as major tributaries to the lower San Joaquin River (Wang, 1986). Shad are not known to spawn in streams within the study area. Juvenile shad apparently rear both in the Sacramento River and north Delta, but during late spring and summer they move further downstream into the west Delta portion of the Estuary before migrating to the ocean in the fall and winter (Baxter et al., 1999; Moyle, 2002). Shad abundance downstream of the west Delta, including San Pablo and Central bays apparently increases in high outflow years (Baxter et al., 1999). Presumably, shad abundance would also be greater during high outflow years in the lower Petaluma and Napa rivers. Because shad rear in brackish and marine environments in the Estuary, starry flounder are commonly found with them in the lowermost, tidal reaches of streams. In the lower Napa and Petaluma Rivers and tidal wetlands, American shad were most frequently associated with Sacramento splittail, Pacific herring, longfin smelt, Delta smelt, threadfin shad, striped bass, inland silverside, tule perch, shiner surffish, Pacific staghorn sculpin, threespine stickleback, and yellowfin goby (Caywood, 1974; CDFG, 1979; Feyrer, 2003, Hieb, 2003).

**Carp.** I found historical references for the occurrence of carp from twenty-two geographically widespread Estuary watersheds, and they can be expected to occur in other streams running through low elevation, heavily urbanized environments (Appendix 3). Carp also commonly occur in Estuary reservoirs and ponds, from where they presumably spread into upstream and downstream tributaries. Leidy (1984) recorded carp from twelve of the 457 sites sampled in 1981. During this study, I collected carp from fourteen (5%) of the 270 sites sampled. Carp are locally common in the lower reaches of several larger watersheds, including Walnut, Alameda, Coyote, and Sonoma creeks and the Guadalupe, Petaluma, and Napa rivers (Caywood, 1974; CDFG, 1979; Leidy, 1984; Buchan et al., 1999; Leidy, this study).

**Ecology.** During this study, carp abundance was positively correlated with stream order, maximum depth, low water clarity, percent open canopy, and conductivity (Table 15). Carp were negatively correlated with dominant substrate size and percent native fish. Carp typically inhabited poorly shaded, deep, turbid pools, with high conductivities and silt substrates typical of highly disturbed, low-elevation, perennial streams (mixed native-nonnative fishes/lower small to large mainstem assemblage). These environmental conditions are similar to those where carp were collected from Estuary streams in 1981 (Leidy, 1984). Carp also commonly occur in Estuary reservoirs.

Carp were never abundant where collected, averaging only two percent of the individuals in collections and typically consisting of one, or a few large adults. Carp rarely occurred alone in samples, being typically associated with five to ten species of mostly nonnative fish species. The most common nonnative associates of carp in 1981 and during this study included western mosquitofish, inland silverside, green sunfish and several other species of centrarchid. The most common native fishes associated with
carp were California roach, hitch, Sacramento pikeminnow, Sacramento sucker, and threespine stickleback.

**Status and Recommendations.** Carp are widespread and locally common and will remain permanent members of lowland fish assemblages in Estuary streams. Perhaps fortunately for native stream fishes, carp in Estuary streams rarely occur in intermittent streams above 100 m elevation, or in perennial streams above 50 m.

**Carassius auratus** (Linnaeus, 1758), goldfish

**Historical Distribution and Status.** Goldfish were first introduced into California in the 1860s, and may have been reared in ponds near Sonoma by 1870 (Poppe, 1880; Dill and Cordone, 1997; Moyle, 2002). Goldfish began to show up in fish collections from Estuary streams and reservoirs beginning in the 1940s, and the pet trade and the increased construction of ponds and reservoirs have likely facilitated their subsequent spread throughout the Estuary, in part, during the 1950s-1970s (Leidy, 1984). I found historical references for the occurrence of goldfish from sixteen Estuary watersheds, but they can be expected to occur in almost any stream running through heavily urbanized areas. The low number of goldfish in historical collections may be because juvenile goldfish have been regularly misidentified as carp, because they are morphologically similar to carp and frequent similar disturbed stream habitats. Leidy (1984) collected goldfish from 16 (4%) of the 457 sites sampled in 1981. During this study, I collected goldfish from only two (< 1%) out of the 270 sample sites, both on lower Walnut Creek.

**Ecology.** Leidy (1984) found that goldfish were most abundant in the moderately shaded, deep, turbid pools with silt and rubble bottoms typical of highly disturbed, low-elevation, perennial streams (mixed native-nonnative fishes/lower small to large mainstem assemblage). During this study, goldfish were collected from a channelized stream with minimal shade and high water conductivity. In 1981, and during this study, goldfish typically occurred with 5-10 mostly nonnative fish species. Common nonnative associates of goldfish included common carp, western mosquitofish, rainwater killifish and various species of sunfish (*Lepomis* spp.). The most common native fishes associated with goldfish were California roach, Sacramento sucker, and threespine stickleback.

**Status and Recommendations.** Goldfish are present in Estuary and Central Valley reservoirs where they are harvested for sale in Asian fish markets (P. Moyle, UCD, personal communication, 2004). Goldfish are likely to remain a regular member of Estuary fish assemblages in urban areas.

**Notemigonus crysoleucas** (Mitchill, 1814), golden shiner

**Historical Distribution and Status.** Golden shiner is native to Atlantic and Gulf Coast watersheds from Nova Scotia, Canada, to southern Texas, including the Mississippi River drainage, Great Lakes, and parts of Hudson Bay (Page and Burr, 1991). The U.S. Fish Commission first introduced golden shiner into California in 1891, in Lake Cuyamaca, San Diego County, and in the Feather River, Butte County, with subsequent introductions into the Central Valley in 1896 (Dill and Cordone, 1997). There is mention of “two shiners [that] were planted in Stow Lake in San Francisco” in 1896, but this artificial lake does not drain to a stream, so shiners likely could not escape from the lake and spread to neighboring waters on their own (California Commissioners of Fisheries, 1897, p. 73). Apparently, golden shiners became widespread and abundant in California following official approval for their rearing and use as commercial bait (Moyle, 2002).

The first record of golden shiners from an Estuary stream is from 1955 in Temescal Creek (Leidy, 1984). Golden shiner are common in many Estuary reservoirs and large ponds, especially those in the southern Estuary (e.g., Lake Chabot, and Del Valle, Cull Canyon, Temescal, Anderson, Coyote, Santa Teresa, Almaden, Vasona, and Lexington reservoirs) where they began to appear in abundance in fish collections beginning in the mid-1960s to early 1970s (Rowell, 1964; Hendricks, 1967; Strohschein, 1970, 1973a; CDWR, 1974; Anderson, 1973; Anderson, 1976a; Scoppettone and Anderson, 1976; Leidy, 1984). Golden shiners have subsequently spread from reservoirs into downstream stream reaches (Leidy, 1984).

Leidy (1984) collected golden shiners from nine (2%) of 457 sampling sites in 1981. During this study, I found golden shiners only at a single site in the lower Alameda Creek flood control channel.

**Ecology.** Leidy (1984) found golden shiner in warm,
clear, pools with silt substrates, often in the low elevation reaches of unshaded, channelized streams. Golden shiners are conspicuously absent from smaller watersheds with no reservoirs, an indication that they are presumably spread by means of bait bucket releases. In 1981 golden shiner were typically associated with a large number of other fish species (Leidy, 1984). Species most commonly associated with golden shiner in high abundances, included Sacramento sucker, hitch, Sacramento blackfish, mosquitofish, green sunfish, and smallmouth bass.

**Status and Recommendations.** Moyle (2002) notes that the ecological effects of golden shiners on native stream fishes are unknown. Because golden shiners have well-established populations in numerous geographically widespread reservoirs and ponds within the Estuary, they will likely remain a member of local assemblages, particularly in the lower reaches (<150 m elevation) of larger, channelized streams (mixed native-nonnative fishes/lower small to large mainstem assemblage).

**Pimephales promelas Rafinesque, 1820, fathead minnow**

**Historical Distribution and Status.** Fathead minnow were first introduced into the Central Valley as bait minnows in the early 1950s (Dill and Cordone, 1997). The earliest record that I found for fathead minnow from an Estuary stream was for Suisun Creek in 1963 (J. Hopkirk, SNSU, personal communication, 1981). Its occurrence in Suisun Creek was reconfirmed in 1972 (UCDPM 72-12). In addition to Suisun Creek, there are records for the occurrence of fathead minnow from three other Estuary watersheds, including Walnut and Coyote creeks, and the Petaluma River. Fathead minnow was first recorded from Coyote Creek in 1977, and it is now well established in the lower watershed downstream from Anderson Reservoir (SJU CD-33; Pit and Bozeman, 1982; Leidy, 1984; SCVWD, 2001; Demgen and Dorsey, 2000). Fathead minnow was first recorded from lower Walnut Creek in 1990, and I collected fathead minnow during this study from the upper Petaluma River in 1993 (HRG, 1990).

**Ecology.** Fathead minnow typically occurs in the lower, highly disturbed reaches of Estuary streams that are often channelized (i.e., mixed native-nonnative fishes/lowest small to large mainstem assemblage). Fathead minnow are most abundant in highly disturbed habitats because they are tolerant of poor water quality conditions, particularly high temperatures, low dissolved oxygen, and poor water clarity (Castleberry and Cech, 1993; Moyle, 2002). Fishes that co-occur with fathead minnow are typically nonnative species including, common carp, goldfish, green sunfish, red shiner, threadfin shad, golden shiner, western mosquitofish, rainwater killifish, and yellowfin goby (Pit and Bozeman, 1982; Leidy, 1984; this study).

**Recommendations.** Moyle (2002) recommends that fathead minnow be banned as bait minnows in California. I strongly endorse this recommendation, in part, because fathead minnow is still restricted to only a few streams in the Estuary and its potential to spread to other drainages from bait bucket introductions may be reduced.

**Cyprinella lutrensis** (Baird and Girard, 1853), red shiner

**Historical Distribution and Status.** Red shiner is native to the Mississippi and Rio Grande river drainages of the western and central United States (Moyle, 2002). It was first introduced into the Colorado River in California between 1948 and 1953 (Hubbs, 1954; Dill and Cordone, 1997). It subsequently spread throughout much of southern California and the San Joaquin River basin where it became firmly established by the early-to-mid 1980s (Jennings and Saiki, 1990).

Within the Estuary, the red shiner is restricted to lower Coyote Creek and the lower Guadalupe River, Santa Clara County, where it was first recorded 1986 (J. Smith, TJSU, personal communication, 1999, as referenced in Moyle, 2002). By the summer of 1999 red shiner occurred from the mouth of Coyote Creek (river kilometer 0) upstream to near Tennant Road (RK 43) (Demgen and Dorsey, 2000). During July 2002 it was the most abundant fish that I collected in lowermost Coyote Creek at a site just downstream from HwY 237. Red shiner has apparently spread into the lowermost reaches of the Guadalupe River, which is connected by tidal channels to lower Coyote Creek (Jones and Stokes Associates, Inc., 1997; D. Salsbery, SCVWD, personal communication, 2003).

**Ecology.** Jennings and Saiki (1990) found that in the San
Joaquin Valley, red shiner was positively correlated with turbidity, pH, conductivity, total alkalinity, total hardness, total dissolved solids, percentage of runs, and degree of human impact, and negatively correlated with maximum stream depth and stream width. Jennings and Saiki (1990) and Brown (2000) also observed a positive correlation between the abundance of red shiner and several nonnative fishes, including common carp, threadfin shad, western mosquitofish, inland silverside, striped bass, and fathead minnow. Within lower Coyote Creek red shiner has been collected in great abundance with the same nonnative fishes recorded by Jennings and Saiki (1990), as well as several native species including, Pacific lamprey, California roach, hitch, roach-hitch hybrids, Sacramento sucker, downstream-migrating steelhead smolts, threespine stickleback, and prickly sculpin (SCVWD, 2001; R. Leidy, USEPA, personal observation, 2002). During July 2002 in lower Coyote Creek, I observed that red shiner was typically the only species occupying riffle and high-velocity run habitats, often at densities estimated at 50 fish/m². Fish collections in lower Coyote Creek beginning in the mid-1980s, and continuing until the late-1990s, indicate that red shiner has spread rapidly upstream approximately 40 km since it was first recorded in the watershed in 1986.

Recommendations. Jennings and Saiki (1990) cite several studies from other Midwestern and southwestern states correlating the expansion of populations of red shiner with the displacement of other fishes with similar ecological requirements. Red shiners may pose a significant threat to native cyprinids in California, although apparently there have been no studies in California to support this hypothesis (Moyle, 2002). In 1981, I observed that California roach and fathead minnow were the most numerous fish in separate shallow pool habitats at several locations on lower Coyote Creek (Leidy, 1984; Leidy, unpublished data). Currently, red shiner has become the numerically dominant cyprinid at many locations, while fathead minnow remains abundant. Although California roach still occur in lower Coyote Creek, they may be less abundant there now than in 1981 (R. Leidy, USEPA, personal observation, 2002). The status of red shiner populations should be regularly monitored in Coyote Creek and the Guadalupe River. Moyle (2002) strongly recommends research into ecological interactions between red shiner and other fishes, particularly native cyprinids, as well as a ban on the use of red shiner as live bait. Lower Coyote Creek still supports several native fish species, including cyprinids such as roach and hitch, and their hybrids, and could serve as a useful location to study red shiner interactions.

Tinca tinca (Linnaeus, 1758),
tench

Historical Distribution and Status. The tench was first introduced into California from Italy in 1922 into a private reservoir near Half Moon Bay, San Mateo County (Shapovalov, 1944d; Cordone and Dill, 1997). According to Shapovalov (1944d), tench was subsequently introduced into ranch reservoirs and sag ponds throughout San Mateo and Santa Cruz counties. It is not known how many of these subsequent introductions were restricted to Pacific coastal drainages or included waters tributary to the Estuary, or whether the introduced populations still persist. There is a 1940 record for a single tench collected from Upper Mud Lake, a tributary to Los Trancos Creek, within the San Francisquito Creek watershed (CAS 75003). No tench were collected in 1981 (Leidy, 1984) or during this study.

Ecology. Tench prefer ponds, sloughs and deep, sluggish reaches of rivers with silty substrates and dense growths of aquatic macrophytes (Moyle, 2002). Moyle (2002) notes that the ability of tench to withstand low dissolved oxygen levels, its preference for silty substrates, and high fecundity poses a potential threat to native California fishes should it spread from reservoirs into stream or natural lake environments.

Recommendations. The status of tench in Mud Lake within the San Francisquito Creek watershed should be assessed. If tench are present in Mud Lake, they should be eradicated to insure that they do not establish a reproducing population in the San Francisquito Creek watershed.

CHARACIDAE (CHARACINS)

Colossoma spp.,
pacu

Historical Distribution and Status. Pacu are native to the Amazon and Orinoco basins of South America (Géry, 1977). Dill and Cordone (1997) identify five specimens of pacu from two estuary watersheds, including four specimens from Stafford Lake on Novato Creek, Marin County,
and one fish from Stevens Creek Reservoir, on Stevens Creek, Santa Clara County. The Stevens Creek specimen was tentatively identified as *C. brachypomum* (R.N. Lea, personal communication, CDFG, 1996, as cited by Dill and Cordone, 1997). One of the Stafford Lake specimens was identified as *C. bidens* (Dill and Cordone, 1997). I am not aware of pacu being collected from either Stevens or Novato creeks downstream from these reservoirs.

**Recommendations.** Pacu are tropical fish that are unlikely to survive low winter temperatures characteristic of Estuary waters.

