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Notes from the Editor

Another year has gone by, and another volume of *California Fish and Game* has been published and distributed to investigators around the world. During 2012, total pages numbered 244, as compared to the 220 pages making up Volume 97 (2011), and the 268 pages that made up Volume 96 (2010). Over the past three years, each volume of the journal has averaged roughly 250 pages. During that period, 53 manuscripts were submitted to be considered for publication, of which 41 were accepted and published and 12 were rejected. Thus, the overall rejection rate for manuscripts considered for publication in the last 3 volumes was roughly 23%. That figure can be expected to increase in the future, however, as more and more investigators submit their work to be considered for publication in California's longest-running professional journal, *California Fish and Game*.

In an effort to minimize expended resources, expand our readership, and decrease publication delays, the California Department of Fish and Wildlife's 100-year-old scientific journal is transitioning to on-line publication in 2013. Back issues continue to be archived on the journal's website (http://www.dfg.ca.gov/publications/journal/) and, in the forseeable future, we expect to have all back issues (up to the most current issue) available online.

As we transition to online publication, we will be phasing out our paid subscriptions. As of 2013, each forthcoming issue will be available online at no charge. Yes... you read it correctly: there will be no fee associated with individual, on-line subscriptions to the journal. Beginning with this issue (99[1], Winter 2013), *California Fish and Game* will be delivered to CDFW employees online only. All current paid subscribers will, however, continue to receive the traditional "hard copy" of the journal for the duration of their subscription. Additionally, a limited number of print copies will continue to be produced for libraries and other archival institutions.

More information on the process to follow to ensure that you continue to receive the journal will be available in the next issue, but additional time is needed to resolve all of the details associated with the transition to electronic distribution; as expected, the process has proven to be more complicated than originally was anticipated. As we move forward into the digital age, those of us that produce *California Fish and Game* thank you for your patience.

Vernon C. Bleich, *Editor-in-Chief*

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The native and introduced fishes of Clear Lake: a review of the past to assist with decisions of the future

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We reviewed the history of Clear Lake, California, and its fish community, including geology, limnology, aquatic biology, and human influences that have shaped the condition of the lake and the composition and abundance of native and introduced fish species. We summarized impacts experienced by the lake and its fish community, identified correlations between native fish abundance and non-native fish introductions and abundance, and described other human impacts. Causal relationships were difficult to ascertain from existing data, but we identified numerous research opportunities that would address these uncertainties, including: (1) field studies of Clear Lake hitch (*Lavinia exilicauda chi*) and largemouth bass (*Micropterus salmoides*) interactions; (2) field surveys to determine the current population dynamics of native fish species, including hitch, Sacramento blackfish (*Orthodon microlepidotus*), and Sacramento pikeminnow (*Ptychocheilus grandis*); (3) development of a hitch population dynamics model to explore the relative importance of potential bottlenecks in the species' life cycle; (4) development of a multi-species computer simulation model to bring together the existing knowledge about the Clear Lake ecosystem, and use of the model to simulate the results of management choices; (5) development of a watershed hydrology model, incorporating predictions of future climate through the 21st century, to predict how spring stream flows may change under climate change, and how this may affect hitch spawning access and timing; and, (6) conduct of a nation-wide survey of lake managers to identify management strategies that have been effective in delaying or halting the invasion of dreissenid mussels, and to discover how invasions have been addressed.

Key words: California, Clear Lake, environmental impacts, history, *Lavinia exilicauda chi*, management, *Micropterus salmoides*, native fishes, non-native fishes, *Orthodon microlepidotus*, *Ptychocheilus grandis*

Clear Lake, California, has complex and intertwined natural and human histories that span millennia. The lake, for which the Pomo Indian name is Lupiyoma (large water; Horne 1975[app]), is the largest natural lake located within the boundaries of California. The fish fauna of Clear Lake has changed drastically over the past 150 years, with declines in the abundance of all native fish species and the extirpation of some (Stone 1876, Jordan and Gilbert 1895, Bairrington 2000[app]), yet the causes of the decline of particular species remain uncertain. This uncertainty complicates discussion of which impacts should be addressed and which restoration actions should be given priority, and hampers the ability to restore native species effectively and efficiently.

Understanding past impacts to the fish species of Clear Lake is important not only to manage the present fish community but also to predict the impacts of future events, impacts, and management strategies. While there is a large body of literature regarding Clear Lake and its fishes, this information has not recently been compiled and synthesized to allow a comparison of the trends in abundance of native and non-native fish species with the pattern and timing of events that may have impacted the fish community from the time of European settlement to the present.

In this paper we provide a synthesis of events at Clear Lake and offer suggestions for future research that may inform lake and fishery management. Our hypothesis was that the patterns of decline in native fish species are correlated with patterns of human impacts, including non-native fish introductions and impacts to habitat. To address this question we identified five goals: (1) summarize the natural habitat features (e.g., climate, geochemistry, soils) of Clear Lake which may influence fish species; (2) summarize trends in native fish abundance; (3) summarize the human activities that may have impacted native fish species, including introductions of non-native fish species; (4) graphically determine correlations between native fish abundance, non-native fish abundance, and other human impacts; and, (5) suggest further research that may help to determine causal relationships and, in turn, assist in the development of management strategies to conserve native fishes.

Materials and Methods

We conducted an extensive literature search to gather information on the natural habitat features of Clear Lake and its watershed, native and non-native fish species, and human activities that may have impacted fishes. We determined the native and non-native fish species present in Clear Lake over time, and estimated the relative abundance of fishes. Data sources included peer-reviewed literature, agency reports and surveys, commercial catch records, California Department of Fish and Game field notes and memoranda, and verbal communications with stakeholders. We compiled a detailed chronology of events at Clear Lake, and graphically compared the trends in relative abundance of native and non-native fish species with the timing of occurrence of human impacts. We described the correlations we observed between native fish species abundance and human impacts, including non-native fish species introductions, in terms of potential causal relationships. We then identified research activities that would clarify causal relationships and guide future management actions.

Results

Natural habitat features.—Clear Lake is located 113 km north of the San Francisco Bay (39° 01' N, 122° 45' W), at an elevation of 396 m (Carpenter et al. 1931). The lake is approximately 27 km long and 2–10 km wide, with 114 km of shoreline (Carpenter et al. 1931, Bairrington 1999[app]). Total water storage capacity of the lake is 1.4 billion m^3 (Bairrington 1999[app]). Depending on lake elevation, the surface area of Clear Lake is 16,000–17,700 ha (Lindquist et al. 1943, Macedo 1991). Average depth of the lake has been reported to be between 6.5 and 8 m, with a maximum depth of 15–18 m (Lindquist et al. 1943, Macedo 1991).

Formation of the lake occurred about 2.5 million years ago (Macedo 1991) when a landslide blocked the Cold Creek outlet (Mauldin 1968). Rising water linked the upper and lower lake portions of Clear Lake (Mauldin 1968). Prior to this event, the upper portion of Clear Lake drained into the East Branch of the Russian River via Cold Creek (Mauldin 1968), while the lower portion of the lake flowed to Cache Creek and into the Sacramento River (Mauldin 1968). Clear Lake is located over numerous faults to the northeast and southwest, and tectonic activity has contributed to the shape of the lake and its drainages. Approximately 0.5 million years ago, Mt. Konocti and Bald Mountain erupted, separating the lake into three basins (Horne 1975[app]): the Upper Arm, Lower Arm, and the Oaks Arm. The largest basin of the lake has a continuous sediment record of at least 75,000 years (Horne 1975[app]). During this time the lake has maintained a steady depth, in spite of an annual sedimentation rate of 0.7 mm due to subsidence from geological activity.

Geological deposits in the Clear Lake basin are rich with copper, zinc, silver, gold, mercury, lead, uranium, and arsenic (Slowey et al. 2007). The Clear Lake basin contains four general soil types: residual soils from sedimentary rocks, residual soils from volcanic flows, soils from old valley-filling material (stream deposits) or recent alluvium, and serpentine soils (Simoons 1952). Soil fertility played an important role in the settlement patterns of the basin as farmers began vast conversions of native habitat to agricultural production.

The lake is fed by several large intermittent creeks (Scotts, Kelsey, Middle, Adobe, Seigler Canyon, and Schindler). Beginning in late spring and extending into late fall, the lower-most reaches of all inlet creeks are void of surface water. Historically, the level of the lake and rate of outflow to the Sacramento River has been regulated by the Grisby Riffle, a natural constriction in the Cache Creek outlet. Following construction and operation of the Cache Creek Dam by the Yolo County Flood Control District, Clear Lake's outflow is still controlled by this riffle (Bairrington 1999[app]).

The Clear Lake basin has a Mediterranean climate with hot, dry summers and cool, wet winters (Simoons 1952, Adam and West 1983, Parker 1994, Bairrington 1999[app]). Winter air temperatures infrequently persist below freezing, while summer temperatures often exceed 37° C (Simoons 1952, Parker 1994). Precipitation generally occurs between October and April, ranging altitudinally from 61 cm at Clear Lake State Park (lake level) to 165 cm on Cobb Mountain (Bairrington 1999[app]). Average surface water temperature of the lake varies from 6° C in winter to 26° C in summer, and some areas may reach 32° C in late summer (Horne 1975[app]). Portions of the lake can freeze, albeit rarely, and the water temperature can drop below 4° C, which is lethal to threadfin shad (*Dorosoma petenense*), and sub-lethal to juvenile bass(*Micropterus salmoides*), giving rise to some predation from catfish holding around benthic warm water vents (P. K. Bairrington, California Department of Fish and Game, personal communication, September 2012). Clear Lake is polymictic (i.e., it mixes frequently during a given year). Since the lake does not usually freeze in winter, wind-mixing recirculates nutrients from deeper waters and bottom sediments. Such frequent mixing, in combination with the Coriolis force, plays a role in the distribution of chemicals and elements throughout the lake (Rueda and Schladow 2003).

Clear Lake is eutrophic and its sediments are naturally high in phosphorus, as opposed to being contributed by municipal or agricultural waste waters (Horne and Goldman 1972, Horne 1975[app]). Blue-green algae are the most prevalent phytoplankton and, while native to the lake, they have historically formed nuisance blooms in spring and fall. In spring the water column quickly reaches 15^{o}C and temporarily stratifies, producing conditions under which blue-green algae may be able to out-compete other spring algae (Horne 1975[app]). During stratified periods, bottom waters may become anoxic and intolerable to most fishes, but release nutrients such as phosphate and ammonia. Storms bring winds that mix the lake, re-oxygenate deeper waters, and bring nutrients to the surface. Calm periods following storms often exhibit blooms of blue-green algae. Excess solar radiation may cause the bloom to die catastrophically, resulting in masses of dead algae and foul odors (Horne and Goldman 1972, Horne 1975[app]). The lake experiences a clear period in mid-summer (Horne 1975[app]), then the blue-green algae *Anabaena* and *Microcystis* appear in late summer. They form a fall bloom as winds increase and bring nutrients to the surface and persist into winter, then decline as light levels decrease due to diminished sunlight and increased turbidity.

Trends in native fish abundance.—In the 1870s the native fish community of Clear Lake probably included fourteen species (Figure 1, Appendix 1). Twelve native species were listed by Stone (1876) in what was the first of numerous surveys to determine the fish fauna of Clear Lake (Cook et al. 1966). These species were: Clear Lake splittail (*Pogonichthys ciscoides*), Clear Lake hitch (*Lavinia exilicauda chi*), Pacific lamprey (*Lampetra tridentata*), prickly sculpin (*Cottus asper*), rainbow trout or steelhead, or both (*Oncorhynchus mykiss*), Sacramento blackfish (*Orthodon microlepidotus*), Sacramento perch (*Archoplites interruptus*), Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis*), thicktail chub (*Gila crassicauda*), threespine stickleback (*Gasterosteus aculeatus*), and tule perch (*Hysterocarpus traski*). A subsequent survey by Jordan and Gilbert (1895) noted the presence of an additional native fish, *Ptychocheilus harfordi*, although they did not actually observe it. Jordan and Gilbert (1895) quoted a local angler's description of the *P. harfordi*: "Much smaller and darker than *P. oregonensis* [Sacramento pikeminnow], with smaller scales and does not take the trolling spoon." We

