

NOAA Technical Memorandum NMFS



FEBRUARY 2011

HISTORICAL OCCURRENCE OF COHO SALMON (*Oncorhynchus kisutch*) IN STREAMS OF THE SANTA CRUZ MOUNTAIN REGION OF CALIFORNIA: RESPONSE TO AN ENDANGERED SPECIES ACT PETITION TO DELIST COHO SALMON SOUTH OF SAN FRANCISCO BAY

Brian C. Spence
Walter G. Duffy
John Carlos Garza
Bret C. Harvey
Susan M. Sogard
Laurie A. Weitkamp
Thomas H. Williams
and
David A. Boughton

NOAA-TM-NMFS-SWFSC-472

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.



NOAA Technical Memorandum NMFS

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

FEBRUARY 2011

HISTORICAL OCCURRENCE OF COHO SALMON (*Oncorhynchus kisutch*) IN STREAMS OF THE SANTA CRUZ MOUNTAIN REGION OF CALIFORNIA: RESPONSE TO AN ENDANGERED SPECIES ACT PETITION TO DELIST COHO SALMON SOUTH OF SAN FRANCISCO BAY

Brian C. Spence¹, Walter G. Duffy², John Carlos Garza¹, Bret C. Harvey³,
Susan M. Sogard¹, Laurie A. Weitkamp⁴, Thomas H. Williams¹, and David A. Boughton¹

¹ National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center, Fisheries Ecology Division
110 Shaffer Road, Santa Cruz, California 95060

² U.S. Geological Survey, California Cooperative Research Unit,
Humboldt State University, Arcata, California

³ U.S. Forest Service, Pacific Southwest Research Station,
Redwood Sciences Laboratory, Arcata, California

⁴ National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center, Conservation Biology Program,
Newport, Oregon

NOAA-TM-NMFS-SWFSC-472

U.S. DEPARTMENT OF COMMERCE

Gary F. Locke, Secretary

National Oceanic and Atmospheric Administration

Jane Lubchenco, Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service

Eric C. Schwaab, Assistant Administrator for Fisheries

Table of Contents

List of Figures	v
List of Tables	vi
Executive summary.....	vii
1. Introduction.....	1
1.1 Central California Coast Coho Salmon listing history	1
1.2 Overview of petition to delist coho salmon south of San Francisco.....	2
1.3 Purpose of the BRT report	4
2. Original (1995) ESU boundary definition for CCC Coho Salmon.....	7
3. Biological organization and structure of salmon ESUs	9
3.1 Terms	9
3.2 Demographic processes	11
3.3 TRT findings on population structure and demographic processes in the CCC Coho Salmon ESU.....	12
3.4 Response to petition.....	14
4. Environmental template and history of the Santa Cruz Mountain region	19
4.1 Ecosystem characteristics in the Santa Cruz Mountains.....	19
4.2 Environmental history of the Santa Cruz Mountains.....	25
4.3 Response to petition.....	30
5. History of artificial propagation and release of coho salmon in streams south of San Francisco	35
5.1 Coho salmon stocking history prior to 1906.....	35
5.2 Stocking of Baker Lake coho salmon: 1906–1910.....	38
5.3 Stocking of coho salmon in Santa Cruz Mountain streams from 1911 to 1941	39
5.4 Post-1941 hatchery activities	41
5.5 Response to petition.....	43
<i>Could coho salmon observed prior to 1906 have been the result of hatchery plantings?....</i>	<i>43</i>
<i>Could the Baker Lake and subsequent introductions account for coho salmon populations that were present during the 1930s?.....</i>	<i>44</i>
6. Genetic data related to the southern boundary of CCC Coho Salmon	49
6.1 Genetic datasets	49
<i>Bjorkstedt et al. (2005)</i>	<i>49</i>
<i>Garza and Gilbert-Horvath, unpublished data</i>	<i>51</i>
<i>Garza et al. in prep</i>	<i>52</i>
<i>Bucklin et al. 2007</i>	<i>53</i>
<i>Garza et al. unpublished</i>	<i>54</i>
<i>Pearse et al. in press</i>	<i>55</i>
6.2 Summary of inference provided by genetic data	58

6.3 Response to petition.....	59
7. Historical evidence of salmon in streams and rivers south of San Francisco.....	61
7.1 Early explorations of coastal California fish faunas.....	61
7.2 Taxonomy and nomenclature of Pacific salmonids in the 19 th century.....	64
7.3 Knowledge of Pacific salmon life histories in the 19 th century.....	70
7.4 Evidence of anadromous salmonids in streams south of San Francisco Bay.....	71
<i>Evidence prior to 1880</i>	71
<i>The writings of Jordan and Gilbert, 1881–1894</i>	75
<i>The 1895 Carmel River Expedition</i>	78
<i>The writings of Jordan and Evermann, 1896–1908</i>	78
<i>Newspaper accounts of salmon in Santa Cruz Mountain streams</i>	79
7.5 Response to petition.....	79
<i>The writings of David Starr Jordan</i>	82
<i>Newspaper accounts of Baker Lake coho salmon introduction</i>	85
<i>Conclusions</i>	86
8. Archaeological evidence for the presence of coho salmon in coastal California South of San Francisco Bay.....	87
8.1 Review of archaeological evidence.....	87
<i>Gobalet 1990</i>	87
<i>Gobalet and Jones 1995</i>	88
<i>Gobalet et al. 2004</i>	88
<i>Gobalet (in press)</i>	89
8.2 Response to petition.....	90
9. Conclusions.....	93
10. References.....	97

List of Figures

Figure 4.1. Level III ecoregions of northern and central California.....	20
Figure 4.2. Map showing the extent of redwood forest on the California coast in 1881.....	21
Figure 4.3. Summer water temperatures in streams of the Santa Cruz Mountains in 2000 and 2005.....	23
Figure 4.4. Example of oxen skidding logs over corduroy road in Big River Basin, Mendocino County, circa 1851-1852.....	26
Figure 4.5. Map showing known locations of sawmills and shingle mills in the Santa Cruz Mountains from 1840 to 1905.....	27
Figure 4.6. Photograph of the California Powder Works diversion dam on the San Lorenzo River.....	29
Figure 5.1. Distribution of hatchery salmon in streams of California from 1873 to 1919.	36
Figure 5.2. Distribution of hatchery salmon by the California Fish and Game Commission from 1871 to 1921.	37
Figure 5.3. Annual precipitation and 3-year running mean of precipitation measured at Santa Cruz, California, for water years 1905 to 2010.	47
Figure 6.1. Bootstrap consensus tree for coho salmon in California.....	50
Figure 6.2. Isolation-by-distance on coho salmon based on pairwise F_{ST} and geographic distance for samples from the CCC-Coho ESU (solid line) and throughout coastal California (dashed line).	51
Figure 6.3. Maximum likelihood phylogeographic tree for coho salmon across nearly the entire range of the species.....	52
Figure 6.4. Maximum likelihood phylogeographic tree for coho salmon in California.....	54
Figure 6.5. Consensus tree from 1000 bootstrap samples of the 2003 coho salmon dataset in Figure 6.4 and the resulting chord distance /neighbor-joining trees.....	55
Figure 6.6. Regression of pairwise genetic distance on the geographic distance between sets of sampling sites of juvenile coho salmon in 2003 from California 23 basins.	56
Figure 6.7. An unrooted neighbor-joining tree showing chord distances (Cavalli-Sforza and Edwards 1967) among 32 California coho salmon (<i>Oncorhynchus kisutch</i>) collections formed by pooling samples within drainages by year class.	57

List of Tables

Table 5.1. Number of coho salmon eggs delivered from Baker Lake Hatchery in Washington to Brookdale Hatchery in Santa Cruz County, California, from 1906 to 1910 and resulting fry output.	38
Table 5.2. Reported plants of hatchery coho salmon fry in streams of the Santa Cruz Mountains from 1911 to 1941.....	40
Table 5.3. Reported plants of hatchery coho salmon in streams of the Santa Cruz Mountains from 1942-present.....	42
Table 6.1. Number of alleles per locus for 18 microsatellites genotyped in 2008 juvenile coho salmon from Santa Cruz and San Mateo county streams.	57
Table 7.1. Putative salmon and trout “species” identified in Suckley 1861 in waters draining to the Pacific Ocean.	66
Table 7.2. Summary of Pacific salmon distribution descriptions written by D.S. Jordan, C.H. Gilbert, and W.B. Evermann from 1881 to 1908.....	76
Table 7.3. Summary of newspaper accounts of salmon in streams of the Santa Cruz Mountains.	80

Executive summary

In November 2003, the National Marine Fisheries Service received a petition from Homer T. McCrary to redefine the southern extent of the Central California Coast Coho Salmon Evolutionarily Significant Unit (CCC Coho Salmon ESU) to exclude populations that spawn in coastal watersheds south of the entrance to San Francisco Bay (i.e., the Golden Gate). The petitioner's primary premise is that the coho salmon populations inhabiting this region for the last century are the result of introductions of nonnative stocks from locations north of San Francisco. The petitioner presented four main lines of information to support his conclusion: (1) historical (pre-1905) accounts suggesting that the southern boundary of the CCC Coho Salmon ESU was at or north of San Francisco Bay, (2) information and historical accounts on stocking of nonnative coho salmon from Baker Lake, Washington, between 1906 and 1910, which the petitioner contended pre-dated any records of coho salmon occurring in streams south of San Francisco Bay; (3) archeological studies conducted in the central California coast region that had failed to detect coho salmon remains in Native American middens; and (4) assertions that the dynamic nature of the physical environment of the Santa Cruz Mountains is not conducive to persistent coho salmon populations.

Subsequent to NMFS' receipt of the November 2003 petition, museum specimens of juvenile coho salmon collected in 1895 (pre-dating the 1906–1910 introduction of Baker Lake coho salmon) from four coastal streams south of the Golden Gate were discovered in the California Academy of Sciences (CAS) ichthyology collection. Upon learning of the CAS specimens, the petitioner filed an addendum (9 February 2004) to the November 2003 petition that challenged the reliability of the specimens and concluded that, even if these specimens were valid, they were not evidence of permanent coho salmon populations in the region. The petitioner asserted that these fish were likely “*a temporary colony established by strays.*”

Over the next two years, several written exchanges between NMFS Southwest Fisheries Science Center (SWFSC), NMFS Regional Office, and the petitioner took place, with NMFS concluding that the petitioned action was not warranted and the petitioner responding by providing additional information and analysis to support his claim. On 13 January 2006, the petitioner sued NMFS for failing to issue the 90-day finding on the petition. On 23 March 2006, NMFS published a 90-day finding in the Federal Register (71 FR 14683) stating that the petitioned action was not warranted. Later in March 2006, the petitioner filed an amended complaint, contending that the NMFS finding that the petition was “not warranted” was arbitrary, capricious, and contrary to law. In February 2010, the Federal Court ruled in favor of McCrary, determining that NMFS acted arbitrarily and capriciously in not accepting the petition for review. Specifically, the Court ruled that NMFS had applied the 12-month standard of review to the petition, rather than the 90-day “reasonable person” standard. In response to this decision, NMFS published a Federal Register notice accepting the petition on 2 April 2010 (75 FR 16745). This resulted in the convening of a new Biological Review Team (BRT) consisting of representatives from NMFS Southwest and Northwest Fisheries Science Centers, as well as fishery experts from the U.S. Forest Service and U.S. Geological Survey, to specifically address the petitioned action and to determine the appropriate southern boundary for the CCC Coho Salmon ESU.

The BRT conducted a review of historical and recent information germane to the petitioned action and the appropriate southern boundary for the CCC Coho Salmon ESU. This review encompassed evidence and arguments contained within the petition and amendment, substantial new information found in the historical literature, and recent analyses of both genetic and archaeological data. Based on this review, the BRT concludes that the available evidence does not support the petitioner's contention that the boundary for CCC Coho Salmon ESU should exclude coastal streams south of the entrance to San Francisco Bay. Further, the BRT concludes that the ESU should be extended southward from its currently defined southern limit at the San Lorenzo River to include the Soquel and Aptos creek watersheds. This conclusion was based on the ecological similarity and close proximity of the Soquel and Aptos creek watersheds to those immediately to the north, coupled with the documented natural recolonization of the Soquel Creek watershed by coho salmon during the 2007–2008 spawning season.

In reaching its conclusions, the BRT considered numerous types of information: (1) historical evidence in the form of museum collection records and both scientific and popular writings related to the occurrence of coho salmon and other salmonids south of the Golden Gate; (2) archaeological evidence related to occurrence of salmonids in coastal California; (3) information on environmental conditions in the region, including the history of anthropogenic disturbance; (4) historical records documenting planting of hatchery coho salmon into streams of the Central Coast region; and (5) modern genetic evidence elucidating the relationship between populations south of the Golden Gate and those to the north, both within and outside the CCC Coho Salmon ESU. The BRT also evaluated the petitioner's arguments that south-of-San Francisco populations do not constitute an important part of the evolutionary legacy of the species.

Historical Evidence

The strongest direct evidence for the occurrence of coho salmon populations south of the Golden Gate is museum specimens of coho salmon collected from four separate watersheds (Gazos, Waddell, Scott, and San Vicente creeks) south of San Francisco in 1895, which are currently housed in the CAS ichthyological collection. These collections resulted from the Stanford-led Carmel River Expedition, which surveyed coastal streams from the Carmel River (Monterey County) north to San Gregorio Creek (San Mateo County). These specimens, which have been confirmed to be coho salmon through morphological analysis by CAS experts, firmly establish the presence of coho salmon south of the Golden Gate prior to the first known stocking of coho salmon in the region, which took place between 1906 and 1910.

The petitioner asserts that the CAS museum specimens are unreliable (1) because they were originally identified in the Stanford ledgers as Chinook and chum salmon and (2) because jars in the Stanford collection were broken in the 1906 earthquake and conceivably could have been “contaminated” with coho specimens from another locality. The BRT was not persuaded by either of these arguments. The BRT found numerous examples where early researchers, including many of the preeminent ichthyologists of the era, had difficulty discriminating among the different species of salmonids, particularly in their juvenile phases. This reflects in part the considerable confusion surrounding the taxonomy and nomenclature of salmonids that prevailed in the 1800s and early 1900s, particularly the use of certain common names such as “dog

salmon” to describe multiple species of salmonids. As to the possibility that these jars were “contaminated” during the aftermath of the earthquake, the BRT concluded this was unlikely due to the fact that (1) there is no evidence that any of the jars in question were broken, and (2) Stanford’s staff took steps to guard against such contamination of specimens when placing fish from broken jars into new jars.

The petitioner gave considerable weight to the early writings of David Starr Jordan and collaborators, who on multiple occasions between 1881 and 1905 described coho salmon as being present or abundant “*from San Francisco northward.*” The petitioner concluded from this that coho salmon were not present in streams south of San Francisco. The BRT felt that the petitioner’s interpretation of Jordan’s writings attributes a precision and accuracy to these early descriptions of species’ ranges that is not supported by the available scientific data or understanding that existed during the late 1800s and early 1900s. The extent of faunal surveys in coastal watersheds of California, including the region between Santa Cruz and the Golden Gate, was insufficient for scientists of that era to precisely define species’ ranges. Further, the ample evidence of confusion in the taxonomy and nomenclature of Pacific salmonids prior to 1910—particularly the confusion between chum and coho salmon arising from the use of the common name “dog salmon” to describe both species—strongly indicates that these early descriptions of species’ ranges must be interpreted with considerable caution.

Numerous other historical records from the 1870s to early 1900s, both scientific and popular, clearly indicate that, in addition to steelhead, at least one species of Pacific salmon regularly occurred in watersheds south of the Golden Gate in numbers sufficient to support both commercial and recreational fisheries. Given current understanding of the ecological requirements, habitat preferences, and historical distributions of the five Pacific salmon species found in North America, the BRT concluded that coho salmon are the most likely candidate to have consistently occupied these watersheds. Although it is possible that Chinook salmon also occurred in streams south of the Golden Gate, the BRT viewed it highly improbable that small local watersheds would have supported Chinook salmon populations but not coho salmon populations.

Archaeological Evidence

The petitioner noted that previous archaeological studies had failed to detect coho salmon in coastal areas south of the entrance to San Francisco Bay, arguing that this supported his hypothesis that coho salmon were not native to the region. However, since the petition was filed in 2003, new archaeological evidence from the Año Nuevo region clearly establishes the presence of coho salmon near the Santa Cruz-San Mateo county border in close proximity to Waddell and Gazos creeks (Adams et al. 2007; Gobalet, in press). Additionally, salmonid vertebrae from middens at Elkhorn Slough near the mouth of the Salinas and Pajaro rivers (northern Monterey County) have been tentatively identified as coho salmon, as have remains from a late-1800s home site in Santa Barbara (Gobalet, in press). One cannot rule out the possibility that coho salmon remains in middens at Año Nuevo and the apparent remains at Elkhorn Slough were ocean-caught fish or fish that were imported to the area from elsewhere through trade. Nevertheless, the archaeological record for occurrence of coho salmon south of

the Golden Gate is now as strong as it is north of San Francisco Bay, where the historical occurrence of coho salmon is not in dispute.

Environmental Suitability

The petitioner contends that the environment of the Santa Cruz Mountains is too harsh or extreme to allow for persistent populations of coho salmon. In support of these arguments, the petitioner and his representatives (Kaczynski and Alvarado 2006) presented several analyses comparing stream discharge and precipitation patterns in the region south of San Francisco with those immediately north of San Francisco Bay in Marin County. The petitioner also argues that both high sediment rates and drought conditions that limit access to spawning streams south of San Francisco create conditions unfavorable for persistent coho salmon populations.

The BRT concluded that historical environmental conditions in the Santa Cruz Mountains were almost certainly conducive to the presence of persistent coho salmon populations in the region, as these conditions are not appreciably different from watersheds immediately to the north where the historical occurrence of coho salmon is not in dispute. The BRT was not persuaded by the petitioner's analyses of flow extremes, as these comparisons failed to account for human alteration to the natural flow regimes in the streams in question (i.e., mandated flow releases from an upstream reservoir in the Marin County stream and substantial water diversion in the two Santa Cruz County streams). Likewise, the BRT found the precipitation comparison to be highly questionable given differences in characteristics of the two measurement sites. Further, even if the minor differences shown in Kaczynski and Alvarado (2006) were representative of the two regions, the BRT was not convinced of the biological significance of such differences.

Nor was the BRT persuaded that high sediment yields would preclude coho salmon from utilizing Santa Cruz Mountain streams. Although these streams are subject to high amounts of fine sediment, this problem is neither new nor unique to the Santa Cruz Mountains. Sediment delivery to streams has undoubtedly increased in response to logging, agriculture, roads, and other developments that have been prevalent in the region since before 1850. Additionally, coho salmon occupy streams such as the Eel River, Mad River, and Redwood Creek (Humboldt County), which have some of the highest sediment yields recorded in the United States. At present there is no clear evidence that pre-logging sedimentation rates differed between the areas north and south of San Francisco.

Likewise, there is no evidence to indicate that high summer stream temperatures limit use by coho salmon. The BRT's examination of modern temperature records indicate that, even under current conditions, many local streams have temperature regimes that are well within the tolerable range for coho salmon. Under historical conditions, prior to modification of riparian forest and substantial water diversions, stream temperatures were almost certainly cooler than at present.

The BRT agrees that current conditions pose significant challenges to coho salmon; however, we conclude that the difficulties coho salmon currently have in persisting in local streams is predominately a function of anthropogenic effects rather than any inherent characteristics of

local watersheds. Substantial modification of streams by intensive timber harvest, tanneries, paper mills, and other human developments began in the mid-1800s. These activities undoubtedly resulted in substantial reductions or extirpation of local coho salmon populations prior to the first ichthyological surveys of Central Coast streams that took place in the late 1890s.

Hatchery History

The history of artificial propagation, broodstock importation, and release of coho salmon in streams and rivers south of San Francisco was reviewed to address three issues germane to the petition: (1) whether the observation of coho salmon in four Santa Cruz Mountain streams in 1895 might have been the result of hatchery introductions, as suggested by the petitioner (McCrary 2004); (2) the likelihood that the substantial numbers of coho salmon that were documented in Waddell Creek during the 1930s and 1940s were the result of the Baker Lake coho salmon introductions that took place in 1906–1910 or subsequent introductions; and (3) whether extant populations of coho salmon in streams south of San Francisco are the result of these and subsequent introductions of nonnative fish. The last of these questions is addressed under “Genetic Evidence” below.

The BRT’s review of historical records found no credible evidence to support the hypothesis that coho salmon observed and collected in 1895 were the result of hatchery plantings and, in fact, found substantial evidence to the contrary. The published records clearly demonstrate that neither federal nor state-owned hatcheries produced or released coho salmon into waters south of San Francisco prior to the 1906 introduction of Baker Lake fish. While some small-scale privately owned hatcheries and rearing ponds operated in the state prior to 1906, the BRT found no evidence that any of these reared or distributed coho salmon south of San Francisco and considers it unlikely since these operations typically relied on eggs or fry from state or federal sources. The only pre-1906 evidence that hatchery propagation of salmon of any kind took place in the region between San Francisco and Santa Cruz is Jordan’s (1887) reference to an attempt to rear “*native salmon and trout*” [emphasis added] in ponds in the Pescadero Creek watershed.

Between 1906 and 1910, approximately 450,000–500,000 eggs from Baker Lake, Washington, were transferred to the Brookdale Hatchery on the San Lorenzo River, and fry produced from these eggs were released into Santa Cruz area waters. Following these introductions, only two additional plantings of hatchery coho salmon occurred between 1911 and 1929, one in 1913 and one in 1915. Consequently, more than four generations passed between 1915 and 1929 during which there is no recorded stocking of coho salmon into streams south of the Golden Gate. The BRT concluded that it was highly unlikely that this limited stocking from 1906 to 1915 could have been responsible for the substantial coho salmon population that was documented in Waddell Creek between 1933 and 1941 (Shapovalov and Taft 1954). The BRT based this conclusion on several considerations. First, the effectiveness of early hatchery practices is debated, given the lack of understanding of fish diseases and nutritional requirements at that time, and the practice of releasing fish as fry likely led to very low survival rates. Second, evidence indicates that the success of transplanted fish generally declines with distance fish are transplanted from their natal streams. This is particularly relevant in the present case, since the Baker Lake coho salmon stock evolved in a cold, snow-melt driven system and had adapted to

these conditions by evolving a unique summer adult run timing that would be highly maladaptive in the Santa Cruz Mountain region. And third, while the release of several hundred thousand coho salmon fry into streams between 1906 and 1928 might seem significant, the high mortality rates that characterize salmonids and other fishes during their early life stages means that these releases would likely have resulted in only a small number of adults returning to the area, even under optimistic survival scenarios.

Genetic Evidence

Within the last decade, a number of genetic datasets have been collected from coho salmon in California that inform the issues raised in the petition and subsequent communications from the petitioner (McCrary 2004, 2005; McCrary et al. 2004), as well as in Kaczynski and Alvarado (2006). Four analyses of population structure are consistent in identifying contemporary coho salmon populations south of the Golden Gate as genetically part of the CCC Coho Salmon ESU (Bjorkstedt et al. 2005; Garza and Gilbert-Horvath, unpublished data; Garza et al. in prep., and Bucklin et al. 2007). These analyses unequivocally demonstrate that the ancestry of south-of-San Francisco populations is not strongly influenced by the introductions of fish from other ESUs documented by Bjorkstedt et al. (2005), Kaczynski and Alvarado (2006), and this report. In addition, while the data do not rule out some contribution of fish imported from other populations within the CCC Coho Salmon ESU (e.g., the Noyo River), the patterns of isolation by distance and population clustering, evident in all of the datasets but particularly in that of Garza et al. (in prep.), rule out the possibility that contemporary coho salmon populations south of the Golden Gate are entirely the result of such importations. Because coho salmon populations within an ESU are, by definition, expected to exchange migrants at rates sufficient to influence each other's demography and evolutionary trajectory, it is not possible to determine whether similarities between populations in the southern and northern parts of the CCC Coho Salmon ESU are due entirely to natural processes, or whether the anthropogenic movement of fish throughout the ESU has also had an effect.

An additional genetic study that has bearing on the question of the appropriate southern boundary for the CCC Coho Salmon ESU involves analysis of tissues from naturally produced juvenile coho salmon collected from Soquel Creek during the summer of 2008. This was the first documented occurrence of successful reproduction by coho salmon in this creek in more than a decade. The genetic evidence indicates these coho salmon (1) showed clear genetic affinity to other populations in the region south of the Golden Gate (Scott Creek), and (2) were the product of a minimum of two reproductive events. The implications of these findings are discussed below.

Evolutionary Legacy

The petitioner initially contended that coho salmon populations south of the Golden Gate were established by the introduction of coho salmon from Baker Lake, Washington, and maintained by subsequent introductions of stocks from both within and outside the ESU. From this, the petitioner concluded that extant populations “do not possess or carry an evolutionary legacy, and

thus, do not qualify for federal listing” (McCrary 2003). Subsequent to the finding of the 1895 CAS coho salmon museum specimens, the petitioner presented a different evolutionary legacy argument, contending that (1) coho populations south of San Francisco were ephemeral populations established by strays from the north, and (2) because they were ephemeral or “sink” populations, they contribute nothing to the evolutionary legacy of the species (or ESU) (McCrary 2004, McCrary et al. 2004, Buchal 2005).

The BRT disagrees with both facets of the petitioner’s latter argument. First, the BRT found no compelling evidence that populations south of the Golden Gate were ephemeral, at least not at the time scales implied by the petitioner (i.e., where the frequency of disturbance events with the potential to cause extirpation of entire populations was sufficient to prevent populations from persisting for any length of time). In its review of environmental data, the BRT found little evidence to suggest that environmental conditions in the Santa Cruz Mountains differ sufficiently from those in the region immediately north of the Golden Gate to result in appreciable differences in the dynamics and extinction risks of populations. We concurred with the assessment of Bjorkstedt et al. (2005), who concluded there were likely at least two populations (San Lorenzo River and Pescadero Creek) with a high probability of persisting at time scales of 100 years or more.

Further, the BRT believes that, in concluding that ephemeral or sink populations could not contribute to the evolutionary legacy, the petitioner is incorrectly applying the evolutionary legacy criterion to *individual populations*, rather than to the ESU as a whole. Consequently, even if the petitioner’s assertion about the ephemeral nature of south-of-San Francisco populations is correct, this does not mean that these populations contribute nothing to the evolutionary legacy of the ESU. Current understanding of metapopulation function indicates that (1) a persistent metapopulation may consist entirely of ephemeral populations, and (2) sink populations can play important roles in metapopulation persistence. In addition, populations at the edge of a species geographic range frequently experience environmental conditions that generate evolutionary novelty; gene flow from these marginal populations to central populations during times of population contraction is an important means for maintaining or enriching genetic diversity of an ESU.

Conclusions regarding the appropriate southern boundary for the CCC Coho Salmon ESU

Following review and discussion of the available information, BRT members voted on the primary question of whether the petitioned action was warranted, allocating ten “yes” or “no” votes on the question “*Does the available evidence support a boundary for CCC coho salmon that excludes coastal streams south of the entrance to San Francisco Bay?*” The vast majority (66 of 70, or 94.3%) of the BRT votes were in the “no” category, with three BRT members casting all 10 of their votes as “no” and the remaining four members casting nine of ten votes as “no.” These results indicate that all BRT members were highly confident in concluding that the CCC Coho Salmon ESU extends to watersheds south of the Golden Gate.

The BRT then discussed whether the available ecological and biological evidence supports the current ESU boundary at the San Lorenzo River. The BRT unanimously concluded there was no

strong ecological or biological justification for the current ESU boundary. There is no significant ecological break before the southern edge of the Santa Cruz Mountains, which marks the transition from the Coast Range ecoregion to the Southern and Central California Chaparral and Oak Woodlands ecoregion. The Soquel Creek and Aptos Creek watersheds are both in close proximity to the San Lorenzo River (6.5 and 10 km to the south, respectively), and historically shared many habitat characteristics with similar-sized coho salmon-bearing watersheds to the immediate north. As such, the BRT considered it improbable that coho salmon would historically have been present in the San Lorenzo River and other watersheds to the north, but not in the Aptos or Soquel Creek watersheds.

Furthermore, recent (2008) observations of juvenile coho salmon in Soquel Creek confirm successful reproduction by coho salmon in this watershed, and genetic evidence indicates these coho salmon (1) showed clear genetic affinity to other populations in the region south of the Golden Gate, and (2) were the product of a minimum of two reproductive events. These observations strongly support including the Soquel Creek watershed within the ESU boundary. The close proximity and environmental similarity between Soquel and Aptos creeks suggest that Aptos Creek should likely be included as well, especially considering the likelihood of coho salmon straying into this watershed from populations to the immediate north. While the BRT believes that Pajaro River tributaries draining the Santa Cruz Mountains (e.g., Corralitos Creek and perhaps others) may have also supported coho salmon, the lack of historical or recent evidence of naturally occurring coho salmon in the Pajaro River watershed makes inclusion of these streams within the ESU more difficult to justify. The BRT concludes, however, that any coho salmon found spawning in Santa Cruz Mountain streams south of Aptos Creek that were not the result of stock transfers should be considered part of this ESU.

1. Introduction

The federal Endangered Species Act (ESA) allows the listing of not only species and subspecies, but also “distinct population segments” of vertebrates. The policy of the National Marine Fisheries Service (NMFS) regarding Pacific salmon is that populations are considered “distinct” for the purposes of ESA if they form an “evolutionarily significant unit” or ESU. To be considered an ESU, a population or group of populations must (1) be substantially reproductively isolated from other populations and (2) contribute substantially to the evolutionary legacy of the species (Waples 1991).

1.1 Central California Coast Coho Salmon listing history

Coho salmon south of the entrance to San Francisco Bay have a long history with respect to the federal ESA. In March, 1993, NMFS received the first petition to list coho salmon inhabiting Scott and Waddell creeks as an endangered species (SCCPD 1993). The petitioner’s main arguments were that Scott and Waddell creeks met the “isolation” criterion (described above) because they were geographically and genetically isolated, and their distinctive life history and habitat characteristics were sufficient to meet the “legacy” criterion. Taken together, the petitioners argued the populations qualified as an ESU that was warranted for listing under the ESA due to steep declines in population abundance (90% in 50 years, 95–98% since the 1800s).

In response to this petition, NMFS began a formal status review that was completed in April 1994 (Bryant 1994). The review concluded that available information did not make a strong case for reproductive isolation of coho populations in Scott and Waddell creeks, but that these populations were part of a larger, yet undefined, ESU.

Before the 1994 status review was completed, NMFS received two additional petitions seeking protection for coho salmon along the West Coast. In response to all three petitions, NMFS initiated a status review of coho salmon in Washington, Oregon, and California, forming a biological review team (BRT) to conduct this review (Weitkamp et al. 1995). The status review had two primary objectives: (1) to define appropriate ESUs of coho salmon within the region, including the ESU to which Scott and Waddell creek coho salmon belonged, and (2) to assess the extinction risk of these ESUs. This effort culminated in the publication of a status review that delineated coho salmon ESUs throughout the Pacific Northwest and California. The southernmost of these ESUs, the Central California Coast Coho Salmon ESU (CCC Coho Salmon ESU), was determined to comprise salmon spawning in streams and rivers from Punta Gorda in the north to and including the San Lorenzo River in central California, including tributaries of San Francisco Bay but excluding the Sacramento-San Joaquin River system. The BRT also concluded that CCC Coho Salmon were, at that time, in danger of extinction. In the year following publication of Weitkamp et al. (1995), additional information on coho salmon presence in the ESU became available and was considered by the BRT. Again, the majority of the BRT concluded that CCC Coho Salmon were in danger of extinction, while a minority concluded the ESU was not in danger of extinction but was likely to become so in the foreseeable future (NMFS 1996).

Following publication of the status review (Weitkamp et al. 1995) and subsequent update (NMFS 1996), NMFS listed the CCC Coho Salmon ESU as “threatened” under the ESA in 1996 (61 FR 56138). In 2003, NMFS initiated a new status review in response to a 2001 court ruling (*Alsea Valley Alliance v. Evans*, 161 F. Supp. 1154 D. Oreg. 2001), in which it was determined NMFS improperly listed only portions (excluding certain hatchery populations) of the Oregon Coast coho salmon ESU. The new BRT again concluded that CCC Coho Salmon were in danger of extinction, citing further declines in abundance and the extirpation or near-extirpation of many populations in the southern portion of the ESU (Good et al. 2005). Based on these findings, NMFS changed the status of the CCC Coho Salmon ESU from threatened to endangered in June of 2005 (70 FR 37160).

1.2 Overview of petition to delist coho salmon south of San Francisco

On 6 November 2003, the National Marine Fisheries Service was petitioned by Homer T. McCrary to redefine the southern extent of the CCC Coho Salmon ESU to exclude populations that spawn in coastal streams south of the entrance to San Francisco Bay (McCrary 2003). The petitioner’s primary premise is that the coho salmon that have occurred in this region for the last century are the result of introduction of nonnative stocks from locations north of San Francisco. Prior to this petition, streams and rivers entering into the northern portion of Monterey Bay were widely accepted to mark the southern extent of the coho salmon’s distribution in North America since Snyder (1912) reported their occurrence in the San Lorenzo River in Santa Cruz County (apparently based on observations made in 1909) and Gilbert (1912) reported collecting juvenile coho salmon from Scott Creek in the spring of 1910.

The petitioner presented four main lines of evidence to support his conclusion. First, the petitioner asserted that historical accounts of the southern boundary of coho salmon in California indicate the southern boundary to be at or north of San Francisco Bay. In support of this, the petitioner cited the writings of Stanford ichthyologist David Starr Jordan and his collaborators over the period from 1876 to 1905, which the petitioner asserts “*unequivocally attest to the absence of coho salmon south of San Francisco.*” Second, the petition provided documentation that coho salmon eggs from Baker Lake, Washington were delivered to the Brookdale Hatchery on the San Lorenzo River over a 5-year period from 1906–1910, as well as newspaper accounts of these introductions, one of which states that coho salmon are native to “*more northern waters from Puget Sound northward.*” The petition further noted that Snyder’s (1912) mention of coho salmon in the San Lorenzo River occurred after hatchery fish from Baker Lake had been planted in the region. Third, the petitioner cited archeological studies conducted in the central California coast region that had failed to detect coho salmon remains in Native American middens. Finally, the petition contended that the physical environment of the Santa Cruz Mountains is not conducive to coho salmon persistence. Specifically, the petitioner argued that the “flashy” nature of local streams coupled with highly erodible soils create conditions that do not allow coho salmon populations to persist. Based on these arguments, the petitioner concluded that, because they believe that coho salmon currently residing in Santa Cruz Mountain streams are the result of plantings of fish from Baker Lake and other sources, protection of these fish is not warranted under the ESA, noting that the Act and subsequent NOAA policy are not intended to protect nonnative fish in unsuitable habitats.

Subsequent to NMFS' receipt of the 6 November 2003 petition, museum specimens of juvenile coho salmon collected in 1895 (pre-dating the 1906–1910 introduction of Baker Lake coho salmon) from four coastal streams (Gazos, Scott, Waddell, and San Vicente creeks) were discovered in the California Academy of Sciences (CAS) ichthyology collection. These specimens were collected by Stanford University researchers on what later became known as the Carmel River Expedition (Böhlke 1953). The specimens were originally part of the Stanford University collection, but were acquired by CAS on permanent loan in the late 1960s. Upon learning of these specimens, the petitioner filed an addendum (dated 6 February 2004) to the November 2003 petition. This addendum acknowledged the existence of the CAS museum specimens, but challenged their reliability because the specimens had originally been identified as chum and Chinook salmon (not coho salmon) in the Stanford ledgers, and because the “accession log appears to be less than a professional job and is somewhat confusing, leading to questions about the chain of custody.” Further, the petitioner contended that “*Even if these data [coho specimens in the CAS collection] are shown to be valid we must be cautious in how we interpret them. Certainly they are not evidence of permanent populations. It is likely these specimens are the result of an ephemeral colony established by strays.*” He suggested that these specimens could be the result of either favorable ocean conditions in years preceding the 1895 collection (leading to temporary colonization) or previous plantings of nonnative fish in the Santa Cruz Mountains (McCrary 2004).

Over the next two years, several written exchanges between NMFS Southwest Fisheries Science Center (SWFSC), NMFS Regional Office, and the petitioner took place. The SWFSC concluded that the petitioned action was not warranted (Grimes 2004, 2005), citing the CAS museum coho salmon specimens, accounts of “silver salmon” in Pescadero and San Gregorio creeks made by Captain Wakeman in 1870 (Redding et al. 1872), the inconclusive nature of archaeological evidence because of the small number of elements examined and general scarcity of salmon remains in middens even where salmon were known to be very abundant, modern genetic evidence that showed fish from Scott, Waddell, and Gazos creeks are somewhat differentiated from but most closely related to other CCC Coho Salmon populations, and the lack of evidence that the climate in coastal areas south of San Francisco differs appreciably from that of areas to the immediate north where coho salmon are acknowledged to be native. The petitioner responded by reiterating and elaborating on previous arguments, challenging the reliability of the 1870 Wakemen account, and providing additional analysis to support the contention that the environment of the region is unfavorable to coho salmon (McCrary et al. 2004). The SWFSC (Grimes 2005) issued a more detailed response, again concluding that the petitioned action was not warranted, which was followed by another response from the petitioner (McCrary 2005), which sought to refute the evidence provided by the SWFSC. In 2006, the petitioner's primary arguments were published in the journal *Fisheries* (Kaczynski and Alvarado 2006), the authors concluding that “*the presence of persistent populations of coho salmon south of San Francisco is improbable.*” Subsequently, a rebuttal was published in *Fisheries* (Adams et al. 2007), which concluded that “*the existing evidence strongly supports coho salmon as being native to streams south of San Francisco, contrary to the arguments of Kaczynski and Alvarado (2006).*”

On 13 January 2006, the petitioner sued NMFS for failing to issue the 90-day finding on the McCrary petition. On 23 March 2006, NMFS issued a Federal Register notice finding that the

petitioned action was not warranted (71 FR 14683). On 31 March 2006, the petitioner filed an amended complaint, contending that the NMFS finding that the petition was “not warranted” was arbitrary, capricious, and contrary to law. On 8 February 2010, the Federal Court ruled in favor of McCrary, determining that NMFS acted arbitrarily and capriciously in not accepting the petition for review. Specifically, the Court ruled that NMFS had applied the 12-month standard of review to the petition, rather than the 90-day “reasonable person” standard. In response to this decision, NMFS published a Federal Register notice accepting the petition on 2 April 2010 (75 FR 16745). This resulted in the convening of a new BRT consisting of representatives from NMFS Southwest and Northwest Fisheries Science Centers, as well as fishery experts from the U.S. Forest Service and U.S. Geological Survey, to specifically address the petitioned action and to determine the appropriate southern boundary for the CCC Coho Salmon ESU.

The BRT was provided all materials related to the petition and the NMFS response, as well as new information germane to the boundary issue. The BRT met for several days in July 2010 to review the available information. Following extensive discussion, the BRT addressed two key questions: (1) Does the available science support a southern boundary for the CCC Coho Salmon ESU that excludes coastal streams south of the entry to San Francisco Bay, and (2) Does the available evidence support a boundary different from the current boundary at the San Lorenzo River? For the first question, the BRT adopted a “likelihood point” method (Good et al. 2005). In this approach, each BRT member distributed 10 likelihood points among the two possible answers: “yes” the available evidence supports a boundary that excludes streams south of San Francisco or “no” the evidence does not support this conclusion. In this manner, BRT members were able to express their uncertainty. A BRT member who was highly confident that the evidence either did or did not support a boundary north of San Francisco, would allocate all 10 points to “yes” or “no”, respectively. One who was entirely uncertain would allocate 5 points to “yes” and 5 points to “no.” Once the BRT reached its conclusion, it then discussed evidence related specifically to where the southern boundary of the ESU should be located, if not at the San Lorenzo River.

1.3 Purpose of the BRT report

This report summarizes evidence relevant to evaluating the petitioned action and establishing an appropriate southern boundary for the CCC Coho Salmon ESU. Evidence considered includes that presented by the petitioner, NMFS, and the scientific publications that followed, as well as new information gathered by the BRT. In reviewing historical records, it became increasingly evident to the BRT that a thorough understanding of the historical ecological and scientific context of the region prior to 1905 is critical for proper interpretation of published scientific and popular accounts of salmonids south of San Francisco. This context includes many facets, including understanding the environmental history of the region, both before and after Euro-American settlement, the history of what was known about the taxonomy, nomenclature, and life history of salmonids prior to 1900, the scientific data (or lack thereof) underlying historical descriptions of species’ ranges during those early years, and the history of artificial propagation of coho salmon in central California.