**ICTALURIDAE (CATFISHES)**

*Ameiurus catus* (Linnaeus, 1758),
white catfish

**Historical Distribution and Status.** White catfish are native to Atlantic and Gulf Slope drainages from New York to Florida (Page and Burr, 1991). In 1874, Livingston Stone first introduced white catfish into California in the San Joaquin River near Stockton (Dill and Cordone, 1997). White catfish are very common in the shallow, vegetated sloughs and channels of the Delta and Suisun Bay (Turner, 1966; Wang, 1986; Baxter et al., 1999).

I found records for white catfish from streams and reservoirs in eight geographically widespread Estuary watersheds including Walnut, Pinole, Temescal, Alameda, and Coyote creeks, and the Guadalupe and Napa rivers (Appendix 3). White catfish also occur in Lake Merced in San Francisco (CDFG, lake and reservoir files, Yountville). The earliest record that I found for white catfish from an Estuary watershed is for Mare Island, near the mouth of the Napa River (Evermann and Latimer, 1910, p. 133). White catfish are found in the lower Napa River where they have been regularly recorded since the 1920s, although extensive sampling by the CDFG from 1973-1979 in the Napa Marshes did not record any (CDFG, 1979; Leidy, 1984; IEP, 2005; USACE, 2006).

White catfish were first recorded in the Alameda Creek watershed in lower Alameda Creek in 1955 (Leidy, 1984). Subsequently white catfish have been collected in Alameda Creek, Shadow Cliffs and Del Valle reservoirs on Arroyo Valle, and in Quarry Lakes near Niles (Leidy, 1984; EBRPD, 1997). The status of white catfish in the Coyote Creek watershed is unclear. There are records for the stocking of white catfish into Anderson Reservoir on Coyote Creek on several occasions in 1962 and 1965, but extensive sampling of the reservoir during the 1970s and 1980s recorded only one fish (Scoppettone and Anderson, 1976; Walkup and Eimoto, 1980). I found no records for the occurrence of white catfish in lower Coyote Creek below Anderson Reservoir. White catfish were also recorded in 1971 from Vasona Lake on Los Gatos Creek, in 1964, 1966, 1973 and 1983 from Calero Reservoir on Calero Creek, as well as from the lower Guadalupe River (SCCPRD, 1972; CDFG, lake and reservoir files, Santa Clara County, Menlo Park; J. Smith, personal communication, 1981). White catfish also occur in lower Walnut and Pinole creeks that are tributary to Suisun and San Pablo bays (Anderson, 1975a; Leidy, 1984). We did not collect white catfish during this study.

**Ecology.** White catfish are most abundant in the shallow, low-velocity backwaters, sloughs and submerged islands of the Delta and Suisun Bay and Marsh (Moyle, 2002). White catfish can tolerate a wide range of salinities, and are often found in salinities ranging between 10-14 ppt (Wang, 1986; Ganssle, 1966). In Estuary watersheds white catfish are apparently most abundant in the estuarine portions of the lower Napa River and marshes, presumably because extensive shallow water, vegetated habitats there are well developed. Interestingly, white catfish apparently do not occur, or are at least uncommon, in the estuarine portions of the Petaluma River, even though conditions there seem suitable.

**Recommendations.** Moyle (2002) suggests that because white catfish are piscivorous, they may be likely to adversely affect native fish assemblages in habitats to which they are introduced. I recommend that white catfish not be introduced into Estuary Reservoirs where they may escape and colonize downstream reaches of stream that support native fishes.

*Ameiurus melas* (Rafinesque, 1820),
black bullhead

**Historical Distribution and Status.** Black bullhead are native to the Great Lakes and Hudson Bay drainages, the
Mississippi basin, and Gulf Coast watersheds from Mobile Bay to northern Mexico (Page and Burr, 1991). There is confusion regarding the exact date that black bullhead were first introduced into California (Dill and Cordone, 1997). Black bullhead were most likely introduced into California in the early 1940s, however there is some evidence that they may have arrived as early as 1874 (Dill and Cordone, 1997; Moyle, 2002). Because black bullhead are likely regularly misidentified as brown bullhead confusion regarding the distributional status of black bullhead in the Estuary and Central Valley streams and reservoirs is not surprising. For example, Dill and Cordone (1997) cite various references for the first occurrence of black bullhead in the Central Valley and Sacramento-San Joaquin Delta from 1940s to early 1950s, respectively. I found what I consider a reliable record for the collection of black bullhead in 1942 from Lagunita Lake within the San Francisquito Creek watershed, Santa Clara County (L. Shapovalov, CAS 20922). Moyle (2002) now considers black bullhead widespread and common in the Central Valley and Estuary. However, between 1980 and 1995 extensive monthly open water, beach seine, and ring-net sampling by the CDFG throughout the Estuary resulted in the capture of only a single black bullhead (Baxter et al., 1999). In addition, a sampling program by the CDFG in Napa Marsh from 1973-1979 collected no black bullhead (CDFG, 1979). That black bullhead was not commonly captured during these studies suggests either that it has a restricted distribution in the Estuary, that it prefers habitats that were not regularly sampled, and/or that it was misidentified with brown bullhead.

A consequence of the confusion regarding the identification of various species of catfishes from the genus Ameiurus is that black bullhead may be more widespread in Estuary watersheds than collection records indicate. I found records for the occurrence of black bullhead from four Estuary watersheds including Walnut, Alameda, and San Francisquito creeks, and the Guadalupe and Napa rivers (Leidy, 1984; Buchan et al., 1999; Trihey and Associates, 1999; Launer, 2005). During this study I collected black bullhead from only two sites, both within the Alameda Creek watershed.

Ecology. Leidy (1984) found that large adults (> 200 mm FL) occurred in the deep pools of moderately disturbed, intermittent streams at intermediate elevations, characterized by silt substrates and intermediate water clarity. Juveniles (< 100 FL) were typically collected in relatively clear, shallow pools, among streamside masses of rooted aquatic and floating aquatic macrophytes, and in warm, shallow pools upstream from large reservoirs (Leidy, 1984). During this study we collected adult black bullhead in the deeper portions of pools with large adult hitch, Sacramento pikeminnow, Sacramento sucker, common carp, and green sunfish. While present in these pools, California roach (typically < 105 mm FL) were confined to shallow pool margins not occupied by black bullhead. Interestingly, black bullhead apparently migrates short distances out of reservoirs into tributary streams. In Arroyo Hondo, I collected adult black bullhead in perennial, cool pools, several kilometers above Calaveras Reservoir with rainbow trout, California roach, prickly sculpin, and largemouth bass.

Recommendations. Moyle (2002) suspects that black bullhead may be regularly misidentified with brown or yellow bullhead. Because of this possible confusion over the identification of bullhead, care should be taken when identifying bullhead collected from Estuary watersheds in the future.

Ameiurus nebulosus (Lesueur, 1819), brown bullhead

Historical Distribution and Status. Brown bullhead is native to the St. Lawrence-Great Lakes system, Hudson Bay, the Mississippi River basin, and Atlantic and Gulf Slope watersheds (Page and Burr, 1991). Brown bullhead was first introduced into California in 1874 near Sacramento (Dill and Cordone, 1997). In the Estuary brown bullhead are geographically widespread occurring in reservoirs, sloughs, and sluggish reaches of stream (Wang, 1986). They are well established in the Delta, Suisun and San Pablo bays, and the lower Sacramento River (Turner, 1966; Wang, 1986; Moyle, 2002). As with other ictalurids, brown bullhead were widely introduced into many local ponds and reservoirs in the Estuary beginning in the 1950s. As a consequence they were one of the earliest non-native fishes to spread from reservoirs into streams.

There are records for brown bullhead from reservoirs and streams in at least eight Estuary watersheds including Walnut, Pinole, San Pablo, San Lorenzo, Alameda, Coyote, Ste-
vens, and San Francisquito creeks, and the Guadalupe, Petaluma, and Napa rivers (Strohschein, 1973b; Caywood, 1974; Anderson, 1975a, b; Leidy, 1984; Wang, 1986; Levy, 1993; EBRPD, 1997; Buchan et al., 1999; Launer, 2005) (Appendix 3). I did not collect any brown bullhead during this study.

Ecology. Brown bullhead is the most geographically widespread ictalurid in California waters primarily because of its broad tolerance for varying water temperatures, turbidities, and salinities, as well as human modified environments (Dill and Cordone, 1997; Moyle, 2002). In the Estuary, it inhabits watersheds in warm, fluctuating reservoirs, channelized reaches of stream in highly urbanized environments, and in the middle-elevation reaches of small streams. In these different aquatic environments it has been found in assemblages comprised of five to eight mostly nonnative fishes, as well as assemblages containing only native fishes such as California roach, Sacramento sucker, three-spine stickleback, prickly sculpin, and occasionally rainbow trout (Leidy, 1984).

*Ameiurus natalis* (Lesueur, 1819), yellow bullhead

Historical Distribution and Status. Yellow bullhead is native to North American waters east of the Rocky Mountains from the Great Lakes to northern Mexico (Moyle, 2002). Moyle (2002) considered yellow bullhead to be restricted to southern California south of the Tehachapi Mountains and records for its occurrence within the Sacramento-San Joaquin system to be misidentified black bullhead because black bullheads are often bright yellow. There is a collection record from 1990 for yellow bullhead from Coyote Creek, Santa Clara County, but it is highly likely that this fish was misidentified (SCVWD, 2001). Yellow bullhead was not collected during this study.

Ecology. The ecology of yellow bullhead in California is reviewed by Moyle (2002).

*Ictalurus punctatus* (Rafinesque, 1818), channel catfish

Historical Distribution and Status. Channel catfish are native to the St. Lawrence River and Great Lakes, portions of Hudson Bay, the Mississippi-Missouri river system, and possibly several drainages of the Atlantic and Gulf slopes, including northern Mexico (Page and Burr, 1991). Channel catfish are relatively common in tidal freshwater to brackish salinity environments of large rivers, channels and sloughs of the northern Estuary including the Delta, Suisun and San Pablo bays, and the lower Sacramento River (Turner, 1966; Wang, 1986; Baxter et al., 1999; Moyle, 2002). Channel catfish have been widely introduced into ponds and reservoirs in the Estuary. They were first planted by CDFG into Anderson Reservoir in 1962 and subsequently spread to lower Coyote Creek by 1966 (R. L. Hassur, SJSU, personal communication, as cited in Fisher, 1973; Scoppettone and Anderson, 1976). They have also been recorded from Coyote Reservoir several kilometers upstream from Anderson Reservoir (Scoppettone and Anderson, 1976). Channel catfish are also known from the Guadalupe River and Stevens Creek watersheds (Eimoto, 1984; Gray, 1985; SCVWD, 1995).

In the Alameda Creek watershed, channel catfish are also found in Del Valle and Shadow Cliffs reservoirs, in a large stock pond on Dry Creek in the Garin Dry Creek Preserve, and in Quarry Lakes adjacent to the lower Alameda Creek flood channel near Niles (Anderson, 1976b; EBRPD, 1997). Other East Bay reservoirs with records for channel catfish include Cull Canyon and Don Castro (San Lorenzo Creek watershed), Lake Chabot (San Leandro Creek), Lake Temescal (Temescal Creek), and Jewell Lake, Tilden Regional Park (Wildcat Creek) (EBRPD, 1997). Channel catfish also occur in larger tributaries to San Pablo Bay, including the lower Napa and Petaluma rivers (Levy, 1993; Gray, 1989a, b; USACE, 2006). Channel catfish were not found during this study.

Ecology. In Estuary watersheds channel catfish inhabit a wide variety of habitat types including large, warm reservoirs, small streams, and the tidal, brackish water environments of larger rivers (mixed native-nonnative fishes/lower small to large mainstem). Moyle (2002) suggests that channel catfish populations may be limited by the availability of suitable spawning sites. In some streams and reservoirs, juvenile and adult channel catfish have been collected indicating successful reproduction; while in others only large adults have been recorded, consistent with Moyle’s suggestion. Channel catfish are piscivorous and prefer stream environments characterized by warm temperatures, high water clarity, sand-gravel-rubble substrates, and complex instream cover (Moyle, 2002).
**Recommendations.** Because the habitat preferences of channel catfish in small streams may be similar to native stream fishes, and because they are piscivorous, channel catfish should not be planted into Estuary streams, reservoirs, or ponds that drain into them.

**OSMERIDAE (SMELTS)**

**Hypomesus nipponensis** (McAllister, 1963), wakasagi

**Historical Distribution and Status.** Wakasagi are native to estuaries and lakes on the island of Hokkaido, Japan (Moyle, 2002). Wakasagi were first introduced into California by CDFG in 1959 (Dill and Cordone, 1997). They were first recorded in the Estuary in 1998 (Aasen et al., 1998, as cited in Moyle, 2002); however, CDFG midwater trawl records indicate that single wakasagi were collected in the Estuary as early as 1974, 1982, and again in 1995 (Baxter et al., 1999; Moyle, 2002). Wakasagi are now considered widespread in the Sacramento River watershed (Moyle, 2002; IEP, 2005). I did not collect wakasagi during this study. A single wakasagi was collected in the lower Napa River in November 2001 (USACE, 2006).

**Ecology.** Moyle (2002) reviews the life history of wakasagi based primarily on studies of populations in Japan and Shasta Reservoir in northeastern California. Wakasagi hybridize with delta smelt in the Delta (Moyle, 2002). The wakasagi collected from the Napa River was 118 mm FL suggesting some fish live two years as suggested by Moyle (2002).

**Recommendations.** Because wakasagi hybridize with Delta smelt and use similar habitats, they pose a serious threat to delta smelt. Populations of Delta smelt at the edge of their range such as those found in the Napa River are characterized by low abundances. These peripheral populations of Delta smelt may be even more threatened than those in the Delta, should wakasagi become established in the lower Napa River. Studies should be conducted on the potential affects of wakasagi on native fishes in the Estuary.

**SALMONIDAE (SALMON AND TROUT)**

**Coregonus clupeaformis** (Mitchill, 1818), lake whitefish

**Historical Distribution and Status.** Unsuccessful attempts to establish lake whitefish in California waters began in 1872 (Dill and Cordone, 1997). In 1879, eggs of lake whitefish were hatched at San Leandro and fish were stocked into Lake Chabot (20,000 fish) on San Leandro Creek and in “San Jose Water Company’s Reservoir,” in Santa Clara County (10,000 fish) (Smiley, 1882a, p. 912).

**Salmo trutta** Linnaeus, 1758, brown trout

**Historical Distribution and Status.** Brown trout are native to Europe, western Asia and northern Africa (Page and Burr, 1981). Efforts to establish brown trout in California waters began in 1893 (Dill and Cordone, 1997). In 1894, 2,715 “yearling” fish were planted in the preserves of the Country Club of San Francisco in Marin County” (Smith 1882, p. 433). There are several records for the 1930s-1940s for the planting of brown trout into the headwaters of Alameda Creek. In 1938, 1,300 and 8,000 “loch leven” trout from the Brookdale and Big Creek hatcheries were planted into Trout and Smith creeks, respectively (tributaries to Arroyo del Valle and Arroyo Mocho creeks) (CDFG, 1938a, b). Brown trout were also recorded from the headwaters of Arroyo Mocho, Isabel, and Alameda creeks (Shapovalov, 1938a, 1944b; CDFG, 1953).

The Coyote Creek watershed also historically contained brown trout. During May 1937, a total of 125,000 brown trout were planted into Coyote Lake and a tributary, Packwood Creek (Shapovalov, 1937). In May 1938, 6,250 “loch leven” from the Big Creek Hatchery were planted into Upper Penitencia Creek in Alum Rock Park May (CDFG, 1938c). Brown trout were regularly caught in Stevens Creek Reservoir from the 1930s until about the mid-to-late 1940s when they disappeared (Dill, 1938; Shapovalov, 1938b, 1942, 1944b, 1946b). Other Estuary watersheds with records for brown trout include the Guadalupe River and the headwaters of Milliken Creek, tributary to the Napa River (Fisher, 1959).

