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HISTORICAL STATUS OF COHO SALMON IN STREAMS OF THE URBANIZED SAN FRANCISCO ESTUARY, CALIFORNIA

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ABSTRACT

The historical status of coho salmon, *Oncorhynchus kisutch*, was assessed in 65 watersheds surrounding the San Francisco Estuary, California. We reviewed published literature, unpublished reports, field notes, and specimens housed at museum and university collections and public agency files. In watersheds for which we found historical information for the occurrence of coho salmon, we developed a matrix of five environmental indicators to assess the probability that a stream supported habitat suitable for coho salmon. We found evidence that at least 4 of 65 Estuary watersheds (6%) historically supported coho salmon. A minimum of an additional 11 watersheds (17%) may also have supported coho salmon, but evidence is inconclusive. Coho salmon were last documented from an Estuary stream in the early-to-mid 1980s. Although broadly distributed, the environmental characteristics of streams known historically to contain coho salmon shared several characteristics. In the Estuary, coho salmon typically were members of three-to-six species assemblages of native fishes, including Pacific lamprey, *Lampetra tridentata*, steelhead, *Oncorhynchus mykiss*, California roach, *Lavinia symmetricus*, juvenile Sacramento sucker, *Catostomus occidentalis*, threespine stickleback, *Gasterosteus aculeatus*, riffle sculpin, *Cottus gulosus*, prickly sculpin, *Cottus asper*, and/or tidewater goby, *Eucyclogobius newberryi*. We found evidence for the occurrence of coho salmon in eight watersheds characterized by the coast redwood, *Sequoia*

***sempervirens*, riparian community. These conditions are more typical of the high rainfall coastal streams directly tributary to the Pacific Ocean that historically had relatively high abundances of coho salmon. All streams known or suspected historically to support coho salmon are characterized by cool summer water temperatures, suitable spawning and juvenile rearing habitat, distinct surface water connections to the estuarine and marine environments, as well as stream flows during the months of February through May suitable for smolt out-migration.**

INTRODUCTION

Assessing the historical status of anadromous salmonids in urbanized environments is difficult because many of the natural habitats and processes important to their survival have been dramatically altered or are no longer present. The task is even more difficult for those species at the edge of their historical geographic range, where population abundance may be naturally low in comparison to the distributional center of their range. Additional complications in any historical assessment is determining what, if any, were the effects of widespread plantings of hatchery salmon in California during the 19th and 20th centuries. Such is the case for coho salmon, *Oncorhynchus kisutch*, an endangered species of salmonid that historically occurred in streams tributary to the San Francisco Estuary (Estuary), California.

Coho salmon historically were distributed in coastal streams of California from the Smith River, Del Norte County, south approximately 560 km to at least the San Lorenzo River, Monterey County (Moyle 2002, B. Spence, National Marine Fisheries Service (NMFS), personal communication). Recent status reviews indicate that natural populations of coho salmon within the Central California Coast Evolutionary Significant Unit (ESU) have declined dramatically over the last 50 years, and populations continue to decline in certain regions (Brown et al. 1994, NMFS 2001, California Department of Fish and Game (CDFG) 2002). The Central California Coast ESU includes populations of coho salmon from Punta Gorda in northern California south to, and including, the San Lorenzo River, in central California, as well as tributaries to the Estuary, excluding the Sacramento-San Joaquin River system in the Central Valley. In 2004, the National Marine Fisheries Service proposed changing the status of coho salmon in the Central California Coast ESU from threatened to endangered under the Endangered Species Act (NMFS 2004). Also in 2004, the California Fish and Game Commission listed coho salmon populations south of Punta Gorda as endangered under the California Endangered Species Act (http://www.dfg.ca.gov).

Historical records suggest that coho salmon occurred in the Sacramento River system, where it was considered the rarest of the five salmon species known to inhabit the Central Valley (Hallock and Fry 1967, Brown et al. 1994). The McCloud River, a major tributary to the upper Sacramento River, probably supported the most inland population of coho salmon in California prior to the completion of Shasta Dam on the Sacramento River in 1944 (Moyle 2002). There is archaeological evidence that Native Americans may have captured coho salmon from several Estuary streams (Gobalet et al. 2004). Coho salmon also historically occurred in streams of the Estuary where they were last documented in the early-to-mid 1980s (Leidy 2004).

Little reliable documentation of coho salmon within Estuary watersheds exists, and existing regional status reviews and distributional information for the species provide incomplete information (e.g., NMFS 2001, CDFG 2002). Lack of documentation of coho salmon in Estuary streams is likely explained by several factors, including 1) the scarcity of coho salmon relative to steelhead, and, in San Francisco Bay, Chinook salmon, even though habitats suitable for coho salmon were available historically in some streams surrounding the Estuary, 2) limited sampling of suitable coho salmon habitats prior to substantial habitat modification and associated population declines, and 3) misidentification of juvenile coho salmon as steelhead. The paucity of information contributed to a perception that coho salmon were neither abundant nor important members of Estuary fish assemblages. Consequently, priorities for salmon restoration in the Estuary have been focused historically on species such as steelhead that were relatively widespread and abundant within the Estuary and, unlike coho salmon, continue to maintain small populations in many Estuary tributaries (Leidy et al. 2005). Information collected during this study suggests that coho salmon may have been more widespread in Estuary watersheds than collection records indicate.

Recovery planning efforts by federal and state agencies for coho salmon within the Central California Coast ESU requires an assessment of their historical status. Therefore, the purpose of this paper is to document the historical distribution of coho salmon in streams tributary to the Estuary.

STUDY AREA

The Estuary is the largest along the Pacific coasts of North, Central, and South America. It is an inland estuary lying between more mesic, cooler Pacific Coast Range streams that drain directly to the Pacific Ocean, and the more xeric, hotter Central Valley. The former are characterized by a historically relatively high abundance of coho salmon, while the latter lies at the historical edge of the coho salmon range (Moyle 2002). Streams tributary to the Estuary are considered part of the Sacramento-San Joaquin Zoogeographic Province based largely on their shared fish faunas (Hopkirk 1973, Leidy 1984, Moyle 2002). Estuary tributaries differ in part from other Central Valley streams because of the more direct marine influence that affects fish assemblage membership. Thus, the species composition of fish assemblages in Estuary streams resembles both Central Valley and coastal streams immediately north and south of the Golden Gate (Leidy 2004).

Sixty-five local watersheds surround the Estuary, and are the focus of this study. Estuary watersheds cover a maximum linear distance of 212 km from north (38°, 39', 34" N) to south (37°, 01', 34" N), and 90 km from east (121°, 24', 24" W) to west (122°, 43', 52" W). Watersheds range in area from 2.8 km^2 to 1813 km^2. Study area watersheds lie within portions of 7 U.S. Department of Agriculture Forest Service ecological sections and 14 subsections (Miles and Goudey 1997). These sections and subsections are derived from a national hierarchical classification based on factors such as climate, physiography, water regime, soils, air, hydrology, and potential natural communities

Table 1. Streams tributary to the San Francisco Estuary with historical evidence supporting the occurrence of coho salmon by date or period of record, evidence type (MS = museum specimen. MR = museum record. SS = stream survey, including standard collection techniques such as electrofishing, seine, fyke, tow or dip-net, or snorkeling. OBS = direct observational account. AA = anecdotal account. SH = suitable habitat present), historical status, and reference or source. Streams are listed in clockwise direction around the Estuary beginning in Contra Costa County.

Watershed, County	Period or record date	Evidence type	Historical status[1]	Reference(s)/Source(s)
(1) Walnut-San Ramon, Contra Costa	Prehistoric; 1950s to mid-1960s	MS[2], AA, SH	PR	CDFG[2, 3] 1977; Leidy 1983; Gobalet et al. 2004; Leidy 2004
(2) San Pablo, Contra Costa	Prehistoric; 1940s to 1950s; pre-1957	MS[2]?, AA, OBS, SH	PR	Evans[4] 1957; Needham and Gard 1959; C. Leggett, personal communication 1976; Nakaji 1975; Gobalet 1990, 1994; Gobalet et al. 2004; Leidy 2004
(3) Strawberry, Alameda	Prehistoric; pre-1939	MS[2], AA, OBS, SH	PR	Shapovalov[5] 1939; Follett 1975; Charbonneau and Resh 1992; Gobalet et al. 2004; Leidy 2004
(4) Temescal Creek, Alameda	Prehistoric; late-18th to early 19th centuries	MS[2], AA?, SH	PR	Schenck 1926; Louderback 1940; Follett 1975; Broughton 1997; Gobalet et al. 2004; Leidy 2004
(5) San Leandro, Alameda-Contra Costa	1877; prior to 1957; likely circa late-1920s	SS, OBS, SH	PR	Evans[4] 1957; Needham and Gard 1959; Leidy 2004 to early-1930s
(6) San Lorenzo, Alameda	Pre-1960s	AA, SH	PS	Skinner 1962; ACFCWCD 2002; Grossinger and Brewster 2003; Leidy 2004