To provide this context, we begin this report with discussion of the types of information that were used by the initial BRT (Weitkamp et al. 1995) to inform ESU boundary decisions in the initial status reviews of coho salmon in general and the CCC Coho Salmon ESU in particular. We then present a general discussion of salmonid ESU organization and structure, emphasizing the potential roles that populations near the periphery of a species' range play in ESU persistence. We then discuss the environmental history of the region, addressing the historical potential for streams of the Santa Cruz Mountains to support coho salmon populations, as well as the history of anthropogenic disturbance in the region, which clearly had an enormous influence on local stream environments and hence the capacity of these systems to support coho salmon. We follow with a summary of what is known about stocking of artificially propagated coho salmon in the region, which is important for interpreting historical accounts of coho salmon prior to 1900, assessing the likelihood that Baker Lake coho salmon successfully colonized local streams, and interpreting modern genetic evidence from coho salmon collected in the region and elsewhere on the West Coast. We then present an analysis of modern genetic data from coho salmon collected in streams south of San Francisco and what it tells us about the relationship between these populations and others within and outside the ESU. We next discuss published historical evidence related to the occurrence of coho salmon south of San Francisco, first reviewing what was known about the taxonomy, nomenclature, and life histories of salmon prior to 1905, and then evaluating the available physical (i.e., museum specimens) and written evidence related to coho salmon and other anadromous salmonids in the region in light of this history. This is followed by a review of archaeological evidence of coho salmon in the region. Each of these sections concludes with a discussion of the petitioner's arguments, and the BRT's assessment of the validity of those arguments given the context that has been provided. We conclude with a summary of the BRT's determination and a recommendation regarding the appropriate southern boundary for the CCC Coho Salmon ESU.

2. Original (1995) ESU boundary definition for CCC Coho Salmon

The ESU boundaries for West Coast coho salmon—from southern British Columbia to Central California—were first delineated in 1994 (Weitkamp et al. 1995). To make this determination, the 1994 BRT evaluated a wide range of information pertaining to West Coast coho salmon, including geography, ecology, and coho salmon genetic and life history traits. Although all of these factors were considered, placement of ESU boundaries was most strongly influenced by environmental data, such as river flow characteristics, precipitation, air and water temperatures, and biogeography (e.g., terrestrial vegetation, freshwater and marine fish faunas). Accordingly, the boundaries correspond to major breakpoints between West Coast ecozones or ecoregions, such as Cape Blanco in southern Oregon and Punta Gorda in northern California.

The reason for this heavy reliance on environmental data, rather than coho salmon life history patterns or genetic data, was twofold. First, although a wide range of life history data for coho salmon was examined, this species exhibits considerably less variation in traits such as age at maturity or timing of adult returns than other salmonid species for which ESUs had been delineated at that time (primarily Columbia River Chinook and sockeye salmon and steelhead). Through most of their range in Washington, Oregon, and California, adult spawning migrations occur in fall or early winter, and the vast majority of coho salmon spend a single year in fresh water and return to spawn at age 3. This lack of variation frustrated efforts to use life history data to inform how coho salmon were responding to environmental variation and therefore indicate possible ESU boundaries.

Second, the genetic data available at the time were based on allozymes, which are less variable for coho salmon than for other Pacific salmonids (Chinook salmon, sockeye salmon, and steelhead) and thus less useful for elucidating population structure. Furthermore, although a large effort was made to sample populations that were geographically under-represented for the status review, these efforts were far from comprehensive, leaving some areas poorly represented in the genetic dataset used to inform ESU boundary decisions.

For central California coho salmon, the 1994 BRT recognized that the rivers draining the Santa Cruz Mountains formed a cohesive group with respect to environmental conditions and, based on this consistency, concluded that the Pajaro River was likely the historical southern limit of coho salmon (Tom Wainwright, NMFS Northwest Fisheries Science Center, Newport, OR, pers. comm.). In determining where the southern boundary of the CCC Coho Salmon ESU should be placed, the BRT relied heavily on information provided in the 1993 status review of coho salmon in Scott and Waddell creeks (Bryant 1994). This status review indicated there were no recent reports of coho salmon in rivers south of the San Lorenzo River, but it also indicated that the recent (post 1976–1977) occurrence of coho salmon in the San Lorenzo River was most likely due to hatchery production. Faced with uncertainty as to whether any coho salmon populations might be present south of the San Lorenzo River and the uncertain origins of coho salmon in the San Lorenzo (native or hatchery), the BRT decided that the San Lorenzo River should be the southern-most basin in the ESU. In making this decision, the BRT explicitly stated that any coho salmon found spawning south of the San Lorenzo River that were not the result of stock transfers should be considered part of this ESU (Weitkamp et al. 1995).

3. Biological organization and structure of salmon ESUs

Because CCC Coho Salmon inhabit the edge of the species' geographic range, consideration of the factors and processes that influence a species range is important in establishing an appropriate southern boundary for this ESU. As summarized by Brown et al. (1996), the geographic range of a species is "*the manifestation of complex interactions between the intrinsic characteristics of organisms—especially their environmental tolerances, resource requirements, and life history, demographic, and dispersal attributes—and the characteristics of their extrinsic environment—in particular those features whose variation in space and time limit distribution and abundance.*" These interactions influence all aspects of a species' geographic range, including its shape, size, internal structure, and geographic boundaries. Because environmental conditions vary through time, these attributes, including range boundaries, can likewise change, with shifts reflecting the interaction between limiting environmental conditions and dispersal/extinction dynamics of the organism (Brown et al. 1996). Thus, from a biological standpoint, the boundaries of a species' (or ESU's) range are somewhat "soft." From an administrative standpoint, however, ESU boundaries must be fixed in space, and defining that space such that it preserves demographic and evolutionary processes within an ESU is paramount.

In this section, we provide an overview of current understanding of the biological organization and structure of Pacific salmon and the processes that give rise to this structure. This understanding informs how NMFS has defined ESUs (the biological units considered for listing of Pacific Salmon under the ESA), as well as the roles that different populations may play in the long-term persistence of an ESU. We begin by defining key terms from the scientific literature, which is important because terms are often used in different ways by different authors. Following this, we give a brief summary of demographic processes emphasized in the scientific literature related to species persistence. We then discuss conclusions reached by the North-Central California Coast Technical Recovery Team regarding the historical structure and function of coho salmon populations south of San Francisco, which incorporated the interaction between environmental conditions and the dispersal dynamics of coho salmon. Finally, we conclude with a response to arguments presented by the petitioner regarding whether coho salmon south of San Francisco contribute to the evolutionary legacy of the ESU.

3.1 Terms

Pacific salmon, interacting with their habitat, tend to self-organize into a hierarchical structure consisting of local breeding units that group into populations, metapopulations, and evolutionarily-significant units at progressively broader spatial and temporal scales. Breeding units are small-scale aggregations of fish that interact in discrete spawning grounds. Populations are often defined as collections of one or more breeding groups of the same species inhabiting the same place at the same time (e.g., Ehrlich and Roughgarden 1987). There are two schools of thought about how to delimit the spatial and temporal scales defining "same place" and "same time:" an operational school and a naturalistic school (Berryman 2002; Camus and Lima 2002). In the operational school, the spatial and temporal scale is set by practical considerations, whereas in the naturalistic school it is set by the properties of the species. Within each of these

schools, there is further variation in the way populations are defined, and this variation is important because it can lead to different interpretations of the same demographic process (Camus and Lima 2002).

A metapopulation is a group of populations that interact by way of dispersal. Dispersal is distinctly different from migration: migration is movement away from and return to a particular set of spawning grounds inhabited by a particular population (i.e., it maintains the integrity of the population), whereas dispersal is movement between populations, such that the dispersing individual spawns in a population different from the one in which it originated. Pacific salmon and trout commonly produce some fraction of migrants that stray to non-natal stream systems (Neave 1958; Quinn 1984; Tallman and Healey 1994) and those fish link a set of populations into a metapopulation.

An evolutionarily significant unit (ESU) is a population or set of populations or metapopulations that (1) is substantially reproductively isolated from other conspecific population units, and (2) represents an important component of the evolutionary legacy of the species (Waples 1991). The dynamics of an ESU are expected to unfold over temporal scales of hundreds or thousands of years and over spatial scales greater than hundreds of kilometers. At this scale, groups of populations interact and adapt to broad environmental conditions. Based on Waples (1991), the ESA listing unit for Pacific salmon is the ESU.

Rates of dispersal among populations within an ESU are expected to greatly exceed rates of dispersal between ESUs. This has important implications for genetic divergence at different biological scales (Moritz 1994; Moritz et al. 1995). ESUs are defined by substantial evolutionary divergence and represent major independent lineages within a species.

A final term that warrants discussion is viability. Viability is the ability of a biological unit—population, metapopulation, or ESU—to persist under expected environmental conditions over some pre-defined time scale. The time scales and the processes involved are often different for viability of populations, metapopulations, and ESUs. By convention, the time scale for population viability is persistence over 100 years (often thought to be the practical limit of probabilistic forecasting at this level of organization). The time scale for metapopulation viability is on the order of 1000 years, and the time scale of ESU viability is longer still, at the scale of broad evolutionary and climatic change. Viability at different levels is linked, but often in non-intuitive ways (reviewed by Hanski and Gaggiotti 2004). Recovery plans are conceived in terms of viability at the level of the ESU, but viability of populations and metapopulations is relevant to ESU viability and figures prominently in recovery plans.

Although the general definitions above seek to define and describe discrete units of organization, in reality, the biological organization of salmonid species represents a continuum, with reproductive isolation most often being a matter of degree rather than an absolute (Ricker 1972). Consequently, defining these units at any level of organization can be challenging. Nevertheless, for our discussion, knowing exactly where such boundaries might lie on the continuum matters less than understanding functional interactions within and among different levels of this hierarchy, as these interactions influence the persistence of salmon at all levels of organization.

3.2 Demographic processes

A metapopulation perspective implies that the spatial geometry (i.e., the size, numbers, and distribution) of suitable habitats plays a role in the dynamics and long-term persistence of a particular species' populations (Rieman and Dunham 2000). Salmonids are generally considered likely candidates for metapopulation structure because (1) they spawn and rear in spatially discrete areas, (2) individual populations exhibit dynamics that are at least partially asynchronous, and (3) dispersal (i.e., straying) among populations is common enough to result in recolonization of vacant habitat patches, but not sufficient to produce perfectly correlated dynamics (Quinn 1993; Bisson et al. 1997; Rieman and Dunham 2000). Although salmonids are likely to exhibit metapopulation structure, the specific nature of this structure will vary as a consequence of life history differences (among species) as well as differences in the quantity and quality of available suitable habitats and the spatial arrangement of these habitats on the landscape (Rieman and Dunham 2000).

The inclusion of multiple viable populations will generally increase the viability of a metapopulation. However, a metapopulation can be viable even if composed entirely of ephemeral populations, provided that certain conditions hold. The most important condition is that the colonization rate—the establishment of new populations in vacant habitat by dispersing individuals—must be at least as great as the extinction rate of the ephemeral populations (Levins 1969). Colonization rate in vacant habitat is commonly found to be a function of the number, size, and distance of nearby extant populations (Hanski 1994). In some situations, asymmetries of size are so great that virtually all colonists come from one or a few large populations (often called “island-mainland” systems, as this pattern supplies an explanation for the community patterns observed on oceanic islands by MacArthur and Wilson (1963, 1967)). In this sort of system, the large “mainland” or “core” populations play a disproportionate role in maintaining sufficient dispersing organisms to establish new populations and counteract the loss of ephemeral populations. The fate of the metapopulation tracks the fate of the core populations; if they are viable, the metapopulation is viable.

In other situations, the sizes of populations may be more similar, so that some threshold *number* of populations (rather than just persistence of the largest populations) is required to keep the colonization rate above the extinction rate (Levins 1969). Since colonization rate also tends to be a function of distances to the sources of colonists, the specific patterns of spatial clustering of populations are also important to determining the threshold number of populations required for viability. For metapopulations consisting of sparsely-distributed and/or small populations, the threshold can be high, so that destruction of a small amount of habitat can abruptly open a process of net extinction in nearby populations. This process feeds back on itself, so that fewer and fewer colonists are available to counteract more and more population extinctions, resulting in a deterministic decline toward extinction (Levins 1969; Kuussaari et al. 2009).

The extinction rate of individual populations is the converse of population viability. It is dependent on many factors, but tends to scale strongly with three emergent properties of populations: mean growth rate; variation in growth rate; and the carrying capacity of the habitat (the population size at which mean growth rate ceases to be positive) (Foley 1994). Because of the last factor, large populations tend to not only produce the most colonists, but also tend to be

the most viable. However, extinction rate is a logarithmic function of the variation in growth rate (commonly called “environmental stochasticity”; Lande 1993; Foley 1994), so large populations can be extinction prone if year-to-year variation in growth rate drives large fluctuations in population size. Population fluctuations are commonly observed in Pacific salmonids, including coho salmon (e.g., Nickelson and Lawson 1998).

The mean growth rate is the long-term average of the number of adult females produced by each adult female in the previous generation. Populations with mean growth rates well above one are very resilient, because they can recover quickly after a few years of poor conditions. If mean growth rate is less than one, the population will decline in size over time. Such populations either decline to extinction, in which case they are ephemeral, or they are sustained by frequent immigration of fish from other populations, in which case they are sink populations. Even though they are not viable by themselves, ephemeral and sink populations can still contribute to metapopulation viability if they provide colonists to vacant habitat or immigrants to extant populations. For example, Howe and Davis (1991) argued that a metapopulation can have a large proportion of organisms reside in sinks and still be viable; they found that under a wide range of circumstances sink populations can (1) promote larger overall metapopulation size, (2) promote larger size of source populations, and (3) extend survival of declining metapopulations.

Overall, the most robust way to ensure a viable metapopulation is to establish conditions that increase carrying capacity, mean growth rate, and stability of growth rate in individual populations, as well as maintain the ability of individuals to disperse between them, so that the metapopulation is composed of multiple viable populations connected by dispersers. However, ephemeral and sink populations can also increase viability at the metapopulation level even though they themselves are not viable.

Many salmon populations fluctuate coherently—good years and bad years coincide across different populations (Mueter et al. 2002a,b). This is expected to affect metapopulation dynamics by producing system-wide pulses of dispersing fish during good years and increased population extinctions during bad years. Such coherence can depress metapopulation viability by eliminating colonists when they are most needed to counteract extinctions—after a series of bad years (“regional stochasticity;” c.f. Foley 1997). Populations that oppose this trend—that are stable or that fluctuate out of sync with other populations—can play a key role in preventing metapopulation-wide extinction by providing colonists at the crucial times. At a regional or metapopulation scale, this asynchrony can result in lower overall interannual variability in abundance than occurs in the individual populations making up the metapopulation (Schindler et al. 2010).

3.3 TRT findings on population structure and demographic processes in the CCC Coho Salmon ESU

As part of the recovery planning process for salmon and steelhead populations in the North-Central California Coast Recovery Domain, the Technical Recovery Team (TRT) delineated the historical population structure for the CCC Coho Salmon ESU. Because the available data did not allow comprehensive analysis of ESU structure along the full continuum of biological

structure, the approach taken to delineating populations combined both operational and naturalistic elements. The TRT first defined each spawning group entering the Pacific Ocean as a demographic unit separate from analogous groups in other direct ocean tributaries (Bjorkstedt et al. 2005). This definition derives from two assumptions: (1) that population structure of anadromous salmonids is determined by freshwater spawning and rearing habitats, strong fidelity to natal streams, and migration pathways that allow dispersal among these habitats; and (2) that saltwater-freshwater boundaries present a greater constraint on dispersal among breeding units than do analogous boundaries (i.e., tributary confluences) that occur within basins. The TRT then considered whether spawning groups within larger river basins might have consisted of multiple populations (i.e., if sufficient physical, behavioral, or selective barriers to effective dispersal existed within the watershed). For the CCC Coho Salmon ESU, the TRT concluded that mechanisms for reproductive isolation were insufficient to promote development of multiple populations in all coastal watersheds except perhaps in the Russian River (Bjorkstedt et al. 2005)

Once population units were defined, these populations were classified into four naturalistic categories based on the projected historical size of populations and modeled dispersal among populations. Because population data from the pre-European-settlement era were not available, the TRT projected historical size using a model of intrinsic habitat potential as a proxy for mean abundance. The four naturalistic categories include functionally independent, potentially independent, dependent, and ephemeral populations (Bjorkstedt et al. 2005). Functionally independent populations are those with a high likelihood of persisting over 100-year time scales and whose dynamics and extinction risk are not substantially altered by exchanges of individuals with other populations¹. Potentially independent populations are those that have a likelihood of persisting in isolation over 100-year time scales, but that are too strongly influenced by immigration from other populations to exhibit independent dynamics. Dependent populations are those that would have a substantial likelihood of going extinct within a 100-year time frame, but that receive sufficient immigration to alter their dynamics and reduce their extinction risks. Ephemeral populations have a substantial likelihood of going extinct within a 100-year time frame in isolation and do not receive sufficient immigration to affect this likelihood (Bjorkstedt et al. 2005).

Several aspects of this framework are particularly important to highlight. First, population designations are based on posited historical attributes of populations prior to the arrival of Euro-American settlers and the substantial modifications of habitat have followed (see Section 4). The current status of a population is not an indication of its historical functional role. Second, dependent populations would include those defined by Pulliam (1988) as “sinks” (i.e., where over the long term, within-habitat production is insufficient to balance mortality), as well as small populations that experience rescue effects, whereby immigration prevents a population from going extinct due to environmental stochasticity. In either case, dependent or “sink” populations may persist indefinitely as long as adjacent populations continue to produce sufficient numbers of strays. Only populations classified as ephemeral populations are, by Bjorkstedt et al.’s (2005) definition, expected to go extinct over relatively short time scales.

Using this framework, the TRT concluded that the region south of the Golden Gate historically comprised two functionally independent populations (Pescadero Creek and the San Lorenzo

¹ This definition derives from the definition of “independent populations” provided by McElhany et al. (2000)

River) and perhaps 10–14 dependent populations (Bjorkstedt et al. 2005; updated in Spence et al. 2008). No populations in the region were identified as “ephemeral,” as none were sufficiently isolated to conclude that their extinction risk would not be influenced by immigrants from nearby populations.

3.4 Response to petition

Between the original petition (McCrary 2003), the petition addendum (McCrary 2004), and subsequent correspondence with the petitioner and his representatives (McCrary et al. 2004; Buchal 2005), the issue of “evolutionary legacy” is raised in several different contexts. The initial petition (McCrary 2003) states the petitioner’s belief that coho salmon were not native south of San Francisco and that populations south of the Golden Gate were established by the introduction of coho salmon from Baker Lake, Washington, and maintained by subsequent introductions of stocks from both within and outside the ESU. From this, the petitioner concluded that extant populations “*do not possess or carry an evolutionary legacy, and thus, do not qualify for federal listing.*” However, the subsequent discovery of CAS museum specimens of coho salmon collected from four Central Coast streams in 1895 confirms that coho salmon were present south of San Francisco prior to any known stocking of coho salmon in the region (see Sections 5 and 7). Nor is the petitioner’s assertion that the extant populations do not “*possess or carry an evolutionary legacy*” supported by genetic analyses of extant coho salmon populations, which show clear affinity between populations south of the Golden Gate and other populations within the CCC Coho Salmon ESU (see Section 6).

The petitioner subsequently presented a different argument regarding the issue of evolutionary legacy, stating that “*no genetic study to date has definitively determined that coho salmon south of San Francisco are genetically distinct and thus constitute an important component in the evolutionary legacy of the species (56 FR 58612, Nov. 20, 1991). Recent attempts to show such a distinction rely on a distortion of facts and a blatant misrepresentation of data*” (McCrary 2004). Subsequently, Buchal (2005) argues that NMFS’ ESU policy requires “*population-by-population*” analysis of the reproductive isolation and evolutionary legacy criteria developed by Waples (1991), further stating that “*We do understand that big rivers with arguably ‘reproductively isolated’ populations in the tributaries may call for further analysis under the ESU policy. Indeed, they are the sole example of ‘groups of populations’ that might properly be considered a single ESU by Waples (1991).*”

The BRT concluded that these statements represent a fundamental misinterpretation of the evolutionary legacy criterion outlined by Waples (1991). The evolutionary legacy criterion applies to the ESU as a whole, *not* to individual populations within an ESU². The biological unit to be conserved, and for which evolutionary legacy should be established, is the ESU, which is presumed to act as a metapopulation (or set of metapopulations). There is no requirement that each constituent population or group of populations within an ESU contribute uniquely to the evolutionary legacy of the species. In fact, the converse is true. If populations south of San Francisco were deemed by themselves to constitute an important part of the evolutionary legacy of the species, then they would have been considered a *separate* ESU. Although the California

² Waples (1991) sometimes used the term “population” as a synonym for “distinct population segment.”

Department of Fish and Game did initially consider coho salmon in Scott and Waddell creeks as a distinct unit and listed these populations under the State Endangered Species Act, NMFS has never made such an argument and has considered these populations part of a larger ESU since the first status review for the Scott and Waddell creek coho salmon was conducted (Bryant 1994; see Section 1.1) and in all status reviews that have followed (Weitkamp et al. 1995; Good et al. 2005). All subsequent analyses of genetic data have supported the ESU boundaries delineated by Weitkamp et al. (1995) (reviewed in Section 6).

In various communications from the petitioner and his representatives, the petitioner acknowledged the CAS coho salmon museum specimens from Gazos, Waddell, Scott, and San Vicente creeks, but argued that these specimens did not constitute evidence of permanent coho salmon populations, concluding that *“It is likely these specimens are the result of an ephemeral colony established by strays”* (McCrary 2004). Responding to a statement by a NMFS scientist regarding the potential for populations south of San Francisco to be continually reinforced by strays from north of the Golden Gate, the petitioner contended that *“straying was far less frequent than the naturally occurring stochastic events which periodically destroyed these fragile, temporary colonies.”*

The assertion that populations south of San Francisco were ephemeral was reiterated in subsequent letters from the petitioner (McCrary et al. 2004) and the petitioner’s attorney (Buchal 2005). In the latter letter, Buchal concludes that *“there is a very important ‘evolutionarily significant’ difference between populations north and south of San Francisco. The northern populations are sources and the southern ones are sinks. This is the most fundamental difference that there is from the standpoint of evolution. Sink populations, by definition, contribute nothing.”* Here, it is not entirely clear if the petitioner and his representatives are drawing a distinction between “ephemeral” and “sink” populations or are using the terms as synonyms, though the BRT suspects the latter interpretation. (As noted in Section 3.2, sink populations are not necessarily ephemeral and may, in fact, persist indefinitely). Regardless of the ambiguity of terms, the petitioner’s basic premise is that (1) coho populations south of San Francisco were ephemeral populations established by strays from the north and (2) because they were ephemeral, they contribute nothing to the evolutionary legacy of the species (or ESU).

The BRT disagrees with both facets of the petitioner’s argument. First, the BRT does not think there is compelling evidence that populations south of the Golden Gate were ephemeral, at least not at the time scales implied by the petitioner (i.e., where the frequency of disturbance events with the potential to cause extirpation of entire populations would be sufficient to prevent populations from persisting of any length of time) nor using the definition of ephemeral employed by the TRT. In its review of environmental data, the BRT found little evidence to suggest that environmental conditions in the Santa Cruz Mountains differ sufficiently from those in the region immediately north of the Golden Gate to result in appreciable differences in the dynamics and extinction risks of populations (see Section 4). Further, the petitioner’s assertion disagrees with the Technical Recovery Team’s conclusion that at least two independent populations (i.e. viable at the 100-yr time scale), as well as a number of dependent populations, likely existed in the region prior to the extensive habitat alteration that followed Euro-American settlement.

More importantly, even if the TRT's conclusions regarding the presence of independent populations south of San Francisco are incorrect, and the populations south of San Francisco were entirely dependent (e.g., sink) or ephemeral populations, that would not imply that they contribute nothing to the evolutionary legacy of the species, as the petitioner and his representatives contend (e.g., Buchal 2005). As noted above, the evolutionary legacy criterion applies to the entire ESU, not to individual populations within the ESU. Thus, any demographic roles that sink or ephemeral populations play in ESU persistence, by definition, contribute to maintaining the evolutionary legacy of the ESU as a whole. As discussed above, sink populations increase overall metapopulation size, increase the size of source populations, and can extend the survival of a declining metapopulation. Likewise, a viable metapopulation (or ESU) can consist entirely of ephemeral populations (Waples 1991). Further, populations at the edge of a species geographic range frequently experience environmental conditions that generate evolutionary novelty and adaptive traits unique to the species. During periods of population contraction, the flow of genes from marginal populations near the edge of a species' range to larger, central populations can be an important means of maintaining or enriching genetic diversity of the ESU as a whole (Scudder 1989; Bisson et al. 1997).

In support of the argument that coho populations south of San Francisco were "ephemeral," Kaczynski and Alvarado (2006) sought to draw parallels between coho salmon observations south of San Francisco and the occasional sightings of pink and chum salmon in Oregon and California streams as far south as the San Lorenzo River. They argued that in such cases, pink and chum salmon are generally considered "*strays and not native populations*," and they concluded that coho salmon south of the Golden Gate should be considered similarly. The BRT concludes that these are not analogous situations. In the case of both pink and chum salmon observations in California, such occurrences represent rare instances of fish straying many hundreds to more than a thousand kilometers from the southern-most persistent populations of each species³. In contrast, there is no dispute that coho salmon were present in San Francisco Bay tributaries (Leidy 2005) and streams immediately north of the Golden Gate (within 50–125 km of San Gregorio and Pescadero creeks) and that they inhabited many if not most watersheds along the northern California coast (see Section 7), including many small watersheds with habitat conditions similar to those found in watersheds south of the Golden Gate (see Section 4).

The BRT agrees with the petitioner that populations near the margins of a species' range may exhibit greater variability in abundance and mean growth rate, and hence have a higher probability of extinction than populations near the center of a species' range. Where we disagree is in whether the minor differences in environmental conditions immediately north and south of the Golden Gate are sufficient to preclude the persistence of coho salmon for extended time periods in watersheds south of the Golden Gate. Moreover, if on the whole, populations of CCC Coho Salmon are more prone to extinction from stochastic events than in other ESUs, the conclusion to draw from this is not that the populations near the edge of the range are unimportant. Rather, because the average extinction rate may be higher across the ESU, the

³ The contiguous distribution of pink salmon ends near the Elwha River near the Strait of Juan De Fuca, Washington. Occasional fish are collected in coastal watersheds of Washington and in the lower Columbia River, and pink salmon are rarely seen in Oregon and California streams (Wydoski and Whitney 2003). Persistent populations of chum salmon currently are found primarily in streams from Tillamook Bay, Oregon, northward, with occasional observations made in southern Oregon and California (Johnson et al. 1997).

contribution of each contributing population to overall ESU persistence becomes greater. That is, the loss of an individual population within this southernmost coho salmon ESU is likely to have a greater relative effect on ESU persistence than a similar loss in an ESU nearer the center of the species' distribution.

4. Environmental template and history of the Santa Cruz Mountain region

Assessing the likelihood that coho salmon populations persisted in watersheds south of San Francisco and interpreting historical records related to the occurrence of coho salmon in the region both require a fundamental understanding of the environment of the Santa Cruz Mountains and how that environment has been modified in the last 170 years. In the sections that follow, we describe the general environmental and ecological setting of the region, the relationship between these environmental characteristics and capacity of stream environments to support coho salmon, and the history of land-use and other anthropogenic activities that have affected that capacity.

4.1 Ecosystem characteristics in the Santa Cruz Mountains

The Santa Cruz Mountains comprise the coastal region of California south of San Francisco Bay and constitute the southern portion of EPA's Coast Range ecoregion (EPA 2007, level III ecoregions). In California, this ecoregion runs nearly continuously from the Oregon border to the southern boundary of the Santa Cruz Mountains (the northern edge of the Pajaro River basin) (Figure 4.1); the only gap occurs along the Marin County coast and near the mouth of San Francisco Bay. Early vegetation maps from this region indicate that redwoods extended through the Marin coastal area, but that most merchantable trees had been removed by the early 1880s (Figure 4.2). The presence of redwood-dominated forests south of San Francisco Bay indicates the presence of climatic conditions appropriate for coho salmon (Moyle 2002) and indeed the historical occurrence of coho salmon in streams north of San Francisco Bay is highly coincident with the coniferous forest zone⁴.

The occurrence of redwoods reflects the ample rainfall in the region, coupled with the moderating influence of the ocean on air temperature and the occurrence of fog during spring and summer, which help keep stream temperatures cool. Late-successional redwood forests also directly influence stream habitat to the benefit of coho salmon (and other salmonid fishes) in a number of ways. The tall overstory canopy provides shading to the stream channel, minimizing the amount of direct solar radiation that reaches the stream surface. Equally important, undisturbed coniferous forests produce an ample supply of large wood to the stream channel that, in turn, mediates many vital processes that shape stream habitats (reviewed in Bilby and Bisson 1998). In coniferous forests, large wood is usually the primary agent forming pools in plane-bedded and step-pool channels, and it influences pool formation in other channel types as well. Large wood contributes to formation of deep pools and slow-water off-channel habitats that coho salmon use as refugia during high flow events, and it provides complex structure that juvenile coho salmon use for cover from predators. Large wood also fosters deposition of gravels that salmonids require for spawning, and it helps dissipate stream energy and stabilize these habitats during high flow events, reducing the likelihood of redd scour. Accumulated bed material in channel and floodplain areas also absorbs water during the wet season, dampening the effect of high flow events, and providing slow release of shallow groundwater during the dry season. Finally, wood influences the retention and routing of organic matter (including salmon

⁴ Coho salmon are sometimes found in streams in the chaparral and oak woodland ecoregions, but usually in association with coniferous vegetation in the riparian zone. The streams of coastal Marin County, such as Lagunitas and Walker creeks, are exemplary.

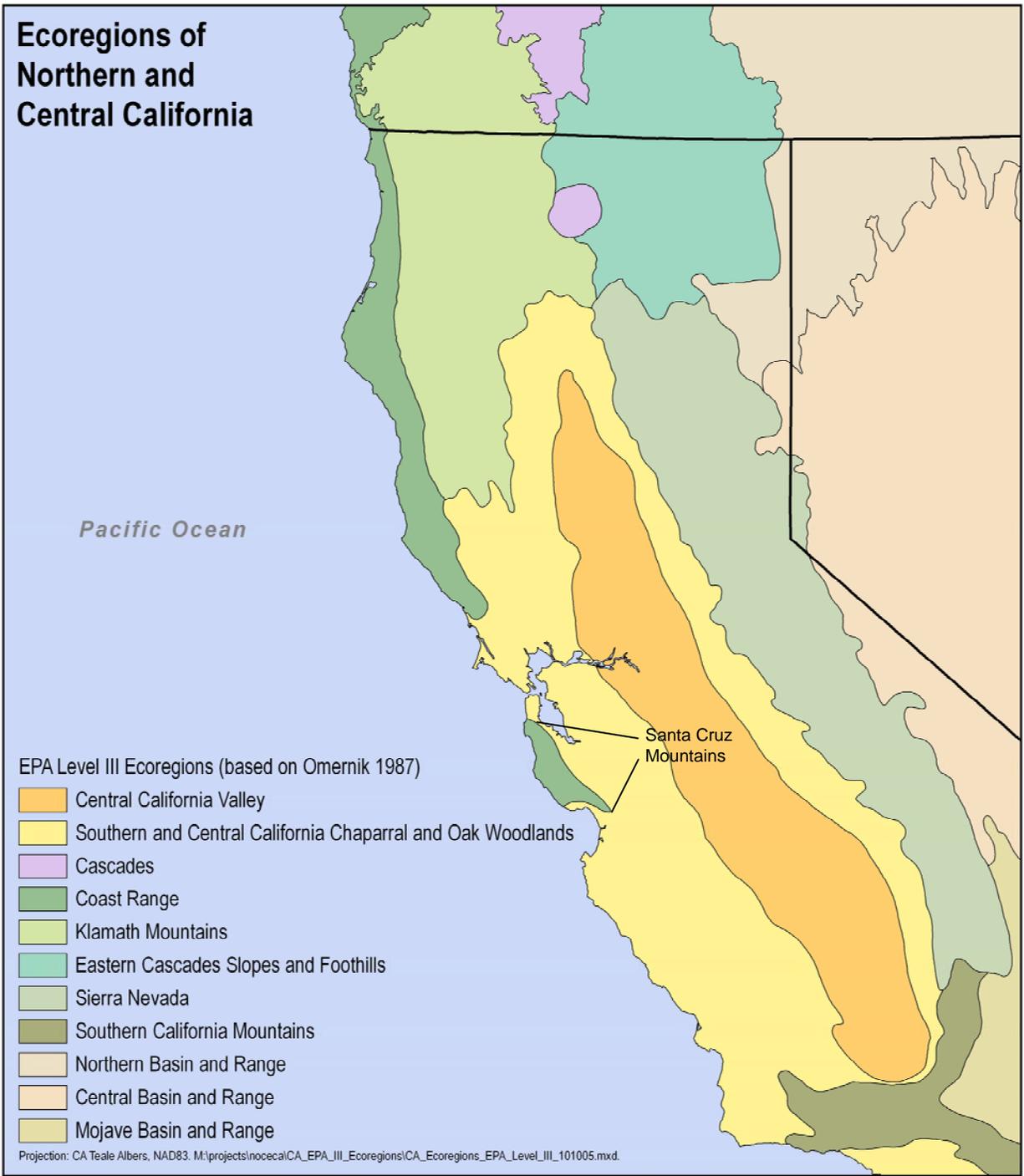


Figure 4.1. Level III ecoregions of northern and central California. Based on Omernik (1987).



Figure 4.2. Map showing the extent of redwood forest on the California coast in 1881. From Sargent (1881).

carcasses), which serves as a source of food for invertebrates that are the primary food of salmonids. All of these functions of riparian vegetation and large wood have tremendous influence on the capacity of streams and rivers to support coho salmon and salmonids in general.

With the above context in mind, we now address specific attributes of streams of the Santa Cruz Mountains that might plausibly preclude coho salmon from occupying streams in the region.

Water temperature is an important variable in determining the suitability of habitat for freshwater fishes, particularly near the margins of a species' range. However, the tolerable range for a species is somewhat difficult to quantify, as it is a function of duration of exposure, availability of food resources, and other factors (Madej et al. 2006). Laboratory studies suggest that the upper lethal temperature for coho salmon lies between 25.5 and 28.8°C (Bjornn and Reiser 1991; McGeer et al. 1991), though the physiologically optimal range is likely between 12°C and 14°C (Brett 1952). Bisson et al. (1988) found that coho salmon stocked into two streams in the blast zone of Mount St. Helens were able to survive in streams where monthly mean temperatures for July and August exceeded 20°C and daily temperatures as high as 29.5°C were recorded. The ability of coho salmon to survive these extremes was likely because of the considerable cooling at night. In the Mattole River in northern California, Welsh et al. (2001) found that coho salmon were generally found in streams where maximum weekly maximum temperatures (MWMT) were about 18.1°C or lower and maximum weekly average temperatures were less than 16.8°C. However, in the West Fork of the Smith River watershed in Oregon, Ebersole et al. (2009) reported the highest densities of juvenile coho salmon occurred in reaches where MWMT was between 18°C and 20°C, and they continued to find fish in reaches where MWMT was between 20°C and 24°C. In the Klamath River basin, juvenile coho salmon have been shown to utilize non-natal tributaries and cool thermal plumes at tributary junctions as thermal refugia when temperatures in the mainstem Klamath River exceed tolerable levels (Sutton and Soto in press).

In the Santa Cruz Mountains, the moderating influences of ocean temperatures and fog on air temperature coupled with extensive shading historically provided by riparian and upland canopies of redwood clearly led to temperature regimes that fall within the tolerable range for coho salmon. Even today, many streams still provide temperature regimes tolerable to coho salmon, despite the fact that anthropogenic activities (e.g., forest canopy removal, water diversions) have undoubtedly caused temperatures to increase in some stream reaches. These conclusions are evidenced in Figure 4.3, which shows stream temperature data recorded in 2000 and 2005 at several sites in six different Santa Cruz Mountain watersheds. For many of these sites, summer temperatures remained remarkably stable between 14°C and 17°C, well within the suitable range for coho salmon (Figure 4.3). Other sites, most notably those on the lower mainstems of Soquel Creek and Waddell Creek and the middle reaches of Pescadero Creek, currently provide conditions that may be stressful for coho salmon (Figure 4.3f,j, and l); however, temperatures are clearly warmer today than they were historically. The lower 7 miles of Soquel Creek has seen extensive development, both urban and agricultural, and the riparian canopy has been greatly diminished along a number of reaches. Additionally, numerous water diversions occur along this reach, which reduce summer flows considerably. Likewise, temperatures in lower Waddell Creek are affected by agricultural development, alteration of riparian vegetation, and water diversions. Pescadero Creek has also likely seen some reduction in canopy due to historical logging practices, but even in those reaches where temperature ranged

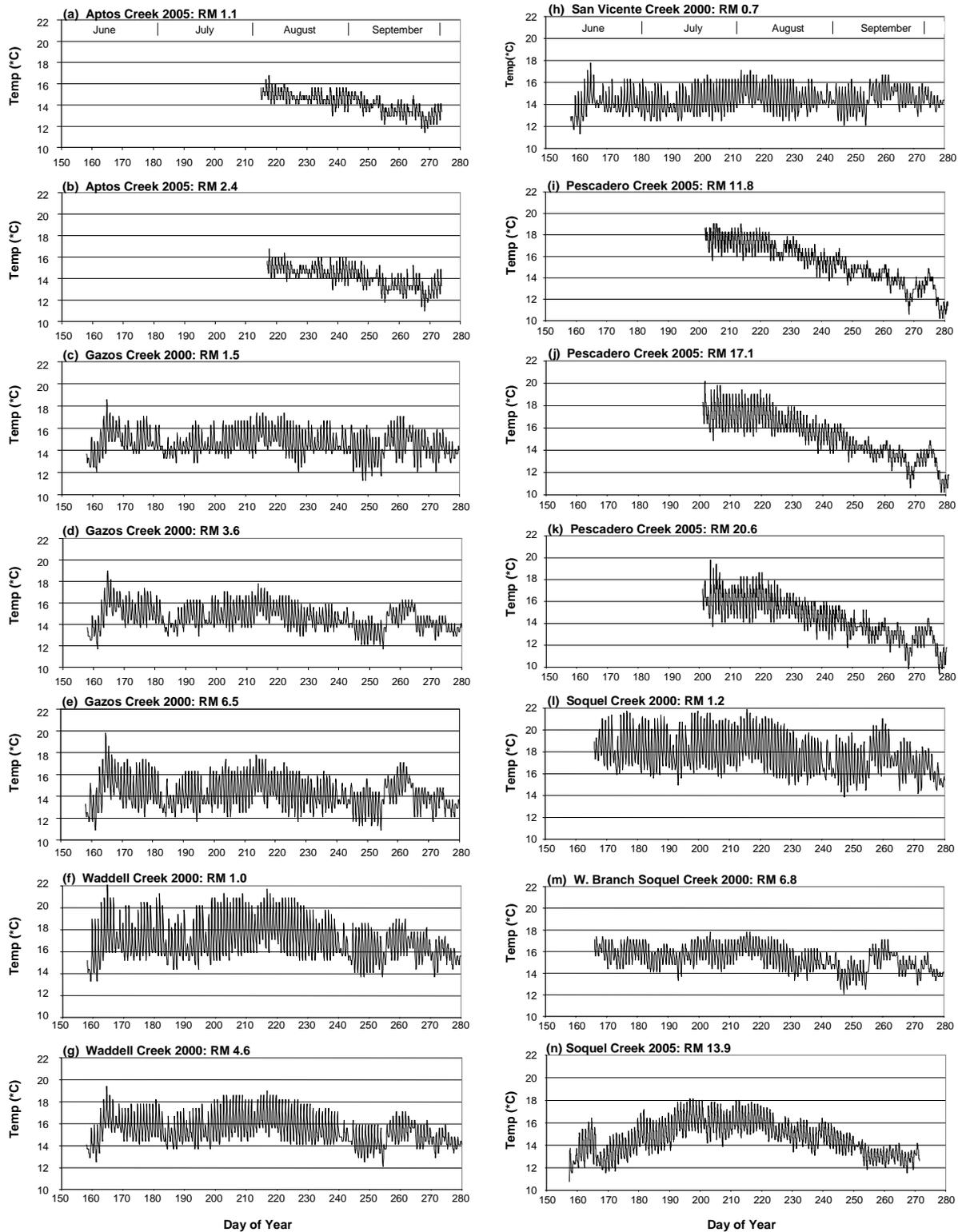


Figure 4.3. Summer water temperatures in streams of the Santa Cruz Mountains in 2000 and 2005. Source: J. Nelson, CDFG, unpub. data (panels a-m) and S. Sogard, NMFS, unpub. data (panel n).

between 16°C and 19°C in 2005, we observed significant numbers of juvenile coho salmon. We also note that in those watersheds where certain reaches tended to be warmer (i.e., Soquel, Pescadero, and Waddell creeks), other reaches in the watershed are clearly in the tolerable range for coho salmon. The ability of coho salmon to utilize thermally heterogeneous stream networks, and their potential to occupy relatively warm water under some conditions (e.g., Bisson et al. 1988; Ebersole et al. 2009) are probably relevant to their historical and current use of streams south of San Francisco Bay.

