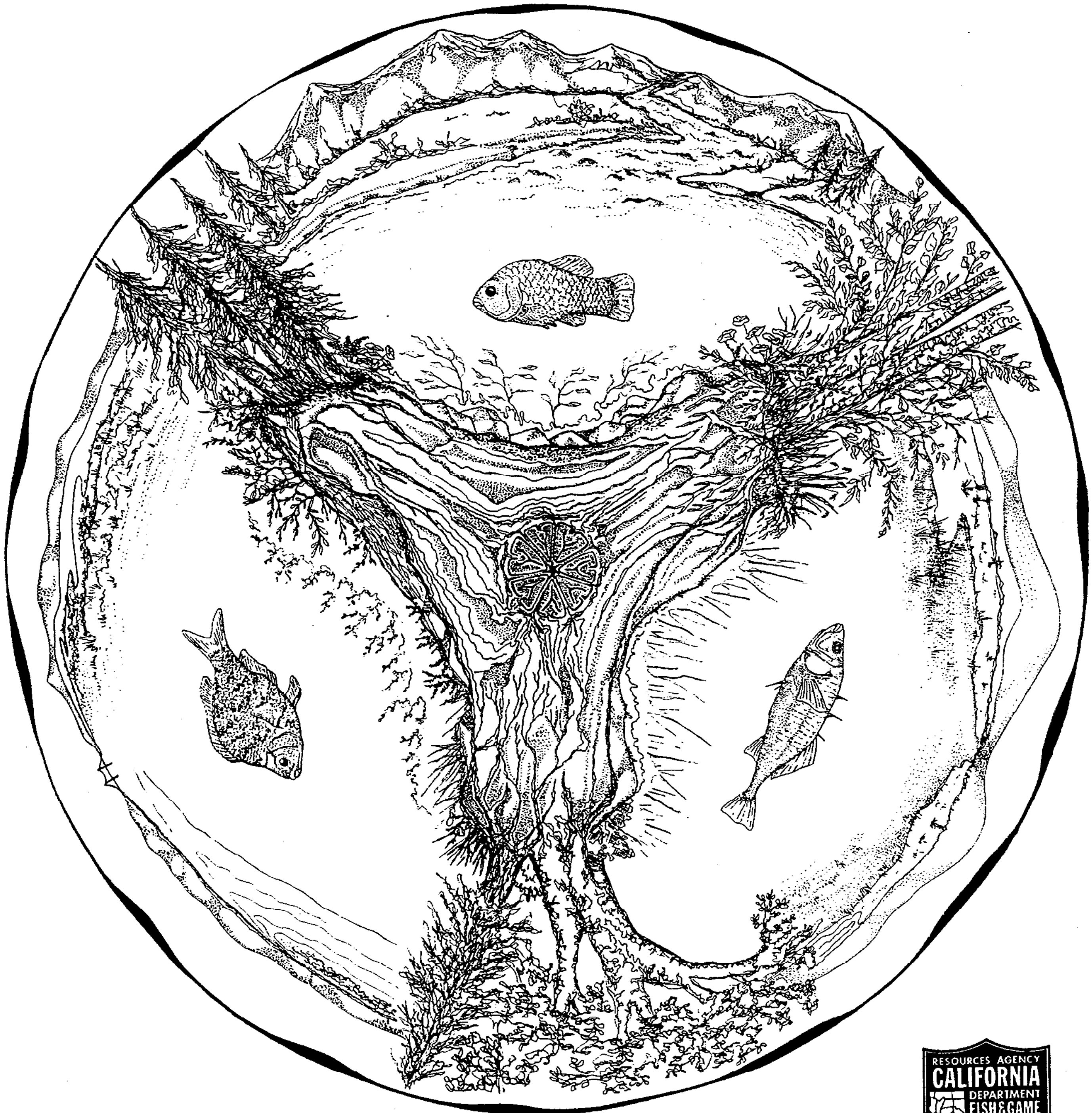
FISH SPECIES OF SPECIAL CONCERN IN CALIFORNIA

Second Edition



CALIFORNIA DEPARTMENT OF FISH AND GAME

RESOURCES AGENCY CALIFORNIA DEPARTMENT FISH & GAME

FISH SPECIES OF SPECIAL CONCERN IN CALIFORNIA

Second Edition

by

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The California Department of Fish and Game commissioned this study as part of the Inland Fisheries Division Endangered Species Project. Specific recommendations from this study and in this report are made as options by the authors for the Department to consider. These recommendations do not necessarily represent the findings, opinions or policies of the Department.

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INTRODUCTION

The freshwater fish fauna of California is in serious trouble. Species, subspecies, salmon runs, and unique populations are on a fast track to extinction (Moyle and Williams 1989). The rapid rate of loss is of more than just local interest: 66 of the 116 native fish taxa are found *only* in California, and many of the remainder are shared with only a few other western states. In the event these fishes are lost from California, they will be globally extinct; there are no populations in some distant or remote location that can be used to resurrect the local populations. These fishes represent millions of years of evolutionary response to the fluctuating and often harsh aquatic environments of the state. As a result, there is extraordinary diversity of form and function among the native fishes. They are found in habitats ranging from tiny desert springs, to rivers that have huge fluctuations in flow, to high mountain streams, to shallow alkaline lakes, to salty estuaries. Although the native fishes are admirably suited for surviving the vagaries of nature, they have done poorly when forced to compete with humans for the waters that are their homes. Most streams have been dammed, diverted, turned inside out by mining, or altered by poor watershed management. Many lakes and marshes have been drained or filled in. Waters of all types have been polluted to one degree or another. Furthermore, numerous non-native fishes have been introduced that compete with or prey on the natives.

In the first edition of this report (Moyle et al. 1989) we delineated the severity of the problem by documenting 52 species, subspecies, or salmon runs that required special protection or management to prevent their ultimate extinction. In addition to these 52 taxa, six forms already were extinct and 15 others had been formally listed as threatened or endangered by the state. In total, these 73 taxa represented 64 percent of the freshwater fish fauna of California. Unfortunately, in the short period since the first report, the situation has become substantially worse, in large part because prolonged drought accelerated the declines of many species. In the present report, we have added seven species accounts (green sturgeon[1], longfin smelt, eulachon, chum salmon, Sacramento late-fall run chinook salmon, southern steelhead, and blue chub) and have removed three (Modoc brook lamprey, delta smelt, and winter-run chinook salmon). The lamprey was removed because we no longer regard it as a valid species, and the delta smelt and winter-run chinook were removed because they have been formally listed by the state as threatened or endangered species. Among the forms included in both editions, 19 have been downgraded to a worse category (e.g., from special concern to threatened or endangered) and only two (Gualala roach and Lahontan lake tui chub) have been upgraded.

In this report, we treat 54 taxa (Table 1), of which 25 are recommended for threatened or endangered status in California and 27 others are regarded as needing special attention to prevent further declines. Two of the species are probably extinct in the state (pink salmon, High Rock Spring tui chub), but we include them because some uncertainty about their status still exists. Presently, nine native fish taxa (including the two above) are extinct in California, and 16 are formally listed as threatened or endangered.

The remaining 38 of the 116 native fish taxa are considered still to be secure. However, even the status of the fishes regarded as secure should not be taken for granted. Five of the species newly included in this report were all regarded as secure in 1989 but were added mainly as the result of better information. At least some of the taxa are known to be declining (e.g., winter steelhead, Pacific lamprey) but have not yet reached the point where inclusion in this report is merited. Other taxa were not included

[1] Scientific names for all fishes are given in Table 1

in this report because of lack of information on their abundance (e.g., three subspecies of hitch, mountain whitefish) or taxonomy (e.g., isolated populations of speckled date, California roach, and tui chub).

The decline of California's fishes, and of other aquatic organisms, will continue, and many extinctions will occur unless the widespread nature of the problem is recognized and a systematic effort is made to protect aquatic habitats in all drainages. Moyle and Yoshiyama (1994) proposed a five-tiered approach to protecting aquatic organisms: (1) formal listing of species in imminent danger of extinction, (2) special management for regional clusters of potentially endangered species with similar environmental requirements (Table 2), (3) creation of a system of Aquatic Diversity Management Areas (ADMAs) that includes representatives of all major aquatic habitats statewide, (4) creation of a statewide system of key watersheds. and (5) development of regional landscape management strategies that include multiple watersheds. An ADMA is an aquatic habitat or ecosystem that has as its first management priority the protection of biodiversity. Small ADMAs are essentially equivalent to Significant Natural Areas in the CDFG Natural Diversity Data Base, a designation used mainly for terrestrial ecosystems. Key watersheds are ADMAs that include entire large (<50 km^2) watersheds that possess their natural flow regime. The task of protecting the native aquatic biota using the recommendations of Moyle and Yoshiyama (1992, 1994), or any other system, is extraordinarily difficult because California's human population is growing rapidly, and the demand for the state's limited water is growing with it. It is, nevertheless, a task well worth undertaking for the preservation of the state's biological and genetic aquatic resources.

METHODS

The first step in creating this report was compiling a list of freshwater fishes of California. This task is not as easy as might be assumed because there are many undescribed populations of fishes around the state whose relationship to described forms is poorly known, yet they seem to have distinctive morphological or ecological characteristics. We included undescribed or poorly described forms in this report if they were listed in Moyle (1976), Hubbs et al. (1979), or in other authoritative sources, or if our personal experience indicated they had a high probability of eventually becoming formally recognized taxa. The poor descriptions and lack of life-history and distributional information for many species indicates a need for more work on them, preferably before they become extinct. The need is particularly acute for the many isolated populations of widely distributed species such as tui chub, California roach, and Sacramento sucker (Brown et al. 1992). The extensive work done on one such species, rainbow trout, demonstrates that many of these populations probably deserve recognition as distinct taxa (Behnke 1992). The forms listed as undescribed subspecies in this report are only the most obvious of these populations. All taxa in this report, however, fit the definition of species in the Federal Endangered Species Act of 1973 as " any species, subspecies, or distinct population that interbreeds in nature" as well as the concept of an Evolutionarily Significant Unit as described in Waples (1991).

The second step for each account was to compile the information on the biology of each taxon from the literature and from unpublished sources, especially CDFG file reports. The information was summarized in a standard format, following that recommended for endangered species petitions by the California Fish and Game Commission: (1) description, (2) taxonomic relationships, (3) life history, (4) habitat requirements, (5) distribution, (6) abundance, (7) nature and degree of threats, and (8) management. Unless otherwise indicated, descriptions and taxonomic histories were based on Moyle (1976). Fish lengths were recorded as total length (TL), fork length (FL), or standard length (SL), although the latter was used wherever possible.

Once the basic information was compiled, we gave each taxon a status rating. This rating was assigned only after consultation with other individuals knowledgeable about the species, although we take full responsibility for the final assignments. The rating system we used was as follows:

Class 1. Endangered or Threatened

These are 25 taxa that conform to the state definitions of threatened or endangered species and could qualify for addition to the official list. This designation does not necessarily mean that the fishes should be added to the list; formal listing may be justifiably avoided or postponed, provided there are ongoing efforts to protect and enhance populations of these fishes, as is currently happening for the four taxa of Goose Lake fishes.

Class 2. Special Concern

These 12 taxa have low, scattered, or highly localized populations and require active management to prevent them from becoming Class 1 species. Most of these species have declined in abundance in recent years and need to have this trend reversed. Some of the species (e.g., Death Valley pupfishes) have highly localized populations that are stable but are faced with long-term environmental threats that may cause a sudden diminution in numbers.

Class 3. Watch List

These are 15 taxa occupying much of their native range, but were formerly more widespread or abundant within that range. Taxa with very restricted distributions (e.g., Eagle Lake tui chub) are also included here. The populations of such species need to be assessed periodically (i.e., every five years) and included in long-term plans for protected waterways (e.g., ADMAs).

Class 4. Secure

These are the 38 species or forms not extinct, not listed as threatened or endangered, and not included in this report. We assume, often based on extremely limited data, that their populations are either stable, expanding or, if declining, still reasonably abundant.

The following agency and institution abbreviations are used in this report: AFS (American Fisheries Society), BLM (Bureau of Land Management), CDFG (California Department of Fish and Game), CDPR (California Department of Parks and Recreation), CVP (Central Valley Project), DWR (California Department of Water Resources), PG&E (Pacific Gas and Electric Company), SWP (State Water Project), UCD (University of California, Davis), USBR (U.S. Bureau of Reclamation), USFS (US Forest Service), and USFWS (U.S. Fish and Wildlife Service).

Species accounts in the first edition of this report were assembled from the literature and files of Moyle and Williams by Wikramanayake. Moyle and Williams then wrote the sections on threats and management and revised other sections. For the second edition, Moyle and Yoshiyama updated and extensively revised all original accounts and added the seven new ones.

ACKNOWLEDGMENTS

Preparation of this report would not have been possible if biologists from all over the state had not shared unpublished information. Most are acknowledged as "personal communications" in the individual sections. Their willingness to provide information and to review individual accounts was one of the more heartening aspects of working on this report. Special thanks, however, are due to: **Camm Swift** of Loyola Marymount University for continually updating us with information on southern California fishes; **Eric Gerstung,** of CDFG, for giving us access to his incredible knowledge of salmonids of the state; **Tom Kisanuki,** of the USFWS, for his frequent dispatches of information on north coast fishes; and **E. Phillip Pister,** Desert Fishes Council, for inspiration and information on Great Basin fishes. We also appreciate the reviews given to sections of the manuscript by Alan Baracco, Betsy Bolster, Paul Chappell, Dan Christensen, John Deinstadt, Susan Ellis, Eric Gerstung, Thomas Haglund, David Lentz, Alan Pickard, Forrest Reynolds, Jerry Smith, Camm Swift, Don Weidlein, and other CDFG fish biologists. Financial support was provided by CDFG through the Endangered and Rare Fish, Wildlife, and Plant Species Conservation and Enhancement Account (Income Tax Check-off) and by The Mead Foundation. We appreciate the final editing and assistance of our contracting officer, Betsy Bolster. Illustrations are by Terry Roscoe.

TABLE 1. Status of native freshwater fishes of California. Only taxa known to have had reproducing populations in the state are included. Ichthyological provinces are abbreviated "S" for Sacramento, "C" for Colorado, "G" for Great Basin, "K" for Klamath, and "L" for South Coastal (Figure 1).

	PROVINCES
Extinct or Extirpated:	
Bull trout, *Salvelinus confluentus*[2/]	S
Thicktail chub, *Gila crassicauda*	S
Bonytail chub, *Gila elegans*[3/]	C
Clear Lake splittail, *Pogonichthys ciscoides*	S
Colorado squawfish, *Ptychocheilus lucius*[3/]	C
Flannelmouth sucker, *Catostomus latipinnis*[3/]	C
Tecopa pupfish, *Cyprinodon nevadensis calidae*	G
Pink salmon, Oncorhynchus gorbuscha [4/] [5/]	S, K
High Rock Spring tui chub, *Gila bicolor* ssp.[5/]	G
Formally Listed as Endangered or Threatened (or under formal consideration):	
Winter-run chinook salmon, *Oncorhynchus tshawytscha*	S
Delta smelt, *Hypomesus transpacificus*	S
Little Kern golden trout, *Oncorhynchus mykiss whitei*	S
Lahontan cutthroat, *Oncorhynchus clarki henshawi*	G
Paiute cutthroat, *Oncorhynchus clarki seleniris*	G
Mohave tui chub, *Gila bicolor mohavensis*	G
Owens tui chub, *Gila bicolor snyderi*	G
Sacramento splittail, *Pogonichthys macrolepidotus*[6/]	S
Modoc sucker, *Catostomus microps*	S
Lost River sucker, *Deltistes luxatus*	K
Razorback sucker, *Xyrauchen texanus*	C
Shortnose sucker, *Chasmistes brevirostris*	K
Desert pupfish, *Cyprinodon macularius*	C
Owens pupfish, *Cyprinodon radiosus*	G
Cottonball Marsh pupfish, *Cyprinodon salinus milleri*[7/]	G
Tidewater goby, *Eucyclogobius newbenyi*	S, K, L
Unarmored threespine stickleback, *Gasterosteus aculeatus williamsoni*	L
Rough sculpin, *Cottus asperrimus*[7/]	S

[2/] Extirpated in California only and programs to reintroduce the species have been established.

[3/] Extirpated in California, but persist in upper Colorado River, State and Federal Endangered Species, with reintroduction programs underway so individuals may occasionally be caught in California waters.

[4/] Extirpated in California but abundant elsewhere.

[5/] Covered in this report

[6/] Under formal consideration for listing by the federal government only.

[7/] Listed by State government only.

TABLE 1 - continued

	PROVINCES
Class 1. Qualify as Endangered:	
Southern steelhead, *Oncorhynchus mykiss irideus*	L
Spring-run chinook salmon, *Oncorhynchus tshawytscha*	S, K
Chum salmon, *Oncorhynchus keta*	S, K
Longfin smelt, *Spirinchus thaleichthys*	K, L
Cowhead Lake tui chub, *Gila bicolor vaccaceps*	G
Red Hills roach, *Lavinia symmetricus* ssp.	S
Santa Ana speckled date, *Rhinichthys osculus* ssp.	L
Shoshone pupfish, *Cyprinodon nevadensis shoshone*	G
Shay Creek threespine stickleback, *Gasterosteus aculeatus* ssp.	L
Class 1. Qualify as Threatened:	
Goose Lake lamprey, *Lampetra tridentata* ssp.	S
Green sturgeon, *Acipenser medirostris*	S, K
Coho salmon, *Oncorhynchus kisutch*	S, K
Summer steelhead, *Oncorhynchus mykiss irideus*	S, K
Eagle Lake rainbow trout, *Oncorhynchus mykiss aquilarum*	G
Goose Lake redband trout, *Oncorhynchus mykiss* ssp.	S
McCloud River redband trout, *Oncorhynchus mykiss* ssp.	S
Goose Lake tui chub, *Gila bicolor thalassina*	S
Amargosa Canyon speckled dace, *Rhinichthys osculus* ssp.	G
Owens speckled dace, *Rhinichthys osculus* ssp.	G
Goose Lake sucker, *Catostomus occidentalis lacusanserinus*	S
Santa Ana sucker, *Catostomus santaanae*	L
Saratoga Springs pupfish, *Cyprinodon nevadensis nevadensis*	G
Amargosa pupfish, *Cyprinodon nevadensis amargosae*	G
Salt Creek pupfish, *Cyprinodon salinus salinus*	G

TABLE 1 - continued

	PROVINCES
Class 2. Special Concern:	
Kern brook lamprey, *Lampetra hubbsi*	S
Late-fall chinook salmon, *Oncorhynchus tshawytscha*	S, K
Kern River rainbow trout, *Oncorhynchus mykiss gilberti*	S
Volcano Creek golden trout, *Oncorhynchus mykiss aguabonita*	S
Coastal cutthroat trout, *Oncorhynchus clarki clarki*	S, K
Blue chub, *Gila coerulea*	K
Arroyo chub, *Gila orcutti*[8/]	L
Clear Lake hitch, *Lavinia exilicauda chi*	S
Pit roach, *Lavinia symm etricus mitrulus*	S
Sacramento perch, *Archoplites interruptus*[9/]	S
Klamath largescale sucker, *Catostomus snyderi*	K
Russian River tule perch, *Hysterocarpus traski pomo*	S
Class 3. Watch List:	
Klamath River lamprey, *Lampetra similis*	K
River lamprey, *Lampetra ayresi*	S, K
Eulachon, *Thaleichthys pacificus*	K
Lahontan lake tui chub, *Gila bicolor pectinifer*	G
Eagle Lake tui chub, *Gila bicolor* ssp.	G
San Joaquin roach, *Lavinia symmetricus* ssp.	S
Monterey roach, *Lavinia symmetricus subditus*	S
Navarro roach, *Lavinia symmetricus navarroensis*	S
Tomales roach, *Lavinia symmetricus* ssp.	S
Gualala roach, *Lavinia symmetricus parvipinnis*	S
Hardhead, *Mylopharodon conocephalus*	S
Owens sucker, *Catostomus fumeiventris*	G
Mountain sucker, *Catostomus platyrhynchus*	G
Bigeye marbled sculpin, *Cottus klamathensis macrops*	S
Reticulate sculpin, *Cottus perplexus*	K
Class 4. Population Status Apparently Secure:	
<u>Petromyzontidae</u>	
Sea-run Pacific lamprey, *Lampetra tridentata tridentata*[10/]	S, K, L
Pit-Klamath brook lamprey, *Lampetra lethophaga*	S, K
Pacific brook lamprey, *Lampetra pacifica*	S, K

[8/] Qualified as Threatened Species in native range.

[9/] Special Concern status for Clear Lake population, Watch List for populations outside native range.

[10/] In decline.

TABLE 1 - continued

	PROVINCES
Acipenseridae	
White sturgeon, *Acipenser transmontanus*	S, K
Salmonidae	
Mountain whitefish, *Prosopium williamsoni*[11/]	G
Fall-run chinook salmon, *Oncorhynchus tshawytscha*[11/]	S, K
Coastal rainbow trout, *Oncorhynchus mykiss irideus*	S, K, L
Winter steelhead, *Oncorhynchus mykiss irideus*[11/]	S, K
Cyprinidae	
Lahontan creek tui chub, *Gila bicolor obesa*	G
Klamath River tui chub, *Gila bicolor bicolor*	K
Pit River tui chub, *Gila bicolor* ssp.	S
Lahontan redside, *Richardsonius egregius*	G
Sacramento hitch, *Lavinia exilicauda exilicauda*[11/]	S
Monterey hitch, *Lavinia exilicauda harengus*[11/]	S
Sacramento roach, *Lavinia symmetricus symmetricus*	S
Sacramento blackfish, *Orthodon microlepidotus*	S
Sacramento squawfish, *Ptychocheilus grandis*	S
Klamath speckled dace, *Rhinichthys osculus klamathensis*	K
Lahontan speckled dace, *Rhinichthys osculus robustus*	G
Sacramento speckled dace, *Rhinichthys osculus* ssp.	S
Catostomidae	
Sacramento sucker, *Catostomus occidentalis occidentalis*	S
Monterey sucker, *Catostomus occidentalis mnioltus*	S
Tahoe sucker, *Catostomus tahoensis*	G
Klamath smallscale sucker, *Catostomus rimiculus*	K
Cyprinodontidae	
California killifish, *Fundulus parvipinnis*	L
Gasterosteidae	
Partially-plated threespine stickleback, *Gasterosteus aculeatus microcephalus*[11/]	S, K, L
Fully-plated threespine stickleback, *Gasterosteus aculeatus aculeatus*	S, K, L
Embiotocidae	
Sacramento tule perch, *Hysterocarpus traski traski*	S
Clear Lake tule perch, *Hysterocarpus traski lagunae*	S

[11/] In decline and probably deserve to be on watch list.

TABLE 1 - continued

	PROVINCES
Cottidae	
Coastal prickly sculpin, *Cottus asper* ssp.	S, K, L
Sacramento prickly sculpin, *Cottus asper* ssp.	S
Clear Lake prickly sculpin, *Cottus asper* ssp.	S
Riffle sculpin, *Cottus gulosus*	S
Pit sculpin, *Cottus pitensis*	S
Upper Klamath marbled sculpin, *Cottus klamathensis klamathensis*	K
Lower Klamath marbled sculpin, *Cottus klamathensis polyporus*	K
Paiute sculpin, *Cottus beldingi*	G
Coastrange sculpin, *Cottus aleuticus*	S, K

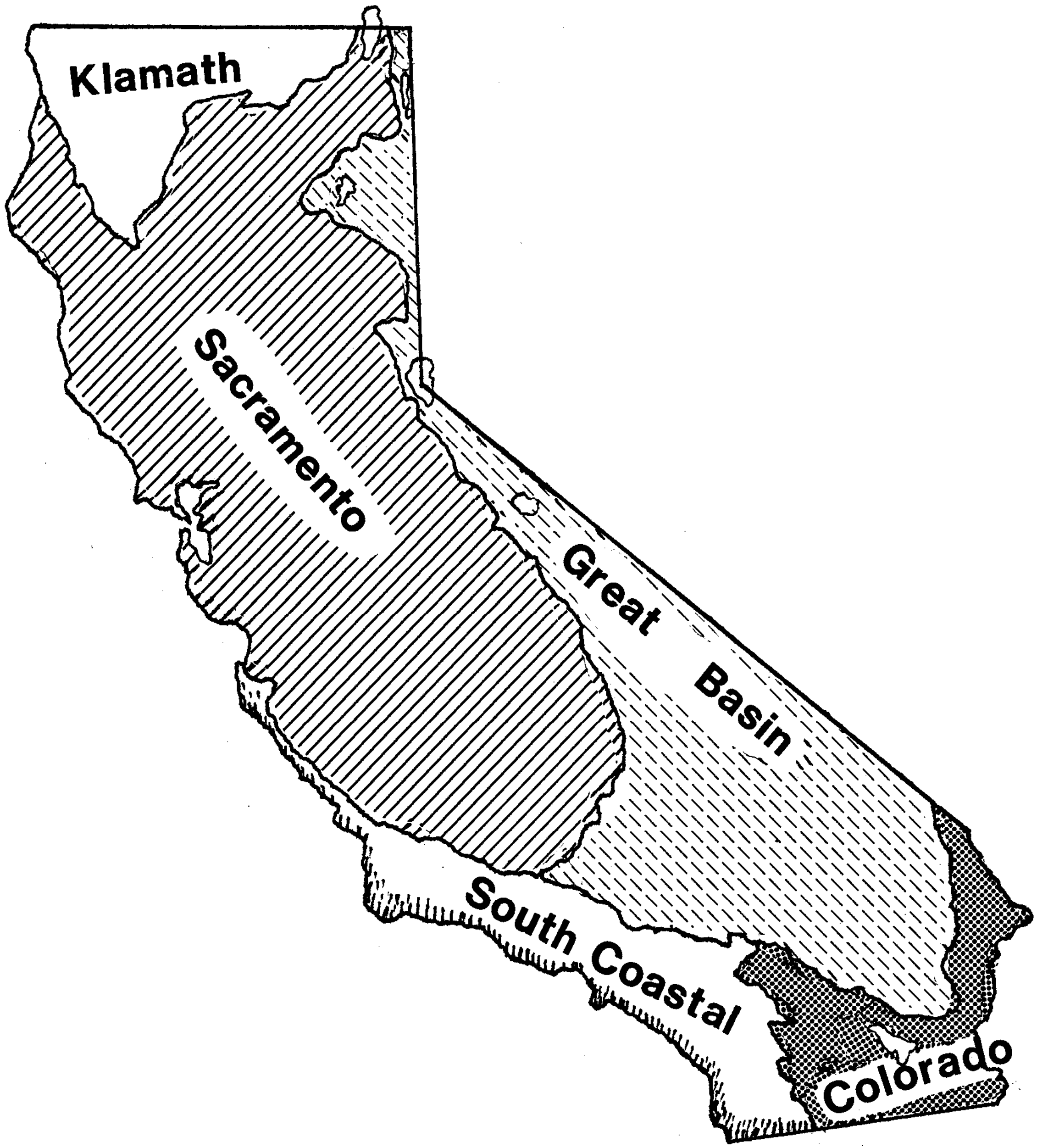


FIGURE 1. Ichthyological Provinces of California (after Moyle 1976).

TABLE 2. Clusters of fish species recommended for coordinated management in ecosystem-level management strategies. The clusters usually exclude most native fishes regarded as secure, although some declining species in the secure category are included and all native fishes are included for isolated bodies of water. This is not an exhaustive list of potential management clusters.

I. Sacramento-San Joaquin Estuary
1. Delta smelt
2. Longfin smelt
3. Sacramento splittail
4. Chinook salmon (four runs)
5. Green sturgeon
6. White sturgeon
7. River lamprey

II. San Joaquin River Drainage
1. San Joaquin roach
2. Red Hills roach
3. Hardhead
4. Kern brook lamprey
5. Fall-run chinook salmon

III. North Coast Streams
1. Coho salmon
2. Summer steelhead
3. Pink salmon
4. Chum salmon
5. Coastal cutthroat trout
6. Green sturgeon
7. California roach subspecies
8. Tidewater goby

IV. Monterey Bay Streams
1. Coho salmon
2. Winter steelhead
3. Monterey roach
4. Monterey hitch
5. Speckled dace
5. Sacramento sucker
6. Tidewater goby

V. Lower Klamath River
1. Coho salmon
2. Spring-run chinook salmon
3. Chum salmon
4. Summer steelhead
5. Coastal cutthroat trout
6. Green sturgeon
7. Longfin smelt
8. Eulachon
9. River lamprey

VI. Upper Klamath River
1. Shortnose sucker
2. Lost River sucker
3. Klamath largescale sucker
4. Klamath River lamprey
5. Blue chub

VII. Rogue River Tributaries
1. Coastal cutthroat trout (landlocked)
2. Reticulate sculpin

VIII. Goose Lake
1. Goose Lake lamprey
2. Goose Lake tui chub
3. Goose Lake sucker
4. Goose Lake redband trout
5. Pit sculpin

IX. Upper Pit River
1. Modoc sucker
2. Pit roach
3. Pit River tui chub
4. Bigeye marbled sculpin
5. Rough sculpin
6. Hardhead

X. Clear Lake
1. Clear Lake hitch
2. Sacramento perch
3. Clear Lake prickly sculpin
4. Clear Lake tule perch
5. Sacramento blackfish

XI. Russian River
1. Russian River tule perch
2. Hardhead
3. Coho salmon
4. Pink salmon
5. Tomales roach
6. Winter steelhead

TABLE 2 - continued

XII. Eagle Lake
1. Eagle Lake trout
2. Eagle Lake tui chub
3. Tahoe sucker
4. Lahontan redside
5. Lahontan speckled dace

XIII. Owens Valley
1. Owens speckled dace
2. Owens tui chub
3. Owens sucker
4. Owens pupfish

XIV. Death Valley
1. Amargosa Canyon speckled dace
2. Amargosa pupfish
3. Saratoga Springs pupfish
4. Salt Creek pupfish
5. Cottonball Marsh pupfish
6. Shoshone pupfish

XV. Southern California Coastal
1. Threespine stickleback (all forms)
2. Santa Ana sucker
3. Santa Ana speckled dace
4. Arroyo chub
5. Southern steelhead
6. Tidewater goby

KERN BROOK LAMPREY
Lampetra hubbsi (Vladykov and Kott)

Status: Class 2. Special Concern.

Description: The Kern brook lamprey is a non-parasitic lamprey endemic to the San Joaquin drainage (Brown and Moyle 1992). Its morphology is like that of other lampreys: eel-like body, no paired fins, and a sucking disc instead of jaws. Larvae, known as ammocoetes, are similar to adults in shape but lack eyes and a well-developed oral disc. The Kern brook lamprey is much smaller than the parasitic anadromous lampreys; adults range from 81 to 139 mm TL and ammocoetes from 117 to 142 mm TL. Ammocoetes are typically larger than adults because non-parasitic lampreys shrink following metamorphosis (Vladykov and Kott 1976). The number of trunk myomeres (i.e. the "blocks" of muscle mass along the body) ranges from 51 to 57 in ammocoetes (Tables 3, 4). In adults, the supra-oral lamina (tooth) typically has 2 cusps, with 4 inner lateral teeth on each side of the disc. The typical cusp formula is 1-1-1-1 (Vladykov and Kott 1976). The sides and dorsum are a grey-brown and the ventral area is white. Dorsal tins are unpigmented, but there is some black pigmentation restricted to the area around the notochord in the caudal fin (Vladykov and Kott 1976).

Taxonomic Relationships: *Lampetra hubbsi* was first described by Vladykov and Kott (1976a) as a dwarf, non-parasitic species in the genus *Entosphenus.* We conform to the nomenclature of Robins et al. (1991) in use of *Lampetra.* Non-parasitic species of lampreys are derived from parasitic anadromous species (Bond and Kan 1973). Thus *L. hubbsi* is thought to be derived from the parasitic *L. tridentatus.* Another small non-parasitic species, *L. richardsoni,* is also found in central California and is differentiated from *L. hubbsi* on the basis of certain anatomical features (Tables 3, 4). *Lampetra richardsoni* is a derivative of *L. ayresi.*

Life History: No documentation of the life history of Kern brook lamprey exists. However, if the life history is comparable to that of other non-parasitic brook lampreys, they should live for approximately 4-5 years as ammocoetes before metamorphosing into adults. Metamorphosis occurs during fall. The adults presumably overwinter and spawn the following spring after undergoing nuptial metamorphosis. Individuals of some species, however, are known to mature neotenically, retaining pre-nuptial pigmentation and body morphology; such lampreys spawn during the summer or the following year after overwintering.

Habitat Requirements: Principal habitats of Kern brook lamprey are silty backwaters of large rivers in the foothill regions (mean elevation = 135 m; range = 30-327 m). In summer, ammocoetes are usually found in shallow pools along edges of run areas with slight flow (L.R. Brown, pers. comm.) at depths of 30-110 cm where water temperatures rarely exceed 25°C. Common substrates occupied are sand, gravel, and rubble (average compositions being 40%, 22%, 23%, respectively). Ammocoetes seem to favor sand/mud substrate where they remain buried with the head protruding above the substrate and feed by filtering diatoms and other micro-organisms from the water. This type of habitat is apparently present in the siphons of the Friant-Kern Canal. Adults likely require the coarser gravel-rubble substrate for spawning.

Distribution: *Lampetra hubbsi* was first discovered in the Friant-Kern Canal, but it has since been found in the lower reaches of the Merced River, Kaweah River, Kings River, and San Joaquin River (Brown and Moyle 1987, 1992, 1993; Fig. 1). In 1988, ammocoetes and adult lampreys were found in several siphons of the Friant-Kern Canal, when they were poisoned during an effort to rid the canals of white bass

(Morone chrysops). The "low-count" lampreys (i.e., low numbers of trunk myomeres) reported from the upper San Joaquin River between Millerton Reservoir and Kerckhoff Dam by Wang (1986) are also most likely *L. hubbsi,* as are similar ammocoetes from the Kings River above Pine Flat Reservoir.

Abundance: Since this species was first discovered in 1976, attempts to fully document its range have been only partially successful. However, data collected to date suggest that this species is a San Joaquin endemic (Brown and Moyle 1992, 1993). Isolated populations of Kern Brook lamprey seem thinly distributed throughout the San Joaquin drainage, and their abundances are probably much reduced. Ammocoetes thrive in the dark siphons of the Friant-Kern Canal, but it is unlikely that there is suitable spawning habitat in the canal, so those individuals probably do not contribute to the persistence of the species.

Nature and Degree of Threat: Populations of this species are thinly scattered throughout the San Joaquin drainage and isolated from one another. Such a fragmented distribution makes local extirpations likely, without hope of recolonization, followed by eventual extinction of the species. The probability of local extirpation is increased by the fact that all known populations are located below dams, where stream flows are regulated without regard to the needs of the lampreys. Fluctuations or sudden drops in flow may isolate or dry up ammocoetes. Channelization or other work on the river banks may eliminate backwater areas required by the ammocoetes. Gravel needed for spawning may be eliminated or compacted, so it cannot be used by adults. Ammocoetes may also be carried to "dead-end" habitats such as the Friant-Kern siphons. Clearly, management of flows in the lower reaches of rivers of the San Joaquin drainage will need to consider the needs of this lamprey in order for the species to persist.

Management: More extensive surveys are needed to determine the present range and distribution of *L. hubbsi,* including determination if ammocoetes use the silty bottoms of siphons in the Friant-Kern Canal. The surveys should focus on adults. Several known areas of suitable habitat should be selected for special management or protection from incompatible uses. Known or probable populations should be monitored by sampling every two to five years.

Table 3. Comparative counts and measurements of lamprey ammocoetes from Vladykov (1973), Vladykov and Kott (1976, 1979), Richards et al. (1982) and Brown and Moyle (unpubl. data). Data from Brown and Moyle are given as mean ± S.D. (above) and range (below). Data of other studies are mean (above) and range (below).

	Lampetra ayresi (Richards et al.)	*L. richardsoni* (Vladykov)	*L. tridentata* (Vladykov and Kott)	*L. hubbsi* (Vladykov and Kott)	*L. hubbsi* (Brown & Moyle)
Total length(mm)	 69 - 119	117 75 - 143	128 117 - 144	130 66 - 140	106 ± 19
Trunk myomeres	65 63 - 67	54 52 - 57	68 66 - 70	55 53 - 57	54 ± 2 51-57

Table 4. Diagnostic characteristics of recently transformed adult lampreys of four species of ***Lampetra.*** Data are from Vladykov and Follett (1958, 1965), Vladykov (1973) and Vladykov and Kott (1976).

	L. ayresi	*L. richardsoni*	*L. tridentata*	*L. hubbsi*
Trunk myomeres	68 (60 - 71)	56 (53 - 58)	66 (63 - 70)	56 (54 - 57)
Cusps on supraoral lamina	2	2	3	2 - 3
Inner lateral "teeth"	3	3	4	4
Cusps on infraoral lamina	8.9 (7 - 10)	7.7 (7 - 10)	5.1 (5 - 6)	5.0 5
Row of posterial "teeth"	absent	absent	present	present'
Parasitic?	yes	no	yes	no

'Absent from two of eleven specimens examined by Brown and Moyle (unpubl. data).

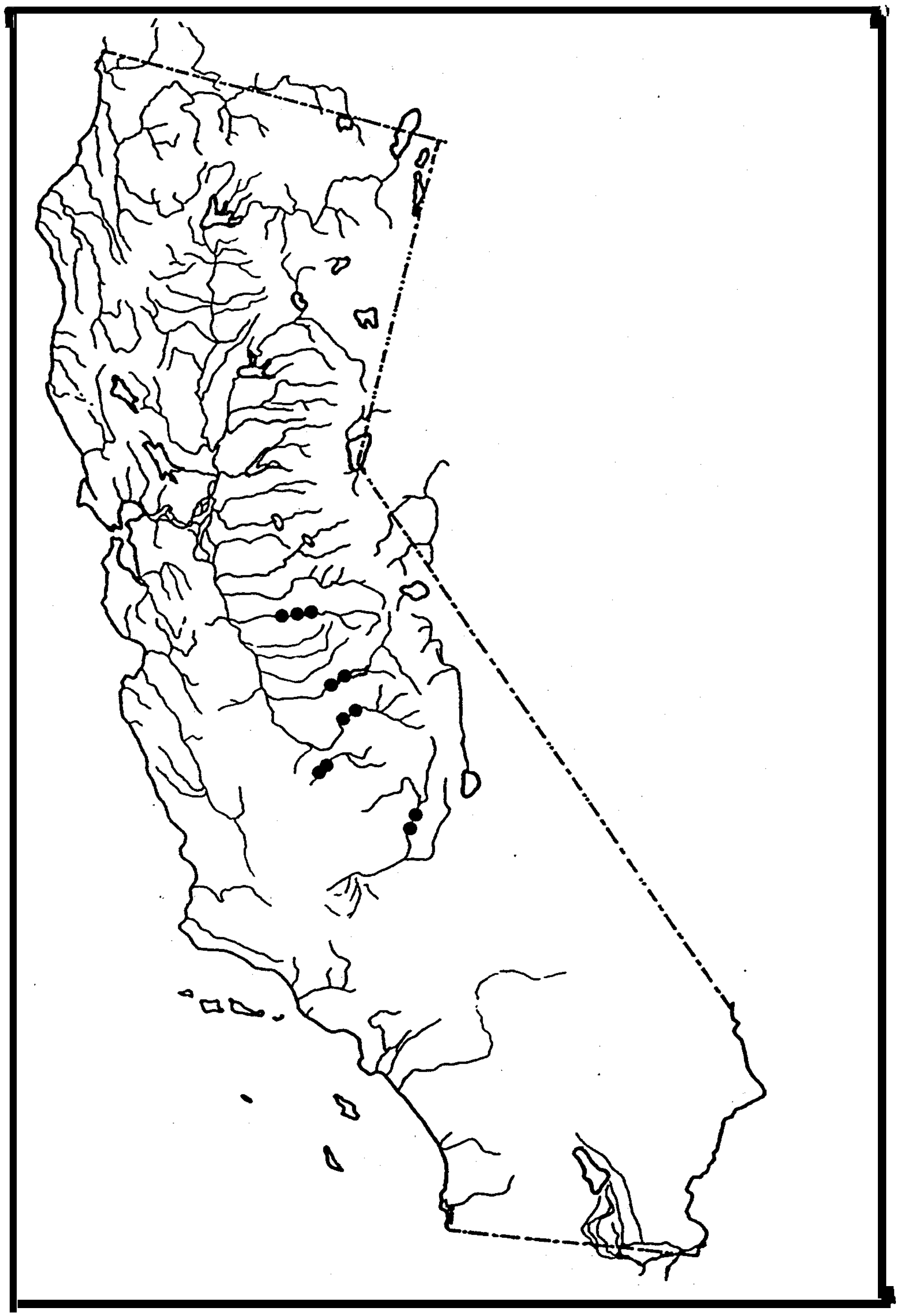


FIGURE 2. Distribution of the Kern Brook lamprey, *Lampetra hubbsi,* in California.

GOOSE LAKE LAMPREY
Lampetra tridentata ssp.

Status: Class 1. Threatened; classified in Oregon as "sensitive-critical," due to its highly restricted range and vulnerability.

Description: This parasitic lamprey is similar to the widespread Pacific lamprey, *L. tridentata tridentata,* except that it is much smaller (adult TL 19-25 cm vs. 30-40 cm for Pacific lamprey). Both forms can be recognized by the sharp, horny plates in the sucking disc, the most distinctive being the crescent-shaped supraoral plate, which has three distinct cusps. The middle cusp is smaller than the two lateral cusps. Adult Goose Lake lamprey are shiny bronze. Ammocoetes can be distinguished from those of the sympatric *L. lethophaga* by the larger number of myomere segments (64-70 between the last gill opening and anus).

Taxonomic Relationships: The Goose Lake lamprey is presumably derived from the sea-run Pacific lamprey from the Klamath drainage. Its closest relatives are found in the confusing complex of lamprey taxa of the upper Klamath River; it is most similar to *L. similis.* It probably also has affinities with the Pit-Klamath brook lamprey, *L. lethophaga,* a nonparasitic species with which it is sympatric (Hubbs 1971). However, Goose Lake and the Pit River drainage to which it connects have been separated from the Klamath drainage since the early Pleistocene (1-3 million years), so it is almost certain that the Goose Lake lamprey deserves recognition as a distinct species or subspecies. Hubbs (1925) recognized the distinctness of this form but did not formally describe it.

Life History: The life history of this taxon is largely unknown, but presumably the adults live for a year or two in Goose Lake, preying on Goose Lake tui chubs, suckers, and redband trout. It is likely that they migrate up suitable tributary streams in winter or spring for spawning. They have to move up far enough to find gravel for spawning and to have enough suitable soft-bottomed habitat downstream of the spawning area for survival of the ammocoetes. Thus, spawning areas may be as much as 20-30 km upstream from the lake. Ammocoetes probably spend 4-6 years in the streams before metamorphosing into adults and moving into the lake.