(7) Alameda, Alameda	Late-1930s; early-to-mid-1960s	AA, OBS, SH	DF	Skinner 1962; J. Hopkirk, personal communication 1981; Alameda Creek Alliance[6] 2002; Leidy 2004
(8) Coyote, Santa Clara	Prior to mid-1950s	AA, OBS, SH	PR	Skinner 1962; Smith 1998; Leidy 2004
(9) Guadalupe-Los Gatos, Santa Clara	1920s-1960s	AA, SH	PS	Skinner 1962; Smith 1999; SCBWMI 2001; Guadalupe-Coyote Resource Conservation District[7] 2001; Johmann[8, 9] 2002; Leidy 2004
(10) San Francisquito, Santa Clara	Prehistoric; circa 1930s-1940s	MS[2]?, AA, SH	PS	Skinner 1962; Guadalupe-Coyote Resource Conservation District[7] 2001; Johmann[8, 9] 2002; Gobalet et al. 2004; Leidy 2004
(11) San Mateo, San Mateo	1860 and 1870s	MS, MR, SH	DF	Museum of Comparative Zoology[10, 11] 1860; Stone 1873; Hallock 1877; Leidy 2004
(12) Arroyo Corte Madera del Presidio, Marin	1940s-1960s, 1981	AA, OBS, SS, SH	DF	Shapovalov 1946; Shapovalov[12] 1946; CDFG[13] 1963; Hallock and Fry 1967; Leidy 1984; Leidy 2004
(13) Corte Madera, Marin	Prehistoric; 1926-1927; 1960s; 1981; 1984	MS[2]?; AA, OBS, SS, SH	DF	California Academy of Sciences[14] 1926; Fry 1936; Follett 1957; Hallock and Fry 1967; Follett 1974; Cronin[15] 1980; Leidy 1984; Emig[16] 1986; Leidy 2004

Table 1 (continued)

Watershed, County	**Period or record date**	**Evidence type**	**Historical status[1]**	**Reference(s)/Source(s)**
(14) Sonoma, Sonoma	Prior to 1960s	SH	PS	Skinner 1962; Leidy 2004; Sonoma Ecology Center 2004
(15) Napa, Napa	Prior to 1960s	AA, OBS, SH	PS	Skinner 1962; USFWS[17] 1968; Emig[18] 1983; Leidy 2004

[1]Refer to Methods for definitions.
[2]Prehistoric archaeological remains.

(Bailey 1994, Goudey 1994, Miles and Goudey 1997). The relatively large number of ecological subregions and subsections within the Estuary is an indication of the great diversity of ecological community types traversed by study area streams.

Because of its geographic location and complex geologic setting, climate in the Estuary is transitional between the Pacific coastal and Central Valley inland extremes (Leidy 2004). The Estuary's climate is more variable than Pacific coastal and Central Valley environments due to the effects of local physiography and the continuous interaction of maritime and continental air masses. The regional climate is Mediterranean with warm, dry summers (May through September) and cool, wet winters (October through April). About 80% of the precipitation falls between November and February, and it is typically associated with low-pressure cells that produce periods of rain for several days followed by periods of 7-10 days of clear weather (Conomos et al. 1985). Mean annual precipitation ranges from 25-30 cm on the edge of the Central Valley, along the bay flats immediately bordering the Estuary and the Santa Clara Valley, to 152 cm at higher elevations in the Santa Cruz Mountains, Marin County hills and valleys, and Mt. St. Helena volcanic flows and valleys regions. Patterns of temperature and precipitation vary on general gradients of increasing summer temperatures and decreasing precipitation from north to south and west to east; however, even these patterns are moderated by increasing precipitation as well as cooler air and stream water temperatures with increasing elevation. Significant local intra-regional variation in rainfall amounts and patterns depends largely on local physiography. For example, within watersheds traversing the bay flats of Santa Clara and San Mateo counties, rainfall annually may average 30 cm, while rainfall amounts in the Santa Cruz Mountains just 10-15 km to the west (upstream) may average 152 cm, a five-fold difference.

Summer stream water temperatures also follow a general elevation gradient, characterized by decreasing temperatures with increasing elevation. In addition to elevation, water temperatures are affected by the existence of extensive faulting, which produces zones of groundwater discharge (i.e., seeps and springs), especially in the northwest-to-southeast trending Coastal and inner-Coastal ranges that intersect many Estuary watersheds. Zones of groundwater discharge may maintain local water temperatures during summer months at 2-4° C lower than adjacent stream reaches. These zones provide refugia for fish such as rainbow trout, and, historically, coho salmon that require cooler temperatures.

Under conditions of natural surface-hydrology, several conditions likely characterized Estuary tributaries in their lower reaches. Streams with large contributing watersheds or streams flowing from areas of high winter rainfall (i.e., Santa Cruz Mountains, Marin County coastal hills, Mt. St. Helena volcanic flows) typically were perennial to the tidal waters of the Estuary. The lower reaches of other streams within watersheds that traverse valley alluvial deposits maintained flows to the Estuary into April and May. By late spring-to-mid summer these streams became intermittent, depending on variation in annual precipitation. They typically consisted of dry-to-nearly-dry alluvial reaches interrupted by long, deep pools underlain by bedrock, with little surface water connection to smaller tributaries. The middle-to-upper reaches of tributary streams were intermittent-to-perennial in summer depending on characteristics of local aquifers.

METHODS

Watersheds With Historical Records

We searched historical records for coho salmon as part of studies by the senior author and others on the distribution and ecology of stream fishes and the historical status of steelhead in the Estuary (Leidy et al. 2005, Leidy 2004). We reviewed published literature, unpublished reports, field notes, and specimens housed at museum and university collections and public agency files. Unpublished sources consisted primarily of documents prepared by private consultants for public agencies as required to demonstrate compliance with various environmental regulations (e.g., environmental impact reports and statements, resource assessments, mitigation monitoring reports). To understand the possible influence of fish hatchery plantings on historical observations of coho salmon in Estuary watersheds, we reviewed annual reports for the years 1871-1940 of fish distributions published by the United States Commission of Fish and Fisheries, Bureau of Fisheries, as well as biennial reports by the California State Board of Fish Commissioners, Commissioners of Fisheries of California, California Division of Game and Fish, and CDFG for the period 1870-1966. These documents typically listed annual fish distributions from hatchery facilities for each species by state, county, and/or stream name. We also reviewed unpublished fish stocking records from 1940 to 2004 housed at the CDFG's Silverado Fish Base, Napa County, California. The Silverado Fish Base has responsibility for planting hatchery fish into Estuary watersheds. Finally, we reviewed unpublished Administrative Reports produced by the California Division of Game and Fish and CDFG that listed annual fish production and distribution in California.

Because historical records varied widely in information quality, we developed criteria to rate the relative reliability of historical records in order to assess the likelihood or probability of the occurrence of coho salmon within Estuary watersheds. For purposes of this study, "historical" means prior to 2004. We assigned a definite (DF) category to watersheds for which there is reliable, direct evidence for the occurrence of coho salmon. Direct evidence is from individuals qualified to identify coho salmon. Direct evidence includes collections or first-hand observations made during stream surveys, and contained in published literature, unpublished biological or archeological reports or surveys, and museum collections and records. Direct evidence sources may be combined with other historical information and observations on the current presence of suitable habitat. The current presence of suitable habitat may be a strong indicator of the historical presence of suitable habitat, especially when combined with other forms of evidence. A probable (PR) rating was used for watersheds for which there is no reliable direct evidence for fish use, but there is an assertion of historical use by a qualified individual and we were able to determine that suitable habitat for coho salmon existed historically. This determination was made using information concerning stream habitat characteristics based on reference data, or knowledge of the current presence of suitable habitat. Finally, the possible (PS) rating was assigned to watersheds for which there is no direct reliable evidence for fish use, but suitable habitat existed historically, or is currently present. Evidence may include anecdotal accounts of the occurrence of coho salmon. Anecdotal evidence of the presence of coho salmon typically consists of unverified personal observations and verbal accounts by individuals with unknown qualifications. Anecdotal evidence typically is the least reliable for confirming the presence of coho salmon, but may be useful when combined with direct evidence. We assigned a PS rating in situations where the qualifications of the individual(s) involved in identifying fish were unknown or unclear.

Historically Suitable Coho Salmon Habitat

The life history and habitat requirements of coho salmon are strict in comparison to other Pacific salmon in California (i.e., steelhead; Chinook salmon, *O. tshawytscha*), which presumably limited the number of streams with historically suitable habitat, especially within the drier, warmer, interior portions of its range in the Estuary. In watersheds for which we found historical information for the occurrence of coho salmon, we developed a simple matrix of five environmental indicators to assess the probability that a stream supported habitat essential for coho salmon survival. Assumptions and environmental indicators that we assessed included the following:

(1) Coho salmon require the presence of an annual, defined surface water connection to tidal waters of the Estuary. Coho salmon exhibit a 3-year life cycle. For populations to persist, adults require annual access to spawning areas and smolts to the ocean environment (Moyle 2002). Only streams with annual surface water connections to estuarine or marine environments through well-defined channels passable to migrating coho salmon would have been likely to support viable populations. The lowermost reaches of several Estuary streams that are located on Holocene alluvial terraces apparently had only intermittent or seasonal connections with marine habitats (San Francisco Estuary Institute[1] 2004, R. Grossinger, San Francisco Estuary Institute, personal communication). While streams with intermittent surface water connections to the Estuary may not have supported coho salmon, these streams may serve as habitat for populations of anadromous and resident rainbow trout that do not require annual access to the ocean to maintain viable populations (McEwan 2001). Therefore, we used historical (circa 1850-1930) topographic maps from various sources depicting stream courses to determine whether there were annual, permanently defined, surface water connections to the marine environment prior to extensive human alteration of watersheds.