High streamflows resulting from winter rainstorms are a common feature throughout the Coast Range ecoregion. While juvenile and adult salmonids can be unaffected by high streamflows (e.g., Harvey et al. 1999) or even utilize them for migration, high streamflows may be detrimental to salmonid early life history stages under some conditions (e.g., Thorne and Ames 1987). Streambed scour when salmonid eggs and embryos are in the gravel is probably the key mechanism linking streamflow and the population dynamics of coho salmon. However, under historical conditions, with redwood trees providing extensive large woody debris in stream channels, the magnitude and spatial extent of streambed scour in low-gradient channels occupied by coho salmon was unlikely to have prevented successful reproduction across a broad range of streamflows. To the north of San Francisco, coho salmon inhabit streams with far greater rainfall, and hence potential for scour, than streams in the Santa Cruz Mountains. Modern observations of flood effects on coho salmon in altered channels do not invalidate this hypothesis because of dramatic reductions in large woody debris in many stream channels over the last 170 years. Streams, and the coho salmon residing in them, are currently far more vulnerable to flood disturbances than they would have been when stream ecosystems were intact prior to degradation by anthropogenic activities.

The absence of significant summer rainfall and corresponding low summer streamflows also characterize the Coast Range ecoregion. In this context, the many observations of coho salmon occupying intermittent streams during summer (e.g., Ebersole et al. 2009) should not be surprising. Once again, coniferous logs in the stream channel can play a critical role in providing habitat, in this case through the formation of relatively deep pools with cover, which are particularly valuable during low or intermittent streamflows. Streams that are intermittent in the dry season may also provide particularly favorable winter habitat for coho salmon (Ebersole et al. 2006). The occurrence of coho salmon in intermittent streams provides one reason why inspection of the ratio of extreme high to low streamflows is not useful in evaluating a stream's potential suitability as habitat for the species.

A final characteristic of some streams south of San Francisco that could conceivably limit their use by coho salmon is the fact that sand bars form across the mouths of some systems during summer and may not be breached until the first significant rains and storm surges during the fall or winter. These barriers can delay entry into streams during the spawning season. However, this situation is not unique to streams south of San Francisco. Coho salmon historically and currently occupy and persist in numerous watersheds with lagoon systems to the north where bar formation also blocks access to and from the marine environment during portions of the year (e.g., Redwood Creek, Humboldt Co.; Caspar Creek, Mendocino Co.). Further, Shapovalov and Taft (1954) reported that coho salmon gained access to Waddell Creek on or before the first

week of January in all nine years of their study, with fish continuing to enter the stream as late as March. This strongly suggests that coho salmon are capable of adapting to favorable windows for accessing spawning streams.

4.2 Environmental history of the Santa Cruz Mountains

In interpreting the historical record regarding occurrence of coho salmon in streams south of San Francisco, it is important to consider the extensive alteration of stream environments that had occurred in the region prior to and during the early 20th century. Numerous human industries and developments clearly had dramatic impacts on the ability of local stream and riverine ecosystems to support coho salmon and other salmonids.

Chief among these development activities was the logging of the vast redwood forests in the Santa Cruz Mountain region. Significant logging began in the Santa Cruz Mountains in the 1840s with the advent of water-powered, mechanized mills. Prior to this time, logging was done using non-mechanized methods—so-called “pit and whipsaw logging” in which trees were felled, a pit dug by hand beneath the log, and the downed trees sawed into boards and shingles using large whipsaws (Rood 1975). In 1842, large-scale industrial logging began with the development of the first water-powered sawmill in the region by Isaac Graham in the San Lorenzo River watershed.

From 1842 to 1875, water-powered mills proliferated throughout the Santa Cruz Mountains. The typical practice was to locate a mill site, enlist loggers to fall trees within a 2–3 mile radius of the site, and then haul the logs to the mill site using teams of oxen (Rood 1975). To facilitate the skidding of logs to the mills, loggers often built “corduroy roads,” which consisted of evenly spaced log segments set perpendicular to the direction of the road that were often built literally on top of streams (Figure 4.4). These roads were sometimes notched and greased with beef tallow to facilitate transport of logs by oxen (Payne 1978). The water-powered mills required streams and rivers to be dammed into ponds and lagoons (Payne 1978). When logging and milling were completed in an area, the mill site was moved to a new location and the process repeated, since it was more efficient to construct a new mill than to haul logs greater distances.

The 1870s saw the emergence of steam-powered sawmills and “steam donkeys”—steam-powered winches that replaced oxen as the primary means of skidding logs to the mill site or transportation network. Additionally, rail systems were developed in several watersheds (e.g., Aptos, Valencia, San Lorenzo) to haul logs to mill sites. These technological advances further accelerated the pace of logging, and the period from 1875 to 1905 marked the apex of the logging industry in the Santa Cruz Mountains.

The cumulative magnitude and spatial extent of early logging was impressive, as evidenced by the number of mill sites established before 1906 (Figure 4.5). Rood (1975) documented more than 300 mill locations during the period 1840 to 1905 west of the crest of the Santa Cruz Mountains, from Tunitas watershed in the north to the Corralitos Creek watershed in the south. Some 130 of these alone were in the San Lorenzo River watershed, and no watershed in the



Figure 4.4. Example of oxen skidding logs over corduroy road in Big River Basin, Mendocino County, circa 1851-1852. Photo by Jerome Ford, acquired from KRIS website: www.krisweb.com/krisbigriver/krisdb/html/krisweb/history/mills.htm.

region was spared. The rapidity with which the redwood forests of the Santa Cruz Mountains were logged is astonishing. By the early 1900s, the timber supply in many watersheds was exhausted. Indeed, by the late 1890s, a movement to preserve some of the last remaining stands of redwoods, led by painter and photographer Andrew P. Hill, gained momentum, culminating in the establishment of Big Basin State Park in the headwaters of the San Lorenzo River and Waddell Creek watersheds in 1902. The original park, the first State Park in California, encompassed approximately 3,800 acres and represented the last significant contiguous stand of old-growth redwoods south of San Francisco.

The impacts of these early logging operations on coho salmon and their habitat were undoubtedly severe. Mill pond dams blocked or hindered access to spawning areas. This is documented in Redding et al. (1892), which reports that a deputy commissioner for the state visited the 12-foot high Hihn Company Dam on Branciforte Creek to negotiate installation of a fish ladder. Construction of corduroy roads likewise would have prevented fish passage, caused substantial damage to the channel bed, and accelerated sediment delivery to streams. The opening of the vegetative canopy and burning of underbrush (to facilitate skidding) would have resulted in increased summer stream temperatures, to the possible detriment of coho salmon. The removal of downed large wood from streams and cutting of riparian forest that provided for

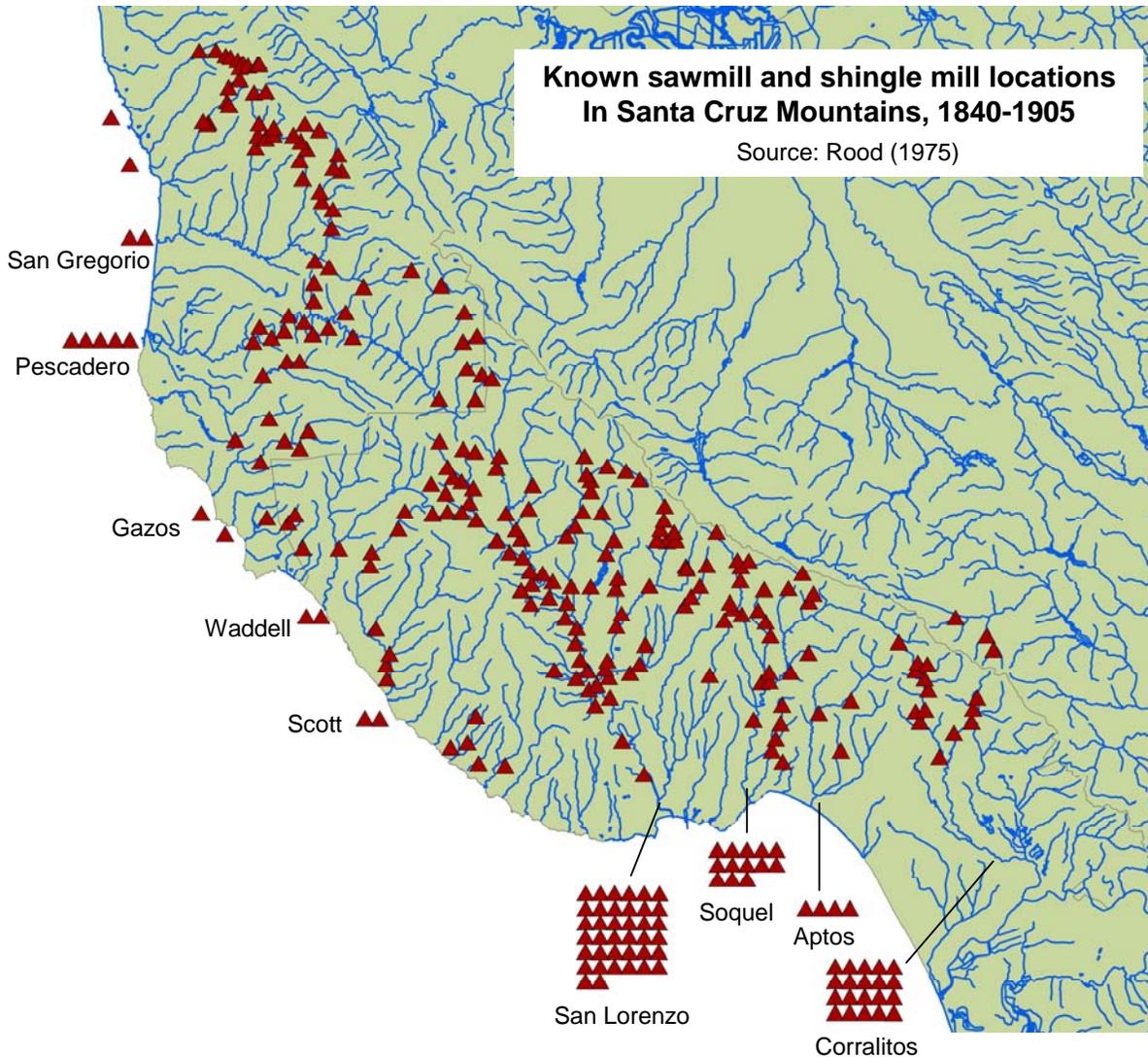


Figure 4.5. Map showing known locations of sawmills and shingle mills in the Santa Cruz Mountains from 1840 to 1905. Triangles over the ocean indicate additional mills for each watershed that were identified as being present but that could not reliably be placed on the map. Adapted from Rood (1975).

wood recruitment had enormous impacts on stream channel structure, and the formation of complex and off-channel habitats that coho salmon depend on as winter refugia. The legacy of these impacts persists to this day.

An impact that received considerable attention at the time was the dumping of sawdust waste from the mills directly into streams and rivers, which was routine practice from the 1840s to the late 1880s. In the 1870s, numerous articles and editorials were published in the local newspapers lamenting the polluting effect of sawdust not only on fishes and other organisms in streams, but also the suitability of creek waters for drinking by livestock and humans. For example, on 3 November 1877, the Santa Cruz Sentinel published the following:

“We have always maintained that lumberman dumping their refuse timber and saw-dust into the San Lorenzo River and its tributaries were committing a nuisance. They are destroying the fish and poisoning the water for human use. A dumb brute has too much sense to drink from the water fresh and inky black from a saw-dust pile. We fear that this fact has something to do with the prolonged existence of diphtheria and other fevers that within the last six months have filled so many new-made graves. Poisoned water is slow poison to the drinker thereof....”

Public outcry eventually led to enactment of a state law in 1889 banning the practice of dumping sawdust in streams, and mill owners were subsequently required to burn or otherwise discard their refuse away from streams (California State Legislature 1889).

Logging was not the only industry in the Santa Cruz Mountain area that would have substantially affected the capacity of streams to produce coho salmon and other salmonids during the 1800s. Between 1843 and 1870, several tanneries were established in the region, which made use of bark from tanoak trees growing in the Santa Cruz Mountain foothills. The first of these was built in what is now known as Scotts Valley in the San Lorenzo watershed in 1843. Within 15 years, several other tanneries were built including the Kirby and Jones Tannery (est. 1850 and moved to Mission Hill in Santa Cruz in 1855), the Porter Brothers Tannery about one mile from Soquel (est. 1853), C. Brown and Company Tannery in Santa Cruz, and the Grove Tannery located on the San Lorenzo River in Santa Cruz (Elliott 1879). This last tannery was washed away by a flood in 1861, but was rebuilt by Jacob Kron. Eventually, the Kron’s Santa Cruz Tannery surpassed Kirby and Jones as the largest tannery in the County, was eventually bought out by the Salz Company, and continued to operate more or less continuously for more than 145 years (Lehmann 2000). Although impacts of the Santa Cruz County tanning industry on local streams and rivers are not well documented and were certainly more localized than those of logging, they were likely not trivial. The large quantities of bark required for tanning necessitated clearing of substantial oak woodlands. In addition to taking the bark for tanning, the remainder of the trees was used to provide barrel staves and to burn as fuel to produce steam to run the plants. Some plants also relied on water for power and so diverted water from streams and rivers. And finally, effluent from riverside tanneries was almost certainly discharged back into streams and rivers.

Several other industries that likely influenced aquatic habitat warrant mention. The California Powder Works, established in 1861 and operated until 1914, manufactured black gunpowder for use in mines and railroad development in California (Elliott 1879; Brown 2008). The plant was located near what is now called Paradise Park, about 6.7 km upstream of the mouth of the San Lorenzo River. To provide water power for the mill, a diversion dam was built approximately 4 river km upstream (Figure 4.6). The water was carried by flume for about 730 meters, where it entered a 366 meter long tunnel that cut through a steep mountain spur to reach the mill site. The 18–24 meter drop in elevation was sufficient to provide power to the mill year round, though Brown (2008) noted that “...*in summer, when the river was low, the CPW [California Powder Works] sometimes had to divert all the San Lorenzo River water into the flume to keep the machinery operating.*” This diversion, which was in place from 1863 to the early 1900s (B. Brown, pers. comm.), left the stream bed dry for a mile and a half during the dry months (Redding et al. 1892). The dam itself posed enough of a fish passage concern that the State Fish Commission negotiated for the owner to install three fish ladders within the flumes to allow passage around the break in flow.



Figure 4.6. Photograph of the California Powder Works diversion dam on the San Lorenzo River. Photograph from the Peyton Family Collection.

Also noteworthy from a fisheries perspective were several paper mills in the region. The San Lorenzo Paper Mill, which operated intermittently from 1861 to 1872, was located on the San Lorenzo River just downstream of the California Powder Works site. To supply power to the mill a dam 5.2 m high and 54.9 m long was built across the San Lorenzo River above the mill and a flume about 1 km long was built to carry water to the mill site (Koch 1973). The dam formed a small lake that at times backed up water all the way to the Powder Works property. Eventually, an agreement was reached by which the Powder Works provided water to the paper mill and the dam was removed (Brown 2008). The dam, obviously, would have provided an obstacle to upstream and downstream migrating salmonids, and effluent from the mill likely affected water quality downstream. The South Coast Paper Mill (1879–1924), located on Soquel Creek near the town of Soquel, discharged highly acidic effluent that killed fish (Johnston 1973) and created what was described as an “*unbearable nuisance to residents of the neighborhood*” (Santa Cruz Daily Surf, 12 Oct. 1885). In response, the mill owners financed construction of a long flume (approx. 2.4 km) that carried waste from the mill around the town of Capitola and directly into the ocean. Water quality problems did not end there, however, as claims were later brought against the mill owners for allowing “*lime water, cocculus indicus, factory refuse, and*

substances deleterious to fish” to run into Soquel Creek (Santa Cruz Surf, 22, Dec. 1897). Another paper mill in the region was the Corralitos Paper and Board Mill (1880s–1902) on Corralitos Creek (Koch 1973). Like the South Coast Paper Mill, local residents concerned about polluted waters battled the mill owner for several years, eventually resulting in an indictment of the owner for “fouling the creek” with waste from his paper mill. The *Santa Cruz Surf* (29 May 1888) reported that “*The witnesses all agreed that there were fish in the stream before the mill was built and that there are none there now.*”

In summary, the BRT concludes that there is little question that significant reduction in the capacities of virtually all Santa Cruz Mountain streams to produce coho salmon and other salmonids had occurred well before the turn of the 20th century. Much of this degradation occurred prior to any attempts by scientists or laypersons to document fishery resources in the region, and certainly before any systematic attempts to survey the fish faunas in the streams of the central California coast region (see Section 7).

4.3 Response to petition

In the petition, subsequent addendum, and other written correspondence, the petitioner contends that the environment of the Santa Cruz Mountains is too harsh or extreme to allow for persistent populations of coho salmon. After reviewing the available information, the BRT disagreed with the petitioner’s contention, and instead concluded that historical environmental conditions of streams within the Santa Cruz Mountains were not sufficiently different from those to the north of San Francisco to preclude coho salmon from establishing sustained populations. Areas both to the north and south of the Golden Gate are part of the Coast Range ecoregion. Ecoregions are so designated because of spatial coincidence in the factors that govern ecosystem structure and function, including climate, hydrology, vegetation, geology, soils, and physiography (Omernik 1987). In the Coast Range Ecoregion, there are clear linkages between the terrestrial and aquatic ecosystems, with the extensive redwood forests historically enhancing coho salmon habitat by providing shade and large wood. A significant ecological transition does occur immediately south of the Santa Cruz Mountains, with the northern edge of the Salinas Valley marking the boundary between cool, wet redwood forests and warm, drier chaparral landscapes, where small relict redwood forests are primarily confined to riparian areas near the coast. However, we find no compelling evidence that streamflows, temperatures, sediment yields, stream access, or other factors were appreciably different in the Santa Cruz Mountains than in areas to the north, where the historical distribution of coho salmon is not in dispute. In the paragraphs that follow, we address specific arguments presented by the petitioner.

The initial petition argues that the hydrology of streams south of San Francisco is too “flashy” to support coho salmon populations (McCrary 2003), flashiness being defined as “a wide dynamic range of flow” (McCrary 2004). In support of this contention, the petitioner presents three separate analyses of stream discharge and precipitation patterns. The first compares stream flows of Lagunitas Creek and the San Lorenzo River, characterizing the “dynamic range” as the maximum recorded flow divided by the minimum flow over the entire period of record from 1982 to 2002, and concluding that this range was about 1.8 times higher for the San Lorenzo River. The BRT was not persuaded by this analysis for two reasons. First, the BRT concluded

that the statistic used to characterize the dynamic range has limited biological meaning for coho salmon. This conclusion is illustrated by the fact that, using the petitioner's calculations, the "dynamic range" of intermittent streams with no measurable surface flow would approach infinity, yet coho salmon can and do persist in such systems (e.g., Ebersole et al. 2009). Further, because this statistic is driven by single extreme events (maximum flow or minimum flow), it has little bearing on the ability of a system to sustain a salmon population over the long term. Second, the petitioner's analysis does not account for the fact that river flows at the USGS gaging station (11460400) on Lagunitas Creek are affected by operations at Peters Dam (Kent Reservoir), which lies upstream. Winter flows measured at the gage underestimate natural flows during periods when Kent Reservoir is being filled, and summer flows are affected by mandated flow releases from the reservoir. These releases must contribute to a targeted flow of at least 6 cfs during the summer months, as measured at USGS gaging station 11460400 (SWRCB 1995), though that target has not always been achieved. These mandated flows took effect in 1995; however, in the 15 years preceding this, there were ongoing negotiations between the State and the Marin Municipal Water District (MMWD), and water was being released from Kent Reservoir during the summer months throughout much of this period (Gregory Andrew, MMWD, pers. comm.). The effect of these releases on measured base flows in Lagunitas Creek, coupled with the failure to account for water diversions in either the San Lorenzo or Lagunitas watersheds renders the petitioner's stream comparison highly dubious.

The petitioner similarly used USGS stream flow data to compare flow regimes in Soquel Creek with those in Lagunitas Creek, arguing that while maximum and mean flows recorded between the two streams were quite similar, the summer base flows were substantially lower in Soquel Creek over the common period of record, falling below 1 cfs on a number of occasions (McCrary 2004). Again this analysis does not consider the mandated flow releases in Lagunitas Creek described above, which are responsible for maintaining flows above 4 cfs during summer. Nor does the analysis account for the fact that water diversions and groundwater pumping have contributed to a significant reduction in summer base flows in Soquel Creek since the 1950s (Chartrand et al. 2003). Although climatic factors also appear to have played a role in base flow reductions in Soquel Creek, the fact that in 1975 water rights in the basin had to be adjudicated among more than 300 claimants strongly suggests that summer flows are substantially affected by diversions and groundwater pumping.

Kaczynski and Alvarado (2006) present an analysis comparing precipitation regimes as measured in Ben Lomond in the Santa Cruz Mountains and Kentfield in Marin County, concluding that the frequency of extreme storms (> 4 inches of rain in 24 hours) is significantly greater in Santa Cruz County than in Marin County. As Adams et al. (2007) point out, the difference in probability of extreme storms is very slight, amounting to only one additional 24-hour rain event of > 4 inches every three years. Adams et al., therefore, concluded that this is unlikely to be biologically significant. The BRT concurred with this conclusion, in part because negative consequences (e.g., redd scour) of high streamflows under historical conditions in Santa Cruz Mountain streams reaches occupied by coho salmon were probably slight. Additionally, the BRT questioned the validity of this comparison given differences in locations of the rain gages used in the analysis. The Ben Lomond station lies in the San Lorenzo Valley on the west side of the Santa Cruz Mountain crest at an elevation of 128 m. In contrast, the Kentfield station sits at a lower elevation (42 m) directly northeast of the 762 m high Mt. Tamalpais and thus experiences

a rain shadow effect. These site differences might easily account for the minor difference in estimated recurrence of high-rainfall events.

Kazcynski and Alvarado (2006) also assert that drought conditions are more severe south of San Francisco, that water temperatures are warmer than north of the Bay, and that during droughts coho salmon may not be able to access spawning streams. While the BRT does not disagree that the environment can at times pose challenges to coho salmon, we do not believe that these conditions are unique to the Santa Cruz Mountains or would account for significantly different dynamics for coho salmon populations immediately north and south of the Golden Gate. As demonstrated above, summer temperatures in many Santa Cruz Mountain streams currently fall in the suitable range for coho salmon, even though many streams are likely warmer now than they were historically due to loss of riparian canopy and water extraction. Coho salmon are capable of surviving in small, even intermittent streams (Ebesole et al. 2009). Adams et al. (2007) note that coho salmon in Scott Creek survived the extreme drought conditions of 1975–1977 and that inland temperatures of coho streams north of San Francisco, such as certain tributaries of the Eel River, are often higher than temperatures in streams south of San Francisco, where fog, redwood cover, and coastal ocean temperatures moderate air temperatures over streams. In addition, Leidy et al. (2005) reported that coho salmon were collected in 1860 in San Mateo Creek, an inland stream draining into San Francisco Bay that likely had warmer temperatures than any of the coast streams under consideration for the petition (Adams et al. 2007).

The petitioner correctly observes that Santa Cruz Mountain streams are subject to high amounts of fine sediment; however, as noted by Adams et al. (2007) this problem is neither new nor unique to the Santa Cruz Mountains. Sediment delivery to streams has undoubtedly increased due to logging, agriculture, roads, and other developments that have been prevalent in the region since about 1840. Additionally, coho salmon occupy streams such as the Eel River, Mad River, and Redwood Creek (Humboldt County), which have some of the highest sediment yields in the United States (Milliman and Syvitski 1992). At present there is no clear evidence that pre-logging sedimentation rates differed between the areas north and south of San Francisco.

Finally, the petitioner and Kazcynski and Alvarado (2006) cite a number of recent references attesting to the difficulties that coho salmon have coping with environmental conditions in the Santa Cruz Mountains as support for their contention that the region never supported persistent populations of coho salmon. Exemplary of this perspective is the following statement from Kazcynski and Alvarado (2006):

“Why did coho populations south of San Francisco begun as hatchery introductions fail to maintain three viable year-classes even with recurrent hatchery support? The simplistic explanation is that past and present habitat disruption due to human activities, which varies dramatically from stream to stream. Yet some of these streams are now in excellent condition and are still incapable of supporting sustainable coho populations (Smith et al. 1997; Smith 2001; West 2002; SCWC 2005).”

The BRT does not dispute that current conditions pose significant challenges to coho salmon, but we strongly disagree with the contention that some Santa Cruz County streams are now in excellent condition. We do not believe there is a single watershed in the Santa Cruz Mountains

that exhibits habitat complexity that comes close to resembling that which existed prior to the anthropogenic disturbances. While some stream *segments* may have significant accumulations of wood, at the watershed scale, all streams in the area are extremely deficient in large wood. This deficiency is due not only to the legacy of past logging practices, but also to an aggressive wood removal program implemented by the County of Santa Cruz following a flood event in the town of Soquel during the El Niño event of 1982. Literally hundreds of debris jams and downed logs deemed to threaten roads and other infrastructure have been removed from area streams in the last 38 years. Even in areas now protected from logging, instream wood supplies remain low because the second-growth riparian stands are not yet producing downed wood in any great quantities. Thus, while certain streams such as Waddell Creek and Scott Creek are in relatively better condition than others in the region, they are far from pristine.

Recognition of the current degraded nature of streams is critical to understanding why extant coho salmon populations in this region are currently in danger of extinction. Forested landscapes in the temperate rain forest are by their nature highly dynamic ecosystems (Benda et al. 1998). The fish that evolved in these systems, including coho salmon, are adapted to these conditions. Adults and juveniles move within the stream network in response to disturbances, whether it is the movement of juveniles from main-channel to off-channel habitats during short-term flood events, or movement to different portions of a watershed when an extreme event such as a major landslide or debris torrent fundamentally alters habitat in a particular stream reach (Reeves et al. 1995; Quinn 1984). Anthropogenic activities influence both the frequency of disturbance events such as landslides, debris torrents, or peak flow events and the response of stream ecosystems to those disturbances (Chamberlain et al. 1991; Furniss et al. 1991). In streams that lack sufficient large woody debris, connections between the stream channel and off-channel refugia are broken, the run-out paths of debris flows are extended, and scouring of substrates by high flows is enhanced. In the highly modified watersheds of the Santa Cruz Mountains, the BRT concludes that the difficulties coho salmon currently have in persisting in local streams is predominately a function of these anthropogenic effects rather than any inherent characteristics of local watersheds.

5. History of artificial propagation and release of coho salmon in streams south of San Francisco

The artificial propagation and release of coho salmon in streams and rivers south of San Francisco is relevant in several ways to the question of whether or not coho salmon were native to streams south of San Francisco. As noted previously, coho salmon eggs were transferred from Baker Lake, Washington, to Brookdale Hatchery during the period 1906 to 1910. Yet there is also evidence of coho salmon presence in the form of museum specimens from four Santa Cruz and San Mateo county streams collected in 1895 that pre-date this hatchery activity. Thus, we first examine the pre-1906 stocking history to assess the likelihood that these 1895 observations were the result of prior hatchery introductions. We then review what is known about the 1906–1910 release of Baker Lake coho salmon into the Santa Cruz region, as well as subsequent introductions (1911 to 1941), to assess the likelihood that the substantial population of coho salmon documented in Waddell Creek during the 1930s and 1940s (Shapovalov and Taft 1954) was the result of hatchery introductions. And finally, we review post-1941 stocking history as it potentially informs interpretation of genetic information collected from coho salmon south of San Francisco in modern times, which is discussed in Section 6 of this report.

5.1 Coho salmon stocking history prior to 1906

The history of hatchery fish production and distribution in California during the 1800s and early 1900s is well documented both in annual reports prepared by the United States Commission on Fish and Fisheries, which detail hatchery activities conducted by the federal government, and in biennial reports prepared by the California State Fish and Game Commission⁵, which describe activities of hatcheries owned by the State. Summaries of this early production and distribution from Federal and State-owned hatcheries are provided in reviews by Cobb (1921) and Shebley (1922), respectively. Collectively, these reports provide no evidence that hatchery coho salmon were released into streams south of San Francisco at any time between 1870 and 1905 (Figures 5.1 and 5.2). Indeed, prior to 1906, hatchery production of coho salmon was extremely limited not only in California, but throughout the Pacific Northwest. The only recorded production of hatchery coho salmon in the state of California during this era occurred at the federally owned Korbelt Hatchery and Redwood Creek substation in Humboldt County during three seasons between 1893–1894 and 1896–1897. All coho salmon produced at these facilities were released back into streams of Humboldt County (Bean 1896; Ravenel 1896, 1898). The only other federal hatcheries in the Pacific Northwest that produced coho salmon during this era were the Baker Lake (Washington) hatchery, which began producing coho salmon in 1900–1901 but did not deliver any coho salmon to California until the 1906 delivery of eggs to the Brookdale Hatchery, and a hatchery on the Rogue River, Oregon, which operated during the 1900–1901, 1903–1904, and 1904–1905 seasons and released all coho salmon fry into Oregon waters (Ravenel 1902; Titcomb 1905a,b; Bowers 1906).

⁵ The California Fish Commission was established in 1870. In 1878, the commission was expanded to become the California Fish and Game Commission. In 1926, the name was again changed to the California Division of Fish and Game.

DISTRIBUTION OF SALMON IN THE WATERS OF CALIFORNIA—Continued.

Year.	Mon- terey Bay and tribu- taries.	Ven- tura River.	Truckee River.	Total.					
	Silver fry.	Chinook fry.	Chinook.			Silver.		Steel- head fry. ^b	
			Eggs.	Fry.	Year- lings, finger- lings, and adults. ^a	Fry.	Adults and year- lings.		
1873.....				20,000	520,000				
1874.....					850,000				
1875.....			250,000	250,000	2,250,000				
1876.....					2,000,000				
1877.....					2,200,000				
1878.....					2,500,000				
1879.....					2,300,000				
1880.....					2,225,000				
1881.....			10,000		2,390,500				
1882.....				80,300	3,991,750				
1884.....					600,000				
1886.....					150,000				
1887.....					200,000				
1888.....					1,290,000				
1889.....					3,668,000				
1890.....					1,494,000				
1891.....					3,575,000				
1892.....					2,966,600	25,000			
1893.....					5,131,950				
1894.....					8,214,900		280,000	353,500	
1895.....					3,935,000		910,000	560,000	
1896.....					15,748,883	250,000		107,808	
1897.....					20,324,701		298,137	262,000	
1898.....					45,101,688			650,000	
1899.....				85,200	25,409,110				
1900.....					6,069,950				
1901.....					4,128,570				
1902.....					18,967,600			301,000	
1903.....					21,657,553			120,000	
1904.....					65,982,130			90,000	
1905.....					102,661,380			108,000	
1906.....					110,204,472			243,000	
1907.....	80,000				75,029,250		80,000	487,000	
1908.....	80,000				66,199,855		80,000	170,000	
1909.....	^c 54,000				31,590,000		42,000	518,200	
1910.....					30,756,002			637,800	
1911.....					33,323,324		2,060,910	1,858,100	
1912.....					26,152,770			2,177,958	
1913.....	25,000				18,472,327		42,320	1,983,500	
1914.....					30,840,964	838,906	2,548,960	3,171,083	
1915.....	71,000	25,000			37,543,150	9,053,635	2,363,762	8,582,500	
1916.....		25,000			34,883,739	5,538,224	2,169,050	5,213,170	
1917.....		25,000			8,144,000	14,628,300	50,000	6,699,420	
1918.....		25,000			14,389,000	10,689,400			
1919.....		25,000			11,070,000	10,287,000	178,000	4,950,000	
Total.....	310,000	125,000	260,000	435,500	908,003,118	51,310,465	11,103,139	571,000	38,684,039

^a Of recent years it has been impossible to show the total number of yearlings, fingerlings, and adults planted, as the State reports do not distinguish them from the fry. Those shown in 1914-1919 were reared by the U. S. Bureau of Fisheries.

^b After 1911 the practice of showing waters in which steelheads were planted was abandoned as the number of streams was becoming unwieldy.

^c Includes 1,200 steelhead fry, which in "Total" column are included under "Steelhead fry."

Figure 5.1. Distribution of hatchery salmon in streams of California from 1873 to 1919. Table is excerpted from Cobb (1921) and does not include all release locations. Note that the value of 54,000 for coho salmon in 1909 in column 1 is in error and should be 42,000, as shown in the total; Cobb inadvertently added 12,000 steelhead fry (not 1,200 as indicated in footnote c) to the coho fry total.

Year of distribution	SALMON							
	Quinnat <i>Oncorhynchus tshawytscha</i>	Atlantic <i>Salmo salar</i>	Landlocked <i>Salmo gairdneri</i>	Silver <i>Oncorhynchus kisutch</i>	Rainbow <i>Salmo gairdneri</i>	Cutthroat <i>Salmo heterolepterus</i>	Large Lake <i>Salmo lakeensis</i>	Eastern Brook <i>Salvelinus fontinalis</i>
1871								
1872	50,000					22,000		6,000
1873	2,000,000							
1874	5,750,000	305						
1875	8,610,000							60,000
1876	7,500,000							
1877	7,000,000				45,000			133,000
1878	14,000,000		50,000		33,500			70,000
1879	7,000,000				61,200	50,000		
1880	7,500,000				32,000			41,500
1881	7,500,000		20,100		23,600			
1882	4,000,000							
1883	1,000,000				95,000			
1884			25,000		214,000			
1885					150,000			
1886	1,200,000				100,000			
1887	200,000				2,000,000	500,000		
1888	1,290,000				50,000	601,000		
1889	2,108,000					1,027,000		
1890	1,320,000				996,000	873,000		83,000
1891	2,798,250		30,000			88,000		
1892	2,651,000				506,500			317,000
1893	2,554,450				754,000	106,000		251,500
1894	7,776,400				1,080,240	2,983,950		266,000
1895	3,435,000				248,500	3,803,000		197,000
1896	15,283,183		250		434,000	3,608,650		
1897	17,268,000					3,783,000		30
1898	31,458,388		700		667,000	3,417,900		85,000
1899	22,214,000				275,000	3,827,350		5,000
1900	2,536,000				883,000	2,385,500		6,000
1901	3,239,000				862,500	95,000		8,000
1902	14,782,540				847,500	630,000		6,000
1903	7,209,621				497,000	747,000		415,000
1904	100,000,000		5,000		515,000	750,000		768,200
1905	105,000,000				790,000	2,303,500		640,000
1906	87,318,495				1,042,500	125,000		794,550
1907	63,697,000				2,003,000			826,000
1908	54,465,000				3,440,000			1,780,000
1909	32,843,945				3,083,500	4,115,000		1,220,000
1910	22,500,000				5,325,000	4,000,000		1,000,000
1911	23,111,000				2,810,600	2,729,751		497,500
1912	18,909,445				6,166,676	8,913,670		931,300
1913	16,277,227		7,835	25,000	2,121,718	2,273,520	87,149	843,350
1914	25,290,615				898,000	4,837,000	143,500	1,025,000
1915	33,313,150			1,517,000	3,501,000	3,124,000		854,000
1916	19,339,738				3,399,920	3,835,270		2,068,500
1917	6,853,000				5,223,500	3,836,000		1,617,500
1918	14,439,000				5,680,500	1,059,500		2,294,500
1919	12,326,200				7,063,500	1,670,700		1,171,500
1920	8,644,000				7,476,500	758,000		1,228,000
1921	9,393,000				10,182,000	520,000	988,000	1,709,000
Total	865,014,647	305	138,885	1,542,000	81,578,454	73,549,261	1,218,649	23,218,930

Figure 5.2. Distribution of hatchery salmon by the California Fish and Game Commission from 1871 to 1921. Table is excerpted from Shebley (1922) and does not show all trout species.

The limited culture of coho salmon by the State of California prior to 1905 is further affirmed in CFGC (1913), which described efforts to capture coho salmon from the Klamath River and rear them at Sisson Hatchery in the upper Sacramento River during the 1910–1911 season. The report states that silver salmon eggs taken on the Klamath River near Klamathon “were shipped to Sisson Hatchery and hatched there, with the result that 700,000 young silver salmon were placed in the Klamath River and 719,000 in the Sacramento River. This was the first effort made in this

state to increase the run of silver salmon; heretofore hatchery propagation having been confined to the Quinnat, or Sacramento salmon.” Although this statement may seem at odds with the known stocking of Baker Lake coho salmon in Santa Cruz County from 1906–1910, it is explained by the fact these activities involved eggs produced at a federal facility and reared at a county-owned hatchery (Brookdale Hatchery was not transferred to the state until 1912); thus, the State of California was not involved in either production or rearing of these Baker Lake fish.

5.2 Stocking of Baker Lake coho salmon: 1906–1910

The first known stocking of hatchery coho salmon into waters of the Santa Cruz Mountain region (or anywhere in California south of Humboldt County) involved eggs brought from the Baker Lake Hatchery in Washington to Brookdale Hatchery on the San Lorenzo River. During the 5-year period 1906 to 1910, reports of the United States Commission on Fish and Fisheries indicate that 500,000 eggs were delivered to Brookdale (Table 5.1). However, there is some uncertainty associated with this total. Bowers (1910) indicates that 50,000 coho salmon eggs were delivered to Brookdale Hatchery in 1909; however, the state-owned Price Creek Hatchery on the Eel River reported receiving a shipment of 52,000 silver salmon eggs from the Santa Cruz [Brookdale] Hatchery on 17 February 1909 and that the resulting fry were released into Price Creek (CBFGC 1910, p. 100). This report, however, conflicts with Cobb (1911), who reported that 42,000 coho fry were released into waters of Monterey Bay tributaries in 1909. Thus, it appears that the total number of Baker Lake coho eggs actually reared at the hatchery lies somewhere between 450,000 and 500,000 during the period from 1906 to 1910.

Documentation on the releases of these coho salmon is incomplete. Cobb (1911) reported 80,000 coho salmon fry being released into “Monterey Bay and tributaries” in both 1907 and 1908, and 42,000 fry released in 1909; however, he does not indicate that fish were released in either 1906 or 1910 (Table 5.1), the other two years that eggs from Baker Lake were brought to Brookdale Hatchery. Whether the 1906 and 1910 fish died or the releases simply were not documented is uncertain. There are also, to our knowledge, no records indicating which streams in the region received plants of the Baker Lake coho salmon.

Table 5.1. Number of coho salmon eggs delivered from Baker Lake Hatchery in Washington to Brookdale Hatchery in Santa Cruz County, California, from 1906 to 1910 and resulting fry output. Egg totals are from Bowers (1907–1911) and fry totals are from Cobb (1921).

Year	Source	Eggs delivered	Fry released	Release locations
1906	Baker Lake, WA	50,000	not reported	not reported
1907	Baker Lake, WA	100,000	80,000	not reported
1908	Baker Lake, WA	100,000	80,000	not reported
1909	Baker Lake, WA	50,000 ⁶	42,000	not reported
1910	Baker Lake, WA	200,000	not reported	not reported

⁶ There are conflicting reports as to whether these fish were planted in Santa Cruz County waters or transferred to the Eel River. See text for details.

Consideration of the origin of the Baker Lake coho salmon is important in assessing the likelihood that these fish successfully populated local streams of the Santa Cruz Mountains. The Baker River watershed lies to the east of Mt. Baker (~48.7°N latitude) in the Cascade Range of northwestern Washington, entering the Skagit River approximately 98 km inland from Skagit Bay. The Baker Lake Hatchery was originally built in 1896 on the shores of Baker Lake, but was moved following construction of two dams on the river in 1925 (Lower Baker Dam) and 1959 (Upper Baker Dam). Surrounded by high mountains, including the heavily glaciated Mt. Baker (elev. 3,285 m), the hydrology of the Baker River system is dominated by runoff from snowmelt. In fact, the highest seasonal snowfall total (95 feet) ever recorded in the United States (and perhaps the world) occurred at Mt. Baker Ski Area in 1998–1999, which lies on the northeast slope of Mt. Baker, just 1.5 km from the divide that separates the Baker River and Nooksack watersheds. The snowmelt-driven hydrology gave rise to a unique adult run timing for Baker Lake coho salmon. In its salmon and stock inventory, WDFW and WWTIT (1992) describe the original Baker Lake coho stock as follows:

“Baker coho are those descended from coho spawned in the Baker System prior to the construction of the dams [Lake Shannon and Upper Baker Dam]. This stock is distinguished from other Skagit River coho on the basis of location of spawning (Baker River system), river entry timing (river entry is July–early August vs. the September–October timing of other Skagit coho), spawning timing (January–February) which is somewhat later than spawners in lower Skagit tributaries, and about the same time as upper tributary spawners, and small size (average size is two to four pounds) vs. the six- to seven-pound-average of other Skagit coho.”