Habitat Requirements: Adults live in shallow, alkaline Goose Lake where they prey on larger fishes. Goose Lake is described in the Goose Lake tui chub account. Like other lampreys, Goose Lake lampreys require gravel riffles in streams for spawning, and the ammocoetes require muddy backwater habitats downstream of the spawning areas. However, the habitat requirements of this lamprey have never been specifically studied.

Distribution: The Goose Lake lamprey is endemic to Goose Lake and its tributaries in Oregon and California. However, the streams most important for spawning and as habitat for the ammocoetes have not been identified with certainty. They have been collected only from Willow, Lassen and Cold (tributary to Lassen Creek) creeks, Modoc County (G. Sato, BLM, pers. comm.; CDFG unpubl. data), but a thorough search of the tributary streams for lampreys has not been done. It is likely that dams now restrict the distribution of ammocoetes by blocking the migration of adults and by drying up suitable habitats downstream. In Lake County, Oregon, a population apparently exists in Cottonwood Reservoir on Cottonwood Creek (Oregon Dept. of Fish and Wildlife, unpubl. data).

Abundance: Goose Lake lampreys were fairly common in the Goose Lake until the lake dried up in the summer of 1992. They were readily collected from large tui chubs caught in gillnets (R. White, USFWS, pers. comm.). The Goose Lake lamprey has a high probability of becoming extinct during a period of prolonged drought if the lake and lower tributaries are dry for several years in a row. However, the ammocoetes may persist for 3-4 years if there is adequate water flowing over the habitats they occupy. The Cottonwood Reservoir population is of unknown size but the reservoir may serve as a refuge, provided a minimum pool is maintained throughout extended drought periods.

Nature and Degree of Threat: The principal threat to the Goose Lake lamprey is dessication of its habitat, Goose Lake and its tributaries. The combination of severe, extended drought and reduced inflow into the lake presumably resulted in accelerated desiccation of the lake during the 1986-1992 drought. Diversions, dams, culverts, and other obstructions may be preventing migrating adults from reaching spawning areas in tributary streams, although the reservoirs may also be serving as refuges for the species. The diversion of water from streams for agriculture and other uses may have reduced or dried up habitats required by ammocoetes. Habitat may also have been lost through stream channelization and erosion caused by livestock grazing in riparian areas. The loss of habitat for ammocoetes is likely to be particularly severe in the lower reaches of the inflowing streams. Although Goose Lake has presumably dried up in the past and the lamprey and other fishes have persisted, recent watershed conditions probably have increased the rate and time span of dessication and reduced access to upstream refuges.

Management: Until recently, the lamprey and other Goose Lake fishes were largely unmanaged which contributed to the likelihood of their extinction. A Goose Lake Fishes Working Group has been formed, however, with representatives from private landowners, federal and state agencies, and nongovernmental organizations with interest in the lake and its fishes to explore management measures for all the fishes (Sato 1992a). The biology and status of the population in Cottonwood Reservoir needs to be investigated, as well as the possibility of establishing similar refuge populations of the species elsewhere. As soon as possible, an investigation of this unusual lamprey's life history and habitat requirements should be conducted to determine what management measures are required. Improving access and flows in streams in California and Oregon, especially Lassen, Willow, and Thomas creeks, would benefit not only the Goose Lake lamprey but also Goose Lake redband trout, sucker, tui chub, and speckled dace.

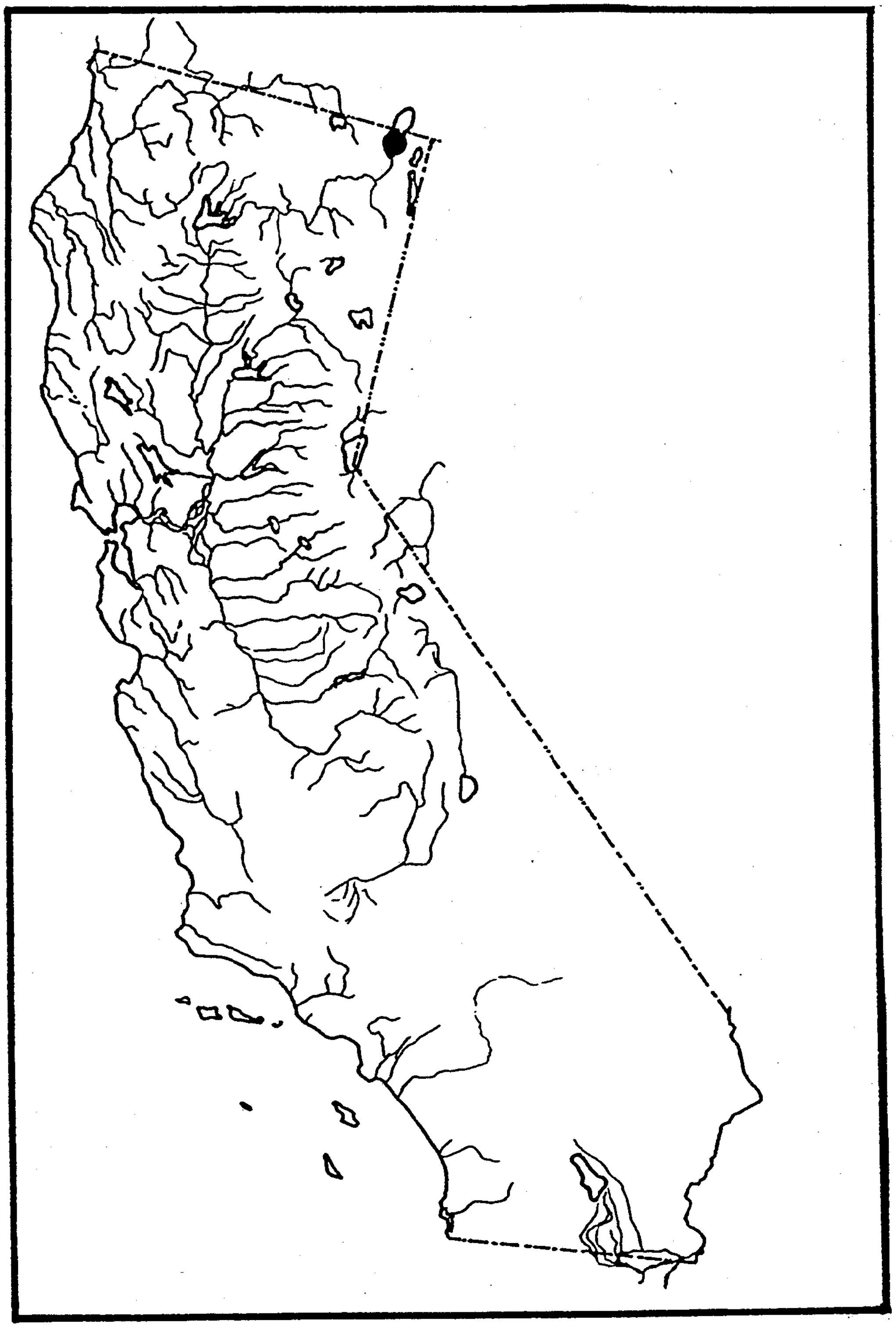


FIGURE 3. Distribution of the Goose Lake lamprey, *Lampetra tridentata* ssp., in California.

KLAMATH RIVER LAMPREY
Lampetra similis (Vladykov and Kott)

Status: Class 3. Watch List.

Description: The Klamath River lamprey is a small (14-27 cm TL, mean 21 cm) predatory lamprey with strong, sharply hooked cusps on the oral plates, most notably three strong cusps on the supraoral plate. It has 10-15 teeth in the anterior field above mouth, 4 inner lateral plates on each side with the typical cusp formula of 2-3-3-2, 20-29 cusps on the transverse lingual lamina (tongue plate), and 7-9 velar tentacles. Trunk myomeres are 58-65 (usually 60-63). The disc length is about 9 percent of the total length and is as wide or wider than the head. The horizontal diameter of the eye is about 2 percent of the total length. Coloration is similar to Pacific lamprey although it is often more heavily pigmented. Ammocoetes have not been described.

Taxonomic Relationships: The Klamath river lamprey was described by Vladykov and Kott (1979) from specimens caught in the Klamath River, California. Four other species of lamprey have also been described from the upper Klamath basin: *Lampetra tridentata* (dwarf Pacific lamprey), *L. lethophaga* (Pit-Klamath brook lamprey), *L. minima* (Miller Lake lamprey), and *L. folletti* (Modoc brook lamprey). The dwarf, landlocked Pacific lamprey is the presumptive ancestor of the other forms. The Pit-Klamath brook lamprey seems to be generally accepted as the standard nonpredatory lamprey of the upper Klamath and Pit River drainages, and the Miller Lake lamprey (now extinct) is accepted as an unusually small predatory form isolated in one Oregon lake. The other forms are more controversial. The Modoc brook lamprey was described by Vladykov and Kott (1976) from specimens obtained from Willow Creek (Modoc County), a tributary to Clear Lake Reservoir on the Lost River. It was described as a nonpredatory species but it apparently is predatory so there seems to be little reason to separate it from the dwarf Pacific lamprey (C. Bond, pers. comm.). As a consequence, it has not been widely accepted as a distinct species (Robins et al. 1991). We agree with this opinion so have not included the Modoc brook lamprey in this edition. Technically, however, the Modoc brook lamprey should continue to be recognized as a species until the designation has been formally refuted in a careful, published analysis. In contrast to the Modoc brook lamprey, the Klamath River lamprey seems to be distinct enough to be regarded as a separate taxon (C. Bond, pers. comm.).

Life History: There is no specific information on the biology of this species although the adults seem to live in the Klamath River itself, as well as lakes and reservoirs, where they prey on the native suckers and cyprinids.

Habitat Requirements: Little is known about the habitat requirements of this species although it is likely that the ammocoetes have requirements similar to those of the Kern brook lamprey.

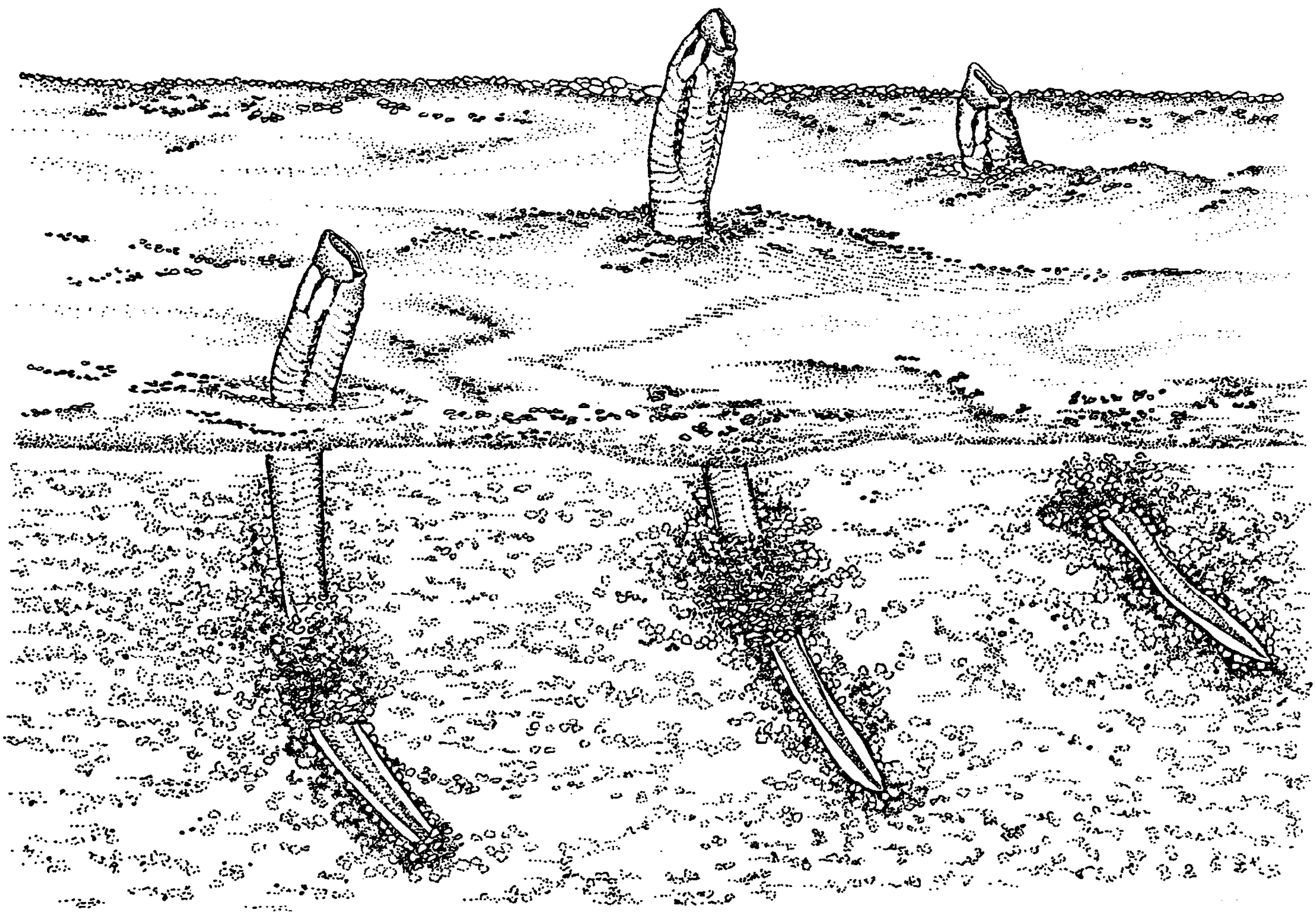
Distribution: This species is known only from the upper Klamath River and Upper Klamath Lake in northern California and southern Oregon. Its exact range, past or present, is not known.

Abundance: Nothing is known about the abundance of this species, nor of other lampreys endemic to the upper Klamath drainage.

Nature and Degree of Threat: The lakes and rivers within their limited range have been severely modified by dams, diversions, and pollution, so it is likely that the both the abundance and range of the Klamath

River lamprey have been diminished. Given the deteriorating state of aquatic habitats in the drainage, especially during the 1986-1992 drought years, it is likely that their numbers are declining.

Management: There is a real need for a systematic survey of the upper Klamath basin for lampreys and other native fishes to determine their status. For the Klamath River lamprey there is a particular need to determine the habitats required for spawning and for ammocoetes. A survey of the magnitude needed would necessarily be a joint venture among state agencies in California and Oregon, as well as federal agencies involved in managing water projects and wildlife refuges in the region. There is also a need for genetic and morphometric studies of the lampreys to unravel the complex taxonomy of the species, in order to determine just what is being managed.



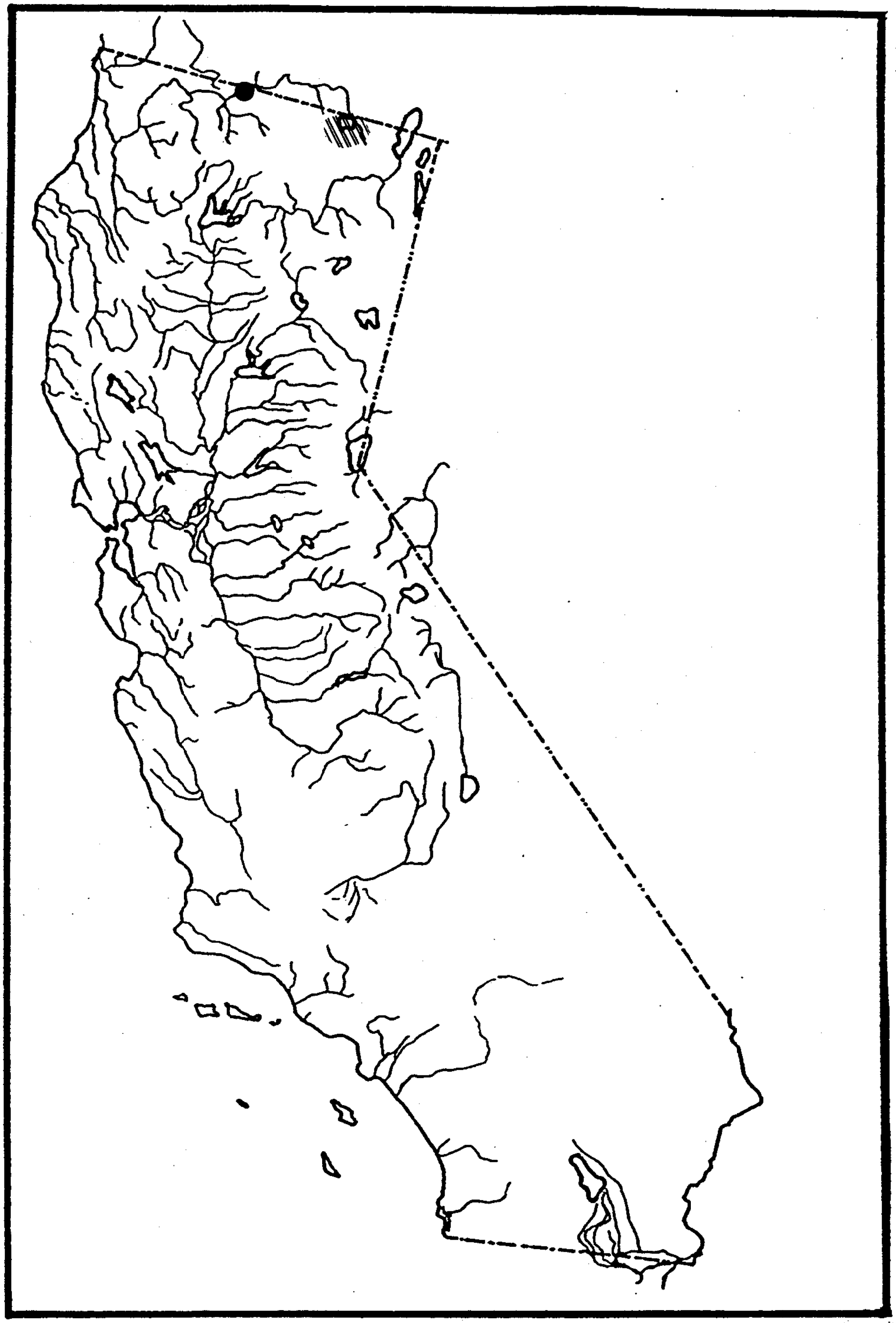


FIGURE 4. Distribution of the Klamath River lamprey, *Lampetra similis*, in California.

RIVER LAMPREY
Lampetra ayresi (Gunther)

Status: Class 3. Watch List.

Description: The river lamprey is small (average length of spawning adults about 17 cm) and predaceous, with an oral disc that is generally at least as wide as the head. The horny plates (teeth in the oral disc) are well developed but become progressively blunter in spawning individuals. The middle cusp of the transverse lingual lamina is well developed. There are three large lateral plates (circumorals) on each side, the outer two bicuspid, the middle one tricuspid. The supraoral plate has only two cusps that often appear as separate teeth, while the infraoral plate has 7-10 cusps. The eye is large compared to other California lampreys, the diameter being 1 to 1.5 times the distance from the posterior edge of the eye to the anterior edge of the first branchial opening. The number of trunk myomeres is high, averaging 68 in adults, and 67 (65-70) in ammocoetes. Adult river lampreys are dark on the back and sides, silvery to yellow on the belly, and the tail is darkly pigmented. As the lamprey becomes sexually mature, the gut degenerates and the two dorsal fins grow closer together, eventually joining. Ammocoetes can be recognized by their pale heads (especially around the gill openings), a prominent line behind the eye spot, and a tail in which the center tends to be lightly pigmented (Richards et al. 1982).

Taxonomic Relationships: In 1855, William O. Ayres described the river lamprey from a single specimen collected in San Francisco Bay and named it *Petromyzon plumbeus.* Unfortunately, that name had already been given to a European species of lamprey. So, in 1870, A. Gunther renamed it *P. ayresi.* In 1911, C. T. Regan decided that this species and the European river lamprey, *Lampetra fluviatilis,* were identical. This diagnosis was accepted until 1958, when the careful redescription of the river lamprey by V.D. Vladykov and W.I. Follett showed that it is indeed a distinct species, *L. ayresi.*

Life History: The biology of river lampreys has not been studied in California so the information in this account is based on studies in British Columbia (Roos et a1.1973, Beamish and Williams 1976, Beamish 1980, Beamish and Youson 1987), where the timing of events in. the life history may not be the same as in California.

The ammocoetes begin their transformation into adults when they are about 12 cm TL, during the summer. The process of metamorphosis may take 9-10 months, the longest known for any lamprey. Lampreys in the final stages of metamorphosis congregate immediately upriver from salt water and enter the ocean in late spring. Adults apparently only spend 3-4 months in salt water, where they grow rapidly, reaching 25-31 cm TL.

River lampreys prey on a variety of fishes in the 10-30 cm TL size range, but the most common prey seem to be herring and salmon. Unlike other species of lamprey in California, river lampreys typically attach to the back of the host fish, above the lateral line, where they feed on muscle tissue. Feeding continues even after the death of the prey. The effect of river lamprey predation on prey populations is minimal (Beamish and Williams 1976). River lampreys can apparently feed in either salt or fresh water.

Adults migrate back into fresh water in the fall and spawn during the winter or spring months in small tributary streams. While maturing in streams, river lampreys shrink in length by about 20 percent. They dig saucer-shaped depressions in gravelly riffles for spawning. Fecundity estimates for two females from Cache Creek, Yolo County, were 37,300 eggs from one 17.5 cm TL and 11,400 eggs for one 23 cm TL (Vladykov and Follett 1958). Adults die after spawning. Ammocoetes remain in silt-sand backwaters and eddies and feed on algae and microorganisms. The length of the ammocoetes stage is not known but it is probably 3-5 years, so the total life span of river lamprey would be 6-7 years.

Habitat Requirements: The habitat requirements of spawning adults and ammocoetes have not been studied in California. Presumably, the adults need clean, gravelly riffles in permanent streams for spawning, while the ammocoetes require sandy backwaters or stream edges in which to bury themselves, where water quality is continuously high and temperatures do not exceed 25°C.

Distribution: River lampreys have been collected from large coastal streams from fifteen miles north of Juneau, Alaska, down to San Francisco Bay. In California, they have been recorded only from the lower Sacramento and San Joaquin rivers and from the Russian River (Lee et al. 1980), but they have not really been looked for elsewhere. Wang (1986) indicates that a landlocked population may exist in upper Sonoma Creek (Sonoma County), a tributary to San Francisco Bay. Throughout their range, they apparently exist only as widely scattered, isolated populations. C. Bond (pers. comm.) has found them only in the Columbia and Yaquina Rivers in Oregon (separated by 182 km). Likewise, they are known only from two large river systems in British Columbia, in the center of their range (Beamish and Neville 1992).

Abundance: Trends in the populations of river lamprey are unknown in California, but it is likely that they have declined, along with the degradation of suitable spawning and rearing habitat in rivers and tributaries. River lamprey are abundant in British Columbia, the center of their range, but there are relatively few records from California, the southern end of their range.

Nature and Degree of Threat: The river lamprey has become uncommon in California, and it is likely that the populations are declining because the Sacramento, San Joaquin, and Russian rivers and their tributaries have been severely altered by dams, diversions, pollution, and other factors. Two tributary streams where spawning has been recorded in the past (Sonoma and Cache creeks) are both severely altered by channelization, urbanization, and other problems.

Management: We cannot manage the river lamprey until we know more about its biology. Its distribution, abundance, life history, and habitat requirements in California all need to be investigated.

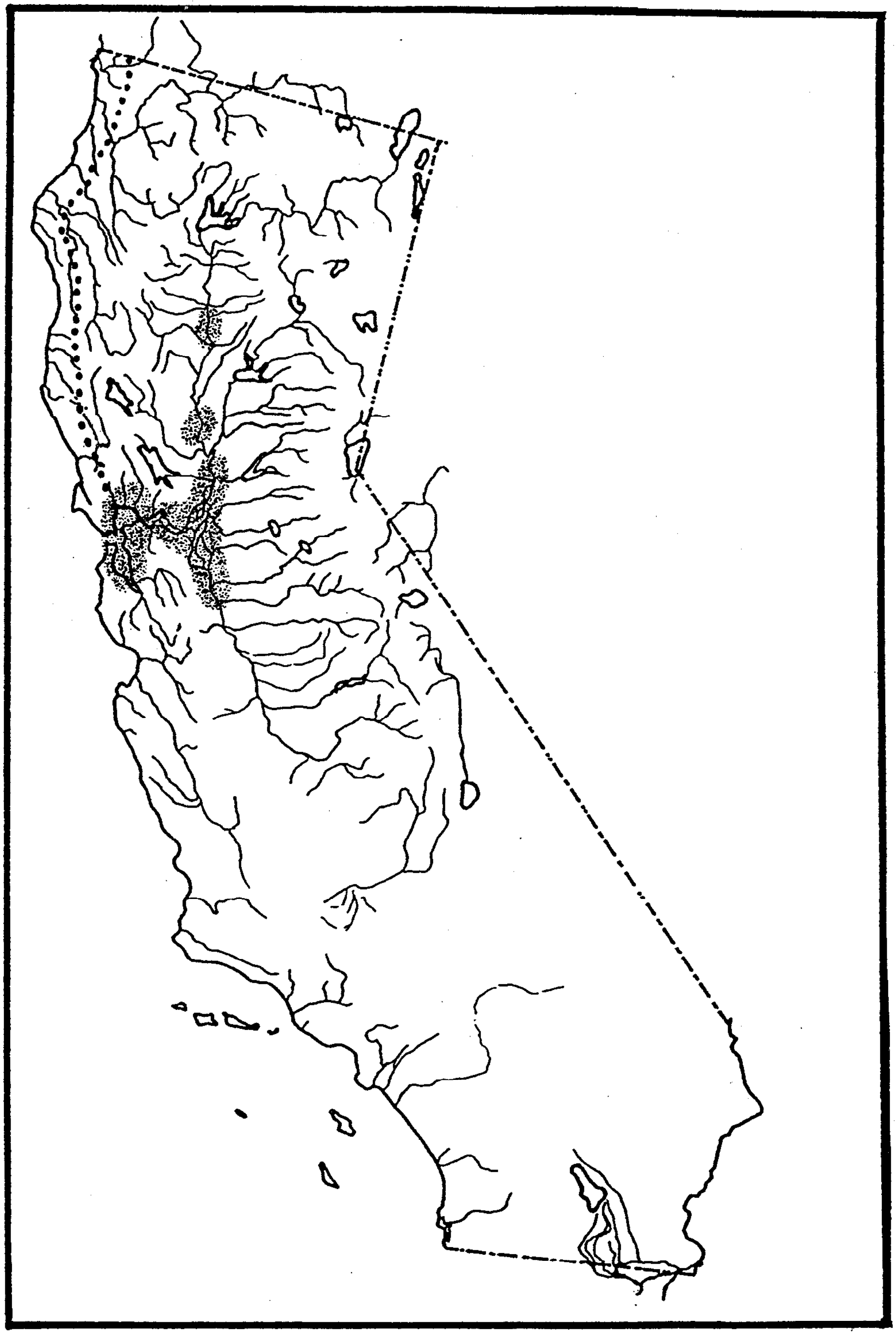


FIGURE 5. Distribution of river lamprey, *Lampetra ayresi*, in California. Dotted line along the north coast indicates probable distribution.

GREEN STURGEON
Acipenser medirostris Ayres

Status: Class 1. Threatened. The green sturgeon is a legal sport fish in Oregon, Washington, and parts of California. It is considered a threatened species in Canada and Russia.

Description: Sturgeons, with their large size, subterminal and barbeled mouths, lines of bony plates on the sides, and heterocercal (shark-like) tail, are among the most distinctive of freshwater fishes. Green sturgeon have a dorsal row of 8-11 bony plates (scutes), lateral rows of 23-30 scutes, and two bottom rows of 7-10 scutes. The dorsal fin has 33-36 rays, and the anal fin, 22-28. Green sturgeon are similar in appearance to white sturgeon *(Acipenser transmontanus),* with which they co-occur, except that the barbels are usually closer to the mouth than to the tip of the long, narrow snout. In addition, there is one or more scutes behind the dorsal fin, as well as behind the anal fin (both lacking in white sturgeon). Body color is olive-green, with an olivaceous stripe on each side and scutes that are paler than the body.

Taxonomic Relationships: The green sturgeon was described from San Francisco Bay in 1854 by W. O. Ayres as *Acipenser medirostris,* the only one of three species he described from the Bay that is still recognized. While there is no question about the validity of this species, the geographic variation in the species has received little attention. It is likely that the Asiatic populations belong to a different species or subspecies although they are morphologically similar to the North American populations and even share some unusual parasites (P. Foley, unpubl.). The Japanese population was described as *Acipenser mikadoi* based on one poorly preserved specimen (Jordan and Snyder 1906). Schmidt (1950) designated the Asian form (the Sakhalin sturgeon in the Russian literature) as a distinct subspecies, *Acipenser medirostris mikadoi.* Recent DNA measurements indicate that the Asian form has approximately twice the DNA content of the North American form (Birstein 1993). Birstein (1993) thus considers them to be two separate species, an Asian form, *A. mikadoi* Hilgendorf and a North American form, *A. medirostris.* Birstein (1993) also suggests that there may be a considerable genetic difference between California populations of *A. medirostris* and those further north.

Life History: The ecology and life history of green sturgeon have received comparatively little study, evidently because of their generally low abundance in most estuaries and their low commercial and sport-fishing value in the past. Adults are more marine than white sturgeon, spending limited time in estuaries or fresh water.

Green sturgeon migrate up the Klamath River between late February and late July. The spawning period is March-July, with a peak from mid-April to mid-June (Emmett et al. 1991). Spawning times in the Sacramento River are probably similar, based on times when adult sturgeon have been caught there (see abundance section, below). Spawning takes place in deep, fast water. In the Klamath River, a pool known as "The Sturgeon Hole" (1.5 km upstream from Orleans, Humboldt County) apparently is a major spawning site, because leaping and other behavior indicative of courtship and spawning are often observed there during spring and early summer (Moyle 1976). In the Sacramento River, angler catches of green sturgeon in the Feather River indicate that this tributary may be a major spawning grounds (P. Foley, pers. comm.).

Female green sturgeon produce 60,000-140,000 eggs (Moyle 1976), which are about 3.8 mm in diameter (C. Tracy, minutes to USFWS meeting on green sturgeon, Arcata, Calif., May 3, 1990). Based on their presumed similarity to white sturgeon, green sturgeon eggs probably hatch around 196 hours (at 12.7°C) after spawning, and the larvae should be 8-19 mm long; juveniles likely range in size from 2.0 to 150 cm (Emmett et al. 1991). Juveniles migrate out to sea before 2 years of age, primarily during summer-fall (Emmett et al. 1991). Length-frequency analyses of sturgeon caught in the Klamath Estuary by beach seine indicates that most green sturgeon leave the system at lengths of 30-60 cm, when they are 1 to 4 years old, although a majority apparently leave as yearlings (USFWS 1982). They apparently remain near estuaries at first, but can migrate considerable distances as they grow larger (Emmett et al. 1991). Individuals tagged by CDFG in San Pablo Bay (part of the San Francisco Bay system) have been recaptured off Santa Cruz, California, in Winchester Bay on the southern Oregon coast, at the mouth of the Columbia River and in Gray's Harbor, Washington (Chadwick 1959, Miller 1972). Most tags for green sturgeon tagged in the San Francisco Bay system have been returned from outside that estuary (D.. Kohlhorst, minutes to USFWS meeting).

Green sturgeon grow approximately 7 cm per year until they reach maturity at 130-140 cm, around age 15-20. Thereafter growth slows down. The maximum size in the Klamath River in recent years has been around 230 cm (USFWS 1982). The largest fish have been aged at 40 years, but this is probably an underestimate (T. Kisanuki, pers. comm.). The largest green sturgeon are typically females and virtually all fish over 200 cm are female (USFWS 1982).

Juveniles and adults are benthic feeders, and may also take small fish. Juveniles in the Sacramento-San Joaquin Delta feed on opossum shrimp *(Neomysis mercedis)* and amphipods *(Corophium* sp.) (Radtke 1966). Adult sturgeon caught in Washington had been feeding mainly on sand lances *(Ammodytes hexapterus)* and callianassid shrimp (P. Foley, unpublished). In the Columbia River estuary, green sturgeon are known to feed on anchovies, and they perhaps also feed on clams (C. Tracy, minutes to USFWS meeting). Adults can reach sizes of 2.3 m FL and 159 kg, but in San Francisco Bay most are probably less than 45 kg (Skinner 1962).

Habitat Requirements: The habitat requirements of green sturgeon are poorly known, but spawning and larval ecology probably are similar to that of white sturgeon. However, the comparatively large egg size, thin chorionic layer on the egg, and other characteristics indicate that green sturgeon probably require colder, cleaner water for spawning than white sturgeon (S. Doroshov, pers. comm.). In the Sacramento River, adult sturgeon are in the river, presumably spawning, when temperatures range between 8-14°C. Preferred spawning substrate likely is large cobble, but can range from clean sand to bedrock. Eggs are broadcast-spawned and externally fertilized in relatively high water velocities and probably at depths >3 m (Emmett et al. 1991). The importance of water quality is uncertain, but silt is known to prevent the eggs from adhering to each other (C. Tracy, minutes to USFWS meeting).

Distribution: In the ocean off North America, green sturgeon have been caught from the Bering Sea to Ensenada, Mexico, a range which includes the entire coast of California. They have been found in rivers from British Columbia south to the Sacramento River in California. There is no evidence of green sturgeon spawning in Canada or Alaska, although small numbers have been caught in the Fraser and Skeena rivers, British Columbia (Houston 1988). Green sturgeon are particularly abundant in the Columbia River estuary and individuals had been observed 225 km inland in the Columbia River (Wydoski and Whitney 1979); presently they are found almost exclusively in the lower 60 km and do not occur upstream of Bonneville Dam (ODFW 1991). There is no evidence of spawning in the Columbia River or other rivers in Washington. In Oregon, juvenile green sturgeon have been found in several of the coastal rivers (Emmett et al. 1991) but spawning has only been confirmed in the Rogue River (A. Smith, minutes to USFWS meeting; P. Foley, unpubl.). In California, green sturgeon spawning has been confirmed in recent years only in the Sacramento River and the Klamath River, although spawning probably once occurred in the Eel River as well (Moyle et al. 1994).

Abundance: In California, green sturgeon have been collected in small numbers in marine waters from the Mexican border to the Oregon border. They have been noted in a number of rivers, but spawning populations are known only in the Sacramento and Klamath Rivers (see below). The following distributional information on green sturgeon in California waters was compiled by Patrick Foley (UCD).

Southern California. Only a few green sturgeon have been reported from the southern California coast (Fitch and Lavenberg 1971). The majority of these fish were less than 100 cm TL and weighed under 4 kg. The largest green sturgeon reported taken in the ocean south of Point Conception was a mature male, 163 cm and 25.7 kg, caught by a commercial fisherman near Dana Point, Orange County (Fitch and Schultz 1978).

Abundance of green sturgeon gradually increases northward of Point Conception. They are occasionally caught in Monterey Bay (G. Cailliet and R. Lea, pers. comm.). A tagged green sturgeon was recovered near Santa Cruz, Santa Cruz County (Miller 1972). Within the holdings of the California Academy of Sciences (CAS) are a skeleton collected at Moss Landing Beach, Monterey County, and a complete specimen acquired from the Santa Cruz Municipal Pier Aquarium (D. Catania, pers. comm.).

Sacramento-San Joaquin drainage. The San Francisco Bay system, consisting of San Francisco Bay, San Pablo Bay, Suisun Bay and the Delta, is home to the southernmost reproducing population of green sturgeon. In fact, green sturgeon were originally described from San Francisco (Ayres 1854). White sturgeon are the most abundant sturgeon in this system; green sturgeon have always been comparatively uncommon (Ayres 1854, Jordan and Gilbert 1883). Intermittent studies by the CDFG between 1954 and 1991 have measured and identified 15,901 sturgeon of both species. Based on these data, a green sturgeon to white sturgeon ratio of 1:9 was derived for fish less than 101 cm FL and 1:76 for fish greater than 101 cm FL (D. Kohlhorst, CDFG, pers. comm.). If we assume that green sturgeon and white sturgeon are equally vulnerable to capture by various gear and that the CDFG population estimates of white sturgeon (11,000-128,000, depending on the year) are accurate (Kohlhorst et al. 1991), then the number of green sturgeon in the estuary longer than 102 cm has ranged from 200 to 1,800 fish (D. Kohlhorst, pers. comm.). These numbers should be regarded as very rough estimates because the above assumptions are shaky.

The numbers of juvenile green sturgeon are presumably even more variable than the number of adults since reproduction is presumably episodic (characteristic also of white sturgeon, Kohlhorst et al. 1991). One indication of this is the numbers of green sturgeon salvaged at the SWP and CVP fish screens in the south Delta, which are mainly juveniles. Between 1979 and 1991, 6,341 fish identified as green sturgeon were captured at the two facilities combined; 32,708 white sturgeon were identified in the same period. Annual numbers ranged from 45 (1991) to 1476 (1983). Other high salvage years were 1982 (1,093) and 1985 (1,377). However, these data are not particularly reliable because of poor quality control of both count and species identification (D. Kohlhorst, pers. comm.). In addition, juvenile sturgeon are probably more vulnerable to entrainment at low or intermediate outflows.

Indirect evidence indicates that green sturgeon spawn both in the Sacramento River and the Feather River. They have been reported in the mainstream Sacramento River as far north as Red Bluff, Tehama County (river km 383) (Fry 1979). Small, young green sturgeon have been taken near Hamilton City, Glenn County (river km 317) (Fry 1979). Additionally, four young green sturgeon were collected at the Red Bluff Diversion Dam in late October, 1991 (K. Brown, pers. comm.). River guides have taken adult green sturgeon at the Anderson Hole, about 6 km above the Hamilton Bridge (G. Jewell, pers. comm.). A dead adult green sturgeon was found on April 18, 1991, at river km 378 (approximately 5 km south of Dairyville, Tehama County), by USFWS biologists (K. Brown, pers. comm.). Live adult green sturgeon have been observed by USFWS crews surveying winter-run chinook salmon, *Oncorhynchus tshawytscha,* in the 16-km reach of river below Red Bluff Diversion Dam in 1991 and 1992 (K. Brown, pers. comm.). In 1991, 20 large sturgeon were sighted in this area between April 3 and May 21. In 1993 and 1994, a number of green sturgeon were caught by anglers in the Feather River (P. Foley, pers. comm.). It is possible that some spawning occurs in the San Joaquin River, because young green sturgeon have been taken at Santa Clara Shoal, Brannan Island State Recreational Area, Sacramento County (Radtke 1966) and a single specimen from Old River is in the CAS collection (D. Catania, pers. comm.). However, fish from these areas could also have come from the Sacramento River.

North Coast. North of San Francisco, green sturgeon are encountered with greater frequency. They are recorded from Tomales Bay (Blunt 1980, D. Catania, pers. comm.) and, while numbers are small, they are roughly equal in abundance to white sturgeon (R. Plant, pers. comm.). A tagged green sturgeon was recovered near Bodega Head (D. Kohlhorst, pers. comm.) and small numbers are taken incidentally by a near-shore halibut fishery centered at Bodega Bay (C. Haugen, pers. comm.). Further north, a single specimen was collected from the Noyo River (D. Catania, pers. comm.).

From the Eel River northward, green sturgeon predominate in the rivers and estuaries along the coast of California, and it is likely that most records of sturgeon caught in rivers between San Francisco Bay and the Klamath River refer to green sturgeon. However, most early references regarding sturgeon from this area failed to identify the species and some reports indicated white sturgeon to be more abundant (Fry 1979). As a result, much confusion has ensued as to the relative abundance of both species throughout this region. Historical accounts from 19th century newspapers (The Humboldt Times) provide the earliest evidence of sturgeon in the Eel River drainage. At this time sturgeon were reported from the mainstem Eel River, South Fork of Eel River and the Van Duzen River (Wainwright 1965). While not confirmatory, length and weights given in these newspaper accounts would be consistent with adult green sturgeon.

In the middle part of this century, two young green sturgeon were collected in the mainstem Eel River and large sturgeon were observed jumping in tidewater (Murphy and DeWitt 1951). Two additional young green sturgeon were taken from the Eel River in 1967 and are in the fish collection at Humboldt State University. Substantial numbers of juveniles were caught by CDFG in the mainstem Eel River during trapping operations in 1967-1970 (Puckett 1976): 22 at Eel Rock in 1967, 53 at McCann in 1967 and 161 in 1969, 221 at Fort Seward in 1968, and smaller numbers at other localities. Green sturgeon have been included in lists of natural resources found in the Eel River Delta (Monroe and Reynolds 1974, Blunt 1980). There have been no green sturgeon collected from the Eel River since 1970. However, CDFG biologists D. McCleod and L. Preston observed a 1+ m long sturgeon, most likely a green sturgeon, in a gravel extraction trench in the mainstem Eel upstream of the Blue Lake Bridge (river mile 16) on May 20, 1992. Likewise, a ca. 1.75 m sturgeon was observed in April 1995 in the lower Eel River when pools were sampled with a boat electrofisher (B. Harvey, USFS, pers. comm.).

Records of sturgeon in the Humboldt Bay system, consisting of Arcata Bay to the north and Humboldt Bay to the south, are almost exclusively green sturgeon. Ten years of trawl investigations in South Humboldt Bay produced three green sturgeon (Samuelson 1973). Records from Arcata Bay are more numerous. On August 6 and 7, 1956, 50 green sturgeon were tagged in Arcata Bay by CDFG biologist Ed Best (D. Kohlhorst, pers. comm.). Total length ranged from 57.2 cm to 148.6 cm with a mean TL of 87.0 cm (± 20.6 cm SD). In 1974, nine green sturgeon were collected over a two-month period in Arcata Bay (Sopher 1974). Total length of these fish ranged between 73-112 cm. The Coast Oyster Company, Eureka, pulls an annual series of trawls in Arcata Bay in order to decrease the abundance of bat rays, *Myliobatis californica.* Green sturgeon are incidentally taken in this operation. Eight green sturgeon collected for parasite evaluation in 1988 and 1989 had total lengths ranging between 78-114 cm. One large individual, 178 cm TL and 18.2 kg, was returned to the bay.

Green sturgeon have been reported from the Mad River (Fry 1979). Recent evidence of their presence is scant and any green sturgeon in the Mad River, due to the river's small size, would likely be limited to the estuary (B. Bamgrover; pers. comm.).

An occasional green sturgeon is encountered in the coastal lagoons of Humboldt County (T. Roelofs, pers. comm.). Big Lagoon and Stone Lagoon are connected to the ocean during part of the year and migrating sturgeon may gain entry at this time. In June 1991, a 120-cm green sturgeon was gillnetted in Stone Lagoon (T. Roelofs, pers. comm.).