(2) Successful spring out-migration of coho smolts requires adequate streamflow conditions during February through May (Hassler 1987, Sandercock 1991). Where available, we reviewed available U.S. Geological Survey streamflow data for daily and mean monthly discharges (cubic feet per second) for the months of February through May, prior to the construction of major dams or water diversions (circa 1898-1950). These data serve as a conservative measure of available unimpaired flows during the

[1]San Francisco Estuary Institute. 2004. EcoAtlas. Oakland, California. http://www.sfei.org.

peak period of coho salmon smolt out-migration.

(3) Adult coho salmon require spawning habitat characterized by the availability of a substrate of suitable size and quality. We considered existing stream reaches with a substrate between 1.3-10.2 cm diameter, and less than 20% fines as suitable for adult spawning coho salmon (Reiser and Bjornn 1979, Bjornn and Reiser 1991). We made no attempt to assess the impacts from land use changes or their effects (e.g., dams, sedimentation) on current substrate composition or quality. Rather, we assumed that the current presence of any suitable substrate for coho salmon is likely to be an indicator of the historical presence of suitable substrate.

(4) Juvenile coho salmon require rearing habitat with adequate water temperatures and pools of sufficient depth containing complex instream, or overhead cover (i.e., boulders, undercut banks, course woody debris, riparian canopy), along stream reaches with gradients not exceeding 5 percent. Juvenile coho salmon prefer habitats where water temperatures for rearing are generally between 12-16° C, and do not exceed 18-20° C for extended periods (Bjornn and Reiser 1991, Welsh et al. 2001, Moyle 2002). While long-term data on stream temperatures is not available for most Estuary streams, we did gather single-event temperature data during summer months when water temperatures are annually the highest and, presumably, the most critical for determining suitability for juvenile coho salmon. We assumed that streams with flowing water and temperatures ranging between 12-18° C during summer months (May-October) were suitable for juvenile coho salmon. We also assumed that juvenile coho salmon required stream reaches with mean water depths greater than 23 cm for rearing (Bjornn and Reiser 1991). In addition, some pools with maximum depths measuring greater than 70 cm must be present (B. Spence, NMFS, personal communication). Mean and maximum water depth measurements were taken within stream reaches and follow the protocol presented in Leidy (2004). Also, we assumed sites suitable for rearing juvenile coho salmon require riparian canopy coverage of > 80%, including trees large enough to provide a source of large woody debris to the stream channel (Flosi et al. 1998). Finally, coho salmon are generally absent from stream reaches with gradients greater than 5%, and are most common at gradients of less than 3% (J. Smith, San Jose State University, personal communication; B. Spence, National Marine Fisheries Service, personal communication). We assumed that stream reaches were suitable for coho salmon if they were characterized by gradients of less than 3% and supported other indicators of suitable spawning and rearing habitat.

(5) Ecological associates such as steelhead, Pacific lamprey, riffle sculpin, and/or tidewater goby were present in Estuary streams with coho salmon. Steelhead, Pacific lamprey, riffle sculpin, and tidewater goby are close ecological associates of coho salmon in coastal Pacific and Estuary streams (Hopkirk 1973, Moyle 2002, Leidy 2004). Steelhead and Pacific lamprey typically require spawning and rearing conditions that overlap broadly with those of coho salmon. We used the presence of one or more of these species as an environmental indicator for the potential presence of coho salmon. In other words, if a stream does not support one or more of these species, then it likely did not contain coho salmon.

Information to assess these environmental indicators was collected from published and unpublished historical literature and recent studies on stream conditions within various Estuary watersheds. Observations and data collected during field study of Estuary streams during the periods 1980-1981 and 1992-2004 also were used to supplement other information sources (Leidy 1984, Leidy 2004). We assumed that if a stream currently supported habitat suitable for coho salmon during the period 1980-2004 that it likely did historically as well.

RESULTS

We found definite evidence that at least 4 of the 65 (6%) Estuary watersheds that we assessed historically supported coho salmon (Table 1). An additional 11 watersheds (17%) also may also have supported coho salmon, but the evidence was inconclusive. Coho salmon were last documented from an Estuary stream in the early-to-mid 1980s. Collections of coho salmon from the open tidal-waters of the Estuary remain rare, supporting the conclusion that the species has been extirpated from the interior portions of its range in the Central Valley (Baxter et al. 1999, Moyle 2002, Leidy 2004).

We found only one record for the planting of hatchery-reared coho salmon into an Estuary stream during the 18th or 19th centuries. In 1960, fingerling coho salmon from the CDFG hatchery in Yountville were planted in Mill Valley Creek (Arroyo Corte Madera del Presidio), Marin County (CDFG files, Yountville Fish Base, Yountville). We located several records for the planting of hatchery-reared sub-catchable and catchable coho salmon into Estuary reservoirs during the 1970s, including: Arroyo del Valle Reservoir and Lake Elizabeth, Alameda County; San Pablo Reservoir, Contra Costa County; and Lake Merced, San Francisco County (CDFG files, Yountville Fish Base). Finally, during the 1970s-1980s the San Francisco Tyee Club reared and released hatchery coho salmon into San Francisco Bay near Tiburon (CDFG files, Yountville Fish Base).

Environmental Characteristics of Coho Salmon Streams

Coho salmon were geographically widespread in the Estuary, with evidence of occurrence within watersheds that drain at least seven ecological subsections (Table 2). The environmental characteristics of streams known historically to contain coho salmon, however, shared several environmental characteristics. Riparian communities were characterized typically by California bay, *Umbellularia californica*, coast redwood, *Sequoia sempervirens*, white alder, *Alnus rhombifolia*, and various species of willow, *Salix* spp. The coast redwood community was found in 8 of 15 watersheds (53%) with some evidence for the occurrence of coho salmon (Table 2). In addition, cool summer water temperatures, suitable spawning and juvenile rearing habitat, low stream gradients (< 3%), distinct surface water connections to the estuarine and marine environments, as well as stream flows during the months of February through May sufficient for smolt out-migration characterized all streams known or suspected historically to support coho salmon (Table 2).

Coho salmon typically were members of three-to-six species fish assemblages

Table 2. Selected environmental characteristics of streams with historical evidence for the occurrence of coho salmon within the San Francisco Estuary, California.

Watershed/ County/area km^2	Ecological subsection[1]	Mean annual precipitation[1] (range cm)	Environmental indicators?[2]	Probable location of suitable spawning and rearing habitat	Current dominant riparian tree species[3]	Associated fish species[3]
(1) Walnut-Pine/ Contra Costa/474	East Bay Hills-Mt. Diablo	61-64	yes	Upper Pine Ck., Little Pine Ck., Arroyo del Cero Ck., San Cantanio (Sans Criante), Bollinger Canyon Ck.	mixed-willow, white alder, California bay, coast live oak	Pacific lamprey, California roach, steelhead, threespine stickleback
(2) San Pablo/ Contra Costa/113	East Bay Hills	51-64	yes	West Fork San Pablo Ck.,middle-to-upper San Pablo Ck.	mixed-willow, white alder, California bay, coast live oak	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead, threespine stickleback, prickly sculpin
(3) Strawberry/ Alameda/5	East Bay Hills	64-71	yes	South Fork Strawberry Ck., upper mainstem Strawberry Creek	mixed-willow, white alder, California bay, coast live oak	steelhead, threespine stickleback

(4) Temescal Creek/	East Bay Hills	64-71	yes	Middle-to-upper mainstem Temescal Ck. bay, coast live oak	mixed-willow, white alder, California stickleback	steelhead, threespine
(5) San Leandro Creek/Alameda-Contra Costa/114	East Bay Hills	64-71	yes	Redwood Ck.,upper San Leandro Ck.,Indian Ck.	coast redwood, mixed-willow, white alder, California bay	Sacramento sucker (juvenile), steelhead, threespine stickleback, riffle sculpin? prickly sculpin
(6) San Lorenzo/ Alameda/124	East Bay Hills	64-71	yes	Crow Ck., Cull Ck., Palomares Ck., middle-to-upper mainstem San Lorenzo Ck.	mixed-willow, white alder, California bay, Fremont cottonwood, western sycamore	steelhead, California roach, Sacramento sucker (juvenile), threespine stickleback, prickly sculpin
(7) Alameda/ Alameda-Santa Clara/1,813	Fremont-Livermore Hills and Valleys Western Diablo Range	51-76	yes	Arroyo Hondo Ck., Calaveras Ck., Stoneybrook Ck., Sinbad Ck.?, Pirate Ck.?, Dry Ck.?, Alameda Ck.-Niles Canyon	mixed-willow, white alder, California bay, coast live oak, western sycamore	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead, threespine stickleback, prickly sculpin

Table 2 (continued)