This unique run timing, coupled with other likely adaptations to the substantially colder environments of the North Cascade region, raise considerable doubt as to the likelihood that these fish would have succeeded in establishing local breeding populations south of San Francisco. We discuss this in greater detail in Section 5.5.

5.3 Stocking of coho salmon in Santa Cruz Mountain streams from 1911 to 1941

In the years following the planting of Baker Lake coho salmon in Santa Cruz County, published information indicates that there was very little artificial propagation of coho salmon or release of hatchery coho salmon into streams of the region. We are aware of only two recorded instances of planting between 1911 and 1928: 25,000 coho fry that were reared at Brookdale Hatchery and released into Scott Creek in 1913, and 71,000 coho fry that were released into Scott Creek and the San Lorenzo River in 1915 (Tables 5.2). In neither of these cases is the source of eggs documented. Following these two plantings, there is a 13-year period from 1916 to 1928 during which there are no records of stocking of coho salmon anywhere in Santa Cruz or San Mateo counties.

Beginning in 1929, there were renewed efforts to rear coho salmon at both Brookdale Hatchery and the newly established Big Creek Hatchery on Scott Creek. Between 1929 and 1941, approximately 1.2 million fry were planted into waters of Santa Cruz and San Mateo Counties, with the majority of these being released in the San Lorenzo River (~674,500), Scott Creek and its tributaries (~198,500), and Soquel Creek (~155,000) (Table 5.2). Egg sources for many of these plantings are not always clear from the records; however, it is evident that fish from Fort

Table 5.2. Reported plants of hatchery coho salmon fry in streams of the Santa Cruz Mountains from 1911 to 1941.

Year	Hatchery	Egg source	Eggs received	Receiving waters									Total fry planted	Source
				San Mateo Co.	Waddell Creek	Scott Creek	San Vicente Creek	San Lorenzo River	Soquel Creek	Pajaro River	Santa Cruz Co. unknown	Out of region		
1911	Brookdale												0	CFGC 1913 ^a
1912	Brookdale												0	CFGC 1913 ^a
1913	Brookdale	unknown	90,200			25,000							25,000	CFGC 1914, p. 89, 91
1914	Brookdale												0	CFGC 1914, p. 94
1915	Brookdale	unknown	unknown			25,000		46,000					71,000	CFGC 1916, p. 229
1916	Brookdale												0	CFGC 1918, p. 75
1917	Brookdale												0	CFGC 1918, p. 79
1918	Brookdale												0	CFGC 1921, p. 120
1919	Brookdale												0	CFGC 1921, p. 123
1920	Brookdale												0	CFGC 1923, p. 115
1921	Brookdale												0	CFGC 1923, p. 118
1922	Brookdale												0	CFGC 1924, p. 89
1923	Brookdale												0	CFGC 1924, p. 92
1924	Brookdale												0	CFGC 1927, p. 106
1925	Brookdale												0	CFGC 1927, p. 109
1926	Brookdale												0	CDFG 1929, p. 148
1927	Brookdale												0	CDFG 1929, p. 144
	Big Creek												0	CDFG 1929, p. 144
1928	Brookdale												0	CDFG 1931, p. 158
	Big Creek												0	CDFG 1931, p. 158
1929	Brookdale	Redwood Cr.	unknown		?? ^b	?? ^b		281,200 ^c					281,200	CDFG 1931, p. 162
	Big Creek												0	CDFG 1931, p. 162
1930	Brookdale	unknown	unknown					134,750 ^c				750	135,500	CDFG 1932, p. 106
	Big Creek	unknown	unknown			6,700 ^c			9,000 ^c	27,625 ^c			43,325	CDFG 1932, p. 106 ^c
1931	Brookdale												0	CDFG 1932, p. 110
	Big Creek												0	CDFG 1932, p. 110
1932	Brookdale	Ft. Seward	50,000					25,500 ^c	6,500 ^c				32,000	CDFG 1934, p. 82-83B
	Big Creek												0	CDFG 1934, p. 82-83B
1933	Brookdale	Prairie Cr.	100,000	300	15,000 ^c	942 ^c		23,050 ^c			18,000	300	57,592 ^d	CDFG 1934, p. 82-83E
	Big Creek												0	CDFG 1934, p. 82-83E
1934	Brookdale	Scott Cr Prairie Cr	64,000 60,000					62,745 ^c	27,750 ^c			5,000	95,495	CDFG 1936, p. 74-75E
	Big Creek												0	CDFG 1936, p. 74-75E
1935	Brookdale	Prairie Cr	50,000								32,025		32,025	CDFG 1936, p. 74-75B
	Big Creek												0	CDFG 1936, p. 74-75B
1936	Brookdale	unknown	unknown								40,095		40,095	CDFG 1938, p. 96-97G
	Big Creek	unknown	unknown								5,248		5,248	CDFG 1938, p. 96-97G
1937	Brookdale	unknown	unknown					23,885 ^c	20,825 ^c				44,710	CDFG 1938, p. 96-97I
	Big Creek	unknown	unknown	8,880		77,205 ^c						150	86,235 ^d	CDFG 1938, p. 96-97I
1938	Brookdale	unknown	unknown					45,800 ^c	40,840 ^c				86,640	CDFG 1940, p. 66-67
	Big Creek	unknown	unknown			77,060 ^c						2,000	79,060	CDFG 1940, p. 66-67
1939	Brookdale												0	CDFG 1940, p. 78-79
	Big Creek	unknown	unknown			103,118 ^c	18,900 ^c		50,000 ^c				172,018	CDFG 1940, p. 78-79
1940	Brookdale												0	CDFG 1944a, p. 74-75
	Big Creek												0	CDFG 1944a, p. 74-75
1941	Brookdale	unknown	unknown								14,685		14,685	CDFG 1944a, p. 80-81
Total				9,180	15,000	315,025	18,900	642,930	154,915	27,625	110,053	8,200	1,301,828	

a. CFGC (1913) does not provide tabular data on releases from Brookdale for 1911 and 1912; however, narratives on pages 30 and 36 make no mention of release of coho fry to Santa Cruz Co. waters.

b. CDFG (1931) indicates that some coho salmon native to Scott Creek were planted in Scott and Waddell Creeks as part of an age validation study. Numbers planted are not reported.

c. Totals for specific watersheds from fish distribution records compiled in Dayes 1987 (pp. 256-327).

d. Totals for Brookdale in 1933 (57,592) and Big Creek in 1937 (86,235) derived from fish distribution records differ slightly from totals given in CDFG (1934) and CDFG (1938), respectively.

Seward (Humboldt County), Prairie Creek (Humboldt County), and Scott Creek provided broodstock during this period.

During this time, records suggest there were two possible releases of coho salmon into Waddell Creek. In 1929, the CDFG Biennial Report for 1928–1930 indicates that 281,200 coho salmon from Redwood Creek stock (Humboldt County) were brought to Brookdale Hatchery and released into the San Lorenzo River and its tributaries (CDFG 1931). However, the biennial report also states that “*Silver salmon reared from the eggs of native fish, by C.L. Frame, foreman of Big Creek Hatchery, were marked and introduced into Scott and Waddell creeks, and the Pajaro River*” as part of an experiment to verify age determinations (emphasis added). The number of fish planted in Scott and Waddell creeks is not given, but this clearly establishes that coho salmon were present in Scott Creek prior to the renewed introductions in 1929. The only other recorded release of coho salmon into Waddell Creek during the 1929–1941 period was a planting of 15,000 fry into upper Waddell Creek in 1933.

In 1940, a flood damaged Big Creek Hatchery and the Scott Creek egg collecting station, and the hatchery was closed. Brookdale Hatchery continued to operate until 1953. However, records indicate that no coho salmon were reared at this facility or released into Santa Cruz waters after 1941 (Table 5.2; CDFG 1944b, 1946, 1948, 1950, 1953).

5.4 Post-1941 hatchery activities

From 1941 to 1962, we found only one published record (46,160 fish of unknown origin planted in 1956) that coho salmon were released into waters of Santa Cruz or San Mateo counties (CDFG 1958). Since 1963, there have been three distinct hatchery efforts in the region that involved coho salmon. From 1963 to 1979, the California Department of Fish and Game planted a reported 446,159 coho salmon, with 72% of these planted into the San Lorenzo (12 plantings) and the remainder being planted in Aptos Creek (9.1%; 4 plantings), Soquel Creek (6.7%; 3 plantings), Scott Creek (6.7%; 3 plantings), Gazos Creek (3.4%; one planting), and Waddell Creek (2.2%; one planting) (Table 5.3). Brood sources for these plantings included Noyo River (58%), the Klaskanine and Alsea rivers in Oregon (13.5% and 10.8%, respectively), and the Green River in Washington (2.2%), with origin of the remainder (15.1%) unknown (Table 5.3).

From 1980 to 1989, an attempt was made by Silver-King Ocean Farms (SKOF) to establish commercial aquaculture in the region. Over the 10-year period, SKOF released approximately 1.1 million coho salmon into Davenport Landing Creek, a small seasonal stream near the town of Davenport (Table 5.3). About 80% of the fish released were young-of-the-year, rather than yearlings. Fish were reared at the small Dufour Hatchery in the San Lorenzo River watershed (Bean Creek), transferred to ponds in King City in the Salinas Valley for a time, and then returned to an artificially constructed lagoon between Davenport Landing and Highway 1, which was maintained by pumping a combination of saltwater from the ocean and freshwater from local wells. Water was treated with chemicals to promote homing back to the Davenport Landing Creek, and fish were released into the ocean during the fall with the onset of rains, usually about a month after arriving at Davenport Landing (Dave Streig, former Big Creek Hatchery manager, Monterey Bay Salmon and Trout Project, pers. comm.). Broodstock for this effort consisted of a

Table 5.3. Reported plants of hatchery coho salmon in streams of the Santa Cruz Mountains from 1942-present. Numbers in ***bold italics*** indicates young-of-year fish released in fall.

Year	Org.	Brood sources (numbers)	Release Locations											Total fry planted		
			Pescadero Creek	Gazos Creek	Waddell Creek	Scott Creek	Davenport Landing Creek	San Vicente Creek	San Lorenzo River	Soquel Creek	Aptos Creek	Monterey Bay				
1956	CDFG	Unknown (46,160)														46,160
1963	CDFG	Alsea R., OR (40,1169); unknown (10,500)										40,169		10,500		50,669
1964	CDFG	Alsea R., OR (8,056); Noyo R., CA (15,008); unknown (32,000)	15,008									40,056				55,064
1965	CDFG	Noyo R., CA (20,330)										20,330				20,330
1966	CDFG	Klaskanine R., OR (40,000)			10,000	10,000						10,000	10,000			40,000
1967	CDFG	Klaskanine R., OR (20,020); Green R. WA (10,003)				10,003						10,010	10,010			30,023
1968	CDFG	Noyo R., CA (30,015)				10,005						10,005	10,005			30,015
1969	CDFG	Noyo R., CA (25,000)										25,000				
1970	CDFG	Noyo R., CA (25,008)										25,008				
1971	CDFG	Noyo R., CA (25,008)										25,008				
1972	CDFG	Noyo R., CA (20,007)										20,007				
1973	CDFG	Noyo R., CA (25,005)										25,005				
1974	CDFG	Noyo R., CA (25,008)										25,008				
1975	CDFG	Noyo R., CA (25,009)										25,009				
1976	CDFG	Noyo R., CA (25,002)										25,002				
1978	MBSTP	Ten Mile R. CA (1,500)												1,500		1,500
1979	MBSTP/CDFG	Noyo R., CA (8,800); unknown WA (25,011)										25,011		8,800		33,811
1980	MBSTP/SKOF	Noyo R., CA (9,540); U. of WA (100,000); U. of WA/Klamath R., CA (63,486); Cowlitz R., WA (21,818); Waddell Cr. (59,781)						245,085							9,540	254,625
1981	SKOF	U. OF WA/Klamath R., CA (24,883); U. of WA (64,255); Cowlitz R., WA (13,191); Toutle R., WA (15,378) Alsea R., OR (81,840); OreAqua, OR (11,062); Davenport Cr. CA (5,333); Waddell Cr., CA (49,401); unknown (3,150)						268,493								268,493
1982	SKOF	U. of WA (4,650); U. of WA (77,743); Cowlitz R., WA (2,800); Noyo R., CA (15,304); Davenport Creek, CA (2,371)						102,868								102,868
1983	SKOF/CDFG	Davenport Cr., CA (17,959); Noyo R., CA (8,000); Klamath R., CA (19,770)						25,959				19,770				45,729
1984	SKOF/CDFG	Davenport Cr., CA (201,824); U. of WA (95,625); Russian R., CA (17,160)						297,449				17,160				314,609
1985	SKOF/MBSTP	Davenport Cr., CA (63,000); Scott Cr., CA (428)					428	63,000								63,428
1986	SKOF/MBSTP	Davenport Cr., CA (102,520); Noyo R., CA (15,860)						102,520				15,860				118,380
1987	SKOF	Davenport Cr., CA (10,000)						10,000								10,000
1988	MBSTP/CDFG	Scott Cr., CA (8,447); Noyo R., CA (20,822); San Lorenzo R., CA (20,445); Davenport Cr., CA (2,400)					2,450					47,264				52,114
1989	MBSTP	Noyo R., CA (25,362); Scott Cr., CA (2,756)					2,756					25,362				28,118
1990	MBSTP	Scott Cr., CA X Noyo R., CA (6,552); Prairie Cr., CA (34,500)					6,552					34,500				41,052
1991	MBSTP	Scott Cr., CA (10,500); San Lorenzo R., CA (19,880)					5,460					24,884				30,380
1992	MBSTP	San Lorenzo R., CA (1,872)										1,872				1,872
1993	MBSTP	Scott Cr., CA (1,860); San Lorenzo R., CA (11,808)					1,860					11,808				13,588
1994	MBSTP	Scott Cr., CA (29,887); San Lorenzo R., CA (4,047)			5,698	18,137						10,099				33,394
1996	MBSTP	Scott Cr., CA (1,209); Scott Cr., CA (10,095)		6,017	2,026	3,261										11,304
1997	MBSTP	Scott Cr., CA (14,908)		8,948	2,980	2,980										14,908
1999	MBSTP	Scott Cr., CA (62)														62
2000	MBSTP	Scott Cr., CA (3,322)														3,322
2003	MBSTP	Scott Cr., CA (30,855)	11,475		6,120	6,120							7,140			30,855
2006	MBSTP/NMFS	Scott Cr., CA (19,547)	12,643		6,175	729										19,547
2007	MBSTP/NMFS	Scott Cr., CA (2,279)				2,279										2,279
2008	MBSTP/NMFS	Scott Cr., CA (3,141)				3,141										3,141
2009	MBSTP/NMFS	Scott Cr., CA (2,591)				1,874				717						2,591

wide range of stocks including a number of Washington and Oregon stocks, smaller numbers of fish from the Klamath and Noyo rivers in California, and hatchery fish that returned to Davenport Creek. Due to poor returns of adult fish and inability to attract them back to Davenport Landing Creek, this aquaculture venture was abandoned in 1989.

The Monterey Bay Salmon and Trout Project (MBSTP) was initiated in 1976 and began releasing coho salmon in 1978. In the first three years of operation, MBSTP released just under 20,000 coho salmon (Ten Mile River and Noyo River broodstock) directly into Monterey Bay. Since then, the program has released approximately 276,000 coho salmon yearlings into the San Lorenzo River (57%), Scott Creek (20%), Pescadero Creek (8%), Waddell Creek (7.8%), Gazos Creek (5%), Aptos Creek (2%), and San Vicente Creek (0.2%). In the 1980s, broodstock included coho salmon from the Noyo and Russian rivers and Prairie Creek (1 planting), but all broodstock used since 1991 have been from Scott Creek and the San Lorenzo River, with fish generally planted back into their stream of origin, excepting recent plantings of Scott Creek coho salmon into Waddell Creek (2 plantings), Pescadero Creek (2 plantings), and Aptos Creek (1 planting) (Table 5.3).

5.5 Response to petition

As noted above, the relevance of the above hatchery history to the petition to delist coho salmon south of San Francisco is three-fold, bearing on (1) the question of whether coho salmon collected in the region prior to 1906 could have been the result of hatchery activities, (2) the likelihood that the substantial numbers of coho salmon that were present in local streams, most notably Waddell Creek, during the 1930s and 1940s (Shapovalov and Taft 1954) were the result of the Baker Lake and subsequent introductions, and (3) whether extant populations of coho salmon in streams south of San Francisco are the result of these and subsequent introductions of nonnative fish. We address the first two of these issues here, deferring discussion of the latter issue until Section 6 of this report, as this is best addressed through the available genetic evidence.

Could coho salmon observed prior to 1906 have been the result of hatchery plantings?

The petition addendum (6 February 2004, pg. 4) states that “*we cannot rule out that the possibility that these coho [the 1895 coho specimens currently in the CAS museum collection] were the result of plantings. We know fish importations to the Santa Cruz Mountains from northern California and elsewhere were occurring at least as early as 1878.*”

The BRT found no credible evidence to support this hypothesis and substantial evidence to the contrary. The published records clearly demonstrate that neither federal nor state-owned hatcheries produced or released coho salmon into waters south of San Francisco prior to the 1906 introduction of Baker Lake fish. Prior to 1906, the only recorded hatchery activity involving coho salmon in the entire state occurred in Humboldt County for a brief period in the 1890s, and historical records clearly document that all fish were distributed back into waters of Humboldt County. While some small-scale privately owned hatcheries and rearing ponds operated in the

state prior to 1906, the BRT found no evidence that any of these reared or distributed coho salmon south of San Francisco, and considers it unlikely since these operations typically relied on eggs or fry from state or federal sources. Indeed, the only reference we found that suggests hatchery propagation of salmon of any kind in the region between San Francisco and Santa Cruz occurred prior to 1906 is Jordan's (1887) reference to an attempt to rear "*native salmon and trout*" in ponds in the Pescadero Creek watershed. Unfortunately, Jordan did not indicate which species of salmon was being propagated, but he did indicate that "*tourists from San Francisco fish here [Pescadero Creek] for salmon in its season.*"

Based on the limited production of coho salmon in hatcheries anywhere in the Pacific Northwest and the lack of any evidence that coho salmon were stocked into waters of the Santa Cruz Mountains prior to 1906, the BRT concludes that it is highly unlikely that the collections of coho salmon from four separate Santa Cruz Mountain watersheds in 1895 by the Carmel River Expedition were the consequence of hatchery activities pre-dating these collections.

Could the Baker Lake and subsequent introductions account for coho salmon populations that were present during the 1930s?

The petition (McCrary 2003) concludes that the first credible observation of coho salmon in the region was that of Snyder (1912), after the introduction of Baker Lake fish, and implies that subsequent observations, including the substantial population of coho salmon in Waddell Creek—120 to 633 adults annually from 1933–1941, with all three brood cycles represented—reported by Shapovalov and Taft (1954), were likely the result of these and subsequent introductions.

The BRT concludes that it is highly unlikely that the introductions of modest numbers of coho salmon fry from Baker Lake and the two plantings that occurred in 1913 and 1915, could account for the substantial numbers of coho salmon that were observed in Waddell Creek by the 1930s. The BRT bases this conclusion on several considerations. First, although culture of salmonids has been practiced for several centuries in both Europe and North America, there is considerable debate as to whether early practices were successful at producing returning adults or establishing populations. In general, it is believed that poor understanding of fish diseases (Lichatowich and McIntyre 1987) and nutritional requirements of fish (Rumsey 1994) resulted in extremely poor survival of hatchery salmon prior to the 1950s. Furthermore, the evidence indicates that all of these early coho salmon releases into Santa Cruz Mountain waters consisted of fry (Cobb 1911)⁷, which are expected to have very low survival rates even with modern hatchery practices (e.g., Flagg et al. 1995), let alone practices used 80–105 years ago.

Additionally, evidence from the modern era suggests that the success of transplanted coho salmon declines with the distance fish are transplanted from their natal streams (Reisenbichler 1988), particularly when the environments of receiving watersheds differ substantially from the source watersheds. For example, Ford et al. (2004) analyzed population genetic structure for

⁷ Streig (1991) noted that when Brookdale Hatchery closed in 1953, it was because it did not have the capacity to rear fish up to the yearling stage.

coho salmon in coastal Oregon populations that had been subject to extensive planting of Puget Sound (Washington) coho stocks during the 1970s and 1980s and found no evidence of introgression of Washington coho salmon into Oregon populations. Utter (2001) noted that evidence of introgression is much more common following introductions of trout than anadromous salmon. He concluded that the lack of introgression in anadromous forms is likely because of the complex series of adaptations that anadromous fish exhibit through the course of their life histories, including timing of adult migration, timing of spawning, period of embryological development, period of freshwater residence, timing of outmigration, and migration patterns at sea, among others (Taylor 1991). Each of these events is influenced by environmental factors such as stream temperature, hydrology, or ocean production cycles, and because these processes are sequential, disruption of one phase is likely to influence subsequent phases. Spatial variation in these factors across a species' range and the local adaptation of stocks to those different conditions likely explain why successful introduction diminishes with distance and dissimilarity between the source and receiving waters.

In the case at hand, successful introduction of Baker Lake fish into streams of the Santa Cruz Mountains seems particularly unlikely. Baker Lake lies some 1,600 km to the north of Santa Cruz. The Baker Lake stock evolved in a cold, snowmelt-dominated system of the northern Cascade Range and is thus adapted to conditions that are vastly different from those found on the central coast of California. The most notable of these adaptations is the summer run timing (July–August) of Baker Lake adults. Run timing of adult salmonids is strongly under genetic control, with local populations being adapted to the local environmental conditions including temperature and stream flow (which determine accessibility), and photoperiod likely providing the primary cue that synchronizes the return of adults to spawning streams (Quinn 2005). The early run timing of Baker Lake coho salmon would be extremely disadvantageous for the environment of the Santa Cruz Mountains since, as noted earlier, many streams in the region bar over during summer and do not become accessible until late November or December in most years. Reconciling the dramatic difference in photoperiod between Baker Lake in July–August (13.6 to 16.0 hours) when Baker Lake fish migrate and Santa Cruz in December–January (9.6–10.3 hours) when local coho salmon migrate is also problematic. Likewise, the timing of outmigration by coho salmon smolts shows a strong latitudinal pattern, with migrations occurring earlier in the southern portion of the range, a pattern that is believed to reflect regional differences in the timing of favorable ocean conditions (Spence and Hall 2010). Photoperiod is again the primary cue that initiates downstream movement and is substantially longer (14.6–15.9 hours) in May when the peak of Puget Sound coho migration occurs, compared to the (12.6–13.7 hours) experienced in the Santa Cruz Region in April, when the peak migration of most coastal California populations occurs. Smolts migrating outside the most favorable window are likely to experience substantially reduced survival.

Additionally, the quantities of coho salmon fry released into Santa Cruz Mountain streams between 1906 and 1928 were relatively modest and would likely have resulted in only a small number of adults returning to the area. Bradford (1995) summarized data related to survival of coho salmon in the early life stages and reported survival from egg-to-fry and egg-to-smolt stages of 20% and 1.5%, respectively, from which a fry-to-smolt survival of about 7.5% is expected. Although somewhat variable, marine survival rates of coho salmon smolts typically average about 2–3% along the coast of Oregon (little information is available for California).

Applying these fry-to-smolt and marine survival rates under the liberal (and unrealistic) assumption that Baker Lake fry survived at rates typical of native populations that are well adapted to their environments, the releases of Baker Lake fry at best might have produced an average of 120 adults in the spawning years 1908–1909 to 1912–1913. The actual number of adults produced was probably considerably smaller, since both freshwater and marine survival rates of transplanted Baker Lake stocks in central California waters would likely have been lower than values reported by Bradford (1995). We would also expect declines in number over subsequent generations due to the maladapted nature of the stock and the degraded environmental conditions that undoubtedly prevailed after the intensive logging in the region (see Section 4).

The petitioner also asserts that the coho salmon observed by Shapovalov and Taft (1954) could have resulted from the plants of coho salmon that occurred in 1929 and 1930 based on personal communication with local residents (McCrary et al. 2004). However, the distribution records from 1929 and 1930 indicate that all of the coho salmon from Brookdale and Big Creek hatcheries were released into the San Lorenzo River, Soquel Creek, and the Pajaro River watersheds (Table 5.2). In fact, the only documented release of nonnative coho salmon into Waddell Creek during the entire Shapovalov and Taft study (1932–1941), occurred in 1933. These fish would not have been reflected in the number of returning adults until the 1934–35 spawning season, a year after Shapovalov and Taft reported substantial numbers of adult migrants. Taft and Shapovalov (1938) provide support to the BRT’s conclusion that Waddell Creek received only minimal stocking during the 1930s, stating that the marked fish released in Scott Creek were hatchery reared whereas those marked in Waddell Creek were naturally spawned, and that “*no ‘planting’ of fish is done at Waddell Creek.*” Thus, the petitioner’s conclusion does not appear supported by the published records.

Finally, the BRT notes that the petitioner presents hypotheses that fundamentally contradict one another. On one hand, the petitioner contends that the “extreme” environments of the Santa Cruz Mountain streams preclude coho salmon from persisting in streams south of San Francisco. Yet, if we accepted the petitioner’s contention that fish observed in the 1930s were the result of hatchery introductions, then it means that a stock that was likely poorly adapted for conditions in central California successfully persisted in these extreme environments absent any additional stocking for more than four generations following the 1915 planting. The plausibility of such an occurrence is diminished further by the fact that average annual precipitation in the region during the period from 1915 to 1930 was lower than at any time over the last 100 years (Figure 5.3).

Based on the sum of this evidence, the BRT concludes that it is highly unlikely that the substantial population of coho salmon observed in Waddell Creek in the 1930s and 1940s, and which Shapovalov and Taft (1954) clearly considered to be native, was the result of the planting of nonnative fish into the region.

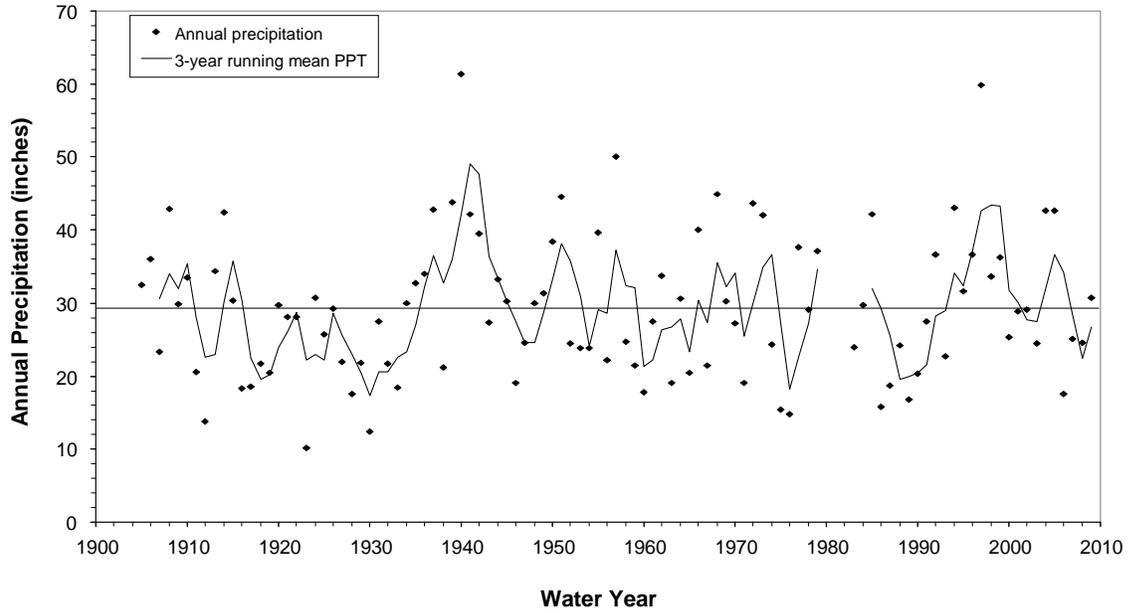


Figure 5.3. Annual precipitation and 3-year running mean of precipitation measured at Santa Cruz, California, for water years 1905 to 2010. Data from National Weather Service station (available from California Department of Water Resources, California Data Exchange Center).

6. Genetic data related to the southern boundary of CCC Coho Salmon

Molecular genetic data are now extensively used in fisheries to provide inference about population structure and the ancestry of populations and individual fish. Over the last decade, a number of genetic datasets have been collected from coho salmon in California that inform the issues raised in the petition and subsequent communications from the petitioner (McCrary 2004, 2005; McCrary et al. 2004), as well as in Kaczynski and Alvarado (2006). The issues these genetic analyses address include the origin and ancestry of coho salmon from the area in question, the biological boundaries of the CCC Coho Salmon ESU, the reliability of salmonid species identification by early ichthyologists, and the historical occurrence of salmonid populations on the central California coast. The datasets consist primarily of population surveys of coho salmon in California, and one throughout the species range, with microsatellite DNA markers. These population genetic markers are the most commonly used tool for genetic analysis of fish populations. The information most pertinent to the BRT's effort comes from several sources including (1) several analyses of coho salmon from California and throughout the species' range conducted by the National Marine Fisheries Service's Southwest Fisheries Science Center (NMFS-SWFSC) over the course of the last decade, (2) a more limited study of California coho populations by Bucklin et al. (2007), and (3) a study of specimens from the National Museum of Natural History that were collected in 1897 and 1909 and originally cataloged as *Salmo irideus* or *gairdneri* (i.e., *O. mykiss*). This latter work involves short sequences of mitochondrial DNA, but is relevant to the issues raised by the petitioners because of the insights it provides into both the state of fish populations and of fishery biology in the period before large-scale artificial propagation of coho salmon in California.

6.1 Genetic datasets

There are a number of molecular genetic datasets relevant to the question of whether coho salmon from the area in question are native fish or are derived from out-of-ESU stocks. The NMFS-SWFSC laboratory has four datasets relevant to defining the southern limit of the CCC Coho Salmon ESU. Bucklin et al. (2007) provide an additional dataset of interest.

Bjorkstedt et al. (2005)

The first dataset of relevance is the one from NMFS-SWFSC described in Bjorkstedt et al. (2005), which resulted from an effort to compile all available data about the CCC Coho Salmon ESU as part of the process undertaken by the multi-species Technical Recovery Team for the North Central California Coast Recovery Domain. The dataset described in that document consists of genotypes for 18 microsatellite genes (loci) in collections of fish from 17 basins in California, including four south of the Golden Gate: Gazos, Waddell, Scott, and San Vicente creeks. Temporal samples from some populations were also included. A total of nearly 4000 fish were genotyped for that dataset and used to assess the relative contributions of temporal and geographic variation to population structure of coho salmon in California. Relevant analyses include the phylogeographic tree (phylogram) and isolation by distance regression. The phylogram (Figure 6.1) shows clearly that coho salmon populations south of the Golden Gate

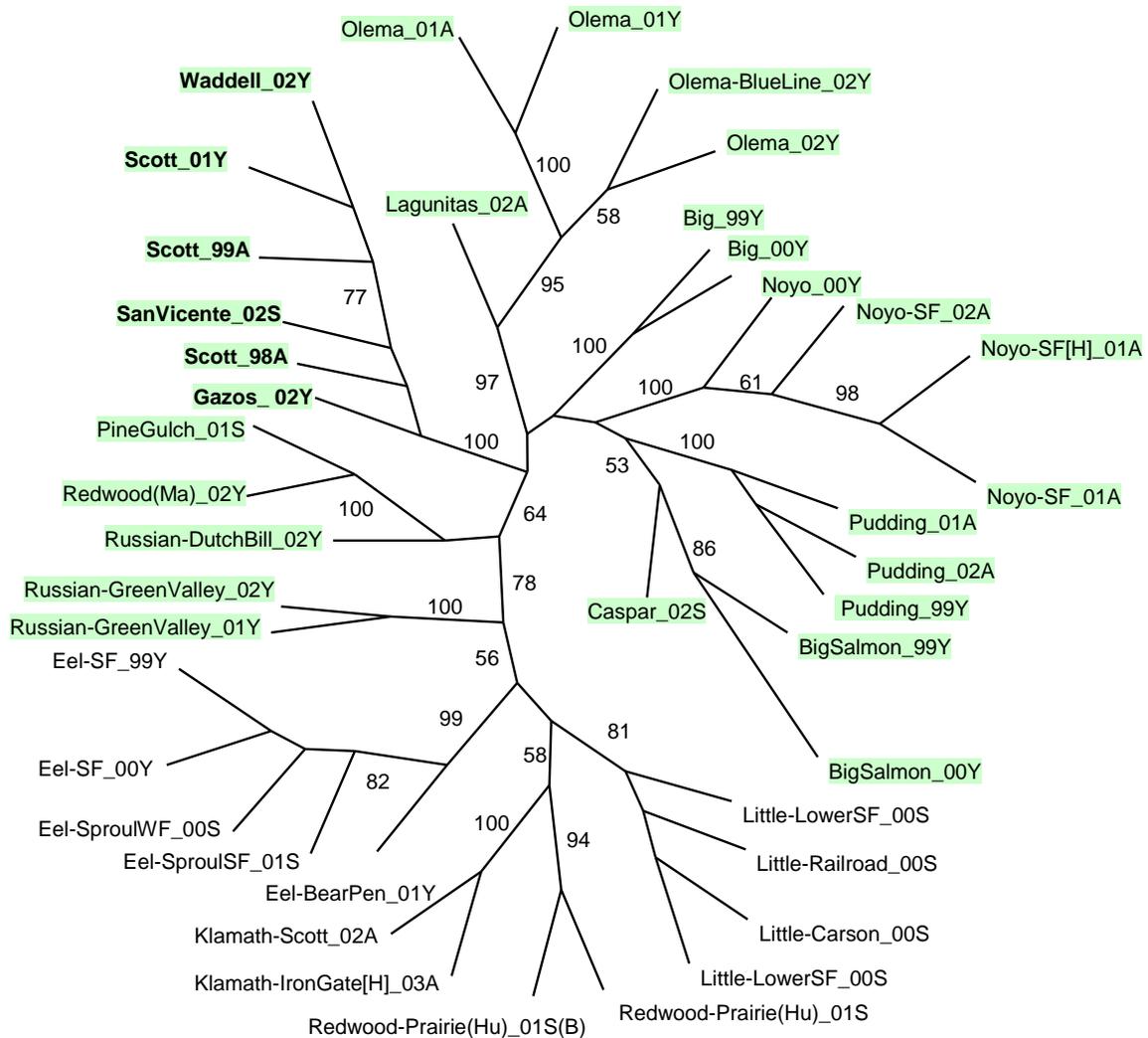


Figure 6.1. Bootstrap consensus tree for coho salmon in California. Consensus tree is based on trees constructed with a neighbor-joining algorithm (Saitou and Nei 1987) using Cavalli-Sforza and Edwards (1967) chord distances calculated for 5000 data sets generated by bootstrap resampling from data for 18 microsatellite loci. Numbers on internal branches indicate the proportion (>50%) of trees in which the indicated node appeared. Samples are identified by watershed and stream, brood year, and life stage (A = adult; S = smolt or outmigrating juvenile; Y = young-of-year juvenile). Hatchery populations are indicated with “[H]”. “Ma” indicates Marin County; “Hu” indicates Humboldt County. Figure modified from Bjorkstedt et al. (2005).

cluster within the CCC Coho Salmon ESU and not with populations in the Southern Oregon/Northern California Coast (SONCC) Coho Salmon ESU. The phylogram also shows that the populations south of the Golden Gate are all closely related as a result of frequent gene flow between them, some of which may have been facilitated by releases of fish raised at the Scott Creek hatchery facility into other area streams (Table 5.3). The isolation by distance analysis (Figure 6.2) shows that there is a strong relationship between geographic and genetic distance in

coho salmon populations both in the CCC Coho Salmon ESU and throughout California. This result demonstrates the importance of migration (straying) in determining population structure of coho salmon in California and in maintaining population viability and genetic diversity.

Garza and Gilbert-Horvath, unpublished data

The second dataset is one modified directly from that described in Bjorkstedt et al. (2005). It consists of genotypes for the same 18 microsatellites in larger numbers of coho salmon, both from basins in California and throughout most of the range of the species. This dataset adds genotypic data from a number of additional populations, including several in California, as well as from Russia, Alaska, and Canada. Also represented are fish from the Puget Sound, Washington, region including the Samish River watershed, which is the watershed immediately north of the Skagit watershed, within which resides the Baker Lake stock that was imported to Santa Cruz waters from 1906 to 1910 (see Section 4). A total of over 6,000 fish were genotyped for this analysis.

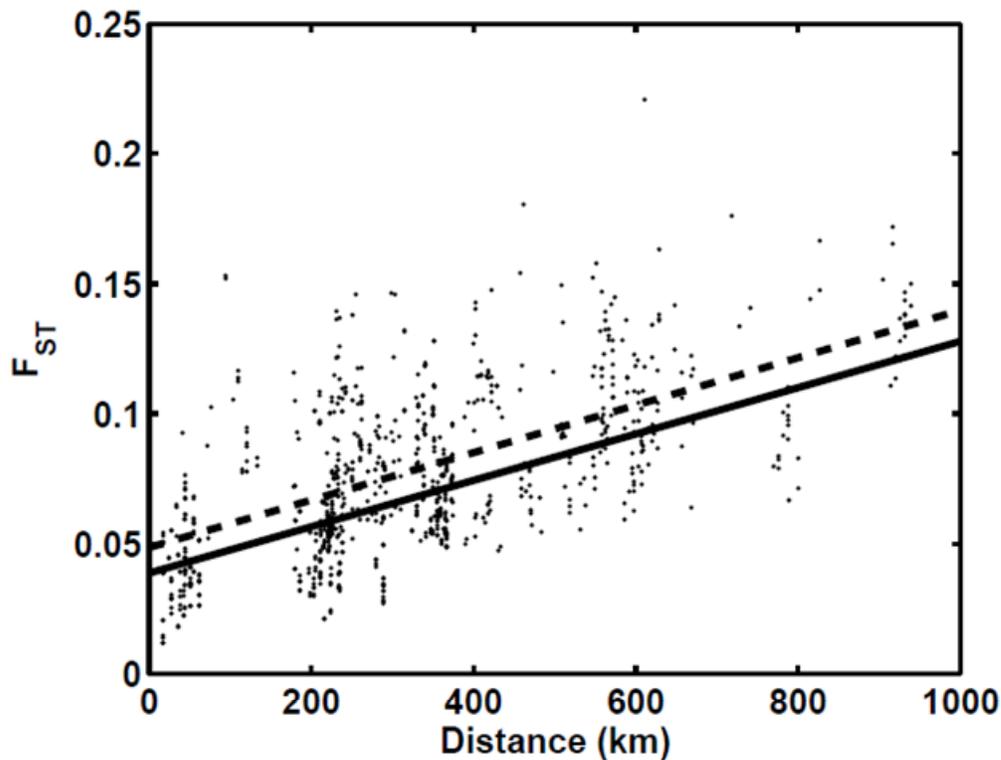


Figure 6.2. Isolation-by-distance on coho salmon based on pairwise F_{ST} and geographic distance for samples from the CCC-Coho ESU (solid line) and throughout coastal California (dashed line). For samples from different basins, geographic distance is calculated as the sum of the length of the coastal contour (omitting major bays such as San Francisco Bay) between stream mouths and the upstream distance of each sample location. For samples from within the same basin, geographic distance is calculated as the distance “as-the-fish-swims” within the stream network. Figure from Bjorkstedt et al. (2005).

Patterns of genetic differentiation that include F_{ST} values (measures of genetic differentiation) and phylogeographic trees (Figure 6.3) all show that fish sampled in the southern extent of the CCC Coho Salmon ESU's range cluster unambiguously with other populations from the CCC Coho Salmon ESU and not with populations from other ESUs, including the Puget Sound/Strait of Georgia ESU. This effectively rules out the possibility that the majority of genetic ancestry from populations of coho salmon south of the Golden Gate derives from an out-of-ESU source.