Klamath and Trinity Rivers. The largest spawning population of green sturgeon in California is in the Klamath River Basin. Both green sturgeon and white sturgeon have been found in the Klamath River estuary (Snyder 1908a, USFWS 1980-91) but white sturgeon are taken infrequently, in very low numbers, and are presumed to be coastal migrants (USFWS 1982). A sturgeon investigation program initiated in 1979 by USFWS found that almost all sturgeon occurring above the estuary were green sturgeon (USFWS 1980-83). Sturgeon primarily use the mainstem Klamath River and mainstem Trinity River, but have also been seen in the lower portion of the Salmon River.

Both adults and juveniles have been identified in the mainstem Klamath River. Adults are taken annually, spring and summer, by an in-river Native American gillnet fishery. The numbers average around 500 fish per year (see below). They have also been taken by sport fishermen as far inland as Happy Camp (river km 172) (unpubl. CDFG Tagging Data 1969-73, Fry 1979, USFWS 1981). However, the usual upstream limit for the spawning migration appears to be Ishi Pishi Falls, upriver from Somes Bar, Siskiyou County (approximately river km 113). A few juveniles have been taken as high up as Big Bar (river km 81) (T. Kisanuki, pers. comm.), but most have been recovered by seining operations directed at salmonids in the tidewater (USFWS, CDFG). Sampling by the USFWS captured 7 juveniles in (June) 1991 and 23 in (June-July) 1992 (T. Kisanuki, pers. comm.).

The Trinity River enters the Klamath River at Weitchpec (river km 70). The earliest green sturgeon described from the Klamath Basin came from the Trinity River (Gilbert 1897). Both adults and juveniles have been identified; 211 sturgeon, between 7-29 cm TL, were captured near Willow Creek, Humboldt County, incidental to a salmonid migration study in July-September, 1968 (Healey 1970). The USFWS has collected juvenile green sturgeon in recent years from the Trinity River, as far up as Big Bar: 2 (in 1989), 0 (1990), 6 (1991) and 36 (1992) (T. Kisanuki, pers. comm.). Adults are caught yearly in a Native American gillnet fishery (USFWS 1980); based on the oral history as recounted by Yurok tribal elders, the Native American fishery has harvested green sturgeon since "historical" times-- at least since the turn of the (20th) century, and quite likely earlier (T. Kisanuki, pers. comm.). Spawning migrants penetrate the mainstem Trinity River up to about Grays Falls, Burnt Ranch, Trinity County (river km 72).

Sturgeon have also been reported to use the South Fork Trinity River, a third-order stream entering above Willow Creek (river km 51) (USFWS 1981). Oral histories from old-time residents confirm this. However, a large flood in 1964 had devastating effects on anadromous fish habitat in this subbasin (U.S. Department of the Interior 1985). Millions of cubic yards of soil were moved into South Fork Trinity River and its tributaries. Channel widening and loss of depth resulted. This event, along with other changes in subbasin morphology, has apparently resulted in the loss of suitable sturgeon habitat. There are no recent sightings from this watershed.

The Salmon River is a fourth-order stream entering the Klamath River at Somes Bar (river km 106). The water in this river is generally clear and becomes turbid only during high run-off periods. Adult sturgeon have been seen swimming in this river by observers standing on bluffs overhead. The approximate limit to upriver migration is at the mouth of Wooley Creek (river km 8), a third-order stream. Juveniles have yet to be found in the Salmon River, however.

<u>Del Norte County.</u> Green sturgeon have been taken during gillnet sampling in Lake Earl (D. McCloud, pers. comm.). Lake Earl is located along the coast of Del Norte County, 8 km north of Crescent City and 11 km south of the mouth of Smith River. It is connected by a narrow channel to Lake Talawa, a smaller lake directly to the west. A sand spit separates Lake Talawa from the ocean and is occasionally breached by winter storms or by human activities. Coastal migrant green sturgeon enter at this time and become trapped after the sand spit is rebuilt (Monroe et al. 1975).

The Smith River is the northernmost river along the California coast, entering the ocean approximately 5 km south of the Oregon border. Blunt (1980) included green sturgeon in an inventory of anadromous species found in the Smith River. They occasionally enter the estuary and have been observed in Patrick's Creek, an upstream tributary 53 km from the ocean (Monroe et al. 1975). Juveniles have not been found.

Nature and Degree of Threat: The green sturgeon is apparently reduced in numbers throughout its range, although evidence is limited. In the Sacramento River, there is no direct evidence of a decline, but the small size of the population and the difficulty of studying it would make a decline hard to document until the population collapses. The reasons for considering the green sturgeon to be a threatened species are as follows:

(1) The exploitation of green sturgeon in commercial, sport, Native American, and illegal fisheries appears to have been excessive for many years. It likely that all these fisheries depend largely on sturgeon from California. Compilation of the data from the various fisheries indicate that about 6,000 to 11,000 green sturgeon were being harvested per year. While there is no direct evidence of a decline, the statistics are very incomplete and it highly likely that fishing pressure has been increasing in recent years. In addition, the average size of the sturgeon being caught declined in the Columbia. This problem is less than it once was, however, because of the 1993 ban on the sport fishery for sturgeon along the north coast, the elimination of the targeted commercial fishery in Washington, and the increase in minimum size for sturgeon in the California sport fishery.

(2) A number of presumed spawning populations have apparently been lost in the last 25-30 years in California (e.g., South Fork Trinity River, Eel River) and the only known spawning populations are in the Sacramento, Klamath, and Rogue (Oregon) rivers, all of which have flow regimes affected by water projects. It is highly probable that these are now the only spawning populations in North America.

(3) The size and structure of their eggs indicate that green sturgeon are adapted for spawning in cold, low-silt water (S. Doroshov, pers. comm.), conditions that probably once existed most consistently in the Sacramento and other rivers above where Shasta Dam is now located. Because Red Bluff Diversion Dam has apparently been a barrier to green sturgeon migration until recently, it is possible that they have been forced to spawn in suboptimal conditions in the lower Sacramento River.

(4) Green sturgeons are potentially in trouble worldwide. Rochard et al. (1990) state in their review of the status of sturgeons worldwide: "Those [species of sturgeon] which do not have particular interest to fishermen *(A. medirostris, Pseudoscaphirhynchus* spp.) are paradoxically most at risk, for we know so little about them (p. 131)" In Japan, Asiatic green sturgeon *(A. mikradoi)* have apparently been extinct for 40 or more years (K. Amaoka, pers. comm.); they once had spawning runs in the rivers of Hokkaido (Otaki 1907). In Russia, the Asiatic green sturgeon is listed as a Category 4 species (probably endangered but with insufficient information to be classified as such). Borodin et al. (1984) note that it has been little studied but "appears to be in great danger of extinction." Fishing for green sturgeon is now officially forbidden in Russia. In Canada, green sturgeon have been given "rare" status (1987) by the Committee on the Status of Endangered Wildlife in Canada (Houston 1988).

More specifically, the major factors likely to be negatively affecting green sturgeon abundance are (1) fisheries, (2) modification of spawning habitat, (3) entrainment, and (4) toxic substances.

1. Fisheries

Sturgeon fisheries "mined" a stock of large, old fish that was probably not able renew itself at annual harvest rates of 8 - 12%. The fisheries that affected green sturgeon occur both within and outside the Sacramento-San Joaquin estuary, although recent changes in fishing regulations have reduced the commercial and sport fisheries. The following are accounts of the local fishery and the two principal "outside" fisheries for green sturgeon.

Sacramento-San Joaquin fisheries. Green sturgeon in this drainage are caught primarily by sport anglers fishing for white sturgeon. If we assume that green sturgeon >102 cm (legal size prior to 1990) were harvested in proportion to their numbers relative to white sturgeon and at the same rate, then exploitation rates had been gradually increasing since 1954 (Kohlhorst et al. 1991). Kohlhorst et al. (1991) recommended several management options to reduce fishery mortality of white sturgeon; the action actually taken has been to increase the minimum harvet size to 46 inches (117 cm) in 2-inch (5 cm) increments and to impose a 72-inch (183 cm) maximum size limit (D. Kohlhorst, pers. comm.). These size limits also allow more white sturgeon females to mature, because they mature at a larger size than males. These regulations also apply to green sturgeon but are less protective of them because a majority of the largest and oldest individuals fall within the permitted size range.

Columbia River Region fisheries. The majority of the green sturgeon harvest occurs in this region; they are caught by commercial fishermen, anglers, and Native American gillnetters. Sturgeon landings are recorded from the Columbia River estuary and from Grays Harbor and Willapa Bay, Washington, to the immediate north of the estuary. There is little or no evidence of green sturgeon spawning in the rivers of this region, and it is likely that the fish harvested here migrated from California or Oregon, as indicated by limited recaptures of tagged sturgeon. Further evidence of the lack of local recruitment into the fishery is that few juvenile sturgeon (<l.3 m) are caught (Emmett et al. 1991).

The commercial catch in the Columbia River region (Columbia River estuary, Grays Harbor, Willapa Bay) has fluctuated considerably, but catches seem to have increased in recent years. Between 1941 and 1951, catches averaged about 200-500 fish per year. Between 1951 and 1971, the catch averaged about 1,400 fish per year (Houston 1988). In recent years an average of 4.7 tons of green sturgeon (ca. 300 - 500 fish) have been harvested each year in Grays Harbor and 15.9 tons (ca. 1,000-1,500 fish) are harvested in Willapa Bay (Emmett et al. 1991). There have also been some notably high catches: in 1986, 6,000 green sturgeon were harvested in the Columbia River estuary (ODFW 1991), and 4,900 were taken in 1987 (ODFW, unpubl. data). These catches occured in a directed gill net fishery which has since been banned (P. Hirose, pers. comm.). Over the past decades, the commercial catch of green sturgeon in the Columbia River has averaged 1,440 fish (for the 1960s), 1,610 (1970s) and 2,360 (1980s); the catch in recent years has been 2,200 fish (1990), 3,200 (1991) and 2,200 (1992) (ODFW, unpubl. data). The Columbia River recreational catch has been consistently below 500 fish per year (ODFW 1991); the catch in recent years has been 141 (1988), 84 (1989), 86 (1990), 22 (1991) and 73 (1992) (ODFW, unpubl. data). Presently, in the Columbia River, green sturgeon are caught almost exclusively (and incidentally) in the fall salmon gillnet fishery in the lower river, below Bonneville Dam (ODFW 1991). Overall, the fisheries in Washington and Oregon seem to have been taking 5,000-10,000 adult green sturgeon per year.

While the numbers of fish taken by the fishery have shown no striking trends, the size of sturgeon being caught has declined over the years. In the 1960s, the mean wieght of sturgeon in the fishery ranged between 17 and 19 kg, while since 1980, the mean weight has usually been between 12 and 14 kg (ODFW, unpubl. data).

Klamath and Trinity Rivers. A small number of green sturgeon is probably taken in the sport fishery here, but the main harvest is by the Native American gillnet fishery. A small but possibly significant number is also taken in an illegal snag fishery. All these fisheries target sturgeon as they move up the river to spawn during the spring and again on fish returning seaward through the estuary, during June-August (USFWS 1990). In the Native American fishery, mainly adult sturgeon (>130 cm FL) are captured (mean length 179 cm FL in 1988). Data on this fishery exist only since 1980 and the available harvest estimates (USFWS 1989; T. Kisanuki, pers. comm.) are biased low because some green sturgeon harvest occurs prior to the annual monitoring activities of the USFWS (T. Kisanuki, pers. comm.). Also, the USFWS monitors only the sturgeon harvest on the Yurok Indian Reservation; catches by the Karuk and Hupa tribal fishermen in the Klamath River basin are undetermined (T. Kisanuki, pers. comm.). With that in mind, the adult harvest estimates for the Klamath system range between 158 fish in 1987 to 810 in 1981, with a mean of 349 (USFWS 1989, 1990; T. Kisanuki, pers. comm.). Adult harvest estimates for 1990 and 1991 are 239 and 309 fish, respectively. There seems to be, as yet, no indication of any recent decline from the catches. However, the green sturgeon fishery is likely to increase as increased restrictions are placed on the harvest of depleted salmon populations in the rivers:

2. Modification of spawning and rearing habitat

The limited information available indicates that green sturgeon spawn in the Sacramento River in deep water somewhere between Knights Landing and Red Bluff. Recent evidence suggests most spawning occurs above Hamilton City (D. Kohlhorst, pers. comm.) or in the Feather River. If they are like white sturgeon, strong year classes are produced episodically, when flows in the river are exceptionally high. Presumably, green sturgeon have a specific set of flow, depth, and substrate requirements for spawning and then for the early life history stages of their young. The flows and channel of the river have been highly modified, so it is likely that suitable conditions for spawning and rearing of green sturgeon occur less frequently now than they once (pre-1940s) did. Similar problems exist in the Klamath and Trinity rivers, although they are less severe.

3. Entrainment

Juvenile green sturgeon and occasional adult sturgeon are entrained on an irregular basis in the South Delta fish facilities of the SWP and CVP. The numbers vary enormously from year to year but we have no idea if the numbers represent a significant part of the population or not. It is likely that most green sturgeon captured at the pumping plants and returned to the Delta survive the experience, but the actual survival rate is not known. The discovery of 5 adult and 33 juvenile green sturgeon in Clifton Court Forebay in 1992 may be cause for concern because it is not known if they can easily move in and out of the forebay.

4. Toxic substances

The effects of toxic substances from heavy metals to pesticides on green sturgeon are unknown. However, the fact they spawn and rear for a short while in the Sacramento River and Delta indicates that heavy exposure levels are possible. The long-lived adults may accumulate contaminants through the food chain, which could interfere with reproduction. Such accumulation of selenium has been observed in white sturgeon but does not seem to have caused any harm (D. Kohlhorst, pers. comm.).

Management: There currently is no active management of the green sturgeon population, beyond what is deemed necessary to protect the white sturgeon fishery. However, the 1994-1996 fishing regulations (Section 5.80) include a year-round closure of the sturgeon sport fishery on the north coast, including the Eel River, Humboldt Bay, Klamath River, Trinity River and Smith River. This will provide a minor reduction in the harvest of green, sturgeon since it is the principal sturgeon caught in this region. The following conservation measures should also be taken to maintain or increase the population:

1. All fisheries that target green sturgeon should be severely limited until more is learned about the biology and abundance of the species. At the very least, special harvest regulations for green sturgeon are needed to reduce the catch of large reproductive females.

2. Detailed studies on life history and ecological requirements are needed. Population assessment and monitoring should be initiated, particularly for the Sacramento-San Joaquin and Klamath River populations. Knowing little about the population status, structure and dynamics of this species means that we presently can neither predict population trends nor objectively manage stocks. The females mature relatively late in life and may not spawn every year, so maintenance of sufficient reproductive potential (i.e., numbers of mature females) in the populations is an important management consideration.

3. An expanded program of tagging green sturgeon in the Klamath and Sacramento rivers should be undertaken, to see what contribution green sturgeon from this area make to the fisheries elsewhere, especially in Washington and Oregon, as well as to determine exploitation rates. This would also help to answer the question as to whether or not the Sacramento and Klamath river stocks are distinct populations.

4. The factors affecting entrainment of green sturgeon in the south Delta facilities should be determined, in order to devise a plan for reducing entrainment. Presumably, entrainment is related to export rates.

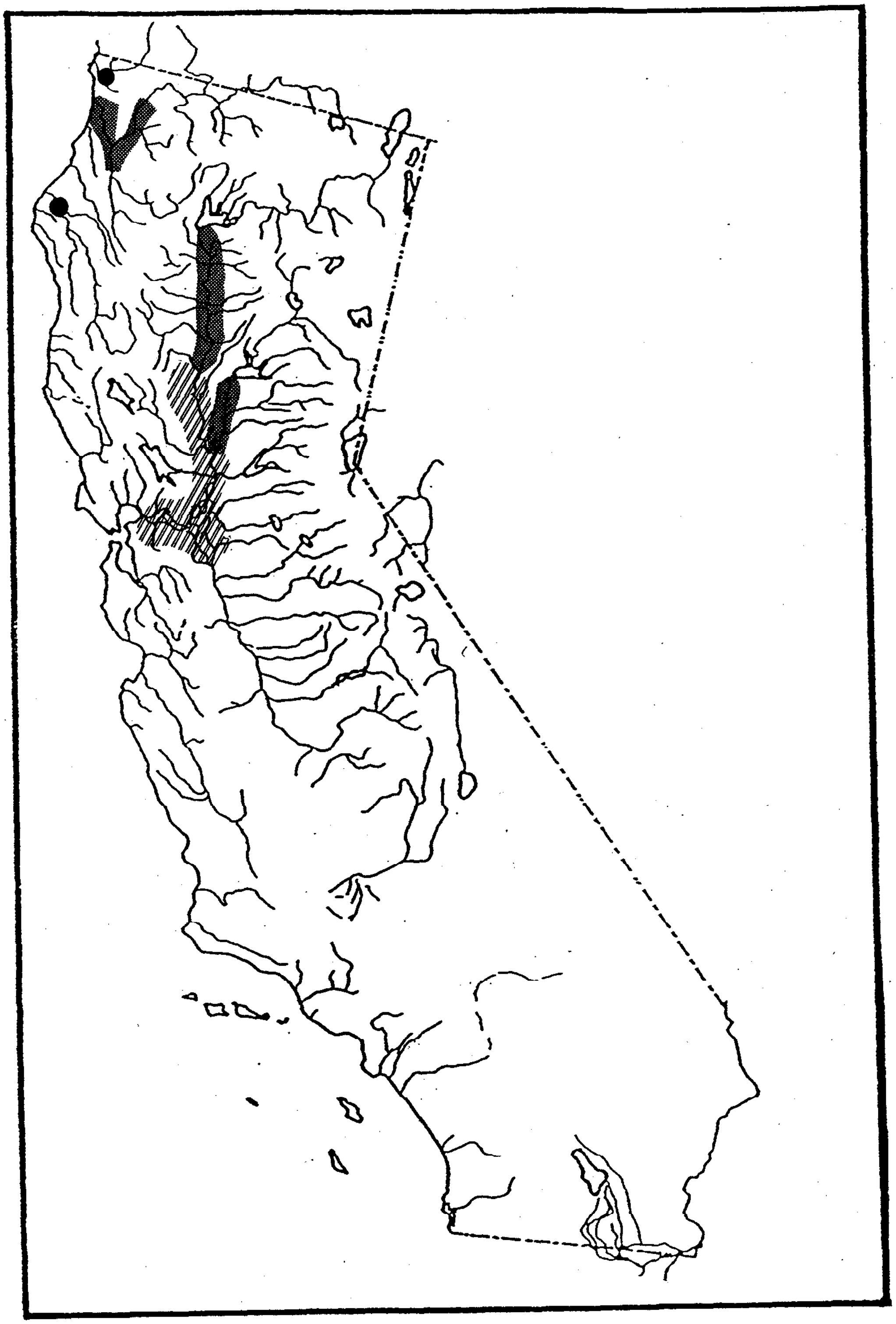


FIGURE 6. Spawning distribution (shaded), migration and rearing habitat (cross-hatched) and recent freshwater occurrences (dots) of green sturgeon, *Acipenser medirostris*, in California.

SPRING-RUN CHINOOK SALMON
Oncorhynchus tshawytscha (Walbaum)

Status: Class 1. Endangered.

Description: Spring chinook are large salmonids, reaching 75-100 cm SL and weighing up to 9-10 kg or more. They have 10-14 major dorsal fin rays, 14-19 anal fin rays, 14-19 pectoral fin rays, and 10-11 pelvic fin rays. There are 130-165 lateral line scales and 13-19 branchiostegal rays on either side of the jaw. The gill rakers are rough and widely spaced, with 6-10 rakers on the lower half of the first gill arch. Reproductive adults are uniformly olive brown to dark maroon, but males are darker than females and have a hooked jaw and snout and an arched back. Chinook salmon are distinguished from other species of salmonids by the body coloration, specifically the spots on the back and tail and the solid black color of the lower gum line. Parr generally have 6-12 parr marks, evenly spaced and centered along the lateral line. The adipose fin of the parr is pigmented along the upper edge but clear at the base. The other fins are clear, except for the dorsal, which may be spotted.

Taxonomic Relationships: The runs of chinook salmon in California are differentiated by the maturity of fish entering fresh water, time of spawning migrations, spawning areas, incubation times, incubation temperature requirements, and migration timing of juveniles. Differences in life histories effectively isolate spring chinook salmon from other runs; thus, the traits are undoubtedly inherited. Allozymic differences between inland populations of California chinook salmon have also been observed, with various degrees of differentiation between rivers within and between drainages (Bartley and Gall 1990). Therefore, each run of salmon could be considered to be genetically distinct to some degree, in some cases even from other runs in the same stream. There seem to be two distinct spring-run chinook populations (stocks) in California: a Sacramento-San Joaquin population and a Klamath-Trinity population. In spite of possibility of some mixing of the stocks in the ocean, the large distance separating the spawning streams of these two populations justifies their being considered, and managed as, separate evolutionarily significant units (gene pools). Other populations may also have existed in smaller coastal streams between the two major river systems, such as the Eel River, but they have been extirpated.

Life History: In general, spring chinook salmon migrate considerable distances up streams to spawn. They enter the rivers from the ocean from March through May, the period of snow-melt flows (Marcotte 1984). These migrating fish are a mixture of age classes ranging from two to five years old although currently, a majority of the fish are three-year olds. While migrating and holding in the river, spring chinook do not feed, relying instead on stored body fat reserves for maintenance and gonadal maturation. They are fairly faithful to the home streams in which they were spawned, using visual and chemical cues to locate these streams. In dry years, some individuals may be blocked from their streams and forced to remain in main rivers.

When they enter fresh water, spring chinook are immature; their gonads mature during the summer holding period (Marcotte 1984). In Deer and Mill creeks, spawning occurs from late August to mid-October. Eggs are laid in large depressions (redds) hollowed out in gravel beds. The embryos hatch following a 5-6 month incubation period and the alevins (sac-fry) remain in the gravel for another 2-3 weeks. Once their yolk sac is absorbed, juveniles emerge and begin feeding. In Deer and Mill creeks, Tehama County, the juvenile salmon during most years spend 9-10 months in the streams, where they feed on drift insects. By the end of the summer, they are 7-11 cm SL (CDFG, unpubl. obs.). The timing of spring-run outmigrant movement from Deer and Mill creeks has not yet been clearly determined, but it seems to be much more variable than for fall-run chinook. Some juveniles may move downstream soon after hatching in March-April and others may move downstream the following fall as yearlings (C.

Harvey, pers. comm.). The outmigrants may spend some time in the Sacramento River or estuary to gain additional size before going out to sea but most have presumably left the system by mid-May. Once in the ocean, salmon are largely piscivorous and grow rapidly.

Adult spring chinook migrate up Deer and Mill creeks from March through June (Vogel 1987 a, b) and aggregate in the middle reaches (Airola and Marcotte 1985). In Deer Creek, most hold and spawn between the Ponderosa Way bridge and upper Deer Creek falls, which apparently is a barrier to migrating fish (Marcotte 1984). In Mill Creek they hold and spawn between the Little Mill Creek confluence and approximately 1.6 km above the Highway 36 bridge, with about 80% of this spawning habitat being within the Lassen National Forest boundary (Marcotte 1984). Many spring chinook move out of the holding areas into the upper watershed when ready to spawn; the rest remain and spawn in the tails of the holding pools.

There does not appear to be a diurnal pattern to migration, but surges in movements seem to occur after rain sufficient to cause a slight discoloration in the water following a period of clear weather. Surges also occur when there is a sudden increase in water temperature (Cramer and Hammack 1952). When daytime water temperatures reach about 27°C, fish usually hold in cooler water in deep pools and migrate upstream at night. The fish hold in deep pools in the upstream reaches during the summer and spawn in early fall. Prespawning activity is usually observed in late August, and intensive nest-building activity and spawning occurs from the first week of September through the end of October (Parker and Hanson 1944). In Deer Creek, spawning was first observed on September 9 in 1991 and 1992 and on August 25 in 1993 (C. Harvey, pers. comm.). Spawning in Deer Creek is usually completed by late September (Moyle, unpubl. obs.). Spawning generally first occurs in the upper reaches of the streams and subsequently in the lower reaches, when water temperatures decrease (Parker and Hanson 1944). Spawning salmon usually are well distributed in the stream section, thus reducing competition for gravel nest sites (Cramer and Hammack 1952). Nests average 4 m^2 (42 ft^2) (n=87) in area.

Historically, spawning adults were mostly large fish that were probably four or five years old. Today, as the result of intense ocean fishing that removes the largest fish, such fish are much less abundant. Based on size, three-year-old fish are now the most common spawners.

Habitat Requirements: For spring chinook adults, numbers holding in an area seem to depend on the volume and depth of pools, amount of cover (especially “bubble curtains” created by inflowing water), and proximity to patches of gravel suitable for spawning (G. M. Sato, unpubl. data). Mean water temperatures in pools where adult chinook held during the summer of 1986 in Deer and Mill creeks were 16°C (range 11.7-18°C) and 20°C (range 18.3-21.1°C), respectively, and for juveniles in Mill Creek the temperature ranged from 13.3-22.2°C (Sato and Moyle 1988). Records indicate that spring chinook in the Sacramento-San Joaquin River system spend the summer holding in large pools where summer temperatures are usually below 21-25°C (Moyle 1976). Sustained water temperatures above 27°C are lethal to adults (Cramer and Hammack 1952). The pools in which the adults hold are at least 1-3 m deep, with bedrock bottoms and moderate velocities (G. M. Sato, unpubl. data; Marcotte 1984). In Deer Creek, preferred mean water velocities measured during 1988 were 60-80 cm sec^{-1} for adults (Sato and Moyle 1988). The pools usually have a large bubble curtain at the head, underwater rocky ledges, and shade cover throughout the day (Ekman 1987). The salmon will also seek cover in smaller “pocket” water behind large rocks in fast water.

Habitat preference curves determined by the USFWS for adult chinook in the Trinity River indicate that pool use declines when depths become less than 2.4 m and that optimal water velocity ranges between 15-37 cm sec^{-1} (Marcotte 1984). Spawning occurs in gravel beds with gravel of a size that fish can excavate. Optimum substrate for embryos has been reported as a mixture of gravel, rubble (mean diameter 1-4 cm) and less than 25 percent fines (less than 6.4 mm diameter) (Platts et al. 1979, Reiser and Bjomn 1979). Juveniles in Deer Creek were found to prefer runs or riffles with gravel substrates, depths of 20-120 cm, and mean water-column velocities of 20-40 cm sec^{-1} (Sato and Moyle 1989).

During downstream migrations in the Sacramento River and Delta, smolts presumably stay close to the banks during the day (near cover) and then move out into open water at night, to migrate. Historically, they may have moved into flooded marshy areas in the Delta to feed but there is little evidence of such activity today.

Distribution: Spring chinook salmon are found in rivers in British Columbia, Washington, Idaho, Oregon, and California, but their populations are depleted throughout this range or maintained by hatchery production (Shepherd 1989). Spring-run chinook also occur in substantial populations in Alaska (Healey 1991), but their genetic affinities with more southern populations are unclear. In California, spring chinook were once abundant in all major river systems. There were large populations in at least 26 streams in the Sacramento-San Joaquin drainage and at least 20 streams in the Klamath-Trinity drainage (CDFG 1990a). Spring chinook are now reduced to scattered populations in the Klamath, Trinity, and Sacramento drainages (Campbell and Moyle 1991), with small numbers (probably strays) found on occasion in the Smith River, Redwood Creek, Mad River, Mattole River, and Eel River. There is no evidence of recent spawning in the latter five rivers.

In the Sacramento-San Joaquin drainage, the principal holding and spawning areas were in the middle reaches of the San Joaquin, American, Yuba, Feather, upper Sacramento, McCloud, and Pit rivers, presumably with smaller populations in most of the other tributaries large and cold enough to support the salmon through the summer. The main populations were all extirpated with the construction of dams, primarily in the 1940s and 1950s, that blocked access to holding areas. Today, the most consistent self-sustaining wild populations in the drainage are in Deer and Mill creeks, Tehama County, with a few fish present in Antelope, Battle, Big Chico, and Beegum creeks in some years (Vogel 1987a,b, Sato and Moyle 1988). Substantial numbers of spring chinook can also be present in Butte Creek, but numbers have been highly variable (100-1,500 fish between 1982 and 1992) and it is not certain if this is a self-maintaining population. Juveniles from CDFG's Feather River Hatchery have been planted there in the past (including 1984 and 1985), and because Pacific Gas & Electric (PG&E) diverts Feather River water into Butte Creek for power production, Feather River Hatchery fish may be attracted to it. Spawning habitat is largely lacking in the reaches above Centerville, but there are adequate spawning gravels and holding pools in the lower reaches. Natural reproduction may nevertheless be disrupted by regulated flow regimes (the stream is regulated for hydroelectricity), high temperatures, poaching, and other human disturbance. Historically, Butte Creek apparently had very small runs of spring chinook in contrast to the large runs of fall chinook that spawned in the creek (Clark 1929). However, in 1989 large numbers of spring chinook occupied Butte Creek and these fish were apparently derived from natural spawning in the creek (F. Meyer, pers. comm.). In the Feather River, a run of fish labeled as spring-run is maintained by hatchery production. In 1986, for example, 1,433 adults were captured and over 1.6 million fingerlings were planted (Schlichting 1988). These fish may also stray into the Yuba River, where apparently spring chinook have been observed in the cold water below Engelbright Reservoir. However, coded wire tag returns indicate that fish labeled as spring-run and fall-run at the hatchery are thoroughly mixed, so there is little reason to regard the Feather River hatchery "spring-run" fish as wild spring chinook.

In the Klamath drainage, the principal remaining run is in the north and south forks of the Salmon River and in Wooley Creek, a tributary to the Salmon River. The South Fork and North Fork of the Trinity River and possibly the New River, also support a few fish (CDFG 1990). The large run of spring chinook in the mainstem Trinity River is apparently maintained entirely by hatchery production.

Abundance: Spring-run chinook salmon of the Sacramento-San Joaquin River system historically comprised one of the largest set of runs on the Pacific coast. Commercial gillnet fishery landings of spring chinook in the Central Valley exceeded 600,000 fish in 1883 (California Fish and Game Commission 1885, cited in CDFG 1990a). Runs in the San Joaquin River alone probably exceeded 200,000 fish at times and it is likely that an equal number of fish were once produced by the combined spring runs in the Merced, Tuolumne, and Stanislaus rivers. However, early historical population levels were never measured (CDFG 1990a). In 1955, the California Department of Fish and Game estimated that with proper water management the San Joaquin drainage could still produce about 210,000 wild chinook salmon per year, with fall-run chinook (originally a minor portion of the San Joaquin salmon runs) replacing the spring-run populations lost to dam construction (CDFG 1955). The last large run in the San Joaquin River occurred in 1945, when 56,000 fish made it up the river (Fry 1961). The San Joaquin River spring chinook run has since been extirpated, primarily due to habitat loss following construction of Friant Dam in 1948. The impact of the dam and efforts to rescue the San Joaquin spring salmon were recorded by CDFG biologist George Warner (1991):

> "In 1948, disaster struck. Friant Dam . . . had been completed and the Bureau of Reclamation assumed control of the river . . . [and] bureau officials diverted water desperately needed by salmon down the Friant-Kern Canal to produce surplus potatoes and cotton in the lower San Joaquin Valley. Only enough water was released in the river to supply downstream canals and some of the pumps."

CDFG crews succeeded in trapping 1,915 spring chinooks and trucking them to the base of Friant Dam. The fish were able to hold in the cold releases through the summer and then spawn successfully in the fall. Unfortunately, when the juveniles attempted to move out to sea, they ended up stranded in a dry stretch of river. In the words of Warner: "The tragic conclusion to the history of the 1948 spring run was that the only beneficiaries of our efforts to salvage a valuable resource were the raccoons, herons, and egrets." Efforts to rescue the run in 1949 and 1950 also failed; thus, San Joaquin spring-run chinook salmon became extinct.

After the demise of the San Joaquin stocks, Sacramento River spring chinook salmon constituted the most abundant natural runs in the Central Valley. As in the San Joaquin drainage, these spring chinook populations were also drastically reduced following construction of barrier dams. Historic run sizes for tributaries to the Sacramento River were estimated by CDFG (1990) to be: 15,000+ above Shasta Dam (McCloud River, Pit River, Little Sacramento River); 8,000-20,000 in the Feather River above Oroville Dam; 6,000-10,000 in the Yuba River above Englebright Dam; and 10,000+ in the American River above Folsom Dam. The Sacramento River drainage as a whole is estimated to have supported spring chinook runs exceeding 100,000 fish in many years between the late 1800s and 1940s (Campbell and Moyle 1991) but these estimates may be low by a factor of 3 or 4 (F. Fisher, pers. comm.)

The decline of spring chinook in the Sacramento drainage began when streams were disrupted by gold mining and irrigation diversions, but the decline accelerated following the closure of Shasta Dam in 1945 and access to major spawning grounds in the McCloud, Pit, and upper Sacramento rivers was cut off. In recent years the decline has continued. CDFG estimates of spawning escapement in the mainstem Sacramento River ranged from 3,600 to 25,000 fish between 1969 and 1980, with an average population of 17,000 fish per year (Marcotte 1984). However, most of these fish are probably hybrids with fall run, because of overlapping spawning times and no spatial segregation. In addition, most probably originated in the Coleman and Feather River hatcheries and were therefore mixed fall and spring run stock to begin with. In Deer and Mill creeks, the estimates of spawning fish averaged 2,300 and 1,200 fish, respectively (Marcotte 1984). Since 1985, the combined yearly totals for both creeks have been less than 900 fish, with the exception of 1989 when there were about 1,300 fish (Table 5). Spawning populations in other tributary streams are considerably less, with an estimated 40-100 fish (incomplete survey in 1983) in Antelope Creek (Airola 1983). The spring chinook numbers in Antelope Creek have dropped during the last few years to <10 individuals per year (Campbell and Moyle 1991; E. Gerstung, pers. comm.). Up to 100 fish have held in Big Chico Creek (Marcotte 1984), but that stream currently supports a much smaller run of probably less than 20 adults (E. Gerstung, pers. comm.). In Butte Creek, numbers have fluctuated considerably from year to year and in the past have been augmented by fish from the Feather

River Hatchery. However, about 1,300 adults held in the creek in both 1988 and 1989. These may have resulted from natural reproduction, but it is also possible that they were fish from the Feather River Hatchery attracted to the creek by the Feather River water PG&E diverts into the creek to run their power house. Recent counts in Butte Creek have dropped to 300+ fish (in 1990), 100+ (1991), and 300+ (1992) (E. Gerstung, unpubl. data).

A number of populations in the Sacramento River have interbred with fall-run fish after dams removed the natural spatial segregation of spawning sites during breeding (Vogel 1987a,b). During the pre-dam period, spatial segregation of the races by downstream and upstream spawning sites maintained their genetic integrity.

The Klamath-Trinity drainage once supported spring-run chinook populations that totaled more than 100,000 fish. This number is probably low because the spring run was apparently the main run of chinook salmon in the Klamath River in the 1800s but by the end of the century it was depleted as the result of hydraulic mining and commercial fishing (Snyder 1931). In each of four Klamath tributaries alone, historic run sizes were estimated by CDFG (1990) to be at least 5,000: Sprague River (Oregon), Williamson River (Oregon), Shasta River, and Scott River. The runs in the Sprague and Williamson rivers were probably extirpated before 1900 as the result of dams constructed in Oregon; if any fish remained, they were eliminated with the construction of Iron Gate Dam across the main river in California in 1965. The run in the Shasta River, probably the largest tributary run in the Klamath drainage, disappeared in the early 1930s as the result of habitat degradation caused by Dwinnell Dam, erected in 1926 (R. L. Elliott, pers. comm.). The smaller Scott River run was extirpated in the early 1970s from a variety of causes.

In the Trinity River, runs that once existed above Trinity Dam included an estimated 5,000+ adults in the upper Trinity River above Lewiston and 1,000-5,000 fish each in the Stuart Fork Trinity River, East Fork Trinity River and Coffee Creek. These runs have all been extirpated (CDFG 1990a). In the Salmon River drainage, an estimated 500-1,500 adults collectively presently use the North and South forks and Wooley Creek each year. This run showed a steady increase from 300 fish in 1981 to about 1,000 in 1988, but dropped to only 250 in 1989 (CDFG 1990a); the most recent run sizes were 413 fish (in 1990), 175 (in 1991) and 330 (1992) (E. Gerstung, pers. comm.). An additional 100-300 fish hold in the South Fork Trinity River, with runs of 82 fish in 1990, 266 in 1991, and 166 fish in 1992. (E. Gerstung, unpubl. data); 7,000 - 11,000 spring chinooks once held in the stream (Healey 1973; La Faunce 1967). The low numbers now using the South Fork are largely the result of the 1964 flood, which triggered landslides that filled in holding pools and covered spawning beds. Since 1979, counts of fish in holding areas (mainly within the South Fork Trinity River upstream from the confluence with Hayfork Creek) have averaged about 115 fish, with counts of about 300 or more in 1975, 1976, and 1979. The two lowest counts, two fish in 1973 and seven in 1989, occurred during dry years (CDFG 1990a).

Overall population trends for spring chinook salmon in California are described in detail by Campbell and Moyle (1991). They reported that more than 20 “historically large populations” of spring-run chinook have been extirpated or reduced nearly to zero since 1940. Four additional runs (Butte, Big Chico, Deer, and Mill creeks) have exhibited statistically significant declines during the same period. The only substantial, essentially wild populations of spring-run chinook remaining in California are in Deer and Mill creeks in the Sacramento drainage and in the Salmon River in the Klamath-Trinity drainage (Campbell and Moyle 1991). Other populations tend to be supported by hatchery stocks.

Nature and Degree of Threat: For spring chinook, historic population declines are attributable mainly to loss of upstream habitat and secondarily to harvest. The causes of the continuing decline in recent decades are presumably related to a combination of factors: poor survival of out-migrants (especially in the Sacramento-San Joaquin Delta), limited access of adults to upstream spawning areas, poaching and other forms of harvest, and other factors such as disease and the interbreeding of wild stocks with hatchery-reared genotypes.

Habitat loss. Because spring chinooks require access to the cold upper reaches of tributary streams, their populations have been declining since the 1860s when many streams were devastated by hydraulic gold mining. Historically, however, the major factor responsible for the extirpation or decimation of spring chinook stocks has been the loss of spawning habitat due to the construction of barrier dams (CDFG 1990a). Starting in 1894 with the construction of LaGrange Dam on the Tuolumne River, access to holding and spawning areas was increasingly blocked by dams diverting water for agricultural and urban use. Major, nearly fatal, blows were struck to spring chinook in California by the closing of Shasta Dam in 1945, Friant Dam in 1948, and Trinity Dam in 1963, which together denied spring chinook access to much of their major spawning and holding areas in California. Dams on the upper Klamath River within Oregon eliminated a large spring chinook population before 1900. All of these dams were constructed without fish passage facilities. For Shasta, Friant, and Trinity dams, it was assumed that hatchery production would replace lost natural production of salmon. This assumption has proven to be false; hatcheries have mainly succeeded in slowing the decline of California's salmon populations and in substituting fall-run (or hybrid) hatchery fish for wild spring chinook. However, some spawning of spring run chinook salmon, presumably of hatchery origin, does take place below Lewiston Dam (which is 11 km below Trinity Dam) in the Trinity River and considerable effort has been made to provide habitat for these fish, mainly by deepening of summer holding pools (A. Barracco, pers. comm.)

Loss or degradation of habitat, stemming from water development, continues to be a problem. Within the Central Valley, water diversions during dry years may dewater the lower reaches of spring chinook salmon streams (e.g. Deer and Mill creeks) during spring and summer, thereby blocking both upstream migration of adults and downstream migration of juveniles (CDFG 1990a). Within the Klamath River drainage, low water flows result in elevated summer temperatures in spring chinook holding areas. Such conditions in the South Fork Trinity and Salmon rivers, for example, have apparently led to increased adult mortality and decreased spawning success (CDFG 1990a).

Harvest. Spring chinook stocks are harvested in both ocean and in-river fisheries. Although the fisheries capture mainly hatchery fish, they are presumably also taking wild fish at least in proportion to their abundance relative to hatchery fish. Given the small size of the remaining runs of wild fish, the take of even a few wild fish may have a significant effect on their populations; yet it is likely that as many as half of the wild fish are taken in fisheries, mainly commercial fisheries. Sport fisheries accounted for an average of 300 fish (annual range 40-900 fish) during 1975-1984 in the upper Sacramento River, but it is not known if many of these were wild fish headed for the tributaries.

In-river harvest occurs by gillnet (used legally only by Native Americans) and by hook-and-line. Harvest-rate estimates for the Native American fisheries of the Klamath River system during 1980-1989 averaged 3,200 fish, with an annual range of 600-6,700 fish (CDFG 1990a). Sport fisheries accounted for an average of 300 fish (annual range 40-900 fish) during 1975-1984 in the upper Sacramento River and an average of 3,400 fish (range 400-9,400 fish) during 1980-1988 in the Trinity River (CDFG 1990a).

Returns of coded-wire tags indicate that upper Sacramento River stocks and Klamath system stocks have different ocean distributions. The former are concentrated between Point Arena and Morro Bay and the latter are most abundant north of Point Arena to Cape Blanco, Oregon (CDFG 1990). Accordingly, the Klamath stocks probably have been less affected by ocean fisheries because of harvest constraints placed on the Northern California and southern Oregon fisheries under the auspices of the Pacific Fishery Management Council. In 1989-1993, ocean harvest rates of Trinity River Hatchery spring chinook were extremely low, perhaps close to zero in 1992 (A. Barraco, pers. comm.). In contrast to the reduced landings in the Klamath Management Zone, the harvest rate index for Central Valley chinook stocks generally has increased in recent years, although it decreased in 1991 and 1992 (A. Baracco, pers. comm.). Total harvest estimates of spring-run chinook, based on fingerling releases by the Trinity River Hatchery (for 1976-1984 broods), have been: ocean fisheries 0.30; in-river fisheries 0.12; combined fisheries 0.42 (CDFG 1990a). Harvest-rate estimates based on age-three ocean recruits ("potential adults") indicate that roughly half of the hatchery-produced adults have been harvested by the fisheries (CDFG 1990a). Based on coded-wire tag data from the Trinity River and Feather River hatcheries, spring-run chinook salmon are harvested by the ocean commercial fishery at a rate somewhat less than fall-run chinook salmon because the spring chinook are available (i.e., legal-sized) for a shorter period of time during the commercial season (CDFG 1990a). Spring-run fish, however, tend to mingle in the ocean with the now more abundant fall-run stocks.

Commercial fisheries may also be affecting the chinook populations indirectly through the continual removal of larger and older individuals. This results in spawning runs made up mainly of three-year-old fish, which are smaller and therefore produce fewer eggs per female. The removal of older fish also removes much of the natural "cushion" the populations have against natural disasters, such as severe drought, which may wipe out a run in one year. Under natural conditions, the four- and five-year-old fish still in the ocean help to keep the runs balanced and can make up for the fish lost. Under present conditions, a loss of a run in one year will result in very low runs three years later, and the loss of runs two or three years in a row can potentially eliminate a population.