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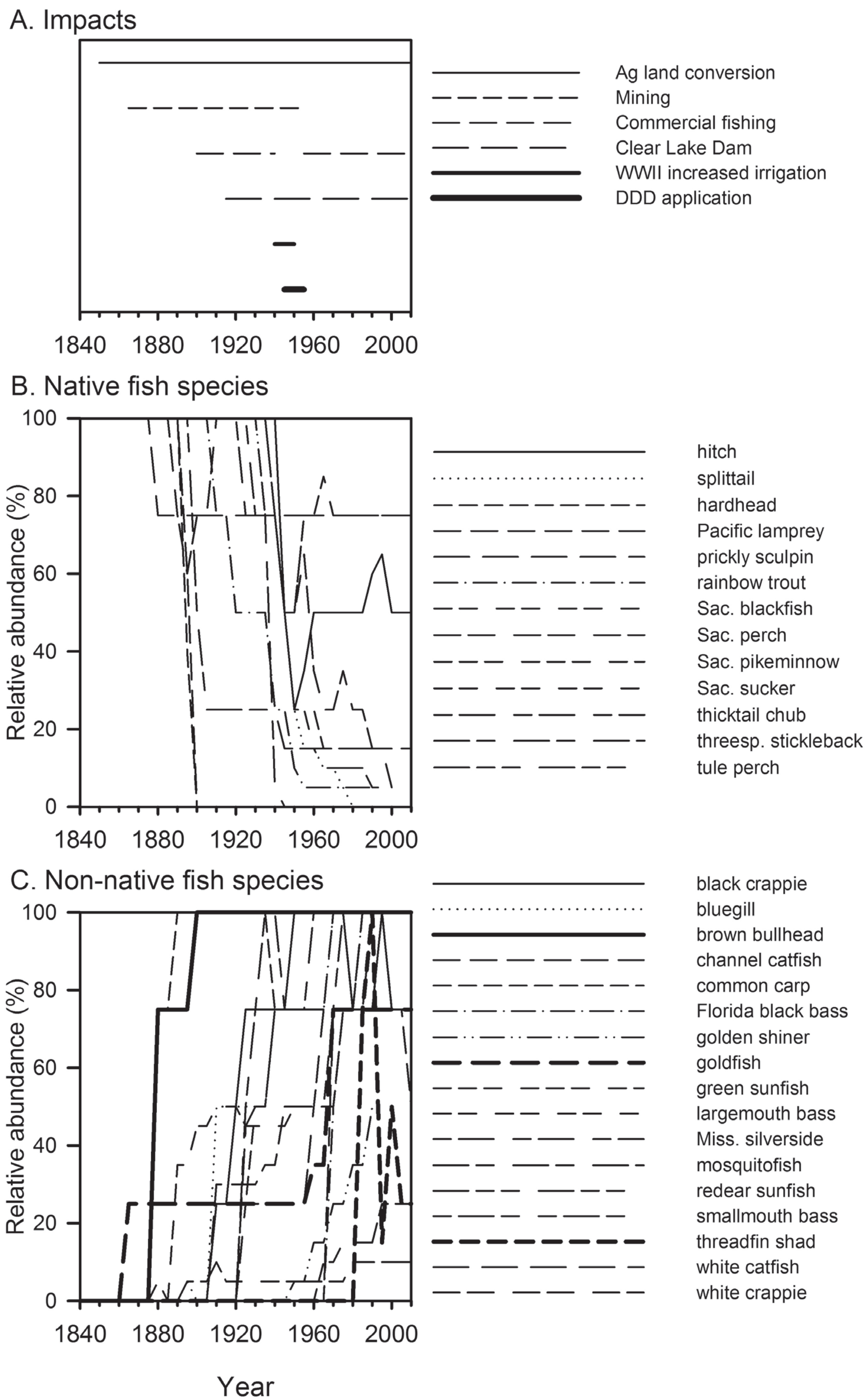
Figure 1.—Environmental impacts and relative abundance of native and non-native fishes at Clear Lake, California. Pacific lamprey and threespine stickleback have not been observed in the lake since 1894, but may still be present in tributaries (Week 1983[app]). We omitted native species California roach, and non-native species brown trout, fathead minnow, and pumpkinseed, due to insufficient information. We also omitted four non-native species whose initial introduction was unsuccessful (lake trout, lake whitefish, mud pickerel/grass pickerel, and yellow perch). Sources of fish abundance data: Stone (1876), Jordan and Gilbert (1895), Coleman (1930), Lindquist et al. (1943), Murphy (1951), Pintler (1957), Cook et al. (1966), Puckett (1972a[app], 1972b), Vestal (1974[app]), Cech (1978[app]), Moyle and Holzhauser (1978), Macedo (1991), Bairrington (1995[app], 1999[app], 2000[app]), Colwell et al. (1997), CDFG (1998[app], 2000a[app], 2000b[app]), Moyle (2002), Rowan (2008[app]), LCVCD (2013[app]), and Hinton (n.d.[app]).



A. Impacts
Ag land conversion
Mining
Commercial fishing
Clear Lake Dam
WWII increased irrigation
DDD application
1840 1880 1920 1960 2000
B. Native fish species
Relative abundance (%)
0 20 40 60 80 100
hitch
splittail
hardhead
Pacific lamprey
prickly sculpin
rainbow trout
Sac. blackfish
Sac. perch
Sac. pikeminnow
Sac. sucker
thicktail chub
threesp. stickleback
tule perch
C. Non-native fish species
black crappie
bluegill
brown bullhead
channel catfish
common carp
Florida black bass
golden shiner
goldfish
green sunfish
largemouth bass
Miss. silverside
mosquitofish
redear sunfish
smallmouth bass
threadfin shad
white catfish
white crappie
Year

suspect that *P. harfordi* may, in fact, have been hardhead (*Mylopharodon conocephalus*), since the angler's description concurs with our observations of hardhead appearance and behavior during angling from several Sierra Nevada streams in 2010 (L. C. Thompson, personal observation, May 2010). However, *P. harfordi* is a synonym for Sacramento pikeminnow, and hardhead were not observed in subsequent surveys of Clear Lake. The hardhead is very similar in appearance to the Sacramento pikeminnow, albeit with a smaller mouth, so it is likely that it was present during Stone's (1876) and Jordan and Gilbert's (1895) visits, but was not identified as a separate species. A fourteenth native species, California roach (*Lavinia symmetricus*), was observed in subsequent surveys (Bairrington 2000[app]).

The highly productive nature of the lake led to historically large populations of native species (Moyle 2002). Early records suggested that the anadromous species, steelhead trout and Pacific lamprey, entered the lake through its outlet, Cache Creek, and then spawned in its tributaries (Stone 1876). These migrations would have been halted by the construction of the Cache Creek Dam in 1915 (Murphy 1951). However, rainbow trout are reportedly still caught occasionally, and may occur near mouths of streams or near cold springs (Bairrington 1999[app]). Historically, hitch were very important to the diets of native peoples (Pomo tribes) and wildlife (Benson and Mauldin 1974, Moyle et al. 1995, Windrem 2008[app]). Hitch were once so abundant that during their upstream spawning migration they would displace one another out of the creeks and onto the bank (Rideout 1899, Benson and Mauldin 1974). Reports stated that "The little streams and tule swamps were filled side to side with fish in such numbers that they could be walked upon" (Murphy 1948a, Benson and Mauldin 1974). Historically, hitch also have been reported spawning in ditches and flooded meadows near tributaries (Moyle et al. 1995, Moyle 2002). However, hitch abundance has declined relative to its pre-1940s levels (Windrem 2008[app]).

All native fish species in Clear Lake have shown general downward trends in abundance (Figure 1), and four native species have been extirpated from the lake (Figure 1). The last recorded observations of hardhead and Pacific lamprey occurred in 1894 (Jordan and Gilbert 1895), although lamprey may persist in tributaries to the lake (Week 1983[app]). Thicktail chub were last seen in 1938 (Cook et al. 1964, 1966), and Clear Lake splittail in 1969 (Puckett 1972a[app], 1972b). Small native populations of rainbow trout have been recorded as resident fish in tributaries to Clear Lake, such as Kelsey Creek, Scotts Creek and Middle Creek, with a few large runs during the 1960s (Cook et al. 1966). Of the 14 species native to Clear Lake only six may still be common: California roach, Clear Lake hitch, prickly sculpin, Sacramento blackfish, Sacramento sucker, and tule perch (Bairrington 2000[app], CDFG 2000a[app], LCVCD 2013[app]).

Anthropogenic impacts.—Historical or contemporary anthropogenic impacts to Clear Lake have included introductions of non-native fish and plant species, artisanal and commercial fishing, farming, water diversions, mining, timber harvesting, recreational activities and, over time, an increase in human population. Below we summarize the major impacts likely to have influenced native fish species.

Introductions of non-native species.—There have been numerous sanctioned and non-sanctioned introductions of non-native fish species into the lake (Table 1). Introduced fishes have played an important, and often conflicting, role in Clear Lake for more than 100 years (Dill and Cordone 1997). Often viewed as a "testing ground" by late nineteenth century fish enthusiasts, Clear Lake was frequently subjected to introductions without consideration of the impacts to native fishes. In fact, early fish biologists introduced fish with disregard to the native species that they viewed as "unworthy" of consideration. Twenty-

Table 1.—Species of fish recorded from Clear Lake, Lake County, California. Presented are scientific name, year(s) of introduction(s) for non-native species, result(s) of introduction(s), the most recent recorded observation, and the citation for information included in the table.

Common name	Scientific name	Year(s) introduced	References	Introduction successful; still present?	Year last reported	References
California roach	*Lavinia symmetricus*	native	N/A	Y	c. 1995	Bairrington 2000[app]
Clear Lake hitch	*Lavinia exilicauda chi*	native	N/A	Y	2012	G.A. Giusti, personal observation, 2013
Clear Lake splittail	*Pogonichthys ciscoides*	native	N/A	N	1969	Puckett 1972b
Clear Lake tule perch	*Hysterocarpus traskii pomo*	native	N/A	Y	2012	LCVCD 2013[app]
hardhead	*Mylopharodon conocephalus*	native	N/A	N	1894	Jordan and Gilbert 1895
Pacific lamprey	*Lampetra tridentata*	native	N/A	N	1894	Jordan and Gilbert 1895
prickly sculpin	*Cottus asper*	native	N/A	Y	2012	G.A. Giusti, personal observation, 2013
rainbow trout/steelhead	*Oncorhynchus mykiss*	native	N/A	Y	c. 1995	Bairrington 2000[app]
Sacramento blackfish	*Orthodon microlepidotus*	native	N/A	Y	2000	CDFG 2000a[app]
Sacramento perch	*Archoplites interruptus*	native	N/A	Y	2000	CDFG 2000a[app]
Sacramento	*Ptychocheilus*	native	N/A	Y	2012	G.A. Giusti, personal

TABLE 1 (CONTINUED)

Common name	Scientific name	Year(s) introduced	References	Introduction successful; still present?	Year last reported	References
pikeminnow	*grandis*					observation, 2013
Sacramento sucker	*Catostomus occidentalis*	native	N/A	Y	2012	G.A. Giusti, personal observation, 2013
thicktail chub	*Gila crassicauda*	native	N/A	N	1938	Cook et al. 1964 and 1966
threespine stickleback	*Gasterosteus aculeatus*	native	N/A	Y	c. 1995	Bairrington 2000[app]
black crappie	*Pomoxis nigromaculatus*	1909	Murphy 1951	Y	2012	G.A. Giusti, personal observation, 2013
bluegill	*Lepomis macrochirus*	1909	Coleman (1930), Murphy 1951	Y	2012	G.A. Giusti, personal observation, 2013
brown bullhead	*Ameiurus nebulosus*	1880	Coleman (1930), Murphy 1951	Y	2012	G.A. Giusti, personal observation, 2013
		1961	McCammon and Seeley 1961			
brown trout	*Salmo trutta*	1924	Murphy 1951, Coleman (1930) saw "European brown, *Salmo fario*" in 1925	Y	c. 1995	Bairrington 2000[app]. Also Coleman 1930, Murphy 1951, Bairrington 1999[app]
common carp	*Cyprinus carpio*	1880	Coleman (1930) saw these in 1925 survey, Moyle and Holzhauser 1978	Y	2012	G.A. Giusti, personal observation, 2013
channel catfish	*Ictalurus punctatus*	c. 1900	Coleman (1930) saw blue catfish, which also has deeply forked tail). Puckett 1972b, Macedo 1991, Dill and Cordone 1997	Y	2012	G.A. Giusti, personal observation, 2013
		1969	Bairrington 1999[app]			
fathead	*Pimephales*	1950s	Dill and Cordone	Y	c. 1995	Bairrington 2000[app]

Common name	Scientific name	Year(s) introduced	References	Introduction successful; still present?	Year last reported	References
minnow	*promelas*		1997, Bairrington 1995[app]			
Florida black crappie	*Pomoxis nigromaculatus*	1985	Macedo 1991, Bairrington 1995[app], 1999[app]; Moyle 2002	Y	2008	K.L. Weber, personal observation via beach seines with Lake County Vector Control, 2008
Florida largemouth bass	*Micropterus salmoides floridanus*	1969-1971	Puckett 1972a[app], Pelzman 1980	Y	2012	G.A. Giusti, personal observation, 2013
golden shiner	*Notemigonus crysoleucas*	1896	Murphy 1951, Dill and Cordone 1997	N	1896	Murphy 1951
		1950	McCammon et al. 1964, Moyle and Holzhauser 1978, Moyle 2002	Y	c. 1995	Bairrington 2000[app]
goldfish	*Carassius auratus*	c. 1860s	Dill and Cordone 1997	Y	2012	G.A. Giusti, personal observation, 2013
green sunfish	*Lepomis cyanellus*	1909	Murphy 1951	Y	2000	CDFG 1998[app], 2000b[app]
lake trout	*Salvelinus namaycush*	1924	Murphy 1951	N	1924	Murphy 1951
lake whitefish	*Coregonus clupeaformis*	1873	Stone 1876	N	1873	Murphy 1951, Dill and Cordone 1997
Mississippi silverside	*Menidia audens*	1967	Cook and Moore 1970. Li et al. 1976, Moyle and Holzhauser 1978, Week 1983[app], Dill and Cordone 1997, Moyle 2002	Y	2012	G.A. Giusti, personal observation, 2013
mud	*Esox americanus*	1896	Murphy 1951	N	1896	Murphy 1951

TABLE 1 (CONTINUED)

Common name	Scientific name	Year(s) introduced	References	Introduction successful; still present?	Year last reported	References
pickerel/grass pickerel	*vermiculatus*					
northern largemouth bass	*Micropterus salmoides salmoides*	1888	Coleman 1930, Murphy 1951, Dill and Cordone 1997	Y	2012	G.A. Giusti, personal observation, 2013
		1969	Pelzman 1980			
		1975	Moyle and Holzhauser 1978			
pumpkinseed	*Lepomis gibbosus*	Uncertain	Bairrington 1999[app]	Y	c. 1995	Bairrington 2000[app]
redear sunfish	*Lepomis microlophus*	1963	Cook et al. 1964	Y	2008	K.L. Weber, personal observation via beach seines with Lake County Vector Control, 2008
smallmouth bass	*Micropterus dolomieu*	1895	Murphy 1951	Y	2012	G.A. Giusti, personal observation, 2013
threadfin shad	*Dorosoma petenense*	c. 1985	Bairrington 1999[app]	Y	2008	K.L. Weber, personal observation via beach seines with Lake County Vector Control, 2008
		c. 1997	Bairrington 1999[app]			
western mosquitofish	*Gambusia affinis*	1925	Murphy 1951	Y	c. 1995	Bairrington 2000[app]
white catfish	*Ameiurus catus*	c. 1874-1880	Murphy 1951	N	--	Murphy 1951 (Table 6, referred to Cal Fish and Game Report, 1895-96)
		1923	Murphy 1951, Dill and Cordone 1997	Y	--	Murphy 1951 (Table 6, referred to Cal Fish and Game Report, 1895-96)
		1961	McCammon and Seeley 1961	Y	2012	G.A. Giusti, personal observation, 2013
white crappie	*Pomoxis annularis*	c. 1925	Coleman 1930, Li et al. 1976, Moyle 2002	Y	1998	CDFG 1998[app], 2000b[app]
yellow perch	*Perca flavescens*	1909	Murphy 1951	N	1909	Murphy 1951

five non-native fish species or sub-species have been introduced to Clear Lake since 1873 (Table 1), of which 21 are still present (Table 1, Figure 1). In addition, blue catfish ("Great Blue, or Fork-Tail Cat", *Ictalurus furcatus*) were reportedly observed in 1925 (Coleman 1930), but subsequent surveys did not mention this species and it may have been the more commonly observed channel catfish (*I. punctatus*) which also has a deeply forked tail. The "brown-spotted cat" (*Ameirus* [sic] *platycephalus* Girard) was reported by Coleman (1930), but subsequent reviewers suggested that this was probably the brown bullhead (*Ameiurus nebulosus*) (Dill and Cordone 1997).