Watershed/ County/area km²	**Ecological subsection[1]**	**Mean annual precipitation[1] (range cm)**	**Environmental indicators?[2]**	**Probable location of suitable spawning and rearing habitat**	**Current dominant riparian tree species[3]**	**Associated fish species[3]**
(8) Coyote/ Santa Clara/917	Fremont-Livermore Hills and Valleys Western Diablo Range	51-76	yes	San Felipe Ck.,Upper Penitencia Ck.	mixed-willow, white alder, California bay, coast live oak, western sycamore	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead, threespine stickleback, riffle sculpin
(9) Guadalupe/ Santa Clara/440	Santa Cruz Mtns.	76-152	yes	Upper reaches of: Los Gatos Ck., Guadalupe Ck.	California bay, coast live oak, coast redwood, Douglas fir, tanbark oak	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead, riffle sculpin
(10) San Francisquito/ Santa Clara-San Mateo/109	Santa Cruz Mtns.	77-152	yes	Bear Ck.,West Union Ck., Corte Madera Ck., Los Trancos Ck.	coast redwood, California bay, white alder, coast live oak, mixed willow	California roach, Sacramento sucker (juvenile),

						steelhead, threespine stickleback, prickly sculpin
(11) San Mateo/ San Mateo/90	Santa Cruz Mtns.	51-127	yes	San Mateo Ck.	coast redwood, California bay, white alder, mixed willow	California roach, Sacramento sucker (juvenile), steelhead, threespine stickleback, riffle sculpin, prickly sculpin
(12) Arroyo Corte Madera del Presidio/Marin/21	Marin Hills and Valleys	76-152	yes	Arroyo Corte Madera del Presidio, Old Mill Ck., Cascade Ck.	coast redwood, California bay, mixed willow	California roach, steelhead, threespine stickleback, prickly sculpin, tidewater goby
(13) Corte Madera/ Marin/73	Marin Hills and Valleys	76-152	yes	Corte Madera Ck., Tamalpais Ck., Ross Ck., Sleepy Hollow Ck., San Anselmo Ck., Fairfax Ck., Cascade Ck.	coast redwood, California bay, white alder, mixed willow	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead,

Table 2 (continued)

Watershed/ County/area km[2]	Ecological subsection[1]	Mean annual precipitation[1] (range cm)	Environmental indicators?[2]	Probable location of suitable spawning and rearing habitat	Current dominant riparian tree species[3]	Associated fish species[3]
						threespine stickleback, riffle sculpin, prickly sculpin, tidewater goby
(14) Sonoma/ Sonoma/440	Mt. St. Helena Flows and Valleys	76-152	yes	Upper Sonoma Ck., Bear Ck., All other tributaries with sufficient March-May flows	coast redwood, Douglas fir, tanbark oak, mixed oak, white alder, California bay	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead, threespine stickleback, riffle sculpin
(15) Napa/ Napa/1,103	Mt. St. Helena Flows and Valleys	76-152	yes	Kimball Canyon. Ck. All other tributaries with sufficient March-May flows	coast redwood, Douglas fir, tanbark oak, mixed oak, white alder, California bay	Pacific lamprey, California roach, Sacramento sucker (juvenile), steelhead,

threespine stickleback, riffle sculpin

[1]After Miles and Goudey (1997).
[2]Refer to environmental indicators of historically suitable coho salmon habitat discussed in Methods.
[3]Compiled from Leidy (2004).

depending on the specific watershed (Table 2). Coho salmon likely always occurred in streams supporting steelhead and Pacific lamprey, two species regularly associated with coho salmon in coastal Pacific drainages (Moyle 2002, Leidy 2004). Other fishes typically associated with coho salmon included California roach, juvenile Sacramento sucker, threespine stickleback, riffle sculpin, and prickly sculpin. In Arroyo Corte Madera del Presidio and Corte Madera creeks, Marin County, coho salmon occurred in the middle-to-lowermost reaches of streams with California roach, Sacramento sucker, threespine stickleback, riffle sculpin, prickly sculpin, and tidewater goby (Fry 1936, Leidy 2004). In the headwater reaches of streams, juvenile coho salmon likely were found with Sacramento sucker and steelhead that also used these streams reaches for spawning and rearing.

General Historical Distribution Patterns

Professor Alexander Agassiz from Harvard University and his associates collected fish from several Estuary streams during the 1850s and 1860s (Leidy 2004). Agassiz's collections from the Estuary are some of the earliest known collections of stream fishes from California, occurring prior to extensive hydrologic modification of Estuary streams. His collection of coho salmon from San Mateo Creek, San Mateo County, in 1860, is the earliest known record of this species for an Estuary watershed, and likely the Sacramento-San Joaquin Fish Province as well (refer to discussion of individual watersheds, below).

Snyder (1905) provided one of the first published descriptions of stream fish communities in the Estuary. Although Snyder described 13 fish species, including rainbow trout, as occurring in streams flowing into San Francisco Bay, he did not note the presence of coho salmon. Interestingly, Snyder (1908) also did not document the presence of coho salmon (or other salmonids) in coastal streams of Oregon and northern California; even though coho salmon were known to commonly occur during this time in many coastal streams of the region (i.e., Klamath and Russian rivers). Apparently, the omission of salmonids from early descriptions of species distributions was not unusual during this period, as Rutter (1908) failed to list Chinook salmon as occurring in the Sacramento and San Joaquin rivers even though spawning runs numbered in the hundreds of thousands of fish (Yoshiyama et al. 2001). Snyder's specific omission of coho salmon from streams tributary to San Francisco Bay may reflect more on such factors as sampling effort and timing (i.e., collections made during summer months when migrating adult fish are absent from streams), as well as his focus presumably on variation in non-salmonid species, rather than the absence of coho salmon from particular streams in the region.

Skinner (1962) discussed the distribution and ecology of coho salmon in his extensive review of fish and wildlife resources of the San Francisco Bay area. Skinner (1962: 66) states "In the Bay Area, silver salmon occur in most of the creeks directly tributary to the Pacific Ocean and at least a few streams tributary to San Francisco Bay." There is no mention in the text of the report of which specific streams tributary to San

Francisco Bay support coho salmon. However, Skinner (1962) does contain two maps (Plates IV and VI) depicting historical salmonid migration routes and probable distributions, as well as the present (circa 1962) distribution of salmonids within the San Francisco Bay, respectively. Specifically, the legend for Plate IV contains a heading for “Silver salmon and/or steelhead – Probable historical distribution” (Table X). Unfortunately, the maps do not differentiate between the distributions of coho salmon and steelhead where they both occur in the same stream. Presumably, a stream could contain only steelhead. Thus, one can assume only that some of the streams depicted on the maps supported coho salmon. In addition, Skinner (1962) does not provide the source(s) used to draw salmonid distributions on the maps. Finally, Skinner (1962) does not include several streams that were known to support coho salmon based in part on information developed by the CDFG (i.e., Arroyo Corte Madera del Presidio and Corte Madera creeks, Marin County). Notwithstanding these omissions, Skinner (1962) does confirm that some tributaries to the Estuary supported coho salmon at least until the early 1960s. We found corroborating evidence supporting the definite, probable, or possible occurrence of coho salmon for six of the twelve watersheds depicted by Skinner as supporting coho salmon or steelhead (Table 1).

Between 1875 and 1980, there are several records for the occurrence of juvenile and adult coho salmon in the surface waters of San Francisco and San Pablo bays (Leidy 2004). Presumably, adult coho salmon could be strays from Pacific coastal populations or fish migrating into Estuary watersheds or the Sacramento River system to spawn. The origin of juvenile coho salmon taken from the surface waters of the Estuary is not clear, but may represent locally spawned fish. From 1980-1995, only a single coho salmon was collected by midwater trawl in 1980 in San Pablo Bay (Baxter et al. 1999).

Brown et al. (1994) conclude that it is likely that prior to extensive hydrologic modifications, the Sacramento River system supported populations of coho salmon. We agree with the conclusions of Brown and Moyle (1991) and Bryant (1994) that presence of coho salmon in more inland locations in the Sacramento River system suggests that suitable habitats in Estuary streams that are geographically closer to the center of the species range likely also contained coho salmon.

Historical Distribution By Watershed

Walnut Creek, Contra Costa County. Gobalet et al. (2004) identifies coho salmon from an archaeological site on Walnut Creek, concluding that the fish probably were captured by Native Americans from within the drainage (Table 1). It is possible that the coho salmon were originally captured in San Francisco Bay and transported to the site adjacent to Walnut Creek. We agree with Gobalet et al (2004) that a likely source of these fish was Walnut Creek based on the likely historical presence of habitat suitable for coho salmon in the watershed (refer to discussion that follows).

Leidy (1983) mentioned anecdotal accounts by local residents of spawning migrations of coho salmon, as well as steelhead, in streams of the Walnut Creek watershed during the 1950s to mid-1960s (Table 1). Additional anecdotal evidence reported by the CDFG also suggested that coho salmon were common in upper Pine Creek, a tributary to lower Walnut Creek, in the 1950s, but became rare in the late-1960s (CDFG[2] 1977). Little Pine Creek flows from the northwest slopes of Mt. Diablo approximately 3 miles to the confluence with Pine Creek. The CDFG[3] (1977) concluded that little Pine Creek provided fair to excellent steelhead and coho salmon habitat, but its potential was limited due to downstream urbanization and associated habitat alterations to Pine and Walnut creeks.