During the summer holding period in freshwater pools many large adult salmon are caught by fishermen, some by poachers but others by anglers who snag them accidentally with spinning lures. The importance of this source of mortality is indicated by the distribution of the fish; they are most abundant in the more remote canyon areas, but scarce in pools close to roads.

<u>Outmigrant mortality.</u> Smolt mortality is probably a major factor affecting spring chinook abundance as it is for all runs of chinook salmon, especially in the Sacramento drainage. Small numbers of outmigrants are presumably entrained at every irrigation diversion along the Sacramento River that is operating during the migration period. At the same time, extensive bank alteration, especially rip-rapping, reduces the amount of cover available to protect the outmigrants from striped bass and other predators. When SWP and CVP pumping rates are high and outflows are relatively low, spring chinook smolts are probably entrained in large numbers, are consumed by predators in Clifton Court Forebay and other off-channel areas, and/or are otherwise diverted from their downstream migration.

<u>Hybridization with fall chinook.</u> Interbreeding of wild spring chinook with both wild and hatchery fall chinook has the potential to dilute and eventually eliminate the adaptive genetic distinctiveness of the few remaining naturally reproducing stocks (e.g., Mill Creek, Deer Creek, Salmon River, South Fork Trinity River). Spring and fall runs of chinook salmon were previously well separated by time and spawning area. Construction of dams eliminated the ancestral spawning areas of spring-run fish in the upper reaches of streams, forcing those runs to use lower elevation areas utilized also by fall-run fish. Differences in run timing also have decreased, thereby increasing the likelihood of genetic mixing (CDFG 1990a). Because the flow of the Sacramento River is regulated by Shasta Dam and other dams, cold water is present in some areas throughout the summer, which may allow greater temporal overlap and, hence, hybridization of the different runs in the Sacramento drainage. At the Feather River Hatchery, spring-run fish were kept separate from other runs by assuming that all salmon taken there before October 15 are spring-run chinook salmon and fish taken after this date are fall-run fish (E. Gerstung, pers. comm.). There is now strong evidence spring and fall stocks inadvertently have been hybridized at the hatchery and now form just one hatchery strain. In the wild, hybridization between hatchery and wild fish almost certainly has occurred in the Trinity River, Sacramento River, Feather River, Yuba River, and, perhaps, Butte Creek (Campbell and Moyle 1991).

The potential threat of mixed stock spring chinook to the remaining wild spring chinook is indicated by the fact that in both the Sacramento and Klamath-Trinity drainages, the majority of "spring-run" chinook salmon are the result of hatchery spawning. Production of presumptive spring-run chinook juveniles at the Feather River Hatchery ranged between 2-3 million fish, while annual adult runs ranged between 800-7,200 fish during 1980-1989. Fish listed as spring-run stock are produced at Coleman

National Fish Hatchery in the upper Sacramento River, but these fish are completely hybridized with fall run chinook (F. Fisher, pers. comm).

Disease. The impact of disease cannot be ruled out as a factor in the recent decline of spring-run chinook salmon. Bacterial kidney disease (BKD) recently was found in all hatchery-reared smolts that were released from the Trinity River Hatchery and had been in residence in the Trinity River for several months, although there was no evidence of the disease in the hatchery stock itself (P. Higgins, pers. comm.). BKD and perhaps other diseases such as infectious hematopoietic necrosis (IHN) could seriously curtail the ability of hatchery operations to bolster production if the hatchery fish are susceptible to infection after release in the wild. Disease(s) originating from hatchery fish may also be a factor in depressing wild stocks. Whether or not disease is affecting wild spring chinook in the Sacramento system is not known and should be investigated.

Management: Ongoing. There is intense interest in the spring chinook salmon on the part of agencies, environmental groups and commercial fishermen because of its historical abundance and because formally listing it as an endangered species would have severe negative effects on the salmon fishery in general. As a result, considerable efforts presently are being made to manage this run, although additional effort will be needed for recovery.

Recent stock assessment and restoration efforts for spring chinook salmon conducted by the CDFG have been summarized (CDFG 1990a). Those efforts include annual surveys of runs, a newly instituted habitat restoration program, enforcement of fishing regulations, installation and maintenance of fish screens and fish ladders, and development and coordination of appropriate water-use plans for specific areas. Within the Sacramento River system, efforts to negotiate changes in water management have resulted in expanded spawning and rearing habitat in Butte Creek, and similar efforts are reportedly in progress for Mill Creek, Deer Creek, and the Yuba River.

The most important management efforts within the Klamath River drainage are also described in the CDFG (1990a) report. The Klamath River and its major tributaries recently have been included within the National Wild and Scenic River System, thereby precluding further water development. A similar action has added Wooley Creek and the headwaters of the North and South forks of the Salmon River to the National Wilderness Preservation System as part of the California Wilderness Act of 1985, thereby precluding road construction and logging in those areas. A multiagency restoration program for the mainstem Trinity River has been implemented. The most recently reported accomplishments. are: increased stream flows below Lewiston Dam; restoration of spawning gravels, placement of sediment traps (e.g., Buckhom Mountain Dam), and aquisition of much of the watershed in Grass Valley Creek; dredging of the mainstem Trinity River and excavation of adult holding pools; improvements at the Trinity River Hatchery and studies to determine instream flow requirements below Lewiston Dam. However, these improvements will probably have little postive effect on wild spring-run chinook populations, because the Trinity River is dominated by hatchery-produced salmon. Protective and restoration measures for the South Fork Trinity currently focus on stabilization of the erosion-prone soils in this drainage. The watershed has been severely degraded since the 1964 flood. Subsequent poor logging practices (including road building) and major fires in 1987 have exacerbated the situation. Recent efforts to rehabilitate the watershed include revegetation projects and construction of erosion control structures. Proposed timber sales within unstable or severely impacted watershed areas have been deferred or halted as the result of suits by environmental groups. Because of the severely degraded condition of the South Fork Trinity watershed, rehabilitation efforts appear to be only in the initial stages, and much work remains to be done.

Erosion and sedimentation control measures have been implemented in the Salmon River drainage, much of which was completed in 1989. Also, a habitat improvement program has been conducted since the 1980s. Efforts have included the placement of boulder and rootwad structures, removal of migration barriers, and placement of hydraulic deflectors and weirs to improve spawning and nursery areas. These activities have been concentrated in the South Fork Salmon River, and presumably they are at least partly responsible for the steady increase in abundance of adults observed in the South Fork Salmon River during 1980-1988 (CDFG 1990a).

The most important remaining natural populations in the Sacramento drainage are in Deer and Mill creeks. During wet or normal years, natural flows are sufficient to enable salmon to surmount the diversion dams in the lower reaches of these streams and reach the holding pools. In dry years, however, diversions of water for irrigation may decrease flows in the lower reaches to such an extent that adults are unable to negotiate dams or critical riffles. Because the diversions are on private land and represent long-held water rights, this problem can only be solved with the cooperation of local landowners or by water-rights acquisition. Since 1989, an agreement between the California Department of Water Resources, Los Molinos Water Company, The Nature Conservancy, and the CDFG has provided water pumped from wells on the Dye Creek Preserve to Tehama County farmers, so that less water would be diverted for agricultural irrigation from Mill Creek. This strategy appears to have been highly successful in maintaining flows in Mill Creek for salmon (A. Weinstein, pers. comm.; CDFG, April 1, 1992 memorandum from S. Capello to S. Ford, Dept. of Water Resources).

In the Delta, the recent (May 1992) decision by CDFG to halt striped bass planting and the inception of a predator removal program in Clifton Court Forebay will probably benefit spring-run chinook populations by reducing predation on outmigrants.

At the present time, a Spring Chinook Work Group, consisting of representatives of various agencies, commercial fishermen, farmers, and others affected by spring chinook conservation efforts are attempting to devise a recovery plan for spring chinook in the upstream habitats of the Sacramento drainage (L. Davies, pers. comm.). It is assumed that if this group can agree to recovery measures, the measures will be adopted by the agencies concerned.

Management: needs. While spring-run chinook salmon have received a great deal of management attention, much more is needed to restore populations to self-sustaining levels. Additional protection is needed at all stages of their life cycle, but the most important is their freshwater stage. Restoration will require such measures as: (1) providing passage of adults to holding and spawning areas, (2) protecting adults in the holding pools, (3) improving access to creeks that can support small populations (e.g., Antelope, Begum, and South Fork Cottonwood creeks), (4) improving the management of regulated streams for wild salmon (e.g., Butte Creek, Trinity River), (5) providing passage flows for out-migrating juveniles, (6) providing better instream habitat for juvenile fish in the main rivers, (7) reduction in take by fisheries, and (8) reducing the effects of hatchery fish on wild populations.

The habitat preservation and restoration programs instituted by CDFG and other agencies should be continued and expanded. A recently proposed recovery strategy for spring chinook in the Klamath River basin (West 1991) should be used as a framework for recovery efforts and could serve as a model for other drainages. However, attempts to recover populations using spawning channels and other artificial means should be done with great caution, if at all. All populations should be monitored annually to determine the effectiveness of the management measures.

The cooperative agreement between private parties and public resource agencies to trade water with the goal of maintaining adequate stream flows in Mill Creek, Tehama County, apparently has benefited the spring chinook run in that stream and therefore deserves to be continued. The process eventually should be applied to other, selected salmon streams, as proposed by CDFG (1990a).

Many large adult salmon holding in pools during the summer are caught by anglers, either intentionally or accidentally, and some by poachers. This source of mortality can be reduced by a combination of more frequent patrolling by wardens and changing angling regulations to either prohibit fishing in principal holding pool areas or to restrict fishing to fly fishing only. The latter angling regulations went into effect in 1994.

Protection of out-migrating juveniles requires a combination of adequate flows in the lower reaches of the streams in March and April and adequate flows in the Sacramento River to move them rapidly downriver and through the Sacramento-San Joaquin estuary. Maintenance of adequate flows in this system not only would benefit spring chinook salmon but also other species that have shown recent significant declines in population levels, such as winter-run chinook, delta smelt *(Hypomesus transpacificus),* longfin smelt *(Spirinchus thaleichthys),* and perhaps Sacramento splittail *(Pogonichthys macrolepidotus).* Water management for this drainage system is a complex and sensitive issue that has immense political and economic ramifications. The fact remains, however, that the salmon populations of the system require adequate flows in order to survive, and appropriate adjustments in water-flow regimes eventually will have to be instituted.

Predator control programs to protect both adult and juvenile fish may need to be initiated. For example, otters may be taking a significant number of the remaining adult salmon in the summer holding pools, especially in the Salmon River. Reducing otter numbers by live-trapping until salmon numbers have recovered may be necessary. Likewise, predation on juvenile salmon by striped bass and other fishes in the Sacramento-San Joaquin estuary probably has been increased by the action of the pumps of the SWP and CVP (which move fish into areas, such as Clifton Court Forebay, where they are more vulnerable to predation), as well as by the planting program to enhance the striped bass population. The recent (May 1992) decision by CDFG to halt striped bass planting and the predator removal program in Clifton Court Forebay will probably benefit spring-run chinook populations, although ultimately the water projects will have to be operated in a way that is more sensitive to the needs of the salmon.

The role of hatchery production of spring-run chinook salmon needs to be carefully evaluated. The true value of hatchery operations to bolstering natural populations of spring chinook depends on the genetic make-up of the hatchery brood stocks. If the brood stock has been genetically compromised by introgression of genes from other populations outside the watershed or from fall-run fish, the overall effects of the hatchery program may be detrimental rather than contributory-- viz., subsequent spawning of hatchery-produced fish with naturally spawned fish may threaten the genetic integrity of the wild populations. Hatchery operations should strive to include a sufficient diversity of locally appropriate genotypes in the brood stock. At the very least, all fish reared in hatcheries should be marked so that their contribution to wild populations can be determined and so that unmarked fish can be released by fishermen.

TABLE 5. Population counts and estimates of spring-run chinook salmon from Deer and Mill creeks. (Data based on counts at diversion dam ladders and spawning surveys conducted by CDFG and USFS.)

Year	Deer Creek	Mill Creek
1954	NE[1]	1789
1955	NE	2967
1956	NE	2233
1957	NE	1203
1958	NE	2212
1959	NE	1580
1960	NE	2368
1961	NE	1245
1962	NE	1692
1963	1702	1315
1964	2290	1628
1965	NE	NE
1966	NE	NE
1967	NE	NE
1968	NE	NE
1969	NE	NE
1970	2000	1500
1971	1500	1000
1972	400	500
1973	2000	1700
1974	3500	1500
1975	8500	3500
1976	NE	NE
1977	467	563
1978	1200	925
1979	NE	NE
1980	1500	500
1981	NE	NE
1982	1500	700
1983	500	200
1984	NE	191
1985	300	121
1986	543	291
1987	200	90
1988	371	572
1989	77	556
1990	458	844
1991	448	319
1992	332	237
1993	259	73
1994	593	723

[1] NE = no estimate

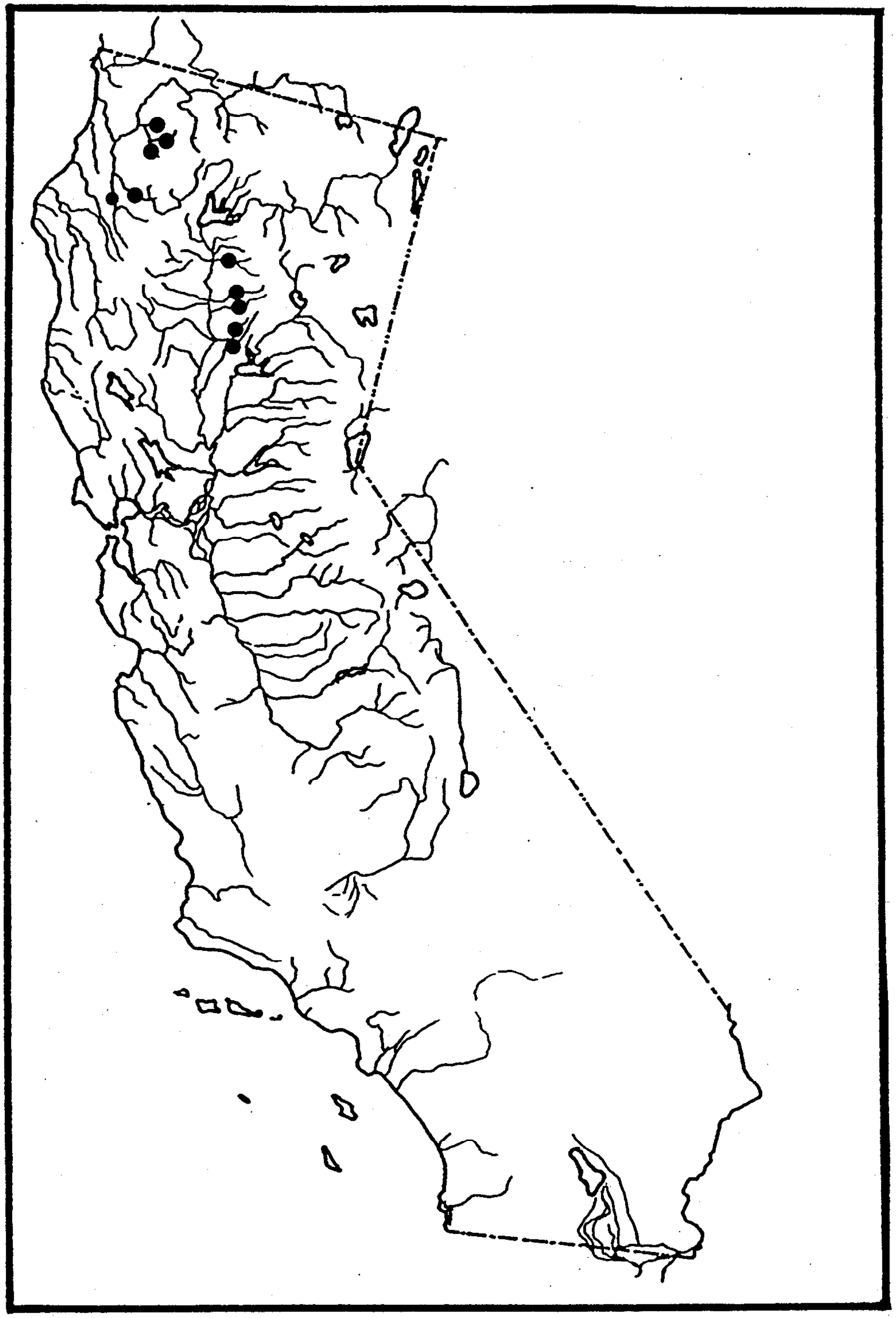


FIGURE 7. Major holding and spawning areas of spring-run chinook salmon, *Oncorhynchus tshawytscha*, in California.

SACRAMENTO RIVER LATE-FALL CHINOOK SALMON
Oncorhynchus tshawytscha (Walbaum)

Status: Class 2. Special Concern.

Description: Late-fall run chinook salmon are morphologically similar to spring-run chinook. They are large salmonids, reaching 75-100 cm SL and weighing up to 9-10 kg or more. They have 10-14 major dorsal fin rays, 14-19 anal fin rays, 14-19 pectoral fin rays, and 10-11 pelvic fin rays. There are 130-165 lateral line scales. Branchiostegal rays number 13-19 on either side of the jaw. The gill rakers are rough and widely spaced, with 6-10 rakers on the lower half of the first gill arch. Reproductive adults are usually uniformly olive-brown to dark maroon; the males are darker than females and have a hooked jaw and snout and an arched back. Some reproductively mature females have been observed to retain their silvery (ocean) coloration even during spawning (K. Marine, pers. comm.). Chinook salmon are distinguished from other species of salmonids by the body coloration, specifically the spots on the back and tail and the solid black color of the lower gum line. Parr generally have 6-12 parr marks, evenly spaced and centered along the lateral line. The adipose fin of the parr is pigmented along the upper edge but clear at the base. The other fins are clear, except for the dorsal, which may be spotted.

Taxonomic Relationships: The runs of chinook salmon in California are differentiated by the maturity of fish entering fresh water, time of spawning migrations, spawning areas, incubation times, incubation temperature requirements, and migration of juveniles. Allozymic differences between inland populations of California chinook salmon have also been observed, with various degrees of differentiation between rivers within drainages and between drainages (Bartley and Gall 1990). Therefore, each run of salmon could be considered to be genetically distinct to some degree, in some cases even from other runs in the same stream.

Life History: The great majority of late-fall chinook salmon appear to spawn in the mainstem of the Sacramento River (R. Painter, pers. comm.), which they enter from October through February (Vogel and Marine 1991). In the past, these migrating fish were a mixture of age classes ranging from two to five years old. At the present time, the spawners are about equally divided between three year old and, four year old fish. While migrating and holding in the river, late-fall chinook do not feed, relying instead on stored body fat reserves for maintenance. Spawning occurs in January, February and March, although it may extend into April in some years. Eggs are laid in large depressions (redds) hollowed out in gravel beds. The embryos hatch following a 3-4 month incubation period and the alevins (sac-fry) remain in the gravel for another 2-3 weeks. Once their yolk sac is absorbed, the fry emerge and begin feeding on aquatic insects. All fry have emerged by early June. The juveniles hold in the river for nearly a year before moving out to sea the following December through March. Once in the ocean, salmon are largely piscivorous and grow rapidly.

Habitat Requirements: The specific habitat requirements of late-fall chinook have not been determined, but they are presumably similar to other chinook salmon runs and fall within the range of physical and chemical characteristics of the Sacramento River above Red Bluff.

Distribution: Sacramento late-fall run chinook are found mainly in the Sacramento River, and most spawning and rearing of juveniles takes place in the reach between Red Bluff and Redding (Keswick Dam). According to Vogel and Marine (1991), however, up to approximately 15-30% of the total iate-fall run can spawn downstream of Red Bluff when “water quality is good”. R. Painter (pers. comm.) indicated that apparent late-fall run chinook have been observed spawning in Battle Creek, Cottonwood

Creek, Clear Creek, Mill Creek, Yuba River and Feather River, but these are at best a small fraction of the total population. The Battle Creek spawners are presumably derived from an artificially maintained run into Battle Creek Fish Hatchery. The historic distribution of the late-fall run is not known, but it probably spawned in the upper Sacramento River and major tributaries in reaches now blocked by Shasta Dam.

Abundance: The historic abundance of late-fall chinook is not known because it was recognized as distinct from fall-run chinook only after Red Bluff Diversion Dam was constructed in 1966. In order to get past the dam, salmon migrating up the Sacramento River had to ascend a fish ladder in which they could be counted with some accuracy for the first time. The four chinook salmon runs present in the river (fall, late-fall, winter, spring) were revealed as peaks in the counts, although salmon passed over the dam during every month of the year. Next to winter-run chinook (now listed as an endangered species by the state and as threatened by the federal government), late-fall run chinook are the least numerous run in the Sacramento River and, like winter-run and spring-run chinook, their numbers have declined since counting began in 1967. In the first 10 years of counting (1967-1976) the run averaged about 22,000 fish; in the last 10 years of counting (1982-1991) the run averaged about 9,700 fish (CDFG, unpubl. data). There have been no counts of 20,000 fish or more since 1975, although 16,000 fish were counted in 1987. The run in 1991 was 7,089 fish (USFWS 1992). Counts for 1992 and 1993 are not available because the gates at Red Bluff Diversion Dam have been opened to allow free passage for winter-run chinook adults and smolts, counting the adult migrants is therefore no longer possible.

Nature and Degree of Threat: For late-fall run chinook salmon, the causes of population declines are poorly understood, but presumably are similar to those of winter-run chinook (Williams and Williams 1991) and spring-run chinook (this report). The principle causes of decline seem to be (1) passage problems over dams, (2) loss of habitat, (3) introgression with other runs, and (4) other factors such as disease and pollutants.

<u>Passage problems over dams.</u> When Shasta and Keswick Dams were built in the 1940s, they presumably denied access of late-fall run chinook to upstream spawning areas where run-off and spring water originating from Mt. Shasta and other areas kept water temperatures cool enough for successful spawning, egg incubation and over-summer survival of juvenile salmon. The effects of Red Bluff Diversion Dam (RBDD) were more subtle and not recognized until fairly recently (Williams and Williams 1991). This dam apparently delays passage to upstream spawning areas and also concentrates predators, increasing mortality on out-migrating smelts (USBR reports). Kope and Botsford (1990) documented that the overall decline of Sacramento River salmon was closely tied to the construction of RBDD.

<u>Habitat loss or deterioration.</u> Large dams on the Sacramento River and its tributaries have not only denied salmon access to historic spawning grounds, but they have reduced or eliminated recruitment of spawning gravels into the river beds below the dams and altered temperature regimes. Loss of spawning gravels in the Sacramento River below Keswick Dam is regarded as a serious problem, and large quantities of gravel are now trucked to the river and dumped in, mainly to provide spawning sites for winter-run chinook. However, it is likely that late-fall run also use these gravel deposits (R. Painter, pers. comm.). Overly warm temperatures can be a problem in this reach, mainly during drought years when flows are reduced to save water in Shasta Reservoir. Also, the reduced reservoir volume during drought years and the inability to tap colder levels of the reservoir have meant that water released below the dam is often warmer than desirable. Efforts being made to provide cooler summer flows for winter-run chinook should also benefit late-fall run chinook.

Fishing. The actual harvest rates of late-fall chinook are not known, but it is highly likely that they are harvested at the same rates as fall chinook, the principal remaining run in the Sacramento River. In general, chinook salmon are harvested in both ocean and in-river fisheries. Although the fisheries are capturing mainly hatchery fish, they are presumably also taking wild fish at least in proportionate abundance relative to hatchery fish. Given the small size of the remaining runs of wild fish, the take of even a few wild fish may have a significant effect on their populations. It is likely that as many as one-half of the wild fish are taken in the fisheries.

Commercial fisheries also may be affecting the chinook populations indirectly through the continual removal of larger and older individuals. This results in spawning runs made up mainly of three-year-old fish, which are smaller and therefore produce fewer eggs per female. The removal of older fish also eliminates much of the natural "cushion" the populations have against natural disasters such as severe drought, which may wipe out a run in one year. Under natural conditions, the four- and five-year-old fish still in the ocean help to keep the runs balanced and can make up for the fish lost during an occasional catastrophe. Under present conditions, a loss of a run in one year will result in very low runs three years later, and the loss of runs two or three years in a row can eliminate a population.

Outmigrant mortality. Smolt mortality is probably a factor affecting late-fall chinook abundance as it is for all runs of salmon in the Sacramento-San Joaquin drainage. Small. numbers of outmigrants are presumably entrained at every irrigation diversion along the Sacramento River that is operating during the migration period. At the same time, extensive bank alteration, especially rip-rapping, reduces the amount of cover available to protect the outmigrants from striped bass and other predators. When SWP and CVP pumping rates are high and outflows relatively low, spring chinook smolts are probably entrained in large numbers, consumed by predators in Clifton Court Forebay and other off-channel areas, or are otherwise diverted from their downstream migration.

Introgression with other chinook salmon runs. The spawning season of late-fall run chinook overlaps somewhat with that of fall-run chinook in January and with winter-run chinook in April. Behavioral or physiological barriers to interbreeding at these times are unlikely, and the extent to which it occurs is not known. Prior to the construction of Shasta Dam, there probably was spatial as well as seasonal segregation among the three runs. However, since these three runs are now forced to spawn in one reach of the Sacramento River, introgression is likely. Introgression of mainstem populations of spring-run, chinook with fall-run chinook apparently has resulted in the loss of the distinctiveness of these runs in the Sacramento River, as indicated by an earlier shift in fall-run arrival in the upper river and a protracted fall spawning period (Vogel and Marine 1991). The blurring of run distinctiveness may also be happening with late-fall run chinook.

Late-fall run chinook are reared in small numbers in Coleman National Fish Hatchery on Battle Creek. Hatchery broodstock selection for late-fall run chinook includes both fish naturally returning to Battle Creek and those trapped at Keswick Dam. An arbitrary separation date (Dec. 15) is used to designate fish returning to Coleman National Fish Hatchery as late-fall run versus fall-run; however, there undoubtedly is overlap in the run timing. Interbreeding of hatchery fish with wild fish has the potential to dilute and eventually eliminate the genetic distinctiveness of the remaining naturally reproducing stock.

Pollution. A potential problem is the liklihood of a major spill of water laden with toxic chemicals from the Iron Mountain mine site, if the Spring Creek retention reservoir spills or bursts. These wastes could wipe out either migrating adults or, more likely, juveniles holding in the river.

Management. At present, less management is done to benefit directly late-fall run chinook salmon than any other run in the Sacramento River, mostly because the least is known about it. This run should benefit considerably from measures being taken to enhance winter-run and fall-run chinook populations in the river. However, studies should be undertaken to understand the environmental requirements of this run better because late-fall run chinook salmon need protection at all stages of their life cycle. A reasonable restoration goal for this run is to have annual runs of 25,000 to 35,000 spawners, with a mean of around 30,000. Restoration will require: (1) providing passage of adults to holding and spawning areas, (2) protecting adults in the spawning areas, (3) providing passage flows for out-migrating juveniles, (4) providing habitat for juvenile fish, (5) regulating the fisheries, and (6) reducing the effects of hatchery fish on wild populations.

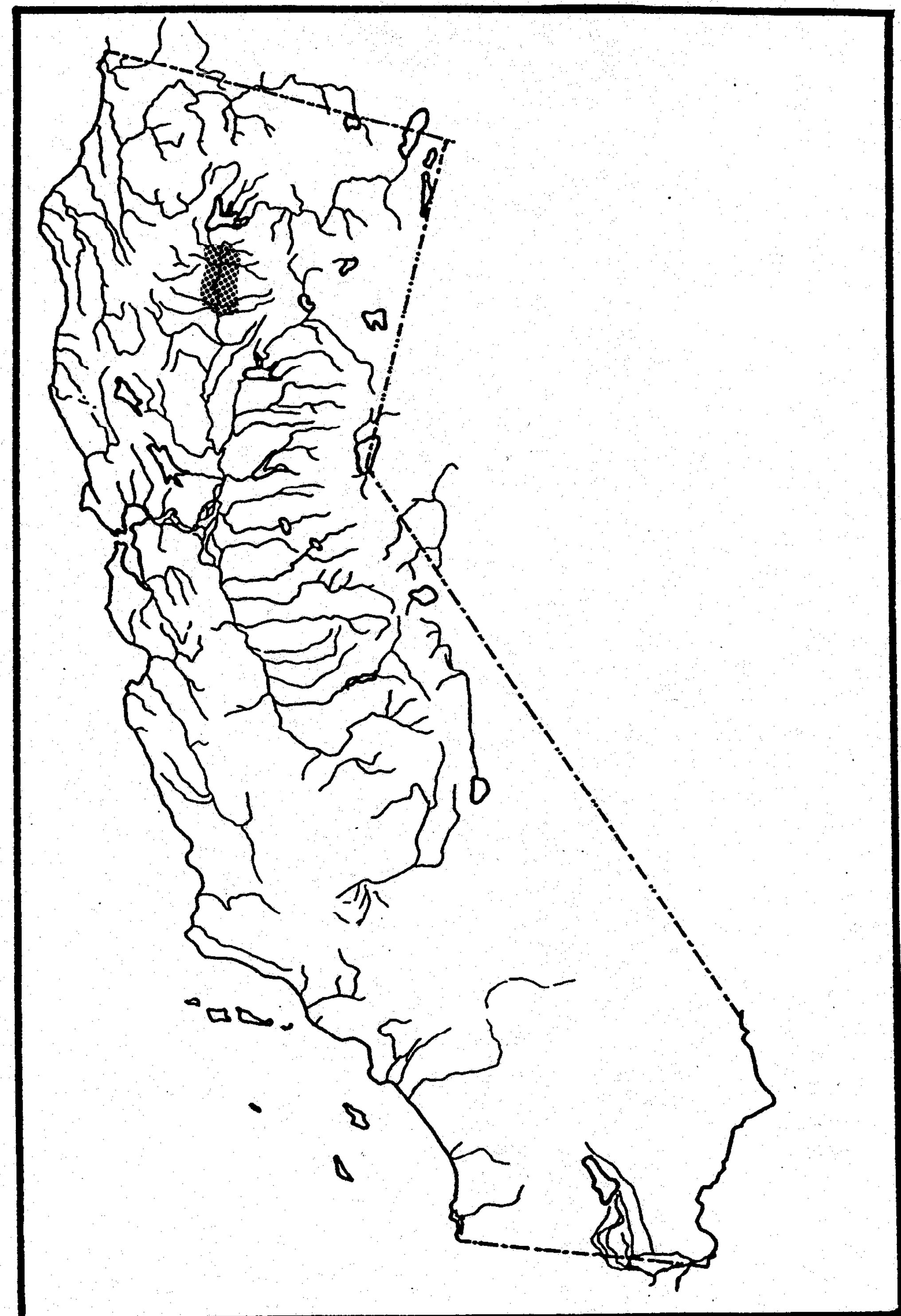


FIGURE 8. Major holding and spawning areas of the Sacramento River late-fall chinook salmon, *Oncorhynchus tshawytscha*.

COHO SALMON
Oncorhynchus kisutch (Walbaum)

Status: Class 1. Threatened.

Description: Coho are fairly large salmon, with spawning adults typically attaining 55-70 cm FL and weighing 3-6 kg. They have 9-12 dorsal fin rays, 12-17 anal fin rays, 13-16 pectoral fin rays, and 9-11 pelvic fin rays. Lateral line scales number 121-148 and the scales are pored. There are 11-15 branchiostegal rays on either side of the jaw. Gill rakers are rough and widely spaced, with 12-16 on the lower half of the first arch.

Spawning adults are dark and drab. The head and back are dark green, the sides are a dull maroon to brown, and the belly is grey to black. Females are paler than males. Spawning males are characterized by a bright red lateral stripe, hooked jaw, and slightly humped back. Both sexes have small black spots on the back, dorsal fin, and upper lobe of the caudal fin. The adipose fin is finely speckled, imparting to it a grey color; except for the caudal, the other fins lack spots and are tinted orange. The gums of the lower jaw are grey, except the upper area at the base of the teeth, which is generally whitish (Fry 1973). Parr have 8-12 narrow parr marks centered along the lateral line. The marks are narrow and widely spaced.

Taxonomic Relationships: Coho salmon are one of five species of Pacific salmon *(Oncorhynchus)* found in California. They do not appear to have the genetically distinct, temporally segregated runs that characterize the more abundant chinook salmon and steelhead trout. However, given the homing capabilities of coho salmon, it is reasonable to expect that at least some coastal areas have their coho populations adapted for local environmental conditions (e.g., with, regard to run timing and other life history characteristics). A recent study of allozyme variation in California coho salmon showed that most variant alleles occurred at three or fewer localities, although the distribution of those alleles did not follow any particular pattern (Bartley et al. 1992). It was concluded that gene flow among California populations was high from an evolutionary perspective, but low in terms of the actual number of individuals (1.4 per generation) being exchanged between populations. Further population genetic studies (e.g., using mtDNA) are needed. Overall, coho populations in California are the southernmost for the species and presumably have adapted to the extreme conditions (for coho salmon) of many coastal streams. There is some indication from allozyme data that California stocks may be somewhat genetically differentiated from stocks in more northern areas (Bartley et al. 1992).

Life History: The life history of the coho salmon in California has been well documented by Shapavalov and Taft (1954) and Hassler (1987). A comprehensive account of coho salmon biology throughout their range is given by Sandercock (1991), and ocean-related aspects are covered by Pearcy (1992). Coho salmon return to their parent streams to spawn after spending one or two years in the ocean (up to three years in Alaska). Jack males may, however, return after one growing season in the ocean (at age two years), but most fish return after two growing seasons in the ocean (age three). The spawning migrations begin after heavy late-fall or winter rains breach the sand bars at the mouths of coastal streams, allowing the fish to move into them. However, migration typically occurs when stream flows are either rising or falling, not necessarily when streams are in full flood. The timing of their return varies considerably, but in general they return earlier in the season in more northern areas and in the larger river systems (Baker and Reynolds 1986). In the Klamath River, the coho run is between September and late-December, peaking in October-November. Spawning itself occurs mainly in November and December (USFWS

1979). The early part of the run is dominated by males, with females returning in greater numbers during the latter part of the run. The coho run in the Eel River occurs 4-6 weeks later than that in the Klamath River; arrival in the upper reaches of the Eel River peaks in November-December (Baker and Reynolds 1986). In the short coastal streams of California, most coho return during mid-November through mid-January (Baker and Reynolds 1986). In the southernmost populations in Scott and Waddell creeks (Santa Cruz County), spawning migrations often do not occur until November or December. (Shapovalov and Taft 1954) and spawning may extend into February (J. Smith, pers. comm.). In Oregon streams, spawning can occur as late as March if drought conditions delay rains or runoff (Sandercock 1991). Coho salmon migrate up and spawn mainly in streams that flow directly into the ocean or in tributaries of large rivers. Generally, coho spawn in smaller streams than those used by chinooks.

Females choose the spawning sites (redds) usually near the head of a riffle, just below a pool, where the water changes from a smooth to a turbulent flow and there is medium to small gravel substrate. Flow characteristics of the redd location usually ensure good aeration, and the circulation facilitates fry emergence from the gravel. Each female, moving upstream, builds a series of redds and deposits a few hundred eggs in each. Thus, spawning may take about a week to complete and a female can lay between 1,400-7,000 eggs. There is a positive correlation between fecundity and size of females. A dominant male accompanies a female during spawning, but one or more subordinate males also may engage in spawning (Hassler 1987). Both males and females die after spawning, athough the female may guard a nest for up to two weeks (Hassler 1987).

Embryos hatch after 8-12 weeks of incubation, the time being inversely related to water temperature. Hatchlings remain in the gravel until their yolk sacs have been absorbed, 4-10 weeks after hatching. Under optimum conditions, mortality during this period can be as low as 10%; under adverse conditions of high scouring flows or heavy siltation, mortality may be close to 100% (Baker and Reynolds 1986). Upon emerging, they seek out shallow water, usually along the stream margins. Initially they form schools, but as they grow bigger the schools break up and juveniles (parr) set up individual territories. Larger parr tend to occupy the heads of pools; smaller parr are found farther down the pools (Chapman and Bjornn 1969). As the fish continue to grow, they move into deeper water and expand their territories until, by July and August, they are in deep pools. Optimal habitat seems to be deep pools containing rootwads and boulders in heavily shaded sections of stream. Growth rates slow down at this stage, possibly due to lack of food or because the fish reduce feeding as a result of warmer temperatures.

During December-February, winter rains result in increased stream flows and by March, following peak flows, fish are feeding heavily on insects and crustaceans and grow rapidly. Toward the end of March and the beginning of April they begin to migrate downstream and into the ocean. Outmigration in California streams typically peaks in mid-May, if conditions are favorable. Migratory behavior is related to rising or falling water levels, size of fish, day length, water temperature, food densities, and dissolved oxygen levels. At this point, the outmigrants are about one year old and 10-13 cm in length. The fish migrate in small schools of about 10-50 individuals. Parr marks are still prominent in the early migrants, but the later migrants are silvery, having transformed into smolts.

After entering the ocean, the immature salmon initially remain in inshore waters close to the parent stream. They gradually move northward, staying over the continental shelf. Coho salmon can range widely in the north Pacific, but the movements of California fish are poorly known. Most coho caught off California in ocean fisheries were reared in coastal Oregon streams (natural and hatcheries). In 1990, for instance, 112,600 coho were caught in commercial and recreational ocean fisheries, which greatly exceeds the present production capability of California populations alone (A. Baracco, pers. comm.). Oceanic coho tend to school together. Although it is not known if the schools are mixed, consisting of fish from a number of different streams, fish from different regions are found in the same general areas.

Adult coho salmon are primarily piscivores, but shrimp, crabs, and other pelagic invertebrates can be important food in some areas.

Habitat Requirements: Coho salmon move upstream in response to an increase in stream flows caused by fall storms, especially in small streams when water temperatures are 4-14°C. Spawning sites are typically at the heads of riffles or tails of pools where there are beds of loose, silt-free, coarse gravel and cover nearby for the adults. Unlike other salmon species, coho salmon redds can be situated in substrates composed of up to 10% tines (Emmett et al. 1991), but spawning success and fry survival generally are favored by very clean gravel (<5% fines) (CDFG 1991). Spawning depths are 10-54 cm, with water velocities of 0.2-0.8 m sec^{-1} (Hassler 1987). Optimal temperatures for development of the embryos in the gravel is 4.4-13.3°C, although eggs and alevins can be found in 4.4-21.0°C water (Emmett et al. 1991). Dissolved oxygen levels should be above 8 mg 1^{-1} for eggs and above 4 mg 1^{-1} for juveniles (Emmett et al. 1991).

Juveniles prefer deep (21 m), well-shaded pools with plenty of overhead cover; highest densities are typically associated with instream cover such as undercut banks or logs and other woody debris in the pools or runs. Juveniles require water temperatures not exceeding 22-25°C for extended periods of time and oxygen and food (invertebrates) levels that remain high. Preferred temperatures are 10-15°C (Hassler 1987); preferred water velocities for juveniles are .09-.46 m sec^{-1}, depending on habitat. High turbidity is detrimental to emergence, feeding and growth of young coho (Hassler 1987, Emmett et al. 1991). Young and adult coho salmon are found over a wide range of substrates, from silt to bedrock.

Distribution: Coho salmon are widely distributed in the northern temperate latitudes. In North America, they spawn in coastal streams from California to Alaska. In Asia, they range from northern Japan to the Anadyr River in the Soviet Union. In California, principal populations are located in the Klamath, Trinity, Mad, Noyo, and Eel rivers, with other populations in smaller coastal streams south to Scott and Waddell creeks, Santa Cruz County. In the Eel River system, they formerly ascended 390 km (246 mi) of stream in 69 tributaries (Mills 1983) of the South Fork Eel, the lower mainstem Eel River, and the Van Duzen River (Brown 1987). Annual runs in the Eel River system in earlier years have been estimated at over 40,000 fish (U.S. Heritage Conservation and Recreation Service 1980); current runs are less than 1,000 fish (Brown and Moyle 1991). Brown and Moyle (1991) found historical records of occurrence of coho in 582 California streams, ranging from the Smith River near the Oregon border to the Big Sur River on the central coast. More recent records of surveys were available for only 244 of the streams; of those streams, 46 % had lost their populations. Generally, the farther south a stream was located, the more likely it was to have lost its coho population (Brown and Moyle 1991). Coho salmon are rare in the Sacramento River even though several attempts have been made to establish runs (Hallock and Fry 1967). It is likely that runs occured at one time at least in tributaries to San Francisco Bay, if not in more interior streams. Coho salmon of hatchery origin also have been stocked in reservoirs such as Lake Berryessa with considerable success. The coho do not reproduce in reservoir tributaries, however, and therefore must be restocked annually to support angling.

Abundance: Historical figures of statewide coho salmon abundance were essentially guesses made by fisheries managers, based on limited catch statistics, hatchery records, and personal observations of runs in various streams. Maximum estimates for the number of coho spawning in the state in the 1940s range from 200,000-500,000 (E.R. Gerstung, pers. comm.) to close to 1 million (Calif. Advisory Committee on Salmon and Steelhead Trout 1988). Coho numbers held at about 100,000 statewide in the 1960s (California Advisory Committee on Salmon and Steelhead Trout 1988), with 40,000 in the Eel River alone (U.S. Heritage Conservation and Recreation Service 1980), and then dropped to a statewide average of around 33,500 for the 1980s (Brown et al. 1994). The reliability of these estimates is uncertain, and so must be viewed only as "order-of magnitude" approximations. Coho salmon in California, including hatchery stocks, presently are less than 6% of their abundance during the 1940s, with probably at least a 70% decline in numbers since the 1960s. Brown et al. (1994) estimated that the total number of adult coho salmon entering California streams in 1988-90 averaged about 31,000 fish per year. However, hatchery fish made up 57% of this total, and many big-river populations contain at least some fish of recent hatchery ancestry. The hatchery stocks, without exception, have in their ancestry fish from other river systems and often from outside California (Brown and Moyle 1991, Brown et al., unpubl.). This may explain the overall lack of genetic differentiation of coho salmon from different California streams (Bartley et al. 1992).

Coho salmon are widely distributed in coastal streams of California. Their populations show large fluctuations, but the general trend has been downward in the wild populations of small coastal streams. Of 582 coastal streams that historically held coho salmon, at least 19% and perhaps up to 40-50% have lost their coho runs (Brown et al. 1994). In Del Norte County, 45% of the streams for which there are reliable records have lost their coho populations, mainly in the Klamath-Trinity system. Corresponding percentages for other counties are: Humboldt County, 31; Mendocino County, 41; Sonoma County, 86. Farther south, the value is 56%, but this excludes streams in the Sacramento drainage and includes streams with extremely low populations that are enhanced by hatchery production. The big-river populations presently are largely maintained by hatchery production. Early accounts indicate that the Sacramento drainage supported coho salmon in the 19th century (U.S. Comm. Fish and Fisheries 1892, Evermann and Clark 1931), but the coho were extirpated before any good records were kept. Historical annual spawning escapements for the Klamath River system have been estimated at 15,400-20,000 fish, with 8,000 for the Trinity River (USFWS 1979). Only 1,700 cohos returned to Klamath Basin hatcheries in 1990 (A. Baracco, pers. comm.) and 3,100 returned in 1991 (CDFG 1992a).