I did not collect any brown trout during this study nor was it collected in 1981 (Leidy, 1984). Whether reproducing populations of brown trout occur in the more remote portions of Mt. Hamilton area streams is not known. It is possible ranchers in the Mt. Hamilton region continue to pe-
periodically plant brown trout in reservoirs and stock ponds for sport fishing, and that some fish manage to escape, or are washed downstream.


Recommendation. Brown trout should be banned from Estuary streams.

Salmo salar Linnaeus, 1758, Atlantic salmon

Historical Distribution and Status. The nonanadromous form of Salmo salar also known as “Schoodic” salmon after lakes in the St. Croix River watershed of Maine and New Brunswick was widely planted in California beginning in 1878 (Dill and Cordone, 1997). The first shipment of 50,000 eggs of Schoodic salmon were shipped to the hatchery located adjacent to Chabot Dam and San Leandro Creek, Alameda County, where they were hatched in March and April 1878 and distributed throughout California (Smith, 1896). Estuary streams and reservoirs that received plants of Atlantic salmon fry between 1878 and 1895 included San Francisquito Creek, San Leandro Creek and Chabot Reservoir, Arroyo de la Laguna, near Sunol, “San Jose Water Company’s Reservoir” in Santa Clara County, “Laguna Honda, San Francisco,” and waters of the Country Club of San Francisco’s preserve in Marin County (Smiley, 1882b; Atkins, 1878, 1882; Smith, 1896). Apparently the salmon were not able to successfully reproduce where planted, although several fish were caught in lakes (likely located within what is now Pt. Reyes National Seashore) in Marin County in 1895 (Smith, 1896).

Salvelinus fontinalis (Mitchill, 1814), brook trout

Historical Distribution and Status. Brook trout are native to the northern half of eastern North America, west to Minnesota and Manitoba, Canada (Moyle, 2002). Brook trout were widely and repeatedly planted in Estuary streams primarily during the 1870s and 1880s, but never established permanent populations. Eggs of brook trout were likely first imported into California in the period 1870-71 where the California Acclimatization Society raised them. Their eggs were hatched at their fish hatcheries near the City Hall of San Francisco and on the grounds of the University of California at Berkeley (Dill and Cordone, 1997; California Commissioners of Fisheries, 1872). Brook trout may have been planted in Lake Merced, San Francisco, as early as 1871, although fish certainly could not reproduce there because of the lack of suitable spawning habitat (Dill and Cordone, 1997).

Smith (1896) and Shebley (1917) claim that the first introduction of brook trout into California was by the California Fish Commission in 1872 which placed 2,000 fish each in the North Fork of the American River, in the headwaters of Alameda Creek, and in San Andreas Reservoir [San Mateo Creek watershed], San Mateo County. Evermann and Clarke (1931, p. 64) reference that “in 1872 [brook trout were] planted...in [the] headwaters of Alameda Ck., and San Andreas reservoir near San Francisco,” in apparent reference to the plants noted above. Smith (1882, p. 434) notes that in 1875 the California Fish Commission distributed brook trout fry, “about 20,000 being placed in lakes and streams in Mendocino, Sonoma, Napa, and Yolo counties; 20,000 in Calaveras Creek, Alameda Creek watershed, and other streams tributary to San Francisco Bay”. In 1877, additional “young fish” were planted in suitable waters in Contra Costa, Alameda, San Mateo, and Santa Clara counties (Smith 1882, p. 434). During March and April 1878, fish from eggs hatched at the State of California’s hatchery at San Leandro were placed into Estuary streams as follows: streams in Alameda County (2,000 fish); San Leandro Creek (5,000); streams in San Mateo and Santa Cruz counties (4,000); Alameda Creek and tributaries (2,000); and Calaveras Creek and small streams, Alameda County (2,000) (California Commissioner of Fisheries, 1880). Woodbury (1890, pp. 15-52) noted that “In all these short coast streams [including those of the Estuary], which become warmer and diminish in volume as the summer advances, they [i.e., brook trout] have not reproduced themselves-at least I can not learn that they have been caught for a number of years past...”

Brook trout were not collected during this study, nor did I find records of its occurrence as part of other historical or recent fish surveys.

Ecology. In California, brook trout are largely restricted to mountain streams and lakes with summer water tem-

FISHES IN STREAMS TRIBUTARY TO THE SAN FRANCISCO ESTUARY
temperatures between 14-19\degree C (Moyle, 2002). The failure of brook trout to become established in Estuary streams even after repeated introductions may be due to a combination of factors such as water temperature, stream discharge patterns, and competitive interactions with native fishes. The headwater reaches of Estuary streams typically have summer and fall water temperatures that average between 17-21\degree C when stream discharge is lowest. Water temperatures during winter would be more suitable to brook trout for spawning; however, streams typically experience several peak discharges that scour the streambed. These environmental conditions also might provide an overall competitive advantage to the native, spring-spawning rainbow trout over the fall-spawning brook trout.

**Salvelinus namaycush** (Walbaum, 1792), lake trout

**Historical Distribution and Status.** Lake trout are native to New England and the Great Lakes watersheds, north into northern Canada and Alaska (Page and Burr, 1991). Dill and Cordone (1997, p. 110) note that in 1926, "some" adult lake trout from the Mt. Shasta Hatchery were sent to the Steinhart Aquarium and "some" were planted in the lakes of Golden Gate Park, San Francisco (California Division of Fish and Game Report for 1926-1928, p. 146, unpublished records of the Division of Fish and Game). I am aware of no other records documenting the planting of lake trout in lakes and streams of the Estuary.

**Ecology.** The ecology of lake trout in California is reviewed by Moyle (2002).

**Fundulidae (Killifishes)**

**Lucania parva** (Baird and Girard, 1855), rainwater killifish

**Historical Distribution and Status.** Rainwater killifish is native to coastal marine and estuarine environments from Maine to Mexico (Page and Burr, 1991). Rainwater killifish were first recorded from the Estuary from Berkeley Aquatic Park, Richmond Tidal Slough, and from the brackish reaches of lower Corte Madera Creek (Hubbs and Miller, 1965; CAS 26355, 26357). On several occasions in 1959, numerous specimens were collected in lower Corte Madera Creek confirming the establishment of populations there (CAS 26359, 26384). In 1961 rainwater killifish were collected from Lake Merritt in Oakland and by 1962 it was recorded from the Palo Alto Yacht Harbor in the southern Estuary (Hubbs and Miller, 1965). By 1963 rainwater killifish had spread into the tidal marshes bordering San Pablo Bay near the mouth of Sonoma Creek (J. Hopp kirk, SNSU, emeritus, personal communication, 1981; CAS fish collection). Ruth (1964) compiled a checklist of vertebrates of the San Francisco Bay region that listed rainwater killifish as localized in occurrence, but common where found. The first records for its occurrence in the Alameda and San Francisquito Creek watersheds are 1966 and 1977, respectively (Leidy, 1984).

Although I found collection records for the occurrence of rainwater killifish from 25 watersheds, it likely occurs in the lower tidal reaches of all streams entering the Estuary (Leidy, 1984; Appendix 3). Leidy (1984) recorded rainwater killifish from 22 (5\%) of the sites he sampled in 1981. I collected rainwater killifish occurred at 8 (3\%) of the sites sampled during this study (Table 6). The difference between the number of samples with killifish in 1981 and during this study is attributable to the fewer samples from the tidal reaches of streams during this study.

**Ecology.** Rainwater killifish are found in salinities ranging from 0-80 ppt (Lonzarich and Smith, 1997; Moyle, 2002). Leidy (1984) collected rainwater killifish from low elevation, warm, turbid pools in brackish salinity (5-10 ppt) waters at within the tidal zone. During this study rainwater killifish were collected from habitats similar to those described by Leidy (1984). Rainwater killifish were positively correlated with water temperature and conductivity, and negatively correlated with elevation, dominant substrate size, and the number of native species (Table 15). Killifish typically inhabited the lower channelized reaches of streams with a poorly developed riparian canopy and a substrate dominated by silt and sand.

Leidy (1984) and this study found rainwater killifish typically associated with one to three nonnative species that were also tolerant of brackish water, including western mosquitofish, yellowfin goby, and common carp. Native species collected in significant numbers with rainwater killifish include threespine stickleback, prickly sculpin,
and staghorn sculpin. While rainwater killifish in Estuary streams are most abundant in brackish salinity water, they did occur in freshwater environments as well. In lower Walnut Creek immediately above tidally influenced reaches, I collected rainwater killifish at salinities between 0-2 ppt with native and nonnative fishes, including goldfish, California roach, Sacramento sucker, pumpkinseed, green sunfish, threespine stickleback, and yellowfin goby.

Status and Recommendations. Rainwater killifish can be expected to occur in the lowermost reaches of all Estuary streams, especially in brackish salinity waters. The effects of rainwater killifish on native stream fishes is not known, but may be limited because killifish are primarily restricted to the lower tidal reaches of streams not typically frequented by native freshwater fishes.

POECILIIDAE (LIVEBEARERS)

Gambusia affinis (Baird and Girard, 1853), western mosquitofish

Historical Distribution and Status. Western mosquitofish are native to Atlantic and Gulf Slope watersheds from New Jersey to Mexico, including the Mississippi River drainage (Page and Burr, 1991). Efforts to establish western mosquitofish in the Estuary for mosquito control likely began during the mid-to-late 1920s following its introduction into California in 1922 (Dill and Cordone, 1997). Steinhardt Aquarium in San Francisco promoted their introduction by offering to give away mosquitofish to interested individuals (Dill and Cordone, 1997). Mosquitofish first began to appear regularly in Estuary streams beginning in the 1940s and by the 1950s was widespread in the Estuary (Leidy, 1984). Collection records during the 1940s for Estuary streams include Green Valley Creek (1940), Coyote Creek (1941), Walnut Creek (1942), Marsh Creek (1945), and Novato Creek (1945) (Leidy, 1984).

In 1981, western mosquitofish were collected from 105 sites (27%) throughout the Estuary between 1 and 859 m elevation (Leidy, 1984). Mosquitofish were found at 21 (8%) of the sites that we sampled during this study at elevations ranging from 1 to 158 m (Table 6). Because of their continued use in vector control, mosquitofish can be expected to occur in all temporary to permanent brackish and freshwater environments of the Estuary.

Ecology. Leidy (1984) found that although mosquitofish were most common in the channelized lower reaches of streams, it was locally abundant in headwater habitats near permanent stock ponds and drainage ditches. During this study mosquitofish were positively correlated with water temperature, low water clarity, percent open canopy, conductivity, and the total number of species (Table 15). Mosquitofish were negatively correlated with elevation, channel gradient, dominant substrate size, and the percentage of native species (Table 15). Mosquitofish are typically found in warm, turbid, low elevation and gradient streams, characterized by pools with silt-sand substrates, low riparian canopy cover, and high conductivities. Mosquitofish were often associated with rainwater killifish near the tidal zone of streams. Because it is widely introduced and tolerant of wide-ranging environmental conditions, mosquitofish are one of the few nonnative species that can be expected to occur in any fish assemblage. It was most commonly associated with other nonnative fishes in the mixed native-nonnative fishes/lowermost small to large mainstem assemblage, and only rarely was found within the rainbow trout/upper mainstem-headwater tributary assemblage.

Status and Recommendations. Mosquitofish will remain a widespread and common nonnative fish throughout the Estuary. Their use for mosquito control should be restricted to temporary waters where they are unlikely to encounter native fish or invertebrates, and where they clearly will be effective in mosquito control.

ATHERINOPSIDAE (SILVERSIDES)

Menidia beryllina (Cope, 1867), inland silverside

Historical Distribution and Status. Inland silversides are native to watersheds of the Atlantic and Gulf coasts, including the Mississippi River drainage and major tributaries, from Massachusetts south and west to the Rio Grande in Texas and New Mexico, as well as Mexico (Page and Burr, 1991). Inland silversides were first introduced into Clear Lake, Lake County, in 1967, from where they spread into the Sacramento River system by the early 1970s (Dill and Cordone, 1997). Moyle et
Means that silversides may be associated with a relatively high number of native and nonnative fish species in Estuary streams (Leidy, 1984). Within the lower reaches of Walnut and Coyote creeks, silversides occurred with a mixture of euryhaline and freshwater fishes of varying abundances, including hitch, Sacramento sucker, threespine stickleback, prickly sculpin, staghorn sculpin, chameleon goby, yellowfin goby, common carp, golden shiner, western mosquitofish, green sunfish, bluegill, pumpkinseed, largemouth bass, smallmouth bass, bigscale logperch, and striped bass. Within low elevation stream reaches above the tidal zone, I found silversides associated with native fishes such as hitch, California roach, Sacramento pikeminnow, Sacramento sucker, and prickly sculpin, as well as nonnatives such as carp, green sunfish, bluegill, and largemouth bass. Leidy (1984) found silversides to be abundant where found, comprising 34 percent of the individuals in collections in which it occurred. During this study, silversides were most abundant in the lower reaches of streams, while it typically occurred as only a few individuals when collected with mostly native fishes higher in a watershed.

**Status.** Inland silversides have rapidly spread throughout the Estuary since their introduction approximately thirty-five years ago. Because of their use by anglers as bait and their tolerance of low salinity waters, silversides can be expected to further expand their range into other Estuary watersheds.

**MORONIDAE (TEMPERATE BASSES)**

*Morone saxatilis* (Walbaum, 1792), striped bass

**Historical Distribution and Status.** Striped bass are native to Atlantic and Gulf Slope watersheds from the St. Lawrence River south to Florida and Louisiana (Page and Burr, 1991). Striped bass were first introduced into California in the Estuary when about 135 fish from New Jersey were released into Carquinez Strait near Martinez in 1879, and was abundant enough in the Estuary to support a large fishery by the 1890s (Dill and Cordone, 1997). The earliest historical record that I could find for its occurrence in an Estuary watershed is for the Napa River in 1927. There are records for the occurrence of striped bass from twelve Estuary watersheds (Appendix 3). It is locally common in the lowermost reaches of the largest watersheds near the tidal zone (e.g., Walnut, Alameda, Coyote, and Sonoma creeks, and the Guadalupe, Petaluma, and Napa rivers).
Historical Distribution and Status. Green sunfish is native to Hudson Bay, the Great Lakes, the Mississippi River, and Gulf Slope drainages from Florida to northern Mexico (Page and Burr, 1991). Green sunfish were first introduced into southern California in 1891, and it began to appear within the San Joaquin Valley beginning sometime around 1910 (Dill and Cordone, 1997). The earliest records that I found for the occurrence of green sunfish in Estuary watersheds is Suisun Creek downstream from Lake Cury (1940), Walnut-San Ramon Creek (1945), and San Francisquito Creek (1956) (Leidy, 1984). There are records for the occurrence of green sunfish from twenty-three Estuary watersheds (Appendix 3). During 1981, it was collected from 34 (7%) of the 457 sampling sites. Green sunfish was the most common nonnative fish encountered during this study, occurring in 23 (15%) of the samples (Table 6).

Ecology. Green sunfish is widespread and locally common in Estuary watersheds because of its tolerance of a wide range of environmental conditions found within streams, reservoirs, stock ponds, and drainage ditches. Leidy (1984) found green sunfish associated with warm, deep, moderately disturbed pools of low to intermediate elevation intermittent streams. During this study, the abundance of green sunfish was positively correlated with stream order, stream gradient, average depth, low water clarity, percent open canopy, conductivity, and the total number of species (Table 15). Green sunfish abundance was negatively correlated with elevation, dominant substrate size, and percent of native species. Juvenile striped bass were collected within lowermost reaches of streams indicating that these environments near the tidal zone may serve as nursery habitat (Leidy, 1984; this study). Adult striped bass were collected in freshwater portions of lower Walnut Creek (elevation 11 m) following moderate to large storm events, indicating that fish may migrate short distances upstream in response to flows.