Arroyo del Cerro Creek also flows from the north slope of Mt. Diablo to join Pine Creek in the City of Walnut Creek. The CDFG[3] (1977) reported that despite its history as a steelhead and coho salmon stream, it did not appear to support an anadromous fishery at the time of the survey. This was due primarily to downstream migration barriers, loss of riparian vegetation, and water diversions and pumping. Some suitable spawning and rearing habitat for coho salmon currently remains in the upper Pine Creek watershed, including habitat in Upper Pine, Little Pine, and Arroyo del Cerro creeks.

Other streams in the Walnut-Ramon Creek watershed that historically may have supported coho salmon based on the presence of suitable habitat include San Cantanio (Sans Criante) and Bollinger Canyon creeks, two headwater tributaries to upper San Ramon Creek (Table 2). Downstream drop structures and culverts have blocked access to potential steelhead and coho salmon spawning and rearing habitat in both tributaries. These streams also have been degraded by flood control activities and adjacent land uses, such as grazing and suburban development. However, remnant reaches with well-shaded pools with cool water temperatures and complex instream cover suggest that under pre-disturbance conditions, these streams provided habitat for steelhead and perhaps coho salmon (Leidy 2004). Channelization for flood control of the lower-most reaches of mainstem Walnut Creek and its major tributaries has almost entirely blocked upstream anadromous salmonid migration routes to suitable spawning and rearing habitat. In addition, urbanization has significantly degraded potentially suitable habitat for coho salmon throughout the watershed. We rate the historical occurrence of coho salmon in the Walnut Creek watershed as probable.

San Pablo Creek, Contra Costa County. Gobalet (1990, 1994) documents the presence of either Chinook salmon or coho salmon from five archeological sites in the vicinity of lower San Pablo Creek. Middens date from the Middle horizon period (1,000 B.C. to A.D. 500). Unfortunately, species identification was not possible and, therefore, although the majority of the fish remains are likely Chinook salmon captured by boat from San Pablo Bay, some of the remains could be coho salmon captured from San Pablo Creek during spawning migrations (Gobalet et al. 2004).

We found a single published reference stating that coho salmon occurred in the San Pablo Creek watershed (Table 1). In their classic study of population variation in rainbow trout in coastal California and Mexico, Paul Needham and Richard Gard (1959: 40) noted that "Formerly it [i.e., San Leandro Creek, Alameda and Contra Costa

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[2]California Department of Fish and Game (CDFG). 1977. River and stream survey files, Pine Creek, upper reach, Contra Costa County, 16 August 1977, Region 3, Yountville, California, 2 p. + map.

[3]CDFG. 1977. River and stream survey files, Arroyo del Cerro, Contra Costa County, 16-17 August 1977, Region 3, Yountville, California, 2 p. + map.

counties] flowed into San Francisco Bay near the City of Alameda and, like nearby San Pablo Creek, originally had runs of both steelhead and silver salmon" (Evans[4] 1957). While Evans' letter never specifically mentions the occurrence of coho salmon in San Pablo Creek, both Needham and Gard were intimately familiar with fishes in San Pablo Creek as a result of extensive fish sampling for research purposes and during annual field sampling trips for Needham's ichthyology class from the University of California, Berkeley. In addition to the above published reference, an avid salmon angler and longtime resident of the City of El Sobrante told the senior author of catching steelhead and coho salmon in San Pablo Creek downstream from San Pablo Dam in the late-1940s and early 1950s (C. Leggett, local resident, personal communication). We do not consider the above accounts as direct evidence and, therefore, have classified the occurrence of coho salmon in San Pablo Creek as probable (Table 1).

Construction of San Pablo Dam in 1918 blocked migration of anadromous salmonids into the upper San Pablo Creek watershed. Historically, the west fork of San Pablo Creek likely would have provided the highest quality spawning and rearing habitat for coho salmon in the upper watershed. The west fork of San Pablo Creek rises in the Oakland-Berkeley Hills and flows east from near the Broadway Tunnel (State Highway 24) for about 2 miles before joining the south fork of San Pablo Creek in the town of Orinda. Today the West Fork is entirely buried under Highway 24, except for a short reach in the uppermost headwaters. Needham and Gard (1959, p. 38-39) observed, "The west fork of San Pablo Creek is a lovely, clean little stream that never dries up in late summer. The quantity of water may fall to only a few gallons a minute, but since the stream is well shaded by trees or passes through tunnels over much of its course, water temperatures seldom get over 70° F [21° C] or approach the upper limits of tolerance for rainbows…. Many cut banks, rocks, boulders, and sunken logs or stumps provide excellent escape shelter. Alders, green bay, and buckeyes shade the stream almost completely over its course."

Zones of groundwater discharge along the Hayward Fault zone that traverses the west fork would have maintained cool summer water temperatures. These zones of groundwater discharge are observable today in remnant reaches of the upper headwaters of the west fork (Leidy 2004). During August of 2002, we recorded water temperatures within several small, well-shaded pools along the upper west fork at between 14.4-17.8° C. Summer water temperatures suitable for rearing coho salmon were likely present historically in the west fork.

Suitable rearing habitat for coho salmon likely was also present historically downstream of San Pablo Dam near the City of El Sobrante, based on my observations of this reach during 1981 and 1999. During fish surveys the senior author observed groundwater seeping from the streambanks of San Pablo Creek throughout this reach. Mid-afternoon water temperatures in pools within these zones of groundwater discharge ranged from 13.9-17.2° C in July 1981, a drought year, to 13.5-14.4° C during late-April

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[4]Evans, W.A. 1957. River and stream survey files, San Leandro Creek, Alameda County. Unpublished letter from W.A. Evans, CDFG, to P.R. Needham, U.C. Berkeley, 21/February/1957, CDFG, Region 3, Yountville, California 1 p.

1999, a year of above-average precipitation. In addition, this reach is currently characterized by complex instream cover in the form of undercut banks and large coarse woody debris (i.e., logs and branches), as well as nearly complete riparian canopy closure. Cool water temperatures are present even in the absence of minimum flow releases from San Pablo Dam. Our observations of habitat conditions in the 1980s-1990s suggest that historically, prior to the construction of San Pablo Dam, much of San Pablo Creek from El Sobrante upstream likely would have contained adequate spawning and rearing habitat for coho salmon.

During April 1974, a single juvenile (38 mm fork length) coho salmon was collected by otter trawl over mudflat in San Pablo Bay in the vicinity of San Pablo Creek marsh and Richmond Sanitary Landfill (Nakaji 1975). The origin of a juvenile coho salmon at this location in the Bay-Estuary is not clear, but suggests that this fish may have been spawned in a nearby stream and subsequently washed or moved downstream.

Strawberry Creek, Alameda County. Gobalet et al. (2004) references the identification of coho salmon remains from an archaeological site near Strawberry Creek by Follett (1975), and concludes that the fish could have been captured during spawning runs from the creek. Follett (1975) concludes that the coho salmon may have been taken either in nearby San Francisco Bay or in Strawberry Creek.

A July 1939 memorandum documents that W. I. Follett, Curator Emeritus of Ichthyology for the California Academy of Sciences, and also an Oakland resident, informed L. Shapovalov of the California Division of Fish and Game that Strawberry Creek "had supported a run of Silver [coho] Salmon." We consider this record very reliable given the source; however, it is likely not based on direct observation by Follett (Shapovalov[5] 1939: 1). Charbonneau and Resh (1992: 298) note that, "Steelhead salmon (*Oncorhynchus kisutch*)" were last noted during spawning migrations on the U.C. Berkeley Campus in the early 1930s. The somewhat confusing reference by Charbonneau and Resh (1992: 298) to "Steelhead salmon" may refer to steelhead, *Oncorhynchus mykiss*, rather than coho salmon. Steelhead are known to occur in all streams where coho salmon were known to occur in the Estuary, so their co-occurrence in Strawberry Creek cannot be ruled out, especially given the California Division of Fish and Game reference during the same period.

The headwaters of Strawberry Creek are crossed by the Hayward fault near the base of the Oakland-Berkeley Hills. Faulting has contributed to the formation of numerous groundwater seeps along the headwater reaches of the North and South Forks of Strawberry Creek. These seeps maintain permanent, cool water habitat in the headwaters, and presumably provided suitable rearing habitat for coho salmon and steelhead trout prior to degradation of the creek beginning in the 1880s (Charbonneau and Resh 1992). The South Fork in Strawberry Canyon still supports remnant stream reaches that contain cool, small, well-shaded pools and we believe that the stream likely contained suitable habitat for coho salmon historically (Leidy 2004, Table 2). In the absence of direct evidence, we consider the historical occurrence of coho salmon in Strawberry

[5]Shapovalov, L. 1939. River and stream survey files, Strawberry Creek, Alameda County, supplementary sheet, CDFG, Region 3, Yountville, California, 1 p.

Creek as probable (Table 1).

Temescal Creek, Alameda County. Fish remains belonging to coho salmon were identified from an archaeological site near Temescal Creek (Broughton 1997, Gobalet et al. 2004). Gobalet et al. (2004) concludes that the coho salmon may have been taken by Native Americans from Temescal Creek. Follett (1975) cites the historical accounts of others (see Louderback 1940, Schenck 1926) of "salmon" in Temescal Creek to suggest that habitat suitable for coho salmon may have been present in Temescal and Strawberry creeks, although the accounts may refer to either steelhead or coho salmon.