Probably the largest concentration of wild fish (with little or no hatchery influence) is in the South Fork of the Eel River, which has been estimated to have runs of about 1,300 fish. The latest (1990) survey, however, indicates a population one-half to one-third that size. This stock seems to be the only remaining wild, big-river coho run in California. Lagunitas Creek (Marin County) supports one of the better small-stream coho runs. This stream and its tributaries historically supported 500-2,000 adult spawners yearly (E. Gerstung, pers. comm.); the 1991-1992 run has been estimated at 500 fish (L. Cronin, pers. comm.). A similar self-sustaining run apparently exists in nearby Redwood Creek. Brown et al. (1994) considered 5,000-7,000 fish to be a realistic assessment of the total number of naturally spawned adults returning to California streams each year since 1987, although this number includes some stocks that contain fish of recent hatchery derivation. Presently, there are probably less than 5,000 wild coho salmon (no hatchery influence) spawning in California each year. Many of these fish are in populations of less than 100 individuals. These small populations are probably below the minimum population size required to preserve the genetic diversity of the stock and to buffer them from natural environmental disasters. There is every reason, therefore, to think that California's coho populations are continuing to decline. Higgins (1992) divides California's coho populations into 18 "stocks", ten of which are considered to be "at high risk of extinction." Abundance of wild coho salmon in both Washington and Oregon also is low and declining (Nehlsen et al. 1991), and the species is classified there as "sensitive-critical" (Weeks 1992). In 1993, the Audubon Society and other groups petitioned the Pacific Fisheries Management Council to ban all harvest of coho salmon south of Canada because of its alarming declines throughout the Pacific northwest. A petition to list all coho salmon populations in Washington, Oregon, and California as endangered was filed with NMFS by a coalition of environmental groups in October 1993. In addition, the populations of coho salmon in Scott and Waddell creeks (Santa Cmz County) were petitioned for endangered status to the state Fish and Game Commission (January 1993, by David Hope).

Nature and Degree of Threat: The threats to a species' survival may be categorized, according to the Endangered Species Act, as follows: "(A) the present, or threatened, destruction, modification, or curtailment of its habitat or range, (B) over-utilization for commercial, recreational, or educational purposes, (C) disease or predation, (D) inadequacy of existing regulatory mechanisms, or (E) other natural or manmade factors affecting its continued existence." For coho salmon all these factors seem to apply. The general reasons for the decline of coho salmon in California are many and well known (Brown et al. 1994): poor land-use practices that degrade streams, especially those related to logging and urbanization; the exacerbating effects of floods and drought; the breakdown of the genetic integrity of wild stocks through planting of hatchery fish; introduced diseases; overharvesting; climatic change. Although all salmon are affected by these factors, their effects on California coho are likely to be particularly severe because virtually all females are three years old. Therefore, well-timed flood or severe drought, in conjunction with one of the above human-caused factors, can eliminate one or more year classes from a stream. There is good evidence that this has already happened repeatedly in coastal drainages, where the decline of coho is linked to poor stream and watershed management. In more northern streams (Mendocino to Del Norte counties), most damage has been done by post-World War II logging practices that remove riparian vegetation and woody debris from channels, cause stream temperatures to increase, till pools with silt and gravel, alter stream channels, and otherwise alter habitats. In more southern streams, road construction, poor farming and grazing practices, and water diversions have been the major causes of coho declines (K. Anderson, pers. comm.). At the present time, populations are so low that even moderate fishing pressure on wild coho may prevent recovery, even in places where stream habitats are adequate. Existing regulatory mechanisms, such as fishing regulations, forest practice rules, and stream alteration agreements, have been inadequate to protect the species in California, Oregon, and Washington, and populations have declined steadily and precipitously as a result.

Management: The key to stopping the decline of coho salmon is to protect their spawning and rearing streams and to restore damaged habitat (Emig et al. 1988). This is a difficult task because it means modifying logging, farming, and road construction activities in dozens of coastal drainages and implementing habitat restoration plans in hundreds of streams. In many streams it means that major reconstruction projects, such as the one underway in Bull Creek, Humboldt Redwoods State Park, must be funded and completed. Closing or greatly restricting the fishery for a few years is also a necessity. Given the large scale of coho problems, innovative approaches to stream restoration must be tied, working with landowners, timber companies, and gravel miners. For example, logging operations in sensitive drainages should be required to add root wads and other large woody debris to streams to create pools. Gravel extraction operations in streams should be managed in such a way that excess gravel is removed to create coho habitat.

Serious consideration should be given to eliminating all production hatchery programs, especially those that rely on non-native stocks. This would reduce the effects of interbreeding of hatchery coho with wild coho, and reduce the spread of hatchery diseases to wild fish. Where population augmentation is deemed necessary, small-scale, on-stream hatchery operations using local wild stock could be used as temporary measures (but must be used with extreme caution, with a firm closure years).

Management goals put forward by the CDFG could reverse the trends if properly implemented, but that will require a major effort involving increased funding, considerable interagency cooperation, and development of an extensive monitoring program. Monitoring the populations is a necessity; spawning streams should be identified and populations should be sampled annually. This would allow population trends to be followed and provide focus for restoration efforts. The challenges of managing such a diffuse resource as coho salmon are considerable, but if the population declines are not reversed soon, we are likely to lose many more populations, including the southernmost populations of the species.

Coho salmon in California qualify for listing as a threatened species under state law. However, preservation and restoration of local populations can be effectively achieved only by cooperative, active, and immediate efforts by the resource agencies, local governments and private or commercial groups directly concerned with the species. Perhaps the first step in restoring coho populations in California would be to establish a Coho Task Force, representing agencies and private groups, that should meet as soon as possible to recommend protective measures and establish restoration priorities. A version of such a group (The Coho Salmon Technical Committee) has been established (1993) by the California Forestry Association to develop recommendations for restoration of coho salmon populations on private timber lands. Major public works funding must be obtained for stream restoration to benefit not only coho salmon but all the other species that depend on healthy streams.

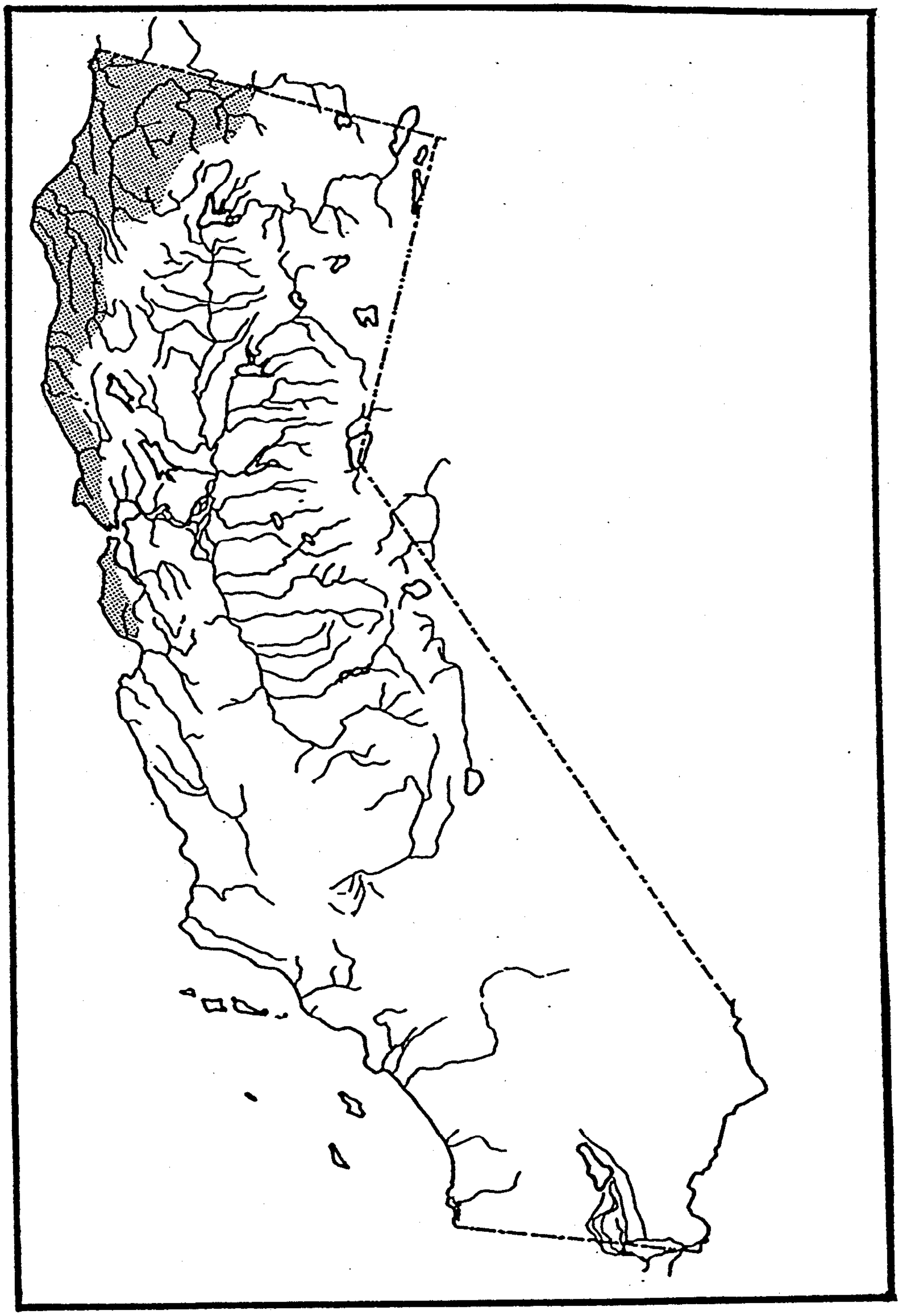


FIGURE 9. Distribution of coho salmon, *Oncorhynchus kisutch*, in California.

PINK SALMON
Oncorhynchus gorbuscha (Walbaum)

Status: Class 1. Extinct or Endangered in California

Description: Pink salmon are the smallest of the Pacific salmon, usually reaching less than 60 cm SL (2.5 kg). Maximum recorded length is 76 cm SL (6.3 kg). They are distinguished from other salmon species by the black oval markings on both caudal lobes and back. The number of gill rakers, which ranges from 16-21 on the lower, first gill arch, is also distinctive (McPhail and Lindsey 1970). The mouth is terminal and there are sharp teeth on both jaws, the vomer, palatines and on the tongue. The dorsal fin has 10-16 complete rays, the anal fin 13-19, the pectoral fin, 14-18 and the pelvic tins 9-11 rays. There are 147-198 scales along the lateral line, Branchiostegal rays number from 10-15 on either side of the jaw.

Marine-phase fish are steel blue to blue-green dorsally, are white ventrally, and have silver sides. The back and upper parts of the lateral surfaces have large black spots which are also present on the adipose and caudal fin lobes (Scott and Crossman 1973). Spawning males have a pronounced hump immediately behind the head (the reason for their other common name, humpback salmon), and the snout is greatly enlarged and hooked. The body color becomes darker, especially on the head and back. The sides become pale red, with brown to olive-green markings. Reproductive females lack the conspicuous hump of the males and resemble trout in general body shape. Their sides are olive green, with long, dusky, vertical markings. Scales in reproductive pink salmon become deeply embedded. Juveniles in fresh water are small (<40 mm) and lack parr marks.

Taxonomic Relationships: This species was first described in 1792 (see Scott and Crossman 1973, for complete synonymy). Nothing is known about the genetic identities of California fish or how they relate to more northern populations. However, biochemical differences have been observed between pink salmon stocks in different river systems (Beacham and Withler 1985), and Russian workers also have noted genetic differences between stocks in different geographical areas (Omel'chenko and Vyalova 1990).

Life History: The life history of pink salmon is well known, so this account briefly summarizes information in Scott and Crossman (1973) and Heard (1991). Pink salmon live for two years although occasionally three-year-old fish are reported. The adults move into fresh water between June and September and spawn from mid-July to late October, depending on the geographic location. Spawning in California has only been recorded in October (Fry 1967). Most pink salmon spawn in the intertidal or lower reaches of streams and river, although upstream migrations of 100-700 km are found in some river systems. Spawning occurs in gravelly riffles with water depths between 20-60 cm. The six redds built by females in the lower Russian River were all situated along the stream edges where the substrate was finer (Fry 1967). No redds were found in the middle portion of the riffle where the substrate was composed of coarser gravel. During nest building, the female lies on her side and excavates a depression approximately 90 cm long and 45 cm deep. The female indicates spawning readiness by sinking down into the redd until her anal fin touches the gravel. The male then swims up alongside and both fish settle down in the redd, quivering and gaping as they release gametes. Once egg deposition is completed, the female coversthe redd with gravel by displacing substrate from the upstream margin of the redd. Females may spawn with several males; the nest area is typically defended by a large dominant male and several smaller, subordinate males. Likewise, a single male will spawn with several females.

A female usually lays 1,200-1,900 eggs during the spawning period, which lasts for several days. Both males and females die a few days to a few weeks after spawning. Embryos hatch after 4-6 months of incubation, presumably in February and March in California. The alevins emerge from the gravel in April or May, at which time the yolk-sac has been absorbed. The fry are about 35 mm TL and immediately begin to migrate downstream into the estuary. Juvenile migration takes place at night and fish move rapidly downstream, usually reaching the estuary in one night. Once in the estuary they form large schools and remain in the inshore areas for several months before moving out to sea. Most juveniles do not remain in fresh water long enough to feed, although those that hatch from redds further upstream have been known to feed on aquatic insects. At sea, juveniles feed on small crustaceans and other invertebrates. Maturing adults feed mostly on fish, squid, euphausiids, amphipods and copepods.

Pink salmon wander great distances while in the oceans and tagged fish have been captured 2,700 km (1,700 mi) from where they were tagged (Omel'chenko and Vyalova 1990). However, they are fairly faithful to their parent streams and return there for spawning. The two-year life span of pink salmon results in distinctive populations which form odd- and even-year spawning runs. Some streams may support major runs of both (odd and even) years whereas others may support major runs of one or the other year. Historically, the southernmost pink salmon fisheries in North America landed large numbers only in odd-numbered years, and in California most records of pink salmon up through the 1950s were for odd years (Hallock and Fry 1967).

Habitat Requirements: Spawning streams for pink salmon have shallow, riffle sections with small gravel substrates. Emmett et al. (1991) summarize the requisite ranges of physical parameters as follows. Optimal temperatures for pink salmon are 5.6-14.4°C; 0.0°C and 25.6°C are the lethal limits. Spawning generally occurs at temperatures of 7.2-12.8°C, with 4.4-13.3°C optimal for hatching. Embryos and alevins require fast-flowing (21-101 cm sec^{-1}) and well-oxygenated (>6 mg 1^{-1}) water for normal development and survival.

Distribution: Spawning pink salmon ascend coastal streams of northern Asia, from Korea through Japan to Siberia (Heard 1991). Along the northwestern Pacific coast of North America they range from the MacKenzie River in the Yukon Territory of Canada south to coastal streams of California. Isolated oceanic records have been documented as far south as La Jolla (Hubbs 1946). However, the largest runs on the southernmost end of their range are in streams tributary to Puget Sound (Hallock and Fry 1967).

In California, small numbers have been reported from the San Lorenzo River (Scotield 1916), the Sacramento River and tributaries (Hallock and Fry 1967), the Klamath River (Snyder 1931), and the Russian, Garcia, and Ten Mile rivers (Taft 1938). One specimen each has also been reported from the Mad River and Prairie Creek, Humboldt County (Taft 1938, Smedley 1952), Lagunitas Creek at the south end of Tomales Bay (B. Cox, pers. comm.), and from Mill Creek, Tehama County (Taft 1938). A pink salmon caught in the Mad River also was reported in the popular press (Arcata Union, Sept. 6, 1928; S. Van Kirk, pers. comm.), which stated that this species had been frequently taken in the Mad River by net fishermen many years earlier. Pink salmon have been observed spawning in the Ten Mile and Garcia rivers (Taft 1938), and there is an additional record of spawning in the lower Russian River, where Fry (1967) observed at least six pink salmon redds in 1955. Irregular occurrences of spawning in some Mendocino County streams also was reported by Roedel (1953). During the 1800s, pink salmon were reported to occur in the Sacramento River, "...which it [sic] ascends in tolerable numbers in October" (Calif. Comm. of Fish. 1881, p. 54). During the 1930s, commercial fishermen on the Sacramento River reportedly captured a dozen or more pink salmon in some seasons (Hallock and Fry 1967). In the period 1949-1958, 38 pink salmon were taken in the Sacramento River system; this included 12 fish from Coleman National Fish Hatchery, 4 in Mill Creek and 3 at Nimbus Fish Hatchery on the American River (Hallock and Fry 1967). Recent occurrences of pink salmon have been infrequent. Within the last two decades, one individual was seen in the Garcia River, and 1 or 2 have been caught every year for several years in the Klamath River system (L.B. Boydstun, pers. comm.). One pink was seen in the American

River by T. Mills (pers. comm.) and 3 more (males) were taken on that river on three separate occasions (R. Ducey, pers. comm.). No pinks have been seen recently at the Feather River Hatchery, the Coleman National Fish Hatchery, Red Bluff Diversion Dam, or in stream surveys in the northern Sacramento River drainage (R. Painter, pers. comm.) and San Joaquin drainage (M. Pisano, pers. comm.). However, limited spawning occurred in the Sacramento-San Joaquin river system during 1989, because seven pink salmon smolts were salvaged at the state J.E. Skinner Fish Protective Facility near Tracy in March, 1990 (D. McEwan, pers. comm.).

Abundance: In Alaska and Canada, pink salmon are extremely abundant and support major commercial fisheries. California is the southern edge of their range so they have never been common here, although they may have occurred in noticeable numbers in the past. In the late 1880s, they were reported to occur in the Sacramento River system as well as in Humboldt County waters, and pinks were included in the salmon catch sent from the northern coast to San Francisco markets (U.S. Comm. Fish and Fisheries, 1892). Taft (1938) cited reports by CDFG wardens that considerable numbers of pink salmon were running in northern California streams in 1937: “many quite large schools of them” in the Ten Mile River, and “several hundreds” in the Garcia River, “spawning all over from the Red Bridge to the western boundary of the Indian Reservation, a distance of about two miles.” They also were observed in the Russian River during that year (Taft 1938). Today, however, pink salmon are extremely rare in California. Most fish recorded in the state are probably fish that strayed while at sea and followed other species of salmon upstream. Their occurrence in the Russian River in 1937 and evidence of limited spawning in 1955 (Fry 1967), would indicate that this “run” may be the southernmost one for the species, except for occasional spawners in the Sacramento River. A run in the Russian River has not been recorded since Fry's report. There have been no reports of pink salmon in that river or surrounding areas of Sonoma and Marin counties for at least the past 12 years (B. Cox, pers. comm.). Given the major changes that have taken place in the Russian River in the past 20 years, such as gravel mining, the construction of Dry Creek Dam, and a number of major pollution events, it is likely that pink salmon no longer spawn there. However, an effort should be made to determine if the fish truly are absent rather than just overlooked.

Nature and Degree of Threat: For pink salmon, threats to their existence in California cannot be clearly identified because of the sparseness of historical data on their abundance and distribution. In fact, they already may be extinct in the state. Because of their tendency to migrate and spawn only short distances upriver from the ocean, pink salmon runs probably would have been adversely affected by the general degradation and diminution of estuaries and the lower reaches of rivers in California.

Management: The first step is to determine if reproducing populations exist anywhere in California. The lower reaches of the Ten Mile, Garcia and Russian rivers should be thoroughly surveyed at the appropriate time of year (mid-September through November) and recent records elsewhere in the state carefully investigated. If viable spawning populations exist, then habitat, flow, and water quality should be protected.

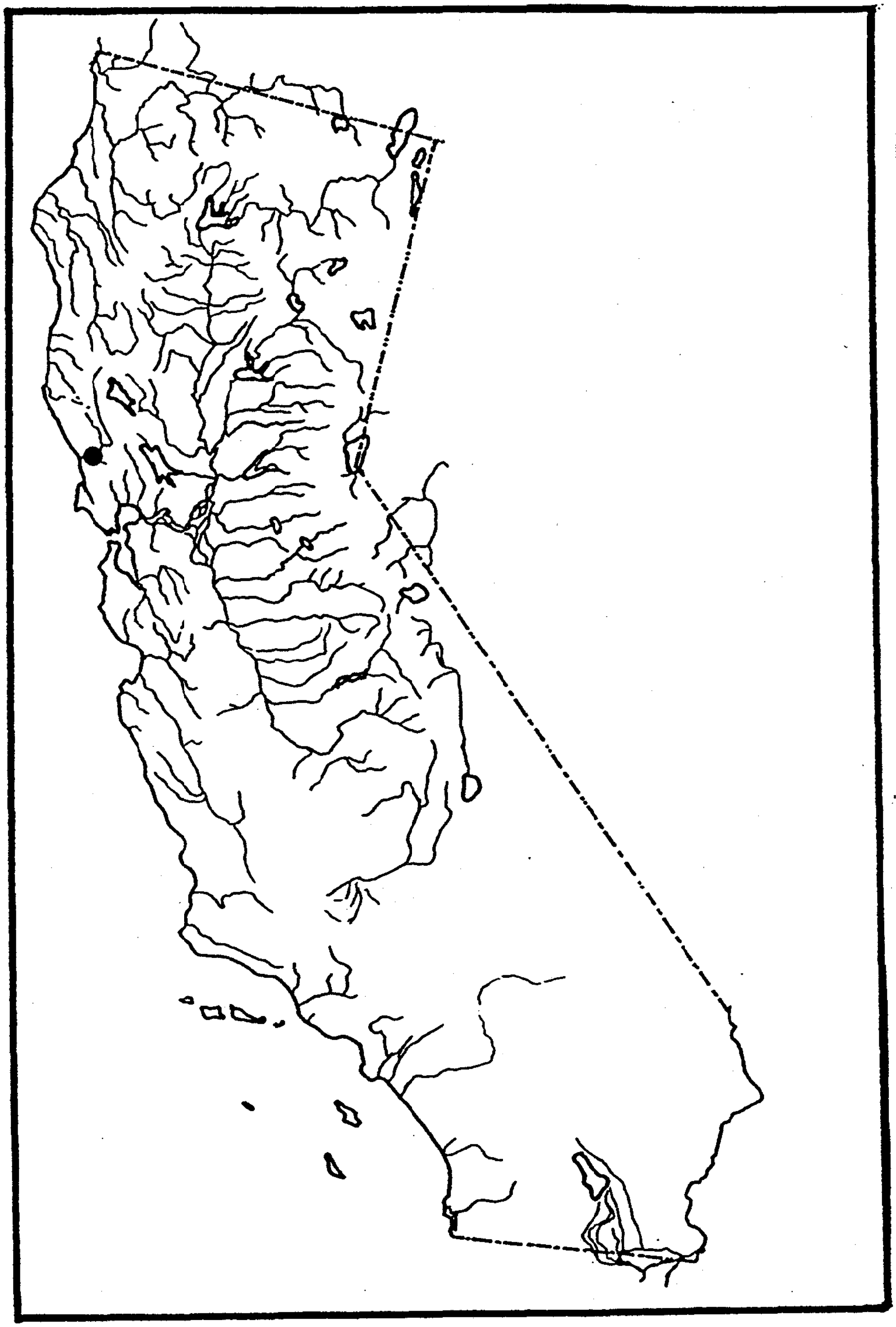


FIGURE 10. Spawning areas of pink salmon, *Oncorhynchus gorbuscha*, in the Russian River, California.

CHUM SALMON
Oncorhynchus keta (Walbaum)

Status: Class 1. Endangered in California.

Description: Chum salmon are second only to chinook salmon (O. tshawytscha) in size, reportedly growing up to about 1 m SL and 20.8 kg in weight, but they typically are less than 80 cm SL. They can be distinguished from other salmon (except sockeye, O. nerka) by the absence of black spots on the back and fins. There are 11-17 short, smooth gill rakers on the lower half of the first gill arch, 10-14 major rays in the dorsal fin, 13-17 in the anal fin, 14-16 in each pectoral fin, and 10-11 in each pelvic fin. The scales (124-153 in the lateral line) are deeply imbedded in spawning fish. Branchiostegal rays are 12-16 on each side of the jaw. Spawning male chum salmon are heavy bodied, slightly humped, and have a long, hooked snout with conspicuous canine-like teeth. They are dark olive on the back and dirty maroon on the sides, with irregular greenish vertical bars on the sides. Females are similar in color, although the maroon color on the sides is less well developed. They also lack a hump and the jaw is less hooked. Parr have 6-14 pale parr marks that seldom extend below the lateral line, and the width of the light areas in between the marks is greater than the width of the marks themselves. There is no spotting on the fins and the back is mottled green, with silvery green sides .

Taxonomic Relationships: The chum salmon is most closely related to the pink and sockeye salmon, forming a subgroup within *Oncorhynchus* (Healy 1991). Despite their typically extensive migrations in the ocean, chum salmon evidently show a strong homing tendency to their natal streams (Salo 1991), which would contribute to the genetic isolation of spawners in different streams. There is some evidence that even within a single river system, genetic differentiation associated with spatial separation of spawners may occur (Salo 1991). Whether this is a general feature of the species is not clear; much further work is needed on the spatial-genetic structuring of chum salmon populations, including those in California.

Life History: Chum salmon are highly migratory and versatile in their use of fresh and marine waters. Nevertheless, because of their economic importance, their life history and habitat requirements have been well studied (reviews in Emmett et al. 1991 and Salo 1991, from which this account is derived). They can spawn in intertidal areas, but some populations in the Amur River, Russia, and the Yukon River of Alaska and Canada spawn 2,500 km or more upriver. Normally, chum salmon migrations occur upriver within 200 km from the ocean. There are no natural, completely landlocked forms. Chum salmon appear unable to hurdle waterfalls and other barriers that present few difficulties of passage to other salmon species. In general, chum salmon (like pink salmon) have a short freshwater and an extensive marine life stage, and they are especially dependent upon estuaries during the nonmigratory juvenile stage. In North America, there is a northern (early-run) stock that spawns from June through September and a southern (late-run) stock that spawns from August through January. In Washington, Oregon, and California, all stocks are late-run. The early-run fish generally spawn in main stems of streams, while the late-run fish spawn in smaller streams which have more favorable winter temperatures.

Adults show strong homing behavior to their natal streams. They spawn at 2-7 years of age, but primarily at ages 3-5. Chum salmon prefer to spawn immediately above areas of turbulence or upwelling. Females are territorial and will dig and spawn in a series of 4-6 nests, each one immediately upstream of the previous spawned-in nest. A decreasing number of eggs is laid in the later nests. The combined set of nests, the redd, averages 2.8 m^2 in size. The female guards her redd until she dies. Males, which are sexually active for 10-14 days, may spawn with several females, and they are physically aggressive toward other males. Large dominant males have a greater chance of obtaining a mate. A subdominant, or satellite, male may sneak spawn-- i.e., he will approach a spawning pair from downstream and attempt to fertilize some eggs. Large females can lay over 4,000 eggs, but average fecundity is 2,400-3,100 eggs per female.

Fertilized eggs are 6.0-9.5 mm in diameter and hatch after about 2-6 months of incubation, usually from December to February. Alevins are 20-24 mm long at hatching and grow to 30-35 mm while in the gravel; they absorb their yolk sac in 30-50 days, and then emerge from the gravel. Fry in fresh water are 30-70 mm long, depending on the distance they must migrate from the spawning grounds to the estuary. The fry typically emerge from the gravel at night and immediately migrate downstream. Migration of fry is mainly nocturnal in some river systems, but they may migrate during daylight in other areas, The fry do not school as strongly as do pink or sockeye fry, and they are attracted to the shade or darkness of aquatic vegetation.

Fry may not feed in fresh water if their downstream migration is short. If they are in fresh water for a lengthy period, the fry will feed on small crustaceans and insects, with chironomid larvae being of particular importance. Significant feeding occurs in estuarine and nearshore marine areas, where they take epibenthic prey such as harpacticoid copepods and gammarid amphipods. As they move into deeper water and grow larger, chums include in their diet calanoid copepods, hyperiid amphipods, crustacean larvae, larvaceans, euphausiids, pteropods and fishes.

Predators of chum fry include coho, chinook and sockeye salmon, rainbow and cutthroat trout, Dolly Varden, sculpins, Pacific cod and some birds (e.g., belted kingfisher and mergansers). At sea, juveniles are eaten by lampreys, sharks and other larger fishes. Bears and large predatory birds such as osprey and bald eagles prey on spawning adults.

Habitat Requirements: Chum salmon adults and maturing juveniles are epipelagic in the ocean, but all stages are bottom oriented in the rivers and streams. Adults migrate upstream in water velocities up to 2.44 m see^{-1} and can spawn while in velocities of 46-101 cm set^{-1}. Upstream migration occurs in water between just above freezing to 21.1°C, with an optimum range of 8.3-15.6°C. Optimum spawning temperatures are 7.2-12.8°C, and oxygen levels should be >80 percent of saturation with temporary drops to not less than 5 mg $O_2 1^{-1}$. Spawning gravels should be 1.3-10.2 cm diameter, but eggs and alevins are found primarily in medium-sized gravel (2-4 cm diameter). In the Columbia River drainage, chum salmon redds were composed of 13% gravel >15 cm, 81% 115 cm, and 6% silt/sand. In a survey of redds in Washington, 80% of the redds were located in depths of 13.4-49.7 cm, with a mean depth of 27 cm. Incubation temperatures range from 4.4-13.3°C, although eggs can survive colder temperatures after they have developed for a period and become cold-tolerant. Optimum outmigration river temperatures for fry are 6.7-13.3°C.

Eggs and alevins occur primarily in fresh water, although spawning in intertidal areas occurs. The fry show preference for saline water after the yolk sac is absorbed and at least some strains thereafter cannot survive extended periods in fresh water. The fry prefer shallow (<1 m) water during their initial out-migration. An acclimation period in estuarine (10-15‰ salinity) conditions may be required prior to entering sea water. Juveniles can be killed by high suspended sediment loads (15.8-54.9 g 1^{-1}).

Distribution: Chum salmon have the widest natural geographical distribution of the Pacific salmons, ranging from Korea up along the Arctic coast of Russia, and from the Mackenzie River on the Canadian Arctic coast of North America southward into central California. Historically, they were reported to occur in "all streams from San Francisco to [the] Bering Straits" (Jordan and Gilbert 1881), and were "said to be abundant in the fall, from Sacramento northward" (Eigenmann 1890). Both adults and juveniles occur in Oregon estuaries south to Coos Bay, except the Umpqua River, and only adults have been reported from the Rogue River (Monaco et al. 1990).

In California, chum salmon are rarely encountered today, although they were undoubtedly more common in the past. Both adults and juveniles occur in the Klamath River on a regular basis (T. Kisanuki, unpubl. data) and the California Academy of Sciences has a small collection of parr taken from the Klamath River in 1944 (Moyle 1976). Adults have been found in Humboldt Bay and the Eel River (Monaco et al. 1990). One individual was observed in Redwood Creek, Humboldt County, in 1983 (D. Anderson, pers. comm.). In the 1880s, chum salmon were a minor portion of the salmon catch from the Humboldt County coast sent to San Francisco markets, and they also occurred in the Sacramento River system along with pink, coho and chinook salmon (U.S. Comm. Fish and Fisheries 1892). Based on a ten-year (1949-1958) survey of the Sacramento River system, during which 68 chums were recorded, Hallock and Fry (1967) concluded that a very small run of that species was present. A few fish still are taken in the Sacramento drainage. A few chum salmon also have been observed annually in the South Fork Trinity River, the apparent remnant of a larger run that existed there prior to the 1964 flood (T. Mills, pers. comm.). Chums have also been reported from the Smith River drainage (J. Waldvogel 1988 and pers. comm.) and spawning has been observed in Mill Creek, Del Norte County (P. Foley, pers. comm.). Chum salmon have been found in ocean waters as far south as San Diego (Eschmeyer et al. 1983), but the southernmost freshwater record has been the San Lorenzo River, Santa Cruz Co. (Scofield 1916).

Abundance: The chum salmon is the second most numerous salmon species in the North Pacific region. They are abundant, however, primarily north of Oregon (Monaco et al. 1990). In California they are rare and have probably always been uncommon, except perhaps in the Klamath-Trinity River drainages. Today, they occur sporadically and in very low numbers. There is evidence of spawning in the South Fork Trinity. In the period 1985-1990, between 1-3 adults were seen or captured every year except 1988, and juveniles were taken on at least six occasions; one pair was observed spawning in 1987, and one fish caught in 1990 was spawned out (T. Mills, unpubl. and pers. comm.). USFWS sampling crews collected 21 chum juveniles and 2 fry in the Trinity River and 4 juveniles in the Klamath Estuary during 1991 (T. Kisanuki, unpubl. data). Small numbers also occur in the Smith River drainage. In the West Branch of Mill Creek, a tributary of the Smith, 1-8 spawning chums were observed in each of the years 1984-1988, entering the stream during mid-December high stream flows (J. Waldvogel 1988, and pers. comm.). No fish were seen in 1989, 1990 or 1991-- years lacking high December flows (J. Waldvogel, pers. comm.), although it is possible that chums were present in- the mainstem Smith River or its other tributary streams during those years.

One chum was observed in the Yuba River in the mid-1970s, five have been taken at the Feather River Hatchery over the last 25 years, but evidently none have been seen at the Coleman National Fish Hatchery (upper Sacramento River) in the last ten years (R. Painter, pers. comm.). Several chums have been seen at the Nimbus Fish Hatchery on the American River, the last one during 1990, and "about eight" were caught by fishermen in the upper American River during one year in the mid-1980s (R. Ducey, pers. comm.). There are no recent records of chums observed during stream surveys in the northern Sacramento River drainage (R. Painter, pers. comm.) or in the San Joaquin drainage (M. Pisano, pers. comm.).

Overall, it appears that the only California rivers that currently are used by chum salmon for spawning are the South Fork Trinity, Klamath and Smith rivers, although the numbers of fish in each river is small. It is highly likely that chum salmon were more abundant in the past, however, and that California populations today are in danger of extinction.

Nature and Degree of Threat: The historic uncommonness of chum salmon in California makes it difficult to identify factors that may have negatively affected their abundance. It is known, however, that chum salmon in general do not migrate far upriver in the southern part of their range (Salo 1991) and the lower reaches of coastal California streams are often the most degraded reaches. Habitat deterioration of spawning areas from logging, road building, mining, and other factors would have contributed to population decreases.

Management: Surveys in the South Fork Trinity, Klamath, and Smith rivers should be continued to monitor the status of the few fish spawning there. The exact timing and place of spawning need to be determined. Suitable habitat, flow, and water quality should be maintained in order to protect and enhance, as a group, the imperiled salmonids (including summer steelhead) in those rivers. Once key spawning areas are known, specific plans for enhancing populations should be established.

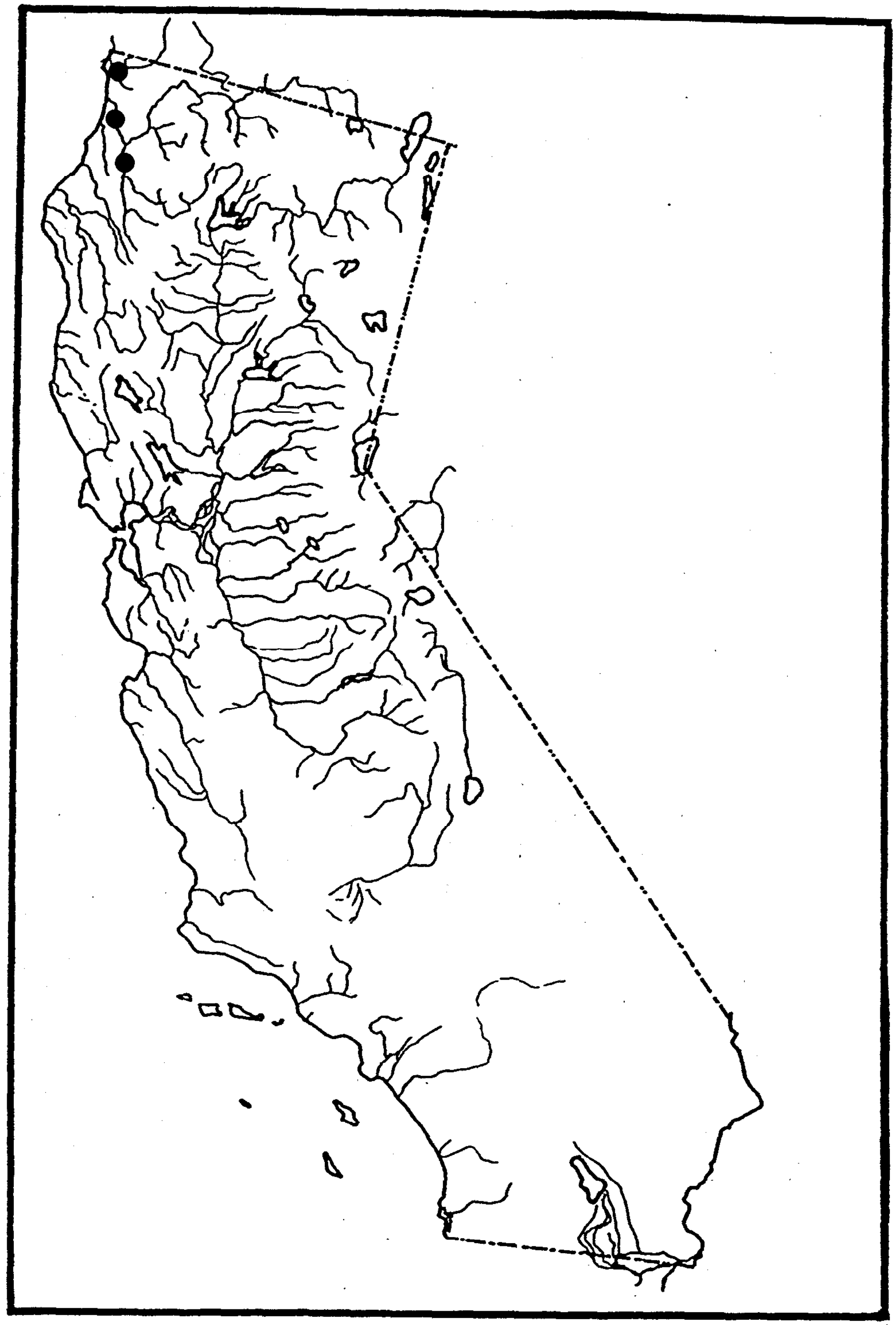


FIGURE 11. Recent freshwater distribution of chum salmon, *Oncorhynchus keta,* in the Smith, Klamath and South Fork Trinity rivers, California.

SUMMER STEELHEAD
Oncorhynchus mykiss irideus (Richardson)

Status: Class 1. Threatened.

Description: Summer steelhead are anadromous rainbow trout *(Oncorhynchus mykiss)* that return to freshwater streams from April through June to await the winter spawning season. Adults are silver laterally, grading into a silver-white ventrally. Dorsal coloration is blue-green with dark spots (Jones 1980). Some adults may also have pale red lateral stripes during the summer. Summer steelhead usually reach 60-80 cm FL (range 48-84 cm from the Eel River system) and weigh 3-4 kg. Males are slightly larger (about 6 cm) than females. They have large mouths with well-developed teeth on both upper and lower jaws, the head and shaft of the vomer, the palatines, and the tongue. Basibranchial teeth are absent. Gill rakers number 16-22 and branchiostegal rays, 9-13. There are 10-12 dorsal fin rays, 8-12 anal fin rays, 9-10 pelvic fin rays, and 11-17 pectoral fin rays. The caudal fin is forked. Scales are small, with 18-35 rows above the lateral line and 14-29 below. The 100-160 lateral line scales are pored.

Smaller fishes (25-35 cm) returning later in the summer and in early fall (usually from late August to early October) are among the steelhead referred to as "half-pounders." These are usually immature fish that have spent only a few months in the ocean and, if they survive their first upstream migration, will return to the ocean in the spring and migrate upstream again as adults the next spring (Barnhart 1986). Many "half-pounders" are not summer steelhead, however.

Taxonomic Relationships: Summer steelhead get their name from their habit of ascending rivers in the spring or, in more northern populations (Oregon-Alaska), in the summer (D. McEwan, pers. comm.). They hold in deep pools in canyons through the summer and spawn in winter. Thus they are distinguished from other steelhead by (1) time of migration (Roelofs 1983), (2) state of gonadal maturity at migration (Shapovalov and Taft 1954), and (3) location of spawning (Everest 1973, Roelofs 1983). Attempts to distinguish juvenile summer and winter steelhead and resident juvenile rainbow trout using otolith nuclei widths, scale circuli densities, and visceral fat content have only been partially successful (Rybock et al. 1975; Winter 1987) primarily because of logistical difficulties in setting up rigidly controlled experiments (Winter 1987). The temporal and spatial isolation of reproductive fish from other steelhead runs presumably serves to maintain their genetic integrity (Barnhart 1986). However, genetic studies usually do not find consistent genetic differences between summer and winter steelhead in the same drainage (e.g., Reisenbichler et al. 1992). The National Marine Fisheries Service in its proposed rule to list as threatened steelhead in the Klamath Mountains Province of northern California and southern Oregon considered both summer steelhead and winter steelhead to be part of the same Evolutionarily Significant Unit (Federal Register 60(51):14253-14261, March 16, 1995). Whether or not summer steelhead from the various drainages prove to be more closely related to winter steelhead within their drainages than to each other, each population still represents a distinct life history phenomenon.

Until recently, steelhead were listed as *Salmo gairdneri gairdneri.* However, taxonomic work shows that steelhead are closely related to Pacific salmon (genus *Oncorhynchus)* and are conspecific with Asiatic steelhead, *Salmo mykiss.* As a result, rainbow trout, including steelhead, are officially recognized by the American Fisheries Society as *Oncorhynchus mykiss* (Smith and Stearly 1989). All steelhead and nonmigratory coastal rainbow trout are usually lumped together as *O. m. gairdneri* or, more recently (Behnke 1992), *O. m. irideus.*

Life History: Summer steelhead migrate up coastal streams and rivers during and soon after the final high flows of April, and the migration continues through June (Puckett 1975, Jones 1980). The migration may extend into July but then tapers off, presumably due, to decreasing flows and increasing temperatures (Jones 1980). Because the largest populations are in the Eel River system and are being managed there as a sensitive species by the USFS, most available information is about this run.