Garza et al. in prep

The third dataset of relevance is similar to the two previously described, in that it is a study of phylogeographic structure of coho salmon populations in California with the same 18 microsatellite loci. However, this dataset results from a focused effort to understand population structure in the two California coho salmon ESUs through dense sampling of juvenile fish from a single cohort (2002–2003 spawning year). This type of sampling removes temporal variance and

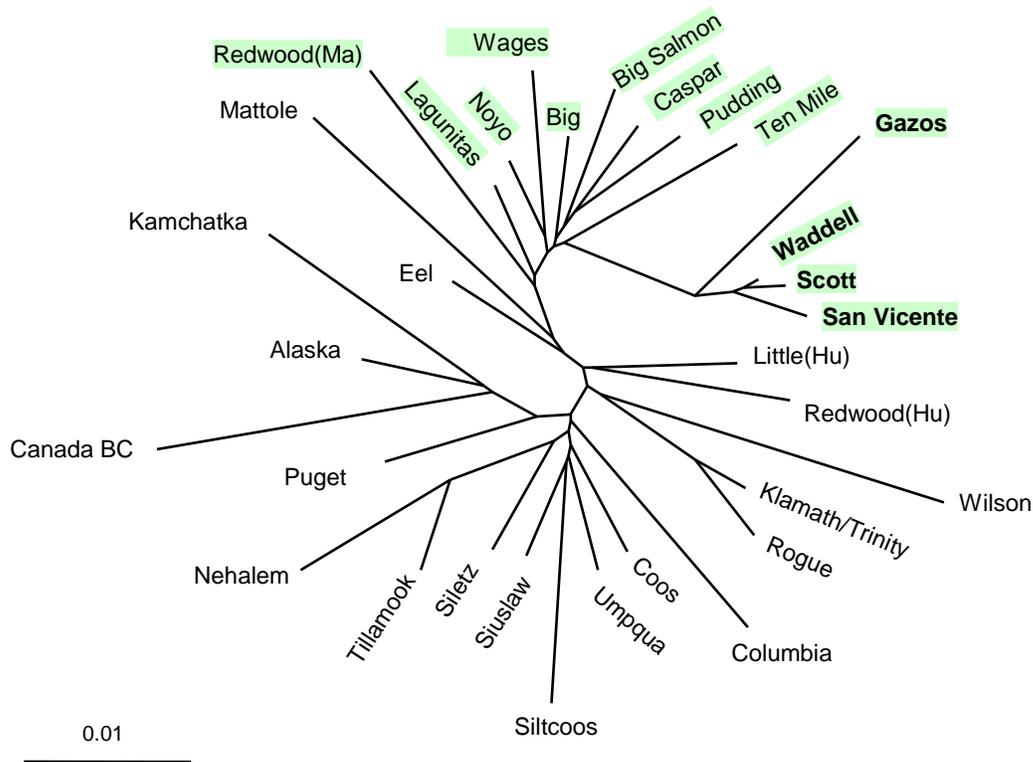


Figure 6.3. Maximum likelihood phylogeographic tree for coho salmon across nearly the entire range of the species. Genotype data from over 6,000 fish typed at 18 microsatellites were used in the tree construction algorithm. Temporal populations within a basin were pooled for the analysis. “Ma” indicates Marin County; “Hu” indicates Humboldt County. Populations highlighted in green are part of the CCC-coho salmon ESU; those in bold are south of the Golden Gate.

ensures that genotypes represent fish resulting from reproduction in the focal stream. A total of 1554 fish from 23 basins spanning nearly the entire range of the species in California were sampled for this dataset. Several samples were collected from the two largest basins in the study, the Eel and Klamath/Trinity rivers, as well as two of the smaller streams, Lagunitas/Olema and Freshwater creeks. South of the Golden Gate, only in Scott Creek were juvenile salmon sufficiently abundant in 2003 for population sampling. Analyses of genetic structure included phylograms, analysis of isolation by distance, and canonical clustering.

Phylograms for this dataset (Figure 6.4 and 6.5) are consistent with those from the other datasets in that they unambiguously cluster the Scott Creek population within the CCC Coho Salmon ESU. Moreover, the greater resolution that comes from removing temporal variance in allele frequencies clarifies two other elements of population structure of coho salmon in California. First, the Scott Creek population clusters with the population from Redwood Creek, which is the first coho salmon population to the north of the Golden Gate, as would be expected for a group of salmon populations within an ESU. This clearly demonstrates that migration, and subsequent reproduction, occurs between CCC Coho Salmon ESU populations to the north and south of the Golden Gate. This result also unequivocally establishes that these southern coho salmon populations could not be derived solely from imported fish (see Table 5.2). Second, the division between the populations in the CCC and SONCC Coho Salmon ESUs is clearly apparent and strongly supported in this dataset, reaffirming the choice of this area as the boundary between the two ESUs. Finally, as with the Bjorkstedt et al. (2005) dataset, this dataset is consistent with a pattern of isolation by distance (Figure 6.6) and the regression is highly significant.

Bucklin et al. 2007

Bucklin et al. (2007) also studied population structure of coho salmon in California using microsatellite loci. This article is the peer-reviewed version of the Hedgecock et al. (2002) study referenced by Kaczynski and Alvarado (2006). This study evaluated samples from 12 basins in California collected primarily in the decade of the 1990s. Although more than one tributary and/or cohort was sampled in several of these basins, the study employed only seven microsatellite loci and thus has less power for elucidating phylogeographic patterns than the datasets discussed previously. Nevertheless, two of their results are relevant to the question of the southern boundary of the CCC Coho Salmon ESU and both are consistent with the data collected by NMFS-SWFSC. The first result of interest is an evaluation of temporal stability within a population, where they found that temporal variation is much smaller than spatial variation in California coho salmon populations, at least on short time scales. The other relevant result is the phylogeographic tree (phylogram) evaluation, which again found that the salmon populations south of the Golden Gate cluster unambiguously with other populations in the CCC Coho Salmon ESU (Figures 6.7).

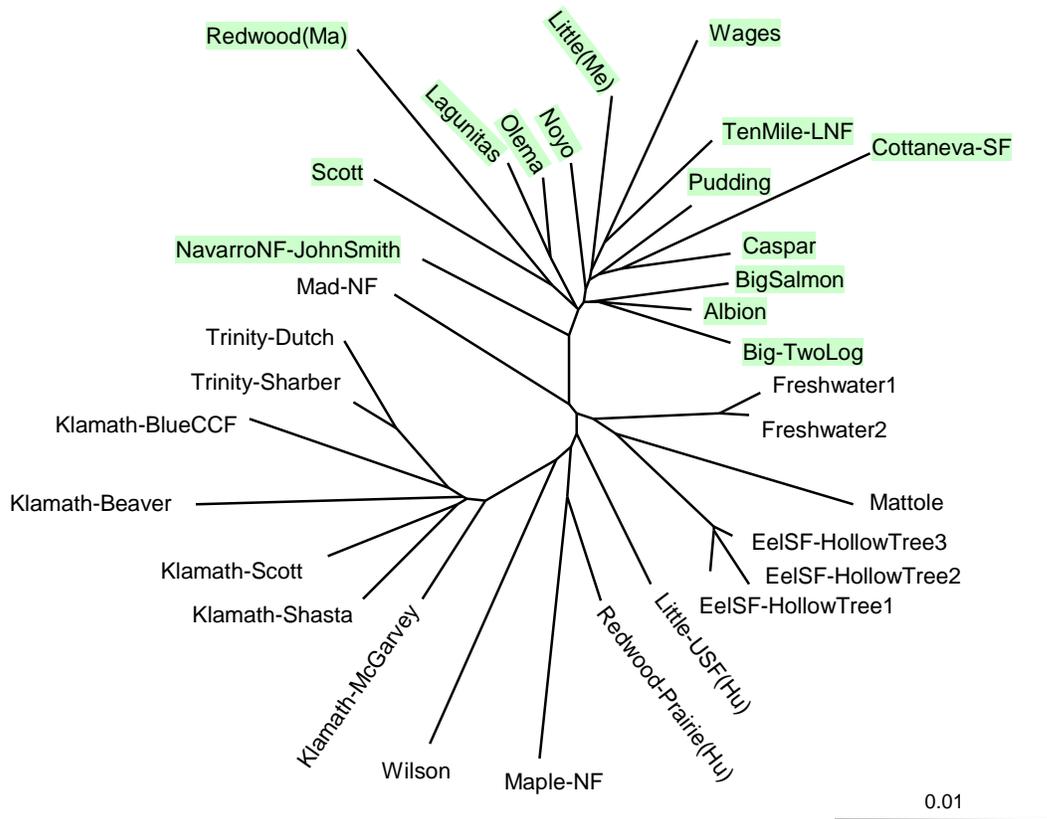


Figure 6.4. Maximum likelihood phylogeographic tree for coho salmon in California. Genotype data from 1554 fish from a single cohort (2003) typed at 18 microsatellites were used in the tree construction algorithm. “Ma” indicates Marin County; “Me” indicates Mendocino County; “Hu” indicates Humboldt County. Populations highlighted in green are part of the CCC-coho salmon ESU.

Garza et al. unpublished

The next relevant dataset consists of genetic analyses of juvenile coho salmon discovered in area streams in 2008 by NMFS-SWFSC biologists during snorkel surveys, and subsequently captured for tissue sampling. These samples came from the San Gregorio (N=28), San Vicente (N=29), and Soquel (N=28) watersheds. The same 18 microsatellite loci as used in the phylogeographic analyses described above were used to genotype these fish and investigate two questions: what are the origins of these fishes’ parents and what is the minimum number of reproductive events that contributed to these juvenile collections? Standard genetic stock identification techniques (e.g., Seeb et al. 2007) were used with a baseline reference database that included representative stocks from all regional California groups of coho salmon. All of the juvenile fish assigned to the south-of-San Francisco representative (Scott Creek) with very high confidence (77 of 85 with 100 % probability, 8 of 85 with probability >99.6%). This demonstrates unequivocally that these juvenile fish were the result of locally produced adult salmon returning to reproduce in area streams.

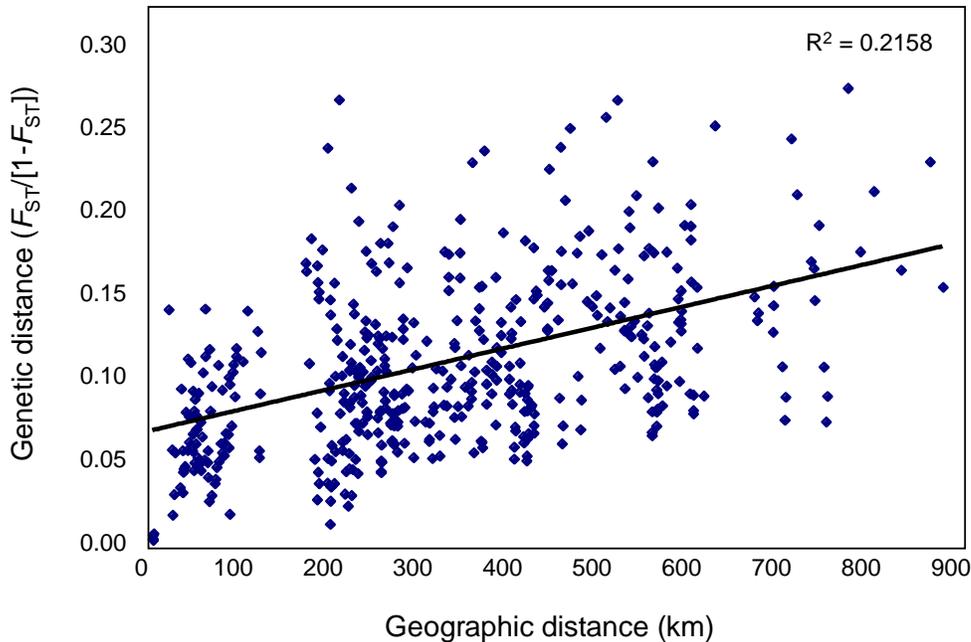


Figure 6.6. Regression of pairwise genetic distance on the geographic distance between sets of sampling sites of juvenile coho salmon in 2003 from California 23 basins. Regression is highly significant: $p < 0.01$.

Smithsonian's Ichthyology collection. The museum specimens are all cataloged as steelhead/rainbow trout (*Salmo gairdneri* or *irideus*) and resulted from surveys that he participated in to catalog fishes in streams from the Salinas River in the south to the Eel River in the north (see Section 7 for elaboration). The results of these expeditions are chronicled in Snyder (1907 and 1912). Genetic analysis of these specimens was difficult because of the degraded state of the genetic material found in them, due both to age and likely fixation with formalin, and only very short segments of mitochondrial DNA could be extracted from them. The results and interpretation of these analyses are reported in Pearse et al. (in press).

Two results from this work are relevant to the question of the southern extent of the CCC Coho Salmon ESU. First, the fish collected in Lagunitas Creek, immediately to the north of the Golden Gate, were almost all (22 of 25) genetically identified as coho salmon and not steelhead. This demonstrates that coho salmon were present immediately to the north of the area in question over 100 years ago and also provides direct evidence that ichthyological luminaries of that time could not reliably identify juvenile salmonids to species (see Section 7 for elaboration). Second, the steelhead data indicate much stronger historical isolation by distance, caused by migration between proximate basins, than currently exists for steelhead populations. This reinforces the importance of metapopulation structure in the maintenance of population viability in salmonids in this region and, coupled with the documented presence of coho salmon in Lagunitas Creek, strongly suggests that coho salmon were present in streams with similar habitat to the south of the Golden Gate.

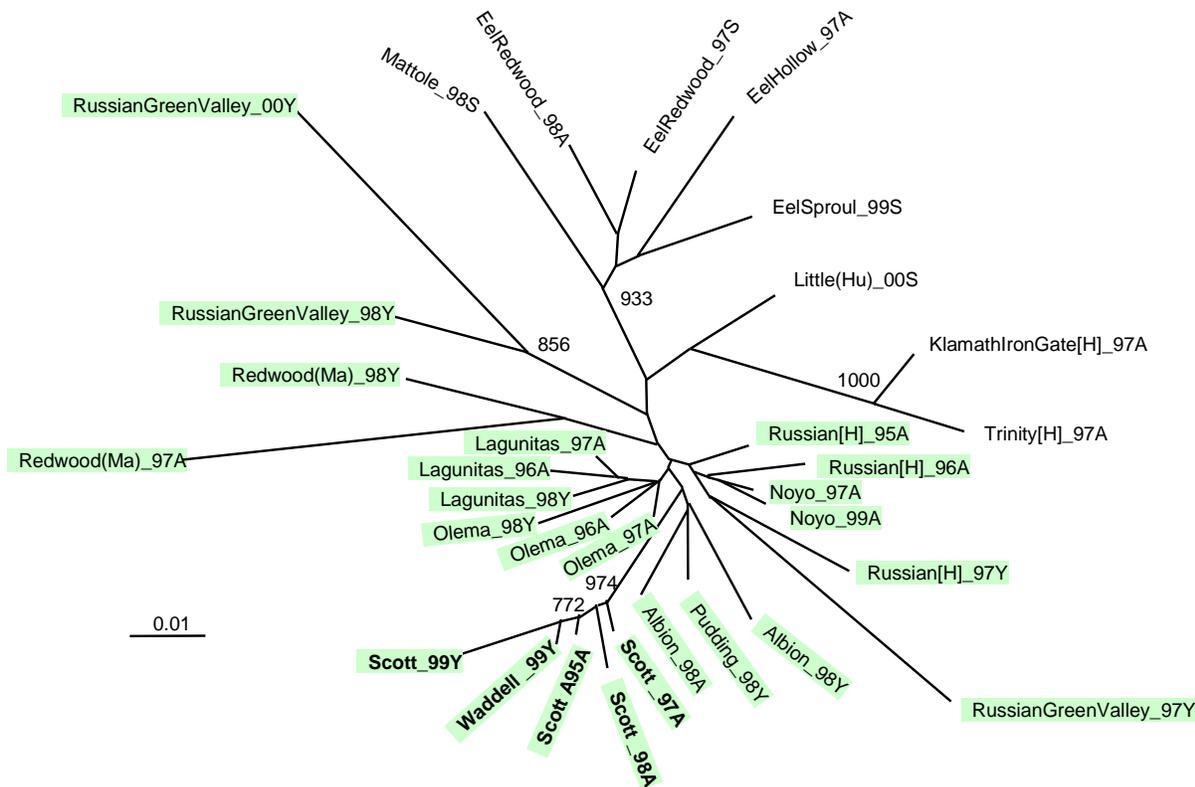


Figure 6.7. An unrooted neighbor-joining tree showing chord distances (Cavalli-Sforza and Edwards 1967) among 32 California coho salmon (*Oncorhynchus kisutch*) collections formed by pooling samples within drainages by year class. Bootstrap values greater than 700 out of 1000 are shown. Figure modified from Bucklin et al. 2007. Labels indicate location, year of collection, life stage (A = adult, S = smolt, and Y = young-of-year). Hatchery populations are indicated with “[H]”. Populations highlighted in green are part of the CCC-coho salmon ESU; those in bold are south of the Golden Gate.

Table 6.1. Number of alleles per locus for 18 microsatellites genotyped in 2008 juvenile coho salmon from Santa Cruz and San Mateo county streams. Sample sizes are listed in the text. More than 4 alleles at a locus indicates more than one reproductive event. Assignment tests found all fish strongly affiliated with the Scott Creek population.

Watershed	Ok13	One11b	One13	OtsG68	OtsG83b	Ssa14	OcL8	Omy111	Ots103	Ots1b	OtsG422	P53	Ok1	O1058	O1080	OtsG3	OG78b	Ssa85	Mean
San Gregorio	2	1	2	4	4	1	3	1	3	2	4	3	3	2	3	2	3	2	2.50
San Vicente	2	1	3	3	4	2	4	1	3	2	2	3	4	4	3	1	4	2	2.67
Soquel	2	1	5	5	5	2	6	1	5	2	6	5	2	5	6	2	6	2	3.78

6.2 Summary of inference provided by genetic data

The genetic analyses described above provide several conclusive results relevant to the petition and subsequent points raised by the petitioner and his representatives. First, the four analyses of population structure are consistent in identifying contemporary coho salmon populations south of the Golden Gate as genetically part of the CCC Coho Salmon ESU, unequivocally demonstrating that their ancestry is not strongly influenced by the introductions of fish from other ESUs that were documented by Bjorkstedt et al. (2005), Kaczynski and Alvarado (2006), and this report (Table 5.2). In particular, the Baker Lake introductions from 1906 to 1910 and the > 500,000 fish from Washington and Oregon stocks imported in the 1980s for use in the Silver-King Ocean Farms operation resulted in little or no ancestors in the extant naturally spawning populations in the region. In addition, while the data do not rule out some contribution of fish imported from other populations within the CCC Coho Salmon ESU (e.g., the Noyo River), the patterns of isolation by distance and population clustering, evident in all of the datasets but particularly in that of Garza et al. (in prep.), rule out the possibility that contemporary coho salmon populations south of the Golden Gate are entirely the result of such importations. Moreover, since coho salmon populations within an ESU are, by definition, expected to exchange migrants at rates sufficient to influence each other's demography and evolutionary trajectory, it is not possible to determine whether similarities between populations in the southern and northern parts of the CCC Coho Salmon ESU are due entirely to natural processes, or whether the anthropogenic movement of fish throughout the ESU has also had an effect. These conclusions are robustly supported, given that the datasets described above include samples collected in both of the last two decades, from different brood years and life stages, and with analyses performed by different research groups using different molecular genetic markers.

The second relevant conclusion is the inference provided by the genetic data about the biological boundaries of the CCC Coho Salmon ESU. The four population-structure datasets all find that the CCC Coho Salmon ESU populations cluster together, to the exclusion of populations in the SONCC ESU. The Garza et al. (in prep.) dataset, expected to be the most powerful for discerning population structure within California, also finds this separation to be very strongly supported by bootstrap resampling analysis. This consistent, strongly supported pattern indicates that the current northern boundary of the CCC Coho Salmon ESU is biologically appropriate. The genetic data from juvenile coho salmon sampled in 2008 in streams from the area in question also provide insight into the southern biological boundary of the CCC Coho Salmon ESU. Analysis of genotypes from the juveniles sampled in Soquel Creek (Table 6.1), which enters the Pacific Ocean about 6.5 km south of the current ESU boundary at the San Lorenzo River, demonstrate that multiple natural spawning events occurred there in 2008. Since these spawning events could not have been the direct result of hatchery releases, they demonstrate that suitable habitat to the south of the current ESU boundary can support coho salmon reproduction and indicate that this stream and perhaps others should be considered within the ESU boundary. The final dataset of relevance involves the analysis of museum specimens collected by Snyder and provides direct evidence that preeminent ichthyologists of that era could not always reliably identify juvenile salmonids to species.

6.3 Response to petition

The original petition, its addendum, and subsequent communications from the petitioner raise several points related to the genetic composition of coho salmon populations south of the Golden Gate (McCary 2003, 2004, and 2005; McCrary et al. 2004). In addition, Kaczynski and Alvarado (2006) cite several lines of genetic evidence for their claims that coho salmon south of the Golden Gate are introduced game fish and not native. They also discuss whether genetic data indicate that coho salmon from south of San Francisco are “different” or not from those in the northern part of the ESU; however, this discussion is based upon what the BRT believes is a misinterpretation of NMFS ESU policy and is thus not directly relevant to the question of where to place the southern boundary of the CCC Coho Salmon ESU (see Section 3).

The petitioner asserts that current populations of coho salmon south of the Golden Gate are the result of hatchery introductions that began with the importation of eggs from the Baker Lake Hatchery (WA) coho salmon stock during the period 1906–1910, and have been maintained by subsequent introductions (McCrary 2003, 2005). Kaczynski and Alvarado (2006) elaborate on this claim, providing a summary of numbers of coho salmon planted in streams south of San Francisco from 1906 to 1990 (Figure 2 in Kaczynski and Alvarado 2006). Most of these fish also originated in populations outside of the CCC Coho Salmon ESU, including the substantial numbers of fish imported to supply the Silver-King Ocean Farms operation in Santa Cruz County (see Table 5.3). The genetic datasets described above consistently rule out the possibility that importations of out-of-ESU salmon contributed substantially to the contemporary populations south of the Golden Gate. This is consistent with other observations of lack of establishment success of salmonids transplanted in streams that are distant from their natal ones (see Section 5 for discussion) and with the fact that the vast majority of the 1.1 million Silver-King Ocean Farms fish were released during fall as age-0 fish from a constructed lagoon on a very small, stream at Davenport Landing (D. Streig, Monterey Bay Salmon and Trout Project, pers. comm.). Survival of fish released in such a manner would be expected to be low, as migration timing is an important determinant of marine survival (Bilton et al. 1984; Spence and Hall 2010).

Several hundred thousand fish from the Noyo River, also part of the CCC Coho Salmon ESU, were imported for the Silver King operation, as well as for release into the San Lorenzo River in the period immediately prior (1965–1979; Table 5.3). While the genetic analyses cannot rule out that these Noyo River fish contributed to contemporary salmon populations in the region in question, it is unlikely for the reasons described above, and the genetic analyses definitively establish that they cannot be the sole contributors. The phylograms and the patterns of isolation by distance in all of the datasets demonstrate that the populations south of the Golden Gate were not founded by the Noyo River imports, and are genetically consistent with the expectations of a set of populations in the same ESU and at the edge of the species range. The data clearly show that migration between populations north and south of the Golden Gate is a major determinant of population structure in the ESU.

Incidentally, Kaczynski and Alvarado (2006) acknowledge that the molecular genetic data indicate “affinity” between the south of the Golden Gate populations and those in the northern part of the CCC coho salmon ESU, and concede that it must be due to straying since the 1906 importation. Kaczynski and Alvarado (2006) also conclude that “*the newest genetic data do not*

support concordance between genetic and geographic structure” but provide no reference to any specific data or how they concluded there is a lack of concordance. In fact, none of the modern genetic data suggest such discord at any spatial scale relevant to the definition of an ESU boundary.

The petitioner also make a series of arguments about how delisting and/or extinction would not result in an important loss of genetic diversity to the species, claiming initially that they are not native and so cannot be important (McCrary 2003), and subsequently that no genetic study has shown that they are “*an important component of the evolutionary legacy of the species*” (McCrary 2004). The petitioner also asserts that “*there is little consensus among geneticists*” (McCrary et al. 2004). The BRT notes that (1) the evolutionary legacy criterion applies at the level of an ESU, not a population or set of populations, and (2) there is in fact considerable consensus among genetic studies about whether the coho salmon populations at the southern extent of the range in California are part of the CCC Coho Salmon ESU, and all molecular genetic studies to date have been consistent on this issue.

7. Historical evidence of salmon in streams and rivers south of San Francisco

Interpreting both scientific and popular historical accounts of Pacific salmonids in California during the mid-to-late 1800s and early 1900s is confounded by two facts. First, systematic scientific exploration and examination of fish faunas in the streams and rivers of California was in its infancy; consequently, the scientific basis underlying early descriptions of species' distributions was quite limited. Furthermore, these early surveys occurred after considerable habitat degradation (primarily due to logging and mining; see Section 4), which likely resulted in substantially decreased abundance of some fish populations and hence the probability of being encountered.

Second, the taxonomy and nomenclature of salmon and steelhead were far from settled during this period. Prior to the 1880s, there was enormous uncertainty regarding the true number of salmon species that occurred in North American river systems entering the Pacific Ocean. Additionally, many common names for salmon were applied to more than one species of Pacific salmon depending on the specific geographic region, sex of the fish, or developmental stage. Fishermen and scientists alike often had (and still do have) difficulty discriminating among the different species, both during the marine phases and, particularly, the juvenile phases. Adding to this confusion was the fact that very little was known about the life histories of the different species, including the timing of adult migration and spawning, the period of freshwater residence, and even whether species were semelparous or iteroparous. All of these factors contributed to the frequent misidentification of species and sometimes conflicting descriptions of each species' historical range. Of particular importance for purposes of this report is the clear confusion between coho and chum salmon, which persisted into the early 1900s.

In the sections below, we first review the extent of scientific surveys of the fish faunas of California in the period from 1850 to the early 1900s, focusing on efforts that involved collection of specimens, rather than general descriptions of species and their ranges. We next discuss the uncertainty surrounding the taxonomy and nomenclature of Pacific salmon during this era, illustrating the difficulties in interpreting published scientific and popular accounts of salmon from this period. With this as context, we then review available evidence regarding the occurrence of anadromous salmonids, and coho salmon in particular, in the region south of San Francisco. Included are discussions of written species accounts (both accounts from specific streams and rivers as well as general descriptions of species distributions), and physical evidence from museum collections. Archaeological evidence is treated in a separate section (see Section 8). We conclude with a discussion of the petitioner's interpretation of the historical record in light of this historical evidence. It is clear from this detailed examination of both scientific and popular writings that (1) early ichthyologists were confusing coho and chum salmon, and (2) in addition to steelhead, at least one salmon species occupied coastal streams of Central California south to Monterey Bay and that this was most likely coho salmon.

7.1 Early explorations of coastal California fish faunas

To correctly interpret the descriptions of species distributions written by David Starr Jordan and other early scientists in the late 1800s and early 1900s, it is important to understand the limited

extent to which the fish faunas of California coastal watersheds had been explored at the time of these early writings. Two sources provide summaries of early scientific investigations of freshwater fish faunas in California. Evermann and Clark (1931) provides a “*critical examination of all literature pertaining to the freshwater fishes of the State, as species or kinds, in order that we might know not only what species are known to occur, in California, but also the geographic distribution of each of those species within the state.*” The expressed purpose of their work was to prepare a distributional catalogue of species that had been recorded from definite localities within California. Böhlke (1953) provided a list of major expeditions undertaken by the faculty and students of Stanford University from 1889 to the early 1950s. The BRT also examined the museum collections at both the California Academy of Sciences and the National Museum of Natural History, where many of the specimens collected by the Stanford Ichthyology group are located, to look for evidence that scientific collections occurred in the Santa Cruz Mountains and elsewhere in coastal California prior to 1906.

The picture that emerges from these records is that the species distribution descriptions written by Jordan and others between 1881 and 1905 were the product of isolated collection efforts made at various localities within the state, few of which occurred in coastal watersheds of California. Evermann and Clark’s (1931) comprehensive summary of early scientific work concluded that the scientific history of the study of freshwater fishes of California began in 1854 with the publication of an account of *Hysterocarpus traski*, or tule perch, from the lower Sacramento River. Many of the earliest accounts of freshwater fishes in California arose from explorations of the Pacific Railway Survey conducted in the early 1850s, which sought to find the most practicable railroad routes from the Mississippi River to California and from the Sacramento Valley northward into Oregon. The vast majority of these collections were from the Sacramento-San Joaquin Valley and San Francisco Bay (Evermann and Clark 1931). Among the early scientific collections from San Francisco Bay tributaries was an 1860 collection of juvenile coho salmon from San Mateo Creek made by Alexander Agassiz. These specimens are currently at the Harvard Museum of Comparative Zoology (MCZ 68471) and appear to be the first scientific collection of coho salmon in California⁸. From 1854 to 1880, fish collections reported from coastal regions of California were limited to a few in San Diego, Monterey, Mendocino County, the Klamath River, and Humboldt Bay (Evermann and Clark 1931). Thus, the freshwater fish faunas of the vast majority of California’s coastal watersheds, including the region of the coast between Monterey and the entrance to San Francisco Bay (i.e., the Golden Gate), appear to have been unknown as of 1880.

Beginning in January 1880, David Starr Jordan and Charles Henry Gilbert undertook a year-long voyage up the Pacific Coast from San Diego to Puget Sound for the purpose of documenting fishery resources along the coast. Their specific charge was “... *to visit or communicate with every post office within five miles of the coast of California, Oregon, and Washington, to list the various species of fishes and other marine animals inhabiting adjacent waters, and to report on their habits, food, and value; also to describe in detail the past, present, and probable future of all industries related to the sea.*” (Jordan 1922). The emphasis of this expedition was collection

⁸ These coho salmon specimens were originally part of a larger lot identified simply as “*Oncorhynchus* sp.” (lot ex-MCZ 7083). In 1984, this lot was determined to include both coho salmon and steelhead and was split into separate lots (coho salmon = MCZ 68471; steelhead = MCZ 52008 and MCZ 7083) (A. Williston, Harvard Museum of Comparative Zoology, pers. comm.). See Section 7.2 for elaboration on the difficulties early scientist had in identifying salmonids during the 1800s.

of marine species, with many specimens obtained from fishermen or at local markets. Of the 350+ specimens from this expedition currently housed in the National Museum of Natural History, only a handful were taken from fresh waters, and virtually all of these freshwater specimens were from the lower Sacramento and Columbia rivers. Among the marine fish collected was an adult coho salmon taken in San Francisco Bay (USNM cat. no. 27222).

From Jordan's account of this expedition (Jordan 1922) and the resulting museum collection records, the trip route and collection localities can be determined. Between January and March, Jordan and Gilbert worked their way up the southern California Coast, stopping at San Diego, San Pedro, Wilmington, Santa Catalina Island, Santa Barbara (and nearby Santa Cruz Island), San Luis Obispo, and then Monterey. While in Monterey, it appears that Jordan or his collaborators ventured up to Soquel (where there was a fishing village), as there are two specimens collected from this town, one a marine species (*Stellerina xyosterna*; USNM cat. no. 27247), and the other *O. mykiss* (identified then as *Salmo irideus*; USNM cat. no. 27173). It is unclear if this latter specimen was collected from fresh water or the ocean. Apparently, Jordan's next stop was in San Francisco, where he stayed for some time, making collections in the Sacramento River as well as near Pt. Reyes. In May of 1880, Jordan traveled directly from San Francisco to Astoria, Oregon, at the mouth of the Columbia River (Jordan 1922). He then continued on to Cape Flattery before entering Puget Sound, where he remained for some time. Two salient points emerge from this trip description. First, there is no evidence that Jordan and Gilbert made any collections (marine or fresh water) along the coast between Santa Cruz and the Golden Gate—the critical area in the debate regarding the southern extent of coho salmon in California. Second, Jordan and Gilbert bypassed the entire northern California coast, most of the Oregon Coast (excepting Astoria), and most of the outer coast of Washington. This latter point is germane when considering Jordan's early descriptions of the distribution of coho salmon and other salmonids in California and elsewhere along the North American coast, which we will cover in Section 7.4.

It was not until the arrival of Jordan and Gilbert to Stanford University⁹ in 1891 that the fish faunas of California received any serious study (Evermann and Clarke 1931). Böhlke (1953) lists the major expeditions undertaken by Stanford University personnel that contributed to Stanford's Ichthyological Collection. The first California expedition led by the Stanford group was the 1895 Carmel River Expedition, led by Cloudsley Rutter. This survey included streams along the coast from the Carmel River (Monterey County) to San Gregorio Creek (San Mateo County) and marked the first attempt to systematically survey streams in the Central Coast region between Santa Cruz and the Golden Gate. Fish collections were made from the Carmel River, Salinas River, Soquel Creek, San Lorenzo River, Wilder Creek, Lidell Creek, Laguna Creek, San Vicente Creek, Scott Creek, Waddell Creek, Gazos Creek, Pescadero Creek, and San Gregorio Creek¹⁰. Details of the findings from this survey are discussed in Section 7.4. Museum records from the National Museum of Natural History indicate that in 1896 and 1897, John Otterbein Snyder, then a student of Jordan's at Stanford who later (1899) joined the faculty, also made

⁹ Jordan was Stanford University's first president and appointed Gilbert as the first Chair of the Zoology Department (Dunn 1996)

¹⁰ The list of streams is based on specimens from this expedition housed in the CAS collection, including catalogue numbers SU 4679, 4672, 4675, 4680, 4670, 4673, 4802, 4799, 4783, 4798, 4685, 4674, 4797, 4756, 4671, 4796, 4667, 4666, 4686, 4668, and 4669.

collections in the Salinas, Pajaro, and San Lorenzo river systems, but there are no collection records from streams between the San Lorenzo River and the Golden Gate.

In 1897, Gilbert and Snyder led a survey of the northern California and southern Oregon coasts (Snyder 1907). This survey began north of San Francisco in the Napa River basin, moved west to Garcia River (southern Mendocino County) and then continued north to the Rogue River, with collections made in a number of California basins in Mendocino, Humboldt, and Del Norte counties. It continued in 1899 with a Snyder-led survey of streams in the Oregon coast region from the Rogue River to the Columbia. The 1897 and 1899 surveys are notable because, although they did not include streams south of San Francisco, they represent the first systematic examination of the freshwater fish faunas of the coastal regions of northern California and Oregon. In 1909, Snyder undertook surveys of the streams tributary to Monterey Bay, results of which were published in Snyder (1912).

Collectively, these records indicate that surveys of the fresh water systems of coastal California were extremely limited until the mid-to-late 1890s. The Carmel River Expedition of 1895 marked the first systematic examination of streams and rivers between the Santa Cruz area and the Golden Gate, with Snyder's visits to the Pajaro and San Lorenzo rivers in 1896–1897 constituting the only other documented visit to Santa Cruz Mountain streams and rivers prior to 1906 that the BRT was able to find. Moreover, the first systematic survey of coastal watersheds of California north of San Francisco Bay did not occur until 1897. Consequently, interpreting the early descriptions of the distributions of various Pacific salmon needs to be made with due caution.

7.2 Taxonomy and nomenclature of Pacific salmonids in the 19th century

Further confounding interpretation of early writings about Pacific salmonids is the fact that the taxonomy and nomenclature of the salmonid family was extremely confused during the 1800s and early 1900s. Although the species of Pacific salmon were first described by Steller in the late 1700s under their Russian vernacular names, which were adopted by Walbaum in 1792 as scientific names (Jordan 1892), in subsequent years, this taxonomic clarity disintegrated. Jordan (1892) describes this disarray as follows:

“Since Steller’s time, writers of all degrees of incompetence, and writers with scanty material or with no material at all, have done their worst to confuse our knowledge of these salmon, until it became evident that no exact knowledge of any of the species remains. In the current system of a few years ago,¹¹ the breeding males of five species known by Steller constituted a separate genus of many species (*Oncorhynchus* Suckley); the females were placed in the genus *Salmo*, and the young formed still another species of a third genus, called *Fario*, supposed to be a genus of trout. The young breeding males (*grilse*) of one of the species (*Oncorhynchus nerka*) made still a fourth genus, designated as *Hypsifario*. Not one of the writers on these fishes of thirty years ago knew a single species definitely, at sight, or used knowingly in their descriptions a single character by which the species are really distinguished. Not less than thirty-five nominal species of *Oncorhynchus* have already been described from the North Pacific, although, so far as is now known, only the five originally noticed by Steller really exist. The descriptive literature of the

¹¹ Jordan inserted a footnote referencing the report of the U.S. Pacific R. R. Explorations, 1858.

Pacific salmon is among the very worst extant in science. This is not, however, altogether the fault of the authors, but is in great part due to the extraordinary variability of appearance of the different species of salmon. These variations are, as will be seen, due to several different causes, notably to differences in surroundings, in sex, and in age, and in conditions connected with the process of reproduction.”

Suckley’s (1861)¹² attempt to synthesize information on the various species of Pacific salmon and trout in North America is illustrative. In this work, Suckley identified no fewer than 26 species of salmon and trout in streams draining into the Pacific Ocean, including 18 he classified as anadromous “salmon” (Table 7.1). Ultimately, these “salmon” were determined to include the five species currently recognized as Pacific salmon (*O. gorbuscha*, *O. keta*, *O. kisutch*, *O. tshawytscha*, and *O. nerka*), as well as anadromous forms of Pacific trout and char, including *O. mykiss*, *O. clarkii*, *Salvelinus malma*, and *S. confluentus*. Additionally, several putative non-anadromous “species” identified by Suckley also turned out to be immature forms of salmon or steelhead (Table 7.1).

The taxonomic relationship among various putative species of Pacific salmon remained uncertain through the 1870s, and resolving these issues became a priority of the newly formed United States Commission of Fish and Fisheries. The report of Commissioner Spencer Baird for the years 1872 and 1873 (Baird 1874) makes this clear, as evidenced in the following description of the Pacific salmon:

“The western salmon (*Salmo quinnat?*¹³)—It is on the west coast of North America alone that salmon occur in anything like the numbers which formerly prevailed in the East, though the species are entirely distinct and peculiar to the Pacific. The waters of California, Oregon, and British Columbia boast of the possession of several kinds, how many of which has not been ascertained, as the different ages and sexes of one have in many instances been described as two or more totally distinct species. One of the objects of the Fish Commission is to solve the problem in question, by securing specimens of all ages and both sexes from all North American localities, and, by critical investigation and comparison, to determine precisely the limitations and relationships of each kind.”

Even as some of the taxonomic uncertainty began to be resolved in the latter part of the 1870s, confusion remained. For example, Lockington (1880), a well-known naturalist and curator of fishes at the California Academy of Sciences wrote the following descriptions of *O. keta* and *O. kisutch* for the California Fish Commission Biennial Report:

Oncorhynchus keta, Silverside Salmon, Cohoe salmon—the *tSUPPITCH* of Dr. Richardson has at length been identified by Professor Jordan as the *keta* of Walbaum. It turns out to be a salmon of the genus *Oncorhynchus*, and not a trout as heretofore supposed. Its previous identification with the so called “Black Trout” of Lake Tahoe is thus found to have been in error. There is but one species of trout yet known from that lake, the presence or absence of teeth upon the hyoid bone being the result of accident or individual peculiarity. The real *tSUPPITCH* or *keta* reaches a length of

¹² Suckley’s 1861 report was written in 1861 at the request of the Smithsonian Institution and was subsequently published (1873) as an appendix to the Report of the Commissioner, United States Commission on Fish and Fisheries.

¹³ The question mark following the scientific name is found in the Baird 1874 report, indicating his uncertainty about whether the numerous “varieties” of Pacific salmon were all part of the same species.

Table 7.1. Putative salmon and trout “species” identified in Suckley 1861 in waters draining to the Pacific Ocean.