The first recorded introduction of non-native fishes at Clear Lake began with the unsuccessful stocking of lake whitefish (*Coregonus clupeaformis*) in 1873 (Stone 1876), although goldfish (*Carassius auratus*) were likely added in the 1860s (Dill and Cordone 1997). Common carp (*Cyprinus carpio*), brown bullhead, and white catfish (*Ameiurus catus*) were introduced by 1880 (Murphy 1951, Davis 1963, Moyle and Holzhauser 1978).

The introduction of northern largemouth bass (*Micropterus salmoides salmoides*) (Coleman 1930, Murphy 1951, Dill and Cordone 1997) and catfish in the 1880s contributed to a booming recreational fishery. By 1910, bass fishing was already considered excellent (Murphy 1951). Bluegill (*Lepomis macrochirus*) and black crappie (*Pomoxis nigromaculatus*) were introduced in 1909 and have maintained abundant numbers since then (Murphy 1951, Bairrington 2000[app]). Young-of-year crappie, bluegill, and bass compete with native species, particularly hitch, for food sources in tule nursery habitat surrounding the lake (Week 1982). Brown trout (*Salmo trutta*) were introduced in 1924 (Coleman 1930, Murphy 1951) and, while rare in the lake, they are reportedly caught and may occur near mouths of streams or near cold springs (Bairrington 1999[app]). Western mosquitofish (*Gambusia affinis*) were introduced in 1925 as an effective means to combat the gnats and mosquitos that plagued the area (Murphy 1951). This introduction also provided a valuable forage food for bass, catfish, bluegill, and crappie (Moyle 2002).

Mississippi silverside (*Menidia audens*) were introduced in 1967 (Cook and Moore 1970), and within one year became the most abundant fish in the lake (Moyle and Holzhauser 1978), providing a new source of prey for piscivores. In 1969 the California Department of Fish and Game introduced 456 Florida strain largemouth bass (*Micropterus salmoides floridanus*) (Puckett 1972a[app], Vestal 1974[app]). The Florida strain may have a faster growth rate than the northern largemouth bass, leading to a greater population growth rate (Moyle and Holzhauser 1978). The illegal introduction of threadfin shad occurred in the mid-1980s and provided yet another forage species for predatory fish (Bairrington 1999[app]); their abundance was short-lived, however, as cold winters in the early 1990s drove them to near extinction. Shad numbers increased in the 2000s, but by 2011 their abundance again was low (T. Knight, Lake County Record-Bee, personal communication, August 2011).

In addition to non-native fish species, other animal and plant species have been introduced, and may impact native fishes. Asian clams are thought to be present in the lake, but to our knowledge no work has been published on their role in the ecosystem. *Hydrilla*, an invasive aquatic plant first observed in Clear Lake in 1994 (Bairrington 1995[app]), provides some habitat value but results in increased applications of herbicide to the lake. The potential impact of dreissenid mussels (e.g., quagga and zebra mussels) is large, but is speculative at this time (Giusti 2010[app]).

Artisanal and commercial fishing.—The Pomo and pre-Pomo peoples of the Clear Lake region have inhabited the basin consistently since 6,000–8,000 years BP (Kaufman

1980, Parker 1994). By 5,000–6,000 years BP, evidence suggests that the entire lakeshore was utilized at some point in the year by the Pomo (Parker 1994). The majority of the population appears to have lived within 8 km of the lakeshore, and between April and May of each year fishing camps were established along the shoreline (Kniffen 1939, Parker 1994). The abundance and variety of fish in Clear Lake (Knapp 1855[app], Joaquin 1989) made fishing a specialized profession where men could trade their catch for other goods (Brown and Andrews 1969). Fishing techniques included fish hooks, spearing, nets, weirs, seine nets, gill nets, scoop nets, fish traps, dams, plant-derived poisons, and simply catching fish by hand (Knapp 1855[app], Brown and Andrews 1969, Joaquin 1989, Moss 1989). During the spring spawning period, Clear Lake hitch, Clear Lake splittail and Sacramento pikeminnow were readily available for capture from the lake's tributaries: "The Indian people around the lake used to collect enough fish in ten days, the usual hitch season, to last a whole year" (Moss 1989). Shortly after capture the fish were grilled, baked, dried, or smoked for preservation (Brown and Andrews 1969).

Commercial fishing has been conducted at Clear Lake since the 1900s for native blackfish, as well as carp and catfishes. The commercial catfish fishery was active from 1900 until 1941, when it was banned by legislative action (Murphy 1951). The commercial fishery for blackfish was banned in 1948 in order to increase the number of juvenile blackfish and, thus, increase Clear Lake's supply of forage for largemouth bass. Blackfish numbers recovered, and by 1954 the commercial fishery was re-instated (Moyle and Holzhauser 1978). Commercial fishing still occurs on the lake, with carp, blackfish, and goldfish comprising most of the catch (CDFG 2000a[app]).

Water management and dams.—Land conversion and water diversions for agricultural uses likely began concurrently with the arrival of European settlers in the Clear Lake basin. The first recorded contact between the Pomo and Europeans was during 1832–1833, when Hudson's Bay Company trappers made their way through the basin (Simoons 1952, Parker 1994). Agricultural production in the Clear Lake basin was, and is, important to the local economy. Agriculture products produced in the basin have included livestock, citrus, figs, walnuts, alfalfa, grain, apples, peaches, pears, and grapes (Carpenter et al. 1931). Between 1966 and 1986, the population of Lake County tripled, increasing municipal land use for housing, as well as municipal water requirements (Follansbee 1996).

Dams have been built on tributaries and the outflow of Clear Lake that impact natural hydrologic functions and flows and could, thereby, affect migratory fish populations. The completion of the Cache Creek Dam (Clear Lake Dam) in 1915 blocked access to spawning areas of anadromous migratory species (Pacific lamprey and steelhead; Murphy 1951). Adobe Creek, Highland Creek, Clover Creek, and Kelsey Creek (Macedo 1994, Lindblom 2004[app], Smythe 2008[app]) have experienced a reduction in fish spawning since the installation of dams and increased irrigation (Murphy 1951, Macedo 1994, Lindblom 2004[app], Smythe 2008[app]). Three of the most critical streams used for by Clear Lake hitch (Kelsey Creek, Seigler Creek, and Adobe Creek) have a total of nine barriers that potentially affect migration (Moyle et al. 1995, Bairrington 2000[app], Chi Council 2007[app], Windrem 2008[app]). Many creeks were channelized in response to frequent flooding and are now bounded by levees (Macclanahan et al. 1972[app], Army Corps of Engineers 1974[app]), although Lake County has begun to restore channelized streams to their more natural instream and riparian conditions. Also, minimum stream flows to allow fish passage and spawning have been established for the Kelsey Creek Detention Structure (Smythe 2008[app]).

Mining.—Mining of the abundant mineral deposits in the Clear Lake Basin commenced in the latter part of the nineteenth century (Anonymous 1859[app], Asher 2003). Though mining techniques have improved substantially, mid-nineteenth and early twentieth century techniques created long-term impacts that are still evident today (Slowey et al. 2007). Historical mining and dredging for gravel has occurred since early settlement (Kim 1999), and must be considered alongside current activities when assessing contemporary stream, marsh and water quality habitat conditions.

The presence of a borax lake and a sulphur bank resulted in the opening of the Sulphur Bank Mercury Mine (SBMM) on the eastern shore of the Oaks Arm of Clear Lake (Anonymous 1859[app]). The mine operated from 1865 to 1957 as a sulfur mine. In 1872, operations expanded to include mercury (Heeraman 1999, Asher 2003, Engle et al. 2008). The mine was ultimately abandoned in 1957 (Chamberlin et al. 1990[app], Suchanek et al. 2000, Asher 2003, Engle et al. 2008). During the 1920s, SBMM operations changed from open cut and shaft mining to removing overburden and waste rock (Suchanek et al. 2000), ultimately creating the Herman Pit. Much of the overburden and waste rock was bulldozed into the lake (Chamberlin et al. 1990[app], Suchanek et al. 2000), causing a dramatic increase in mercury entering the lake (Richerson et al. 2000, Suchanek et al. 2000, Asher 2003). In the 1950s a waste rock dam was built in an attempt to decrease mineral and acidic water flow from Herman Pit to Clear Lake (Asher 2003, Engle et al. 2008). However, the dam actually resulted in more mercury and other minerals entering the lake, due to water seeping through the waste rock and into the lake (Asher 2003, Engle et al. 2008).

Mercury can bioaccumulate in fish and other wildlife (specifically fish-eating birds) and, ultimately, result in health issues for humans (Ross 2001, Asher 2003, Thompson 2004[app]). In the 1970s, scientists discovered that fish in Clear Lake had significantly elevated levels of mercury in their tissues (Suchanek et al. 2000, Asher 2003). As a result, health advisories occurred in the 1980s regarding fish consumption (Asher 2003, Thompson 2004[app]). Due to the large amounts of pollution entering the lake from the SBMM each year, the mine was designated an Environmental Protection Agency Superfund Site in 1990, and steps have been taken to stop pollutants from entering the lake (Heeraman 1999, Asher 2003, Engle et al. 2008).

In addition to the SBMM, smaller scale mining and dredging for gravel in tributary streams have occurred since early settlement (Kim 1999), altering stream gravels and impacting fish spawning habitat. Mining on Kelsey, Scotts, and Middle creeks has further impacted spawning habitat by lowering the water table, thereby causing creeks to go dry earlier in the summer than under natural, unimpaired flows (Moyle 2002).

To summarize, the declines in abundance of Clear Lake native fish species are correlated with many of the human impacts described in this section. The first declines began in the 1880s (Figure 1B), by which time the human impacts included the start of land conversion to agriculture, water diversions, the introduction of several non-native fish species, and mining (Figure 1A, C). Declines in the abundance of more native fish species began between the 1890s and 1930s, and were correlated with the previously mentioned impacts, plus commercial fishing, the construction of the Clear Lake Dam, and the addition of approximately ten more species of non-native fish. A large wave of declines in native fish species abundance began in the 1940s. While commercial fishing was halted during this period, the other impacts continued, irrigation withdrawals from streams increased during World War II, and dichloro-diphenyl-dichloroethane (DDD) applications began (Hunt and Bischoff 1960, Cook and Connors 1963). Few new non-native fish species were introduced, but those already present in the lake increased in abundance. From the 1960s to present, some native fish populations continued to decline in abundance, while others stabilized or showed short term increases. During this period mining activities and DDD applications were halted, while commercial fishing resumed. New non-native fish species were introduced, and most non-native fish species increased or maintained abundance.

Discussion

As described above, Clear Lake and its fishes have experienced substantial changes in the past 150 years. A suite of major impacts is correlated with the decline of many native fish species, while many introduced fish species (except threadfin shad) have increased in abundance. While it is impossible to infer causality from these multiple impacts, since the 1840s all native fish species declined in abundance, and several have been extirpated from the lake (Figure 1).

The downward trends of native fish species abundance in Clear Lake can be attributed to numerous human impacts including the introduction of non-native fish species, land use change, dams, water diversions, and mining. However, because so many impacts occurred simultaneously or in quick succession, fish abundance may be correlated with multiple impacts. Thus, it is difficult to identify what proportion of a given native species' decline is attributable to a given human impact or increase in abundance of a non-native species and, in turn, to determine what restoration actions will be most effective.

To illustrate this point, numerous explanations have been suggested for the decrease in hitch abundance, the most prevalent being that irrigation demand causes streams to dry up earlier than normal, so adult and juvenile hitch lack sufficient time to migrate to and from the lake (Murphy 1948a, 1951; Benson and Mauldin 1974; Moyle et al. 1995; Moyle 2002; Windrem 2008[app]). Changes in stream flows have been caused by diversions for irrigation, domestic needs, and declining annual precipitation (Macedo 1994, Moyle et al. 1995). Additionally, dams along Adobe, Highland, Clover, and Kelsey creeks block or impair upstream migration for hitch (Macedo 1994, Lindblom 2004[app]). Past gravel mining contributed to the down-cutting of some stream channels and created fish migration barriers, often at older road crossings (Lindblom 2004[app]). Stream gravel provides crucial incubation habitat for the non-adhesive hitch eggs (Murphy 1948a).

In dry years, spawning by hitch may be limited because they cannot migrate up tributaries to Clear Lake. Hitch may be forced to spawn in the lake; however, in the lake there is often heavy egg predation (Kimsey 1960, Moyle et al. 1995). Additionally, those juvenile hitch that do survive predation and drying stream conditions are further stressed by the lack of suitable nursery habitat (Moyle et al. 1995, Windrem 2008[app]). Since 1840, approximately 85% of juvenile hitch rearing habitat and emergent vegetation has been destroyed or altered (Bairrington 1999[app]). It is generally perceived that introduced fish species have negatively affected hitch populations, competing both for food and space, while some introduced fishes are also aggressive predators that feed on all life stages of hitch (Geary 1978, Moyle et al. 1995, Moyle 2002). Acid mine drainage may also have affected hitch abundance, as it has been linked to decreased ecological diversity, habitat loss, and bioaccumulation (Asher 2003).

Research needs.—It may be possible to clarify the role of these impacts and inter-species relationships through research targeted to reduce the uncertainty in our understanding of Clear Lake and its fishes. Here we describe six research needs and outline approaches to address them, including field studies, modeling, and surveys.