In the Eel River system, summer steelhead migrate to the upper reaches of the Middle Fork Eel and the Van Duzen rivers where they hold in deep pools during the summer months (Puckett 1975, Jones 1980). Easthouse (1985) reported a record number of 280 fish in a single pool in the Middle Fork Eel River, but most pools contain fewer fish. Usually, there is no period of peak migration, as indicated by the frequency of fish trapped in a weir on the Van Duzen River (Puckett 1975). In the Middle Fork Eel, males dominate the early part of the run, with females migrating in greater numbers toward the latter part (Smith and Elwell 1961). The gonads of the migrating fish are immature and do not begin to mature until the fish have spent 8-10 months in freshwater (Roelofs 1983). Thus spawning occurs from late December through April (Jones 1980), but the exact information on the duration, location, and extent of spawning is unknown (Puckett 1975, Jones 1980, Roelofs 1983). Fecundity has been estimated at 2,000 to 3,000 eggs per female.

In the Rogue River, Oregon, summer steelhead spawn in small headwater streams with relatively low (<50 cfs) winter flows (Roelofs 1983). Most of these streams are intermittent and dry up in the summer. If spawning behavior is similar in California, this indicates that (1) the adults move into smaller tributary/headwater streams for spawning and (2) the fry move out of the smaller natal streams into larger tributaries soon after emerging. In the Rogue River tributaries, spawning began in late December, peaked in late January, and tapered off by March. Roelofs (1983) suggested that use of small streams for spawning may reduce egg and juvenile mortality because the eggs are less susceptible to scouring by high flows and predation on juveniles by adults is decreased due to lower spawning adult densities in smaller streams.

Scale analyses indicate that summer steelhead migrate to sea when 1-3 years old (Puckett 1975). Of these, the majority smolt at 2 years (79%), some at 3 years (17%), and very few at 1 year (4%). Most return at age 3 (46%) or age 4 (44%) and smaller proportions return at age 2 (1%) and at age 5 (9%) (Puckett 1975). About 9 percent of the returning fish are repeat spawners (Jones 1980). In some northern California and southern Oregon rivers, some summer steelhead spend only a few months in the ocean and return to freshwater to overwinter; they then migrate back to the ocean in the spring. These immature fish (usually weighing about one-half pound) are called “half-pounders” (Emmett et al. 1991). Analysis of scales collected from adult summer steelhead in tributaries to the mainstem Klamath River reveal that virtually all have a half-pounder life history (E. Gerstung, pers. comm.).

Smaller fry usually migrate passively during the night and larger fry actively move out by day (Roelofs 1983). Migrating adults seldom feed, and stomachs examined are mostly empty or contain only a few aquatic insect larvae (Puckett 1975). Studies of hatchery-reared summer steelhead in British Columbia also suggest that they feed little, if at all, during the summer (Smith 1960).

Habitat Requirements: Steelhead habitat requirements have been reviewed in Barnhart (1986). Water depth does not seem to be critical to migrating fish because they usually migrate when stream flows are high, but a minimum depth of 18 cm is required. Water velocities greater than 3-4 m sec^{-1} may impede their upstream progress. They spawn in cool, clear, well-oxygenated streams. Water velocity and depth measured at redds are 23-155 cm sec^{-1} and 10-150 cm, respectively, and diameters of the gravels are typically 0.64-13 cm. They are known to spawn in intermittent streams, but the juveniles emigrate into perennial streams soon after hatching (Everest 1973). Summer water temperatures where they are found range from 10-15°C, with a sustained upper limit of 20°C but optimum requirements vary with season and life stage. Under conditions of fluctuating temperatures, summer steelhead may withstand temperatures as high as 27°C for short periods of time (M. Morford, pers. comm.). Dissolved oxygen requirements for spawning anadromous fish generally should be at least 80 percent of saturation, with temporary levels not less than 5.0 mg l^{-1} (Reiser and Bjornn 1979).

A survey of the Eel River drainage indicated that the best steelhead spawning gravels are located at Balm of Gilead Creek, North Fork of the Middle Fork Eel River, and in the Middle Fork from Hoxie Crossing to the North Fork of Middle Fork (Jones 1980). Redds have been observed in the Middle Fork approximately 0.5 km below the North Fork (Jones 1980). Migrating fish require deep (>3 m) holding pools (Puckett 1976, Roelofs 1983), with cover such as underwater ledges, caverns and bubble curtains which they seek when disturbed (Puckett 1975, Roelofs 1983).

Distribution: Along the eastern Pacific, rainbow trout, including steelhead, are distributed from Southern California north to Alaska and west to Siberia (Sheppard 1972). In California, summer steelhead runs have been recorded from the Middle Fork Eel River, main stem Eel River, Van Duzen River, Mad River, North Fork Trinity River, New River (a tributary to the Trinity), South Fork Trinity River, Canyon Creek (in the Trinity River system), the Klamath River drainage (Dillon, Elk, Indian, Red Cap, Bluff, and Clear creeks), Salmon River, Wooley Creek (a tributary to the Salmon River), Redwood Creek and Smith River (Puckett 1975, Roelofs 1983). Up to 50% of California summer steelhead are concentrated in the Middle Fork Eel River (Puckett 1975). Records indicate that runs also occurred in the North Fork Eel River, Black Butte River, Woodum Creek, Larabee Creek and Mattole River. In the Middle Fork Eel River, returning steelhead usually hold in deep pools between Bar and Uhl Creeks during the summer and fall (Jones 1980). However, the locations of the holding areas vary depending on accessibility, water temperatures, and water flows (Easthouse 1985).

Abundance: We know little about the past abundance of these fish; quantitative records of summer steelhead numbers exist only for the recent two or three decades (Roelofs 1983). Given the habitat available, however, it is likely that summer steelhead in California today represent only a small fraction of their original numbers. Native Americans depended on summer steelhead for subsistence, and they were frequently harvested and preserved in the fall of the year in conjunction with the harvest of big game. For example, large numbers of summer steelhead occurred in the North Fork Eel River just downstream from the confluence of Hulls Creek. Native Americans from the Covelo Indian Reservation as recently as in the early 1960s travelled annually to this area to harvest deer and fish and preserve. their catches on the spot (M. Morford, pers. comm.).

In most river systems in which they occur, summer steelhead have declined considerably in the past 30 to 40 years. Most populations in California are represented by less than 100 fish each (Table 6). The three-year average population estimate for 1989-1991 exceeded 500 fish in only three streams: Middle Fork Eel River, North Fork Trinity River, and New River. Seventeen populations averaged <100 fish each, and 12 populations averaged <20 fish each. Because the "effective" (breeding) population sizes (sensu Meffe 1986) are probably less than the actual counts, many populations may be close to or below the minimum size needed for long-term survival. These estimates are of fish holding in pools in midsummer, and the number surviving to spawn in the winter probably is considerably less. Most of the populations were severely affected by the extraordinary floods of 1964. Although their habitat is gradually recovering from this disaster, the number of summer steelhead has fluctuated widely without any upward trends. The status of each major population is a follows:

<u>Smith River.</u> Only 10-20 fish are estimated to occur in each of five tributaries in recent years, less than 100 fish total, but this stream may never have supported summer steelhead in large numbers (Roelofs 1983).

Eel River. Summer steelhead remain in two tributaries, the Van Duzen River and the Middle Fork Eel River. The former run is less than 100 fish per year. The Middle Fork run is the largest in California and is estimated to be between 400-1,700 fish per year. Recent counts have been at the low end of this range, likely due to the prolonged drought. Poaching that occurs after the annual surveys have been completed in the summer may result in even lower numbers in the reproductive population.

Mad River. In the 1940s and early 1950s, Shapovalov and Taft (1954) indicated that 600-700 summer steelhead used this river each year. Present counts are highly variable, but in most years the estimates are less than 100 fish. These populations may be derived from hatchery fish from Washington or from hybrids between native and hatchery stock. The native fish were severely depleted and perhaps eliminated in the 1960s by poaching, especially at the Sweasy Dam fish ladder.

Mainstem Trinity River. Moffett and Smith (1950) indicate that summer steelhead were common in the upper mainstem Trinity River in the 1940s. This population apparently persisted through the early 1960s but is probably now extirpated (B. Curtis, 1992, CDFG files), presumably due to the effects of Trinity and Lewiston dams.

North Fork Trinity River. There is little historical information on summer steelhead in this stream, but recent data indicate that the population flucuates between 200 and 700 fish per year. Given that this stream has been heavily altered by mining, it is likely that runs were much higher in the past (Roelofs 1983).

South Fork Trinity River. There is no historical information on summer steelhead in this stream. Present estimates are now less than 70 fish per year.

New River. This tributary to the Trinity River was presumably a major summer steelhead stream in the past, but it is highly accessible and heavily dredged for gold. The estimate in 1992 was 359 fish, compared with the 1979-1991 average of 380.

Klamath River. Summer steelhead are known from six small tributaries, most with populations of less than 100 fish. About half of the 800-1,200 fish usually found in these streams are found in the inaccessible portions of Clear and Dillon creeks (Roelofs 1983). Runs were very low during 1992, perhaps because of unusually high summer water temperatures, in the mainstem river (E. Gerstung, pers. comm.).

Salmon River. Despite the presence of suitable spawning and holding areas, the two forks of the Salmon River combined now only support less than 100 fish per year. The 1990 complete census of the Salmon River showed 48 summer steelhead (DesLaurier and West 1990).

Wooley Creek. Like the Salmon River, to which Wooley Creek is tributary, this rather inaccessible stream has maintained a run of steelhead that is usually 100-300 fish per year. However, in 1991 through 1993, the run was less than 50 fish per year (R. Elliott, pers. comm.).

Redwood Creek. It has only recently been recognized that this small coastal drainage supports summer steelhead with runs of 4-44 fish per year. Given the degraded nature of much of the drainage, it probably supported larger runs in the past.

In short, California now supports 1,500 to 4,000 summer steelhead. These fish are divided among at least 25 isolated populations, many on the verge of extinction.

Nature and Degree of Threat: Summer steelhead populations have declined from a combination of factors including habitat loss, overharvest, disturbance, and effects of hatchery practices.

Habitat loss. Poor watershed management (poorly designed roads, poor logging practices) has increased erosion, causing deep pools to fill with gravel which decreases the amount of holding habitat and increases the vulnerability of the fish to poachers and predators. Such practices may also decrease summer flows, raising water temperatures to levels that may be stressful or even lethal to the fish. Poor watershed management probably exacerbated the effects of the 1964 floods in almost all drainages containing summer steelhead. These floods deposited in pools enormous amounts of gravel that originated from landslides and mass wasting, especially from areas with steep slopes that had been logged. These floods not only filled in pools, but widened stream beds and eliminated riparian vegetation that served as cover and kept streams cooler. The gravel accumulated from the 1964 floods is gradually being scoured out of the pools, but much of it still remains. The potential for further mass wasting along the Eel and Trinity rivers is high, because logging is still occurring on steep slopes and recent fires may be contributing to soil instability (increased by road building for salvage logging). In short, accumulation of gravel in stream beds in recent years has reduced the amount of suitable habitat for summer steelhead.

One indirect effect of habitat loss is an increased vulnerability of the remaining fish to predation. For example, as adult populations are reduced and habitat becomes more restricted, it is more difficult for them to withstand the effects of natural predation, particularly that of river otters. Otter predation on summer steelhead is heaviest when populations of suckers and crayfish, the preferred food of otters, are low, such as occurred in the Middle Fork Eel River following the 1964 flood (A. E. Naylor, pers. comm.). The impact of otters on summer steehead therefore probably varies from year to year, but could be serious during years when steelhead numbers are already low from other causes.

During low-flow years, outmigrating juveniles may suffer heavy mortality when moving downstream, especially if trapped in pools that have become too shallow and warm for them in summer as the result of gravel deposition. In some streams, water diversions may reduce flows in natural water courses such that those former habitats are almost or completely drained. Unscreened diversions may directly transport young steelhead to unsuitable areas. In the Eel River, squawfish *(Ptychocheilus grandis)* predation on outmigrating juveniles in pools with little cover may be a growing problem. This predatory cyprinid was illegally introduced into the river around 1980 and is building up populations at the present time (L. Brown and P. Moyle, unpub. data).

Overharvest. Perhaps the most immediate threat to summer steelhead is poaching during the summer in the canyon pools. The steelhead are unusually vulnerable at this time because they are conspicuous, aggregate in pools, and are prevented from leaving pools by low stream flow. They can thus be snagged from the bank or speared by divers. For example, CDFG biologist D. McCleod has observed poaching on the Van Duzen River population; in a closed-to-fishing section on private land, far from public access, he found the viscera of several large steelhead in one pool. Roelofs (1983) indicated that the most stable populations of summer steelhead are in the most inaccessible streams on public land, whereas those that are showing signs of severe decline are in areas that are most accessible to people.

The most severe immediate threat by poaching is to the population in the Middle Fork of the Eel River, which constitutes one-quarter to one-half the summer steelhead in California. Counts indicated the population to be 449 fish in 1990 (Table 6) and 516 fish in 1992 (D. McEwan, pers. comm.), two of the lowest counts in recent years. The area was for several years without the protection of a game warden or other law enforcement officials, and there were reports of extensive poaching of fish in late summer of 1988 after the counts for that summer had been completed (M. Morford, pers. comm.). An attempt to briefly resurvey part of the area in which fish had been counted earlier revealed no fish (W. Jones, pers. comm.). As of 1989, however, a game warden has been assigned to patrol the Middle Fork Eel River drainage (A. E. Naylor, pers. comm.). Poaching may also be occurring in other populations of summer steelhead, but they are monitored less closely than the Middle Fork Eel population. Roelofs (1983) indicated that poaching is a factor affecting populations of summer steelhead in at least the North Fork of the Trinity, New River, and some tributaries to the Klamath River. The South Fork of the Trinity is also heavily poached (P. Higgins, pers. comm.). In addition to poaching, adults may be lost in other fisheries:

-- They may be taken legally by anglers as they move upstream towards their holding pools, during the spring.

-- The unrestricted high seas gillnet fishery for squid and other species may have been killing steelhead from California streams. The impact of marine fisheries on steelhead in general is poorly known, but such fisheries may be a source of ocean mortality.

-- The gillnet fishery of Native Americans in the Klamath River may be having an adverse impact on summer steelhead populations in that river, although the large mesh size used probably allows most steelhead to pass safely (A. E. Naylor, pers. comm.).

Disturbance. Even where habitats are apparently suitable, summer steelhead may be absent because of continuous disturbance by humans. Heavy use of a stream by gold dredgers, swimmers, and rafters may stress the fish. This may make them less able to survive natural periods of stress (e.g., high temperatures), less able to spawn or to survive spawning, and more likely to move to less favorable habitats. Because disturbance makes the fish move around more, they are also more likely to be observed and captured by illegal anglers.

Hatchery practices. Hatchery-reared steelhead, especially those of exotic strains, can have adverse effects on wild fish. For example, summer steelhead in the Mad River Hatchery are derived from fish brought in from the Washougel River in Washington in 1971 (Roelofs 1983). The effects of hatchery fish on wild stocks of summer steelhead are not known, but wild stocks may be decreased through (1) competition between hatchery and wild juveniles, (2) genetic swamping of small wild populations by large populations of strays from hatcheries, and (3) increased harvest of wild fish because wild and hatchery fish cannot be distinguished by anglers. Hatchery fish, especially of nonnative origin, cannot be regarded as replacements for wild fish because they are less likely to persist in the face of natural environmental fluctuations to which native wild fish are well adapted.

Management: Comprehensive management recommendations have been made by Jones and Ekman (1980) and Roelofs (1983). However, summer steelhead numbers have not increased in response to management efforts. Present management focuses on allowing the populations to recover naturally, to the point where some harvest will be possible during their migratory period. In reality, summer steelhead in California have suffered from benign neglect. At least one management program, that of the Middle Fork Eel River, does provide for midsummer population counts and the review of some land management activities that may threaten the continued existence of summer steelhead. However, factors that limit the rebuilding of this population and other populations are not being addressed. For example, the Sierra Club filed suit against the USFS regarding approval of the Ant Ridge timber sale, alleging potential impacts to summer steelhead habitat in the Middle Fork Eel River. Management plans for & population need to be formalized. Management should consist of a mixture of (1) better protection of summering areas from poachers, (2) better watershed management to keep summer flows up and temperatures down, (3) better regulation of adult harvest during the migrations, (4) better management of downstream reaches to favor outmigrating smolts, (5) rebuilding of present populations through natural and artificial means, including habitat improvement, (6) restoration of populations that have become extinct and (7) some protection of adults and juveniles from predation.

The problem with poaching has been severe in recent years because of inadequate law enforcement. Although fishing is prohibited in many areas and fines for violations are high, protection of summer steelhead populations may require special guards or streamkeepers for a number of years.

Where populations are exceptionally low, some relocation of natural predators, mainly otters, may be necessary until steelhead populations are large enough to withstand natural predation.

Improvement of summer steelhead habitat has not been a priority program for the CDFG, although reduction in summer carryover habitat has been repeatedly identified as a critical limiting factor. The initiation of habitat improvement projects in recent years (1988-1990; CDFG 1990b) is an ambitious step in the right direction and should receive continued funding and encouragement.

There is also a considerable need for research on summer steelhead populations in California, especially to (1) determine the genetic identities of each population, (2) determine the extent of possible summer holding areas, (3) determine the distribution of spawning areas and whether they may require special protection, (4) determine the habitat requirements of out-migrating smolts, and (5) determine the effects of gold dredging and disturbance from recreation on adults. For most populations, there is a need to accurately determine the populations and to identify the factors that limit their numbers.

TABLE 6. Summer Steelhead Populations in Northern California Streams 1977 - 1992[1]. Data provided by E. Gerstung, Calif. Dept. of Fish and Game. Data are preliminary, subject to revision.

YEAR	1992	1991	1990	1989	1988	1987	1986	1985
Middle Fork Eel River	516	691	449	726	711	1550	1000	1463
Van Duzen River	0+6hp	31(38)	4(5)	4(5)	42(49)	52(54)	NS	NS
S. Fork Trinity River	29	9(43)	66	37	30	NS	73(100)	3(20)
Hayfork Creek	NS	0	NS	NS	NS	NS	NS	NS
N. Fork Trinity River	369	825-1037	554	347(600)	624	36(300)	NS	57(112)
Canyon Creek	6	3	15	NS	32	0	NS	10
Upper Trinity River	NS	13	8	16	9	6	9	5
New River	272+87hp	500-600	343	600	204(350)	(300)	NS	NS
Blue Creek	NS	NS	1	0	NS	NS	NS	NS
Bluff Creek	23+85hp	9	14	14	33	59	73	6
(late run)	(both runs)	40	77	44	40	41		17
Red Cap Creek	6+18hp	2	7	23(33)	25(35)	29(40)	NS	18
Camp Creek		0	3	7	0	1	0	NS
Dillon Creek	NS	88	74	294(320)	38(60)	77	NS	NS
Clear Creek	47+78hp	76	91	920	678(700)	512	428(458)	162(222)
Indian Creek	27	8	12	154	41	NS	NS	NS
Elk Creek	22+101hp	76	31	150(188)	63	31	NS	NS
Salmon River	24	21	15	13	128	NS	NS	NS
N. Fork Salmon River	16	17	12	17	8(32)	4(19)	6(28)	8(37)
S. Fork Salmon River	59	26	21	11(66)	155(200)	20(84)	13(78)	9(54)
Wooley Creek	17+21hp	25	73(76)	234(244)	379(481)	280(291)	NS	290(307)
S. Fork Smith River	8+3hp	13	8(10)	4(6)	12(16)	NS	NS	NS
N. Fork Smith River	NS	0	NS	NS	NS	NS	NS	NS
Middle Fork Smith River	13+21hp	11	21	1	2	NS	NS	NS
Mad River	34	66(76)	33(47)	20(28)	60(85)	18(22)	15(25)	52(71)
Redwood Creek	5	15	14	0	8	15	19	44

YEAR	1984	1983	1982	1981	1980	1979	1978	1977
Middle Fork Eel River	1524	666	1051	1600	1052	1298	377	654
Van Duzen River	58	13(16)	8	7(8)	25	31		
S. Fork Trinity River	8(30)	NS	26	NS	NS	5		
Hayfork Creek	NS	5	0	NS	0	0		
N. Fork Trinity River	179	160	193(210)	219	456	320	200(300)	NS
Canyon Creek	20	3	20	3	6			
Upper Trinity River	9	NS	2	3	1	1	1	
New River	335(340)	NS	114(300)	236(250)	320(355)	344(360)		
Blue Creek	NS	0	0	NS	4	3	3	
Bluff Creek	26	11	37	16	17	41		
(late run)	22	12	57	41	20			
Red Cap Creek	10	12	45	NS	10			
Camp Creek	0	NS	NS	NS	2			
Dillon Creek	(200)	300(500)	295	194	236(268)			
Clear Creek	156(167)	257(275)	610	270(300)	241(251)	79(110)	1810(1882)	NS
Indian Creek	NS	NS	15(17)	NS	1(7)	NS	421	
Elk Creek	58	NS	249	47	90	NS	408	
Salmon River	NS	NS	120	NS	36			
N. Fork Salmon River	NS	NS	41	13(60)	69			
S. Fork Salmon River	NS	NS	223	10(60)	166			
Wooley Creek	92(96)	78	353	245(269)	165(177)	160(206)	105(135)	510(658)
S. Fork Smith River	NS	NS	5(7)	0(3)				
N. Fork Smith River	NS	NS	2	NS	0	NS	1	
Middle Fork Smith River	NS	NS	2	NS				
Mad River	134(188)	31(40)	167	6(50)	2(16)			
Redwood Creek	44	7	3	16				

[1]Estimates in parentheses were obtained by expanding data to unsurveyed sections; data collected on diving surveys. NS = No Survey. hp = half-pounders. Additional data for earlier years follow. Middle Fork Eel River (years in parentheses): 792 (1976), 11149 (1975), 1522 (1974), 1422 (1973), 200-1500 (before 1972). Van Duzen River: 90-300 (before 1972). N. Fork Trinity River: 28(42) for 1976. Upper Trinity River: 21-128 (before 1972). Clear Creek: 224 (1975), 116 (1972). Wooley Creek: 124 (172) for 1975, 45 (50) for 1972. Mad River: 15 (30) for 1974, 2 for 1972, 100-500 prior to 1972.

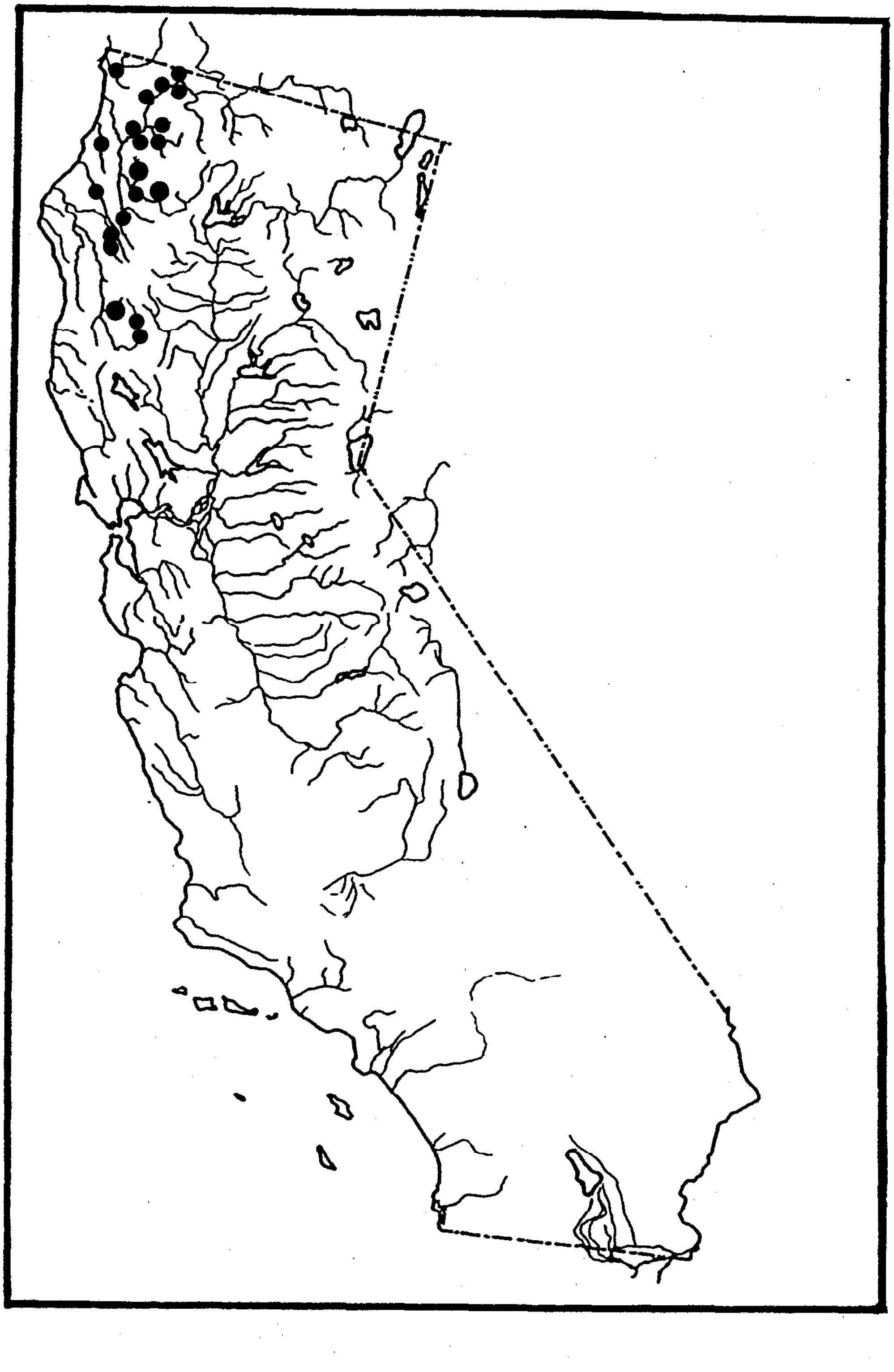


FIGURE 12. Spawning streams of summer steelhead trout, *Oncorhynchus mykiss irideus*, in California.

SOUTHERN STEELHEAD
Oncorhynchus mykiss irideus (Richardson)

Status: Class 1. Endangered.

Description: Steelhead are sea-run rainbow trout that have large mouths with well-developed teeth on both upper and lower jaws, the head and shaft of the vomer, the palatines, and on the tongue. Basibranchial teeth are absent. Gill rakers number 16-22 and branchiostegal rays, 9-13. There are 10-12 dorsal fin rays, 8-12 anal fin rays, 9-10 pelvic fin rays, and 11-17 pectoral fin rays. The caudal fin is forked. Scales are small, with 18-35 rows above the lateral line and 14-29 below. The 100-160 lateral line scales are pored. Southern steelhead have been reputed to attain a large size, up to 9 kg or more (Hubbs 1946, Titus and Erman, unpubl. ms.), comparable to sizes attained by northern winter-run steelhead in some north coast streams of California (E. Gerstung, pers. comm.).

Taxonomic Relationships: Southern steelhead are winter-run steelhead that persist in streams that have warm, dry lower reaches on the coastal plain, which present substantial migration passage problems to and from distant headwater spawning and rearing habitats. Their occurrence in such a demanding environment suggests the development of distinctive ecological and physiological adaptations. According to J. J. Smith (CSU, San Jose), river basins with southern steelhead are also drier, resulting in exaggerated effects of year to year rainfall variation, Most streams from San Luis Obispo County southward are definitely "southern steelhead streams", and the Pajaro, Salinas, and Carmel rivers in Monterey County are ecologically similar. The wetter coastal streams between the Carmel River and SLO County are ecologically more like steelhead streams in northern California (J. Smith, pers. comm.). This broad ecological definition of southern steelhead is the one used by Titus et al. (in press) in their monograph on the status of steelhead in California south of San Francisco Bay.

A narrower definition of southern steelhead is emerging from ongoing genetic studies which are helping to define "metapopulations" within the general ecological type described above. Genetic groupings may conform to the concept of an evolutionary significant unit of the biological species (sensu Waples 1991). Both allozyme studies (Berg and Gall 1988) and mitochondrial DNA studies (J. Nielsen, pers. comm.) indicate that a north to south gradient of genetic characteristics occurs along the California coast. However, the mtDNA studies also indicate that steelhead populations found south of Point Conception may form a distinct genetic unit (J. Nielsen, Abstract, Amer. Fish. Soc. meeting, July 26-29, 1993, Sacramento). Because Point Conception is also a major zoogeographic boundary for marine organisms, the mtDNA studies may mean that steelhead entering streams south of this point probably do not intermingle much in the ocean with fish from more northern localities.

Until the mtDNA and other genetic studies are completed, we prefer to use the broader ecological definition for southern steelhead, recognizing that southern steelhead are probably several distinct stocks. However, all these stocks are in decline and need special protection to preclude extinction.

Life History: Southern steelhead have received little study, although the life-history characteristics of steelhead in general are well known (Emmett et al. 1991). Winter steelhead in California typically spawn from December to May, but mostly in January-March (E. Gerstung, pers. comm.), and spent fish may return to the ocean and spawn again in a later year. The frequency of repeat spawning varies according to the stock and with habitat quality (Emmett et al. 1991), and it is not known if repeat spawning is common among southern steelhead. Juvenile steelhead remain in fresh water 1-4 years (usually 1-3 in California) and then spend 1-5 years (usually 2-3 in California) in the ocean (Emmett et al. 1991, E.

Gerstung, pers. comm.). Southern steelhead, however, probably spend less time in fresh water because of the often inhospitable conditions in the lower reaches of southern California streams; they may, therefore, migrate to the ocean or have greater dependence on coastal lagoons during their first year (E. Gerstung, memorandum to R. Rawstron, CDFG, November 22, 1989). Early emigration may also occur because of rapid growth in the warm, productive streams, allowing the juveniles to reach smolt size at a younger age. Because of frequent drought in southern California, the streams may be inaccessible during some years so that adult steelhead are forced to spend additional years in the ocean before having a chance to spawn. The increased growing time in the ocean, plus richer food sources in southern coastal waters due to the reduction of marine mammals there, might account for the large size (9+ kg) evidently attained by steelhead in some southern California streams (e.g., the Santa Ynez River); these fish may have been 5-6 years old, compared to the typical 4-year old spawners (E. Gerstung, memorandum to R. Rawstron, CDFG, November 22, 1989). However, during wet years a high percentage of the southern steelhead returning to spawn have spent only one year in the ocean, indicating that a bet-hedging strategy of attempting to spawn every year is adaptive in this unpredictable environment (J. Smith, pers. comm.). Despite the intermittent nature of southern California streams, steelhead production during wet years was probably higher in these streams than in northern California streams because of greater biological productivity and more favorable growing temperatures (E. Gerstung, pers. comm.)

The ability of some southern steelhead to survive in warm (>21°C) isolated pools (Higgins 1991) possibly is due to greater physiological tolerances to higher temperatures and lower oxygen levels than are shown by other steelhead stocks. However, the relative physiological capabilities, and their possible genetic basis, of southern steelhead have not been studied. Although juvenile steelhead in the Columbia River (Oregon-Washington) spend little time in that estuary (Dawley et al. 1986, Emmett et al. 1991), juvenile steelhead in central California streams evidently do spend considerable time rearing in estuaries (Smith 1987, 1990). It has been surmised that steelhead in southern California also rely heavily on estuaries, because many of their streams seasonally had very low flows or dried completely in the alluvial fan areas (Higgins 1991). In addition, although many lowland stream areas were perennial, they also may have dried out during the driest years (C. Swift, pers. comm.). Evidently large numbers of juvenile southern steelhead often could be caught in coastal lagoons in the 1930s and earlier (Swift et al. 1993). Most of the estuaries today are much shallower and warmer than they were originally. A particularly severe problem is the lack of adequate inflowing fresh water, which keeps lagoons cool, deep, and thermally unstratified (J. Smith, pers. comm.).

Steelhead in general are known to have well-developed homing abilities (Moyle 1976), although it has been suggested that southern steelhead commonly stray from their natal streams (Higgins 1991). Straying, if it actually occurs at significant levels in southern steelhead, may be selectively advantageous because it would allow spawners to opportunistically utilize more favorable streams when their natal streams dried up or were blocked by sand berms (Higgins 1991). An additional feature of southern steelhead is that they "miraculously" reappeared in large spawning runs when flows became suitable in streams that had been dry or otherwise inaccessible during the previous one or more years. The implication is that the fish, finding their natal stream unavailable during a given year, return the following year(s) until access can be gained.

Habitat Requirements: The basic environmental requirements for southern steelhead probably are similar to those of more northern steelhead stocks, although it is likely that southern steelhead have greater physiological tolerances to the warmer and more variable conditions they commonly encounter in southern California streams (Higgins 1991). Major streams in southern California originate in the coastal mountains and often cross broad alluvial areas before flowing into the sea. These low-elevation alluvial flats present inhospitably warm and fluctuating temperatures and the streams themselves may be intermittent. The higher-elevation headwaters, therefore, are the primary spawning and rearing areas for steelhead today, although lowland reaches once may have been important, especially in wet years. It is likely that the largest steelhead populations historically occurred in streams where the upstream spawning and rearing habitats were closest to the ocean, such as in the Ventura, Santa Clara and Santa Ynez rivers (M. Cappelli, in USFWS 1991).

San Mateo Creek, a former steelhead stream, typifies the southern California streams (Higgins 1991, Woefel 1991). Its headwaters lie in the Santa Ana and Santa Margarita mountains, where winter temperatures can drop below freezing and annual rainfall averages about 63 cm near Elsinore Peak. The creek descends the mountains through a deeply cut canyon. The steep and rocky upper San Mateo Creek and its tributaries contain pools that harbored juvenile steelhead during, the summer, while the depositional areas in the canyon probably served as the spawning areas. Flows in the upper reaches may be as low as 0.5 cfs during the summer and can average over 500 cfs during wet months. The lower reach of the creek flows along 17 km of alluvial valley to the coast, where average rainfall is 34 cm per year. Large quantities of natural sediment deposition evidently have rendered the lower stream course unstable and unsuitable for spawning. During the dry season, the creek went underground even in times prior to human-related water losses, thus presenting a temporally impassable barrier to steelhead. This stretch of the creek now is permanently dry, due to the lowered water table. The creek reemerges about 8.4 km from the ocean to mark the upper end of the estuary. The estuary has been substantially diminished in extent since the end of World War II (Higgins 1991). Originally the native riparian vegetation along the coastal reach of the creek probably was dominated by arroyo, red, and yellow willows, but introduced tamarisk recently has been replacing the native species. In the upper reaches, the dominant riparian plants are poison oak, wild grape, and wild rose. The terrain around the creek near the coast is covered with grasses and coastal scrub, southern oak and woodland higher up, and chaparral on the mountain slopes, all of which are subject to tire. Periodic fires and subsequent erosion may be an integral feature of this environment, posing particularly challenging conditions to the steelhead of these southern streams.

Distribution: Swift et al. (1993) state that at least a few southern steelhead have been found in virtually every coastal stream in Monterey, San Luis Obispo and Santa Barbara counties north of Point Conception within the last ten years. Southern steelhead evidently once utilized most of the major coastal streams in southern California as well. Today they still occur in Malibu Creek, Ventura River, Santa Clara River, and Santa Ynez River, although in greatly reduced numbers. Swift et al. (1993) also report recent records for Mission and Atascadero creeks (Santa Barbara County) and Mulholland, Big Sycamore, and Topanga canyons (Los Angeles County). Steelhead have been extirpated from at least 11 southern California streams: San Luis Rey River, San Mateo Creek, Santa Margarita River, Rincon Creek, Maria Ygnacio River, Los Angeles River, San Gabriel River, Santa Ana River, San Onofre Creek, San Juan Creek, San Diego River, and Sweetwater River (Nehlson et al. 1991, Swift et al. 1993). Steelhead have been caught in the lower Tijuana River, bordering Mexico (Hubbs 1946), and runs are known to have occurred historically in Baja California streams (Barnhart 1986). Southern steelhead historically may have occupied as much as 15% of the winter steelhead range in California, but the present distribution in southern California has been reduced to perhaps 1% of the stream miles they formerly inhabited (E. Gerstung, memorandum to R. Rawstron, CDFG, November 22, 1989).

Abundance: Southern steelhead have been either significantly depleted or extirpated in all rivers and streams in which they historically occurred. Estimates of historical run sizes are highly subjective and probably correct only within an order of magnitude (USFWS 1991). They nonetheless attest to the substantially higher numbers of southern steelhead that once existed. Past runs have been estimated at 7,000-9,000 fish in the Santa Clara River, 4,000-6,000 for Matilija Creek (a tributary to the Ventura River), and 20,000 for the Santa Ynez River (USFWS 1991). In 1940, CDFG personnel "rescued more than 525,000 young steelhead trout . . . from the drying Santa Ynez River" (Shapovalov 1940). CDFG rescue operations also saved 9,800 juveniles from isolated pools in the lower San Mateo Creek in 1939, and the Department proposed at that time that a recreational fishery be promulgated in this highly productive stream (Higgins 1991).

There have been no comprehensive surveys conducted in recent years to provide a reliable estimate of total population size for southern steelhead. The current number of steelhead using southern California streams south of Point Conception is unknown, but judging from recent accounts they probably number in the several hundreds, an indisputable severe decline from historical levels. There are at most only three or four streams and rivers that presently support significant remnants of southern steelhead runs. The largest extant stock probably occurs in the Santa Ynez River, where "a substantial number" were reportedly taken by anglers in 1993 (F. Reynolds, CDFG memorandum to B. Bolster, October 13, 1993). Another stock occurs in the Ventura River, aided by the preservation efforts of local citizens groups. In May 1991, 14-25 adult steelhead were observed in the upper estuary of the Ventura River (R. Leidy, EPA, memorandum to B. Harper, USFWS, May 8, 1991), but no steelhead were reported in 1992 and only one pair was reported in 1993 (F. Reynolds, ibid.). An annual run numbering up to 60 spawners in some years has persisted in Malibu Creek (USFWS 1991); this is the southernmost self-sustaining run of southern steelhead. Consistent stream flows in Malibu Creek have been maintained since the late 1960s, aided in the 1980s by influx from the Tapia Water Reclamation Facility. It has been suggested that the perennial flows may have attracted remnants of southern steelhead runs that have been extirpated from other streams, and therefore Malibu Creek could be a valuable "genetic repository of locally adapted steelhead" (Higgins 1991). A fourth remaining stock may exist in the Santa Clara River drainage, mainly in Sespe Creek (within the National Condor Sanctuary), which still contains considerable steelhead habitat, and perhaps Santa Paula Creek. Adult steelhead were observed in Santa Paula Creek in March 1987 and 1988 (B. Harper, unpubl. data), but none were found in March 1991 or in January 1992 (S. Parmenter, pers. comm.; D. McEwan, CDFG memorandum, March 26, 1992). Other streams that have had at least a few steelhead when flows were sufficiently high are Santa Rosa Creek (San Luis Obispo County), Arroyo de La Cruz (near San Simeon), San Simeon Creek, San Luis Obispo Creek and Gaviota Creek (USFWS 1991). It is not known if any of these runs are self-sustaining:

In terms of the stream habitat presently utilized, southern steelhead occur in about 16 km of the Ventura River, 5 km of Malibu Creek, 16 km of the Santa Ynez River, and, if they still occur there, within 80 km of suitable habitat in Sespe Creek (E. Gerstung, pers. comm.). The once large steelhead runs in San Mateo Creek and Santa Margarita River have been completely eliminated (Higgins 1991). Other now extirpated runs occurred in the San Luis Rey, San Diego, and San Dieguito rivers, and San Onofre Creek (all in San Diego County), Santa Ana River and San Juan Creek (Orange County), San Gabriel River (Los Angeles County), Sisquoc River (Santa Barbara County) and the Cuyama River (USFWS 1991). A detailed stream-by-stream account of southern steelhead distribution and abundance is currently being completed by R. Titus, W. Snider (CDFG) and D. Erman (UCD).

Nature and Degree of Threat: Habitat loss, including loss of water flows, and the failure to protect the runs due to inadequate regulatory measures have been the major, or at least the most conspicuous, causes of the decline of southern California steelhead. In the Santa Clara River drainage, for example, a diversion dam in the lower river blocked migration of adults and juvenile steelhead and diverted the fish to percolation basins where they perished (Comstock 1992). Other dams in the upper watershed on Piru and Castaic creeks blocked access to upstream areas and, because of flow changes, eliminated spawning and rearing habitats below the dams. A diversion dam on Santa Paula Creek similarly blocked access of steelhead to upstream habitats (Comstock 1992). Land development, dams, and degradation of southern California estuaries have probably significantly decreased potential steelhead juvenile rearing areas. It is unknown to what extent other factors affect southern steelhead populations. An early newspaper account noted a high level of parasitic worm infestations in trout from San Mateo Creek (Santa Ana Daily

Register 1916, cited by Higgins 1991); however, reliable studies on the impact of disease and parasites on southern steelhead stocks are lacking.

Management: Preservation of southern steelhead will require (1) immediate protection and rebuilding of existing runs and (2) reestablishment of runs in streams and rivers that historically were highly productive (e.g., San Mateo and Matilija creeks). Pumping of groundwater and impoundments or diversions associated with population expansion and land development will continue to be the major threat to stream habitat and steelhead survival in southern California. Water removal from streams now containing critically low numbers of steelhead should be restricted in order to leave minimum flows for fish in both streams and lagoons. Rehabilitation of estuaries is also needed, although this will require better watershed management to reduce the input of sediments and to increase freshwater inflows. The artificial breaching of lagoons, such as Santa Clara lagoon, may pose a problem if large numbers of steelhead use the lagoons as rearing habitat. The environmental impact of development projects, therefore, should be carefully evaluated and appropriate mitigative measures incorporated.

Return water from sewage treatment plants may provide an important means by which to recharge streams and groundwater. The effective allocation of recycled water could be instrumental in maintaining and rebuilding steeelhead runs (e.g., the Tapia Treatment Plant on Malibu Creek and Lompoc treatment facilities in the Santa Ynez drainage), Further studies are needed to determine the importance of southern California estuaries as steelhead rearing habitat, and if appropriate, management measures for maintaining and enhancing estuarine habitat will need to be clearly defined.

The reestablishment of southern steelhead in streams from which they were extirpated also should be eventually pursued. The feasibility of reintroduction and suggested plans of action are discussed in detail by Higgins (1991) for San Mateo Creek and the Santa Margarita River. Removal of dams and other obstructions that serve little current purpose (e.g., Matilija Dam in the Ventura River drainage) also should be considered. Plans are underway to remove the now defunct Malibu (Rindge) Dam on Malibu Creek, which will increase steelhead habitat from 4.0 stream km to at least 12.1 km (minutes to July 12, 1992 meeting for the Malibu Dam Steelhead Restoration Project, Las Virgenes Municipal Water District). Construction of fish passage facilities across dams to allow steelhead access to additional spawning and rearing habitat are critical to preservation and recovery efforts; examples are the recently completed fish pass for the Vern Freeman Diversion Dam on the lower Santa Clara River (Higgins 1991) and proposed modification of a barrier to allow fish passage in Gaviota Creek (USFWS 1991).