Scientific name	Common names	Location	Modern identification
I. Anadromous salmon: species running up into fresh water to spawn; the young remaining there for a greater or less time, then returning to the sea, in which they continue to abide, except during the period of reproduction (Salmon.)			
a. Intermaxillaries of males long, decurved, projecting, and hooking downward considerably beyond the top or knob of the lower jaw (Subgenus <i>Oncorhynchus</i>)			
1. <i>Salmo scouleri</i> , Richardson	Hook-nosed salmon; fall salmon	Pacific coast (Puget Sound, Columbia R, Chiloweyuck Lk, Fraser R)	<i>O. gorbuscha</i>
2. <i>Salmo proteus</i> , Pallas	Hump-backed salmon	Alaska coast (Puget Sound, but not Columbia or S. of Juan de Fuca)	<i>O. gorbuscha</i>
3. <i>Salmo cooperi</i> , Suckley	Cooper’s salmon; little red salmon; [Ta-ah-nia]	Columbia River; Okanakani (Okanagan) River	<i>O. tshawytscha</i>
4. <i>Salmo dermatinus</i> , Richardson	[red-fish, tleukh-ko]	Bering Sea	<i>O. keta</i>
5. <i>Salmo consuetus</i> , Richardson		Yukon River, Arctic America	<i>O. keta</i>
6. <i>Salmo canis</i> , Suckley	Dog salmon, spotted salmon, [Le Kai]	NW Coast of America (Puget Sound)	<i>O. keta</i>
b. Jaws of adult males when fresh-run, symmetrical and either subequal or the point of the lower jaw received in a notch between premaxillaries.			
† Without red spots; not feeding in fresh water, except from caprice			
8. <i>Salmo quinnat</i> , Richardson	The California salmon	West coast of U.S. (from San Francisco northward)	<i>O. tshawytscha</i>
9. <i>Salmo confluentus</i> , Suckley	Towalt salmon	Northwest coast (Chiloweyuck Lk, Puget Sound,	<i>Salvelinus confluentus</i>
10. <i>Salmo aurora</i> , Girard	Red-char; salmon	Columbia River	<i>uncertain</i>
11. <i>Salmo argyreus</i> , Girard		West coast	<i>O. tshawytscha</i>
12. <i>Salmo paucidens</i> , Richardson	Weak-toothed salmon	Fraser River	<i>O. nerka</i>
13. <i>Salmo tsuppitch</i> , Richardson	White salmon; silvery-white Salmon trout	Columbia River	<i>O. kisutch</i>
14. <i>Salmo clarkii</i> , Richardson	Clark’s salmon	Columbia River	<i>O. clarkii</i>
16. <i>Salmo gairdneri</i> , Richardson	Gairdner’s salmon	Columbia River; northwest coast of America	<i>O. mykiss (su.)</i>
17. <i>Salmo truncatus</i> , Suckley	The short-tailed salmon	Columbia River, Fraser River	<i>O. mykiss</i>
18. <i>Salmo richardi</i> , Suckley	Richard’s salmon; Suk-kegh salmon	Fraser River	<i>O. tshawytscha</i>
†† Spotted with red; feeding freely in fresh water			
19. <i>Salmo campbelli</i> , Suckley	Campbell’s salmon	Columbia River	<i>Salvelinus malma</i>
II. Non-anadromous species (not running up from the sea, but living entirely in freshwater or only occasionally passing down to sea. [Trout]).			
c. Spotted with red or black; found in flowing fresh water; feeding, spawning, and spending the greater part of the year in the same; retiring to deep, still water in the winter; access to salt water usually relishes, but not indispensable.			
†† Black-spotted			
26. <i>Salmo iridea</i> , Gibbons	Pacific brook-trout	California streams	<i>O. mykiss</i>
27. <i>Salmo masoni</i> , Suckley	Mason’s trout	Columbia River	<i>O. mykiss</i>
29. <i>Salmo lewisi</i> , Girard	Missouri trout	Rocky Mtn slopes N. of South Pass; Kootenay R.	<i>O. clarkii</i>
30. <i>Salmo brevicauda</i> , Suckley	Short-tailed trout	Puget Sound waters	<i>O. clarkii</i>
d. Trout found in deep rivers or lakes, ascending shallow streams to spawn			
† Black-spotted			
31. <i>Salmo gibsii</i> , Suckley	Columbia salmon trout	Columbia River	<i>O. clarkii</i>
33. <i>Salmo kennerlyi</i> , Suckley	Kennerly’s trout; Chiloweyuk red salmon-trout	Chiloweyuck Lake (BC); Fraser’s River.	<i>O. nerka</i>
34. <i>Salmo warreni</i> , Suckley	Warren’s trout	Fraser’s River	<i>O. tshawytscha (immature)</i>
†† Red-spotted			
35. <i>Salmo bairdii</i> , Suckley	Baird’s trout; red-spotted Rocky Mtn. trout	Clark’s Fork of Columbia R. & tribs.	<i>S. malma</i>
36. <i>Salmo parkii</i> , Suckley	Parker’s River trout	Kootenay River; Rocky Mtns.	<i>S. malma</i>
e. Lake trout: passing lives in deep freshwater lakes.			
43. <i>Salmo newberryi</i> , Girard	Newberry’s salmon	Klamath River	<i>O. mykiss</i>

fifteen to eighteen inches, and a weight of four or five pounds. When in the ocean, it feeds on crustacean, herring, etc. This salmon is said to be very superior in Quinalt River, where it is abundant and is salted by the Indians, as it is also at Neah Bay, at which point it was formerly canned. Professor Jordan saw it in Seattle, and speaks of it as abundant in Puget Sound and Cape Flattery, as well as for some distance north and south from thence. As a food fish, it ranks with the young of the quinnat. It runs up the Eel River, California, and has been taken in the Sacramento.

O. kisutch, Dog salmon—This, the true Dog Salmon, occurs in Puget Sound, Fraser River, etc. In most characters, it agrees with the last species [*O. gorbuscha*]; but the scales are larger, and the aspect of the fish different. The males, when they enter the rivers in the fall, have reddish transverse bands alternating with greenish, and become blotched with these colors as they ascend. The females are bright and silvery on entering the rivers.

From these descriptions, it is clear that Lockington reversed the scientific names of these two species: his *O. kisutch*, or “Dog salmon” is, in fact, *O. keta*, and vice versa. Two years later, Lockington (1882) wrote the following:

“During his stay on the Pacific coast, Professor Jordan thoroughly investigated and cleared up the mystery in which the species of the genus *Oncorhynchus* (Pacific salmon) had been wrapped by a crowd of naturalists who at various times had described as distinct, forms which now have been proved to be due to age, sex or season. There are only five species, the quinnat, chouicha, or king salmon, the most important of all from an economic point of view; the blue-back, or red-fish, *O. nerka*, examples of which, found high in the rivers and in the lakes, have long figured as a distinct species from their brethren of the lower waters; the silver salmon, *O. kisutch*; the fall salmon, *O. keta*, and the dog salmon, *O. gorbuscha*.”

While Lockington contended that Jordan had “cleared up the mystery,” confusion obviously lingered, as Lockington now referred to pink salmon (*O. gorbuscha*) as “dog salmon.”

Jordan and Gilbert (1881) did in fact resolve some of the long-running confusion about the number of Pacific salmon, reducing the vast list of Suckley down to the five species recognized today. Nevertheless, it is amply evident from early records that confusion about taxonomy and identification of Pacific salmonids lingered for decades. Some of this confusion arose from the fact that certain common names were applied to more than one species, depending on the geographic region. The term “dog salmon,” while generally confined to chum salmon in modern times, was applied to other species as well, as indicated in Lockington (1880, 1882) above. In a description of *O. keta*, Jordan (1884a) makes the following statement:

“This species, during the period of its run in the fall, generally goes by the name of ‘Dog Salmon,’ under which name the males of the Silver Salmon, and even of the Quinnat, are often confounded with it.”

In the same publication, Jordan’s description of the pink salmon, *O. gorbuscha*, states:

“The English-speaking people call it generally the ‘Hump-back Salmon,’ and often the ‘Dog Salmon’.”

In book on the vertebrates of the northern United States published in the same year, Jordan (1884b) assigns the name “Dog Salmon” to *O. nerka*.¹⁴ Thus, in the mid-1800s, we have the term “dog salmon” applied to all five species of Pacific salmon: chum, pink, coho, Chinook, and sockeye salmon.

Even 70+ years after Lockington (1880) and Jordan (1884a,b) were published, Shapovalov and Taft (1954), in their study of coho salmon and steelhead in Waddell Creek (Santa Cruz County), felt compelled to write the following:

“One popular misconception that has existed among the various parts of the Pacific Coast is that the hook-nosed salmon, called ‘dog salmon’ by local residents, form a distinct species. Such fish are simply males whose snouts have become hooked and elongated during the spawning season. This phenomenon takes place to a greater or lesser extent in all the species of Pacific salmon and to some extent in steelhead. A distinct species of salmon, the chum salmon (*Oncorhynchus keta*), is sometimes also known as dog salmon, but occurs comparatively infrequently in California. Common names applied to the silver salmon are jack salmon (applied especially to young males), dog salmon, or hookbill (applied to males with hooked snouts and red sides), coho, and silversides”

There are several other pieces of evidence that suggest that fish identified as “dog salmon” in coastal California streams were very likely coho salmon. In 1902, Cloudsely Rutter—the same Rutter that led the 1895 Carmel River Expedition during which coho salmon were found in four Santa Cruz and San Mateo County streams but misidentified as *O. keta* and *O. tshawytscha*—published an account of an experimental planting of Chinook salmon from the Sacramento River into Lagunitas Creek (known then as Paper-mill Creek) in Marin County about 25 miles north of the Golden Gate. In describing the location of the experiment, Rutter (1902) notes:

“Paper-mill Creek is not suitable for quinnat salmon, being entirely too small, but it is frequented by dog salmon and steelheads.”

Although chum salmon have been occasional visitors to Lagunitas Creek, coho salmon have been consistently reported in the stream since the 1800s (see Section 6), and the current population is among the largest remaining within the CCC-ESU. We believe there is a high likelihood that the fish Rutter called “dog salmon” were in fact coho salmon.

The difficulty early researchers had in correctly identifying the juveniles of different salmon species is further illustrated in the works of Snyder. In 1909, Snyder and his colleagues collected juvenile salmonids from Lagunitas Creek. Among the collections were fish they identified as *Salmo iridea* (i.e., *O. mykiss*), which are now currently in the National Museum of Natural History collection (NMNH Accession No. 75327). Recent genetic analysis has shown that 22 of 25 fish identified as *S. iridea* are, in fact, coho salmon (see Section 6). These collections were made shortly after Rutter was conducting his Lagunitas Creek studies, providing further evidence

¹⁴ Although this book focuses on fishes of the eastern United States, descriptions of Pacific salmon species are provided in an addendum, and Jordan indicates that the list includes “all the species thus far known from the United States, as the general interest felt in this group of fishes seems to render this arrangement desirable.” Interestingly, Jordan (1884b) makes no mention of *O. kisutch* in this book, underscoring the continued uncertainty regarding the true number of Pacific salmon species.

that Rutter either mistook coho salmon for chum salmon, or was using the term “dog salmon” to describe coho salmon.

Additionally, in 1907, Snyder published an extensive description of fishes in coastal streams of Oregon and Northern California based on his (and Gibert’s) 1897 and 1899 surveys discussed in the previous section. Importantly, these surveys were conducted in late June and July, 1897 (California and Oregon south of the Rogue River) and from July to September 1899 (Oregon from Rogue River to the Columbia). In his 1907 description of *Oncorhynchus keta*, Snyder writes that the species

“Occurs in all except the smallest streams between the Sacramento and Columbia rivers. The young of this salmon were apparently more abundant than those of any other.”

Given the time of year that Snyder and his colleagues conducted their surveys (i.e., summer), it is highly improbable that the observed juveniles were *O. keta*. Chum salmon migrate to sea almost immediately upon emerging from the gravel (late winter or early spring in the southern portion of their range), with peak emigration typically occurring in March and April and only rarely extending into June (Johnson et al. 1997). Although occasional fish might be observed as late as June, it is exceedingly unlikely that this species would have been “*more abundant than those of any other*” salmon in surveys conducted primarily in July–September. Snyder (1931) tacitly acknowledged this error in 1931, when he wrote “*Humpback and dog salmon are not common enough anywhere in the State [California] to be of commercial importance; in fact, they are so rarely seen as to be unknown to any but the most observant fisherman.*”

The confusion between coho and chum salmon was clearly affirmed by Gilbert (1912). Gilbert explicitly acknowledged that he and his contemporaries and predecessors had commonly misidentified juvenile coho salmon as chum salmon in the past, as evidenced in his description of dog salmon (*O. keta*):

“Less is known of the life history of the dog salmon than any of the species thus far considered. Our knowledge of the young is entirely due to Chamberlain [1907], who secured them on their seaward migration as fry, some with remnants of the yolk still attached. They were not associated with larger individuals which could be considered yearlings. As stated by Chamberlain, ‘records of the occurrence of large individuals in streams have not been authenticated, and, so far as is known, all leave fresh water as soon as they are able to swim.’ Records of yearling dog salmon have been made by the writer [Gilbert] and by others in the streams of Washington, Oregon, and California, but all such have been founded on incorrect identification of the coho yearlings.”

Gilbert’s admission has obvious and enormous implications for interpreting early collection records and writings related to the distributions of both coho and chum salmon prior to 1912.

Another common name that warrants discussion is the term “quinnat salmon.” Although in modern times, the term “quinnat” is generally listed as a synonym for the Chinook salmon, *O. tshawytscha*, this has not always been the case. Prior to 1900, the term quinnat salmon was used both as a general term to describe the suite of Pacific salmon species and as a more specific term for Chinook salmon. Jordan (1892) illustrated this when he wrote:

“They [the Pacific Coast salmon] have been placed in another genus known as *Oncorhynchus*. For the lack of any other common name they are always spoken of as and will always be canned, as long as the canning industry lasts, under the name of Salmon. The Chinook name, *Quinnat*, was early applied to them, and if we feel the need of some other name to distinguish them from real salmon [Atlantic species] we may call the Pacific Coast salmon Quinnat or Quinnat Salmon. These species all live in the ocean, ascend the rivers in spring and summer, spawn in fresh water in the fall, the young, as soon as they are able to swim, floating tail foremost down river and growing rapidly as soon as they reach the ocean and the peculiar ocean food. There are five species of these Quinnats, which will be described farther on.”

Jordan (1892) then goes on to describe the Chinook salmon (*O. tshawytscha*) as the “true Quinnat,” as well the other four species of Pacific Salmon (*O. nerka*, *O. kisutch*, *O. keta*, and *O. gorbuscha*). Consequently, one cannot assume that references to quinnat salmon in the 1800s necessarily mean just Chinook salmon.

7.3 Knowledge of Pacific salmon life histories in the 19th century

Appropriate interpretation of historical writings about Pacific salmon in coastal streams also requires an understanding of what was known about Pacific salmon life histories at the time, which again was quite limited. For example, up until the late 1870s, it was not known that adults of all true Pacific salmon species die following spawning. This is evident in Suckley (1861; reprinted in 1873), who in describing *Salmo scouleri* (later determined to be *O. gorbuscha*) stated that “*During the month of April, they suddenly disappear, probably returning by floods to salt water, although the Indians say that but few return to the sea,*” and later, that “*The Indians say that many individuals return to the sea.*” Likewise, in his description of *Salmo canis* (i.e., *O. keta*), Suckley wrote “*They [the Indians] say that most of the individuals return to the sea after spawning, many more comparatively than do of the S. scouleri.*” For most other putative salmon and trout species, Suckley did not comment on whether these were semelparous or iteroparous, though he did indicate that the local (Puget Sound) Indians thought the *Salmo proteus* (i.e., *O. gorbuscha*) died following spawning and that the Skagit River tribes thought the *S. quinnat* (i.e., *O. tshawytscha*) did likewise.

The question of whether Chinook salmon die after spawning remained unanswered until sometime after the late 1870s. Hallock (1877) implied that Livingston Stone had answered this question through research conducted on the McCloud River (upper Sacramento basin), stating that he “*settled the question finally, and proved beyond a shadow of doubt, that of all of the thousands of Sacramento salmon that spawned in the McCloud, not one in a hundred returned to sea alive.*” However, Stone (1880) wrote that, while he believed all Chinook salmon in the McCloud River died after spawning, he also believed that “*the Sacramento salmon which spawn near the sea are, many of them, able to return to salt water, but that the salmon which spawn as far away from the ocean as the McCloud River and upper tributaries of the Sacramento are too much exhausted after spawning to find their way back to the sea alive.*” Thus, the invariant semelparous reproductive strategy of Pacific salmon was not recognized until sometime later.

Other aspects of salmon life history and ecology were also poorly understood. For example, understanding of the juvenile life stages was extremely limited all through the 1800s. Indeed, it

was not until the Alaskan field studies of Chamberlain (1907) and Gilbert's (1912) groundbreaking work on aging of salmon using scales that a more comprehensive understanding of the periods of freshwater and marine residence of the five Pacific salmon species began to emerge. This lack of understanding of the early life histories of salmon undoubtedly contributed to some of the misidentifications of juvenile specimens discussed in the preceding section (i.e., Snyder would not likely have mistaken juvenile coho salmon for chum salmon had he understood the early life histories of each species). Additionally, the hypothesis that salmon home to their natal streams was favored by some scientists but strongly opposed by others, including Jordan (1904a). Jordan based his conclusion on an erroneous assumption that salmon “*mostly remain in the ocean within a radius of twenty, thirty, or forty miles from its mouth*” and that the tendency to return to “parent streams” was a matter of proximity rather than any homing ability.

7.4 Evidence of anadromous salmonids in streams south of San Francisco Bay

With the history of scientific exploration in California and the state of scientific understanding of Pacific salmonid taxonomy and ecology in the 1800s establishing an appropriate context, we now examine the direct evidence of the occurrence of salmon in general, and coho salmon in particular, in the streams of the Santa Cruz Mountains.

Evidence prior to 1880

The first published mention of salmon in streams of coastal San Mateo and Santa Cruz counties comes from a report by Captain E. Wakeman, excerpts of which are published in the first biennial report of the California Commissioner of Fisheries (Redding et al. 1872). Wakeman was commissioned to examine and report on the fisheries of San Francisco Bay as well as streams and rivers entering the Pacific Ocean south of the Golden Gate. The report includes descriptions of streams from Pilarcitos Creek near Half Moon Bay south to Pescadero Creek.

Wakeman's accounts of the fisheries of two streams in the region, San Gregorio and Pescadero, read as follows:

“San Gregoria (sic)—Is a fine clear water trout stream, four miles from Tunis, and connects to the ocean about one mile below the San Gregoria House. At full sea, the salmon, from fifteen to twenty pounds, and the silver salmon, from two to fifteen pounds, enter this stream during their spawning season, which is from October to March, when they go out to sea again. These fish have been taken several miles up the stream during the rainy season, when, owing to strong current, most of the sawdust had been washed out. Six miles up this stream is Templeton's steam sawmill, and a few miles further up, on a northern branch of this stream, is Gilbert's sluice mill, and a few miles up this same branch is L.P. Pharis' steam shingle mill. All these mills dump their sawdust and blocks into the stream, which so poisons the water that it has become an intolerable nuisance to all the settlers along the stream below, and will soon exterminate the trout.”

“Pescadero stream—Is three miles from Pompona [Pomponio] Creek, and is a fine clear water trout stream, empties into the sea about two miles below the town, and connects, one mile from the beach, with the Butena River [Butano Creek], which is also a fine clear water trout stream

running to the southeast; is about twenty feet wide, and six feet deep. For six miles this makes a fine resort for the salmon and silver salmon from the sea which frequent these waters, with other lesser sea fish, for the purpose of spawning. From October to March, a wagon load of these beautiful fish, weighing from two to thirty pounds, are taken daily and sold all along the road, as high up as Spanishtown [Half Moon Bay], at seventy-five cents per pound. These fish are only taken during the spawning season, they being a deep water fish and go out to sea in March. Three miles up the Pescadero stream is Hayward's steam sawmill, and three miles further up is Anderson's sawmill, run by a turbine wheel, having a well constructed dam, built of hewn logs, well secured right across the creek. The dam is twenty feet long and about ten feet high, built in eighteen hundred and sixty-two, and all the water from above passes through the sluiceway at the turbine wheel. As the water has never been half way up to the top of this dam, since it was built, no fish have ever passed. A sluiceway with stop waters in it for fish could be introduced through this dam near its base and outside the sluiceway for the wheel, this being the only place where the box could reach the water below, as all the rest of the bed of the stream is dry. Large quantities of sawdust and blocks are deposited in the stream below the dam; fish are found dead, their eyes eaten out by the strong poisonous acids in the water, and their bodies covered beneath the skin with disgusting blisters, like the small pox, whilst the inside is as black as ink. The waters are rendered at times wholly unfit for use..."

Wakeman's account of Pescadero Creek continues with additional discussion of the harmful effects of sawdust on the fish of Pescadero Creek, concluding that "*unless some other method be adopted to get rid of it [sawdust], such as burning it or repairing roads with it, there will not be a breed of trout left in a few years.*"

From Wakeman's account, it is evident that at least two species of anadromous salmonid were present in both San Gregorio and Pescadero creeks and were abundant enough to support a local fishery. Because of the vagaries of salmonid nomenclature from this period, interpreting Wakeman's description of "salmon and silver salmon" is difficult. There is little doubt that steelhead were present in these two streams. The timing of spawning migrations (beginning in October) is strongly suggestive of salmon, which tend to enter streams earlier than steelhead (though occasional steelhead may enter coastal streams as early as late October). Wakeman's reference to fish going back out to sea, at first glance, might be interpreted to suggest that all of the fish in question were steelhead. However, as discussed in Section 7.3, it was not known in the 1870s that the true Pacific salmon species all die following spawning. Collectively, the BRT concludes that the parsimonious interpretation of the Wakeman account is that at least one species of salmon spawned in these two streams along with steelhead. Whether that species was most likely coho salmon or some other species will be addressed later. Wakeman's account also provides a glimpse into the substantial impacts of early logging practices on the capacity of Central Coast streams to support salmon and trout (see Section 4.3).

In 1873, Charles Hallock published *The Fishing Tourist: angler's guide and reference book*, a 239-page guide to salmon and trout fishing in North America. Though not a scientist, Hallock made extensive use of the scientific literature and often quoted recognized experts. In his description of "good trout streams on the coast" of California, Hallock mentions both San Gregorio and Pescadero creeks as also supporting runs of salmon (Hallock 1873). His specific reference to "wagon loads" of salmon being taken from October to March from these streams suggests that he obtained some information directly from Wakeman's account.

A second description of salmon in the central California coast region is found in Hallock (1877). Here, Hallock quotes from Horace D. Dunn, whom is identified as an authority on the natural history and culture of salmon:

“The first run of salmon is found in the mouths of numerous small rivers and creeks that flow into the Pacific Ocean from the coast range of mountains from the Carmel River, near Monterey, north to the boundaries of Oregon. The grilse make their appearance around the middle of October, followed in November by the adult fish. These remain at tide water, waiting for the rise caused by the heavy rains of December, which enables them to reach their spawning beds at the heads of the streams. The coast salmon are said to be a distinct variety from those spawning in the Sacramento River and its tributaries, and return to the ocean in March and April. With these salmon comes a large species of trout, known here as salmon trout, which have similar habits, and return to sea about the same time....”

Clearly, Dunn affirms that at least two species of anadromous fish inhabited streams entering Monterey Bay, one of which (salmon trout) was undoubtedly steelhead. Also intriguing is Dunn’s statement that the coast salmon are said to be a distinct variety from those spawning in the Sacramento River. And again, we also see evidence that early scientists were unaware that salmon die after spawning.

Dunn also wrote a letter to Spencer Baird, Commissioner of the U.S. Commission on Fish and Fisheries, regarding a proposal to introduce San Joaquin River salmon to East Coast states south of the Potomac River (Dunn 1880). In this letter, Dunn states

“It seems to me that the San Joaquin salmon will not be as good for such purpose as the salmon which frequent the rivers which empty direct into the Pacific along the California coast from Monterey north. This last variety makes its appearance at the mouths of the coast steams from the middle of October to November, waiting the annual winter rains to swell the streams, up which they go to their spawning beds. The spawning takes place in December and January, the spent fish returning to the ocean in February and March. These fish, in good condition, have been caught weighing 25 pounds....I would also call your attention to a fish commonly called salmon-trout, which visits our coast rivers about the same time as the salmon do, probably two weeks later. This fish is trout shaped, being longer and rounder than the salmon, and of proportionately, less weight....They have been caught weighing 20 pounds, from 8 to 10 pounds being a common weight.”

Again, Dunn makes clear reference to both salmon and steelhead in streams entering Monterey Bay. As to the species of salmon, the letter is unclear. Since the description is not confined to species entering Monterey Bay and includes coastal basins throughout California, not just Monterey Bay, he could be referring to coho salmon, fall Chinook salmon, or both.

In 1879, Captain Cleveland Rockwell, a surveyor, topographer, and cartographer for the U.S. Coast and Geodetic Survey and an avid fly fisherman, published a quite succinct description not only of the salmon in streams of the Central Coast region but also the dynamics of coastal watersheds subject to sand bar formation. His description, published in *Forest and Stream* (30 October 1879), reads as follows:

“The salmon which enter the small streams on the lower coast of California are I think a distinct variety of salmon, and I do not know what name has been given to them by Professor Baird, the eminent authority on salmon in the United States. Those streams having their rise in the lowest range of mountains, are short, and during the dry season are closed at their mouths by the prevailing northwest winds and surf washing up the sands which form a bar across the mouth. These salmon appear to be waiting outside the barred entrance to these streams until such time as the barrier shall break away and give them entrance to the fresh water. This bar of sand is piled higher and higher through the long dry summer, and the fresh water from the stream and the salt water washing over the bar forms a large lagoon of brackish water that backs up the bed of the stream a mile or two. Then comes a winter storm and the overcharged lagoon suddenly cuts a crevasse through the bar and may be nearly emptied of its waters in one tide; when immediately the salmon rush in through the breach and may be found in many deep pools above the mouth. They take the fly very readily and are gamy and active on the line. These lagoons are seldom surrounded with brush, and generally the casting is easy, though the pools being near the shore, the angler should take the precaution of standing far enough away to prevent the fish from seeing the motion of the rod, as they are readily alarmed and will make directly for the inlet through which the surf is breaking, and go out to sea. These salmon seldom weigh over eight or ten pounds. The streams to the south of San Francisco Bay closed at their mouth are the Pescadero, San Gregorio, San Lorenzo, San Carpofero, Arrogo La Cruz, Santa Rosa, and many others. The larger streams or rivers above San Francisco Bay are also frequented by the salmon which may be taken by the fly. Some of these rivers are not closed at their mouths, such as Russian river, the Gualala, Navarro, Noyo, and many others.

C.R.¹⁵ Portland,
Oregon”

Rockwell’s clear description of the physical processes of Central Coast streams indicates intimate familiarity with the dynamics of these coastal systems, which he gained spending winters in the San Francisco Bay area from 1868–1878 and conducting surveys of the California Coast from Cape Mendocino as far south as Point Conception (Stenzel 1972). Furthermore, elsewhere in the *Forest and Stream* article, Rockwell provides descriptions of *Salmo quinnat* (run-timing and size suggesting Spring Chinook salmon) in the Columbia and Sacramento rivers, “Steel Heads” in these same systems, Silver Sides (size and run timing suggesting fall Chinook salmon) in the Columbia, and “dog salmon” (size suggesting chum salmon, though could also include other fall-spawning species) of lower Columbia River, as well Puget Sound and coastal streams. Rockwell’s familiarity with these salmonids arose during his tenure as Chief of the geodetic survey of Oregon from 1869 into the 1880s, when he surveyed and mapped the lower Columbia River from the mouth to Portland, Oregon (Gaston 1911; Stenzel 1972). The fact that Rockwell clearly was discriminating the salmon of the central California coast from Chinook salmon and steelhead he observed on the Columbia River suggests these Central Coast salmon were likely coho salmon. The size, run timing, and behavior of the fish are all consistent with this interpretation.

¹⁵ Although authorship of the *Forest and Stream* (1879) article is attributed simply to “C. R., Portland Oregon,” a near-verbatim version of the last seven paragraphs of this article under Rockwell’s full name was reprinted in *The Pacific Monthly* in 1903.

The writings of Jordan and Gilbert, 1881–1894

In 1881, the year following their exploration of the Pacific Coast, Jordan and Gilbert (1881) published the first of several articles and book on the fishes of both the Pacific Coast and North America in general (Table 7.2). Their first description of the distribution of coho salmon reads simply “*Sacramento River to Puget Sound and northward.*” This entry is not surprising given that Jordan and Gilbert had collected coho salmon from San Francisco Bay during their 1880 expedition. A year later, Jordan and Gilbert (1882) listed coho salmon as “*abundant from San Francisco northward,*” and in 1892, Jordan wrote that the “Silver salmon” predominates in Puget Sound and “*in most of the streams along the coast.*” However, Jordan (1894) stated that the species was “*not common south of the Columbia, but sometimes taken in California.*” This latter description sharply underscores the limits of the information available to Jordan regarding distribution and abundance of coho salmon in California and Oregon at this time, as coho salmon clearly were once very abundant in coastal streams of Oregon and northern California. Based on cannery records, Meengs and Lackey (2005) estimated that the aggregate run size for coho salmon in coastal Oregon watersheds was more than 2 million fish annually in the 1880s. The lack of accuracy in Jordan’s 1894 description is not surprising since Jordan and Gilbert do not appear to have made any stops along the coast between San Francisco and Astoria during their 1880 Pacific Coast expedition (see Section 7.1). Also of interest is Jordan’s (1894) description of *O. keta*, which states that the species is “*most common to the northward, and are not often taken in California.*” As we will see, this contrasts sharply with later descriptions.

In addition to these general faunal references, Jordan (1887) also published a manuscript describing the fisheries of the Pacific Coast. In this paper, we find the only mention in any of Jordan’s writings of a stream between Santa Cruz and the Golden Gate: Pescadero Creek. Jordan’s text reads as follows:

“At Pescadero Creek there is only one professional fisherman. He fishes with a gill-net at the mouth of Pescadero Creek. An attempt is being made here to stock ponds with native salmon and trout. These ponds are located 3 miles up the creek...Tourists from San Francisco fish here for salmon in its season. The run of salmon up the creek is said to have been lessened, owing to the seals, 20 or 30 of which are often observed, in spawning season, to take up a position at the mouth of the stream, almost entirely preventing the salmon from running up. Those who escape alive, when caught bear marks of the seal’s teeth.”

Again, we have clear reference to native salmon occurring (along with trout) in Pescadero Creek in sufficient numbers to support a professional fisherman and to attract recreational fishers from San Francisco. Unfortunately, Jordan does not provide any information that would allow determination of the species of salmon. Nor is it clear where Jordan came by this information. As noted above, we have found no direct evidence (either explicit mention or field collections) that Jordan stopped in Pescadero during the 1880 Pacific Coast expedition. If he did make a stop, it would have been between March and May, and so he would not have encountered adult salmon. These facts, coupled with the lack of specificity regarding the particular species, suggest that Jordan was relying on second-hand accounts from local residents or fishermen.

Table 7.2. Summary of Pacific salmon distribution descriptions written by D.S. Jordan, C.H. Gilbert, and W.B. Evermann from 1881 to 1908.

Publication	Species				
	Coho (<i>O. kisutch</i>)	Chinook (<i>O. tshawytscha</i>)	Chum (<i>O. keta</i>)	Pink (<i>O. gorbuscha</i>)	Sockeye (<i>O. nerka</i>)
Jordan & Gilbert 1881 (petitioner cites this as Jordan and Gilbert 1876–1919)	Sacramento River to Puget Sound and northward; very abundant in summer and fall	From Ventura River northward to Behring’s Straits, ascending Sacramento, Rogue’s, Columbia, and Frazer’s Rivers in spring...; in fall ascending these and probably all other rivers in greater or lesser abundance	San Francisco to Behring’s Straits; very abundant in the fall when it runs in all streams, but not to great distance	Sacramento River northward to the Arctic Sea; abundant in Puget Sound on alternate years	From Columbia River to the Aleutian Islands; the principal salmon of Frazer’s River; unknown in Eel River, Rogue River, and Sacramento
Jordan & Gilbert 1882	A small salmon ascending streams in fall to no great distance. Abundant from San Francisco northward	Ventura River to Alaska and northern China, ascending all large streams. Especially abundant in the Columbia and Sacramento rivers, where it is the principal salmon...it ascends the large streams in spring and summer	San Francisco to Kamtschatka, ascending all streams in the fall, and spawning no great distance from the sea; abundant in Behring’s Straits	Pacific coast and rivers of North America and Asia from Oregon northward; not rare; occasionally taken in Sacramento	Columbia River to Kamtschatka; generally abundant, especially northward; ascending streams in spring to great distances, and often frequenting mountain lakes in fall
Jordan 1892*	Of these species, the Blue-back [sockeye] predominates in Fraser River and in the Yukon River, the Silver salmon in Puget Sound, the Quinнат in the Columbia and the Sacramento, and the Silver salmon in most of the streams along the coast. All the species have been seen by us in the Columbia and in Fraser River and in waters tributary to Puget Sound. Only the King salmon has been noticed south of San Francisco. Its range has been traced as far south as Ventura River. Of these species, the King Salmon and Blue-back salmon habitually “run” in the spring, the others in the fall.				
Jordan 1894	This species is not common south of the Columbia, but is sometimes taken in California	Its southern limit is, so far as known, the Ventura River	This species and the next [<i>O. gorbuscha</i>] are most common to the northward, and are not often taken in California	See description for <i>O. keta</i> .	The Blue-back salmon is rarely seen south of the Columbia River, and probably never in California. In Alaska, it far outnumbered all other kinds
Jordan and Evermann 1896	Of these species, the Blue-back (<i>O. nerka</i>) predominates in Fraser River and the Yukon River, the Silver salmon (<i>O. kisutch</i>) in Puget Sound, the Quinнат (<i>O. tshawytscha</i>) in the Columbia and the Sacramento, and the Silver salmon in most of the streams along the coast. All the species have been seen by us in the Columbia and in Fraser River and in waters tributary to Puget Sound. Only the King salmon has been noticed south of San Francisco. Its range has been traced as far south as Ventura River. Of these species, the King Salmon and Blue-back salmon habitually “run” in the spring, the others in the fall.				
	Abundant from San Francisco northward, especially in Puget Sound and the Alaskan fjords.	Alaska, Oregon, and California, southward to Ventura River, and to northern China, ascending all large streams; especially abundant in the Columbia and Sacramento rivers, where it is the principal salmon.	San Francisco to Kamchatka, ascending all streams in the fall, and spawning at no great distance from the sea; abundant in Bering Straits.	Pacific Coast and rivers of North America and Asia from Oregon northward; not rare; occasionally taken in the Sacramento, where it is called “Lost Salmon”	Klamath and Rogue rivers northward to Kamchatka and Japan; generally abundant especially northward...The principal salmon of Alaska.
Jordan & Evermann 1902–1905, 1908	Of the species of <i>Oncorhynchus</i> , the blueback (<i>O. nerka</i>) predominates in Fraser River and in the Yukon River, the silver salmon (<i>O. kisutch</i>) in Puget Sound, the quinnat (<i>O. tshawytscha</i>) in the Columbia and the Sacramento, and the dog salmon in most of the streams along the coast. All the species have been seen by us in the Columbia and in Fraser River; all but the blueback in the Sacramento; and all in waters tributary to Puget Sound. Only the quinnat or king salmon has been noticed south of San Francisco. Its range has been traced as far as Ventura River. Of these species, the king salmon and blueback salmon habitually “run” in the spring, the others in the fall.				

Table 7.2 (continued).

	Species				
	Coho (<i>O. kisutch</i>)	Chinook (<i>O. tshawytscha</i>)	Chum (<i>O. keta</i>)	Pink (<i>O. gorbuscha</i>)	Sockeye (<i>O. nerka</i>)
Jordan and Evermann 1902–1905, 1908 (cont.)	It reaches a length of 15 inches, and a weight of 3 to 8 pounds and is abundant from San Francisco northward along both the American and Asiatic coasts, entering the shorter coastal streams in late fall. . . . In our waters, it is especially abundant in Puget Sound, the fjords of Alaska, and in the shorter rivers of Washington and Oregon.	It is found on both coasts of the Pacific, from Monterey Bay, California, and China, north to Bering Straits, ascending all large streams, especially the Sacramento, Columbia and Yukon, in all of which it is very abundant.	It is found usually in great abundance from the Sacramento northward to Kamchatka and Bering Straits, ascending all suitable streams in the fall, and spawning at no great distance from the sea in smaller streams, which they enter in marvelous numbers, crowding upon each other in the most appalling manner.	It is found on the Pacific Coast and ascending rivers of America and Asia from California and Japan northward. In the rivers of Alaska it appears every year in great abundance; in Puget Sound there seems to be a periodicity in its movements, the runs of the alternate, odd years (1887, 1889, etc.) being much larger than in the even years. In the Sacramento River it occurs each year but in very limited numbers and is there known as the lost salmon	The blueback salmon is found from the coast of southern Oregon, north to northern Alaska and Kamchatka, and Japan. It has occasionally been reported from the Sacramento and Klamath Rivers, but is not at all common south of the Columbia.
Jordan 1904b	Of these species the blue-back or red salmon predominates in Fraser River and in most of the small rivers of Alaska, including all those which flow from lakes. The greatest salmon rivers in the world are the Nushegak and Karluk in Alaska, with the Columbia River, Fraser River, and Sacramento River farther south. The red and silver salmon predominate in Puget Sound, the quinnat in the Columbia and the Sacramento, and the silver salmon in most of the streams along the coast. All the species occur, however, from the Columbia River northward; but the blue-back is not found in the Sacramento. Only the quinnat and dog salmon have been noticed south of San Francisco. . . . The quinnat and blue-back salmon, the “noble salmon,” habitually “run” in the spring, the others in the fall.				
Jordan 1907	Identical to Jordan 1904b except for spelling of the “Frazer” River				

* The 1892 report by Jordan was published as Bulletin No. 4 to the California Board of Fish Commissioners and subsequently reprinted as part of the Biennial Report of the State Board of Fish Commissioners for years 1891 and 1892.

The 1895 Carmel River Expedition

The 1895 Carmel River Expedition¹⁶ discussed above produced juvenile coho salmon from four different streams in the region between Santa Cruz and the Golden Gate. As described in Adams et al. (2007), these collections are currently in the California Academy of Sciences (CAS) museum collection, and included 11 coho salmon from Waddell Creek (SU 4667; Rutter and Scofield) and 4 coho salmon from Scott Creek (SU 4749; Rutter and Seale), all of which were collected on 5 June 1895. Additionally, 1 coho salmon and 1 Chinook salmon¹⁷ from San Vicente Creek (SU 4685; Rutter and Scofield) and 1 coho salmon from Gazos Creek (SU 4686; Rutter and Pierson) were collected by the same party but are undated. They were likely collected within a day or two of the Waddell and Scott creek collections¹⁸. As this was the only expedition that involved all four participants (Böhlke 1953), there is little doubt that these specimens were collected during the same collecting trip (Adams et al. 2007). All of these coho salmon specimens were originally misidentified as *O. keta* or *O. tshawytscha* in the Stanford collections (Kaczynski and Alvarado 2006; Adams et al. 2007), which is not surprising given difficulty early researchers had in discriminating among species, particularly the juvenile phases about which little was known at the time (Sections 7.2 and 7.3). Identifications of these fish were corrected to coho salmon while the specimens were still in the possession of Stanford University, and these identifications have been confirmed through morphological analysis by Drs. John McCosker and Tomio Iwamoto of CAS (D. Catania, CAS, pers. comm., 14 December 2004). In addition to the coho salmon specimens, steelhead (then identified as *Salmo irideus*) specimens were also collected from each of the four localities (Gazos Creek, SU 4666, Waddell Creek, SU 4796, SU 4671, SU 4756; Scott Creek, SU 4674; and San Vicente Creek, SU 4798). Thus, irrespective of the apparent misidentifications, the collectors were clearly discriminating between at least two different species of juvenile salmonid.

The writings of Jordan and Evermann, 1896–1908

In 1896, Jordan and Barton Warren Evermann published the book *The fishes of North and Middle America*. The general description of the five salmonid species was virtually identical to that found in Jordan (1892) (Table 7.2). The specific description for coho salmon describes it as “*Abundant from San Francisco northward, especially in Puget Sound and the Alaskan fjords,*” a substantial departure from his Jordan’s 1894 statement that it the coho salmon was “*not common south of the Columbia, but sometimes taken in California.*” In 1902, Jordan and Evermann published the first edition of the book “*American Food and Game Fishes,*” a book that was printed again in 1903, 1904, 1905, and 1908, each time with identical descriptions of the salmon species distributions. In these books, the general description of the distributions of the five Pacific salmon species is nearly identical to the description from Jordan and Evermann (1896), with one notable exception: the authors now state that it is the “dog salmon,” not the “Silver salmon,” that predominates in most of the streams along the coast. This difference is noteworthy because these writings follow the 1897 expedition of Snyder and Gilbert up the northern

¹⁶ The Carmel River Expedition included Cloudsley Rutter, Alvin Seale, Norman Scofield, and Charles Pierson.

¹⁷ Adams et al. (2007) report that the SU 4685 contains two fish identified as coho salmon; however, one of these fish was determined by McCosker or Iwamoto to be a Chinook salmon (D. Catania, CAS, pers. comm., 18 November 2004).