Status. Striped bass in the Estuary may be as abundant today as historically (P. Moyle, UCD, personal communication, 2004). Striped bass will likely remain locally common within the lowermost estuarine reaches of large watersheds, where they will prey on native fishes such as Sacramento splittail. I recommend an unlimited take fishery be developed for striped bass, with no size limits.

**CENTRARCHIDAE (SUNFISH, BASS, CRAPPIES AND RELATIVES)**

*Lepomis cyanellus* Rafinesque, 1819, green sunfish

Historical Distribution and Status. Green sunfish
tation of California roach from several small streams in the Sierra Nevada foothills of central California. Efforts to discourage landowners from planting green sunfish in stock ponds could reduce green sunfish numbers in intermittent headwater streams, thereby benefiting native fishes such as California roach, as well as other sensitive aquatic organisms associated with these habitats (e.g., red-legged frog, *Rana aurora*, and foothill yellow-legged frog, *Rana boylii*).

**Lepomis gulosus** (Cuvier, 1829), warmouth

**Historical Distribution and Status.** Warmouth are native to the Mississippi River, Great Lakes, Atlantic and Gulf coast drainages, and parts of New Mexico (Page and Burr, 1991). Warmouth apparently became well established in the Delta region of the Estuary by the 1940s and is now present in streams of the Central Valley floor and several Sierra Nevada foothill reservoirs (Dill and Cordone, 1997; Moyle, 2002). Warmouth are known to occur in three reservoirs within the Estuary: Lake Chabot within the San Leandro Creek watershed; and Don Castro (Palomares Creek) and Cull Canyon (Cull Creek) reservoirs, within the San Lorenzo Creek watershed (EBRPD, 1997; P. Alexander, EBRPD, personal communication, 2002). We did not collect warmouth during this study.

**Ecology.** There is no information on the ecology of warmouth from the few Estuary reservoirs where it is found. Moyle (2002) provides a review of the ecology of warmouth in California.

**Lepomis gibbosus** (Linnaeus, 1758), pumpkinseed

**Historical Distribution and Status.** Pumpkinseed is known from only four Estuary watersheds. The earliest record for the Estuary is that of a single pumpkinseed collected in 1961 from Vasona Reservoir on Los Gatos Creek (Guadalupe River watershed), Santa Clara County (CDFG, lake and survey files, 9 June 1961, Yountville). Subsequently, juvenile and adult pumpkinseeds were collected from Vasona Reservoir in 1973 and 1976, and from the lower Guadalupe River in 1981 (Strohschein, 1973a; Curtis and Anderson, 1976; J. Smith, SJSU, personal communication, 1981). Pumpkinseed has also been recorded from Coyote and Anderson reservoirs in the Coyote Creek watershed (Scoppettone and Anderson, 1976; Walkup and Eimoto, 1980). Apparently, pumpkinseed spread from these reservoirs downstream where they have been recently recorded from lower Coyote Creek (HRG, 1994; SCVWD, 2001). Pumpkinseed also is known to occur in the San Francisquito Creek watershed in Searsville Lake, Lake Lagunita, and in scattered locations throughout the stream (Launer, 2005). In the northern Estuary, pumpkinseed has been collected from the Walnut Creek watershed in 1980 from lower San Ramon Creek (Leidy, 1983; Wang, 1986). The presence of pumpkinseed in lower Walnut Creek was reconfirmed during this study in 1993.

**Ecology.** Leidy (1983, 1984) and this study found pumpkinseed to be locally common within the warm, deep, turbid pools of lower Walnut-San Ramon Creek within the mixed native-nonnative fishes/lower small to large mainstem assemblage. In Walnut Creek pumpkinseed were most commonly associated with other nonnative fishes including several ictalurids and centrarchid species, inland silverside, and western mosquitofish. Native fishes most commonly collected with pumpkinseed in Walnut Creek include Sacramento sucker and threespine stickleback. Hybrids between pumpkinseed and redear sunfish, bluegill, and green sunfish were common in the Walnut-San Ramon Creek watershed.

**Lepomis macrochirus** Rafinesque, 1819, bluegill

**Historical Distribution and Status.** Bluegill sunfish are native to the St. Lawrence River, Great Lakes, Mississippi River, and Atlantic slopes drainage south, including Gulf Slope watersheds to Texas and New Mexico (Page and Burr, 1991). Bluegill was likely first introduced into California around 1908 (Dill and Cordone, 1997). I found early records for the occurrence of bluegill in Estuary watersheds for Suisun Creek downstream from Lake Curry (1940), San Pablo Creek (1943), and Alameda Creek (1953) (Leidy, 1984). There are records for the occurrence of bluegill from nineteen Estuary watersheds (Appendix 3). During 1981, bluegill was collected from only eight (2%) of the 457 sampling sites. Bluegill was found at 11 (4%) of the sites sampled during this study (Table 6). The low numbers of collections of bluegill in 1981 and during this study likely reflect its preference for reservoirs and
ponds, habitats I did not often sample. Bluegill can be expected in most permanent ponds and reservoirs throughout the Estuary.

**Ecology.** Leidy (1984) and this study found bluegill to be most abundant at intermediate elevations in the warm, deep, turbid pools of intermittent and perennial streams downstream from reservoirs or ponds. Bluegill was also locally common in the deep pool habitats within the mixed native-nonnative fishes/lowermost small to large mainstem assemblage, as exemplified within the Coyote Creek and Walnut Creek watersheds. Bluegill was most commonly associated with other nonnative fishes including several ictalurids and centrarchid species, and western mosquitofish. Hybrids between bluegill and other centrarchids such as redear sunfish, pumpkinseed, and green sunfish were common in the Walnut-San Ramon Creek watershed. Native fishes most commonly collected with bluegill include Sacramento sucker and threespine stickleback. On rare occasions individual bluegill would be found below permanent headwater stock ponds; their occurrence was there likely the result of farm pond spills and washouts.

*Lepomis microlophus* (Günther, 1859), redear sunfish

**Historical Distribution and Status.** Redear sunfish are native to Atlantic and Gulf Coast watersheds from South Carolina to Texas, and in the Mississippi River to southern Indiana and Illinois (Page and Burr, 1991). Redear sunfish likely were first introduced into California in the Colorado River sometime from 1948-1951 (Dill and Cordone, 1997). From the Colorado River, they were intentionally introduced to several Southern California reservoirs in 1954, and subsequently transferred to the CDFG’s Central Valley Hatchery from where they were planted into private ponds in the San Joaquin Valley beginning in 1955-56 (Dill and Cordone, 1997). They now occur in waters throughout the Central Valley. The earliest records that I found for redear sunfish for an Estuary watershed is 1962 when redear sunfish were planted by the CDFG into Anderson Reservoir on Coyote Creek (Anderson, 1976a). In April and May 1965, the CDFG planted redear sunfish again into Anderson Reservoir and in Page Percolation Ponds on Los Gatos Creek (Guadalupe River watershed), respectively (Johnson, 1965; Anderson, 1976a). The Page Percolation Ponds were subsequently drained and cleaned during July 1965; however, most of the redear sunfish were rescued and replanted upstream in the drainage into Lexington Reservoir (Johnson, 1965). Interestingly, the original fish planted in Page Percolation Ponds during May of 1965 had already successfully reproduced by July. By 1969 redear sunfish was recorded in Santa Teresa Park Pond that receives water from a canal from Anderson Reservoir (Hendricks, 1969). During the 1970s populations of redear sunfish were well established in several reservoirs in the southern Estuary including Lexington Reservoir within the Guadalupe River watershed, and Coyote Reservoir, upstream from Anderson Reservoir, and Cottonwood Lake, adjacent to lower Coyote Creek (Wood, 1970; Anderson, 1973; Strohschein, 1974; Scoppettone and Anderson, 1976; Paulsen, 1978). Leidy (1984) collected redear sunfish from four sites within Coyote Creek, the Guadalupe River, and Sanchez Creek. I found redear sunfish at only three (1%) sites during this study (Table 6). As with bluegill sunfish, the low numbers of sites with collections of redear sunfish in 1981 and during this study likely reflect its preference for reservoirs and ponds, habitats not typically sampled. Redear sunfish can be expected in many permanent ponds and reservoirs throughout the Estuary.

*Micropterus dolomieu* Lacepède, 1802, smallmouth bass

**Historical Distribution and Status.** Smallmouth bass are native to the St. Lawrence, Great Lakes, Hudson Bay, and Mississippi River watersheds (Page and Burr, 1991).
Smallmouth bass were first introduced into California into the Napa River and Alameda Creek in 1874 (Stone, 1875; Evermann and Clark, 1931; Dill and Cordone, 1997). The introduction consisted of seventy-three fish from Lake Champlain, Vermont, planted in Napa Creek (California Commissioners of Fisheries, 1876; Stone, 1875; Dill and Cordone, 1997). An additional twelve smallmouth bass from the St. Joseph River, Michigan, were also planted in the Napa River and Alameda Creek (California Commissioners of Fisheries, 1876; Stone, 1875; Dill and Cordone, 1997). A second shipment of smallmouth bass were introduced into Lake Temescal, (Temescal Creek watershed), Alameda County, in 1874 (Dill and Cordone, 1997). Apparently, several plants of smallmouth bass in California originated from fish planted in reservoirs of the Spring Valley Water Company in San Mateo County (Dill and Cordone, 1997). In 1879, twenty-two adult smallmouth bass were planted in Crystal Springs Reservoir (San Mateo Creek watershed) (California Commissioners of Fisheries, 1878, 1880; Dill and Cordone, 1997). Smallmouth bass were taken from Crystal Springs Reservoir in late-1870s and planted in the Russian River (Dill and Cordone, 1997).

Smallmouth bass have been recorded from five Estuary watersheds including San Lorenzo, Alameda, and Coyote creeks, and the Guadalupe and Napa rivers (Appendix 3). Leidy (1984) and this study confirmed the recent presence of smallmouth bass from Alameda Creek and the Napa River.

**Ecology.** Within the Napa River smallmouth bass was found within the long, shallow, sand-gravel pools of the mixed native-nonnative fishes/middle mainstem-lower large tributary assemblage. Smallmouth bass were associated in the Napa River with native fishes including hardhead, Sacramento pikeminnow, California roach, Sacramento sucker, threespine stickleback, tule perch and prickly sculpin. Within Alameda Creek smallmouth bass were associated with species of the mixed native-nonnative fishes/lower large mainstem assemblage that utilized large, warm, deep pools with dense aquatic vegetation. Associated species included Sacramento pikeminnow, hitch, Sacramento blackfish, Sacramento sucker, prickly sculpin, golden shiner, inland silverside, bluegill, green sunfish, and bigscale logperch.

**Status.** Smallmouth bass likely will remain a locally common in the larger Estuary watersheds because reservoirs are a permanent source of bass to streams. The effects of smallmouth bass on native fishes are unknown. There is some evidence that smallmouth bass have negative effects on hardhead in streams where they occur together (Brown and Moyle, 1993). Moyle (2002) observes that large adult smallmouth bass may reduce Sacramento pikeminnow through predation under reduced flow conditions.

**Micropterus salmoides** (Lacepède, 1802), largemouth bass

**Historical Distribution and Status.** Largemouth bass are native to the St. Lawrence-Great Lakes system, Hudson Bay, and the Atlantic Slope, Mississippi River, and Gulf Slope watersheds (Page and Burr, 1991). Two subspecies, the northern largemouth bass (*M. s. salmoides*) and Florida largemouth bass (*M. s. floridanus*) have been introduced into California (Dill and Cordone, 1997). Genetic differences between the two taxa suggest they are likely separate species (Moyle, 2002). Largemouth bass likely were first introduced into southern California and the Sacramento Valley in 1891 (Dill and Cordone, 1997). The first record for the occurrence of largemouth bass in an Estuary watershed is for Lake Merced (San Francisco), and Crystal Springs Reservoir (San Mateo Creek watershed) in 1895 (Dill and Cordone, 1997).

Largemouth bass have been recorded from seventeen Estuary watersheds (Table 6). Many first records for the occurrence of largemouth bass in Estuary streams are from the 1950s and 1960s. The spread of largemouth bass in Estuary watersheds is correlated with the completion of numerous large reservoirs during the 1940s to 1960s. Largemouth bass can be expected to occur in permanent ponds and reservoirs throughout the Estuary. Largemouth bass were collected from 22 (5%) of 457 sites that I sampled in 1981 (Leidy, 1984). I collected largemouth bass from seven (3%) sites during this study (Table 6). Almost all large reservoirs and permanent ponds of the Estuary support populations of largemouth bass.

**Ecology.** Leidy (1984) found that largemouth bass occurred primarily at low to intermediate elevations within deep, warm, turbid pools with silt-sand substrates. Examples include these habitats in the Estuary include the
lower reaches of Walnut, Alameda, Coyote, and Sonoma creeks, and the Guadalupe, Petaluma, and Napa rivers. During this study, I collected largemouth bass almost exclusively from mid-elevation sites (mean elevation =120 m). These sites had habitat similar to that supporting the mixed native-nonnative fishes/lower mainstem and assemblage and the mixed native fishes/middle mainstem-lower large tributary assemblage. These sites were typically either upstream or downstream of large reservoirs and were characterized by deep, warm pools with intermediate water clarity and the presence of aquatic macrophytes. Nonnative fishes found at these sites with largemouth bass include carp, black bullhead, inland silverside, western mosquitofish, green sunfish, and bluegill. Native fishes associated with largemouth bass at these sites include California roach, hitch, Sacramento pikeminnow, Sacramento sucker, and prickly sculpin. Observations during this study are consistent with Leidy (1984), who observed that largemouth bass was often found with a greater diversity of native fishes compared to nonnative species at any one site. Largemouth bass commonly occur in deep pools downstream and upstream from reservoirs.

**Status.** Largemouth bass likely will remain a widespread and locally common member of Estuary stream fish assemblages in part, because reservoirs provide a permanent source of bass to streams. Largemouth bass are likely major predators on juvenile native fishes, including anadromous salmonids (Moyle, 2002). Studies on the impacts of largemouth bass on native fishes are needed, as well as strategies to control their numbers in some situations (P. Moyle, UCD, personal communication, 2004).

**Micropterus coosae** Hubbs and Bailey, 1940, redeye bass

**Historical Distribution and Status.** Redeye bass are native to the headwaters of the Mobile Bay, Chattahoochee, and Savannah River basins of Alabama, Tennessee, Georgia, South Carolina, and North Carolina (Page and Burr, 1991). Redeye bass were planted in the Central Valley at several locations in the mid-1960s and apparently have become established in the Delta portion of the Estuary (Dill and Cordone, 1997; Moyle, 2002). Because they are easily confused with smallmouth bass, redeye bass may be more widespread in Central Valley streams than collection records indicate (Moyle, 2002). Redeye bass have been recorded from Del Valle Reservoir (Arroyo del Valle Creek) within the Alameda Creek watershed (EBRPD, 1997; P. Alexander, EBRPD, personal communication, 2002). We did not collect redeye bass during this study.

**Ecology.** Redeye bass have successfully invaded the foothill reaches of the Cosumnes River watershed where they have displaced native cyprinids and the Sacramento sucker (P. Moyle, UCD, personal communication, 2002). Moyle (2002) attributes the success of redeye bass in the Cosumnes River, and elsewhere, to their broad feeding and habitat requirements, small adult size, and aggressive behavior toward other fishes.