Numerous, short coastal streams that arise in the coastal mountains (Transverse Range) of Santa Barbara and Ventura counties may represent significant steelhead habitat. These streams generally have perennial headwaters, often containing rainbow trout, and the streams connect with the ocean annually during the rainy season. Although the potential carrying capacities of the individual streams are low, in aggregate they could support a viable steelhead stock (S. Parmenter, pers. comm.). Resolution of fish passage problems and restoration of steelhead runs in these streams, therefore, could be an effective way of conserving southern steelhead genetic resources (S. Parmenter, pers. comm.).

In-depth physiological and genetic studies of southern steelhead are needed in order to (1) determine the extent of their ecological and genetic uniqueness and (2) to identify their current geographical distribution relative to more northern strains.

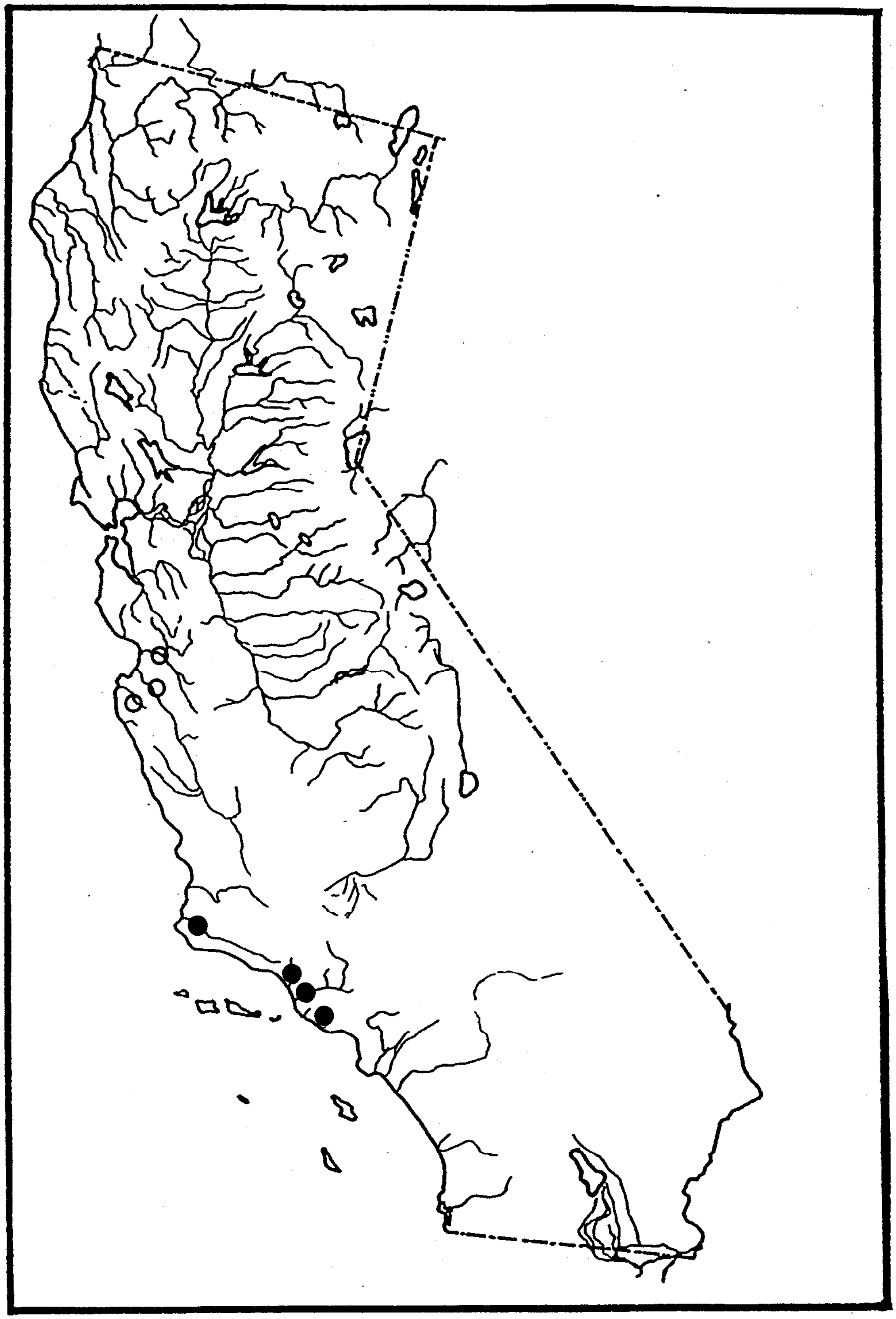


FIGURE 13. Distribution of southern steelhead, *Oncorhynchus mykiss irideus*. Solid dots indicate populations that show genetic (mtDNA) differences from northern winter steelhead stocks. Open circles are populations that ecologically resemble southern steelhead.

EAGLE LAKE RAINBOW TROUT
Oncorhynchus mykiss aquilarum (Snyder)[11/]

Status: Class 1. Threatened.

Description: This subspecies is similar to other rainbow trout in gross morphology, but differs slightly in meristic counts (Table 7) and in possessing 58 chromosomes rather than the 60 present in most other rainbow trout (Busack et al. 1980).

TABLE 7. Meristic characteristics (mean ± SD) of Eagle Lake and other western trout. (Modified from Busak et al. 1980.)

Character	Eagle Lake trout	Rainbow trout	Cutthroat trout	Redband* trout
Lateral series	138.3 ± 1.47	135	166	162
Scale rows above lateral line	27.4 ± 0.28	25	37	33
Gill rakers	19.2 ± 0.25	19	24	16
Pyloric caeca	57.0 ± 2.5	55	48	36
Branchiostegal rays	10.9 ± 0.11	12	11	10
Pectoral rays	14.3 ± 0.14	15	14	13
Pelvic rays	10.0 ± 0.06	10	9	9
Vertebrae	62.0 ± 0.23	64	62	61

*McCloud River redband.

Taxonomic Relationships: Snyder (1917) described this trout as a subspecies of rainbow trout, *Salmo gairdneri aquilarum.* However, Hubbs and Miller (1948) examined Snyder's specimens and concluded that Eagle Lake rainbow trout were derived from hybridization between native Lahontan cutthroat trout and introduced rainbow trout, although Miller (1950) later retracted the hybridization theory. Needham and Gard (1959) then suggested that the Eagle Lake rainbow trout was descended from introduced or immigrant rainbow trout from the Feather or Pit River drainages. Behnke (1965, 1972) proposed a redband-rainbow hybrid origin, although redband trout are now considered to be rainbow trout subspecies. More recently, Busack et al. (1980), in an extensive electrophoretic, karyotypic, and meristic analysis, found that even though the Eagle Lake trout is electrophoretically and meristically close to other rainbow trout, its karyotype (of 58 chromosomes) is distinctive, suggesting that the Eagle Lake rainbow trout is derived from immigration or unrecorded introduction of a rainbow trout with 58 chromosomes. Given the distinctive morphology, ecology, and physiology of this form, it is highly unlikely that the Eagle Lake

[11/]This account was greatly improved by comments from Paul Chappell, California Department of Fish and Game.

trout is derived from an introduction. It is possible that rainbow trout originally gained entrance to the Eagle Lake drainage via upper Pine Creek and an ancient connection with a headwater tributary of the North Fork Feather River or Pit River (E. Gerstung, pers. comm.).

Life History: Eagle Lake trout are late maturing (at 3 years) and long-lived (up to 11 years), although trout older than 5 years are rare (McAfee 1966). Originally, they presumably spent at least their first year of life in Pine Creek, reaching 15-20 cm FL before entering the lake. They then grew to about 40 cm in their second year (first year in the lake), 45 cm in the third, 54-55 cm in the fourth, and 60 cm in the fifth year (McAfee 1966). The fish became mature in their third year, moving up Pine Creek to spawn in response to high flows in March, April, or May. Mature females produce 2,500- 3,000 eggs.

The life history of these fish is now different from the original pattern because Pine Creek has become unsuitable for spawning (see below). As the fish move up Pine Creek in the spring, they are trapped by CDFG. The eggs and sperm are stripped from the fish for artificial spawning. The embryos are then taken to Crystal Lake and Darrah Springs hatcheries where they are reared for 14-18 months for stocking the lake. The fish are marked and planted at 30-40 cm FL (CDFG, unpubl. data). A total of 25,000 of these fish is planted in Pine Creek "estuary" so that spawners will home to the trap, while another 25,000 are planted at the south end of the lake in November (P. Chappell, pers. comm.). These marked "wild" fish are then trapped for spawning each year in Pine Creek. The marks are used to eliminate sibling crosses (inbreeding) and to select for longer lived fish to compensate for longevity reductions that may have been caused by past hatchery practices (R. Elliott, pers. comm.).

In addition to these "wild" fish, 150,000 "domestic" Eagle Lake trout are planted each year at the south end of the lake, The "domestic" trout are derived from brood stock kept at the Mt. Shasta Hatchery and are reared at Darrah Springs Hatchery. 'Most of the fish derived from hatchery broodstock are planted in the southern portion of the lake (generally in April or May), where they survive better initially and contribute more to the lake fishery. They are not used for spawning even if trapped at Pine Creek.

The diet of the trout varies with age and season. Newly planted trout in their first year in the lake feed mainly on zooplankton, including *Daphnia* spp. and *Leptodora kindti,* and on benthic invertebrates, especially leeches and amphipods. By August; most of the trout switch to feeding on young-of-year tui chubs (King 1963, Moyle, unpubl. data).

Habitat Requirements: Eagle Lake trout spend most of their life in Eagle Lake, a large (24 km long by 3-4 km wide), highly alkaline (pH 8-9) lake. The lake consists of three basins, two of them averaging 5-6 m deep, the third averaging 10-20 m and reaching a depth of nearly 30 m. The shallow basins are uniform limnologically, and water temperatures may exceed 20°C in the summer. The deep basin stratifies, so in late summer most of the trout are in the deeper, cooler water of this basin. Otherwise, they are found throughout the lake.

Eagle Lake trout are stream spawners. They formerly migrated over 45 km upstream to spawn in the shaded, gravelly upper reaches of Pine Creek. Young then spent their first year (perhaps two) in the stream before moving into the lake during high run-off periods. During the summer, upper Pine Creek is a "typical" spring-fed trout stream, flowing at 1-5 cfs through meadows and deep forest, with modest gradients. Today, the degraded nature of Pine Creek and the high demand of the lake fishery requires Eagle Lake trout be propagated in a fish hatchery. Barriers have been constructed to exclude spawners from tributaries because flows are too short in duration for successful incubation and rearing, with the exception of flows in Papoose Creek. Some spawning has also been observed along gravelly shores of the north end of the lake, but it is not known if such spawning results in any recruitment to the population (P. Chappell, pers. comm.).

Distribution: Eagle Lake rainbow trout are endemic to Eagle Lake, Lassen County. They have been planted in numerous waters throughout California, where they are maintained from hatchery stocks originating from trout captured at the Pine Creek Spawning Station and from domestic brood stock. The trout have also been exported to other states and to Canada. It is unlikely that naturally reproducing populations of genetically pure Eagle Lake trout are present in any of these planted waters.

Abundance: Naturally spawned Eagle Lake rainbow trout were once enormously abundant in the lake. According to Purdy (1988), "In the spring months of the 1870s and 1880s, when trout were spawning, huge quantities were being caught. It was not unusual to hear that wagon loads of trout, some weighing as much as 600 pounds were being brought into Susanville where they were sold at local markets for twenty-five cents a pound (p. 14)." This exploitation occurred at the same time as extensive logging in the drainage, heavy grazing in the meadows, and the first construction of railroad grades across the meadows and streams, all of which altered the stream channel. Although commercial fishing for trout was banned in California in 1917, the Eagle Lake trout populations remained low, presumably because of the poor condition of Pine Creek (and probably Papoose Creek as well) and the establishment of predatory largemouth bass and brown bullheads in the lake. During the 1930s lake levels dropped as the result of diversion of water through the Bly Tunnel combined with prolonged drought during the 1930s, which together reduced access of the trout to Pine Creek. Even with the return of wetter conditions, the trout populations showed little sign of recovery. In 1950, one pair of trout was captured from Pine Creek and about 2,000 fertilized eggs were taken to Crystal Springs Hatchery. The 600 trout that resulted were used for brood stock (Purdy 1988). Regular trapping operations began in 1959, when 16 trout were captured and spawned. In the next five years the numbers captured varied from 45 to 391 (McAfee 1966).

Currently, about 150,000 trout are planted in the lake each year of both domestic and wild origin, supporting a major sport fishery for "trophy" trout. Hundreds of trout are trapped each year at the mouth of Pine Creek. For example, in 1987 CDFG collected nearly 2.3 million eggs from the trapped fish (Purdy 1988). There is probably little or no natural reproduction, because most of the fish captured by anglers show signs of a year or more in a hatchery environment (mainly damaged or missing fins).

Nature and Degree of Threat: Threats to Eagle lake trout fall into five categories: habitat destruction, hatchery rearing, overexploitation, disease and introduced species.

<u>Habitat destruction.</u> Historically, the greatest single factor threatening the Eagle Lake rainbow trout has been the poor condition of the Pine Creek watershed. The biggest changes were the result of logging, grazing, and railroad and road building. Besides deforesting large chunks of the watershed and creating erosion-prone roads, logging activity in the region resulted in a railroad being built across the Pine Creek drainage, restricting flow of the creek at one point and channelizing the streambed. This situation worsened when State Highway 44 was built parallel to the railroad and forced the stream through several culverts. The combination of culverts and channelized stream created a nearly impassible velocity barrier for the trout. Grazing of livestock has been (and continues to be) a problem because livestock concentrate around the stream. In the lower reaches of the stream (Pine Creek Valley, etc.) most of the riparian vegetation is gone and the wet meadows have been so compacted that they have been largely converted into dry flats dominated by sagebrush. As the result of all these activities acting on the stream for nearly 100 years, the lower creek has cut down into the former meadow 1-2 m and has become more intermittent in flow during the summer, with flows diminishing rapidly in the spring. As a consequence, the stream (especially the key spawning and rearing areas around Stephens Meadow) is nearly inaccessible to spawning adults and contains less habitat for juvenile fish. As noted below, many of these problems are now being addressed by a multiagency Coordinated Resource Management (CRMP) group,

Even the lake habitat for the trout is not completely secure. The Bly Tunnel continues to be a threat to the lake. Although it was blocked off, it still discharges, through an eight inch pipe in the plug, 12 cfs of Eagle Lake water into Willow Creek for downstream water right holders., While some of the water coming from the tunnel may be spring water, most of it is Eagle Lake water because chemically it is nearly identical to Eagle Lake water (Moyle et al. 1991). This is important because the lake is less likely to become severely alkaline in a prolonged drought if it has more water in it to start with.

Hatchery rearing. Eagle Lake trout are completely dependent on hatchery production for survival. If CDFG had not begun trapping these fish in the 1950s, they would now be extinct. Prior to this, they presumably persisted only because occasional wet years permitted access to upstream spawning areas through degraded stream channels and because the fish were exceptionally long-lived. Even now, occasional fish manage to make it through the fish trap and spawn successfully in upstream areas during wet years (Moyle, unpubl. data). The danger in the present program is that fish are gradually being selected for survival in the early life history stages in a hatchery environment, rather than in the wild. Complete dependence on hatcheries for maintaining the species is undesirable because the survival of the species then becomes dependent on the vagaries of hatchery funding and management and to threats from disease and genetic disorders. Fortunately, the present management program for Eagle Lake trout is aimed at establishing a self-sustaining wild population again, although hatchery production is regarded as being a perpetual necessity in order to sustain the trophy fishery (P. Chappell, pers. comm.).

Disease. A continual threat to the survival of Eagle Lake trout is exotic diseases, either in the three trout hatcheries or by introduction into the lake by hatchery-reared fish.

Introduced species. Many different species have been introduced into Eagle Lake in the past, but none have persisted because of the lake's alkalinity. However, because of Eagle Lake's large size and accessibility, it is likely that other species will be introduced illegally and eventually one may succeed, altering the ecology of the lake. Ironically, introduced species are most likely to become a problem in the lake if lake levels rise and alkalinity decreases, as happened in the early 1900s, when largemouth bass and brown bullhead became abundant in the lake. The only exotic species in the drainage now is brook trout *(Salvelinus fontinales),* which are abundant in Pine Creek. Predation and competition by brook trout in Pine Creek may prevent reestablishment of Eagle Lake trout, so a program to eliminate this exotic in contemplated (P. Chappell, pers. comm.).

Management. The present hatchery and planting programs have been successful and should be continued. There is presently a CRMP program underway (since 1986) to restore Pine Creek so that the natural life cycle of Eagle Lake trout can be resumed and the quality and quantity of water flowing into the lake improved. This should be possible, as most (86%) of the Pine Creek drainage is on USFS lands. Many restoration experiments in the drainage are now underway, such as fencing, erosion control measures and well drilling to provide water away from the stream. Many of the suggestions for grazing control in Platts and Jensen (1991) are being implemented. One major factor presently preventing recovery is the velocity barrier to upstream migration that exists below Highway 44, although a study by Jones and Stokes, Inc., through the CRMP process, has provided methods to solve the problem. Current plans also include elimination of brook trout from the upper reaches of Pine Creek. Once Eagle Lake rainbows are re-established, fishing in the creek would have to be closely regulated, presumably with catch and release regulations. A key segment of the upper creek that is suitable for spawning and rearing is Stephen's Meadow, which is privately owned. An agreement must be worked out with the landowner that will allow this segment to be managed for Eagle Lake trout. A similar situation exists in Papoose Meadows, on Papoose Creek, the only other stream where Eagle Lake trout once spawned naturally.

Given the enthusiasm and dedication of the agency personnel working on the Pine Creek CRMP (and on the Eagle Lake shore grazing CRMP) and the general cooperativeness of local ranchers and landowners, the restoration of naaturally spawning populations of Eagle Lake trout seems highly likely. Like the efforts to restore Goose Lake fishes, this could be another demonstration of the success of the CRMP process, where a species is restored without resorting to formal listing as threatened or endangered. However, the efforts to rehabilitate Pine and Papoose creeks do need to be accelerated because even with the best efforts possible, it is likely to be many years before significant natural reproduction will be acheived with lake-run fish.

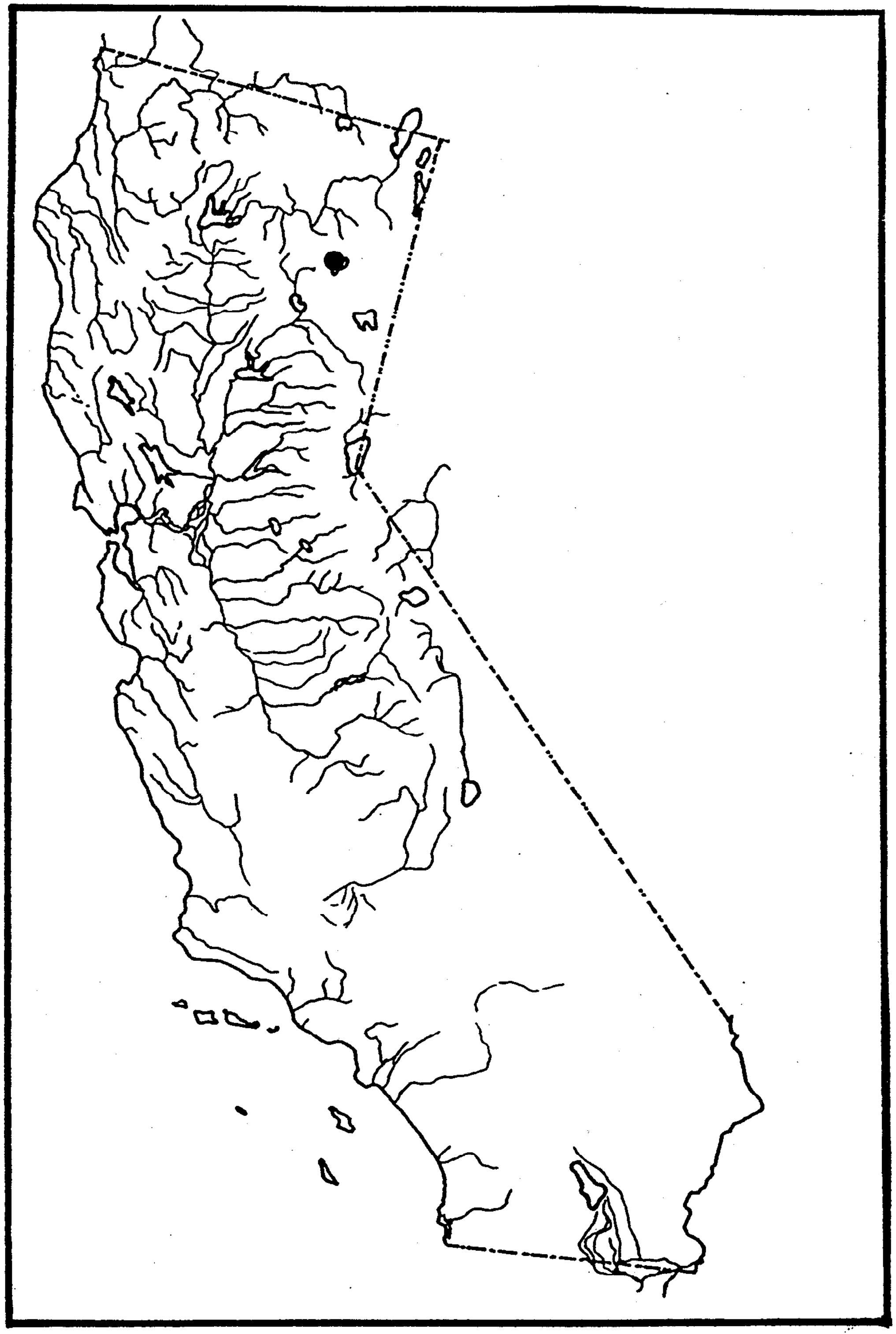


FIGURE 14. Distribution of Eagle Lake rainbow trout, *Oncorhynchus mykiss aquilarum*, in California.

KERN RIVER RAINBOW TROUT
Oncorhynchus mykiss gilberti (Jordan)

Status: Class 2. Special Concern.

Description: This subspecies is similar to other rainbow trout (Table 7), but its coloration is brighter and it has heavy spotting over most of its body (see Moyle 1976).

Taxonomic Relationships: Like the other members of the rainbow trout complex in the Kern River system, the taxonomic status of this subspecies has been controversial. D. S. Jordan's designation of this fish as a distinctive subspecies of rainbow trout was accepted until Schreck and Behnke (1971) described it as a population of golden trout. Their decision was based mostly on comparisons of lateral scale counts and on aerial surveys that led them to believe that there were no effective barriers on the Kern River which might have served to isolate trout in the Kern River from the Little Kern River. However, in a subsequent analysis, Gold and Gall (1975) determined that the populations were effectively isolated genetically and physically. *Meristic* (Gold and Gall 1975) and genetic (Berg 1987) characteristics of *O. m. gilberti* are sufficiently distinctive to warrant its subspecific status (Berg 1987). Genetically, this subspecies is intermediate between the coastal rainbow trout *(O. m. irideus)* and the Little Kern golden trout *(O. m. whitei)*(Berg 1987). Berg (1987) speculated that its origin was due to natural hybridization and introgression with coastal rainbow trout and Little Kern golden trout, followed by isolation. Behnke (1992) regards *O. m. whitei* and *O. m. gilberti* to be so similar that he is equivocal as to whether or not the subspecies designations are valid. However, because *whitei* is already formally recognized as threatened, Behnke recommends keeping the subspecies separate for management purposes.

Life History: No life history studies have been done on this subspecies, but its life history is probably similar to other rainbow trout populations in large rivers (see Moyle 1976 for details).

Habitat Requirements: Little information is available on Kern River rainbow trout, but in general the habitat requirements should be similar to other rainbow trout (see Moyle 1976 for details).

Distribution: This subspecies is endemic to the Kern River and tributaries, Tulare County (Fig. 14). It was once widely distributed in the system; in the mainstem it probably existed downstream as far as Keyesville (below where Isabella Dam is today) and in the South Fork upstream as far as Onyx, where an impassable barrier exists. Today, remnant populations live in the Kern River from Durrwood Creek Junction Meadow, in Rattlesnake and Osa creeks, and possibly upper Peppermint Creek, Salmon Creek, and others (D. Christenson and S. Stephens, pers. comm.). Much of their remaining habitat is in Sequoia National Forest (29+ km) and Sequoia National Park (40+ km).

Nature and Degree of Threat: This native trout of the mainstem Kern River and tributaries has only recently been recognized as persisting in a genetically pure form (Berg 1987). Previously, it was thought to have disappeared through introgression with nonnative rainbow trout (Gerstung 1980). As a consequence, little attention has been paid to other threats to its existence. Primary threats to remaining populations are introgression with hatchery rainbow trout, habitat losses from poor management, and stochastic events such as floods, drought, and fire. For example, some of its present habitat suffered from the Flat Fire of 1976 and subsequent landslides that filled in pools and deposited silt in spawning areas.

In addition, introduced beaver have significantly altered the river in Kern Canyon in Sequoia National Park, flooding meadows and increasing braiding and meandering in the channel (D. Lentz, pers. comm.).

Management: Efforts are being made to identify streams still retaining Kern River rainbow trout; extensive collections of fish for genetic analysis were made in 1991-1993. A management plan for the upper Kern River basin (above Isabella Reservoir) was completed in 1995 (Stephens et al. 1995). The plan contains recommendations for enhancing the native trout populations, based on extensive sampling done in 1992. Problems addressed in the plan include grazing in riparian areas and heavy recreational use of the basin. Population surveys to monitor trout populations and identify habitats in need of improvement are scheduled on a five year interval. To reestablish populations of large Kern River rainbow, anglers are now allowed to keep only two fish in most of the upper basin, with a maximum length of 10 inches (25 cm). CDFG ultimately plans to replace non-native rainbow trout stocked in tributary streams with catchable size Kern River rainbow trout if hatchery production of the native trout is successful. According to the management plan, if native hatchery production is unsuccessful, stocking of nonnative rainbows in tributary streams will stop.

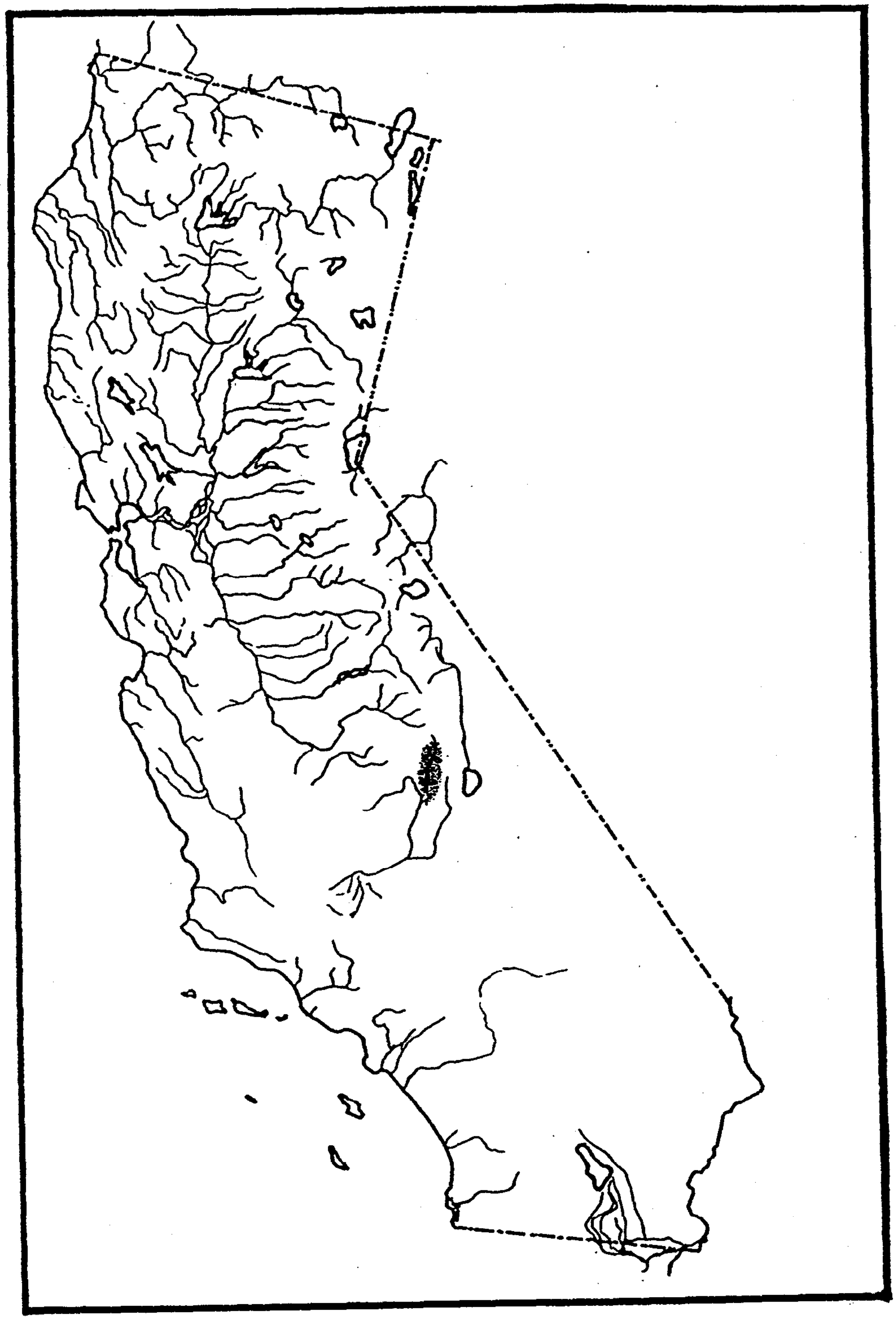


FIGURE 15. Distribution of Kern River rainbow trout, *Oncorhynchus mykiss gilberti*, in California.

VOLCANO CREEK GOLDEN TROUT
Oncorhynchus mykiss aguabonita Berg

Status: Class 2. Special Concern (in native range).

Description: The Volcano Creek golden trout, like other golden trout, is characterized by the bright red to red-orange on the ventral surface and head. The lower lateral surfaces are a bright gold with a central red-orange lateral band. The dorsal surface is a deep olive-green. Young and most adults have about 10 parr marks centered along the lateral line. The parr marks on adults are considered to be a genetic characteristic (Needham and Gard 1959), but they are not always present. Large spots are present, mostly on the dorsal and caudal fins, and smaller spots are scattered on the back and sides above the lateral line and forward of the caudal peduncle. The pectoral, pelvic, and anal fins are orange. The anal fins also have white to yellow tips, preceded by a black band. The dorsal fin has a white to orange tip.

Basibranchial teeth are absent and there are 17-21 gill rakers. There are 175-210 scales along the lateral line and 34-45 scales above the lateral line. There are 8-10 pelvic rays. Pyloric caeca number 25-40 and vertebrae 58-61.

Taxonomic Relationships: The systematics and taxonomic relationships of this taxon has been the subject of much confusion and controversy (Moyle 1976, Behnke 1992). Originally, three species of golden trout were described; *Salmo aguabonita* from the South Fork Kern River (Volcano Creek), *S. whitei* from the Little Kern River, and *S. roosevelti* from Golden Trout Creek. However, the first two forms were eventually recognized as subspecies of *S. aguabonita, S. a. aguabonita* and *S. a whitei,* whereas *S. roosevelti* was shown to be a color variant of *S. a. aguabonita.* Recently, Berg (1987), in a detailed study of the taxonomic relationships of rainbow trout in California, concluded that the two recognized subspecies of golden trout are more closely related to the Kern River rainbow trout *(O. m. gilberti)* than to each other. Therefore, the Volcano Creek golden trout is considered a subspecies of rainbow trout and classified as *O. m. aguabonita.*

Life History: In small streams, golden trout have slow growth rates, reflecting the low productivity and short growing season of the cold waters they inhabit (Knapp and Dudley 1990). They can live up to nine years, which is remarkably long for a stream-dwelling trout. In streams, they typically attain 3-4 cm by the end of their first summer of life, 7-8 cm SL by the end of their second summer, 10-11 cm SL by the end of their third summer and grow 1-2 cm per year thereafter, reaching a maximum size of 19-20 cm SL (Knapp and Dudley 1990). Introduced populations in lakes grow somewhat faster; they reach lengths of 4-5 cm FL during the first year, 10-15 cm by the second year, 13-23 cm during the third, and 21-28 cm by the fourth year (Curtis 1934). In lightly fished lakes, golden trout will reach 35-43 cm FL by the seventh year. The largest on record from California weighed 4.5 kg and was taken from Virginia Lake, Madera County.

Golden trout become reproductive by their third or fourth year and spawn when water temperatures reach 7-10°C, usually in late June and July. They spawn in gravel riffles in streams; only rarely will they spawn in lakes. A female is capable of laying between 300-2,300 eggs, depending on her size (Curtis 1934). The embryos hatch within 20 days at an incubation temperature of 14°C. The fry emerge from the gravel two to three weeks after hatching, at which time they are about 25 mm TL. In lake populations, fry move into the lakes from the spawning streams when they are about 45 mm TL.

Golden trout will feed on any autochthonous or allochthonous invertebrates, mostly adult and larval insects. Although the bright coloration makes them highly visible, there are very few natural predators in the range occupied by this subspecies (Moyle 1976). Thus, the bright coloration has been proposed as an adaptation for reproductive advantage. However, the bright coloration has also been implicated as providing camouflage against the bright colors of the volcanic substrates in the clear, shallow streams (Needham and Gard 1959). When these trout are removed from the mountainous streams and brought down to low elevation streams, they may lose the brightness and take on dull gray and red colors (Needham and Gard 1959).

Habitat Requirements: Golden trout are native to streams of the Kern Plateau of the southern Sierra Nevada, at elevations above 2,300 m. Because the valleys of the plateau were not subjected to Pleistocene glaciation, they are broad, flat, and filled with alluvial gravel, creating wide meadows through which the streams meander. The streams are wide, shallow, and exposed, with limited riparian vegetation to provide cover for the trout. The bottoms consist largely of sand, gravel, and some cobble. The water is clear and usually cold, although summer temperatures can fluctuate from 3 to 22°C (Knapp and Dudley 1990). The exposed, downcut nature of the streams is largely the result of heavy grazing of livestock, which began in the 1860s, causing compaction and accelerated erosion of the loose alluvial deposits (Odion et al. 1988).

Distribution: The Volcano Creek golden trout is native to Golden Trout Creek (of which Volcano Creek is a small tributary) and the South Fork of the Kern River (Berg 1987, Fig. 15), in the upper Kern River basin. However, this fish has been translocated into many other waters within and outside California, including the Cottonwood Lakes not far from Golden Trout Creek. The lakes have served as a source of golden trout eggs for stocking other waters. As a result of stocking in California, they are now found in more than 200 high mountain lakes and streams outside their native range (Moyle 1976). Golden trout planting has been terminated in all lakes within National Parks. About 100 lakes have thus lost their golden trout populations (E. Gerstung, pers. comm.).

Abundance: Within their native range, Volcano Creek golden trout occur at densities of 8-52 fish per 100 m of stream (0.02 - 0.17 per m^2), with the lowest densities occuring in the most degraded reaches of stream (Knapp and Dudley 1990). Presumably, densities were much higher before livestock began grazing the drainage. These trout are common in a number of streams and lakes outside their native range, but these populations should not be regarded as having long-term viability because of their tendency to disappear after hybridizing with rainbow trout.

Nature and Degree of Threat: The principal threat to Volcano Creek golden trout is the continuing degradation of their streams from livestock grazing, which continues (legally) even though the streams are now located in the Golden Trout Wilderness Area (Inyo National Forest). Predation and competition from introduced brown trout *(Salmo trutta)* are a continuous threat. Brown trout were largely eradicated from their streams in the early 1980s and barriers were constructed to prevent their reinvasion. Golden trout in the South Fork Kern River are in jeopardy from reinvasion of brown trout because the two gabions (wire structures filled with rocks) used as barriers are deteriorating due to corrosion of the wires and to erosion of the rocks by sediment-laden, high stream flows (E. Gerstung, pers. comm.). The barriers were temporarily repaired in 1992, but the repairs are unlikely to hold beyond 1995 (D. Christenson and S. Stephens, pers. comm.). Efforts are ongoing to find ways to greatly improve the barriers or to construct more permanent structures in other locations. In 1993, CDFG biologists found a reproducing population of brown trout above the lowermost barrier. How the trout got there is not known, but it would be relatively easy for an angler to have moved fish over the barrier.

Management: Because this trout has been widely introduced throughout the Sierra and the Rocky Mountains it is probably safe as a subspecies, although it can be argued that the introduced populations are on a different evolutionary trajectory from the native populations. It is important, therefore, that the original gene pools of golden trout in Golden Trout Creek and South Fork Kern River be protected as (1) a source for future fish transplants, (2) a stock that can be genetically compared with introduced populations and (3) an aesthetic measure. The drainage should be managed in a manner beneficial to golden trout. The most urgent management measure is the immediate repair or replacement of deteriorating fish barriers that keep brown trout out of the South Fork Kern drainage. Because accessible barriers that have golden trout on one side and brown trout on the other are inherently flawed (by the ease of moving fish over the barrier), other solutions must be found. D. Christensen and S. Stephens suggest (pers. comm.) that " It would seem appropriate to construct a bedrock barrier downstream of Monache Meadows in the gorge area or even further downstream in the drainage, and extend the Volcano Creek population. This would provide a permanent barrier with a great deal less public access." Other management measures must include elimination of or severe restrictions on grazing and the restoration of degraded riparian areas. Any brown trout or rainbow trout populations present in the drainage (e.g., Monache Creek) should be eliminated and barriers constructed where necessary to prevent reinvasions.

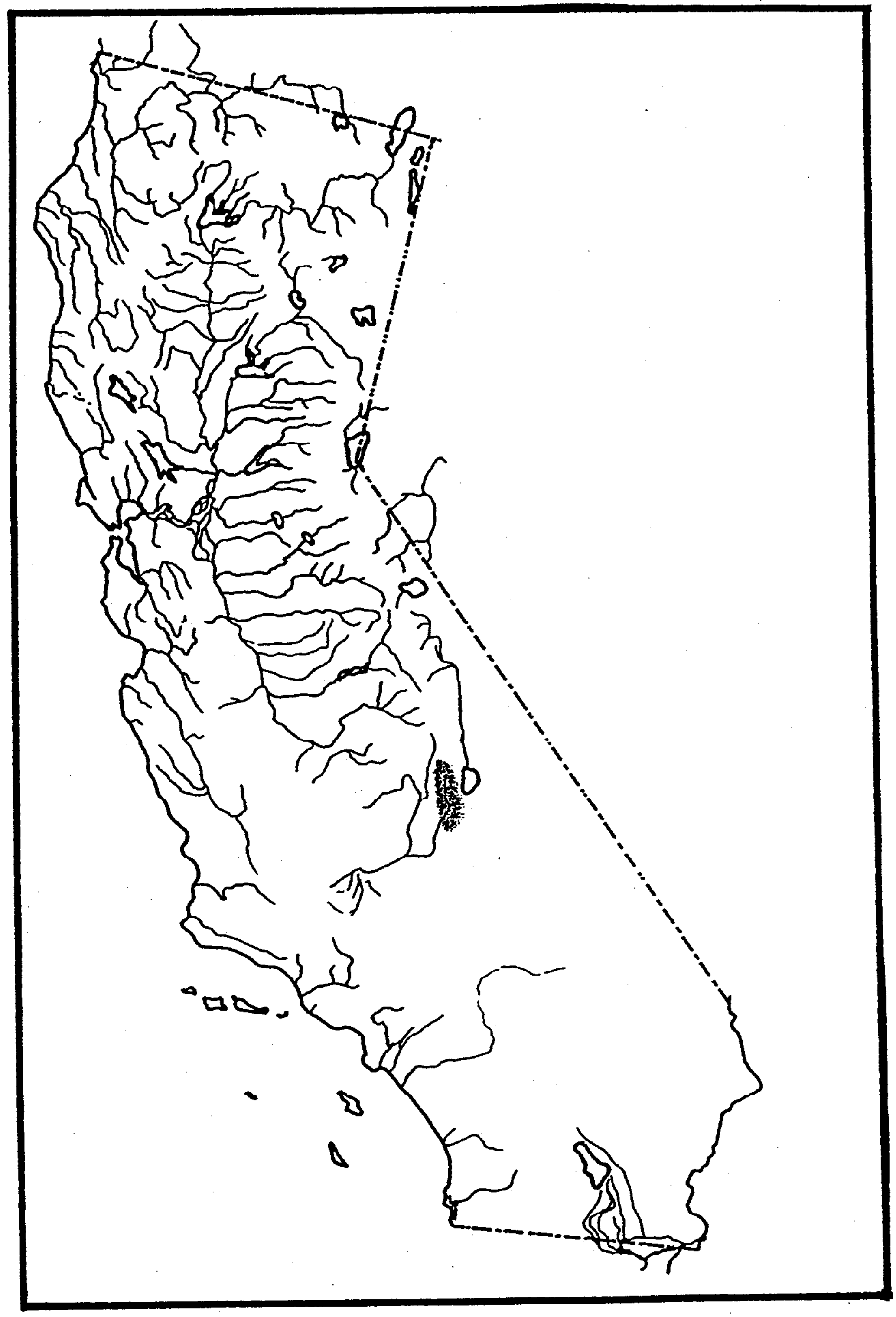


FIGURE 16. Native range of the Volcano Creek golden trout, *Oncorhynchus mykiss aguabonita*, in California.

GOOSE LAKE REDBAND TROUT
Oncorhynchus mykiss ssp.

Status: Class 1. Threatened.

Description: The body shape of Goose Lake redband trout is similar to that of rainbow trout. It has a yellowish to orange body color with a brick-red lateral stripe. The dorsal, anal, and pelvic fins are white-tipped. Stream-dwelling adults retain parr marks, while lake-dwelling adults become silvery-grey in color. The Goose Lake redband trout has two ecological types: a lake-dwelling form that attains lengths of 450-500 mm TL and a stream-dwelling form that rarely grows larger than 250 mm TL (J. Williams, unpubl. data). Behnke (1992) examined six specimens collected by J. O. Snyder in 1904 from Cottonwood Creek in the Oregon portion of the basin. These fish had 21-24 (mean=23) gill rakers, 61-64 (mean=63) vertebrae, and averaged 30 scales above the lateral line and 139 scales in the lateral series. More recent collections from Thomas Creek, Oregon, and Lassen and Davis creeks, California, may have been influenced by hatchery rainbow trout introductions because they exhibited gill raker counts that averaged 20-21 (Behnke 1992).