It is unclear to what extent bass predation affects the hitch population. Field studies of hitch and largemouth bass could provide knowledge about their interactions. For example, the frequent bass fishing tournaments held at Clear Lake offer an opportunity to tag bass in order to determine post-release movements of bass, the frequency of recapture, bass population trends, and the potential for interaction between bass and hitch at particular locations around the lake. Bass captured during fishing tournaments could be tagged (Guy et al. 1996) prior to release, which typically occurs at a centralized location. Members of the public, including Clear Lake residents, local anglers, local tackle shops, and bass tournament anglers, would be notified of the presence of tagged bass, and would be asked to report the time and place that tagged bass are recaptured. This "citizen scientist" approach would be a cost-effective way to collect recapture data. If tournament bass stomach contents were examined following weigh-in, it may also be possible to determine the proportion of bass diet contributed by hitch and other prey species, and to extrapolate the biomass of prey species consumed. The citizens of Lake County have shown a longstanding commitment to Clear Lake (e.g., Chi (hitch) Council, Lake County Invasive Species Council), so it is likely that such a project would attract strong participation.

The current population dynamics of native fish species, including hitch, Sacramento blackfish, and Sacramento pikeminnow, are uncertain. While these species have declined in abundance relative to historical conditions, a lack of detailed knowledge of their life histories contributes to management and challenges. Field surveys could be conducted to determine within-lake distribution, movement, growth rates, diet, age structure, and size-related mortality.

Among the native fish species of Clear Lake, the hitch attracts considerable public attention and scrutiny of trends in abundance and potential limiting factors. A hitch population dynamics model could be developed to help determine the relative importance of potential bottlenecks in the species' life cycle (e.g., spawning habitat availability, young-of-year outmigrant survival, and juvenile in-lake survival). The model would incorporate current knowledge of hitch biology and new information gained from the previously mentioned field studies, and suggest which intervention(s) could be most beneficial.

The complexity of the Clear Lake food web and the multitude of environmental impacts and non-native fish introductions make it challenging to track the interconnections and to predict the outcome of management actions. The considerable economic value of the bass sport fishery and associated tournaments to Lake County complicates management of the lake. While bass prey on native species, it may be possible to determine whether a management regime exists that will allow the bass fishery to continue while also ensuring the long term survival of native species. Computer modeling approaches such as ECOPATH (Pauly et al. 2000) can be used to bring to together the existing knowledge about an ecosystem, including feeding networks, production of species (biomass), predation mortality, and fisheries catch. The model can then be used to simulate management choices, and to predict resultant changes in the abundance of species of concern. For example, an ECOPATH model was constructed for Lake Victoria in Africa's rift valley (Moreau et al. 1993), where changes in the fish community mirror changes in Clear Lake. A diverse assemblage of catfish, cichlids, and haplochromine species was present in Lake Victoria until the late 1970s when the Nile perch (*Lates niloticus*), a highly predatory species, was introduced (Moreau et al. 1993). The sudden increase in predation by Nile perch reduced the native diversity to three dominant species, a situation that may be comparable to the effect of bass on native species in Clear Lake.

In this paper we have focused on past and current conditions affecting Clear Lake fishes, but changes in climate predicted for California as a whole (Hayhoe et al. 2004) raise the question of how future climate conditions may affect the Clear Lake watershed. A watershed hydrology model, incorporating predictions of future climate through the 21st century, could be constructed to predict how spring stream flows are affected by climate change, and how this may affect hitch spawning access and timing (e.g., see Thompson et al. 2012). Such a model would allow better targeting of stream restoration activities and fish passage projects.

Dreissenid mussels have recently been introduced into water bodies in southern California, and the Lake County Invasive Species Council was formed to coordinate local efforts to prevent the spread of mussels into Clear Lake (Giusti 2010[app]). These efforts are ongoing, but the large number of public access points surrounding Clear Lake makes it difficult to screen incoming vessels effectively, leaving the lake vulnerable to introductions. A nation-wide survey could be developed and administered to managers of lakes with access conditions similar to Clear Lake; the survey could identify management strategies that have been effective in delaying or halting invasions of dreissenid mussels, and how invasions have been addressed.

In conclusion, the native fish species of Clear Lake have declined in abundance since the 1840s, likely due to the effects of a suite of human impacts. While some species have been extirpated, many also survive, offering the opportunities to develop management strategies for recovery and persistence. Implementation of research and management experiments, such as those described herein, can increase our understanding of which impacts have been most devastating, inform development of management plans, and help to determine what restoration actions will be most effective.

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Appendix I: Historical time line of Clear Lake and its fishes

The following timeline summarizes key events in the Clear Lake basin, including the introduction of non-native fish species, loss of native fish species, harvest of native and non-native fishes, weather patterns, and environmental impacts. Full citations are listed in Literature Cited or in Appendix II.

- Pre-1840
  - Historically Clear Lake hitch have been very important to the people (Pomo Tribes) of Clear Lake as a staple food in their diets (Benson and Mauldin 1974, Windrem 2008[app])
- 1840
  - European settlers first appear in the Clear Lake area (Bairrington 1995[app], 1999[app])
- c. 1860s
  - Goldfish introduced (Dill and Cordone 1997)
- 1866
  - Borax and soda found in large quantities near Clear Lake (Anonymous 1866[app])
  - Miners are extracting 2.7 metric tons/day of sulphur. They believe the mines can produce up to 9 metric tons/day (Anonymous 1866[app])
  - Perch and trout are taken from Clear Lake in large numbers weighing between 1.4 and 6.8 kg (Anonymous 1866[app])
- 1870
  - Cinnabar, mercury and sulphur are mined at Sulphur Bank Mercury Mine until 1957 when the mine is closed (Harnly et al. 1997)
- 1873
  - 25,000 lake whitefish are introduced into Clear Lake by the California Fish Commission (CFC) (Stone 1876, Murphy 1951, Dill and Cordone 1997), but the introduction proved unsuccessful
  - Fish species observed in Clear Lake: Clear Lake splittail, Clear Lake hitch, Pacific lamprey, prickly sculpin, rainbow trout and/or steelhead, Sacramento blackfish, Sacramento perch, Sacramento pikeminnow, Sacramento sucker, thicktail chub, threespine stickleback, tule perch (Stone 1876)
- 1878
  - 1,000 catfish were placed in Clear Lake by the CFC (Murphy 1951)
  - Large carp ponds established around Clear Lake (Cobb Mountain, Anderson Springs, and Boggs Mill between Glenbrook and Kelseyville) (Benson and Mauldin 1974)
- 1880
  - Start of successful fish introductions into Clear Lake (Moyle and Holzhauser 1978)
  - First white catfish[a] introduction of 74 individuals by CFC is unsuccessful (Murphy 1951)
  - Brown bullhead and common carp are introduced into Clear Lake (Moyle and Holzhauser 1978)

- 1888
    - Largemouth bass are introduced into Clear Lake by the CFC (Murphy 1951, Dill and Cordone 1997)
- 1894
    - Fish species observed in Clear Lake: Clear Lake splittail, Clear Lake hitch, Pacific lamprey, prickly sculpin, rainbow trout and/or steelhead, Sacramento blackfish, Sacramento perch, Sacramento pikeminnow, Sacramento sucker, thicktail chub, threespine stickleback, tule perch, *Ptychocheilus harfordi* (hardhead or Sacramento pikeminnow) (Jordan and Gilbert 1895)
- 1895
    - Smallmouth bass unsuccessfully introduced into Clear Lake by the CFC (Murphy 1951)
    - Sacramento pikeminnow are abundant (Cook et al. 1966)
    - Sacramento perch are becoming scarce possibly due to the introduction of carp (Cook et al. 1966)
    - Thicktail chub are common (Cook et al. 1966)
    - There are 13 native fish species and four introduced species in the lake (Bairrington 1995[app], 1999[app])
- 1896
    - Three grass pickerel[a] are unsuccessfully introduced. Also, 296 golden shiner are introduced into three California lakes including Clear Lake. The Clear Lake introduction was unsuccessful. Both introductions were sanctioned by the CFC (Murphy 1951, Dill and Cordone 1997, Moyle 2002)
- 1899
    - The fish are so abundant that they are crowding each other out of the tributaries (Kelsey Creek) where they spawn. Clear Lake hitch spawning runs last several days (Rideout 1899, Benson and Mauldin 1974, Dill and Cordone 1997)
- 1900
    - Carp are abundant in the lake (Mauldin 1968)
- 1903
    - Reports of rainbow trout in the lake (Dill and Cordone 1997)
- 1908
    - Clear Lake supports a huge catfish fishery (Altouney et al. 1966[app], Dill and Cordone 1997)
- 1909
    - Black crappie (successful), yellow perch (unsuccessful), bluegill (successful) and green sunfish (successful) are all introduced by the CFC (Murphy 1951, Moyle 2002)
- 1910
    - Largemouth bass fishing in Clear Lake is already good (Murphy 1951)
    - There is a large Clear Lake hitch run on Kelsey Creek but many fish die due to quick drying of the creek (Mauldin 1968)

- 1912
    - Sacramento pikeminnow are most dense in Kelsey Creek (Mauldin 1968)
- 1914
    - Rainbow trout are common in Clear Lake before the building of Cache Creek Dam in 1915 (Cook et al. 1966
- 1915
    - The Cache Creek Dam (on the only outlet from Clear Lake) is built (Murphy 1951; Kimsey 1957; Bairrington 1995[app], 1999[app])
- 1923
    - Second white catfish[a] introduction; successful (Murphy 1951, Dill and Cordone 1997)
- 1924
    - Heavy rains (Coleman 1930)
    - 135,000 brown trout and lake trout are introduced (Murphy 1951, Dill and Cordone 1997). Lake trout introduction is unsuccessful
- 1925
    - A drought occurs dropping the lake level 0.5 m (Coleman 1930)
    - Mosquitofish are successfully introduced (Murphy 1951)
    - Clear Lake splittail are very abundant (Coleman 1930, Hopkirk 1974)
    - Streams and tule swamps are filled side to side with fish (Benson and Mauldin 1974)
    - It has been noted that at Clearlake Oaks the fish were so abundant that you could walk upon them (Benson and Mauldin 1974)
    - White crappie are observed (Coleman 1930)
- 1926
    - An eruption at the bottom of Soda Bay releases large amounts of sulfuric acid resulting in a fish kill (Coleman 1930)
    - Thicktail chub are becoming less common in the lake (Cook et al. 1966)
- 1929
    - Clear Lake still supports a huge catfish fishery (Altouney et al. 1966[app], Dill and Cordone 1997)
- 1930s
    - Sacramento sucker are common (Cook et al. 1966)
    - There is a good Clear Lake hitch run on Kelsey Creek but in the last mile of the creek many fish died for an unknown reason (Mauldin 1968)
- 1930s-1951
    - Catfish were 80.0% of the catch (Puckett 1972b)
- 1930
    - Many young fish in Clear Lake (Coleman 1930)
    - Sacramento perch are abundant within the lake (Murphy 1948a)
    - Clear Lake splittail are abundant (Cook et al. 1966)

- 1932-1936
  - There is increase in rough fish catch in California due to their abundance in Clear Lake (Davis 1963)
  - Catch from Clear Lake is 133,810 kg/yr (Bairrington 1999[app])
- 1938
  - Thicktail chub are last seen (Cook et al. 1964, 1966)
  - Sacramento pikeminnow are abundant (Cook et al. 1966)
  - Some fish species within Clear Lake, from most to least abundant: Clear Lake splittail, Clear Lake hitch, carp, white catfish[a], Sacramento perch (Lindquist et al. 1943, Hopkirk 1974)
  - Clear Lake hitch are abundant (Cook et al. 1966)
- 1940s
  - Sacramento pikeminnow, Clear Lake splittail, thicktail chub populations crash (Cook et al. 1966)
  - Sacramento perch populations are reduced (Cook et al. 1966)
- 1940
  - Reports of fish kills (Lindquist et al. 1943)
  - Clear Lake splittail abundant but shortly after 1940 their numbers begin to decline quickly (Cook et al. 1966)
- 1941
  - Catfish fishing is banned (Bairrington 1999[app])
- 1943
  - Sacramento perch is moderately abundant (Cook et al. 1966)
  - Large Clear Lake splittail and Clear Lake hitch runs (Lindquist et al. 1943)
  - Fish species known to be in Clear Lake (Lindquist et al. 1943): White catfish[a], bluegill, black crappie, Sacramento perch, Clear Lake hitch, Clear Lake splittail, carp, largemouth bass, green sunfish, Sacramento blackfish, thicktail chub, Sacramento pikeminnow, Sacramento sucker, prickly sculpin[b]
- 1943-1944
  - Kelsey Creek held a big Clear Lake hitch run but it is the last successful spawning season for some time (Murphy 1948a)
- 1944
  - A drop in fishing quality (Murphy 1951)
- 1946
  - Almost no Clear Lake hitch have been spawning (Murphy 1948a)
  - Clear Lake splittail are almost absent (Murphy 1951, Hopkirk 1974)
- 1946-1947
  - Sacramento perch have maintained small, healthy populations (Cook et al. 1966)
- 1946-1950
  - Sacramento blackfish, carp, and Sacramento suckers have fair population numbers; Clear Lake hitch, Sacramento pikeminnow, and Clear Lake splittail are rare (Murphy 1951)