**Recommendations.** Presumably redeye bass became established in Del Valle Reservoir by water transfers from the California Aqueduct system. While there is little information on the population status of redeye bass in Del Valle Reservoir, there is always the possibility that it could spread from the reservoir into downstream reaches of Arroyo del Valle and other Alameda Creek tributaries. Redeye bass are well adapted to Central Valley foothill stream environments where they have been shown to displace native minnows and Sacramento sucker (Moyle, 2002). Because the Alameda Creek watershed contains stream environments similar to these Central Valley foothill streams, as well as diverse native minnow-sucker assemblages, the presence of redeye bass in the drainage is of significant conservation concern. Del Valle Reservoir and downstream reaches of Arroyo Del Valle should be regularly monitored to assess the status of redeye bass. Care should be given to the accurate identification of redeye bass as it is easily confused with the closely related smallmouth bass, which is also known to occur in the Alameda Creek watershed (Moyle, 2002).

**Ambloplites rupestris** (Rafinesque, 1817), rock bass

**Historical Distribution and Status.** Apparently the first attempted introduction of rock bass into California was by Livingston Stone who in 1874 planted four adults, originally from Vermont into Napa Creek (Stone, 1875). According to Evermann and Clark (1931, p. 67), “Nothing has been heard of them since.” Although several
subsequent attempts to introduce rock bass were made throughout California, the permanent establishment of reproducing populations has not been successful (Dill and Cordone, 1997).

**Pomoxis annularis** Rafinesque, 1818, white crappie

**Historical Distribution and Status.** White crappie is native to the Great Lakes, Hudson Bay and Mississippi River watersheds, and Gulf drainages from Alabama to Nueces River, Texas (Page and Burr, 1991). White crappie is less common in Estuary watersheds than black crappie. Apparently, the first plant of white crappie in Northern California was in 1951 when 3,780 fish were planted from CDFG's Central Valley Hatchery into Coyote Reservoir, Santa Clara County (CDFG, fish planting receipt 1951; see also Dill and Cordone, 1997). White crappie spread from Coyote Reservoir downstream into lower Coyote Creek where they were first recorded in 1964, and they subsequently have been collected there in 1966, and the 1980s and 1990s (see Table 7g in Buchan et al., 1999). White crappie has been recorded from Anderson Reservoir, which lies on Coyote Creek downstream from Coyote Reservoir (Wood, 1970; Scoppettone and Anderson, 1976).

Other Estuary watersheds with records of white crappie include the Guadalupe and Napa rivers, and San Lorenzo Creek (CDFG, river and stream files, Yountville; Leidy, 1984). Leidy (1984) collected white crappie from Sage Creek, Napa River watershed, just above Lake Hennessey. White crappie was not collected during this study.

**Ecology.** White crappie are primarily a reservoir species, and self-sustaining stream populations probably only exist in the Estuary in lower Coyote Creek. Records for white crappie in streams typically are from fish that have washed downstream from reservoirs or juveniles trapped in pools that remain in former tributary streams as reservoir waters recede during summer. There is some evidence that white crappie populations are reduced or replaced by black crappie in reservoirs that contain both species. For example, while white crappie occurred in surveys of Anderson Reservoir in the early 1970s, they seemed to have disappeared from surveys in the late-1970s and early 1980s, while black crappie increased in abundance (CDFG, lake and reservoir files, Yountville).

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**Pomoxis nigromaculatus** (Lesueur, 1829), black crappie

**Historical Distribution and Status.** Black crappie are thought to be native to the Atlantic and Gulf slopes to Texas, the St. Lawrence-Great Lakes-Mississippi River watersheds, from Manitoba and Quebec south to the Gulf of Mexico (Page and Burr, 1991). Apparently the first planting of black crappie in California's Central Valley was sometime from 1916-1919. They subsequently became abundant, especially in reservoirs (Dill and Cordone, 1997; Moyle, 2002).

Although apparently more common in the Estuary than white crappie, black crappie only occur occasionally in fish collections from streams and are rarely abundant. Black crappie however, is locally common in the Estuary in reservoirs and small permanent ponds into which it has been introduced for sport fishing. The first record found for its occurrence in an Estuary watershed was in 1940 downstream from Lake Curry on Suisun Creek, Solano County (UMMZ 131515). Black crappie is found in several reservoirs within the Alameda, San Leandro, San Lorenzo, Coyote and San Francisquito creeks, and Guadalupe River watersheds of the southern Estuary, including Cull Canyon, Don Castro, Chabot, Shadow Cliffs, Coyote, Anderson, Lexington, and Vasona reservoirs (Scoppettone, 1976; Curtis and Anderson, 1976; Scoppettone and Anderson, 1976; Walkup and Eimoto, 1980; Pit and Bozeman, 1982; EBRPD, 1997; Launer, 2005). It has established stream populations downstream from several of these reservoirs (Scoppettone and Smith, 1978; Leidy, 1984; HRG, 1994; SCVWD, 1995; EBRPD, 1997; SCVWD, 2001).

I located records for the occurrence of black crappie from fourteen Estuary watersheds (Appendix 3). Leidy (1984) collected black crappie from three geographically widespread watersheds, including Alameda Creek, and the Guadalupe and Napa rivers. Black crappie was not collected during this study.

**Ecology.** Black crappie is primarily a reservoir and large pond species in the Estuary. They are typically found in large, warm, deep pools downstream from reservoirs from which they have escaped. Juvenile black crappie also may be found immediately upstream from reservoirs
in isolated pools within a stream that become exposed as reservoir water levels recede during summer and fall (Leidy, 1984). Black crappie is typically associated in pools with other introduced centrarchids such as smallmouth and largemouth bass, bluegill, green sunfish and black bullhead (Leidy, 1984).

**PERCIDAE (PERCHES)**

*Esox masquinongy* Mitchell, 1824, muskellunge

**Historical Distribution and Status.** Muskellunge were first introduced into California in May 1893, when 93,000 fry from New York were planted into Lake Merced near San Francisco, apparently in an effort to control common carp (Smith, 1896, as cited in Dill and Cordone, 1997). The planting of muskellunge into California did not result in the establishment of reproducing populations (Dill and Cordone, 1997).

*Percina macrolepida* Stevenson, 1971, bigscale logperch

**Historical Distribution and Status.** Bigscale logperch are abundant in the Delta and they are occasionally collected in Suisun Marsh (P. Moyle, UCD, personal communication, 2004). Bigscale logperch are known from three Estuary watersheds, including Alameda and Coyote creeks, and the Petaluma River (Caywood, 1974; Moyle et al., 1974; Leidy, 1984; SCVWD, 2001). They were first introduced into Del Valle Reservoir in the Alameda Creek watershed in the 1970s, as a result of water transfers from the Central Valley via the Tracy pumping plant and South Bay Aqueduct (CDWR, 1974; Moyle et al., 1974). In 1981, Leidy (1984) collected bigscale logperch from Arroyo Mochi Creek, near a location where water is released into the creek in summer from the South Bay Aqueduct. Logperch presumably is “reintroduced” on a regular basis into Alameda Creek system via water transfers. I collected logperch in the lower Alameda Creek flood channel in 1993, indicating that it has spread throughout the lower Alameda Creek watershed.

**Ecology.** In California, logperch occur in a relatively wide range of habitats including reservoirs, brackish sloughs, and warm, moderate-to-large-sized streams with substrates composed of silt-sand, gravel, and rubble (Marchetti, 1998; Moyle, 2002). Logperch are often associated with emergent vegetation along the edge of streams and sloughs (Moyle, 2002). Interestingly, in 1981, I collected logperch in the Livermore Valley reach of the Alameda Creek watershed with exclusively native fishes, including Sacramento sucker, California roach, and hitch. Following its spread downstream into the lower watershed, I collected logperch with both native and nonnative fishes including hitch, Sacramento blackfish, Sacramento sucker, Sacramento pikeminnow, prickly sculpin, golden shiner, inland silverside, bluegill, green sunfish, and smallmouth bass. In the lowermost tidal reaches of the Petaluma River and Coyote Creek logperch are associated with nonnative fishes such as inland silverside, rainwater killifish, striped bass, and staghorn sculpin. In Suisun Marsh, logperch have been found in salinities of up to 4.2 ppt (Moyle, 2002). The apparent tolerance of logperch for slightly brackish salinities may allow it to spread into the lower reaches of other Estuary streams, especially those bordering Suisun and San Pablo bays.

*Perca flavescens* (Mitchill, 1814), yellow perch

**Historical Distribution and Status.** In 1984, a reproducing population of yellow perch was discovered by CDFG and EBMUD biologists in Lafayette Reservoir within the Walnut Creek watershed (Dill and Cordone, 1997; Moyle, 2002). Subsequent sampling of Lafayette Creek below the reservoir and Walnut Creek in the 1980s and 1990s by CDFG, and during this study from 1992-1997, has not recorded any yellow perch. Lafayette Reservoir does not have an outlet into Lafayette Creek so yellow perch cannot escape into the watershed through reservoir discharges. However, the possibility of intentional introduction of yellow perch into the watershed by reservoir anglers remains a possibility.

**Ecology.** Moyle (2002) contains a review the ecology of yellow perch in California.

**Conservation Status and Recommendations.** The status of yellow perch populations in Lafayette Reservoir should be regularly monitored. Stream reaches down-
stream from Lafayette Reservoir should be sampled annually in order to provide early detection of yellow perch should they escape into the watershed. Because Lafayette Reservoir is a relatively small body of water, serious consideration should be given to the complete eradication of yellow perch within the reservoir.

**CICHLIDAE (CICHLIDS)**

*Cichlasoma octofasciatum* (Regan, 1903), Jack Dempsey

Historical Distribution and Status. The Jack Dempsey is native to Central America on the Atlantic slope from southern Mexico to Honduras (Conkel, 1993). In 1986, three specimens were collected by CDFG in Lafayette Creek in the Walnut Creek watershed (letter from C. Swift, Associate Curator, Ichthyology, Natural History Museum, Los Angeles, to F. Hoover, CDFG, dated 17 September 1987; LACM 44336-1, 70-122 mm SL). Subsequent sampling in Lafayette Creek by CDFG and during this study failed to collect any additional Jack Dempsey. It is likely that an aquarium enthusiast released the three specimens of Jack Dempsey collected in 1986.

Recommendations. Jack Dempsey is a tropical fish that are unlikely to survive low winter temperatures characteristic of Estuary waters. Lafayette Creek should be sampled regularly as part of monitoring for yellow perch (refer to recommendations for yellow perch, above) in order to provide early detection should Jack Dempsey reappear in the stream.

**GOBIIDAE (GOBIES)**

*Acanthogobius flavimanus* (Temminck and Schlegel, 1845), yellowfin goby

Historical Distribution and Status. Yellowfin goby is native to the estuaries and near coastal waters of China, Korea and Japan (Moyle, 2002). They were first introduced into California in the lower San Joaquin River near Stockton in 1963, and by 1966 had spread throughout the Estuary (Brittan et al., 1963, 1970). There are records for the occurrence of yellowfin goby from eleven Estuary watersheds, although it probably occurs in the tidal estuarine portions of most watersheds (Table 6). Yellowfin goby are regularly collected during fish surveys in the tidal reaches of the Napa River (IEP, 2005). Leidy (1984) collected yellowfin goby from seven (2%) sites in 1981. Yellowfin goby were found at only eight (5%) sites during this study, largely because tidal sites were generally not sampled (Table 6).

Ecology. Yellowfin goby is an estuarine species that lives in the silt and mud substrates of shallow subtidal and intertidal habitats near the mouths of streams. Yellowfin goby can tolerate abrupt changes in water salinity and therefore, may be found in the salt, brackish, or freshwater reaches of streams (Moyle, 2002). The abundance of yellowfin goby was positively correlated with stream order, average and maximum depth, wetted channel width, water temperature, low water clarity, percentage open canopy, and conductivity (Table 15). Yellowfin goby was negatively correlated with elevation, dominant substrate size, and percent native species. Leidy (1984) and this study found yellowfin goby associated primarily with other estuarine fishes including inland silverside, striped bass, rainwater killifish, threespine stickleback, Pacific staghorn sculpin, longjaw mudsucker, chameleon goby, and starry flounder. Within the freshwater reaches of stream yellowfin goby also occasionally occurred with prickly sculpin and Sacramento sucker. In the tidal riverine wetlands of the Napa River yellowfin goby also was collected with tule perch.

*Tridentiger trigonocephalus* (Gill, 1859), chameleon goby

Historical Distribution and Status. Chameleon goby was first introduced into the Estuary presumably in the early-to-mid-1960s, presumably from ship ballast (Brittan et al., 1963; Ruth, 1964). It is now geographically widespread and abundant in tidal waters of the Estuary (Baxter et al., 1999). It has been collected in tidal waters of Coyote Creek and the Guadalupe River in the southern Estuary, and the Petaluma and Napa rivers that flow into San Pablo Bay (Stevenson et al., 1987; Levy, 1993; Hieb, 2003; IEP, 2005). In 1994, I collected chameleon gobies at two sites in sloughs of the Napa River Marsh.
Ecology. Chameleon goby is primarily a polyhaline to euhaline species, and therefore does not typically occur in low salinity reaches of streams. In the Napa River, I collected chameleon goby at salinities of 38-42 ppt. A review of the ecology of chameleon goby in the Estuary can be found in Baxter et al. (1999).

**Tridentiger bifasciatus** Steindacher, 1881, shimofuri goby

Historical Distribution and Status. Shimofuri goby is a euryhaline species native to estuaries bordering the Sea of Japan and the northwest Pacific Ocean in Japan and China (Pietsch et al., 2000). Several sources cite the first confirmed record of shimofuri goby in California from Suisun Marsh in 1985 (Matern and Fleming, 1995; Moyle, 2002). However, Baxter et al. (1999) contains a record for the collection by CDFG of shimofuri goby from the Estuary in 1984, followed by its regular collection during the years 1986-1995. Because collections of shimofuri goby were likely confused with the nonnative chameleon goby, shimofuri goby probably was introduced into the Estuary sometime prior to 1984, but the exact date is not known. Beginning in 1996, shimofuri goby has been collected from brackish marshes of the Napa and Petaluma rivers adjacent to San Pablo Bay where it now appears to be common (Feyrer, 2003; Hieb, 2003; IEP, 2005; USACE, 2006). In 1997, I collected several shimofuri gobies from a single site within a tidal reach of lower Grayson Creek upstream from its confluence with Walnut Creek. I was unable to locate collection records for other Estuary streams, but shimofuri goby can be expected to occur in the brackish waters of other Estuary watersheds bordering San Pablo and Suisun bays.

Ecology. Following its likely introduction in the early 1980s, Shimofuri goby has rapidly spread throughout shallow (<2 m) tidal marsh and slough habitats throughout the northern Estuary (Matern, 2001; Moyle, 2002). In the Napa and Petaluma rivers, shimofuri goby was collected in species rich assemblages of native and nonnative fishes, including Sacramento splittail, Pacific staghorn sculpin, prickly sculpin, threespine stickleback, longjaw mudsucker, Pacific herring, striped bass, western mosquitofish, inland silverside, American shad, threadfin shad, and yellowfin goby (Feyrer, 2003; Hieb, 2003). In Grayson Creek, shimofuri goby was associated with common carp, western mosquitofish, pumpkinseed, striped bass, yellowfin goby, Sacramento sucker, and prickly sculpin.

Status. Because of its tolerance for brackish salinities (<17 ppt), high water temperatures (up to 37ºC), aggressive behavior toward other fishes, high fecundity, and apparent exploitation of underutilized food sources, shimofuri goby can be expected to spread into the lower reaches of other streams in central and southern Estuary (Matern, 2001; Moyle, 2002). The potential for shimofuri goby to adversely affect other native fishes that occur in brackish environments in the Estuary is unknown.
PART VI

Discussion

above
Los Heucus Ranch, Santa Clara County. Many large ranches in the Diablo Range still support intact native fish assemblages and these landscapes will be critical components of effective conservation strategies for fishes and other aquatic organisms.