¹⁸ A collection of steelhead from Lagoon [Laguna] Creek, which is the next watershed south of San Vicente Creek, was made on 6 June 1895; thus it is likely that San Vicente was sampled on or about that day.

California coast, during which Snyder (1907) erroneously concluded that “dog salmon” were the most abundant salmon in the streams of northern California and southern Oregon (see Section 7.1). It appears that Jordan accepted Snyder’s observations as accurate and so revised his description. Also worth mentioning is the range description for Chinook salmon, which now reads “*It is found on both coasts of the Pacific, from Monterey Bay, California, and China, north to Bering Straits...*” Why Jordan abandoned his previous assertion that Chinook salmon ranged as far south as the Ventura River (some 420 km south of Monterey Bay) is not clear.

Also noteworthy are Jordan’s (1904b) paper published in the State Fish and Game Commission’s biennial report and his 1907 book “*Fishes*.” Both of these documents state that “*Only the quinnat and dog salmon have been noticed south of San Francisco*” (Table 7.2). These statements mark the first references to “dog salmon” occurring south of San Francisco Bay. The BRT believes there is a high likelihood that these references to “dog salmon” reflect the putative collections of “*O. keta*” made by the Carmel River Expedition that were later determined to be coho salmon. A similar conclusion was reached by Adams et al. (2007).

Newspaper accounts of salmon in Santa Cruz Mountain streams

In addition to searching the scientific literature from the 1800s, the BRT also did a limited search of two local newspapers that were published during the late 1800s in Santa Cruz to determine whether any additional information on the occurrence of coho salmon in area streams could be found. Specifically, we searched indexed references to salmon, fish, or fishing in the Santa Cruz Sentinel and Santa Cruz Daily Surf. As the Sentinel index appeared incomplete, we also looked more closely at newspapers from a limited period (1880 to 1885), focusing on the months November to February, the most likely time that salmon would be entering local streams. In total, we found 25 references to salmon and salmon fishing (or spearing), as well as two references to “salmon trout” (i.e., steelhead), in area streams including the San Lorenzo River, and Pescadero, Waddell, Scott, and Laguna creeks (Table 7.3). Not surprisingly, given the state of knowledge of salmonids during this era, the newspaper accounts do not indicate the particular species of salmon observed. Nor can we be certain that all the references to “salmon” are actually salmon and not steelhead. Nevertheless, the fact that fish began running into streams in significant numbers beginning in November and December and continued into March (and later for steelhead), coupled with the occasional references to large individuals weighing up to 28 pounds and periodic references to “salmon trout,” suggests that both salmon and steelhead were present in these streams on a recurring basis.

7.5 Response to petition

The petitioner (McCrary 2003, 2004; McCrary et al. 2004), as well as Kaczynski and Alvarado (2006), present two main lines of historical evidence that they suggest indicates coho salmon were not native to local streams: (1) the writings of David Starr Jordan during the period 1881 and 1905, and (2) local newspaper accounts surrounding the importation of Baker Lake coho salmon to area streams that imply these plantings represented the introduction of a new species to the waters of the Santa Cruz County.

Table 7.3. Summary of newspaper accounts of salmon in streams of the Santa Cruz Mountains.

Newspaper	Date	Quote
Santa Cruz Sentinel	4 Apr. 1874	Salmon trout, very large, are also frequently caught at Laguna Creek
Santa Cruz Sentinel	10 Dec. 1881	Catchers of salmon beware, take care. You are spotted.
Santa Cruz Sentinel	19 Feb. 1881	There has been a number of fine large salmon caught in Beeding's Creek, a small branch of the Pescadero. They must have gone up in great numbers during the flood; the water is too muddy yet in Pescadero Creek to find them. Should there be no more rain for the next ten days, the boys will have fine sport salmon hunting.
Santa Cruz Sentinel	26 Feb. 1881	An unusual number of salmon are being caught in the Pescadero and Butano creeks, their weight being from twenty-eight pounds downward.
Santa Cruz Sentinel	29 Dec. 1883	The boys are now spearing salmon in the San Lorenzo River
Santa Cruz Sentinel	21 Nov. 1884	The spearing of salmon at the mouth of the river is a sport now being indulged in. The salmon are not as plentiful as formerly.
Santa Cruz Sentinel	29 Nov. 1884	Salmon have commenced running up the streams of this county
Santa Cruz Sentinel	5 Dec. 1884	Four salmon were caught in the river Wednesday
Santa Cruz Sentinel	24 Dec. 1884	Salmon are reported as running up the San Lorenzo River.
Santa Cruz Sentinel	11 Jan. 1885	Mike Keenan saw a school of salmon in the river near the Big Trees Thursday. All Keenan had with him was a pocket-knife. With it he killed three salmon, the largest of which weighed twelve pounds. He says he would have killed at least fifty if he had had a pitchfork with him. This sounds like a fish story, dear reader
Santa Cruz Sentinel	22 Jan. 1885	A couple of young men, who were spearing for salmon Tuesday afternoon at the mouth of the river, slipped off the rocks and fell in the water.
Santa Cruz Sentinel	6 Feb. 1885	A 10 ½ pound salmon was landed by Mrs. Judge Rice. The fish had ascended a small stream that runs through her chicken yard. She saw, caught him with thumb and fingers in gills, and fresh fish for the family was the result.
Santa Cruz Sentinel	10 Feb. 1885	A man shot a twelve pound salmon at the mouth of the river Sunday. There is no law against shooting salmon, but there is one against shooting in the mouth of the river. Some parties living between this city and the Powder Mill have traps in the river with which to catch salmon. An Indian caught twelve salmon with a hook Sunday.
Santa Cruz Sentinel	11 Feb. 1885	A party of men were at the mouth of the river spearing for salmon Monday evening by the light of a bonfire. One of the salmon spears slipped and fell into the river in his efforts to catch a salmon.
Santa Cruz Sentinel	12 Feb. 1885	Salmon are plentiful in Pescadero Creek. On Monday nineteen were caught.
Santa Cruz Sentinel	14 Feb. 1885	Salmon are plentiful in Waddell creek. Parties have been fishing with a seine for several days, and have caught a large number. Waddell creek seems to be the place for the boys to go to catch salmon.
Santa Cruz Sentinel	17 Feb. 1885	Four salmon were caught at the mouth of the river Sunday. A man fired four shots at a salmon Sunday afternoon.

Table 7.3 (continued).

Santa Cruz Sentinel	18 Feb. 1885	Last Saturday Albert Cook and Wm. Majors put a fish pole in a hole at Scott's Creek and all at once the pole began to wiggle. The fishermen threw a hook into the water and pulled out salmon after salmon, until forty were piled on the bank. The aggregate weight of the salmon was 335 pounds. This is the biggest haul of salmon out of one hole ever known in the county. If there is anything we like it is salmon from Scott's Creek, and if the lucky fishermen lay one (or more) on our table we will not decline to accept it. Our number is 104 Pacific Ave, so you needn't be mistaken as to where to leave the salmon.
Santa Cruz Sentinel	26 Feb. 1885	A small boy, who was wading in the river Sunday, caught a salmon weighing nine pounds with his hands. The salmon, in its efforts to get away, pulled the boy under the water twice.
Santa Cruz Daily Surf	1 Jul. 1884	Howard Coult the enterprising young druggist at Felton, is also becoming a proficient "trout compeller." He goes out at 4 o' clock these charming mornings and returns at 6, laden with the most dainty and toothsome of salmon trout.
Santa Cruz Daily Surf	22 Jan. 1887	Some fine salmon have been taken in the river lately.
Santa Cruz Daily Surf	4 Mar. 1889	Numbers of persons take pleasure in spearing salmon in the river at night. The mode of procedure is to place a powerful lantern so that it will reflect on a shallow riffle where the hunter can see the fish and spear them. Half a dozen lights can be seen along the river about midnight every night.
Santa Cruz Daily Surf	3 Feb. 1890	Salmon spearing has been a favorite pastime of late on the upper Corralitos. When that stream receded last week from the Amesti and other overflowed sections several salmon were left in the pools and were soon caught by fishermen.
Santa Cruz Daily Surf	19 Feb. 1891	Big Basin of Santa Cruz County [Big Basin description excerpt]. ...The streams abound with trout and salmon.
Santa Cruz Daily Surf	9 Mar. 1891	"Fatty" Buelna while bathing at the mouth of the river yesterday scared a salmon into shallow water and after a short struggle captured him. The salmon weighed about twenty pounds.
Santa Cruz Daily Surf	10 Jan. 1896	More salmon have been caught in Pescadero this winter than for many years. Will Octoby and Neston Armas are the champions so far, each having speared over 80 fish.
Santa Cruz Daily Surf	9 Dec. 1897	Spearing salmon is the current sport. The river, for some distance from the mouth, is lined with men and boys who are armed with spears.

The writings of David Starr Jordan

The petitioner's interpretation of Jordan's writings presumes that Jordan and other scientists of his era had detailed, accurate, and spatially extensive information on the fish faunas of the coastal watersheds of California, including those along the Central Coast from the San Lorenzo River to the Golden Gate, as a basis for their descriptions of species distributions. The petitioner goes so far as to state that Jordan "*conducted stream surveys of the area and repeatedly attested in writing to the absence of coho salmon south of San Francisco. He did not simply visit Waddell Creek. He conducted scientific observations of the entire Pacific Coast including Central Coast creeks, which were unambiguously documented and reported in McCrary (2003).*"

The BRT's review of the available scientific literature related to salmon and other freshwater species indicates that these assumptions and assertions are not supported (see Section 7.1). There were few scientific collections of fish of any kind from coastal watersheds in California prior to the mid-1890s. All evidence indicates that Jordan and Gilbert's 1880 expedition of the Pacific Coast was focused almost exclusively on marine species, with the lone exceptions being collections of freshwater and euryhaline fishes made in the lower Sacramento and Columbia rivers. We find no direct evidence that Jordan and Gilbert sampled coastal streams between Santa Cruz and the Golden Gate, or any other coastal streams and rivers on the West Coast of North America during this expedition besides the Sacramento and Columbia rivers. Moreover, Jordan and Gilbert apparently bypassed a substantial portion of the northern California and Oregon coasts, there being no collection records between Point Reyes, California, and Astoria, Oregon. Nor is there any evidence that collection efforts by other researchers were of sufficient spatial extent to rigorously establish the southern boundary of any of the salmonid species prior to the mid-to-late 1890s (i.e., the 1895 Carmel River Expedition and the 1897 northern California survey of Snyder and Gilbert; see Section 7.1).

The published records indicate that the Carmel River Expedition of 1895 marked the first formal survey of streams and rivers in the central California coast region, and this survey produced juvenile coho salmon in four different watersheds (Gazos, Waddell, Scott, and San Vicente creeks), specimens of which are currently housed at CAS and have been confirmed to be coho salmon. The petitioner and Kaczynski and Alvarado (2006) have challenged the reliability of these specimens based on (1) the fact that the specimens were originally identified as chum and Chinook salmon, and not coho salmon, and (2) the possibility that the coho specimens currently in these four jars may have resulted from contamination from another source following damage to the Stanford collection during the 1906 earthquake.

The BRT was not persuaded by either of these arguments. As clearly demonstrated in section 7.2, the misidentification of species—in particular, coho and chum salmon—was commonplace in this era when there was substantial confusion surrounding the taxonomy and nomenclature of Pacific salmon and a poor understanding of the early life stages of these species. The correct identification of these fish as coho salmon was made sometime later by unknown museum staff, most likely before the Stanford collection was transferred to the CAS (D. Catania, CAS, pers. comm., 14 November, 2004). Further, the timing of these collections (June) and size of individuals (50–85 mm) is most consistent with coho salmon, which reside in fresh water for a full year. Three of the four lots (SU 4667, SU 4685, and SU 4686) were originally identified as

chum salmon. However, chum salmon emigrate shortly after emergence in the spring at very small sizes (usually < 50 mm); thus, a June collection of fish > 50 mm would be highly unlikely. Thus, the most parsimonious explanation is that the 1895 specimens collected by the Carmel River Expedition were coho salmon that were misidentified. Adams et al. (2007) reached the same conclusion.

The BRT also concluded that the hypothesis that the museum specimens or labels were mixed up after the San Francisco earthquake also lacks support. As noted by Böhlke (1953), in the days that followed the earthquake “*an effort was made to match specimens with data, this work being done by each member of the ichthyological group who had most actively been working on the specimens concerned*” and the group discarded specimens that could not be reliably be matched with their original collection information. Those bottles that had been broken received a label indicating such, though “*a careless curatorial assistant later removed these labels from about half of the jars*” (Böhlke 1953). For the four jars in question to have been “contaminated,” the following would be required: (1) each of the jars in question was broken during the earthquake, (2) a fifth jar from another location containing juvenile coho salmon of similar size also broke and was in close enough proximity to mingle with specimens from the other four jars, (3) all four replacement jars were contaminated with fish from this fifth broken jar, despite the fact that Stanford staff clearly took great care to avoid such occurrence, (4) all four replacement jars from the Central Coast region received labels indicating the original jars had broken during the earthquake, and (5) all four jars had subsequently had these labels removed by the curatorial assistant. While this scenario is not entirely out of the realm of possibility, the parsimonious explanation is that the CAS collection jars contain coho salmon collected at the four Central Coast localities by the Carmel River Expedition, especially since there is no evidence that any of the jars in question were broken.

The petitioner (McCrary 2005), as well as Kaczynski and Alvarado (2006), assert that even if the specimens are shown to be valid, they are not evidence of persistent populations. They speculate that these observations could have resulted from either planting of hatchery fish or “*temporary propagule year-class coho colony*” resulting from unusually favorable conditions for salmon in the early 1890s (McCrary 2005; Kaczynski and Alvarado 2006), citing a large return of Chinook salmon to the Sacramento in 1892 as evidence of these favorable conditions (Redding et al. 1892). The BRT has found no credible evidence that non-native hatchery coho salmon were ever distributed in coastal watersheds of Santa Cruz or San Mateo counties prior to the 1906 planting of Baker Lake coho salmon (reviewed in Section 5). Likewise, the hypothesis that these fish could have been the result of unusually favorable conditions is highly speculative. The case might be more compelling if this was a single instance of coho salmon being observed in a local stream where surveys in other years clearly indicated the absence of coho salmon. However, the published record indicates that the Carmel River Expedition was the first and only scientific survey of streams in the region north of Santa Cruz to the Golden Gate that took place prior to 1906 and that coho salmon were found in four separate watersheds during this survey. Furthermore, newspaper and other popular accounts indicate that salmon (in addition to steelhead) were abundant and predictable inhabitants of local streams. The BRT thus concluded that it is unlikely that these observations represent a temporary colonization event, particularly given the lack of compelling evidence of environmental constraints that would prevent coho salmon from persisting for extended periods in Santa Cruz Mountain watersheds (see Section 4).

The historical record leaves little question that at least two and possibly more species of anadromous salmonids inhabited streams south of San Francisco to the Monterey Bay. One of these was clearly steelhead. We can then ask which of the species of Pacific salmon (coho, chum, pink, sockeye, or Chinook salmon) is the most likely to inhabit and persist in streams south of San Francisco given each species' ecological requirements, habitat affinities, and known distributions. We believe the answer is clearly coho salmon. In addition to having been reported in 11 different watersheds south of San Francisco (Spence et al. 2005)¹⁹, coho salmon have been reported from nearly every accessible watershed along the entire coast of northern California, from San Francisco Bay north to the Oregon border, including many watersheds that are smaller and offer less habitat than streams such as Waddell and Scott creeks (Spence et al. 2005; Bjorkstedt et al. 2005). In contrast, the historical evidence indicates that pink, chum, and sockeye salmon are only occasional visitors to California. Substantial and persistent populations of pink salmon occur only from Puget Sound (48° N latitude) northward, with none on the Washington Coast. Small numbers of pink salmon occur sporadically in the Columbia River, and pink salmon have occasionally been observed in streams of coastal Oregon and Northern California as far south as the San Lorenzo River (Scofield 1916); however, there is no evidence to suggest persistent populations of pink salmon ever occurred anywhere in California (Hard et al. 1996; Moyle 2002; Quinn 2005; Gustafson et al. 2007). Likewise, significant spawning populations of chum salmon occur in coastal watersheds from northern Oregon (Alsea River and Tillamook Bay) northward (Salo 1991). As with pink salmon, chum salmon have occasionally been reported in southern Oregon and northern California as far south as the San Lorenzo River (Scofield 1916), but they have long been recognized as infrequent visitors to California (Snyder 1931; Salo 1991; Gustafson et al. 2007) and there is little evidence of persistent chum salmon populations anywhere in the state. Sockeye salmon, which in the vast majority of their range are dependent on lakes for juvenile rearing, are the least likely candidate, having rarely been reported in California.

This leaves only fall-run Chinook salmon as a plausible candidate besides coho salmon²⁰. The BRT does not discount the possibility that Chinook salmon periodically spawned in streams south of San Francisco (most likely the two largest watersheds in the region, the San Lorenzo River and Pescadero Creek), and indeed the presence of a juvenile Chinook salmon from San Vicente Creek collected during the Carmel River Expedition indicates that they sometimes did. However, the ecological requirements and habitat preferences of Chinook salmon are decidedly different from those of coho salmon. Chinook salmon prefer larger rivers (Healey 1991) whereas coho salmon are typically found in smaller watersheds or smaller tributaries in larger streams (Sandercock 1991). There are countless small watersheds in coastal California and elsewhere in the Pacific Northwest where coho salmon occur but fall Chinook salmon either do not occur or occur only sporadically. The converse, however, is rarely true, and to our knowledge the exceptions are exclusively interior streams (e.g., Columbia River and Sacramento River tributaries) where migration distances are great, gradients are too steep for coho salmon to negotiate, or summer temperatures are too warm to support coho salmon. The notion that

¹⁹ In addition to the 10 watersheds documented by Spence et al. (2005), coho salmon were also reported in Laguna Creek during 2005 (E. Freund, NNMS SWFSC, unpub. data).

²⁰ Spring Chinook salmon occur almost exclusively in watersheds where hydrology is strongly influenced by snowmelt, large groundwater sources, or both. Neither of these conditions occurs in the Monterey Bay region.

Chinook salmon populations could persist in small coastal streams where coho salmon cannot. This defies all we know about the comparative ecology of these two species.

Moreover, if the petitioner's contention that environmental conditions were too harsh for coho salmon to persist, then why would Chinook salmon not be excluded by these same processes? Because Chinook salmon spawn lower in watersheds than coho salmon, they would be more vulnerable to floods and sedimentation, and they would be equally if not more vulnerable to droughts that limited entry to streams that bar over during the summer and fall since they generally migrate and spawn earlier. The only plausible advantage they might have over coho salmon is that they exhibit more variability in their age at maturity. However, the lack of persistent populations of fall Chinook salmon in most of the smaller watersheds of the California coast south of Punta Gorda (Humboldt County) indicates they would be far less likely to occur in streams such as Gazos, Scott, Waddell, and San Vicente creeks than would coho salmon.

Newspaper accounts of Baker Lake coho salmon introduction

The petitioner (McCrary 2003), as well as Kaczynski and Alvarado (2006) quote several newspaper and magazine sources (Santa Cruz Morning Sentinel, 20 December 1905; Mountain Echo December 1905 and 24 March 1906; letter to the editor from W. Welch, *Forest and Stream* 13 July 1907) that imply that the importation of Baker Lake, Washington, coho salmon to Brookdale Hatchery and subsequent planting into Santa Cruz waters would add new species to Santa Cruz County streams.

The BRT agrees that these accounts suggest the writers were promoting the establishment of a 'new' species for fishermen. However, these articles have to be interpreted in the context of the habitat conditions that existed at the time. As detailed in Section 4, the Santa Cruz Mountains at that time had been subjected to 60+ years of intensive logging that employed practices that were undoubtedly extremely damaging to stream habitats. Logging in the San Lorenzo River, Soquel Creek, Aptos Creek, Corralitos Creek, Scott Creek, and Pescadero Creek was particularly intense (see Figure 4.5). Thus, the impression that coho salmon were not present may reflect the fact that coho salmon populations in most watersheds had likely been extirpated or substantially reduced in size. Additionally, the same *Forest and Stream* article that mentioned the stocking of Baker Lake Silver salmon into Santa Cruz waters also mentions that there initially was "*lukewarm public sentiment*" to the establishment of Brookdale Hatchery. Thus, it is possible that the hatchery manager sought to build public support for the hatchery by extolling the benefits of establishing a "new" fishery. Regardless, the BRT concluded that these newspaper accounts do not provide sufficient evidence that coho salmon were *not* present in local streams prior to 1906 to override the other evidence that clearly establishes the coho salmon's presence in Santa Cruz Mountain streams before this introduction.

Kaczynski and Alvarado (2006) also speculate that if coho salmon had been available, then the Brookdale Hatchery manager would have used these fish as brood stock, rather than importing them from elsewhere. Again, the BRT was not persuaded. There are countless examples of salmon stocks being transferred, often great distances, to watersheds where the species was already present. A case in point was the transfer of millions of Chinook salmon from the Baird,

Mill Creek, and Battle Creek stations in the upper Sacramento River to Price Creek Hatchery in the Eel River during the early 1900s (see e.g., CBFGC 1910; CFGC 1913).

Conclusions

The BRT agrees with the petitioner that, with the exception of the CAS coho museum specimens, which unequivocally establish coho salmon in four streams south of the Golden Gate prior to the first known plantings of nonnative coho salmon in the region, there is a general lack of species-specific information on coho salmon in local streams prior to 1906, when the first out-of-ESU transfers occurred. The conclusion that the petitioner and Kaczynski and Alvarado (2006) draw from this is that coho salmon were not present in the region. After reviewing the available historical literature, the BRT comes to a different conclusion. We conclude the lack of more frequent specific references to coho salmon in the region reflects (1) the scarcity of scientific collections or surveys that had been done in the Central Coast region (and throughout California) from the 1850s to the early 1900s, (2) the substantial confusion in taxonomy and nomenclature that pervaded during this time, even after more formal surveys of California's coastal watersheds began in the mid-1890s, and (3) the extensive environmental modification that had already occurred in the region, which undoubtedly reduced the abundance of coho salmon and other salmonids in these watersheds. The petitioner and Kaczynski and Alvarado (2006) are attributing a precision and accuracy to Jordan's early descriptions of species' ranges that we believe is not supported by these data. The lack of information and uncertainty in species ranges is clearly evident in the progression of Jordan's descriptions of the distributions of both coho salmon and chum salmon, which vacillate between statements suggesting that each of these species was abundant in California versus those where they were either occasional or infrequent visitors. Regardless of the lack of more specific references to coho salmon, there are numerous references to the occurrence of "salmon" in streams entering Monterey Bay and the coastal region north of Santa Cruz to the Golden Gate, and there are many instances where both salmon and steelhead are described from the same streams and rivers, with no indication that these observations of salmon were in any way unusual. Given the ecological requirements, habitat preferences, and historical patterns of distribution of coho salmon and the other Pacific salmon, the BRT concludes that the occurrence of persistent coho salmon populations constitutes the most parsimonious explanation for these observations.

8. Archaeological evidence for the presence of coho salmon in coastal California South of San Francisco Bay

Archaeological studies can provide important evidence for the distribution of plant and animal species by documenting their use by earlier human inhabitants (Gobalet and Jones 1995). Such evidence can be particularly valuable for assessing species distributions in locations where populations were extirpated before their occurrence was documented. While these studies can be helpful in establishing presence, conclusions about both distribution and abundance must be made cautiously because relative representation in middens may not necessarily reflect relative abundance. This is particularly true of fishes for several reasons. First, differences in mineralization and bone density can affect preservation in middens. Second, how certain fishes were handled or prepared may affect the likelihood that they would be deposited or recognizable in middens. Third, scavengers may consume or displace bones from midden sites. And fourth, remains of certain species are simply easier to recognize than others (Gobalet et al. 2004). For these reasons, even archaeological deposits in close proximity to known important salmon fishing locations sometimes do not yield significant numbers of salmonid bones (Chance and Chance 1985; Plew 2000; cited in Gobalet et al. 2004). In addition, although identification of skeletal elements of fishes in the genus *Oncorhynchus* is relatively straightforward, discriminating among the different species of *Oncorhynchus* is more difficult (K. Gobalet, pers. comm.).

In this section, we provide a brief review of the primary archaeological literature addressing fishery remains at Native American historical sites in central California. The primary literature consists of four papers authored by Dr. Kenneth W. Gobalet, California State University, Bakersfield. Although these papers report broadly on fisheries, our review is limited primarily to evidence of salmonid remains.

8.1 Review of archaeological evidence

Gobalet 1990

The earliest of these publications (Gobalet 1990) presents findings from an archaeological investigation of site CA-Mnt-229 located on Elkhorn Slough in Monterey County, California. Gobalet (1990) reported identification of 27 species of fishes from this site on Elkhorn Slough. Among the 2,235 archaeological elements he identified, 1,624 (73%) were from freshwater fishes, while 388 (17%) were from euryhaline fish species and 223 (10%) were from marine species. Elements of euryhaline fishes included 31 epural (caudal) vertebrae of steelhead (*Oncorhynchus mykiss*). Gobalet (1990) made no mention of coho salmon in this paper.

Gobalet (1990) dated fish remains identified from Elkhorn Slough as being from 700 to 2,500 years old. He suggested that the fishes found in this study were consistent with current knowledge of historical conditions in Elkhorn Slough: although today it is essentially a marine embayment, prior to the early 1900's the Salinas River entered Monterey Bay through Elkhorn Slough, resulting in more diverse habitat than exists today.

Gobalet and Jones 1995

Gobalet and Jones (1995), expanded knowledge of historical Native American fisheries in the region with an investigation of fish remains from 51 archaeological sites on the central California coast from San Mateo to San Luis Obispo counties. The sites investigated represented exposed rocky coastal sites, lagoon-estuary habitats and freshwater drainages. The authors presented their analysis of more than 77,000 elements of fish remains that they determined were deposited between 6200 B.C. and 1830 A.D.

Gobalet and Jones (1995) found remains of more than 80 species of marine and freshwater fishes at these sites and reported that taxonomic composition varied among habitats. While large inshore marine fishes (e.g. rock fishes, *Sebastes* spp.; ling cod, *Ophiodon elongates*; kelp greenling, *Hexagrammos decagrammus*; cabezon, *Scorpaenichthys marmoratus*; and monkeyface prickleback, *Cebidichthys violacius*) were most common in rocky coast habitats, moderately small schooling fish species (e.g., Pacific herring, *Clupea pallasii*; Pacific sardine, *Sardinopsis sagax*; northern anchovy, *Engraulis mordax*; topsmelt, *Atherinops affinis*; jacksmelt, *Atherinopsis californiensis*; and California grunion,) were most common at lagoon-estuary and freshwater sites. They identified remains of steelhead at Elkhorn Slough, Morro Bay and freshwater sites in the Pajaro-Salinas Basin, but commented on the relative rarity of steelhead in the remains. They also noted the absence of other Pacific salmon (e.g. Chinook or coho salmon) in the remains and commented that this group was apparently absent from central California coast streams south of the San Lorenzo River (but see discussion of Gobalet [in press] below).

Gobalet et al. 2004

Almost a decade passed before the next primary publication on this topic, a comprehensive investigation of fishes in the archaeological record of California (Gobalet et al. 2004). This paper reviews archaeological records of fish remains from throughout California and includes 152,000 fish remain elements not previously examined, including 18,000 elements from the coastal area between San Francisco and San Diego. The authors' objectives in this paper were to gain a better understanding of Native American fisheries in California and the prehistoric distributions of freshwater and anadromous fishes in the region. They report regional variation in historical use of fishes by Native Americans.

Gobalet et al. (2004) found that prehistoric intertidal fisheries were especially important at San Francisco Bay sites, including bat rays (*Myliobatis californica*), sturgeons (*Acipenser* spp.), Chinook salmon (*Oncorhynchus tshawytscha*), clupeids, and atherinopsids, as well as less common species. The same sites also revealed the former presence of various freshwater species, including steelhead and coho salmon, in tributary streams from which they were extirpated prior to modern surveys.

In the Central Valley, Chinook salmon remains were the most abundant salmonid found at Sacramento River sites. In the San Joaquin River basin, however, no salmonids were found at

archaeological sites south of the San Joaquin River's confluence with the Calaveras River (near the City of Stockton).

Steelhead were identified from remains at nine sites within five different watersheds or areas south of San Francisco Bay, ranging from Santa Cruz County to San Diego County. Gobalet et al. (2004) also reported *Oncorhynchus* spp. from two sites, Big Creek in Monterey County, and Santa Margarita River in San Diego County. These specimens were not identified to species.

Gobalet et al. (2004) commented that the rarity of salmonids in archaeological materials suggested that the ethnographic record overstated the importance of salmonids to Native Americans of California, while at the same time understating the importance of other fishes. For example, although ethnographic records suggest that Chinook salmon were important to Native Americans in the Central Valley, the authors found that salmonids made up only 6.3% of the fish bones from this region, and no salmonids were found south of San Joaquin County, despite the fact that sizable salmon and steelhead runs occurred in the Stanislaus, Tuolumne, Merced, upper San Joaquin, and other San Joaquin River tributaries (Yoshiyama et al. 2001). Regarding salmonids in the Central Coast region, the authors suggested too little sampling has been completed to rule out their presence at locations that had appropriate habitat and where early reports indicated they were present.

Gobalet (in press)

The most recent paper on this topic (Gobalet in press) addresses the southern extent of coho salmon distribution specifically. This paper reports the author's findings from newly examined material from five locations in coastal California south of San Francisco, including Año Nuevo State Reserve (CA-SMA-18) and Pillar Point (CA-SMA-151) in San Mateo County, a combined gravel sample from two sites in Santa Cruz County (CA-SCR-25/81), a Victorian household in Santa Barbara (CA-SBA-3505H), and several sites in Playa Vista in Los Angeles County (CA-LAN-54, -62, -63, -64, -193). Skeletons from museum collections housed at the California State University at Bakersfield, California Academy of Sciences, and University of California at Davis were used as references. In addition, Gobalet (in press) re-examined eight archaeological elements from Elkhorn Slough that had previously been identified as steelhead (Gobalet 1990, Gobalet and Jones 1995). With the Elkhorn Slough samples, the author restricted his re-examination of vertebrae to those aged as three-year-old fish, so as to exclude salmonids that would likely not be coho salmon.

From the newly examined materials, Gobalet (in press) identified 12 archaeological elements as being remains of salmonids. Of these, nine were identified as representing steelhead and three were identified as representing coho salmon. Of the three coho salmon remains, one was from the historic home site in Santa Barbara and two were from the Año Nuevo State Reserve site. The two coho salmon samples from Año Nuevo were examined by three experts in independent, blind tests. All three experts identified one of these vertebrae as being from coho salmon. The second vertebrae was identified as a coho salmon by two of the experts, while the third expert was equivocal, but settled on a steelhead identification (Gobalet in press).

Of the eight three-year-old vertebrae re-examined from the Elkhorn Slough site, Gobalet (in press) concluded that three were possibly coho salmon based on surface architecture and the three-year age.

Evidence of coho salmon in the archaeological record from California is sparse, particularly in the coastal region. Prior to the publication of Adams et al. (2007), in which Gobalet's finding of coho salmon from Año Nuevo is described, and additional work described in Gobalet (in press), there had been only one documented report of coho salmon from archaeological remains in coastal California, that being in Del Norte County. A possible second case of either coho salmon or Chinook salmon in archaeological remains had been recorded from Mendocino County. Beyond that, 14 records of coho salmon had been documented from archaeological sites along San Francisco Bay and Suisun Bay tributary streams.

The most recent study by Gobalet (in press) provides evidence that coho salmon were historically present in streams at least as far south as Santa Cruz County. If identifications of vertebrae from Elkhorn Slough are independently confirmed as being from coho salmon, evidence of historical coho salmon presence would be extended to northern Monterey County. Because of the lack of historical records of coho salmon from the Santa Barbara region, Gobalet (in press) concluded that the single vertebrae identified from archaeological remains at the historic home site in Santa Barbara was likely from a marine-caught fish; however, a freshwater origin for this specimen cannot be ruled out.

8.2 Response to petition

The petitioner (McCrary 2003, 2004, 2005; McCrary et al. 2004) reviewed archaeological studies published prior to 2005 (Gobalet 1990; Gobalet and Jones 1995; Gobalet 2000; and Gobalet et al. 2003²¹) and concluded from these studies that the failure to detect coho salmon in Native American middens from the Central Coast region supported the contention that coho salmon did not occupy streams south of the Golden Gate. Much of the ensuing debate between NMFS and the petitioner revolved around what could be inferred from this “negative evidence” given the number of archeological elements that had been examined (Gobalet et al. 2004; Grimes 2004, 2005; Kaczynski and Alvarado 2006). Gobalet et al. (2004) cautioned that because of the paucity of materials from coastal sites in Santa Cruz and San Mateo counties, “*far more sampling is required to use the archaeological record as definitive evidence for the absence of coho salmon from this section of the coast.*” The lack of definitive archaeological evidence of coho salmon in coastal watersheds between San Francisco Bay and Del Norte County (Gobalet et al. 2004), a region that clearly supported persistent, large populations of coho salmon, further highlights the risk of over-interpreting negative findings in archaeological studies.

The recent findings of coho salmon specimens from middens at Año Nuevo, possibly Elkhorn Slough, and as far south as Santa Barbara County described in Adams et al. (2007) and Gobalet (in press) render these discussions moot. Based on the most recent archaeological evidence, the BRT concludes (1) archaeological evidence from the Año Nuevo site establishes the historical

²¹ The Gobalet et al. 2003 manuscript was the review draft of the Gobalet et al. (2004) manuscript published in the Transactions of the American Fisheries Society.

presence of coho salmon as far south as Santa Cruz County, (2) independent confirmation of vertebrae identified from the Elkhorn Slough site may extend the south limit of historical coho salmon distribution to northern Monterey County, and (3) archaeological documentation of historical presence of coho salmon south of San Francisco Bay is now as strong as evidence for the species' presence north of San Francisco Bay (Gobalet, in press).

The BRT recognizes that one cannot rule out the possibility that coho salmon remains in middens at Año Nuevo and the apparent remains at Elkhorn Slough were ocean-caught fish or fish that were imported to the area from elsewhere through trade. Regardless, with the recent finding of these coho salmon remains, the petitioner's contention that the lack of archeological evidence supports his assertion that coho salmon were not native south of San Francisco is no longer valid.

9. Conclusions

Following review and discussion of the available information, BRT members voted on the primary question of whether the petitioned action was warranted using the FEMAT approach described in Section 1.2. Specifically, each BRT member allocated ten “yes” or “no” votes on the question “*Does the available evidence support a boundary for CCC coho salmon that excludes coastal streams south of the entrance to San Francisco Bay?*” The vast majority (66 of 70, or 94.3%) of the BRT votes were in the “no” category, with three BRT members casting all 10 of their votes as “no” and the remaining four members casting nine of ten votes as “no.” These results indicate that all BRT members were highly confident in concluding that the CCC Coho Salmon ESU extends to watersheds south of the Golden Gate.

The primary reasons supporting this conclusion were as follows:

- (1) Coho salmon currently occupy watersheds of the Santa Cruz Mountains and have been present since the first definitive records for the area were made in 1895. Genetic evidence indicates that extant populations south of the Golden Gate are clearly part of the CCC Coho Salmon ESU, and there is no genetic evidence to suggest that these populations resulted from transfers of out-of-ESU stocks.
- (2) The BRT concluded that interpretation of historical records (or lack thereof) must be done in the appropriate historical context. Scientific surveys of fish faunas in coastal watersheds in California, including the Central Coast region, were virtually nonexistent prior to 1895, when the Stanford-led Carmel River Expedition surveyed streams between the Carmel River and San Gregorio Creek. This survey produced juvenile coho salmon from four different watersheds in the region between Santa Cruz and the Golden Gate, firmly establishing their presence in Central Coast watersheds prior to any known stocking of coho salmon in the region.
- (3) The petitioner’s interpretation of the writings of David Starr Jordan attributes a precision and accuracy to Jordan’s early descriptions of species’ ranges that the BRT concludes is not supported by the available scientific data or scientific understanding during the late 1800s. The extent of faunal surveys in coastal watersheds of California, including the region between Santa Cruz and the Golden Gate, was insufficient for scientists of that era to precisely define species’ range ranges. Further, the ample evidence of confusion in the taxonomy and nomenclature of Pacific salmonids prior to 1910—particularly the confusion between chum and coho salmon—strongly indicates that these early descriptions of species’ ranges must be interpreted with considerable caution.
- (4) Numerous historical records, both scientific and popular, clearly indicate that, in addition to steelhead, at least one species of Pacific salmon regularly occurred in watersheds south of the Golden Gate in numbers sufficient to support both commercial and recreational fisheries. Given current understanding of the ecological requirements, habitat preferences, and historical distributions of the five Pacific salmon species, the BRT concluded that coho salmon are the most likely candidate to have consistently occupied these watersheds. Although it is possible that Chinook salmon also occurred in streams south of the Golden Gate, it is improbable that local watersheds would have supported Chinook salmon populations but not coho salmon populations.

(5) The BRT concluded that historical environmental conditions in the Santa Cruz Mountains were almost certainly conducive to the presence of persistent coho salmon populations in the region, as these conditions are not appreciably different from watersheds immediately to the north where the historical occurrence of coho salmon is not in dispute. Substantial modification of streams by intensive logging and other human developments began in the mid-1800s and likely resulted in substantial reductions or extirpation of local coho salmon populations prior to the first scientific explorations.

(6) Although at the time the petition and addendum were submitted archaeological studies had failed to detect coho salmon in coastal areas south of the entrance to San Francisco Bay, new archaeological evidence from Año Nuevo clearly establishes the presence of coho salmon in close proximity to Waddell and Gazos creeks. Additional archaeological evidence suggests the presence of coho salmon at Elkhorn Slough near the mouth of the Salinas and Pajaro rivers and perhaps even as far south as Santa Barbara. The BRT recognized that one cannot rule out the possibility that coho salmon remains in middens at Año Nuevo and the apparent remains at Elkhorn Slough were ocean-caught fish or fish that were imported to the area from elsewhere through trade. Nevertheless, the archaeological record for occurrence of coho salmon south of the Golden Gate is now as strong as it is north of San Francisco Bay.

(7) The BRT was not persuaded by the petitioner's argument that populations south of the Golden Gate consisted entirely of ephemeral or "sink" populations and, therefore, these populations could not contribute to the evolutionary legacy of the ESU. Based on the amount and characteristics of stream habitats in the Santa Cruz Mountains, the BRT concurred with the TRT's conclusion that certain populations within the region had a high probability of persisting at time scales of 100 years or more (Bjorkstedt et al. 2005). Further, the BRT believes that, in concluding that ephemeral or sink populations could not contribute to the evolutionary legacy, the petitioner is incorrectly applying the evolutionary legacy criterion to *individual populations*, rather than to the ESU as a whole. Consequently, even if the petitioner's assertion about the ephemeral nature of south-of-San Francisco populations is correct, this does not mean that these populations contribute nothing to the evolutionary legacy of the ESU. Current understanding of metapopulation function indicates that (1) a persistent metapopulation may consist entirely of ephemeral populations, and (2) sink populations can play important roles in metapopulation persistence. In addition, the BRT notes that populations at the edge of a species range frequently are subjected to unique environmental conditions to which they may develop adaptive traits that are unique to the species. Marginal populations are therefore potentially extremely important parts of the evolutionary legacy of the ESU and of the species as a whole.

The BRT then discussed whether the available ecological and biological evidence supports the current ESU boundary at the San Lorenzo River. The BRT unanimously concluded there was no strong ecological or biological justification for the current ESU boundary. As discussed in Section 2, the 1994 BRT recognized that streams draining the Santa Cruz Mountains formed a cohesive group with respect to environmental conditions and concluded that the historical distribution of coho salmon likely extended into tributaries of the Pajaro River that drain the Santa Cruz Mountains. The decision to delineate the southern boundary at the San Lorenzo River was based in part on the absence of recent (at that time) documented occurrences of coho salmon

in watersheds south of the San Lorenzo River. The current BRT concurred with the 1994 BRT's conclusion that there is no strong ecological reason that the distribution of coho salmon would have stopped at the San Lorenzo River; there is no significant ecological break before the southern edge of the Santa Cruz Mountains, which marks the transition from the Coast Range ecoregion to the Southern and Central California Chaparral and Oak Woodlands ecoregion. The Soquel Creek and Aptos Creek watersheds are both in close proximity to the San Lorenzo River (6.5 and 10 km to the south, respectively), and historically shared many habitat characteristics with similar-sized coho salmon-bearing watersheds to the north. The BRT believed it highly unlikely that coho salmon populations would have been present only in the San Lorenzo and other watersheds to the immediate north (i.e., San Vicente, Scott, Waddell, and Gazos creeks), but not in Soquel or Aptos creeks. Recent (2008) observations of juvenile coho salmon in Soquel Creek (see Section 6) confirm successful reproduction by coho salmon in this watershed, and genetic evidence indicates these coho salmon (1) showed clear genetic affinity to other populations in region south of the Golden Gate, and (2) were the product of a minimum of two reproductive events. These observations strongly support including Soquel Creek watershed within the ESU boundary. The close proximity and environmental similarity between Soquel and Aptos creeks suggest that Aptos Creek should likely be included as well, especially considering the likelihood of coho salmon straying into these watersheds from populations to the immediate north. While the BRT believes that Pajaro River tributaries draining the Santa Cruz Mountains (e.g., Corralitos Creek and perhaps others) may have also supported coho salmon, the lack of historical or recent evidence of naturally occurring coho salmon in this watershed makes inclusion of these streams within the ESU more difficult to justify. The BRT concludes, however, that any coho salmon found spawning in Santa Cruz Mountain streams south of Aptos Creek that were not the result of stock transfers should be considered part of this ESU.