- 1947
    - Few Clear Lake hitch have been spawning but a dam release caused a freshet and some fish spawned (Murphy 1948a)
- 15 June 1947
    - Sacramento perch are seen spawning in Clear Lake (Curtis 1949)
- 1948
    - Clear Lake hitch spawning runs are in serious decline (Murphy 1948a)
    - Clear Lake hitch are rare (Cook et al. 1966, Mauldin 1968)
    - Sacramento perch are scarce, possibly due to the bluegill introduction (Murphy 1948b)
    - The Sacramento blackfish fishery is banned to create more largemouth bass food (Murphy 1950, McCammon et al. 1964, Moyle and Holzhauser 1978)
    - Beach seines show the most prominent fish in Clear Lake appear to be largemouth bass, bluegill, sculpin and Sacramento blackfish (Murphy 1949)
- September 1949
    - TDE (DDD) (dichloro-diphenyl-dichloroethane) treatment of Clear Lake for pest control (specifically the Clear Lake gnat, *Chaoborus astictopus*) begins (Hunt and Bischoff 1960, Cook and Connors 1963, Cairns and Parfitt 1980)
- 1949
    - 1,000 Nesting pairs of western grebes (*Aechmophorus occientalis*) are found around the lake (Hunt and Bischoff 1960)
    - Significant numbers of Sacramento perch in Clear Lake (Curtis 1949)
    - The once prosperous catfish fishery closes (Dill and Cordone 1997)
- 1949-1964
    - 226,796 kg dichloro-diphenyl-trichloroethane (DDT) used for pest control on the lands around Clear Lake for agriculture (Cairns and Parfitt 1980)
- 1950s
    - Sacramento perch is common in the lake (Cook et al. 1966)
    - Fathead minnow introduced (Moyle 2002)
    - Percentage of fish catch for 1950s (Puckett 1972b): Centrarchids (80.0%), bass (5.0-10.0%), crappie (2.0-56.0%)
- 1950
    - Second golden shiner introduction (McCammon et al. 1964, Moyle and Holzhauser 1978, Dill and Cordone 1997)
    - There are 12 native fish species and 8 introduced species in the lake (Bairrington 1995[app], 1999[app])
- 1951
    - Sacramento pikeminnow are now almost extinct from the lake; Sacramento perch and trout are very scarce (Murphy 1951)
    - Fish species known to be in Clear Lake (Murphy 1951):
        - Native species - rainbow trout, Sacramento sucker, Sacramento blackfish, Clear Lake hitch, Sacramento pikeminnow, thicktail chub, Clear Lake splittail, California

roach[a], Sacramento perch (<1%) and Clear Lake tule perch, prickly sculpin[b], threespine stickleback
    - Introduced species: carp, white catfish[a] (70%), brown bullhead (2%), mosquitofish, largemouth bass (10%), green sunfish, bluegill, black crappie (not over-exploited)

- July 1951
  - Gnat larvae are found in the lake (Hunt and Bischoff 1960)
- September 1954
  - Second TDE treatment of Clear Lake (Hunt and Bischoff 1960, Cook and Connors 1963, Cairns and Parfitt 1980)
- December 1954
  - 100 western grebes found dead in and around the lake (Hunt and Bischoff 1960)
- 1954
  - White crappie are stocked (Li et al. 1976, Moyle 2002)
  - The Sacramento blackfish fishery is reinstated (it had been banned in 1948) (Moyle and Holzhauser 1978)
- March 1955
  - More dead western grebes are found (Hunt and Bischoff 1960)
- 1955-1956
  - The gnat problem begins to increase again (Hunt and Bischoff 1960)
- 1956
  - Observations of Clear Lake hitch spawning in Clear Lake, and of carp eating Clear Lake hitch eggs (Kimsey 1960)
- 25 April 1957
  - Clear Lake hitch are observed spawning around the Clearlake Oaks portion of the lake (Kimsey 1960)
- 3 May 1957
  - Clear Lake hitch are observed spawning in the lake at 1900 hours. There are no observations of Clear Lake hitch spawning in Middle Creek and Lyons Creek (Kimsey 1960)
- 9 May 1957
  - No Clear Lake hitch were observed spawning in Schindler Creek (Kimsey 1960)
- September 1957
  - Third TDE treatment of Clear Lake. 54,431 kg of TDE have been used (Hunt and Bischoff 1960, Cook and Connors 1963, Cairns and Parfitt 1980)
- December 1957
  - 75 western grebes found dead; eventually linked to TDE usage. A few of the western grebes were analyzed and it was discovered they had over 1,600 mg/L DDD in their bodies (Hunt and Bischoff 1960, Linn and Stanley 1969)
- 1957
  - Sulphur Bank Mercury Mine closes down (Harnly et al. 1997)
  - Over-fishing does not appear to be an issue for fish populations (Kimsey 1957)

- 1958
  - Decreasing TDE levels in animals (Linn and Stanley 1969)
- March 1958
  - Several types of fish are analyzed to see how much DDD remained in their system. Results ranged from 40.0 mg/L in carp to 2,500 mg/L in brown bullhead (Hunt and Bischoff 1960)
- July 1958
  - More analyses show white catfish[a] and largemouth bass contain the largest amounts of DDD (Hunt and Bischoff 1960)
- 1958-1959
  - Less than 25 nesting pairs of western grebes located around the lake. This is down from 1,000 in 1949 before TDE treatments began (Hunt and Bischoff 1960)
- 1960s
  - 5,443 kg of Sacramento blackfish taken from Clear Lake via seining (Davis 1963)
  - Nine adult and zero juvenile Sacramento perch found in the lake (Cook et al. 1966)
- 1960
  - Heavy commercial fishing in Clear Lake (Davis 1963)
  - Largemouth bass comprise 42.0% of the catch (Puckett 1972b)
- 1961
  - Huge stocks of white catfish[a] and brown bullhead are placed in Clear Lake (McCammon and Seeley 1961)
  - Clear Lake splittail are almost absent (Cook et al. 1964, Benson and Mauldin 1974)
- 1961-1962
  - Beach seine hauls contain 20.0% Clear Lake hitch and Sacramento blackfish (Geary 1978)
- 1962
  - The lake experiences *Anabaena* blooms, low zooplankton levels and a decrease in chironomids (Cook and Connors 1963)
  - Methyl parathion is applied annually (3-4 times/summer) (Cook and Connors 1963, Apperson et al. 1976)
  - Adobe Creek and Highland Springs Dams are built (ICE 1997[app])
  - Clear Lake hitch and Sacramento blackfish are abundant (Cook and Connors 1963)
- 7 April 1962
  - Clear Lake hitch are present in Seigler Canyon Creek (Swift 1965)
- 12 April 1963
  - Clear Lake hitch are present in a ditch near Lakeport (Swift 1965)
- 1963
  - Redear sunfish introduced (Cook et al. 1964)
  - Rainbow trout are not found in the lake but there are some populations that subsist in the lake's tributaries (Cook et al. 1966)
  - Brown trout are known in the Clear Lake watershed and have possible limited occurrence in the lake (Cook et al. 1964)

- 1964
  - Sacramento perch found in low numbers (Cook et al. 1964)
  - There are 12 native fish species and 12 introduced species in the lake (Bairrington 1995[app], 1999[app])
  - Clear Lake hitch occur in low numbers (Cook et al. 1966)
  - No observations of the threespine stickleback or California roach[a] (Cook et al. 1964)
- 1965
  - Threespine stickleback is rare in the lake (Cook et al. 1966)
- 1966
  - Clear Lake splittail populations are stressed (Cook et al. 1966)
  - Pacific lamprey are not observed in the lake (Cook et al. 1966)
  - Sacramento blackfish appear in large numbers (Cook et al. 1966)
  - Prickly sculpin appear in good numbers (Cook et al. 1966)
  - Clear Lake tule perch is reasonably abundant (Cook et al. 1966)
  - Sacramento perch are considered rare (Cook et al. 1966)
  - Thicktail chub may be extirpated by this point (Cook et al. 1966)
- October 1967
  - 3,000 Mississippi silverside[c] are introduced into Clear Lake as a forage fish, reduction of plankton and to assist in gnat and midge control. This was not authorized by the CFC (Cook and Moore 1970, Li et al. 1976, Geary 1978, Moyle and Holzhauser 1978, Week 1983[app], Dill and Cordone 1997, Moyle 2002)
- 1968
  - Beach seining shows Mississippi silversides[c] are the most abundant fish in the lake (Cook and Moore 1970, Moyle and Holzhauser 1978)
- 1969
  - 1,000 mg/L TDE detected in some animals (Linn and Stanley 1969)
  - Percentage of catch for 1969 (Puckett 1972b, Macedo 1991): Black crappie (36.9%), bluegill (22.8%), white crappie (19.1%), brown bullhead (6.9%), largemouth bass (5.0%), green sunfish (2.0%), channel catfish (1.0%), Clear Lake hitch/Clear Lake splittail/ Sacramento blackfish/Sacramento perch/redear sunfish (<1.0%)
  - Fish species thought to be in Clear Lake (Puckett 1972b): Rainbow trout, Sacramento sucker, carp, goldfish, golden shiner, Sacramento blackfish, Clear Lake hitch, Sacramento pikeminnow, thicktail chub, Clear Lake splittail, California roach[a], fathead minnow, channel catfish, brown bullhead, mosquitofish, largemouth bass, green sunfish, redear sunfish, bluegill, Sacramento perch, white crappie, black crappie, Mississippi silverside[c], Clear Lake tule perch, prickly sculpin[b], threespine stickleback
  - Commercial fishing (Puckett 1972b):
    - Sacramento blackfish catch is 88,450 kg
    - Carp catch is 109,769 kg
- April 1969
  - Planting of northern largemouth bass due to decrease in largemouth bass numbers (Puckett 1972b, Pelzman 1980)

- 1969-1971
  - Florida largemouth bass are introduced (Moyle and Holzhauser 1978, Pelzman 1980, Dill and Cordone 1997)
- 1969-1983
  - Intermittently through these years channel catfish were restocked in Clear Lake (Bairrington 1999[app])
- 1969-1993
  - Intermittently through these years largemouth bass were restocked in Clear Lake (Bairrington 1999[app])
- 1970s
  - Clear Lake hitch numbers continue to decline (T. Knight, Lake County Record-Bee, personal communication, August 2008)
- 1970
  - Mississippi silverside[c] population is growing quickly (Puckett 1972b, Moyle 2002)
- 1971
  - Although Clear Lake hitch numbers are in decline there is still a substantial run on Kelsey Creek (Benson and Mauldin 1974)
- 1972
  - Crappie equal 56.0% of catch (Macedo 1991)
- 1973
  - The Sacramento perch population appears stable (Aceituno and Nicola 1976)
  - Beach seine hauls contain <1.0% Clear Lake hitch and Sacramento blackfish (down from 1961-1962 numbers of 20%) (Geary 1978)
  - Clear Lake splittail and thicktail chub thought to be extirpated from the lake (Hopkirk 1974)
- 1974
  - Observations of large fish kills due to drying of creeks during spawning (Benson and Mauldin 1974)
- 1975
  - 40,000 northern strain largemouth bass are introduced into the lake (Moyle and Holzhauser 1978)
- 1976
  - Anderson Marsh temporarily converted to agriculture (Bairrington 1995[app], 1999[app])
  - Mississippi silverside[c] population is somewhat low resulting in less competition with native species (Geary 1978)
  - April-October electrofishing results, from most to least abundant (Week 1983[app]): Mississippi silverside, bluegill, carp, Clear Lake tule perch, green sunfish, prickly sculpin, black crappie, goldfish, largemouth bass, white catfish, Sacramento blackfish, Clear Lake hitch, brown bullhead, white crappie, channel catfish, Sacramento perch
- Late 1970s
  - White crappie population declines and never fully recovers (Moyle 2002)

- 1980s
  - Kelsey Dam is built (T. Knight, Lake County Record-Bee, personal communication, August 2008)
- 1982
  - August electrofishing results, from most to least abundant (Week 1983[app]): Mississippi silverside, bluegill, carp, Clear Lake tule perch, largemouth bass, green sunfish, prickly sculpin, black crappie, goldfish, white catfish, Sacramento blackfish, Clear Lake hitch, brown bullhead, white crappie, channel catfish, Sacramento perch
  - Pacific lamprey and threespine stickleback have not been observed in the lake since 1894, but may still be present in tributaries (Week 1983[app])
- 1984
  - Clear Lake hitch are seen spawning in storm drains (T. Knight, Lake County Record-Bee, personal communication, August 2008)
- 1985
  - Florida black crappie are introduced (Macedo 1991; Bairrington 1995[app], 1999[app]; Moyle 2002)
  - Threadfin shad introduced (illegally). They undergo a population boom which threatens Clear Lake hitch populations because they occupy the same niche in the food web (Geary 1978; Bairrington 1995[app], 1999[app]; Moyle 2002)
- 1988
  - Clear Lake has green, yellow-green, and blue-green algae (Macedo 1991)
  - Percentage of catch by species (Macedo 1991): bass 67.0%, bluegill 15.0%, crappie 6.0%, catfish/Clear Lake hitch/carp/perch 12.0%
  - Sacramento perch population up to 1.0% from <1.0% in 1969 and 1976 (Macedo 1991)
  - Crappie population in decline (Macedo 1991)
- Late 1980s
  - Few juvenile largemouth bass are found in seines (Bairrington 1999[app])
- 1990
  - Sulphur Bank Mercury Mine becomes a superfund site (Harnly et al. 1997)
- 1990-1991
  - Threadfin shad die off but Mississippi silverside[c] numbers increase (Bairrington 1999[app], Moyle 2002)
- 1991
  - From this time on, no live bait harvesters have been on Clear Lake (Bairrington 1999[app])
  - Catfish are documented using the spawning structures (Bairrington 1999[app])
  - Juvenile fish experience a population boom (Bairrington 1999[app])
  - Catfish catch abundances in the sport fishery (Macedo 1991, Dill and

Cordone 1997), from most to least abundant: brown bullhead, white catfish[a], channel catfish

- 1993-1995
  - Shad population crashes (Bairrington 1995[app], 1999[app])
- 1993
  - Placement of spawning gravel at Anderson Marsh and Clear Lake State Park (Bairrington 1999[app])
  - Kelseyville Main Street Bridge fish ladder put in to aid Clear Lake hitch in getting upstream to spawn. Does not appear to be as effective as planned. There are still obstructions further upstream (T. Knight, Lake County Record-Bee, personal communication, August 2008; P.F. Windrem, Chi Council, personal communication, August 2008)
- October – December 1993
  - Tule transplants between Nice and Lucerne to create fish nursery areas (Bairrington 1999[app])
- 1994
  - Hydrilla found in the lake (Bairrington 1995[app], 1999[app])
- 1995
  - Past and present fish in Clear Lake (Bairrington 1999[app]):
    - Native species: rainbow trout, Pacific lamprey, Sacramento sucker, Sacramento blackfish, Clear Lake hitch, Sacramento pikeminnow, Clear Lake splittail, thicktail chub, Sacramento perch, Clear Lake tule perch, California roach[a], prickly sculpin, threespine stickleback, hardhead
    - Introduced species: goldfish, carp, brown bullhead, channel catfish, white catfish[a], largemouth bass, smallmouth bass, bluegill, redear sunfish, green sunfish, mosquitofish, Mississippi silverside[c], threadfin shad, fathead minnow, pumpkinseed
  - Sacramento perch numbers are stable while crappie numbers are in decline (Moyle 2002)
- 1997
  - Threadfin shad illegally reintroduced into the lake (Bairrington 1999[app], Moyle 2002)
- 2002
  - Clear Lake tule perch, Clear Lake hitch, Sacramento blackfish and prickly sculpin are the four native species of Clear Lake fishes that have managed to persist in large numbers since the introductions of non-natives in the 1880s (Geary and Moyle 1980, Moyle 2002)
- 2008
  - Sacramento perch believed to be gone from Clear Lake (D.L. Woodward, Lake County Vector Control District, personal communication, August 2008)

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[a] White catfish (*Ameiurus catus*) was also referred to as fork-tailed catfish (Jordan and Gilbert 1895) and by the scientific name *Ictalurus catus* (Murphy 1951). Grass pickerel

(*Esox americanus vermiculatus*) was also referred to as mud pickerel (Murphy 1951). California roach (*Lavinia symmetricus*) was formerly referred to as western roach (*Hesperoleucus symmetricus*) (Murphy 1951).