Photo: Tim Vendlinski.
Distributional And Ecological Patterns

The majority of native fishes are geographically widespread, and a moderate to high number of individuals characterizes each population. A relatively smaller number of native species are characterized by low population abundances. Several native species have no or little existing information on their abundances. Of the 33 species of native fishes recorded historically from Estuary streams, at least 24 species (71%) still have reproducing populations (Table 6). Thirteen species (38%) may be considered geographically widespread with generally moderate-to-high population abundances, including five primarily estuarine species (white sturgeon, staghorn sculpin, shiner perch, longjaw mudsucker, and starry flounder), three species supporting both estuarine and stream populations (threespine stickleback, prickly sculpin, and tule perch), one species with resident and anadromous populations (rainbow trout/steelhead), and four species with exclusively non-estuarine or resident stream populations (California roach, Sacramento pikeminnow, Sacramento sucker, and riffle sculpin). Although tule perch are widespread among Estuary watersheds, their abundance varies with geographic region. In the southern Estuary, tule perch populations appear to be relatively small and isolated in a few watersheds (i.e., Coyote Creek, Guadalupe River, and possibly Alameda Creek). In contrast, tule perch are abundant locally in estuarine and riverine environments of several watersheds in the northern Estuary (i.e., Napa River, Sonoma Creek, Petaluma River, and lower Green Valley Creek). Riffle sculpin also are geographically widespread, but their occurrence is limited to only 12 watersheds throughout the Estuary (18% of the total number of watersheds).

Although geographically widespread within the Estuary, the relative abundance of rainbow trout within individual watersheds varies from low to high (Leidy et al., 2005b). Rainbow trout/steelhead abundances vary depending on total Estuary outflow and local streamflow conditions and thus, great variability often exists among years and between age classes in the abundance of fish within any given watershed. In addition, the status of presumed anadromous and resident rainbow trout may differ within a watershed. For example, within the Alameda and Coyote Creek watersheds, resident rainbow trout may be locally abundant in the headwaters, while anadromous populations below dams in the lower watershed are threatened with extinction. The current population structure of steelhead in all Estuary watersheds is poorly understood. For example, there are no reliable estimates for the number of adult steelhead for any watershed. Steelhead smolts also migrate downstream through estuarine environments, but the extent of estuarine rearing in the study area is also poorly understood. Recent analysis predicted that fifteen Estuary watersheds currently support viable (i.e., functionally independent) or potentially viable steelhead populations (Bjorkstedt et al., 2005).

Hitch, Sacramento blackfish, Sacramento splittail, longfin smelt, and Delta smelt exhibit a relatively narrow geographic distribution within Estuary streams, but where found, often are locally abundant (Table 6). Longfin smelt, Sacramento splittail and Delta smelt abundances are positively correlated with total Estuary outflow, and therefore their population abundances fluctuate widely and may be low in dry years (Moyle, 2002). Suitable habitat for longfin smelt, splittail, and Delta smelt is limited in all but the largest Estuary watersheds. Hitch currently is restricted to less than fifteen watersheds, although they may be locally abundant. Hitch historically have been abundant in lower Coyote Creek downstream from Anderson Reservoir, but the recent spread of red shiner in the lower watershed may adversely impact hitch and other native cyprinids. In contrast, although Sacramento blackfish were found in only nine (13%) watersheds, their populations appear to be secure largely because of their tolerance of the poor water quality characteristics in the lower reaches of larger urbanized streams.

Species with narrow geographic ranges and generally low population abundances in Estuary streams include green sturgeon, Sacramento splittail, hardhead, Sacramento perch, and Delta smelt (Table 6). Concern over declining populations of green sturgeon led to a 2001 petition for its listing as threatened or endangered under the Federal Endangered Species Act (ESA) (Environmental Protection Information Center et al., 2001). Consequently, on April 6, 2005, the NMFS proposed listing green sturgeon populations south of the Eel River, including the Estuary and Sacramento-San Joaquin River as threatened under the ESA (70 Federal Register 17386). In Estuary streams, green...
sturgeon presumably occurs only occasionally in the tidal portions of the Napa, and possibly, Petaluma rivers. Sacramento splittail are restricted primarily to the estuarine environments of larger streams in the northern Estuary, including the Napa and Petaluma rivers and lower Walnut Creek. Sacramento splittail have been collected in lower Coyote Creek as recently as 1997, but they likely only rarely occur there as transitory individuals during years of high total Estuary outflow. Hardhead are found only in Alameda Creek and the Napa River where they are restricted to the middle mainstem reaches. In the Napa River, hardhead occur in only about 5-8 km of the middle reaches of the watershed. The status of hardhead in the Alameda Creek watershed is poorly understood, but apparently hardhead persist in low abundance within and immediately downstream of Niles Canyon. Because of their restricted distributions and relatively low population abundances, hardhead presumably are susceptible to extirpation. Native populations of Sacramento perch may persist only in small numbers in the Alameda Creek watershed. Apparent recent population declines in the lower watershed and Calaveras Reservoir suggest their status at these locations is precarious at best.

Chinook salmon, longfin smelt, rainbow trout/steelhead, and in the southern Estuary, tule perch, are generally widespread but may exhibit low population abundances in some watersheds (Table 6). Historically, Chinook salmon may have occurred only in a few of the larger Estuary watersheds (e.g., Guadalupe River, San Leandro Creek, Napa River), but their status has been poorly documented (Appendix 3). Beginning about the mid-1980s, however, spawning runs of Chinook salmon were observed in increasing numbers within several geographically widespread Estuary watersheds. Evidence exists for the recent occurrence of Chinook salmon from at least twelve Estuary watersheds (Appendix 3). Population abundances in these twelve watersheds appear low because of the relatively small size of the run (i.e., likely ranging between a few to five hundred adult fish), and variable spawning success (i.e., egg hatching and juvenile survival). The increased abundance of Chinook salmon in Estuary watersheds is correlated with the release of fish of hatchery origin in the lower Estuary. Recent genetic analyses for some Estuary watersheds indicate that Chinook salmon are of hatchery origin.

The status of several other native species is either poorly understood or entirely unknown. For example, little information is available on the population status of Pacific river, and western brook lampreys. Pacific lamprey is geographically widespread in the Estuary, occurring in at least twelve watersheds; however, the status of these populations is not known. Even less information is available on the distribution and status of river and western brook lamprey in the Estuary. While river lamprey have been collected regularly in low numbers since 1985 by the CDFG during sampling of the open waters of the Estuary (Baxter et al., 1999), the status of their populations in tributary streams is not known. Western brook lamprey is known only from samples taken in Coyote Creek during the 1920s, and its current status in Coyote Creek is unknown.

In addition to lampreys, the status of two other species is unknown. Speckled dace historically occurred in Coyote and Alameda creeks. Speckled dace likely was extirpated from Coyote Creek following the 1976 drought (Smith, 1999). In Alameda Creek, speckled dace may persist in remote and inaccessible headwater reaches that have not been thoroughly sampled.

The status of coastrange sculpin is unknown and records for its occurrence may be based on misidentification. Possible historical records exist for its occurrence in the Napa and Petaluma rivers, but it has not been recorded there in 55 and 20 years, respectively. Adult chum and pink salmon have recently been recorded from the lower Guadalupe and Napa (chum salmon only) rivers, but their current status is unknown.

Three fish species are extinct in Estuary watersheds. The thicktail chub historically occurred in at least six watersheds. The last record for its occurrence is Coyote Creek in 1898 (Appendix 2). Coho salmon may have occurred in as many as fifteen (23%) Estuary watersheds; however, the last records for their occurrence are from the Corte Madera and Arroyo Corte Madera del Presidio creeks watersheds in the early-to-mid 1980s (Appendices 2 and 3; Leidy et al., 2005a). Tidewater goby historically were known from several northern and central Estuary locations, but they were last collected from Corte Madera and Novato creeks, Marin County, in the late 1950s. Presumably this goby disappeared from several other tidal lagoons in the Estuary.
during the 1960s. Attempts to collect tidewater goby from several historical locations during the 1990s were unsuccessful (R. Swenson, TNC, personal communication, 1999).

Estuary streams contain identifiable fish assemblages (i.e., fish zones or communities) that are related to environmental gradients. Estuary stream fish occur as broadly overlapping species assemblages or longitudinal zones in response to gradients in environmental conditions. Distinct species assemblages are most evident at the extremes of the environmental gradient (i.e., upper mainstem and tributary sites compared to lower large mainstem sites).

Results from this study are largely consistent with the findings and conclusions of other studies of fish assemblages and environmental gradients within the Sacramento-San Joaquin Fish Province (Murphy, 1948; Hopkirk, 1973; Moyle and Nichols, 1973, 1974; Saiki, 1984; Smith, 1982; Moyle et al., 1982; Brown and Moyle, 1993; Brown, 2000; Marchetti and Moyle, 2001; May and Brown, 2002; Moyle, 2002). These earlier studies identified between three and five overlapping fish zones or assemblages, each characterized by distinct species associations and environmental conditions.

As a geographic transition zone between North Coast and Central Valley Province watersheds, Estuary stream assemblages share characteristics of both regions. Individual Estuary streams typically contain three to five of the following assemblages defined by the dominant fish within the assemblage, and/or the general hydrogeomorphic unit supporting the assemblage.

Rainbow trout/upper mainstem-headwater tributary assemblage (Figure VI.1). Within the Sacramento-San Joaquin Fish Province, the rainbow trout assemblage has been described for the Central Valley (Murphy, 1948; Moyle and Nichols, 1974; Brown and Moyle, 1993; Brown, 2000; Marchetti and Moyle, 2001; May and Brown, 2002; Moyle, 2002), Clear Lake (Hopkirk, 1973), Pajaro/Monterey Bay (Smith, 1982), Pit River (Moyle and Daniels, 1982; Moyle, 2002), McCloud River (Moyle and Daniels, 1982), and Upper Kern (Moyle, 2002) subprovinces. In the Estuary, the rainbow trout assemblage typically occurs in medium to high gradient streams with cool water temperatures, high water clarity, and relatively low conductivity. Streams often are narrow with shallow pools and short riffles, and high riparian canopy coverage. Combinations of gravel, cobble, boulders, and bedrock characterize the substrate. Within the Mt. St. Helena Flows and Valleys, Marin Hills and Valleys, Santa Cruz Mountains ecological subsections, the rainbow trout assemblage often occurs within riparian communities characterized by coast redwood, Douglas fir, western creek dogwood, California bay, and tanbark oak (Table 2). Within the drier East Bay Hills-Mount Diablo, Western Diablo Range, Diablo Range, and Ultrabasic Complex ecological subsections, riparian communities typically are dominated by several species of willow, oak, California bay, and coulter and grey pine.

Dominant native fishes within this assemblage are rainbow trout, which may occur alone, or with raffle or prickly sculpin. Within the upper tributaries of several watersheds (including Alameda, Coyote, and Corte Madera creeks, among others), California roach, juvenile Sacramento sucker, and occasionally threespine stickleback also are present in this assemblage, especially in the downstream areas of the rainbow trout zone. Historically, speckled dace also would have occurred within the rainbow trout assemblage in the upper Alameda Creek watershed.

Downstream from migration barriers this assemblage resembles the anadromous fishes assemblage typical of many coastal northern California streams described by Moyle (2002), and is characterized by anadromous rainbow trout (steelhead), coho salmon (historically), and Pacific lamprey. Estuary streams such as Arroyo Corte Madera del Presidio and Corte Madera creeks, Marin County, San Mateo Creek, San Mateo County; and, San Leandro Creek, Alameda County, also historically supported coho salmon that used medium-sized, cool tributary, or upper mainstem sites, for spawning and rearing.

Mixed native fishes/middle mainstem-lower large tributary assemblage (Figure VI.2a-d). This assemblage was confined to warm, low to mid-gradient mainstem and lower large tributary reaches above 50 m elevation. Streamflow ranged from intermittent to perennial, with medium to large, long, deep pools, between shallow, wide riffles. Substrate composition varies considerably, ranging from sand-dominated pools to gravel-cobble-boulder riffles and runs. Water clarity typically is high and riparian canopy coverage low. Conductivities are moderate to high.

PART VI DISCUSSION
VI.1
Rainbow trout/upper mainstem-headwater tributary assemblage, upper Coyote Creek watershed, Santa Clara County.

VI.2a-d
a. Mixed native fishes/middle mainstem-lower large tributary assemblage, Arroyo Hondo Creek, Alameda County.
b. Mixed native fishes/middle mainstem-lower large tributary assemblage, Upper Coyote Creek, near Gilroy Hot Springs, Santa Clara County.
c. Mixed native fishes/middle mainstem-lower large tributary assemblage, Sonoma Creek, Sonoma County.
d. Mixed native fishes/middle mainstem-lower large tributary assemblage, Napa River, Napa County.
In the larger (> 400 km²) Estuary watersheds (e.g., Napa River, Sonoma Creek, Alameda Creek, Coyote Creek, Guadalupe River, Walnut Creek), there are typically 8-10 species present. In the Napa River and Sonoma Creek watersheds, species include Pacific lamprey, Sacramento sucker, Sacramento pikeminnow, hardhead (Napa River and possibly Alameda Creek, only), California roach, tule perch, prickly sculpin, raffle sculpin, and threespine stickleback. In Alameda and Coyote creeks, this assemblage also contains hitch. Historically, Sacramento perch would have occurred within this assemblage, but it has been effectively extirpated from these watersheds. Within smaller Estuary watersheds (< 400 km²), several native species may be absent from this assemblage or in very low abundances, including Sacramento pikeminnow, hitch, and tule perch.

**Mixed native-nonnative fishes/lower small to large mainstem assemblage** (Figure VI.3a-b). This assemblage is characteristic of the lowermost mainstem reaches of many streams within the largest watersheds ranging from the tidal zone upstream to about 20 m elevation within the largest watersheds. Many of these stream reaches flow through highly urbanized environments, and are channelized for flood control or bank stabilization. Stream gradient is low, and the channel often is wide and composed almost entirely of large, deep, pools with silt and sand substrates. Summer water temperature and conductivity are high, and water clarity, riparian canopy coverage, and cover are low.

Nonnative fishes typically characterize this assemblage, although native fishes often are present in lower abundances (i.e., semi-random pattern of dominance and occurrence). Dominant nonnative fishes include common carp, goldfish, golden shiner, red shiner, brown bullhead, channel catfish, green sunfish, bluegill, pumpkinseed, redear sunfish, largemouth bass, smallmouth bass, inland silverside, western mosquitofish, and bigscale logperch. Rainwater killifish, striped bass, and yellowfin goby often occur within this assemblage nearest the tidal zone. Native fishes occurring as common members of the assemblage include Sacramento sucker, Sacramento blackfish, threespine stickleback, and prickly sculpin and, near the tidal zone, staghorn sculpin.

**Estuarine fishes/tidal riverine assemblage**. (Figure VI.4). The estuarine fishes assemblage described by Moyle (2002) focuses largely on the Delta, Suisun Bay, and northern California coastal Pacific streams, not on estuarine fish assemblages of streams tributary to San Francisco Bay. Stream fishes utilizing estuarine environments must be able to tolerate seasonal, daily, and hourly changes in salinities attributable to tidal cycles, total river discharge, and local stream discharge. The estuarine assemblage is most evident within the tidal portions of the larger Estuary watersheds including the Petaluma River, Napa River, Sonoma Creek, Walnut Creek, Alameda Creek, Coyote Creek, and the Guadalupe River, although all tributaries regardless of watershed size have estuarine conditions near their mouths.