Historically, the upper reaches of Temescal Creek likely supported habitat suitable for coho salmon (Table 2). However, in the absence of conclusive direct evidence, we consider the historical occurrence of coho salmon in Temescal Creek as probable.

San Leandro Creek, Alameda and Contra Costa Counties. We found only one reference to coho salmon in the San Leandro Creek watershed. As noted above in the discussion of San Pablo Creek, California Division of Fish and Game Warden George Smalley reported runs of coho salmon and steelhead in San Leandro Creek "…in the early days" and "…that after the completion of the Upper San Leandro Reservoir a run still persisted to the base of the dam for many years" (Evans[4] 1957). However, it is not clear whether the reference is based on direct observation or a second-hand account.

The status of coho salmon in San Leandro Creek is confused by early historical accounts of several species of the genus *Oncorhynchus* from the watershed. There are references in the 1870s for the occurrence of "quinnant" or Chinook salmon in lower San Leandro Creek and Lake Chabot (U.S. Commission on Fish and Fisheries 1877, California Commissioners of Fisheries 1878). Chinook salmon purportedly maintained populations for several years following the construction of Lake Chabot in 1875 (California Commissioners of Fisheries 1878). Unlike coho salmon, Chinook salmon are occasionally known to establish viable reservoir populations in California and elsewhere, and there is the remote possibility that populations of Chinook salmon temporarily became established in the lake by fish trapped above the dam. Chinook salmon may have established temporary populations in San Andreas Reservoir after its completion in 1870, as well (Stone 1873, refer to San Mateo Creek discussion, below).

Landlocked steelhead are known to maintain viable populations in Chabot Reservoir and several tributary streams (Gall et al. 1990). In addition, Lake Chabot was stocked irregularly in the 1870s and 1880s with "schoodic" or the landlocked form of Atlantic salmon, *Salmo salar*, originally from Maine (Leidy 2004). The above circumstances raise the possibility of misidentification of the various species of *Oncorhynchus* and *Salmo* in the San Leandro Creek watershed. We consider the California Division of Fish and Game record for the historical occurrence of coho salmon in San Leandro Creek reliable, especially since we believe that suitable habitat was present in the watershed. The validity of records for historical presence of Chinook salmon is strengthened by the fact that individuals presumably competent to identify salmon worked at the State-hatching house at Lake Chabot. Therefore, San Leandro Creek may have historically supported two or possibly three species of *Oncorhynchus*. It is also possible that only steelhead were present in the watershed.

Headwater tributaries of San Leandro Creek, particularly San Leandro, Redwood, and Indian creeks, lie within the well-shaded, narrow canyons of the Oakland Hills that are dominated by the coast redwood-bay laurel riparian communities. Geologically, this portion of the East Bay Hills is intensively folded and faulted and the headwater streams contain perennial pools maintained by groundwater seeps. Stream gradients are typically < 3 %. The tributaries currently function as spawning and rearing habitat for landlocked steelhead that migrate out of Upper San Leandro Reservoir. Historically, San Leandro Creek from the present site of Lake Chabot upstream would have likely served as spawning and rearing habitat for coho salmon. Because of the lack of direct evidence, we consider the occurrence of coho salmon in San Leandro Creek as probable.

San Lorenzo Creek, Alameda County. Skinner (1962, Plate IV) identified San Lorenzo, Crow, Cull, and Palomares creeks as probable historical migration routes and habitat for silver salmon and/or steelhead prior to 1962. Skinner (1962, Plate VI) also identified San Lorenzo, Crow, and Cull creeks as "lightly used streams" by steelhead and/or coho salmon in circa 1962, but again did not identify which streams, if any, were used by coho salmon. Landowners also have reported coho salmon in Crow Creek during the 1960s (Alameda County Flood Control and Water Conservation District and Hagar Environmental Services 2002).

Early-19th Century Euro-Americans described the mainstem of San Lorenzo Creek as a perennial stream fed by springs and characterized by a well-developed riparian canopy of willows throughout its length (Grossinger and Brewster 2003). Historical photographs of the middle-mainstem reaches depict a low-gradient (<3%), well-shaded, stream with a gravel-cobble substrate (Grossinger and Brewster 2003). Urbanization has eliminated suitable habitat for coho salmon that may have existed historically within the San Lorenzo Creek watershed (Leidy 2004).

Alameda Creek, Alameda County. We classified the occurrence of coho salmon in Alameda Creek as definite. There is some anecdotal evidence that coho salmon were known to have occurred in Alameda Creek in the late-1930s (John Hopkirk, personal communication, 1981). Skinner (1962, Plate IV) identified Alameda, Calaveras, San Antonio, Indian, La Costa, Arroyo de la Laguna, Arroyo del Valle, Arroyo las Positas, and Arroyo Mocho creeks as probable historical migration routes and habitat for silver salmon and/or steelhead prior to 1962. Unfortunately, Skinner did not differentiate specific streams used by coho salmon, nor cite his information source. Skinner (1962, Plate VI) also identified Alameda, lower San Antonio, lower Arroyo de la Laguna, and lower Arroyo del Valle creeks as "lightly used streams" by steelhead and/or coho salmon in circa 1962, but again did not identify which streams, if any, were used by coho salmon.

Probably the most compelling evidence for the occurrence of coho salmon in the Alameda Creek watershed is photographic evidence during the 1940s to 1960s (Alameda Creek Alliance[6] 2002). An angler in Niles Canyon caught and photographed two adult coho salmon in February 1964 (Alameda Creek Alliance[6] 2002). An angler also

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[6]Alameda Creek Alliance. 2002. Photographs taken of fish caught by (1) H. Janssen, February 11, 1964, along concrete wall on Old Pottery Road, and (2) R. Mills, circa 1940s-1950s, Alameda Creek watershed. From files of Alameda Creek Alliance, Canyon, California.

caught an adult coho salmon sometime during the 1940s to 1950s in Sinbad Creek, a tributary to Alameda Creek near the head of Niles Canyon (Alameda Creek Alliance[6] 2002). The date of the 1964 photograph suggests that the fish were on their spawning migration. That two adult fish were caught also indicates that they may have been part of a larger spawning migration, although their occurrence as strays cannot be ruled out.

The most likely location of historically suitable habitat for coho salmon was in the small, perennial tributaries to Alameda Creek (i.e., Dry, Stoneybrook, Pirate), mainstem Alameda Creek at Little Yosemite, headwaters to San Antonio Creek (i.e., La Costa and Indian creeks), and Calaveras Creek, and its primary tributary Arroyo Hondo Creek, below migration barriers. Construction of Calaveras and San Antonio reservoirs in 1925 and 1964, respectively, would have destroyed and isolated significant reaches of potentially suitable coho salmon habitat. Augmentation of summer flows in the Niles Canyon reach of Alameda Creek beginning in the 1920s may have artificially improved habitat for coho salmon during spring and summer months. However, the operation of instream percolation dams for groundwater recharge in Alameda Creek downstream from Niles Canyon likely would have blocked out-migrating coho salmon smolts.

*Coyote Creek, Santa Clara County***.** We are aware of only a single reference to the occurrence of coho salmon in the Coyote Creek watershed. Apparently coho salmon may have been present in Coyote Creek into the 1950s prior to the completion of Anderson Dam (L. J. Hendricks, Emeritus, San Jose State University, personal communication, as cited in Smith 1998). The apparent persistence of coho salmon in the watershed into the 1950s suggests that some spawning and rearing habitat was located in the watershed downstream from Coyote Reservoir that was completed in 1936 and blocked access to about 310 km^2 of the watershed upstream from the reservoir. Whether the Coyote Percolation Reservoir constructed in 1934 on lower Coyote Creek below the present site of Anderson Reservoir was a complete barrier to migrating salmon is not known.

Historically, suitable habitat for coho salmon in the Coyote Creek watershed was likely restricted to the San Felipe Creek and Upper Penitencia Creek watersheds and possibly perennial reaches of Coyote Creek, and a few spring-fed tributaries upstream from Gilroy Hot Springs. Assuming the Coyote Percolation Reservoir was not a complete barrier to coho salmon; the construction of Anderson Dam would have eliminated any coho salmon that occurred in the San Felipe Creek watershed that now flows into Anderson Reservoir. However, if the Coyote Creek Percolation Reservoir were a migration barrier, then only Upper Penitencia Creek would have provided suitable habitat for coho salmon after 1934.

We believe that San Felipe Creek currently contains habitat potentially suitable to coho salmon (Leidy 2004). During early June and late-July 1997, the senior author recorded water temperatures within the San Felipe Creek watershed within pools containing rainbow trout between 11-13.3° C and 14.4-17.7° C, respectively. Zones of groundwater discharge along the Calaveras Fault zone that traverses the watershed maintain cool summer water temperatures.

Upper Penitencia Creek, which enters lower Coyote Creek near its mouth and drains the steep coastal hills to the east also may have contained suitable coho salmon habitat.