[b] Prickly sculpin (*Cottus asper*) is native to Clear Lake. Riffle sculpin (*Cottus gulosus*) was never present in Clear Lake (Jordan and Gilbert 1895; Murphy 1951; P.B. Moyle, University of California Davis, personal communication, August 2008).

[c] The species of silversides introduced into Clear Lake was Mississippi silversides (*Menidia audens*) not inland silversides (*Menidia beryllina*) as some literature suggests. Previously the two species were considered one species but they are currently considered two distinctly separate species (Nelson et al. 2004; P.B. Moyle, University of California Davis, personal communication, August 2008).

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Sympatry in California tiger salamander and California red-legged frog breeding habitat within their overlapping range

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Co-occurrence of two or more species of bi-phasic amphibians—those whose larvae develop in aquatic habitats and become terrestrial, air-breathing adults at metamorphosis—is extremely common in North America (Petranka 1998, Lannoo 2005, Stebbins and McGinnis 2012). In California, sympatry in amphibians occurs among a wide range of genera and species, including various assemblages of *Ambystoma, Taricha, Dicamptodon*, *Pseudacris, Spea, Anaxyrus, Rana, Lithobates,* and others (Storer 1925, Petranka 1998, Stebbins 2003, Lannoo 2005). The terrestrial stages of northwestern salamander (*Ambystoma gracile*) and California giant salamander (*Dicamptodon ensatus*), for instance, are commonly found under the same cover and often breed in the same aquatic habitats (Storer 1925, Stebbins 2003). Similarly, the rough-skinned newt (*Taricha granulosa*) and California newt (*T. torosa*) are often found together in both terrestrial and aquatic breeding habitat where the species overlap (Stebbins 2003, Stebbins and McGinnis 2012).

The California tiger salamander (*Ambystoma californiense*) is associated with uplands within grasslands, oak savanna, open oak woodlands, and localized areas of coastal scrub and chaparral in central California (Storer 1925, Trenham 2001, Wang et al. 2009). This species is known to reproduce in vernal pools, stock ponds, artificial wetlands and, occasionally, in slow-flowing swales and creeks situated near other suitable breeding habitat (Storer 1925, Twitty 1941, Trenham et al. 2001, Alvarez 2004a, Alvarez et al. impress). The range of California tiger salamanders overlaps other native amphibians including Santa Cruz long-toed salamander (*A. macrodactylum croceum*), Sierran treefrog (*Pseudacris sierra* [= Pacific treefrog; *P. regilla*]), western toad (*Anaxyrus boreas*), western spadefoot toad (*Spea hammondii*), and others (Storer 1925, Twitty 1941, Anderson 1968, Feaver 1971, USFWS 2003).

The California red-legged frog is closely associated with aquatic freshwater habitats surrounded by grasslands, chaparral, woodlands, and other forest habitat types (Storer 1925, Hayes and Jennings 1988, Bulger et al. 2003, Allaback et al. 2010). Like the California tiger salamander, the range of the California red-legged frog overlaps, and the species is frequently sympatric with, other native amphibians in their aquatic breeding habitat, including California newt, rough-skinned newt, Sierran treefrog, western toad, and American bullfrog (*Lithobates catesbeianus*) (Storer 1925, Feaver 1971, Hayes and Tennant 1985, Rathbun 1998, Cook and Jennings 2007).

Distinct population segments of the California tiger salamander are listed as either endangered or threatened under the federal Endangered Species Act, and threatened under the California Endangered Species Act. The California red-legged frog is listed as threatened under the federal Endangered Species Act and is a species of concern within California. Both species are in decline (Fisher and Shaffer 1996; USFWS 2002, 2003), and mitigation development and land management decisions for one species may affect both.

When rare animals are sympatric and also protected by state or federal law, the management implications may be substantial. This is particularly true when management activities require actions within aquatic breeding sites for a specific listed species. If management activities are focused on one species and the other is not considered, the actions may result in changes to reproductive success, elimination of habitat for one or more life stages, or direct or indirect harm of the untargeted, but sympatric, species.

We report here numerous accounts of sympatry in the breeding habitat of two protected amphibians that have not been reported elsewhere that may affect management of both species. We used data collected during various independent amphibian larval survey projects over a large area within the range of California tiger salamander and California red-legged frog (Figure 1, Table 1). The data in this report came from sites where each of us worked ≥2 years, and where we visited sample sites multiple times. During our respective investigations, each of us considered the phenology of both species in order to increase their potential detection within habitat that was surveyed. Specifically, our surveys were timed such that both species were known to be, or presumed to be, in their larval life stages during sampling efforts (i.e., typically March through July), which occurred prior to drying of most ephemeral ponds in each drainage.

Our sampling sites included ponds with a wide range of physical characteristics including: perennial and ephemeral; natural and constructed water bodies; turbid to clear waters; large and small aquatic sites (0.1 acres–8.1 acres); deep and shallow water bodies (0.4 m–15 m); low to high elevation sites (25 m–1000 m); sites nested within grasslands, woodlands, and chaparral; water bodies that were grazed and ungrazed; and

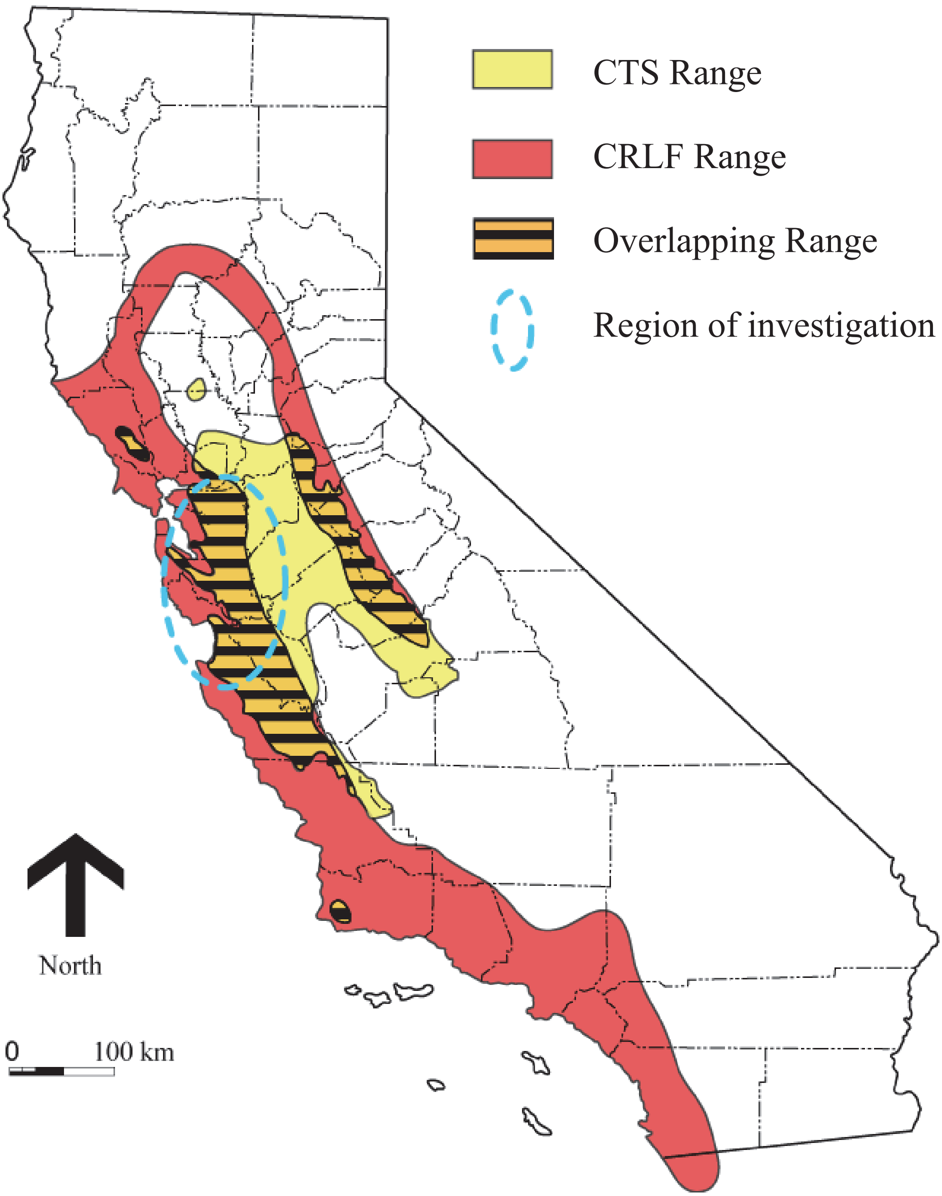

FIGURE 1.—The ranges of California tiger salamander (CTS) and California red-legged frog (CRLF), areas of overlapping range, and the region of our sites of investigation in Alameda, Amador, Butte, Calaveras, Colusa, Contra Costa, El Dorado, Fresno, Glenn, Kern, Kings, Lake, Los Angeles, Madera, Marin, Mariposa, Mendocino, Merced, Monterey, Napa, Nevada, Orange, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Diego, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus, Tehama, Tulare, Tuolumne, Ventura, Yolo, and Yuba, counties, California, 2012. Geographical distributions of CTS and CRLF were adapted from Fisher and Shaffer 1996, USFWS 2002, USFWS 2003, and Stebbins 2003.

Table 1.—Location and frequency of observed sympatry of California tiger salamanders (CTS) and California red-legged frogs (CRLF) in Alameda, Contra Costa, Monterey, and Santa Clara counties, California, 2012. The number of water bodies surveyed within each watershed (*n*) are categorized by major habitat type.

County	Watershed	Water Body	*n*	CTS and CRLF Sympatric
Alameda	Corral Hollow	stock pond	2	1
	Corral Hollow	creek	1	1
Contra Costa	Bethany	stock pond	11	10
	Brushy	creek	1	1
	Brushy	stock pond	9	6
	Cayetano	stock pond	4	1
	Kellogg	stock pond	90	76
	Marsh	stock pond	5	2
	Tassajara	stock pond	3	3
Monterey	Robinson Canyon	stock pond	5	3
	Potrero Canyon	stock pond	7	3
Santa Clara	Arroyo Aguaje	stock pond	42	4
	Las Animas	stock pond[a]	22	6
	Shingle Valley	stock pond[b]	18	11
Total			220	128

[a] four ponds in this watershed were categorized by MLA as "stock pond/impoundment"
[b] all ponds in this watershed were categorized by MLA as "stock pond/impoundment"

those characterized by large amounts of emergent vegetation (~75% cover) to no emergent vegetation (0% cover), as well as other characteristics. We made no effort, however, to analyze physical characteristics because we did not always measure those characteristics during the surveys. We included all ponds surveyed within a watershed without regard to a subjective standard for suitability. In most cases, investigators used seines and hand-held dip nets to capture specimens; occasionally, species were detected visually during site visits.

This investigation was not originally coordinated among the respective authors. Data sets from each author were collected in different or overlapping years, and our data were assembled by the lead author and analyzed *a posteriori*. Therefore, specific methodologies were not necessarily consistent among our respective sites. Some investigators used systematic timed surveys that were concluded if target species and numbers were collected, while other investigators dip-netted or seined a specific number of times per linear distance of pond edge. We also recognize that these species do not naturally occur in ponds to the extent we see them today, yet the majority of sites at which we focused survey efforts were of this habitat type. Further, we recognized the inherent bias in analyzing these disparate data, and acknowledge that our analyses may result in an underestimation of the phenomenon of overlapping breeding habitats.

Each investigator was able to identify larvae of both species during single survey efforts. On numerous occasions, both species were present within the same dip net or seine haul. Among the four counties in which we worked, the larvae of California tiger salamanders and California red-legged frogs were sympatric in 12% to 100% of water bodies investigated. When our data were combined, within the 218 ponds and two creeks, we detected sympatry between these two species at 58.2% of sites. We found California tiger salamanders and California red-legged frogs to be sympatric within breeding habitat in 12 watersheds in four counties in California in the same year.

Methodological differences could have resulted in the underestimation of aquatic breeding habitat overlap—a bias that may further indicate sympatry of breeding habitat between the two species. Our data generally came from observations conducted during other work, which resulted in some confounding factors, as follows: (1) California tiger salamanders rarely breed in creeks (Alvarez et al., in press), and we encountered them only while surveying for California red-legged frogs. Creek habitats were not surveyed with the same regularity, seasonal timing, and thoroughness as were ponds, and this may have caused us to underestimate co-occurrence in lotic habitat. (2) California red-legged frogs are only rarely observed in vernal pools, which often have short hydroperiods, so efforts to detect specimens in ephemeral pools may have underestimated their use of that habitat type. (3) In some pond habitats (i.e., warm-water ponds), the relatively compressed ontogeny of the California tiger salamander allows some individuals to reach a large size relatively early in the season. This is especially true in perennial ponds and under certain conditions where overwintering members of this species can grow very large (Alvarez 2004b, Wilcox et al. in press). These large individuals can, and will, feed on the larvae of anurans, and predation could contribute to an underestimate of the presence of California red-legged frogs (see Feaver 1971). (4) Perennial and long-lived ephemeral pond systems can accumulate large amounts of submergent aquatic vegetation, which can reduce detection rates of one or both species. Finally, (5) recent work has shown that California tiger salamanders can persist in uplands surrounding aquatic breeding habitat and may breed only intermittently (once in two to eight years), causing the species to be undetectable during aquatic breeding habitat surveys over multiple-years (Trenham et al. 2000; J. A. Alvarez and M. A. Shea, unpublished data).