Native fishes characteristic of the tidal riverine assemblage within large watersheds include white sturgeon, green sturgeon, Sacramento splitfin, Delta smelt, longfin smelt, threespine stickleback, prickly sculpin, Pacific staghorn sculpin, tule perch (northern Estuary region), shiner perch, longjaw mudsucker, and starry flounder (Table 4; Appendices 2 and 3; Hopkirk, 1962; Caywood, 1974; Madrone Associates, 1977; CDFG, 1979; Moyle et al., 1985; Stauffer Chemical Company, 1986; Wang, 1986; Stevenson et al., 1987; Herbold et al., 1992; USFWS, 1993a; Sommer et al., 1997; SCVWD, 2001; Baxter et al., 1999; Goals Project, 2000; Feyrer, 2003; Hieb, 2003; USACE, 2006). Sacramento perch likely occurred historically within the low-salinity portions of the lower Napa River marshes.
Tidewater goby also was present historically within estuarine environments of the smaller watersheds of Corte Madera and Novato creeks, Marin County. Nonnative fishes characteristic of tidal riverine habitats within the larger watersheds include black bullhead, brown bullhead, white catfish, channel catfish, wakasagi, rainwater killifish, western mosquitofish, inland silverside, striped bass, yellowfin goby, shumofuri goby, and chameleon goby (Table 5; see also references above).

Two other possible Estuary fish assemblages not clearly established by the TWINSPLAN and CCA analyses also occur in Estuary streams. These assemblages have been described for other subprovinces within the Sacramento-San Joaquin Province (Moyle, 2002).

**Reservoir-affected assemblage/lacustrine assemblage** (Figure II.13). Natural lakes within the Estuary historically were fishless, except for floodplain lakes adjacent to larger streams such as Willow Marsh, within the Alameda Creek watershed, and Laguna Seca, within the Coyote Creek watershed. Approximately 43 major reservoirs that support assemblages of mostly nonnative fishes are known in watersheds of the San Francisco Estuary. This assemblage is associated with artificial reservoirs and large ponds, including the reservoir pool and stream reaches immediately upstream and downstream from the impoundment within the reservoir fluctuation zone (Smith, 1982; Moyle, 2002). Reservoir assemblages may lay within other Estuary fish assemblages in the upper-to-middle elevation reaches of watersheds where most reservoirs are sited. For example, Calaveras and San Antonio reservoirs, Alameda Creek watershed, and Anderson and Coyote reservoirs, Santa Clara County, were constructed at sites historically characterized by the mixed native fishes/middle mainstem-lower large tributary assemblage. Other Estuary reservoirs, such as Upper and Lower Crystal Springs reservoirs, San Mateo Creek watershed, were built within areas characterized by the rainbow trout/upper mainstem-headwater tributary assemblage. The mixed native fishes/middle mainstem-lower large tributary and rainbow trout/upper mainstem-headwater tributary assemblages still occur in reaches above and below the reservoirs.

Reservoir assemblages may consist of resident reproducing (i.e., periodically stocked, game and forage fishes), as well as several native fishes tolerant of lacustrine environments. Native fishes able to maintain reproducing populations in reservoirs and their tributary streams include Pacific lamprey, Sacramento blackfish, Sacramento pikeminnow, Sacramento sucker, rainbow trout, prickly sculpin, Sacramento perch, and tule perch.

Common nonnative fishes dominating reservoir assemblages include threadfin shad, common carp, goldfish, golden shiner, black bullhead, brown bullhead, white catfish, channel catfish, inland silverside, green sunfish, bluegill, redear sunfish, largemouth bass, white crappie, and black crappie. Stream reaches immediately above and below reservoirs may contain nonnative reservoir species not typically found in similar stream environments in the absence of reservoirs. For example, Arroyo Hondo Creek upstream from Calaveras Reservoir supports a rainbow trout/upper mainstem-headwater tributary assemblage containing rainbow trout, California roach, prickly sculpin, and Sacramento sucker. Individual adult black bullhead and largemouth bass are scattered within the deeper pools of Arroyo Hondo Creek immediately upstream from Calaveras Reservoir from which they immigrated.

Releases of water into streams below reservoirs often result in the downstream spread of nonnative fishes. The extensive spread of nonnative species into downstream reaches following their initial introduction in reservoirs is evident for several Estuary watersheds (e.g., Alameda Creek, Coyote Creek, and Guadalupe River). Smith (1982, p. 132) aptly termed this assemblage below reservoirs in the Pajaro River watershed, the “reservoir-escape, introduced fishes association.”

**California roach/small, warm, intermittent tributary assemblage** (Figure VI.5). This assemblage is characteristic of small intermittent streams with low overhead riparian cover, high summer water temperature (> 28° C), and low dissolved oxygen, and is dominated by California roach (Moyle, 2002; this study). California roach often occur in great abundance in small isolated pools. This assemblage is typically found downstream from the rainbow trout/upper mainstem-headwater tributary assemblage, or it replaces the rainbow trout assemblage in more arid watersheds of interior regions of the Estuary (e.g., Diablo Range). Fishes regularly found with California roach in-
PART VI  DISCUSSION

VI.3

a. Mixed native-nonnative fishes/lower small to large mainstem assemblage, lower Walnut Creek, Contra Costa County.

VI.4

Estuarine fishes/tidal riverine assemblage, lower Napa River, Napa County.

VI.5

California roach/small, warm intermittent tributary assemblage, upper Coyote Creek watershed, Santa Clara County.
clude juvenile Sacramento sucker that often were mixed with shoals of roach in pools. The nonnative green sunfish also is occasionally observed in the deeper pool habitats where this assemblage is found.

Ecological gradients as measured by stream fish assemblages generally are shorter or more compressed in Estuary streams compared to those of the larger Central Valley Subprovince watersheds. Central Valley watersheds generally are much larger as measured by watershed area and longitudinal profile than Estuary watersheds. As such, environmental gradients tend to be longer and fish assemblages more distinct than in Estuary streams (Moyle, 2002). Central Valley watersheds that drain from the Sierra Nevada support a distinctive and well-developed deep-bodied fishes assemblage in their lower reaches on the valley floor (Moyle and Nichols, 1974; Brown, 2000; May and Brown, 2002). With few exceptions, geographically extensive, alluvial, lowland riverine environments are poorly developed in Estuary watersheds. As a result, the mixed native-nonnative fishes/lowermost small to large mainstem assemblage (analogous to the deep-bodied fishes assemblage of Moyle, 2002) is restricted to relatively short reaches within a few of the largest watersheds, particularly Alameda Creek, Coyote Creek, Sonoma Creek, and the Petaluma River. Similarly, the rainbow trout/upper mainstem-headwater tributary assemblage is less extensive than in the Central Valley Subprovince. This is explained by two factors (1) the greater availability of headwater environments in the Sierra Nevada compared to the Estuary, and (2) the introduction of trout into historically fishless streams of the Sierra Nevada.

Although Estuary and Central Valley streams share a common pool of freshwater dispersant stream fishes, Estuary streams support saltwater dispersant species not typically found in the Central Valley. Estuary watersheds support mixed-freshwater and estuarine-marine fish assemblages. Because of the historical connection to Sacramento River system during periods of lower sea levels, Estuary streams share freshwater dispersant fish species found in the Central Valley. Relatively recent (5,000 – 8,000 years before present) changes brought on by rising sea levels have created a relatively short, but extremely variable, gradient in water salinities at the mouths of every Estuary watershed (see III. Zoogeographic Relationships, above). Water salinities within the marine-estuarine-riverine transition zone in each Estuary watershed vary based primarily on complex interactions between the tides, total Delta outflow, individual watershed size, and local streamflow. Unlike the Central Valley, Estuary watersheds are dominated by saltwater dispersant fishes (euryhaline marine and obligatory freshwater-salt water dispersant species in Tables 4 and 5). Estuary streams generally exhibit a greater diversity of aquatic habitat types, as well as alpha and beta species diversity, than Central Valley watersheds of comparable size. Fish assemblage structure in this ecological transition zone is not well understood. Contrary to Moyle (2002), this research supports the inclusion of streams of the Estuary within a separate zoogeographic subprovince of the Sacramento-San Joaquin Province. As discussed above, Estuary streams display several zoogeographic and ecological characteristics distinct from Central Valley streams.

Estuary streams and fish assemblages are transitional ecologically from coastal Pacific to Central Valley watersheds. As discussed previously, Estuary streams display ecological conditions and species assemblages transitional between north and central coastal Pacific drainages and Central Valley watersheds. Thus, Estuary streams exhibit characteristics of both geographic regions. In addition to containing more saltwater dispersant fishes than the Central Valley, Estuary streams also support more freshwater dispersant fishes than coastal Pacific drainages. For some species, such as coho salmon, a gradient of decreasing population abundance exists from coastal Pacific, to Estuary and to Central Valley watersheds. In addition, Estuary watersheds support fishes uniquely adapted to estuarine conditions (e.g., Sacramento splittail, Delta smelt). Finally, Krejsa (1965) and Hopkirk (1973) note that populations of prickly and riffle sculpin exhibit geographic variation in morphology from coastal Pacific to Central Valley (i.e., inland) populations. According to Hopkirk (1967, p. 185), morphological “...intergradation between coastal and inland populations [of prickly and riffle sculpin] apparently occurs in drainages of the San Francisco Bay system.” The extent to which stream fishes exhibit morphological and/or molecular variation from conspecifics within watersheds proximate to the Estuary remains to be investigated.

Freshwater dispersant fishes are geographically isolated within individual Estuary watersheds from one another.
All Estuary watersheds are tributary to the tidal portions of the Estuary where salinities may reach 36 ppt. Salinity acts as a barrier to the movement of freshwater dispersant stream fishes. There is a north-to-south gradient of increasing water salinity in tidal portions of the Estuary, suggesting that stream fishes in the southern Estuary generally are more isolated from adjoining watersheds than in the northern Estuary. The extent to which the proximity of the mouths of adjacent watersheds accommodates the transfer of native freshwater is unknown. Localized populations of freshwater dispersant species such as California roach, Sacramento pikeminnow, hardhead, and riffle sculpin presumably are more vulnerable to extirpation than other fishes within individual watersheds because there is no opportunity for re-colonization from adjacent populations. Historically, Central Valley freshwater dispersant fishes could migrate between watersheds during average runoff years because of seasonally continuous freshwater connections. An evolutionary consequence of isolation of local populations of stream fishes in the Estuary may be species divergence in response to watershed specific environmental conditions, as shown for California roach in the San Joaquin drainage (Brown et al., 1992; Jones, 2001).

Small Estuary watersheds and relatively undisturbed stream reaches within larger watersheds support assemblages dominated by native fishes. Several small (< 150 km²) watersheds support fish assemblages dominated (as measured by relative and total population abundance) by between three to seven native fishes. These assemblages contain 70-90% of the native species expected to occur under pre-European historical conditions. For example, several Marin County streams support intact native assemblages of fishes, including Pacific lamprey, California roach, Sacramento sucker, rainbow trout, prickly sculpin, riffle sculpin, and threespine stickleback. Native fishes historically (now extirpated) present in some Marin County streams include coho salmon, tule perch, and tidewater goby. Within several larger watersheds (> 150 km²), native fishes dominate from the headwaters and upper tributaries downstream through the middle mainstem and lower large tributaries. For example, within Napa River and Sonoma Creek, native fishes are numerically dominant along a longitudinal gradient in assemblages of one to nine species (see V. Results, above).

The lower reaches of several highly urbanized watersheds contain diverse assemblages of native and nonnative fishes. Although nonnative fishes tend to dominate assemblages within the lower urbanized reaches of watersheds, native fishes also are present. The result is that several large urbanized watersheds contain variable abundances of native and nonnative species. For example, species present within the lowermost reaches of Walnut, Alameda, and Coyote creeks at any given time (mixed native-nonnative fishes/lowest most small to large mainstem assemblage) may include six to twelve nonnative and two to five native fishes (Appendix 3).

The relative abundance of native and nonnative fishes is correlated with several characteristic environmental variables at sites within Estuary streams. Sites dominated by native fishes have several general environmental characteristics. Native fishes generally occur in relatively undisturbed stream environments, but this pattern varies with species and local conditions within and between watersheds. Species composition of the rainbow trout/upper mainstem-headwater tributary assemblage consists primarily of rainbow trout alone, or rainbow trout with riffle sculpin. The rainbow trout assemblage displays a wide geographic distribution generally at elevations >100 m in the coastal hills and mountains surrounding the Estuary. Rainbow trout and riffle sculpin had the highest elevation distribution of any native species.

Other characteristic environmental conditions associated with the rainbow trout assemblage include narrow channels with moderate to high gradients with clear, cool, shallow pools and riffles. Riparian canopy coverage was greatest for all native species. The substrate consisted of gravel, cobble, boulder and bedrock. Conductivity is the lowest for all native fishes. Land use is rural consisting of undeveloped range and woodlands in mixed public and private ownership.

Environmental characteristics associated with native fishes within the middle mainstem-lower large tributary assemblage include low gradient, moderately deep, warm pools, with a high percentage of open riparian canopy (low shading). Pools are separated by short, shallow riffles. The dominant substrate is typically mixtures of sand and gravel. Water conductivity is usually high. This assemblage is
often also characterized by 4 to 8 native species. For example, in the Napa River and Sonoma Creek the assemblage contained a diverse array of six to nine native species, including Pacific lamprey, California roach, Sacramento pikeminnow, hardhead (Napa River), Sacramento sucker, riffle sculpin, prickly sculpin, threespine stickleback, and tule perch.

**Conservation**

**Why Do Estuary Streams Support Assemblages of Native Fishes?** The San Francisco Estuary is one of the most urbanized in the United States. The number of people living within the Estuary region is more than 7 million with the population projected to exceed 8.7 million people by 2030 (Association of Bay Area Governments, 2006). Human activities over the last 150 years have modified the environments of all streams surrounding the Estuary. Urbanization is known to adversely affect native stream fishes worldwide and Estuary fishes are no exception (Leidy and Fiedler 1985; Brown et al. 2005). Adverse effects on tributary streams include: urbanization; agricultural conversion; the release of water-borne pollution and contaminants; grazing; water diversions and groundwater extraction; dredging and waterway modification, including channel alteration for flood control; construction of dams and reservoirs; sedimentation; and the introduction of nonnative aquatic organisms (Leidy, 1984; San Francisco Estuary Project, 1997; The Bay Institute, 1998). Notwithstanding these impacts to Estuary streams, this study shows that many watersheds contain healthy assemblages of native fishes. For the following text, I discuss six reasons why I believe Estuary watersheds maintain native assemblages of fishes.

First, headwater and upper mid-elevation environments (i.e., stream orders 1-3, or elevations > 125 m) of many Estuary watersheds are in non-urbanized, forest and range-land communities (Figure VI.6a-b). For example, approximately 80% of the upper reaches of the Coyote Creek and Alameda Creek watersheds are within forest and range-land communities (Buchan et al., 1999; SCCWMI, 2001). Within the Coyote Creek watershed, the upper reaches of Arroyo Aguague, San Felipe, Little Coyote, Middle Fork Coyote, Soda Springs, Grizzly, and many other unnamed streams lie within non-urbanized landscapes (SCCWMI, 2001). Native fish assemblages typically characterize these non-urbanized lands (e.g., rainbow trout/upper mainstem-headwater tributary and mixed native fishes/middle mainstem-lower large tributary assemblages). Many rural lands are within large public land holdings (e.g., Henry Coe State Park at approximately 32,000 hectares). In addition, there are mid-elevation stream reaches (40-100 m elevation) within some watersheds (e.g., Sonoma Creek and the Napa River within the northern Estuary) characterized by non-urbanized, agricultural lands that contain assemblages dominated by native fishes. Finally, suburban environments (e.g., Marin County) characterized by low-density housing contain stream reaches that support relatively intact assemblages of native fishes.