The upper watershed within Alum Rock Park contains habitat potentially suitable for coho salmon, although natural cascades and waterfalls block the additional suitable habitat in the uppermost reaches of Upper Penitencia Creek and its major tributary, Arroyo Aguague Creek (Leidy 2004).

Guadalupe River-Los Gatos Creek, Santa Clara County. Coho salmon are listed as historically occurring in the Guadalupe River (Santa Clara Basin Water Management Initiative 2001, Guadalupe-Coyote Resource Conservation District[7] 2001, L. Johmann[8, 9] 2002). The evidence is based on observations of coho salmon in the Guadalupe River system by longtime local residents and anglers, made mostly between the 1920s to 1960s (Johmann[8, 9] 2002). We believe that the Guadalupe River watershed possibly supported coho salmon based on multiple historical accounts of "salmon" utilizing the stream; some from individuals qualified to identify salmon, and based on the presence of suitable habitat conditions.

Based largely on the locations of fish collections made in 1895 by Snyder (1905), Smith (1999) concluded that historically the Guadalupe River and Los Gatos Creek likely supported heavy steelhead use throughout. Smith (1999: 3) observed for lowland reaches that, "Based on historical fish records, it seems likely that most of the channel on the two streams [i.e., Guadalupe River and Los Gatos Creek] was originally narrow and well-shaded and often provided cool water summer habitat suitable for heavy steelhead use." Cool summer water temperatures and a narrow, well-shaded channel are conditions that also would be favored by coho salmon.

The upper watersheds of the Guadalupe River, Los Gatos, and Alamitos creeks lie within zones of high precipitation and movement along the San Andreas Fault has created extensive zones of groundwater discharge. These streams currently contain habitat conditions suitable for coho salmon spawning and rearing; however, several large dams now block these stream reaches. The construction of several reservoirs, including Williams Reservoir (1895), Vasona Percolation Reservoir (1935), Austrian Dam-Lake Elsman (1950), and Lexington Reservoir (1953) blocked high quality coho salmon spawning and rearing habitat and altered flow regimes on Los Gatos Creek and several tributaries. On Guadalupe Creek, Guadalupe Dam was completed in 1935, blocking coho salmon access to Guadalupe and Los Capitancillos creeks. Access to potentially suitable habitat on Alamitos Creek and two tributaries, Herbert Creek and Barrett Canyon, was blocked with the construction of Almaden Reservoir in 1936. Anecdotal accounts, historical conditions in the lower watershed, and current habitat conditions in the upper watershed argue for the possible occurrence of coho salmon

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[7]Guadalupe-Coyote Resource Conservation District. 2001. Historic salmonid references. Available at 888 North First Street, Rm. 204, San Jose, California 95112. http://www.gcrcd@pacbell.net.

[8]Johmann, L.M. 2002. Documented accountings of salmonids in south bay waters. Unpublished report, 4 pp.

[9]Johmann, L.M. 2002. Reported accountings of salmonids in south bay waters. Unpublished report, 4 pp.

in the Guadalupe River watershed.

San Francisquito Creek, Santa Clara and San Mateo Counties. Gobalet et al. (2004) notes that the unidentified remains of salmonids from an archaeological site near San Francisquito Creek are possibly from coho salmon. Whether the coho salmon were captured by Native Americans in San Francisquito Creek or from nearby San Francisco Bay is unknown.

As in the Guadalupe River watershed, coho salmon are listed as historically occurring in San Francisquito Creek (Santa Clara Basin Water Management Initiative 2001, Guadalupe-Coyote Resource Conservation District[7] 2001, L. Johmann, personal communication). Local residents and anglers reported the presence of coho salmon in the watershed.

There is evidence that San Francisquito Creek was characterized by perennial flow to the Bay-Estuary until the early 1900s. The most likely location of historically suitable habitat for coho salmon was in perennial, well shaded reaches of mainstem San Francisquito Creek, and several small, perennial tributaries including Los Trancos, Corte Madera, Bear, and West Union creeks. These streams rise in the coast-redwoods of the Santa Cruz Mountains along the traverse of the San Andreas Fault Zone. Construction of Searsville Lake on San Francisquito Creek in 1890 blocked access to Corte Madera Creek and its tributaries. There is extensive groundwater pumping in the watershed by local residents that likely has severely reduced summer base flows and salmonid rearing habitat.

San Mateo Creek, San Mateo County. In 1860, Alexander Agassiz collected eight coho salmon from San Mateo Creek, San Mateo County (Museum of Comparative Zoology[10] 1860). The collection was prior to the construction of San Andreas and Lower Crystal Springs reservoirs on upper San Mateo Creek, in 1870 and 1888, respectively, which blocked fish access into much of the upper watershed. Presumably, some of the highest quality spawning and rearing habitat for coho salmon occurred within, and upstream from, the site of the reservoirs where riparian forests would largely have been dominated by coast redwood, California bay, mixed willow, and white alder. Upper San Mateo Creek runs directly along the San Andreas Rift Zone, characterized by extensive groundwater discharge. Interestingly, Agassiz's specimens of coho salmon were originally collected with rainbow trout and California roach (Museum of Comparative Zoology[11] 1860). The latter two species are often found together along with either riffle sculpin or prickly sculpin in the headwater reaches of Estuary streams (Leidy 1984).

There are early references to the likely occurrence of either Chinook and/or coho salmon in San Andreas Lake and Crystal Springs reservoirs, although the identification and source of the fish is not clear. In a review of hunting and fishing within San Francisco County, Hallock (1877: 15) notes that "…San Andreas [Reservoir is filled], chiefly with silver salmon of generally moderate size." Stone (1873: 201) describes

[10]Museum of Comparative Zoology, Harvard, ichthyology collection nos. MCZ 7123: 4 and MCZ 68471: 4. Cambridge, Massachusetts.

[11]Museum of Comparative Zoology, Harvard, ichthyology collection nos. MCZ 7083: 24, MCZ 52008: 39, and MCZ 1971: 21. Cambridge, Massachusetts.

juvenile and adult *Oncorhynchus* from "San Andrea's [San Andreas] lower reservoir" that may also be coho or Chinook salmon based on his description of morphology and coloration. Stone (1873: 201) describes the fish as "silvery" or "silver trout" with "no colored spots," observing that the fish "very much resembles [a] salmon smolt." The timing of the observations of *Oncorhynchus* within the reservoirs is consistent with an explanation that the fish were trapped following the initial damming of San Mateo Creek to form San Andreas Reservoir in 1870. Chinook salmon are known to persist in reservoirs and their tributaries, as apparently was the case in Chabot Lake in Alameda County following the damming of San Leandro Creek (see discussion, above). It is also possible that the fish described by Hallock and Stone were anadromous or "landlocked" steelhead trapped in the reservoir. Landlocked steelhead are known to grow to large size and attain a silvery coloration in other reservoirs in the Estuary, where they migrate into tributary streams to spawn (Leidy 2004).

Arroyo Corte Madera del Presidio, Marin County. Shapovalov (1946: 3-4) observed, "It is possible that in past years, and perhaps even recent times, Silver Salmon have also utilized these streams [*i.e.*, Arroyo Corte Madera del Presidio and Old Mill Creek] for spawning purposes." Shapovalov[12] (1946) recommends the stocking of coho salmon in the watershed, based on his finding that suitable spawning and nursery habitat for this species existed in the watershed at the time of his survey in 1946. Hallock and Fry (1967: 15) noted that coho salmon rarely occurred in the Sacramento-San Joaquin system, "although there were and perhaps still are spawning runs in a least two small Marin County streams tributary to San Francisco Bay. These are Corte Madera Creek and Arroyo Corte Madera Del Presidio. The latter is often called Mill Valley Creek."

There is a 1946 reference to the use of Old Mill Creek, a tributary to Arroyo Corte Madera del Presidio, by "sea-run steelhead and other salmonids" (Shapovalov[12] 1946: 2). We located a 1960 CDFG record for the stocking of 2,080 coho salmon fingerlings into Mill Valley Creek (CDFG, Silverado Fish Base files, Yountville, California, 17 June 1960). There is also a 1963 reference for Arroyo Corte Madera del Presidio Creek and its tributaries serving as "Important spawning and nursery area[s] for steelhead and possibly salmon" (CDFG[13] 1963: 1). These references are likely referring to the presence of coho salmon in these waters in addition to steelhead.

Leidy (1984) collected and released a total of two adults and five juvenile coho salmon from two sites on lower Arroyo Corte Madera del Presidio in 1981 (18 September 1981, 2: 176-197 fork length; 5:56-101 fork length). The fish were collected from a small, well-shaded, shallow pool with a gravel-cobble substrate. The water temperature was 13.3° C. This collection and another on the same date in Corte Madera Creek are likely the last known records for coho salmon in the streams within the Estuary.

Arroyo Corte Madera del Presidio is perennial and is characterized by riparian

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[12]Shapovalov, L. 1946. River and stream survey files, Old Mill Creek, Marin County, field note, California Department of Fish and Game, Region 3, Yountville, California. 2 pp.

[13]CDFG. 1963. River and stream survey files, Arroyo Corte Madera del Presidio and tributaries, 16 July 1963, Region 3, Yountville, California. 3 pp.

communities dominated by coast redwood, California bay laurel, and several willow species. Water temperature and rearing habitat is suitable for coho salmon.