In addition to breeding-period sympatry within the aquatic breeding habitat type, California red-legged frogs and California tiger salamanders, which are known to overwinter as larvae in separate locations, may also overwinter together (Fellers et al. 2001, Alvarez 2004b, Wilcox et al. in press). The presence of overwintering larvae of one or both species should be considered in the timing of management actions affecting aquatic breeding habitat or adjacent areas. Other management concerns, such as hydroperiod, extent of emergent vegetation, presence of potential predators, or intermittent breeding, may also vary between the two species. Nonetheless, our observations suggest that aquatic breeding habitat that is preserved or created within the range of both species—although frequently developed and managed for only one species—may well be utilized by both. In our aggregate observations we detected both species in the same aquatic breeding habitat 58.2% of the time, and over a large geographic area. This degree of overlap suggests that management techniques used for one species may very well benefit, or potentially harm, the other when both species are present. As a result, habitat requirements of both species should be carefully considered when developing or managing aquatic breeding sites, particularly ponds, within the overlapping range of these amphibians. Additional investigations may further validate the pattern of sympatry among California tiger salamanders and California red-legged frogs within different aquatic habitats, and over a large area within their overlapping geographic ranges.

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Group size dynamics of female Roosevelt elk in Redwood National and State Parks, California

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Roosevelt elk, *Cervus elaphus roosevelti*, have inhabited the area in and around Prairie Creek and lower Redwood Creek drainages in Redwood National and State Parks for at least a century (Harper et al. 1967). In this small (<60 km^2) geographic area, five distinct groups of elk have been identified (Franklin et al. 1975, Bowyer 1981, Jenkins and Starkey 1982, Weckerly et al. 2004). These groups are mainly comprised of females, juveniles and sub-adult males, and we refer to them as female groups. The individuals in these groups are socially bonded and may spend their entire lives together (Leib 1973, Franklin et al. 1975, Weckerly 1999, Bowyer 2004). The high degree of social bonding may be associated with the landscape configuration and arrangement of habitats, lack of timber harvest or forest fires that alter composition of habitats, and availability of foraging habitat (Jenkins and Starkey 1982, Weckerly 2004). Foraging habitat for elk in this landscape is primarily grassland that occurs in discrete patches in the lowlands of the coastal redwood (*Sequoia sempervirens*) forest; forage in grasslands is of much higher quality and more abundant than in forests (Jenkins and Starkey 1982, Weckerly 1999).

Since the female groups in the Prairie Creek and lower Redwood Creek drainages occupy a small geographic area, the environmental settings experienced by each group of elk likely are similar and, if that is the case, temporal changes in group sizes should also be similar. If temporal variation among group sizes is correlated, the five herds can be considered as a single unit for management purposes. If temporal variation among groups is not correlated, then management options for each female group should be considered separately from the others. Our study was conducted in order to ascertain whether or not temporal variation in sizes of female groups was correlated across 14 years.

The Prairie Creek and lower Redwood Creek drainages are located in the western portion of Redwood National and State Parks (RNSP; 41° 20' N, 124° 2' W), Humboldt County, California (Figure 1). To include the Gold Bluffs Beach herd, our study extended 3 km to the west of the Prairie Creek drainage and to the north of the lower Redwood Creek (Franklin et al. 1975). The climate is maritime, and extreme seasonal variations are rare;

Figure 1.—Map of the Prairie Creek and Lower Redwood Creek drainages in Redwood National and State Parks, Humboldt County, California, showing herd ranges of Roosevelt elk described in this paper. The ranges were delineated based on locations where elk were observed from 1997–2010. There were 10 counts each year (except for 1998 and 1999 when only 5 counts occurred) for the Boyes and Davison groups, and one to four counts each year of the other groups.

annual temperatures range from an average of 7.2° C in winter to an average of 20.5° C in summer. Average rainfall is 175 cm per year. The Prairie Creek and lower Redwood Creek drainages are composed of a series of meadows interspersed within temperate rainforests, and are strongly influenced by coastal fog, especially in the summer. The forests within RNSP are dominated by coastal redwood and Sitka spruce (*Picea sitchensis).* Other common tree species include bigcone Douglas-fir (*Pseudotsuga menziesii*), tanoak (*Lithocarpus densiflorus*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*) and red alder (*Alnus rubra*). The groups of elk occupied a series of grasslands (meadows) that exist within an area of approximately 60 km^2 (Weckerly 1996). Meadow vegetation is composed of annual and perennial grasses and forbs, including California oat grass (*Danthonia californica*), soft chess (*Bromus hordeaceus*), redtop (*Agrostis alba*), and bracken ferns (*Pteridium aquilinum*) (Weckerly et al. 2001).

Data were collected from September through February each year from 1997 to 2010. Elk were counted by FWW and park biologists one to ten times each year (Weckerly 1996, 2007). Because female groups inhabit distinct meadows most of the time, sighting probabilities of females are high (≥0.90) (Franklin et al. 1975, Jenkins and Starkey 1982, Weckerly 2007). Hence, the probability of detecting all females, juveniles and sub-adults in a group was quite high across four or more counts (e.g., the probability of detecting all elk was 0.99 across four counts, $1–(1–0.9)^4 = 0.99$), and we treated our count data as a reliable index to group sizes. The highest count was accepted as the group size for any particular year. Elk groups were identified by name based on the area they utilized: Boyes, South Operations Center (SOC), Gold Bluffs, Levee, and Davison. The Boyes and Davison groups were counted by FWW and the SOC, Gold Bluffs, and Levee groups were counted by park biologists. Growth rate for each year was calculated using the standard geometric growth rate formula, N_{t+1}/N_t, where t is the year.

The growth rates for the five groups were estimated using Excel. Pearson's correlation coefficients were estimated between growth rates of all possible pairs of groups. We also tested whether correlation coefficients were statistically significant (P-value <0.05; Sokal and Rohlf 2012).

There was a general decline in size of all five groups over 14 years (Figure 2). The largest number of animals occurred in the Levee group, which had 38 females in 2000. In 2010, the Boyes group consisted of only two individuals. The Boyes group had the lowest average annual growth rate at 0.79. The group with the highest average growth rate was the Levee group (1.03, $SD = 0.26$). The three other groups showed similar average growth over the 13 years of the study, Davison (0.97, 0.15), SOC (0.97, 0.17) and Gold Bluffs (0.98, 0.30).

We did not detect any strong correlations between the growth rates of nine out of the ten pairwise comparisons (Table 1), but there was a significant negative correlation between the SOC and Boyes groups. We view that correlation as spurious for two reasons. First, these two groups were the farthest apart of all the herds (Figure 1). We are hard pressed to offer ecological reasons why these groups should have growth rates that were associated, while groups that are closer to each other had uncorrelated growth rates. Additionally, because there was only one significant correlation detected among the ten correlations estimated, the single significant correlation might be due to random chance (Sokal and Rohlf 2012).

The geographic area in which the groups exist is relatively small (<60 km^2), and the ecological conditions throughout the region where the groups exist are probably similar;

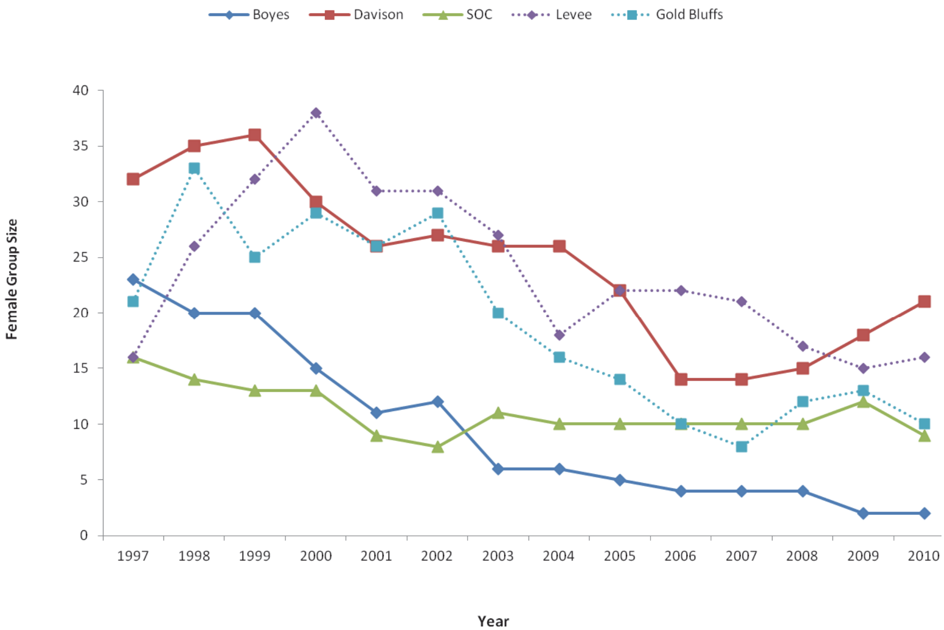

FIGURE 2.—Line plot showing the maximum group size of each of the five female groups of elk in the Lower Prairie Creek drainage of Redwood National and State Parks, Humboldt County, California, 1997–2010.

TABLE 1.—Pearson's correlation coefficients among growth rates for female elk groups in the Lower Prairie Creek Drainage of Redwood National and State Parks, Humboldt County, California, 1997–2010. Numbers in italics are the associated *P*-values.

	Group			
Group	Boyes	Davison	SOC	Levee
Davison	0.13			
	0.66			
SOC	-0.63	<-0.01		
	0.02	*0.99*		
Levee	0.10	0.02	-0.17	
	0.75	*0.95*	*0.59*	
Gold	0.11	0.34	-0.11	0.38
Bluffs	*0.71*	*0.26*	*0.72*	*0.21*

thus, it is reasonable to expect synchrony in group size changes. Gogan and Barrett (1994) showed that fecal nitrogen values, an indicator of diet quality, were similar for animals from the Boyes and Gold Bluffs groups. Weckerly et al. (2004) showed that cropping rates of females from the Boyes and Davison groups that foraged in different meadows were similar. Also, risk from predators should be similar, as elk predators such as mountain lions and black bears exist throughout the Prairie Creek and lower Redwood Creek drainages (Harper et al. 1967). Nonetheless, there are also dissimilarities among the areas in which the groups exist. For example, the Boyes group inhabits a meadow intersected by U.S. Highway 101 and individuals are at a higher risk of collision with vehicles. Individuals in the Gold Bluffs area may wander out of the park and, thus, be more vulnerable to harvest on properties that lie adjacent to the parks. This is also true of the SOC and Levee herds, from which some animals have been taken by hunters when they leave the parks.

Uncorrelated growth rates among the herds in such a small geographic area may be due to the ecological conditions within the Prairie and lower Redwood Creek drainages. Site fidelity has been noted before in elk groups, especially among the female members (Jenkins and Starkey 1982, Weckerly 1996, Van Dyke et al. 1998, Weckerly et al. 2001, Millspaugh et al. 2004). Ecological reasons that have been postulated for this behavior include the benefits that the group receives through the maintenance of site fidelity and social bonding. Social bonding among females promotes knowledge transfer of prime foraging patches and how to lower the risk of predation (Harper et al. 1967, Franklin and Leib 1979, Millspaugh et al. 2004). The climate in the Prairie Creek and lower Redwood Creek drainages in Redwood National and State Parks is relatively consistent and forage is available throughout the year (Harper et al. 1967). There might be few benefits to forage acquisition for groups that venture out of their occupied meadow.

We conclude there was little temporal synchrony among groups in abundance dynamics. Maximum size of all five groups declined from the late 1990s to 2010. However, both the Davison and Levee group showed an early increase in group size, with Davison showing a general increase in individuals from 2006 to 2010 and Levee from 2009 to 2010 (Figure 2). The Boyes group may have gone extinct in 2011 (F. W. Weckerly, unpublished data). Since a general decline in group size is evident within the elk groups in the Prairie and lower Redwood Creek drainages, annual monitoring of each individual group is warranted.

Monitoring of the female groups in the Prairie and lower Redwood Creek drainages can be conducted with less logistical burdens and cost than conventional aerial survey techniques. Due to the high sighting probabilities of females, counts do not need to be adjusted for imperfect detection when estimating group size. Since adult female survival often has the greatest impact on population persistence in polygynous species (Gaillard et al. 1998), monitoring of female group sizes will provide useful information on long-term distribution, abundance, and viability of elk in the lower Prairie and Redwood Creek drainages (Weckerly 1996, Weckerly et al. 2004). Even in a small geographic area, group dynamics of distinct elk herds can behave differently.

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Pink salmon *(Oncorhynchus gorbuscha)* in the Salinas River, California: new record and historical perspectives

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Pink salmon *(Oncorhynchus gorbuscha)* are widely distributed in northern latitude coastal streams of North America and Asia, but the Puget Sound region is generally regarded as the southernmost extent of their recent spawning range on the west coast of North America (Heard 1991). Although observations of them are now uncommon, pink salmon have long been known to occur in California (Jordan and Evermann 1896, Moyle 2002, Moyle et al. 2008) and have even been reported south of the San Francisco Bay in the San Lorenzo River (Monterey Bay; Scofield 1916), Lagunitas Creek (Tomales Bay; Moyle et al. 2008), the Sacramento River and its tributaries (Hallock and Fry 1967) and, in 1945, the Scripps Institution of Oceanography verified the identity of a pink salmon that had been caught as far south as La Jolla, California (Hubbs 1946).

On 24 August 2011, four pink salmon were captured on the Salinas River, Monterey County, California, approximately 7 km upstream of the river mouth. Three of the four fish were male and had prominent spawning morphology (a humped back and hooked snout). Photographs of the fish (Figure 1) were taken moments after capture and were used by local experts to verify their identity. After being photographed, the fish were returned to the Salinas River.

From its headwaters in the La Panza Range of San Luis Obispo County, the Salinas River travels approximately 275 km in a northwesterly direction to its mouth (36° 44' 58"N, 121° 48' 18"W) in the Monterey Bay, California. At its terminus, the Salinas River forms a seasonally perched lagoon. The Monterey County Water Resources Agency (MCWRA) implemented the Salinas Valley Water Project (SVWP) in 2010, which included construction of a surface water diversion facility (36° 42' 32" N, 121° 45' 2" W; hereafter SRDF).