10. References

- Adams, P.B., Botsford, L.W., Gobalet, K.W., Leidy, R.A., McEwan, D.R., Moyle, P.B., Smith, J.J., Williams, J.G., and Yoshiyama, R.M. 2007. Coho salmon are native south of San Francisco Bay: a reexamination of North American coho salmon's southern range limit. *Fisheries* 32(9): 441–451.
- Baird, S.F. 1874. Report of the Commissioner for 1872 and 1873. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Bean, T.H. 1896. Report on the propagation and distribution of food-fishes. Pages 20–80 *In* Report of the Commissioner for the year ending June 30, 1894. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Benda, L.E., Miller, D.J., Dunne, T., Reeves, G.H., and Agee, J.K. 1998. Dynamic landscape systems. Pages 261–288 *In* R.J. Naiman and R.E. Bilby (editors). *River ecology and management: lessons from the Pacific Coastal Ecoregion*. Springer, New York.
- Berryman, A.A. 2002. Population: a central concept for ecology? *Oikos* 97(3): 439–442.
- Bilby, R.E., and Bisson, P.A. 1998. Function and distribution of large woody debris. Pages 324–346 *In* R.J. Naiman and R.E. Bilby (editors). *River ecology and management: lessons from the Pacific Coastal Ecoregion*. Springer, New York.
- Bilton, H.T., Morley, R.B., Coburn, A.S., and Van Tyne, J. 1984. The influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity; results of releases from Quinsam River Hatchery, B.C., in 1980. Canadian Technical Report of Fisheries and Aquatic Sciences 1306. Nanaimo, BC: 98 p.
- Bisson, P.A., Nielsen, J.L., Ward, J.W. 1988. Summer production of coho salmon stocked in Mount St. Helens streams 3–6 years after the 1980 eruption. *Transactions of the American Fisheries Society* 117(4): 322–335.
- Bisson, P.A., Reeves, G.H., Bilby, R.E., and Naiman, R.J. 1997. Watershed management and Pacific salmon: desired future conditions. Pages 447–474 *In* D.J. Stouder, P.A. Bisson, and R.J. Naiman (editors). *Pacific salmon and their ecosystems: status and future options*. Chapman and Hall, New York.
- Bjorkstedt, E.P., Spence, B.C., Garza, J.C., Hankin, D.G., Fuller, D., Jones, W.E., Smith, J.J., and Macedo, R. 2005. An analysis of historical population structure for evolutionarily significant units of Chinook salmon, coho salmon, and steelhead in the North–Central California Coast Recovery Domain. NOAA Technical Memorandum NMFS-SWFSC-382. 210 p.
- Bjornn, T.C., and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. Pages 83–138 *In* W.R. Meehan, editor. *Influences of forest and rangeland management on salmonid*

fishes and their habitats. American Fisheries Society Special Publication No. 19, Bethesda, Maryland.

- Böhlke, J. 1953. A catalogue of the type specimens of recent fishes in the natural history museum of Stanford University. *Stanford Ichthyological Bulletin* 5: 1–167.
- Bowers, G.M. 1906. The propagation and distribution of food-fishes. Bureau of Fisheries Document No. 602, 64 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1905 and special papers. Government Printing Office, Washington, D.C.
- Bowers, G.M. 1907. The distribution of food fishes during the fiscal year 1906. Bureau of Fisheries Document No 613, 78 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1906 and special papers. Government Printing Office, Washington, D.C.
- Bowers, G.M. 1908. The distribution of fish and fish eggs during the fiscal year 1907. Bureau of Fisheries Document No 630, 78 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1907 and special papers. Government Printing Office, Washington, D.C.
- Bowers, G.M. 1909. The distribution of fish and fish eggs during the fiscal year 1908. Bureau of Fisheries Document No 644, 93 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1908 and special papers. Government Printing Office, Washington, D.C.
- Bowers, G.M. 1910. The distribution of fish and fish eggs during the fiscal year 1909. Bureau of Fisheries Document No 728, 103 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1909 and special papers. Government Printing Office, Washington, D.C.
- Bowers, G.M. 1911. The distribution of fish and fish eggs during the fiscal year 1910. Bureau of Fisheries Document No 740, 112 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1910 and special papers. Government Printing Office, Washington, D.C.
- Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. *Canadian Journal of Fisheries and Aquatic Sciences* 52(6): 1327–1338.
- Brett, J.R. 1952. Temperature tolerance of young Pacific salmon, genus *Oncorhynchus*. *Journal of the Fisheries Research Board of Canada* 9(6): 265–323.
- Brown, B. 2008. The California Powder Works and San Lorenzo Paper Mill: self-guided tour. Paradise Park Masonic Club, Santa Cruz, CA. (Excerpts available online at <http://www.santacruzpl.org/history/articles/511/>)
- Brown, J.H., Stevens, G.C., and Kaufman, D.M. 1996. The geographic range: size, shape, boundaries, and internal structure. *Annual Review of Ecology and Systematics* 27: 597–623.
- Bryant, G.J. 1994. Status review of coho salmon populations in Scott and Waddell Creeks, Santa Cruz County, California. National Marine Fisheries Service, Southwest Region, Protected Species Management Division, Santa Rosa, CA. April 1994, 104 p.

- Buchal, J.L. 2005. Petition to redefine southern boundary of Central California Coho ESU. (email dated 5 December 2005 from James L. Buchal, Murphy & BuchalLLP, Portland OR, to Russ Strach, Assistant Regional Administrator for Protected Resources, NMFS Southwest Region, Sacramento, CA.
- Bucklin, K.A., Banks, M.A., and Hedgecock, D. 2007. Assessing genetic diversity of protected coho salmon (*Oncorhynchus kisutch*) populations in California. *Canadian Journal of Fisheries and Aquatic Sciences* 64(1): 30–42.
- California State Legislature. 1889. Chapter LXV. An Act to amend an Act entitled “An Act to establish a Penal Code,” approved February 14, 1872, relating to the depositing of sawdust in the waters of this state [Approved March 4 1889]. Twenty-eighth session of the State Legislature, pp. 61–62.
- Camus, P.A., and Lima, M. 2002. Populations, metapopulations, and the open-closed dilemma: the conflict between operation and natural population concepts. *Oikos* 97(3): 433– 438.
- Cavalli-Sforza, L. and Edwards, A. 1967. Phylogentic analysis: models and estimation procedures. *American Journal of Human Genetics* 19:233–257.
- CBFGC (California Board of Fish and Game Commissioners). 1910. Twenty-first biennial report of the Board of Fish and Game Commissioners of the State of California for the years 1909–1910. State Printing Office, Sacramento, CA.
- CDFG (California Fish and Game Commission). 1929. Thirtieth biennial report for the years 1926–1928. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Division of Fish and Game). 1931. Thirty-first biennial report of the Division of Fish and Game for the years 1928–1930. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Division of Fish and Game). 1932. Thirty-second biennial report of the Division of Fish and Game for the years 1930–1932. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Division of Fish and Game). 1934. Thirty-third biennial report of the Division of Fish and Game for the years 1932–1934. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1936. Thirty-fourth biennial report of the Division of Fish and Game for the years 1934–1936. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.

- CDFG (California Department of Fish and Game). 1938. Thirty-fifth biennial report of the Division of Fish and Game for the years 1936–1938. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1940. Thirty-sixth biennial report of the Division of Fish and Game for the years 1938–1940. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1944a. Thirty-seventh biennial report of the Division of Fish and Game for the years 1940–1942. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1944b. Thirty-eighth biennial report of the Division of Fish and Game for the years 1942–1944. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1946. Thirty-ninth biennial report of the Division of Fish and Game for the years 1944–1946. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1948. Fortieth biennial report of the Division of Fish and Game for the years 1946–1948. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1950. Forty-first biennial report of the Division of Fish and Game for the years 1948–1950. California Department of Natural Resources, Division of Fish and Game. State Printing Office, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1953. Forty-second biennial report of the Department of Fish and Game for the years 1950–1952. California Department of Fish and Game, Sacramento, CA.
- CDFG (California Department of Fish and Game). 1958. Biennial report of the California Department of Fish and Game 45. 1956–1958. California Department of Fish and Game, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1913. Fish and Game Commission twenty-second biennial report for the years 1910–1912. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1914. Fish and Game Commission twenty-third biennial report for the years 1912–1914. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1916. Fish and Game Commission twenty-fourth biennial report for the years 1914–1916. State Printing Office, Sacramento, CA.

- CFGC (California Fish and Game Commission). 1918. Fish and Game Commission twenty-fifth biennial report for the years 1916–1918. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1921. Fish and Game Commission twenty-sixth biennial report for the years 1918–1920. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1923. Fish and Game Commission twenty-seventh biennial report for the years 1920–1922. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1924. Fish and Game Commission twenty-eighth biennial report for the years 1922–1924. State Printing Office, Sacramento, CA.
- CFGC (California Fish and Game Commission). 1927. Fish and Game Commission twenty-ninth biennial report for the years 1924–1926. State Printing Office, Sacramento, CA.
- Chamberlain, F.M. 1907. Some observations on salmon and trout in Alaska. Bureau of Fisheries Document No. 627, 112 p. + plates. *In* Report of the Commissioner of Fisheries for the fiscal year 1906 and special papers. Government Printing Office, Washington, D.C.
- Chamberlain, T.W., Harr, R.D., and Everest, F.H. 1991. Timber harvesting, silviculture, and watershed processes. Pages 181–205 *In* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19, Bethesda, Maryland.
- Chartrand, S., Hecht, B., and Shaw, D. 2003. Soquel Creek watershed assessment: geomorphology and baseflow hydrology. Report prepared by Balance Hydrologics, Inc. for the Santa Cruz County Resource Conservation District, Capitola, CA. 89 p. + tables and figures.
- Cobb, J.N. 1911. The salmon fisheries of the Pacific Coast. Bureau of Fisheries Document No. 751, 179 p. *In* Report of the Commissioner of Fisheries for the fiscal year 1910 and special papers. Government Printing Office, Washington, D.C.
- Cobb, J.N. 1921. Pacific salmon fisheries. Appendix 1 to the report of the Commissioner of U.S. Fisheries. Bureau of Fisheries Document No. 902. Government Printing Office, Washington, D.C. 268 p.
- Dayes, C. 1987. Fish hatchery operations in Santa Cruz County: historical references to the Big Creek and Brookdale hatcheries. Prepared for the Monterey Bay Salmon and Trout Project. (Available at McHenry Library, Special Collections, University of California at Santa Cruz.)
- Dunn, H.D. 1880. Do the spawning salmon ascending the Sacramento River all die without returning to the sea? (Letter from Dunn to Prof. Spencer F. Baird dated September 26, 1876, with comments by Livingston Stone). Pages 815–818 *In* Part VI. Report of the Commissioner for 1878. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.

- Dunn, J.R. 1996. Charles Henry Gilbert (1859-1928): an early fishery biologist and his contributions to the knowledge of Pacific salmon (*Oncorhynchus* spp.). *Reviews in Fisheries Science* 4(2): 133–184.
- Ebersole, J.L., Colvin, M.E., Wigington, P.J., Leibowitz, S.G., Baker, J.P., Church, M.R., Compton, J.E., Cairns, M.A. 2009. Hierarchical modeling of late-summer weight and summer abundance of juvenile coho salmon across a stream network. *Transactions of the American Fisheries Society* 138(5): 1138–1156.
- Ebersole, J.L., Wigington, P.J., Baker, J.P., Cairns, M.A., Church, M.R., Hansen, B.P., Miller, B.A., LaVigne, H.R., Compton, J.E., Leibowitz, S.G. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. *Transactions of the American Fisheries Society* 135(6): 1681–1697.
- Ehrlich, P., and Roughgarden, J. 1987. *The science of ecology*. Macmillan Publishing Company, New York. 612 p.
- Elliott, W.W. 1879. *Santa Cruz County California. Illustrations with historical sketch of the County*. Indexed edition. The Museum of Art and History at the McPherson Center. Santa Cruz, CA.
- EPA (Environmental Protection Agency). 2007. Level III ecoregions of the continental United States. Map produced by National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency. (Available at EPA Western Ecology Division http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm)
- Evermann, B.W., and Clark, H.W. 1931. A distributional list of the species of freshwater fishes known to occur in California. Division of Fish and Game of California, *Fish Bulletin* No. 35. 67 p.
- Flagg, T.A., Waknitz, F.W., Maynard, D.J., Milner, G.B., and Mahnken, C.V.W. 1995. Impacts of hatcheries on native coho salmon populations in the lower Columbia River. *American Fisheries Society Symposium* 15: 366–357.
- Foley, P. 1994. Predicting extinction times from environmental stochasticity and carrying capacity. *Conservation Biology* 8(1): 124–137.
- Foley, P. 1997. Extinction models for local populations. Pages 215–246 *In* I.A. Hanski and M.E. Gilpin (editors). *Metapopulation biology: ecology, genetics, evolution*. Academic Press, San Diego, CA.
- Ford, M.J., Teel, D., Van Doornik, D.M., Kuligowski, D., and Lawson, P.W. 2004. Genetic population structure of central Oregon Coast coho salmon (*Oncorhynchus kisutch*). *Conservation Genetics* 5(6): 797–812.

- Furniss, M.J., Roelofs, T.D., and Yee, C.S. 1991. Road construction and maintenance. Pages 297–323 *In* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19, Bethesda, Maryland.
- Gaston, J. 1911. Portland, Oregon, its history and builders: in connection with the antecedent explorations, discoveries and movement of the pioneers that selected the site for the great city of the Pacific. Volume III. The S.J. Clarke Publishing Co., Chicago-Portland.
- Gilbert, C.H. 1912. Age at maturity of the Pacific Coast salmon of the genus *Oncorhynchus*. (Document 767, issued 20 March 1913). Bulletin of the Bureau of Fisheries 32: 1–22 + plates.
- Gobalet, K.W. 1990. Prehistoric status of freshwater fishes of the Pajaro-Salinas River system of California. *Copeia*. 1990(3): 680–685.
- Gobalet, K.W., and Jones, T. L. 1995. Prehistoric Native American Fisheries of the Central California Coast. *Transactions of the American Fisheries Society*. 124(6): 813–823
- Gobalet, K.W., Schulz, P.D., Wake, T.A., and Siefkin, N. 2004. Archaeological perspectives on Native American fisheries of California, with emphasis on steelhead and salmon. *Transactions of the American Fisheries Society*. 133(4): 801–833
- Gobalet, K.W. *In press*. A native Californian's meal of coho salmon (*Oncorhynchus kistutch*) has legal consequences for conservation biology. *In* M.A. Glassow and T.L. Joslin (editors). Exploring methods of faunal analysis: perspectives from California archaeology. Cotsen Institute of Archaeology Press, University of California, Los Angeles.
- Good, T.P, Waples, R.S., and P. Adams, P. (editors). 2005. Updated status of federally listed ESUs of west coast salmon and steelhead. NOAA Technical Memorandum NMFS-NWFSC-66: 598 p.
- Grimes, C.B. 2004. Memorandum dated 16 July 2004 from C.B. Grimes (Director, NMFS Southwest Fisheries Science Center, Santa Cruz Laboratory) to William Fox (Director, NMFS Southwest Fisheries Science Center, La Jolla, CA) regarding reconsideration of the status of coho salmon south of San Francisco. (AR 053).
- Grimes, C.B. 2005. Memorandum dated 17 March 2005 from C.B. Grimes (Director, NMFS Southwest Fisheries Science Center, Santa Cruz Laboratory) to R. McGinnis (Regional Administrator, NMFS Southwest Region, Long Beach, CA) regarding coho salmon south of San Francisco. (AR 067).
- Gustafson, R.G., Waples, R.S., Myers, J.M., Weitkamp, L.A., Bryant, G.J., Johnson, O.W., and Hard, J.J. 2007. Pacific salmon extinctions: quantifying lost and remaining diversity. *Conservation Biology* 21(4): 1009–1020.

- Hallock, G. 1873. The fishing tourist: angler's guide and reference book. Harper & Brothers, Franklin Square, New York.
- Hallock, G. 1877. The sportsman's gazetteer and general guide. Forest and Stream Publishing Company, New York.
- Hanski, I. 1994. A practical model of metapopulation dynamics. *Journal of Animal Ecology* 63(1): 151–162.
- Hanski, I., and Gaggiotti, O.E. (editors). 2004. Ecology, genetics, and evolution of metapopulations. Elsevier Academic Press, Burlington, MA.
- Hard, J.J., Cope, R.G., Grant, W.S., Waknitz, F.W., Parker, L.T., and Waples, R.S. 1996. Status review of pink salmon from Washington, Oregon, and California. U. S. Department of Commerce, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-NWFSC-25: 131 p.
- Harvey, B.C., Nakamoto, R.J., White, J.L. 1999. The influence of large woody debris and a bankfull flood on movement of adult resident coastal cutthroat trout during fall and winter. *Canadian Journal of Fisheries and Aquatic Sciences* 56(11): 2161–2166.
- Healey, M.C. 1991. Life history of Chinook salmon. Pages 310–393. *In* C. Groot and L. Margolis (editors). Pacific salmon and their ecosystems. UBC Press, Vancouver, British Columbia.
- Hedgecock, D., Banks, M., Bucklin, K., Dean, C.A., Eichert, W., Greig, C., Siri, P., Nyden, B., and Watters, J. 2002. Documenting biodiversity of coastal salmon (*Oncorhynchus* spp.) in northern California. University of California at Davis, Bodega Marine Laboratory, Bodega Bay, CA.
- Howe, R.W., and Davis, G.J. 1991. The demographic significance of “sink” populations. *Biological Conservation* 57(3): 239–255.
- Johnson, O.W., Grant, W.S., Kope, R.G., Neely, K., Waknitz, F.W., and Waples, R.S. 1997. Status review of chum salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-32. 280 p.
- Johnston, P.D. 1973. Aptos and the mid-Santa Cruz County area from the 1890s through World War II. Interviewed and edited by Elizabeth Spedding Calciano. University of California Santa Cruz Library. (Available online at <http://library.ucsc.edu/reg-hist/johnston>).
- Jordan, D.S. 1884a. The salmon of the Pacific. Pages 474–479 *In* G.B. Goode (ed), The fisheries and fishery industries of the United States. Section I. Natural history of useful aquatic animals. Government Printing Office, Washington, D.C.

- Jordan, D.S. 1884b. Manual of the vertebrates of the northern United States including the district east of the Mississippi River, and north of North Carolina and Tennessee, exclusive of marine species. Jansen, McClurg & Company. Chicago.
- Jordan, D.S. 1887. The fisheries of the Pacific Coast. Pages 589–629 *In* G.B. Goode (editor). The fisheries and fishery industries of the United States. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Jordan, D.S. 1892. Salmon and trout of the Pacific Coast. Pages 44–58 *In* Biennial report of the State Board of Fish Commissioners of the State of California for the years 1891–1892. State Printing Office, Sacramento, CA.
- Jordan, D.S. 1894. Salmon and trout of the Pacific Coast. Pages 125–141 *In* Thirteenth Biennial Report of the State Board of Fish Commissioners of the State of California for the years 1893–1894. State Printing Office, Sacramento, CA.
- Jordan, D.S. 1904a. The parent-stream theory of the return of salmon. Pages 98–102 *In* Eighteenth Biennial report of the State Board of Fish Commissioners of the State of California for the years 1903–1904. State Printing Office, Sacramento, CA.
- Jordan, D.S. 1904b. Pacific species of salmon and trout. Pages 75–97 *In* Eighteenth Biennial report of the State Board of Fish Commissioners of the State of California for the years 1903–1904. State Printing Office, Sacramento, CA.
- Jordan, D.S. 1907. Fishes. Henry Holt and Company. New York.
- Jordan, D.S. 1922. The days of a man: being memories of a naturalist, teacher, and minor prophet of democracy, volume one, 1851–1899. World Book Company, Yonkers-on-Hudson, NY.
- Jordan, D.S., and Evermann, B.W. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, North of the Isthmus of Panama. Bulletin of the United States National Museum No. 47. Government Printing Office, Washington, D.C.
- Jordan, D.S., and Evermann, B.W. 1902. American food and game fishes. A popular account of all the species found in America north of the equator, with keys for the ready identification, life-histories and methods of capture. Doubleday, Page & Co. New York. (reprinted in 1903, 1904, 1905, and 1908).
- Jordan, D.S., and Gilbert, C.H. 1881. Notes on the fishes of the Pacific coast of the United States. Proceeding of the United States National Museum 4: 29–70.
- Jordan, D.S., and Gilbert, C.H. 1882. Synopsis of the fishes of North America. Bulletin of the United States National Museum No. 16. Government Printing Office, Washington, D.C.

- Kaczynski, V.W., and Alvarado, F. 2006. Assessment of the southern range limit of North American coho salmon: difficulties in establishing natural range boundaries. *Fisheries* 31(8): 374–391.
- Koch, M. 1973. *Santa Cruz County, parade of the past*. Valley Publishers, Fresno, CA.
- Kuussaari, M., Bommarco, R., Heikkinen, R.K., Helm, A., Krauss, J., Lindborg, R., Ockinger, E., Partel, M., Pino, J., Roda, F., Stefanescu, C., Teder, T., Zobel, M., and Steffan-Dewenter, I. 2009. Extinction debt: a challenge for biodiversity conservation. *Trends in Ecology & Evolution* 24(10): 564–571.
- Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. *American Naturalist* 142(6): 911–927.
- Lehmann, S. 2000. Economic development of the city of Santa Cruz 1850–1950. Pages 10–14 *In* Fully developed context statement for the City of Santa Cruz. Prepared for City of Santa Cruz Planning and Development Department. Santa Cruz, CA. (Available online at <http://scplweb.santacruzpl.org/history/work/edindtan.shtml>).
- Leidy, R.A., Becker, G., and Harvey, B.N. 2005. Historical status of coho salmon in streams of the urbanized San Francisco estuary, California. *California Fish and Game* 91(4): 219–254
- Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bulletin of the Entomological Society of America* 15(3): 237–240.
- Lichatowich, J. A. and J.D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. Pages 131–136 *In* M.J. Dadswell, R.J. Klauda, C.M. Moffitt, R.L. Saunders, R.A. Rulifson, and J.E. Cooper (editors). *Common strategies of anadromous and catadromous fishes*. American Fisheries Society Symposium 1. Bethesda, Maryland.
- Lockington, W.N. 1880. Report on the edible fishes of the Pacific Coast, U.S.A. Pages 16–66 *In* Report of the Commissioners of Fisheries of the State of California for the year 1880.
- Lockington, W.N. 1882. Sketch of the progress of North American ichthyology in the years 1880–1881. *The American Naturalist* 16(10): 765–772.
- MacArthur, R.H. and Wilson, E.O. 1963. An equilibrium theory of insular zoogeography. *Evolution* 17(4): 373–387.
- MacArthur, R.H. and Wilson, E.O. 1967. *The theory of island biogeography*. Princeton University Press, Princeton, New Jersey.
- Madej, M.A., Currens, C., Ozaku, V., Yee, J., and Anderson, D.G. 2006. Assessing possible thermal rearing restrictions for juvenile coho salmon (*Oncorhynchus kisutch*) through thermal infrared imaging and in-stream monitoring, Redwood Creek, California. *Canadian Journal of Fisheries and Aquatic Sciences* 63(6): 1384–1396.

- McCrary, H.T. 2003. Petition to redefine the southern extent of the Central California Coho ESU. (Letter dated 23 November 2003 to R. McInnis, Acting Regional Administrator, NOAA Fisheries, Southwest Region, Long Beach, CA).
- McCrary, H.T. 2004. Addendum to the petition to redefine the southern extent of the Central California Coho ESU, submitted to NOAA Fisheries on November 6, 2003. (Letter dated 6 February 2004 to R. McGinnis, Acting Regional Administrator, NOAA Fisheries, Southwest Region, Long Beach, CA).
- McCrary, H.T. 2005. Response to the NOAA Fisheries, Santa Cruz Laboratory's second review of the November 6, 2003 petition from Homer T. McCrary concerning coho salmon south of San Francisco. (Letter dated 10 May 2005 to R. McGinnis, NOAA Fisheries, Southwest Region, Long Beach, CA.).
- McCrary, H.T., Alvarado, F., and Briggs, R.O. 2004. Response to the NOAA Fisheries, Santa Cruz Laboratory review of the November 6, 2003 petition from Homer T. McCrary concerning coho salmon south of San Francisco. (Letter to dated 18 October 2004 to R. McGinnis, Regional Administrator, NOAA Fisheries, Southwest Region, Long Beach, CA.).
- McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt E.P. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. NOAA Technical Memorandum NMFS-NWFSC-42. 156 p.
- McGeer, J.C., Baranyi, L., and Iwama, G.K. 1991. Physiological responses to challenge tests in six stocks of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 48(9): 1761–1771.
- Meengs, C.C., and Lackey, R.T. 2005. Estimating the size of historical Oregon salmon runs. Reviews in Fisheries Science 13(1): 51–66.
- Milliman, J.D., and Syvitski, J.P.M. 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountain rivers. The Journal of Geology 100: 524–544.
- Moritz, C. 1994. Defining 'evolutionary significant units' for conservation. Trends in Ecology and Evolution 9(10): 373–375.
- Moritz, C., Lavery, S. and Slade, R. 1995. Using allele frequency and phylogeny to define units for conservation and management. Pages 249–262 In J. L. Nielsen (editor). Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17. Bethesda, Maryland.
- Moyle, P.B. 2002. Inland fishes of California. University of California Press.
- Mueter, F.J., Ware, D.M., and Peterman, R.M. 2002a. Spatial correlation patterns in coastal environmental variables and survival rates of salmon in the north-east Pacific Ocean. Fisheries Oceanography 11(4): 205–218.

- Mueter, F.J., Peterman, R.M., and Pyper, B.J. 2002b. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (*Oncorhynchus* spp.) in northern and southern areas. *Canadian Journal of Fisheries and Aquatic Sciences* 59(3): 456–463.
- Neave, F. 1958. The origin and speciation of *Oncorhynchus*. *Transactions of the Royal Society of Canada* 52: 25–39.
- Nickelson, T. E., and Lawson, P.W. 1998. Population viability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: application of a habitat-based life cycle model. *Canadian Journal of Fisheries and Aquatic Science* 55(11): 2382–2392.
- NMFS (National Marine Fisheries Service). 1996. Status review update for coho salmon from Washington, Oregon, and California. Draft document prepared by the West Coast Coho salmon Biological Review Team, 20 December 1996, 47 p. plus tables, figures, and appendices.
- Omernik, J.E. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77(1): 118–125.
- Payne, S.M. 1978. A howling wilderness: the Summit Road area of the Santa Cruz Mountains 1850–1906. Loma Prieta Publishing Co., Santa Cruz, CA.
- Pearse, D.E., Martinez, E., and Garza, J.C. *In press*. Disruption of historical patterns of isolation by distance in coastal steelhead. *Conservation Genetics*. Advance issue published online on 28 December 2010, DOI: 10.1007/s10592-010-0175-8.
- Pulliam, H.R. 1988. Sources, sinks, and population regulation. *American Naturalist* 132: 652–661.
- Quinn, T.P. 1984. Homing and straying in Pacific salmon. Pages 357–362 in J. D. McCleave, G.P. Arnold, J.J. Dodson, and W.H. Neil, editors. *Mechanisms of migration in fish*. Plenum, New York.
- Quinn, T.P. 1993. A review of homing and straying of wild and hatchery-produced salmon. *Fisheries Research* 18: 29–44.
- Quinn, T.P. 2005. *The behavior and ecology of Pacific salmon and trout*. University of Washington Press, Seattle.
- Ravenel, W. de C. 1896. Report on the propagation and distribution of food-fishes. Pages 6–72 *In Report of the Commissioner for the year ending June 30, 1895*. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Ravenel, W. de C. 1898. Report on the propagation and distribution of food-fishes. Pages XVIII–CXXIV *In Report of the Commissioner for the year ending June 30, 1897*. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.

- Ravenel, W. de C. 1902. Report on the propagation and distribution of food-fishes. Pages 21–110 *In* Report of the Commissioner for the year ending June 30, 1901. United States Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Redding, B.B., Throckmorton, S.R., and Farwell, J.D. 1872. Report of the Commissioners of Fisheries of the State of California for the years 1870 and 1871. State Printing Office, Sacramento, CA.
- Redding, B.B., Wilson, R.E., and Morizio, J. 1892. Biennial report of the State Board of Fish Commissioners for the years 1891–1892. State Printing Office, Sacramento, CA.
- Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., and Sedell, J.R. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Pages 334–349 *In* J. L. Nielsen (editor). Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17. Bethesda, Maryland.
- Reisenbichler, R.R. 1988. Relation between distance transferred from natal stream and recovery rate for hatchery coho salmon. *N. Am. J. Fish. Manage.* 8: 172–174.
- Ricker, W.E. 1972. Heredity and environmental factors affecting certain salmonid populations. Pages 27–160 *in* R.C. Simon and P.A. Larkin (eds). The stock concept in Pacific salmon. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Institute of Fisheries, Vancouver.
- Rieman, B.E., and Dunham, J.B. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. *Ecology of Freshwater Fish* 9: 51–64.
- Rockwell, C.R. 1879. Salmon fishing on the Pacific. *Forest and stream: a journal of outdoor life, travel, nature study, shooting, fishing, yachting.* 13(13): 769.
- Rood, R.C. 1975. The historical geography and environmental impact of the lumber industry of the Santa Cruz Mountains. Senior thesis. University of California at Santa Cruz.
- Rumsey, G.L. 1994. History of early diet development in fish culture, 1000 B.C. to A.D. 1955. *Progressive Fish-Culturist* 56: 1–6.
- Rutter, C. 1902. Natural history of the quinnat salmon. A report of investigations in the Sacramento River, 1896–1901. *Bulletin of the U. S. Fish Commission* 22: 67–141.
- Saitou, N., and Nei, M. 1987. The neighbor-joining method: a new method for constructing phylogenetic trees. *Molecular Biology and Evolution* 4: 406–425.
- Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pages 231–309 *In* C. Groot and L. Margolis (editors). Pacific salmon and their ecosystems. UBC Press, Vancouver, British Columbia.

- Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 395–445 In C. Groot and L. Margolis (editors). Pacific salmon and their ecosystems. UBC Press, Vancouver, British Columbia.
- Sargent, C.S. 1881. Map of a portion of California showing the distribution of the redwood forests with special reference to the lumber industry. Department of Interior, Tenth Census of the United States (<http://www.redwood.forestthreats.org/range.htm>).
- SCCPD (Santa Cruz County Planning Department). 1993. Petition to list central California coast coho salmon as an endangered species. Petition to National Marine Fisheries Service, Southwest Region, 3 March 1993, 32 p. + attachments.
- Schindler, D.E., Hilborn, R., Chasco, B., Boatright, C.P., Quinn, T.P., Rogers, L.A., and Webster, M.S. 2010. Population diversity and the portfolio effect in an exploited species. *Nature* 465: 609–613.
- Scofield, N.B. 1916. The humpback and dog salmon taken in San Lorenzo River. *California Fish and Game Quarterly* 2(1): 41.
- Scudder, G.G.E. 1989. The adaptive significance of marginal populations: a general perspective. Pages 180–185 In C.D. Levings, L.B. Holtby, and M.A. Henderson (eds). Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105.
- Seeb L.W., Antonovich A., Banks M.A., Beacham T.D., Bellinger M.R., Campbell M., Decovich N.A., Garza J.C., Guthrie C.M., Moran P., Narum S.R., Stephenson J.J., Supernault K.J., Teel D.J., Templin W.D., Wenburg J.K., Young S.F., Smith C.T. 2007. Development of a standardized DNA database for Chinook salmon. *Fisheries* 32(11): 540–552.
- Shapovalov, L. and Taft, A.C. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game, Fish Bulletin No. 98: 303 p.
- Shebley, W.H. 1922. A history of fishcultural operations in California. *California Fish and Game* 8(2): 62–99.
- Snyder, J.O. 1907. The fishes of the coastal streams of Oregon and northern California. *Bulletin of the Bureau of Fisheries* 27: 153–189. (Bureau of Fisheries Document No. 638 issued October 21, 1908).
- Snyder, J.O. 1912. The fishes of streams tributary to Monterey Bay, California. *Bulletin of the United States Bureau of Fisheries* 32: 47–72. (Bureau of Fisheries Document 776, issued July 24, 1913).

- Snyder, J.O. 1931. Salmon of the Klamath River, California. Division of Fish and Game of California, Fish Bulletin No. 34.
- Spence, B.C., Harris, S.L., Jones, W.E., Goslin, M.N., Agrawal, A., and Mora, E. 2005. Historical occurrence of coho salmon in streams of the Central California Coast Coho Salmon Evolutionarily Significant Unit. NOAA Technical Memorandum NMFS-SWFSC-383. 80 p.
- Spence, B.C., Bjorkstedt, E. P., Garza, J.C., Smith, J.J., Hankin, D.G., Fuller, D., Jones, W.E. Macedo, R., Williams, T.H., and Mora, E. 2008. A framework for assessing the viability of threatened and endangered salmon and steelhead in the North-Central California Coast Recovery Domain. NOAA Technical Memorandum NMFS-SWFSC-423. 173 p.
- Spence, B.C., and Hall, J.D. 2010. Spatiotemporal patterns in migration timing of coho salmon (*Oncorhynchus kisutch*) smolts in North America. Canadian Journal of Fisheries and Aquatic Sciences 67: 1316–1334.
- Stenzel, F. 1972. Cleveland Rockwell: scientist and artist, 1837–1907. Schulz, Wack, and Weir. Portland, OR.
- Stone, L. 1880. Notes on letter of Mr. Horace D. Dunn to Prof. Spencer F. Baird, dated San Francisco, September 26, 1876. Pages 817-818 *In* Report of the Commissioner for 1878. U.S. Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Stone, G., Van Sicklen, F.W., Connell, M.J., Henshaw, W.G. 1910. Twenty-first biennial report of the Board of Fish and Game Commissioners of the State of California for the years 1909–1910. State Printing Office, Sacramento, CA.
- Streig, D. 1991. History of fish cultural activities in Santa Cruz County with reference to Scotts and Waddell creeks. Monterey Bay Salmon and Trout Project, Davenport, CA.
- Suckley, G. 1861. On the North American species of salmon and trout. Pages 92–160 *In* Report of the Commissioner, United States Commission on Fish and Fisheries, 1872–1873. (published 1873).
- Sutton, R., and Soto, T. *In press*. Juvenile coho salmon behavioural characteristics in Klamath River summer thermal refugia. River Research and Applications. Advance issue published online on 7 Oct 2010, DOI: 10.1002/rra.1459.
- SWRCB (State Water Resources Control Board). 1995. Order amending water rights and requiring changes in water diversion practices to protect fishing resources and to prevent unauthorized diversion and use of water. October 26, 1995. (available online at http://www.swrcb.ca.gov/waterrights/board_decisions/adopted_orders/orders/1995/wro95-17.pdf)

- Taft, A.C., and Shapovalov, L. 1938. Homing instinct and straying among steelhead trout (*Salmo gairdnerii*) and silver salmon (*Oncorhynchus kisutch*). California Fish and Game 24(2): 118–125.
- Tallman, R.F. and Healey, M.C. 1994. Homing, straying, and gene flow among seasonally separated populations of chum salmon (*Oncorhynchus keta*). Canadian Journal of Fisheries and Aquatic Sciences 51: 577–588.
- Taylor, E.B. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98: 185–207
- Thorne, R.E., and Ames, J.J. 1987. A note on variability of marine survival of sockeye salmon (*Oncorhynchus nerka*) and effects of flooding on spawning success. Canadian Journal of Fisheries and Aquatic Sciences 44: 1791–1795.
- Titcomb, J.W. 1905a. Report on the propagation and distribution of food fishes. Pages 29–74 *In* Report of the Commissioner for the year ending June 30, 1903. U.S. Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Titcomb, J.W. 1905b. Report on the propagation and distribution of food fishes. Pages 25–120 *In* Report of the Commissioner of Fisheries for the fiscal year ending June 30, 1904. U.S. Commission of Fish and Fisheries. Government Printing Office, Washington, D.C.
- Utter, F. 2001. Patterns of subspecific anthropogenic introgression in two salmonid genera. Reviews in Fish Biology and Fisheries 10: 265–279.
- Waples, R.S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Marine Fisheries Review 53(3): 11–22.
- WDFW (Washington Department of Fish and Wildlife) and WWTIT (Western Washington Treaty Indian Tribes). 1992. 1992 Washington State salmon and steelhead stock inventory. Appendix 1. Puget Sound Stocks, North Puget Sound Volume. WDFW, Olympia, WA.
- Weitkamp, L.A., Wainwright, T.C., Bryant, G.J., Milner, G.B., Teel, D.J., Kope, R.G., and Waples, R.S. 1995. Status review of coho salmon from Washington, Oregon, and California. U. S. Department of Commerce, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-NWFSC-24: 258 p.
- Welsh, H.H., Jr., Hodgson, G.R., Harvey, B.C., Roche, M.F. 2001. Distribution of juvenile coho salmon in relation to water temperatures in tributaries of the Mattole River, California. North American Journal of Fisheries Management 21: 464–470.
- Wydoski, R.S., and Whitney, R.R. 2003. Inland fishes of Washington. Second edition, revised and expanded. American Fisheries Society, Bethesda, MD in association with University of Washington Press., Seattle and London.

Yoshiyama, R.M., Gerstung, E.R., Fisher, F.W., and Moyle, P.B. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71–176 *In* R. L. Brown (editor). Contributions to the biology of Central Valley salmonids. Fish Bulletin 179, Volume I.

RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (<http://swfsc.noaa.gov>). Copies are also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (<http://www.ntis.gov>). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

- NOAA-TM-NMFS-SWFSC-462 Serious injury determinations for cetaceans caught in Hawaii longline fisheries during 1994-2008.
K.A. FORNEY
(October 2010)
- 463 Spawning biomass of Pacific sardine (*Sardinops sagax*) off the U.S. in 2010.
N.C.H. LO, B.J. MACEWICZ, and D.A. GRIFFITH
(October 2010)
- 464 Ecosystem survey of *Delphinus* species cruise report.
S.J. CHIVERS, W.L. PERRYMAN, N.M. KELLAR, J.V. CARRETTA,
F.I. ARCHER, J.V. REDFERN, A.E. HENRY, M.S. LYNN, C. HALL
A. JACKSON, G. SERRA-VALENTE, T.J. MOORE, C. SURREY-MARSDEN,
and L.T. BALLANCE
(October 2010)
- 465 Oregon, California and Washington line-transect and ecosystem (ORCAWALE) 2008 cruise report.
J. BARLOW, A.E. HENRY, J.V. REDFERN, T. YACK, A. JACKSON,
C. HALL, E. ARCHER, and L.T. BALLANCE
(October 2010)
- 466 A forward-looking scientific frame of reference for steelhead recovery on the south-central and southern California coast.
D.A. BOUGHTON
(October 2010)
- 467 Some research questions on recovery of steelhead on the south-central and southern California coast.
D.A. BOUGHTON
(October 2010)
- 468 Is the September 1 river return date approximation appropriate for Klamath River fall Chinook?
M.R. O'FARRELL, M.L. PALMER-ZWAHLEN and J. SIMON
(November 2010)
- 469 Assessment of the Pacific sardine resource in 2010 for U.S. management in 2011.
K.T. HILL, N.C.H. LO, B.J. MACEWICZ, P.R. CRONE, and
R. FELIX-URAGA
(December 2010)
- 470 AMLR 2009/10 Field Season Report.
A.M. VAN CISE, EDITOR
(December 2010)
- 471 Rationale for the 2010 revision of stock boundaries for the Hawai'i insular and pelagic stocks of false killer whales, *Pseudorca crassidens*.
K.A. FORNEY, R.W. BAIRD, and E.M. OLESON
(December 2010)