Corte Madera Creek, Marin County. Gobalet et al. (2004) notes that Follett (1957, 1974) identified remains from the genus *Oncorhynchus* from archaeological sites near Corte Madera Creek. These remains may be from steelhead, Chinook salmon, and/or coho salmon.

We found a 1926 record for the collection of 10 juvenile coho salmon at the "Mouth of San Rafael [Corte Madera] Cr" (California Academy of Sciences[14] 1926). In a study of the life history of California roach, Fry (1936) noted the occurrence of coho salmon in San Anselmo Creek, a tributary of Corte Madera Creek. Fry (1936) also described San Anselmo Creek as perennial with well shaded pools, complex instream cover in the form of woody debris, and long, relatively deep pools. Hallock and Fry (1967: 15) found that coho salmon rarely occurred in the Sacramento-San Joaquin system, "although there were and perhaps still are spawning runs in a least two small Marin County streams tributary to San Francisco Bay. These are Corte Madera Creek and Arroyo Corte Madera Del Presidio."

Coho salmon were observed in Fairfax Creek, a tributary to Corte Madera Creek, during their spawning runs as late as 1965 (Cronin[15] 1980). Coho salmon were thought to spawn historically upstream from the town of Fairfax (Cronin 1980[15]). Leidy (1984) collected and released coho salmon from lower Corte Madera Creek in 1981 (18 September 1981, 2: 64 mm fork length). The fish were collected from a relatively long, moderately deep, well-shaded pool with a gravel-cobble substrate. The water temperature was 14.4° C. In January 1986, fourteen adult coho salmon were observed in Corte Madera Creek, but these fish may have originated from a 1983 transplant of approximately 600 coho salmon fry from Lagunitas Creek, a nearby coastal Pacific drainage (Emig[16] 1986). Finally, Rich (2000, Table 1) documents several anecdotal records (i.e., "no written records found") for the occurrence of coho salmon in tributaries of Corte Madera Creek, including Ross, San Anselmo, Sleepy Hollow, Fairfax, and Cascade creeks. Suitable habitat for coho salmon is present in all these tributaries (Table 2).

Sonoma Creek, Sonoma County. Skinner (1962) notes the occurrence of coho salmon and/or steelhead in Sonoma Creek. Although the Sonoma Creek watershed supports a regionally significant run of steelhead, we were unable to locate any historical evidence for the occurrence of coho salmon within the watershed (Leidy et al. 2003). Recent studies indicate that habitat suitable for coho salmon may be present within several headwater tributaries of the Sonoma Creek watershed (Leidy 2004,

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[14]California Academy of Sciences. 1926. Fish collection, 18 Mar 1926, collected by E. C. Scofield, catalog no. SU 59662: 10. San Francisco, California.

[15]Cronin, L.T. 1980. Restoration of Corte Madera Creek. Letter from L.T. Cronin, California Council of Trout Unlimited, to the California Department of Water Resources, 29 November 1980. California Department of Fish and Game, Region 3, Yountville, California. 2 pp.

[16]Emig, J.W. 1986. River and stream survey files, Corte Madera Creek, Marin County. 24 January 1986. California Department of Fish and Game, Region 3, Yountville, California. 1 p.

Sonoma Ecology Center 2004).

Napa River, Napa County. The Napa River historically and currently supports the largest run of steelhead within the Estuary (Leidy et al. 2005). In a 1966 study, the U.S. Fish and Wildlife Service, in cooperation with the CDFG, estimated that the Napa River supported an annual run of approximately 4,000 adult coho salmon (U.S. Fish and Wildlife Service[17] 1968). This run has since been eliminated. Unfortunately, the 1966 report did not provide evidence in support of this run size estimate for coho salmon in the Napa River watershed. A single coho salmon was captured in the Napa River Marsh in 1982, but the origin of this fish was not known (Emig[18] 1983).

Suitable habitat for coho salmon within the Napa includes several tributary streams flowing east and west to the mainstem Napa River from the narrow, well-shaded canyons of the Sonoma, Mayacama, and Vaca ranges. Coast redwood-Douglas fir, white alder, and oak-tanoak riparian communities characterize the tributaries. Zones of groundwater discharge are common along fault zones on the headwater reaches of many of these streams.

DISCUSSION

Estuary streams display ecological conditions and fish assemblages transitional between north and central coastal Pacific and Central Valley watersheds (Leidy 2004). In addition to containing more saltwater dispersant fishes than the Central Valley, Estuary streams also support more freshwater dispersant fishes than Pacific coastal drainages. For some species such as coho salmon, under historical conditions there was a gradient of decreasing population abundance from coastal Pacific, to Estuary, and to Central Valley watersheds. In the Estuary, coho salmon utilized habitats characterized by environmental conditions similar to those more commonly found in the high-rainfall coastal streams directly tributary to the Pacific Ocean that historically had relatively high abundances of coho salmon.

Other than our assessment, no review of the historical distribution of coho salmon in Estuary watersheds considered distribution records in the context of essential habitat requirements. As a result, previous studies likely have underestimated use of Estuary watersheds by coho salmon historically (Leidy 1984, Brown *et al.* 1994, Weitkamp et al. 1995, Adams et al. 1999, NMFS 2001, CDFG 2002). We found definite evidence that at least four Estuary watersheds (6%) historically supported coho salmon, with some evidence for their probable occurrence in another six watersheds (9%). Thus, we conservatively estimate that between 6-15% of Estuary watersheds

[17]U.S. Fish and Wildlife Service. 1968. Analysis of fish habitat of Napa River and tributaries, Napa County, California, with emphasis given to steelhead trout production. File memorandum, dated October 21, 1968, U.S. Fish and Wildlife Service, River Basin Studies, Sacramento, California. 22 p.

[18]Emig, J. W. 1983. River and stream survey files, Napa River, Napa County, field note dated 15 December 1983. California Department of Fish and Game, Region 3, Yountville, California. 1 p.

likely supported coho salmon.

Coho salmon are known to stray between watersheds (Shapovalov and Taft 1954, McElhany et al. 2000). However, coho salmon stray rates are highly variable, making generalizations about the magnitude of dispersal between watersheds difficult (McElhany et al. 2000). We were unable to make any generalizations about the origins of coho salmon spawners migrating into non-natal watersheds. Therefore, the possibility exists that some historical observations of single to a few coho salmon in Estuary watersheds cited in this study are the result of straying behavior in hatchery and/or wild spawners. Our review also indicates that the planting of coho salmon of hatchery origin in Estuary streams was likely extremely rare. This is not the case, however, for hatchery-reared steelhead, which received widespread and repeated plantings in Estuary watersheds.

Observations of coho salmon in a stream, especially migrating adult fish, also does not necessarily confirm the presence of a persistent population (B. Spence, NMFS, personal communication). As noted, adult coho salmon observed in a stream may be stray fish of hatchery origin rather than members of a persistent population. Because populations of coho salmon in Estuary streams are at the edge of their geographical range they may be relatively small and therefore, extremely vulnerable to localized extinctions (J. Smith, San Jose State University, personal communication).

Coho salmon showed a potentially broad geographic distribution in the Estuary, occurring in streams within seven ecological zones or subsections. This broad geographic distribution likely reflects the ability of coho salmon to adapt to local environmental conditions of their natal stream (CDFG 2002). Environmental characteristics of streams known historically to contain coho salmon shared several characteristics, most notably year-round cool water temperatures. Zones of groundwater discharge associated with faulting probably played an important role in maintaining suitable water temperatures for rearing coho salmon within the warmer, interior regions of the Estuary (e.g., Walnut, Alameda, and Coyote creeks). Coho salmon definitely occurred in three watersheds, and probably another two watersheds, characterized by the coast redwood riparian community, which is more typical of the high- rainfall coastal streams directly tributary to the Pacific Ocean that historically had relatively high abundances of coho salmon. All streams known or suspected to support coho salmon historically were characterized by distinct surface water connections to estuarine and marine environments, as well as stream flows during the months of February through May suitable for smolt out-migration.

CONCLUSIONS

Coho salmon populations have experienced declines throughout California attributable primarily to human activities, including water diversions, creation of migration barriers, streambed alteration for flood control, impaired water quality, removal of riparian vegetation, disruption of natural hydrological processes, and reduced instream habitat complexity (CDFG 2002). Physical changes to Estuary watersheds from urbanization have not only resulted in the extirpation of coho salmon but have made the assessment of the historical suitability of streams difficult. Consequently, we believe existing status reviews likely have underestimated the historical use of Estuary streams by coho salmon. Our best estimate indicates that a minimum of approximately 6-15% of Estuary watersheds likely contained coho salmon historically. Recovery goals for coho salmon in California include reintroduction into suitable stream habitats (CDFG 2002). Recent efforts to prioritize streams for the restoration of coho salmon within the Central Coast ESU include two Estuary watersheds, Arroyo Corte Madera del Presidio and Corte Madera creeks, Marin County (CDFG 2002). We recommend that the potential for the reestablishment of coho salmon into other watersheds with suitable habitat conditions be explored, especially watersheds where seasonal flow releases from large reservoirs have the potential to restore instream flows within stream reaches that supported coho salmon in the past.

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