FIGURE 1.—Male pink salmon captured in the Salinas River, Monterey County, California; this is one of 4 individuals captured at the same location (36° 44' 58" N, 121° 48' 18" W) on 24 August, 2011. Photograph by Tom D. Skiles.

The SRDF is located approximately 7 km upstream from the river mouth on the mainstem Salinas River and includes an inflatable Obermeyer dam that impounds and diverts surface water (maximum head of 3 m above sea level) between 30 April and 1 October, a pump station, and a fish ladder. In order to supply surface water to the SRDF during dry summer months, the MCWRA increased summer releases from Nacimiento and San Antonio reservoirs. Those reservoirs lie approximately 160 km upstream from the river mouth. Prior to implementation of the SVWP, the Salinas River would typically dry in the summer months and the lagoon would remain disconnected or "closed" until fall or winter storm flows breached the lagoon. In the summer of 2011, however, the Salinas River flowed from Nacimiento Reservoir to the mouth of the lagoon and, as a result, was open to the Monterey Bay.

In 2011, erosion downstream of the fish ladder necessitated in-channel structural repairs. In August, the MCWRA installed a temporary coffer dam perpendicular to river flow, approximately 90 m downstream of the diversion facility. The area between the inflated Obermeyer and the temporary coffer dam was dewatered so that heavy equipment could enter the channel. As the work area was being dewatered, fish were rescued from isolated pools using long-handled dip nets. The four pink salmon were located in one such pool, immediately downstream of the Obermeyer dam.

There is a long history of pink salmon (also known as humpback salmon) occurrences over widely dispersed points along the northern California coast, and even in the Central Valley system (e.g., Snyder 1931, Taft 1938, Hallock and Fry 1967, Moyle et al. 2008). During the late-19th century, pink salmon were included in the commercial salmon catch sent to San Francisco markets from Humboldt County fisheries on the north coast of California that, in that early period, comprised only bay and in-river fishing (Collins 1892).

For the early Central Valley salmon fishery, the California Fish Commission (CFC 1880:53) reported that pink salmon were found in the Sacramento River, which they ascended "in tolerable numbers in October." Jordan and Evermann (1923:150d) also wrote of pink salmon, "In the Sacramento River it occurs each year but in very limited numbers and is there known as the lost salmon" (also Jordan and Evermann 1896:478). It is evident that pink salmon were occasionally observed, but were a very minor component of the native Central Valley salmonid fauna recognized by early Sacramento River commercial fishermen. Indeed, Hallock and Fry (1967:13) reported, "Many commercial gill-net fishermen who formerly fished for salmon in the Sacramento River have also fished for pink salmon in Alaska. These men recognize the species and some of them remember having taken an occasional pink in the Sacramento. Vincent Catania, a former Sacramento River gill-net fisherman now employed by the Department of Fish and Game, estimated that 30 years or so ago, in some seasons, the entire fishing fleet would take perhaps a dozen of these fish. Other fishermen recall the number as being higher than this." Notably, several pink salmon were caught at the U.S. Fish Commission's Baird Station on the McCloud River in September 1891, >480 km upriver from the San Francisco Bay-Estuary. As reported by Station Superintendent George B. Williams (USFC 1894: LVII), "In the latter part of September, after the close of the first run of the quinnat [Chinook] salmon, there were caught in one of the traps two females and one male of the humpback salmon (*Oncorhynchus gorbuscha*), which were spawned, the eggs hatched at the station, and in February the fry planted in the McCloud River."

Pink salmon continued to occur in the Central Valley through the 20th century. One specimen was reported at the U.S. Bureau of Fisheries egg-taking station on Mill Creek in 1933 (Taft 1938). In a concerted review of records from salmon studies and hatchery operations in the Central Valley during 1949–1958, Hallock and Fry (1967:13) found that a total of 38 pink salmon had been "taken, identified, and recorded from the Sacramento River system." In contrast to adults, reports of pink salmon progeny are exceedingly rare anywhere in California, but in March 1990 seven pink salmon smolts reportedly were salvaged at the State's J. E. Skinner Fish Protective Facility near Tracy (D. McEwan, California Department of Fish and Game [CDFG], personal communication, 17 October 1990).

In the early 20th century, Snyder (1931) indicated that pink salmon had been reported from the Salinas River, but he presented no data or documentation in support of his statement. According to Snyder (1931:16), "Humpback [pink] and dog [chum] 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. Both species occur as far south as Salinas River."

Over subsequent decades, pink salmon repeatedly appeared in California coastal streams, occasionally in substantial numbers. Taft (1938:198) cited reports from CDFG wardens that in 1937 there were "many quite large schools of them" in Ten Mile River in Mendocino County, "several hundreds" in the Garcia River in Mendocino County, "spawning all over from the Red Bridge to the western boundary of the Indian Reservation, a distance of about two miles" and unspecified numbers were observed in the Russian River. Subsequently, small numbers of pink salmon have been caught from, or have been observed spawning in, the Russian River, Sonoma and Mendocino Counties, in occasional years (Fry 1967). For example, a sport fisher landed two pink salmon (1 male, 1 female) from the Russian River in October 1955; those two spawners were acquired by a CDFG agent who subsequently found four additional spawned-out pink salmon carcasses (2 males, 2 females). Later that month, a CDFG biologist observed pink salmon spawning on "at least six different nests" with several females and males, plus another decomposed post-spawn (female) carcass (Fry 1967).

In more recent years, adult pink salmon occurred in the Russian River in 2003 and 2008 (Chase et al. 2005; S. Chase, Sonoma County Water Agency [SCWA], personal communication, 22 October 2012) and in the lower Garcia River during multiple years (including at least 23 pink salmon redds in the lower Garcia River in 2003), while small numbers of juvenile pink salmon were caught in outmigrant traps on Redwood Creek in 2000, 2002, 2004 and 2005 (Moyle et al. 2008). In September and October of 2011 three pink salmon were captured and identified in Big Creek and its tributary, Devils Creek, in Monterey County (36° 4' N, 121° 35' W; approximately 80 km south of the mouth of the Salinas River) within the University of California's Landels-Hill Big Creek Reserve (T. H. Williams, National Oceanic and Atmospheric Administration, personal communication, 11 January 2012). Most records of adult pink salmon in California are for odd years, possibly suggesting a relationship to the Puget Sound runs which are mostly (12 of 13 runs) odd-year spawners (Hard et al. 1996). Although pink salmon are occasionally caught further south in the ocean (Hubbs 1946, Moyle 2002), the pink salmon captured on the Salinas River, Big Creek, and Devils Creek are the southernmost verifiable accounts of this species in fresh water on the west coast of North America.

The pink salmon captured on the Salinas River clearly were in spawning morphology and their timing is consistent with spawning patterns of the species (Hard et al. 1996). Operation of the SVWP created a passage opportunity that in most years had not existed. The 2011 findings suggest that pink salmon have the ability to establish new populations if opportunities present themselves. Despite our incomplete understanding of salmonid straying, there are recognizable population-scale benefits to this behavior. For example, straying may lead to the colonization of new habitat (Milner and Bailey 1989) or, conversely, to the avoidance of degraded habitat (Leider 1989). On the other hand, it is likely that central-coastal California streams were, on occasion, utilized by small runs of pink salmon that went unnoticed because of their short residence time in fresh water and their tendency to spawn in the lowermost reaches of streams, which made them difficult to detect in small numbers (Moyle 2002).

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James D. Yoakum (1926–2012)

The wildlife profession lost a dedicated colleague on 21 November 2012 with the passing of Jim Yoakum. Born in Templeton, California, Yoakum served in the U.S. Navy from 1944 to 1947. Using the GI Bill, he was the first in his family to attend college, and graduated with a degree in wildlife management from Humboldt State College in 1953. Jim proceeded on to Oregon State University on a fellowship and, in 1957, he completed his thesis on Oregon's pronghorn population under the supervision of Dr. Arthur Einarson.

Shortly thereafter, Jim was hired as the Bureau of Land Management's (BLM) first wildlife biologist, and was stationed in Ely, Nevada, where he also wrote a newspaper column on wildlife. His writing and photographs attracted the attention of Nevada BLM Director J. Russell Penny, who wanted Jim to highlight BLM's role in maintaining important wildlife habitat. Eventually, Jim published the first brochure featuring wildlife on public lands.

As BLM's wildlife representative, Jim had numerous demands on his time including the rebuilding of bighorn sheep populations on public lands. When the Devil's Hole pupfish was threatened with extinction from groundwater pumping, Jim attended the fledgling Desert Fishes Council meetings. Yoakum incurred the wrath of Nevada BLM Director Nolan Keil when he transferred funds from Elko to Las Vegas to build a wild horse exclusion fence to protect pupfish, but U.S. Secretary of Interior Stewart Udall praised his effort. In contrast to most BLM employees, who tended to relocate every few years, Yoakum spent his entire career as a wildlife biologist in Nevada. In 1967, he purchased land in Verdi, on the California-Nevada border, and this became his home — shared with his dogs, his garden, and his various collections of pronghorn art and Navy plates. Over the years, Jim also had acquired a near complete collection of *California Fish and Game*, and he provided duplicate issues from his collection to help others accomplish that goal.

Yoakum retired from BLM in 1986, but continued working with pronghorn as a consultant and researcher, and also taught classes at the University of Nevada. In 1990, Jim was very excited that the California Department of Fish and Game pursued the translocation of pronghorn antelope from Likely Tables, in Modoc County, to the Carrizo Plain, San Luis Obispo County, near his birthplace. During retirement, he continued to give presentations and publish, amassing >50,000 photographs and >50 professional papers. Among those are a number of chapters on habitat management techniques that appeared in several editions of *The Wildlife Techniques Manual*. Jim's magnum work, published in 2004, was *Pronghorn Ecology and Management*, which he co-authored with Bart O'Gara, and for which they shared The Wildlife Society's Outstanding Editorship Award in 2005.

Jim was a strong and dedicated supporter of the Biennial Pronghorn Workshop, which in December 2012 held its 25th meeting. In 2002 he was the recipient of its Berrendo Award, given in recognition of substantive contributions to the ecology and conservation of pronghorn. Additionally, Jim was an active member of the Desert Bighorn Council for nearly five decades, and attended the 50th Anniversary Meeting of that organization in 2007.

Yoakum was an advocate for all wildlife professionals, and was active in The Wildlife Society (TWS) — which he became a member of in 1952 — and he was especially active in the Western Section of TWS. Working with other wildlife professionals, Jim helped to produce an educational program called "Silver Mammals" that was distributed to Nevada schools and libraries, and led to the production of "Golden Wildlife," a series of photographs with accompanying natural history summaries about California wildlife. In recognition of Jim's many contributions, The Western Section established the James D. Yoakum Award to recognize individuals that have provided outstanding long-term service, support, and commitment to furthering the Section's goals and facilitating its programs and operations. The Yoakum Award is unique, in that it recognizes service to the organization, rather than contributions to wildlife management or conservation.

Jim has been quoted as saying, "Wildlife has been my entire life. All my life." Jim's many friends — some of whom were initially surprised by what they interpreted to be a gruff personality, but that shared his love of wildlife and the outdoors — enjoyed his social, hospitable, and well-informed (but sometimes dogmatic) conversations, during which he often played the role of Devil's advocate. Those of us that knew Jim would likely emphasize his friendliness and collegiality, in addition to his commitments to wildlife conservation and the wildlife profession.

Perhaps the most meaningful acknowledgment of Jim's contributions appeared on a memory page (http://wildlifeprofessional.org/western/memorial_view.php), and was posted by a close friend and colleague who wrote, "Jim leaves a big void of scientific expertise and knowledge about a species few today seem to care about. But more importantly, Jim's deep commitment and caring for sound stewardship, even when it was unpopular with the agencies, is becoming a rarity in our profession. He leaves a legacy few can match." — *Friends and colleagues of James D. Yoakum* [adapted, in part, from http://wildlifeprofessional.org/western/memorial_view.php]

Books Received and Available for Review

Individuals interested in reviewing any of the books listed below should contact the editor (Vern.Bleich@wildlife.ca.gov) and indicate an interest in doing so.

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

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

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

Letter to the Editor

Dear Editor:

I read with some amusement your note in the fall issue regarding problems removing the closures on mailed issues (so I'm not the only one!). There is a solution to removing the sticky closures, albeit a somewhat cumbersome one. Although this sounds like a lot of work, it takes only a few minutes.

1. Purchase rubber cement thinner (available at arts supply stores)
2. Slit the closures and open the issue
3. Generously apply the thinner to a rag or paper towel
4. Open the issue to the *inside* of the cover
5. Apply the thinner to the area opposite (i.e., on the backside of) the closure(s) — soaking the paper. Because the plastic closures are impervious to the thinner, it is critically important to *apply it to the back side* to moisten the adhesive.
6. Turn the cover over and easily peel off the closure(s)
7. Rub a thinner-moistened rag on the surface where the closure(s) were attached to remove residual adhesive
8. Repeat this on both the front and back covers
9. The white strip with the bar code can also be removed with this technique, but can be applied to the upper surface of the strip, as it's pervious to the thinner
10. The thinner will evaporate and leave no stain on paper

Regards,
/S/ Phil Lebednik

Information for Contributors

California Fish and Game is a peer-reviewed, scientific journal focused on the biology, ecology, and conservation of the flora and fauna of California or the surrounding area, and the northeastern Pacific Ocean. Authors may submit papers for consideration as an article, note, review, or comment. The most recent instructions for authors are published in Volume 97(1) of this journal (Bleich et al. 2011), and are accessible through the California Department of Fish and Wildlife web site (www.dfg.ca.gov/publications).

Planning is in progress to provide an avenue for authors to submit manuscripts directly through the web site, and to enable restricted and confidential access for reviewers. In the meantime, manuscripts should be submitted by e-mail following directions provided by Bleich et al. (2011). The journal standard for style is consistent with the Council of Science Editors (CSE) Style Manual (CSE 2006). Instructions in Bleich et al. (2011) supersede the CSE Style Manual where differences exist between formats.

Authors of manuscripts that are accepted for publication will be invoiced for charges at the rate of $50 per printed page at the time page proofs are distributed. Authors should state acceptance of page charges in their submittal letters. The corresponding author will receive a PDF file of his or her publication without additional fees, and may distribute those copies without restriction. Plans are underway to make the complete series of *California Fish and Game* available as PDF documents on the California Department of Fish and Wildlife web site.

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