Second, sixty-four percent (n = 21) of the Estuary’s 33 native stream fish species are either euryhaline marine (6 species) or saltwater dispersant, obligatory freshwater fishes (15 species). Estuarine and marine fishes utilize the lower tidal portions of many Estuary streams. Dominance in Estuary streams by saltwater dispersants likely is explained by several factors. Anadromous and amphidromous fishes comprise 43% of the freshwater species in Estuary streams. Presumably, anadromous fishes utilized streams within the Estuary region prior to the most recent rise in sea levels beginning 8,000-10,000 ybp. Fossil remains of a salmonid (Salmonidae) dated from early Pleistocene from the east side of San Francisco Bay, Alameda County, indicate the presence of perennial, cold, headwater streams (Casteel and Adam 1977). Historically, several anadromous species in the genera Oncorhynchus, Lampetra, and Gasterosteus have benefited from the proximity to ocean and estuarine environments of hundreds of kilometers of suitable freshwater habitat for spawning and rearing. Saltwater dispersant fishes also may be able to maintain or recolonize habitats in watersheds from which they have been extirpated by natural events and/or human activities.

Third, estuarine and marine fishes utilize the lower tidal portions of many Estuary streams. By definition estuarine environments are areas where river-derived freshwater mixes with higher salinity ocean water. Water salinities at any given location within the tidal portions of the Estuary may vary from near 0 ppt (freshwater) to 36 ppt (in excess of open ocean salinities). Tidal reaches of streams, in particular, are environments that exhibit widely fluctuating salinities over hourly, daily, seasonal, and multi-year
cycles in response to the complex interactions of freshwater discharges, tidal cycles and winds. In response to variable salinities, the tidal stream reaches are characterized by fish assemblages composed of euryhaline marine and estuarine species that shift in dominance in response to temporal and spatial shifts in water salinities and life history strategies.

For example, the lower tidal portions of several larger Estuary streams, particularly the Napa River, Napa County; Sonoma Creek and the Petaluma River, Sonoma County; Walnut Creek, Contra Costa County, Alameda Creek, Alameda County; and Coyote Creek and the Guadalupe River, Santa Clara County, support fresh water to brackish water tidal riverine environments. Tidal freshwater and brackish environments provide suitable conditions for a variety of native species tolerant of variable salinities, most notably white sturgeon and green sturgeon, Sacramento splittail, Delta smelt, longfin smelt, topsmelt, threespine stickleback, prickly sculpin, Pacific staghorn sculpin, tule perch, shiner perch, tidewater goby, longjaw mudsucker, and starry flounder, among others (Appendix 3). Smaller watersheds without well-developed estuaries typically support fewer euryhaline species, but will support native species such as threespine stickleback, Pacific staghorn sculpin, and prickly sculpin. These estuarine species comprise a significant portion of the species found in some Estuary watersheds.

Fourth, saltwater at the mouths of all Estuary watersheds is a barrier to the invasion of nonnative, obligatory freshwater dispersant fishes. Presumably, in the Central Valley nonnative fishes can invade watersheds through largely continuous freshwater environments that connect them. Only during periods of extremely high total estuarine discharge can nonnative freshwater fishes disperse between Estuary watersheds, particularly in the southern portions of the Estuary. Saltwater dispersal barriers may benefit native fish assemblages by reducing the frequency of opportunities for invasion and establishment of nonnative fishes.

Fifth, many Estuary watersheds lack large permanent reservoirs. There are approximately 45 Estuary watersheds that do not contain major reservoirs (> 50 acre-feet capacity). Reservoirs contribute to the spread of nonnative fishes in two primary ways. Reservoirs serve as continuous sources of nonnative fishes to downstream and tributary reaches. Second, the operation of reservoirs designed to store large volumes of water alter the natural hydrograph downstream from the dam. For these reasons, native fish assemblages may benefit from the lack of large reservoirs. Watersheds with small-to-moderate-sized reservoirs are typically characterized by a more natural flood regime in downstream reaches compared to reservoirs with greater storage capacities.

Sixth, native fishes have benefited from management practices including stream restoration projects throughout the Estuary. Several geographically large tidal estuarine and riverine wetland restoration projects have been completed to the benefit of native fish communities, and many more are in the planning and implementation stages (The Wetland Project Tracker, 2006). For example, the Napa River floodplain restoration project implemented in 2000 has restored several thousand acres of tidal riverine and floodplain habitats utilized by native estuarine fishes (USACE, 2006). Other examples of stream restoration projects benefiting native fishes include projects to remove migration barriers to steelhead and Chinook salmon in the Guadalupe River, Coyote Creek, and San Franciscuito Creek watersheds in the southern Estuary (D. Salisbury, SCVWD, personal communication, 2003). Several restoration projects in highly urbanized environments also have benefited native fishes. Restoration of portions of the lower reaches of Codornices Creek, Alameda County, has resulted in the reestablishment of steelhead and other native fishes in a highly urbanized setting. Efforts to restore the headwaters of Sausal Creek in the Oakland Hills will presumably benefit resident rainbow trout (Leidy et al., 2005b). Finally, native fishes including California roach, Sacramento sucker, threespine stickleback, and prickly sculpin have been reintroduced to the headwaters of Strawberry Creek on the U.C. Berkeley campus (Charbonneau and Resh, 1992). There are dozens of other planned and completed restoration projects within Estuary watersheds that already, or in the near future, will benefit native fishes (The Wetland Project Tracker, 2006).

**How Can Estuary Streams Contribute Significantly to the Conservation of Native Fishes within the Sacramento-San Joaquin Fish Province?** Conservation strategies aimed at fishes within the Sacramento-San Joaquin Province should place much greater emphasis on
the protection and management of native fishes in Estuary watersheds, rather than focusing primarily on streams of the Central Valley. Many Estuary watersheds already support healthy assemblages of native fishes and for this reason alone, conservation strategies focused here are likely to be more successful. In addition, from a societal perspective, there exists strong public and political support for the protection of aquatic biodiversity in streams surrounding the Estuary. Several measures can be implemented in Estuary watersheds to conserve native stream fishes.

(1) Develop an Estuary-wide stream monitoring strategy. Scientifically based monitoring is necessary to assess baseline conditions, as well as spatial and temporal changes to aquatic biodiversity, and, therefore serves as an effective foundation for setting subsequent research priorities and management decisions (USEPA, 2002). The first step in the implementation of a conservation strategy to protect native Estuary stream fishes is the establishment of an effective, unified regional monitoring strategy. Without systematic monitoring, baseline ecological conditions and the success of conservation measures in protecting native fishes cannot be evaluated effectively. Such a monitoring strategy should include the development of a regional hydrogeomorphic classification for streams and the establishment of a suite of stream reference sites encompassing representative fish assemblages as well as fishless waters. A reference framework will provide baseline information on the range of environmental conditions within Estuary streams. Once established, reference conditions can be used in the setting of restoration goals, assist in project design in the context of environmental permitting, and be used to monitor the relative success of restoration activities. An Estuary-wide monitoring strategy for stream fishes could be developed using a subset of the sampling stations established during this study. An integral part of any monitoring strategy should include focused sampling to determine the population status of several species whose conservation status is uncertain (e.g., all lamprey species, speckled dace, salmonids, and Sacramento perch).

(2) Protect and manage low order (i.e., Strahler stream orders 1-3), headwater, tributary streams. These streams are characterized by a range of hydrologic regimes (i.e., ephemeral to perennial), may contain fish or be fishless, and typically account for greater than seventy percent of the total linear stream miles in many watersheds. The headwaters of many Estuary watersheds that lie at greater than 100 m elevation currently are within public and private protected parks and wildlands. This may explain in part, why healthy assemblages of native fishes persist within the upper reaches of several of these watersheds. However, other headwater streams are threatened with destruction and chronic degradation through filling and other alterations related primarily to urbanization. Headwaters streams are in many ways most important to overall watershed health providing multiple hydrologic, biogeochemical, and ecological benefits to downstream receiving waters, including the fish communities and urban population centers (Rosenberg, 2003). Alteration of headwater streams will have negative affects to downstream receiving waters, primarily through changes in the hydrograph as impervious surfaces are increased in headwater areas (Meyer and Wallace, 2001; Paul and Meyer, 2001, Konrad and Booth 2005). Downstream waters are easier to restore if the headwaters are intact. Several headwater species in the Estuary also occur in downstream stream reaches, so headwaters can serve as a source of potential native colonizers.

(3) Take a “Protect the Best” conservation approach focused on riverine landscapes. Conservation actions should be directed at largely intact native stream fish assemblages and their habitats within the Estuary. Focused protection and management of native fish assemblages that approach historical reference conditions should be given high priority by local, state, and federal agencies and public and private land stewards. This “protect the best” approach to conservation of native fishes is likely to be most cost effective because many of these stream habitats are already encompassed within public parks and wildlands that are managed to protect biodiversity.

Four assemblages within the Estuary (i.e., rainbow trout/upper mainstem-headwater tributary; anadromous fishes/small to medium, cool, tributary; California roach/small, warm, intermittent tributary; and mixed native fishes/middle mainstem-lower large tributary) are characterized by native fishes. These assemblages are increasingly threatened within the Central Valley, but are well represented within several Estuary watersheds. The mixed native fishes/middle mainstem-lower large tributary assemblage of me-
dium to large watersheds in the Estuary is perhaps the most threatened with changing land use practices and could benefit most from an aggressive conservation strategy that includes acquisition and management. For example, the acquisition and/or protection through a conservation incentive program of lands bordering the middle reaches of the Napa River and Sonoma Creek would contribute greatly to the protection of native fish assemblages.

(4) Develop a strategy for the reintroduction of native fishes into streams of historical occurrence. Streams with intact assemblages of native fishes combined with historical and archaeological data could be used to build a reference framework to infer past species distributions. Several watersheds with suitable habitat potentially could benefit from the reintroduction of native fishes. For example, there may be opportunities to introduce California roach into several small streams where it historically occurred or was likely to have occurred (e.g., San Leandro Creek, lower Wildcat Creek, and upper San Pablo Creek) from populations in adjacent watersheds. Reintroduction programs also could provide opportunities for natural experiments into those ecological processes and mechanisms important in the structuring fish communities. Priority should be given to restoration strategies for regionally extirpated or declining species such as coho salmon, steelhead, speckled dace, Sacramento perch, and tidewater goby.

(5) Manage reservoirs and other impoundments to benefit native fishes through the establishment of natural flow regimes. Altered flow regimes are recognized increasingly as having adverse effects on native fishes, perhaps most notably by promoting the invasion and establish of alien species (Bunn and Arthington, 2002; Marchetti and Moyle, 2001; Marchetti et al., 2004). Fourteen reservoirs in Estuary watersheds have a storage capacity of approximately ≥ 10,000 AF (Table 3). Modified operation of these reservoirs for the benefit of native fishes through changes to the amount and timing of water releases could help restore remnant or extirpated populations of steelhead and possibly coho salmon in stream reaches below reservoirs with suitable habitat. In addition, seasonal flow releases during late-winter to early spring months that mimic natural flood flows are likely to benefit native fishes over alien fishes in downstream reaches (Brown and Ford, 2002). For the thousands of permanently flooded ponds and reservoirs (<50 AF storage capacity), there should be a focused management program to eradicate non-native fishes and encourage re-stocking with appropriate native species (e.g., Sacramento perch, Sacramento blackfish, hitch). Such small reservoir and pond management programs could potentially be supported through local Resource Conservation Districts under the Natural Resources Conservation Service, which traditionally have effective working relationships with local landowners, and/or through local mosquito abatement districts (Figure VI.7).

(6) Conduct an assessment of the projected effects of various climate change scenarios on stream and floodplain environments. There is a growing body of information on the possible environmental effects of global climate change (i.e., IPOC, 2007). An assessment should be made of how future projected changes in physical factors such as sea level, precipitation, and other global and local climatic and weather patterns are likely to influence Estuary stream environments and fish communities. For example, sea level rise may have significant effects on tidal and non-tidal reaches of confined urbanized streams by shifting salt- and brackish-water environments in an upstream direction. Thus, sea level rise could reduce the extent of freshwater environments with potentially dramatic changes to existing fish assemblages. Assessment of potential future climatic scenarios will help stakeholders wisely plan, prioritize, and implement stream and floodplain restoration projects (see (7), below).

(7) Identify opportunities for restoring riverine floodplain functions. Floodplain environments are important to maintaining the physical, chemical, biological functions of streams, including native California fishes (Crain et al., 2004; Ribeiro et al., 2004). Low elevation (<100 m) reaches of many Estuary streams have been confined artificially as a result of urbanization and agricultural activities. Artificial reduction of stream cross-sectional area increases bed shear stress and may reduce the diversity of instream habitat important to native fishes by increasing channel and bank erosion while decreasing channel bed microtopography. Opportunities to increase stream cross-sectional area, especially flood prone width, with the goal of enhancing instream microtopography and adjacent flood plain terrace functions should be iden-
a. Diablo Range, Alameda County.

b. Diablo Range, Santa Clara County.

Sizer Flat Reservoir, Santa Clara County. Photo: Tim Vendilinski.
tified. For example, there may be opportunities to direct public and private funds toward the restoration of floodplain buffers or meander zones in agricultural settings, and toward the strategic removal and/or modification of key individual hard-engineered structures (i.e., buildings, parking lots, and non-functioning flood control structures) in more urbanized floodplain settings. Successful restoration of floodplain functions will necessarily require implementation of measures “outside of the channel” in order to reduce the effects of impervious surfaces and the artificial extension of drainage networks on surface hydrologic patterns, sediment transport dynamics, and instream and floodplain habitats. Importantly, in addition to benefiting native fishes, floodplain restoration will contribute to increased flood protection for adjacent land uses.

(8) Establish demonstration reaches that showcase stream restoration activities. Demonstration reaches function to educate the public on the environmental benefits of implementation of an array stream restoration practices to the conservation of native fishes and their habitats (Barrett and Ansell, 2003; Murray-Darling Basin Commission, 2004). Demonstration reaches could be positioned within a watershed at sites with impaired or degraded ecological functions in order to maximize environmental benefits, as well as community awareness of restoration activities. Demonstration reaches also could be designed to incorporate public participation in various ongoing restoration activities. Ideally, oversight of a demonstration stream reach program could be housed within a state agency, such as the San Francisco Regional Water Quality Control Board, which could serve to advertise demonstration reaches to promote and foster public participation. As Estuary stream reaches are restored and restoration goals are achieved, new demonstration reaches showcasing emergent technologies and methods can be added.
PART VII

Literature Cited


Murray-Murphy, G. and R. Pintler. 1950. The 1949 fishery of Conn Valley Reservoir, Napa County.

Murphy, G. 1949. The 1947 and 1948 Fishery of Conn Valley Reservoir, Napa County.

Murphy, G. 1943. Sexual dimorphism in the minnows.


Smith, J. J. 1991. Summary of fish sampling results for the streams of San Francisco Bay Department's peninsula watershed lands near Crystal Springs Reservoir. Unpublished report, Department of Biological Sciences, San Jose State University, San Jose, California. 8 pp. + 16 data sheets.

Smith, J. J. 1998. Steelhead and other fish resources of western Mt. Hamilton streams. Unpublished report, Department of Biological Sciences, San Jose State University, San Jose, California. 17 pp.

Smith, J. J. 1999. Steelhead and other fish resources of streams of the west side of San Francisco Bay. Unpublished report, Department of Biological Sciences, San Jose State University, San Jose, California. 11 pp.


Stauffer Chemical Company. 1986. Equivalent protection study for Stauffer Chemical Company Martinez Sulfuric Acid Plant. Stauffer Chemical Company, Martinez, CA.


APPENDICES

Appendix I
Watersheds of the San Francisco Estuary, California

Appendix II
Historical References for Native Stream Fishes for the Period 1854-1981, San Francisco Estuary, California

Appendix III
Presence of Fish Species by Watershed, San Francisco Estuary, California