Taxonomic Relationships: Redband trout are inland forms of rainbow trout (Behnke 1992). In an extensive electrophoretic analysis of the biochemical-genetic integrity of redband trout in California, Berg (1987) determined that all California redband trout were separable from cutthroat trout, with no indication of past redband trout/cutthroat trout introgression. Although the redband trout populations he examined (inland redband, stream-dwelling Goose Lake redband, and McCloud River redband) are related to coastal rainbow trout, each is distinctive enough to warrant subspecific status (Berg 1987). Despite this evidence, Behnke (1992) suggests that the meristic characters of the Goose Lake trout indicate that hybridization has taken place in the past with introduced coastal rainbow trout. No genetic differences between the lake and stream forms in the Goose Lake drainage have been documented, although Berg (1987) only sampled the stream form. Behnke (1981) documented meristic differences between lacustrine and resident stream forms of redband trout in the Klamath Basin, and it is possible such differences exist in the Goose Lake Basin as well, although they may be phenotypic rather than genetic. Among the various redband trout subspecies, the Goose Lake form may be most closely related to the redband trout of nearby Warner Basin, Oregon. This conclusion was based on the lower vertebral counts and higher gill-raker counts of redband trout in both basins (Behnke 1992). Behnke (1981) reported that the redband trouts of Goose, Lake and Warner Basin probably were established prior to the invasion by rainbow trout from the Columbia River into other nearby basins. The Goose Lake redband trout has not yet been assigned a subspecific name but Behnke (1992) tentatively suggests that the Goose Lake trout, along with various redband trout populations in isolated Oregon basins, could be placed together in *O. mykiss newberrii.* Regardless of its ultimate nomenclatural home, there is adequate evidence to regard the Goose Lake redband trout as an evolutionarily significant unit that is worthy of special protection efforts.

Life History: There are two life history strategies present in the Goose Lake redband trout: a lake strategy and a headwater stream strategy. Lake fish live in Goose Lake where they grow to large size and spawn in the tributary streams. Headwater fish remain small and spend their entire life cycle in the streams. It is likely, although unproven, that the two forms represent one population because the aperiodic dessication of Goose Lake presumably has eliminated the lake forms repeatedly in the past.

In California, the lake-dwelling form spawns, (or spawned) in the tributaries and headwaters of Lassen and Willow creeks. If sufficient flows are available, they spawn primarily in Cold Creek, a small tributary of Lassen Creek, and in Buck Creek, a small tributary of Willow Creek. Upstream of its confluence with Cold Creek, a steep, rocky gorge apparently prevents spawners from ascending further up Lassen Creek. In Oregon they formerly spawned in Thomas Creek and its tributaries and possibly in Cottonwood and Drews creeks. In recent years, the largest spawning run occurred in Lassen Creek (J. Williams, unpubl. data). Although large spawners had been observed in lower Willow Creek, diversion structures prevented most or all the fish from reaching suitable spawning and rearing habitat in Buck Creek. Buck Creek has been severely degraded by irrigation diversion structures, but it has considerable potential for improvement as a spawning stream. Spawning migrations occurred in Willow and Lassen creeks during late March 1988. Adults returned to the lake in April. Young trout may spend one or more years in the stream before moving down into Goose Lake. In the lake, the trout presumably feed on the abundant Goose Lake tui chub. Growth seems to be rapid, as scales from 6 spawning fish (27-48 cm) taken in 1967 indicated that they were all 3 years old (CDFG files).

The life history of the stream-dwelling form has not been studied, but it is presumably similar to that other redband and rainbow trout that live in small, high-elevation streams. Such trout typically spawn in their third spring and live four to five years.

Habitat Requirements: These fish can survive an extended duration of warm temperatures (15-20°C), and the high alkalinity and turbidity that exist in Goose Lake in summer that would be lethal to most other trouts. Redband trout in tributaries have survived short duration temperatures as high as 29°C. Spawning areas are located in high-elevation sections of tributary streams and are up to 40-50 km from the lake. Prior to spawning, adults must have access from the lake to spawning areas. In every stream this means negotiating extensive agricultural areas characterized by water diversions, erosion, and channelization. Logjams and beaver dams also may prohibit or restrict upstream movement of spawners during low-flow conditions. After spawning, adults and eventually the young must have passage back to Goose Lake. The spawning sites themselves must be nondegraded reaches of streams with clean gravels and suitable riparian cover for maintenance of cool water temperatures. Goose Lake redband have been observed to spawn in lower reaches of Willow and Lassen creeks when access to upstream areas is blocked (P. Chappell, pers. comm.), but siltation and high temperatures probably preclude successful recruitment in the lower reaches of these streams. The habitat requirements of the stream-dwelling form are presumably similar to other populations of redband trout that occupy small, cool, high-elevation streams.

Distribution: The Goose Lake redband is endemic to Goose Lake and its major tributaries (Lassen and Willow creeks in California and the extensive Thomas Creek system and Crane Creek in Oregon) as well as to smaller streams such as Cottonwood and Pine creeks in California and Augur, Bauer, Camp, Cox, Drews, Snyder Meadow, Shingle Mill, and Warner creeks in Oregon. Berg (1987) reported that Joseph, Parker, and East creeks, tributaries of the upper Pit River in California, contained trout genetically similar to Goose Lake redband.

Abundance: The Goose Lake redband trout population historically has undergone major fluctuations, being depleted during series of dry years and recovering in wet periods. In the 1930s, for example, Goose Lake was almost completely dry, which decimated the lake-dwelling subpopulation; reestablishment of the lake population presumably resulted from colonization by stream-dwelling fish (E. Gerstung, pers. comm.). The lacustrine population was severely depleted during the 1976-1977 drought, recovered during the wet early 1980s, and again dropped precipitously during the 1986-1992 drought. Goose Lake dried up in 1992 and there is little reason to think any of the lacustrine fish or their descendents have persisted. In the past, interviews with local residents indicate that both sport and commercial fisheries existed for Goose Lake redband trout and that large runs occurred in local creeks, especially Thomas Creek in Oregon. The last spawners in Thomas Creek were observed in the early 1970s. Together, tributaries in

Oregon at one time supported runs of several thousand fish, but storage dams, diversion structures, and habitat degradation eliminated these runs. Lassen Creek presently is the only stream still easily accessible to spawning redbands in years when there is water in the lake. Numbers of spawning fish in this stream fluctuated from ten or so individuals to several hundred, but the creek appears to have the potential to support perhaps 1,000 spawning fish under optimal flow conditions (E. Gerstung, pers. comm.). The only large run documented in recent years in Lassen Creek was in 1988 when several hundred spawners were present (J. Williams, unpubl. data), which suggests that there were fewer than 1,000 adults in Goose Lake. In 1989, only about a dozen fish appeared in the creek, and there was no evidence of successful spawning; no lake-run fish have been observed in the creek since that time (G. Sato, pers. comm; M. Yamagiwa, pers. comm.).

The stream form of the Goose Lake redband trout apparently exists in about 15 small headwater streams and the numbers in each population are not known. It is safe to assume, however, that numbers in these streams became reduced during the drought, as stream flows declined.

Nature and Degree of Threat: Goose Lake redband trout are threatened by many factors, but habitat modification of the streams and the lake are the biggest threats.

Habitat modification. Populations of the lake-dwelling form were intially reduced because the spawning habitat in streams was largely unavailable. Lake-dwelling trout disappeared when the lake dried up in 1992, with no residual populations left in the spawning reaches of the streams. Most of the former spawning streams have been channelized in their lower reaches, as well as dammed and diverted. These changes effectively blocked the large runs that once existed. In some areas. passage problems have been exacerbated by beaver dams. In addition, potential spawning areas have been degraded from human activities in the drainage (livestock grazing, roadbuilding, logging, etc.) which did not pay sufficient attention to maintaining aquatic and riparian habitats. Such activity reduces riparian and pool cover needed by the spawning adults and can cause the accumulation of silt in spawning riffles, smothering the eggs. Only Lassen Creek had a small run in recent years, and even that stream was blocked at times by culverts, beaver dams, and debris jams. Because of water diversions and loss of wetland areas in the drainage that once helped to retain water and streamflows, Goose Lake probably dried up faster than usual. However, there is evidence that Goose Lake dried up in the 1420s, in the 1630s, and 1926 (with low lake levels from 1925 to 1939). Thus the key to the survival of the Goose Lake trout (and other fishes) was presumably conditions in the lower reaches of the streams. During the dry periods, the lake dwelling trout persisted either (1) by maintaining populations in the lower reaches of the tributary streams, which assumes the streams had year-round flows, or (2) by repeated recolonization from the resident populations in the headwaters, which assumes that fish from headwater populations are capable of adopting the potadromous habit.

The headwater streams containing redband trout have been heavily grazed, resulting in reduced riparian cover and, in places, down-cutting to bedrock. The impact of grazing has been reduced in recent years through a combination of fencing, rotational grazing, installation of erosion control structures, and planting of willows (H. Jasper, pers. comm.). Roads are also a problem on some streams, especially where culverts may be barriers to fish movement or where the road-cuts are a source of silt. Some streams have multiple problems. For example, Auger Creek in Oregon has poor water quality as the result of road building, channelization, and waste materials from uranium mines. Overall, the stream populations are few, small, and isolated and are therefore vulnerable to extinction due to natural events, especially where stream and riparian habitats have been degraded.

Much of the critical stream habitat for Goose Lake redband trout is on private land and much of the water they depend upon is diverted through riparian water rights. Thus, their long-term survival depends on the close cooperation of private landowners with agencies. Most of the remaining habitat is either in Fremont or Modoc National Forest, much of which is leased for livestock grazing. Cooperative efforts to improve stream habitats on both public and private land have been undertaken, but much more needs to be done.

Overexploitation. When lake-dwelling fish are moving upstream to spawn, they are extremely vulnerable to angling or poaching, especially when confined below an artificial barrier. This may have been a factor in the decline of the Lassen and Willow creek populations, although the lower reaches of the Goose Lake streams were closed to angling during much of the drought period. There were no particular restrictions on fishing in the headwater streams, so the fish there were presumably subject to depletion by angling. In 1992, all headwater streams were closed to angling until it can be demonstrated they can sustain fisheries.

Introduced species. Brook, brown, and rainbow trout have been introduced into streams of the Goose Lake drainage in the past. Brown trout are now well established in two California tributaries, Pine and Davis creeks. California has not stocked any rainbow trout in the drainage since 1980, when electrophoretic studies indicated that the native trout were distinct; planting of hatchery rainbow trout apparently has continued in Oregon tributaries, however (R. Elliott, pers. comm.). The potential for future introductions (presumably illegal) to disrupt the native trout populations through disease, hybridization, predation, or competition remains. Numerous attempts have also been made to introduce warmwater fishes, including striped bass, into the lake, but they have been largely unsuccessful, presumably because of the lake's alkalinity. This does not preclude the possibility that at some time fish or invertebrate species could be introduced that would disrupt the lake ecosystem as it exists today. A number of warmwater game fish species have already become established in reservoirs and farm ponds within the Oregon portion of the drainage. The fathead minnow *(Pimephales promelus),* an introduced species, is now established within both the Oregon and California portions of the drainage.

Management: The need for special management of Goose Lake redband trout is implicit in the designations given to it by various state and federal agencies: (1) USFWS, Category 2 Candidate Species; (2) USFS, Region 5, Management Indicator Species; (3) USFS, Region 6, Sensitive Species, and (4) ODFW, Sensitive Species.

The long-term goal of management should be to restore Goose Lake redband trout populations to the point where they have self-sustaining populations in both the lake and the streams. In recent years, there has been considerable interest in preserving this unusual trout and other endemic fishes. As a result, a Goose Lake Fishes Working Group was formed. The group's membership represents private landowners, state and federal agencies, nongovernmental organizations and universities. This group is developing a management plan for the trout and other fishes (G. Sato, pers. comm.). In the lower reaches of most streams, the main actions taken in the past by agencies have been attempts to make culverts passable to trout, although a fish ladder was installed over a major diversion dam on Thomas Creek in 1992 by the ODFW. In Willow and Lassen creeks, CDFG removed natural and artificial migration barriers. Headcut control, bank stabilization, and other protective measures have also been undertaken on a number of streams in recent years (H. Jasper, pers. comm.).

The biology of the Goose Lake trout is poorly known so there is an urgent need for studies on the genetic identities of the remaining populations, and on its life-history and habitat requirements. It is particularly important to discover whether trout from the creeks will recolonize the lake once it fills with water again. An experimental program should begin to reestablish the lake population from stream populations. For a restoration program to be successful, it will be necessary to intensively manage (1) lake habitat, (2) valley-floor stream habitat, (3) spawning and rearing habitat and (4) headwater habitat for stream-dwelling populations. It will also be necessary to develop cooperative management programs among landowners, agencies, and interest groups.

Lake habitat. The native fish assemblage in Goose Lake can be maintained only if there are adequate lake levels in most years and if refuges for the fish exist during dry years. The abundant tui chub population has been an excellent food resource and presumably accounts for the large size attained by the trout. Introductions of exotic fishes or invertebrates that could alter the forage base or add another predator should be banned, including the planting of hatchery trout in both California and Oregon. Management to provide a sport fishery should focus on improving conditions for redband trout rather than on stocking exotic predatory fishes. The effects of water diversions on lake levels needs to be assessed.

Valley-floor stream habitat. The valley floor surrounding Goose Lake is largely devoted to agriculture. Streams in the valley do not provide year-round trout habitat but are critical for passage of Goose Lake redband trout to and from spawning areas (assuming the lake population can be re-established). To the best of our knowledge, adults migrate to spawning areas during late March or early April and return to the lake in late April. Early placement of boards in seasonal diversion dams, therefore, can prevent either the upstream movement of adults or the return of adults and young back to Goose Lake. In California, Willow and Lassen creeks are critical spawning streams. The valley-floor section of Willow Creek is typically impassable to adult redband moving upstream. A diversion structure downstream of Highway 395 has been particularly harmful and prevented most adult spawners from moving upstream in 1988 despite recent attempts to install a fish ladder. Major modification of this structure is needed to allow upstream movement of spawners. On both Lassen and Willow creeks, agreements with landowners are needed to coordinate timing of board placements in diversion structures. Screens are also needed on irrigation structures to prevent diversion of young and adults into fields.

Spawning and rearing habitat. Willow and Lassen creeks contain the only remaining spawning habitats for lake-dwelling Goose Lake redband in California, although Willow Creek is of marginal quality (M. Yamagiwa, pers. comm.). Depending on water flows and access past barriers, Buck Creek (a tributary of Willow Creek) and Cold Creek (a tributary of Lassen Creek) may serve as spawning areas. Cold Creek alone is known to have held several hundred spawners in past years (E. Gerstung, pers. comm.) Access to Cold Creek is generally good, but access to Buck Creek is impeded downstream of Highway 395 (noted above) and at its confluence with Willow Creek. At present, a diversion structure often diverts the flows of lower Buck Creek from Willow Creek. This problem should be corrected through an agreement with the landowner. The upper Willow Creek watershed has been severely degraded by human activity. Increased erosion control measures should be implemented on upper Willow Creek and tributaries. Changes in management could include changes in livestock grazing practices, installation of juniper revetments, planting of willows in streambanks, and other appropriate measures to increase riparian habitat and stabilize the stream channel. Similar measures need to be taken in Oregon streams, especially in the Thomas Creek drainage, where a fish ladder has been constructed over the major diversion dam across the lower creek.

Because of the small size of spawning streams and the large size of adults, spawning redband trout are susceptible to poaching. Therefore, once the lake-dwelling populations are re-established, patrols will probably be necessary to prevent poaching as adults congregate below diversion structures and in shallow spawning areas.

Headwater habitat. Headwater streams in California were closed to angling in 1992 as a first step toward enhancing the headwater populations. Eventually, however, an expanded habitat improvement program should be instituted. The extent of the habitat occupied by stream-dwelling Goose Lake redband trout needs to be documented and a management plan developed for these streams to enhance the trout populations. It is particularly important to improve quality and quantity of riparian habitat. A promising development along these lines is the Lassen and Willow Creek Water Quality Improvement Project proposed by the Goose Lake Resource Conservation District, which is currently awaiting funding.

Coordination. All efforts to improve conditions for Goose Lake redband trout should be accompanied with efforts to inform and involve all interested parties, especially landowners in the drainage and the major land management agencies (USFS, BLM). Close coordination of California and Oregon resource agencies is also necessary for proper management of the redband trout. It is particularly important that runs of lake-dwelling trout be reestablished in Thomas Creek in Oregon, because this is the largest tributary drainage and, presumably once supported the largest runs of trout. Agreements should be made with ODFW to establish protective angling regulations and to prevent introductions of exotic fishes into Goose Lake. No nonnative fish should be introduced into Goose Lake or tributary streams so that the genetic integrity of native redband trout and the integrity of the lake's unique biotic communities can be preserved.

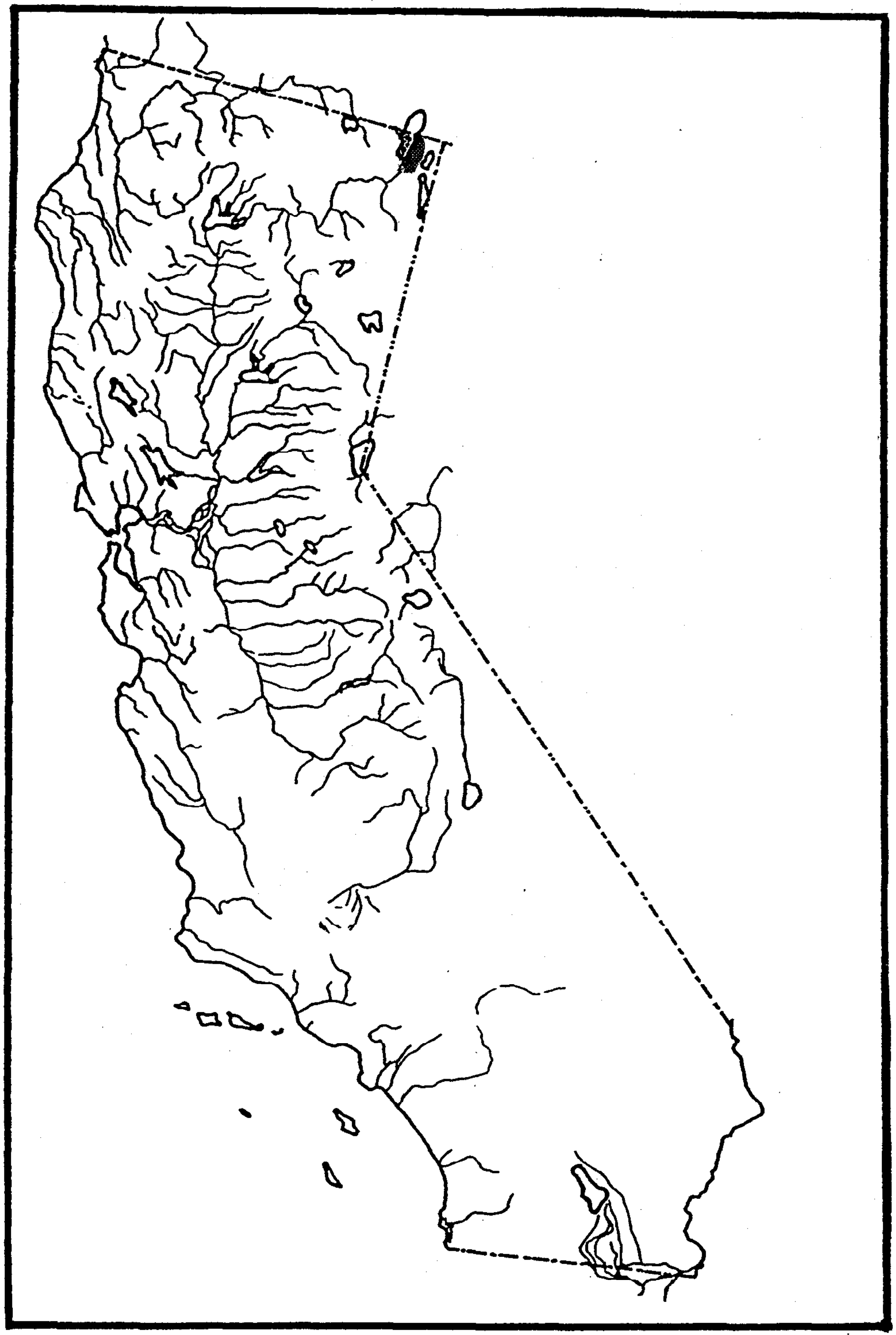


FIGURE 17. Distribution of the Goose Lake redband trout, *Oncorhynchus mykiss* ssp., in California.

MCCLOUD RIVER REDBAND TROUT
Onchynchus mykiss ssp.

Status: Class 1. Threatened.

Description: The following description is based on the Sheepheaven Creek population (Hoopaugh 1974, Gold 1977) that seems to have a narrower range of characters than is found throughout the range of the subspecies. Behnke (1992), however, considers this population to best represent the subspecies because it is unlikely to have had any history of hybridization with introduced rainbow trout. Overall body shape of this redband trout is similar to the "typical" trout shape as exemplified by rainbow trout. It has a yellowish to orange body color with a brick-red lateral stripe. The dorsal, anal, and pelvic fins are white-tipped. Adults retain parr marks. Gill rakers number from 14-18 (average=16), which is the lowest number known from any rainbow trout population (Behnke 1992). Pyloric caeca number 29-42, which is also low. However, the number of scales along the lateral line (153-174) and above the lateral line (33-40) are greater than in most rainbow trout. Pelvic fin rays are 9-10 and branchiostegal rays range from 8-11. Many, but not all, of the trout have basibranchial teeth, a characteristic normally associated with cutthroat trout.

Taxonomic Relationships: The taxonomic status of redband trout has been under much debate. Legendre et al. (1972) suggested that redband trout are interior rainbow trout closely related to the group of trout that includes Arizona trout *(O. apcache),* Gila trout *(O. gilae),* Kern River rainbow trout *(O. m. gilberti),* golden trout *(O. m. aguabonita),* and Mexican golden trout *(O. chrysogaster)*. However, Miller (1972) disputed this relationship, suggesting instead that redband trout represent a derivative of an ancestral form that also gave rise to the California golden trout. Recent electrophoretic studies by Berg (1987) suggest that the three known redband lineages (inland redband, Goose Lake redband, and McCloud redband), were independently derived from a "coastal rainbow trout-like" common ancestor and are now genetically distinct lineages that warrant recognition as subspecies of rainbow trout. Behnke (1992) places redband trout from the McCloud drainage in the subspecies *O. mykiss stonei,* along with populations of presumed redband trout from the Pit River drainage. He states, however, that *"stonei* is not a biological subspecies - only a practical one (p. 190)." Given the uncertain (but probably hybridized) nature of the Pit River "redbands" (Berg 1987) and the evidence that the McCloud River fish represent a distinct evolutionary lineage, there is little reason not to recognize it as a biological subspecies.

Life History: Little is known about the life history of this fish. Redband trout caught from Sheepheaven Creek were in reproductive condition in June, suggesting that they spawn in late spring. The largest fish caught during a 1973 survey (Hoopaugh 1974) was 208 mm FL, and the population was then estimated at 250 fish over 80 mm FL. Four size classes were found in the stream. The life history of redband trout in the upper McCloud River is presumably similar to that of rainbow trout in comparable waters (Moyle 1976).

Habitat Requirements: Habitat requirements for the McCloud River redband are derived from conditions of Sheepheaven Creek (Hoopaugh 1974; Moyle 1976) and the McCloud River. Sheepheaven Creek is a small, spring-fed stream at an elevation of 1,433 m. Water temperature in summer typically reaches 15°C and the flow drops to 0.03 m^3 set^{-1} (1 cfs). The stream flows for about 2 km from the source and then disappears into the stream bed. However, during times of drought the flow drops to a trickle and the stream becomes intermittent; as a consequence summer temperatures of the water can exceed 22°C. The portion of the upper McCloud River inhabited by redband trout usually flows at 1.2 m^3 set^{-1} (40 cfs) through a steep canyon. It is extremely clear and cold (<15°C). Nevertheless, in 1992 (the fifth year of drought), the river was dry from its headwaters down to Bundoora Springs. Some tributaries, such as Moosehead Creek, also nearly dried up.

Distribution: McCloud River redband trout have been reported from creeks tributary to the McCloud River such as Sheepheaven, Tate, Edson, and Moosehead creeks (Miller 1972; Hoopaugh 1974; Berg 1987) and from the McCloud River above Middle Falls. Redband trout from Sheepheaven Creek were transplanted into Swamp Creek in 1972 and 1974 and into Trout Creek in 1977 (J. Hayes, pers. comm.). They are now established in both streams.

Abundance: There is little information available on the trends in McCloud River redband trout populations. However, the smaller tributaries containing the trout have been degraded and the main river has been subject to fishing and introduction of hatchery rainbow trout, so it is highly likely that numbers are much less than they once were. The 1987-1992 drought resulted in severe reductions in the populations in Sheepheaven, Edson, and Moosehead creeks; populations in other waters fared better (E. Gerstung, pers. comm.).

Nature and Degree of Threat: Long-term survival of populations of redband trout in small creeks like Sheepsheaven Creek poses problems because the streams may be largely dry during drought years and the process accelerated by poor watershed management, including grazing of livestock in the riparian areas. Many such streams are located on private or National Forest land managed for timber harvest, so minimal attention is paid to managing the streams for native trout. The populations are more secure in the main river, although much of the river flows through private land that has been heavily logged. Because of its size and the high water quality of the springs that feed it, the river seems to be in good condition. However, the McCloud River has been proposed as a site for hydroelectric dams, and poor watershed management from road construction, logging, and grazing have degraded water quality.

The McCloud River receives substantial numbers of stocked hatchery rainbow trout during the summer to support a "put-and-take" fishery. CDFG studies (J. Hayes, pers. comm.) indicate that the hatchery fish apparently do not survive to spawn. Studies by Gall et al. (1981) confirmed that the McCloud River redband trout has maintained its distinct genetic character despite the stocking of rainbow trout. However, the repeated introductions of hatchery fish could result in the introduction of exotic diseases or parasites to the redband trout populations. Reproducing populations of brown and brook trout are present in the McCloud River as well, and under the right conditions (poor watershed and fisheries management) they could eventually eliminate redband trout from many of the streams through competition and predation.

Management: Most management attention for this subspecies has been focused on the Sheepheaven Creek population, which was once regarded as the only redband trout population in California. Because it was threatened with extinction due to logging of the tiny drainage, some fish were transplanted to Trout and Swamp creeks in 1977. Little special attention has been paid to the population in the main river.

We recommend the following management actions:

-- Have all waters containing McCloud River redband trout in Shasta-Trinity National Forest be given special management protection so that maintaining redband trout populations and the native assemblage of aquatic organisms is the highest priority of watershed management. It is clear that the drainage would benefit from a Cooperative Resource Management Planning Process, involving private landowners and concerned agencies, such as is being proposed by USFS (R. Elliott, pers. comm.). This process is especially important for the initiation and acceleration of watershed restoration efforts.

-- Acquire as much of the private land along the upper river above Middle Falls as possible. About half of the river frontage was acquired during 1990 (E. Gerstung, pers. comm.). The river here has both high aesthetic and recreational values that are compatible with protecting redband trout.

-- Acquire private land that contains small stream populations, especially the land around Sheepheaven Creek.

-- Evaluate the effects of angling regulations and hatchery stocking procedures on redband trout. So far, redband trout have maintained their integrity despite frequent stocking of rainbow trout in the river in the last 80-90 years. However, probably the best management procedure would be to eliminate the stocking of hatchery fish and to institute catch-and-release fishing regulations for the redband trout, emphasizing the special wild qualities of this subspecies. However, it will be difficult to obtain public acceptance of this because of the intensive public use and long tradition of catchable trout stocking in much of the area.

-- Continue the program of establishing instream barriers to isolate tributary populations of redband trout to prevent contamination by nonnative trout.

-- Conduct more complete genetic and taxonomic evaluations to provide a better basis for a subspecies description. In addition, repeat electrophoretic studies periodically to determine if any hybridization between redband and rainbow trout is occurring.

-- Conduct a life history investigation, including habitat requirements of various life stages.

-- Establish a regular monitoring program for redband trout populations.

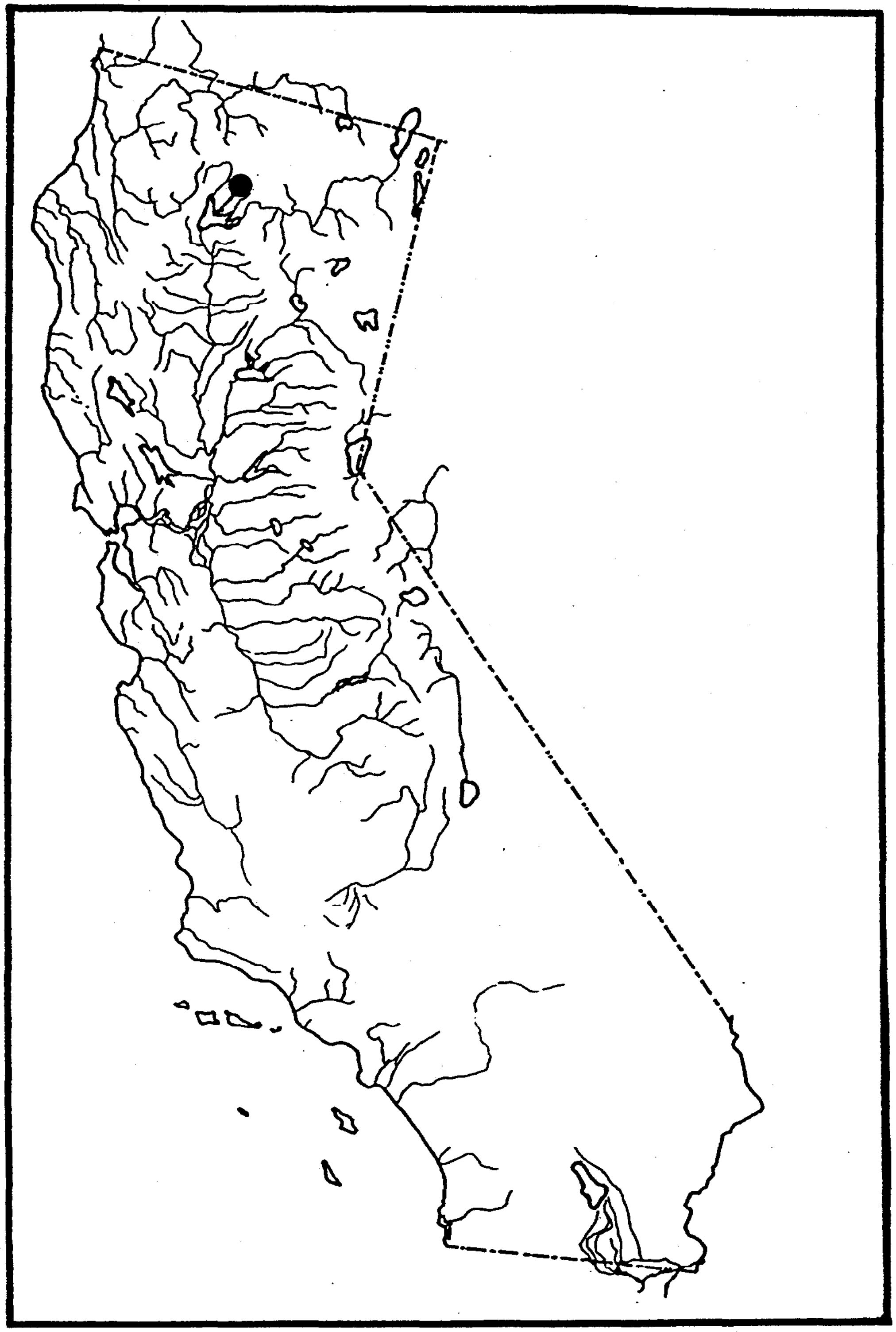


FIGURE 18. Distribution of the McCloud River redband trout, *Oncorhynchus mykiss* ssp., in California.

COASTAL CUTTHROAT TROUT
Oncorhynchus clarki clarki (Richardson)

Status: Class 2. Special Concern.

Description: Coastal cutthroat trout are similar to rainbow trout in gross morphology and color. They can, however, be differentiated by the heavier spotting, especially below the lateral line and in the posterior part of the body. Spots also are commonly present on anal and paired fins, which are otherwise uniformly colored. The trout are characterized by "cutthroat" marks, which range from yellow to orange to red, on the skin folds on either side of the lower jaw (Scott and Crossman 1973). Cutthroat marks are seldom visible until the fish become at least 80 mm TL. Overall, however, coloration is extremely variable within the species (Dewitt 1954, Scott and Crossman 1973). Cutthroat trout also have larger mouths (longer maxillary bones) and more slender bodies than rainbow trout. The teeth are well developed on both jaws, vomer, palatines, tongue, and on the basibranchial bones. The dorsal fin has 9-11 rays, the anal tin 8-12 rays, the pelvic fins 9-10 rays, and the pectoral fins 12-15 rays. The caudal fin is moderately forked. There are 15-28 gill rakers on each arch and 9-12 branchiostegal rays. Scales are smaller than those of rainbow trout and there are 140-200 along the lateral line. Anadromous forms occasionally reach 75 cm FL (8 kg) but fish in excess 40 cm FL and 2 kg are unusual. Individuals in landlocked population rarely exceed 30 cm FL. Parr have 9-10 widely spaced oval-shaped parr marks centered along the lateral line.

Taxonomic Relationships: Despite earlier taxonomic controversy (Needham and Gard 1959, La Rivers 1962, Scott and Crossman 1973), the coastal cutthroat is now recognized as one of three valid California subspecies of *O. clarki* (Moyle 1976). The other two subspecies in California are Lahontan cutthroat *(O. c. henshawi)* and Paiute cutthroat *(O. c. seteniris).*

Life History: Coastal cutthroat trout are ecologically similar to rainbow trout, but when sympatric the cutthroat trout are usually found in the smaller headwater streams whereas rainbow trout are found in the larger, main rivers (Hartman and Gill 1968). Cutthroat trout also typically spawn and rear higher upstream than steelhead trout and coho salmon, which are competitively dominant (Pauley et al. 1989). Some coastal cutthroat trout may spend their entire lives in fresh water, but most are anadromous, spending the summers in saltwater habitats. Thus, most summer fish in the streams are of the first-year age class, but a few may be older non-anadromous fish or anadromous forms that have been landlocked by swiftly receding water levels (Dewitt 1954). Scott and Crossman (1973) presented a comprehensive description on their life history, based mostly on coastal cutthroat trout from Canadian waters, and Dewitt (1954) described the life history of California populations. The following account is derived from descriptions by these authors and from Pauley et al. (1989).

In northern California, coastal cutthroat trout begin to migrate up spawning streams in August-October following the first substantial rainfall. In the Alsea River estuary, Oregon, most upstream migration occurs during August-September (Giger 1972). Redwood Creek and the Mad, Klamath, and Smith rivers are among the significant spawning streams in California. Ripe or nearly ripe females have been caught from September to April, indicating a prolonged spawning period. Age at first spawning ranges from 2-4 years, and cutthroat trout can repeat spawn in subsequent years, although post-spawning mortality may be high. The fish are relatively short-lived at 4-7 years. Sexually mature cutthroat trout show precise homing migrations to their natal streams. Females excavate redds in clean gravel with their tails. The completed redd measures approximately 350 mm in diameter by 100-120 mm in depth. After spawning is completed, the female will cover the redd with about 150-200 mm of gravel by displacing the substrate upstream of the redd. Each female will dig a number of redds sequentially. Spawning can take place during the day or at night.

Fecundity ranges from 1,100-1,700 eggs for females between 200-400 mm TL. Among similar-sized fish, first-time spawners are more fecund than second-year spawners. Embryos are 4-5 mm in diameter, orange-red in color, demersal and adhesive. They hatch following 6-7 weeks of incubation. The alevins remain in the gravel for an additional 1-2 weeks until the yolk-sac is absorbed. Thus, fry emerge from March to June (Dewitt 1954). Once they emerge, the juveniles move out of the small streams and into the larger rivers (or lakes). Often their distribution is determined by the presence of other salmonid species; in competitive interactions with either coho salmon or rainbow (or steelhead) trout, juvenile cutthroat trout are usually displaced from the preferred pools to riffles. Coastal cutthroat trout normally attain 3-4 cm FL by the first summer of life. Some fish migrate to sea during their first year, but others spend up to five years in freshwater before migrating to coastal waters. They remain close inshore and most will remain within the estuary. Cutthroat trout evidently remain in schools during their saltwater residence (Giger 1972). They may spend one or several years in seawater, but will migrate upstream each year to spawn.

Young and juveniles feed mostly on aquatic and drift insects, microcrustaceans, and occasionally on smaller fish. Adults feed on insects, crustaceans, salmon eggs and other fish, and they become more piscivorous as they increase in size. In freshwater, adult cutthroat trout prey upon small fishes such as threespine stickleback *(Gasterosteus aculeatus),* sculpins *(Cottus* spp.), and juvenile salmon and trout *(Oncorhynchus* spp.). In the marine environment, cutthroat trout feed on various crustaceans and fishes, including Pacific sand lance *(Ammodytes hexapterus),* salmonids, herring and sculpins. Marine predators include Pacific hake *(Merluccius productus),* spiny dogfish *(Squalus acanthias),* harbor seals *(Phoca vitulina)* and adult salmon (Pauley et al. 1989). Freshwater predators include the usual array of herons, mergansers, kingfishers, otters, snakes, and piscivorous fishes.

Habitat Requirements: Coastal cutthroat prefer small, low gradient coastal streams and estuarine habitats. Optimal streams are cool (<18°C), well shaded, and with an abundance of instream cover. The preferred habitat is similar to that used by coho salmon (Pauley et al. 1989, CDFG 1991a). Other environmental constraints are summarized by Pauley et al. (1989). Preferred temperatures are 9-12°C, with spawning temperatures ranging between 6-17°C (Pauley et al. 1989). Cutthroat trout generally avoid water with <5 ml 1^{-1} of dissolved oxygen during the summer, and feeding and movement of adults are inhibited at turbidities >35 ppm. Egg survival can be reduced to less than 10 percent if sediment levels exceed 103 ppm, combined with dissolved oxygen levels <6.9 mg 1^{-1} and water velocities in the redd of <55 cm h^{-1}. Cutthroat fry prefer water velocities <0.30 m set^{-1}, with the optimum being <0.08 m set^{-1}; they prefer shallower and slower water than do older life stages. Summer flows in the natal streams average 0.12 m^3 set^{-1} (Pauley et al. 1989). Adults that spend the winter in streams inhabit pools with fallen logs or undercut banks, but boulders, depth and turbulence provide alternative forms of "cover" if woody debris is unavailable (Gerstung 1993).

Stream sections with small or moderate-sized gravel substrates are essential for spawning. Gravel size utilized for spawning has been variously reported as 2-5 cm, 0.6-10.2 cm, and 0.16-0.64 cm, and survival of embryos is inversely related to the amount of fine sediments present. Cutthroat trout usually choose the tails of pools in small streams to spawn in, preferring the headwater tributaries of larger streams. Spawning occurs at water velocities of 0.3-0.9 m set^{-1} in northern California, but cutthroat trout have been observed to spawn in small streams in Oregon with flows as low as 0.01-0.03 m^3 set^{-1} (Pauley et al. 1989).

Distribution: Coastal cutthroat are found in coastal streams from the Eel River, Humboldt County, to Seward in southeastern Alaska (Scott and Crossman 1973). In California, they occur in streams from the

Oregon border south to tributaries of Salt Slough at the mouth of the Eel River (Gerstung 1981). In 1989, coastal cutthroat in California were considered to be present in 176 streams (many of them small tributaries to larger streams) that included 1,100 km (700 miles) of accessible habitat (compared with >9,650 km in Oregon; Gerstung 1993), as well as four coastal lagoons (E. Gerstung, unpubl. data). Total occupied habitat covered 3,700 acres (Gerstung 1993). Thirty percent of these populations are in the Smith River drainage, 6% in the Rogue River drainage, 13% in the Klamath River drainage, 8% in the Redwood Creek drainage, 8% in the Mad River drainage, 10% in the Humboldt Bay drainage, 6% in the Eel River (Salt Slough) drainage, 14% in other small coastal drainages, and 5% in coastal lagoon drainages (E. Gerstung, unpubl. data). A detailed account of their distribution in streams and lagoons in northern California drainages is given by Gerstung (1993). There are more coastal cutthroat trout populations in the more northern drainages because the cutthroat are able to use streams further inland. They occur throughout the Smith River drainage and in the California headwaters of the Illinois and Applegate rivers (tributaries to the Rogue River) (Gerstung 1993). In the Smith River drainage, populations can be found 70-90 km inland, while in the Klamath River drainage they occur 30 km inland In the Klamath drainage, cutthroat trout have been observed upstream up to Horse Linto Creek, a tributary of the Trinity River. They occur as far upstream as Fortuna in the Eel River, and in the Mad River system they are limited to the lower river drainage (Gerstung 1993). Some of the inland populations are no longer anadromous, such as those in Eliot Creek in the Rogue drainage and in Little Jones Creek in the Klamath drainage. Landlocked coastal cutthroats from Eliot Creek were transplanted by M. Coots (pers. comm.) in 1958 to Twin Valley Creek, a headwater of Indian Creek in the Klamath Drainage. This population, although started with just six fish, is apparently still extant (M. Coots, pers. comm.).

Abundance: Total estimates of historical and current spawning escapement and harvest rates of coastal cutthroat trout in California do not exist (Gerstung 1993). In the Smith River drainage, the best known angling stream for coastal cutthroat trout in California and where the largest California populations occur (Gerstung 1981), cutthroat trout constitute a minor portion of the salmonid population in tributaries that are accessible to anadromous salmonids. Diving surveys (in 1980, 1982, 1988, 1990 and 1991) in the South and Middle forks produced counts of 10-65 cutthroat trout (>12 in long) per mile, and creel censuses indicated harvests of 10-24 cutthroat per mile. In smaller Smith River tributaries, densities of juvenile cutthroat trout range from <50 per mile where juvenile steelhead are present to 800 per mile where other anadromous fishes are absent (Gerstung 1993). Angling for cutthroat trout in the Smith River estuary, once considered good (prior to 1964), now is considered only “fair” (Gerstung 1993).

“Speckled trout”, presumed to be coastal cutthroat trout, were reported in early newspaper accounts to be very abundant and readily caught in most tributary streams of Humboldt Bay (CDFG, unpubl. report). Although sea-run populations have been severely depressed, there still appear to be resident populations in 16 bay tributaries spanning about 177 km of habitat. In the Mad River system, high population densities of apparently resident cutthroat trout have been observed in Widow White, Mill and Lindsey creeks, and “a good sport fishery” exists in the Little River (Gerstung 1993).

Big Lagoon supports a limited fishery for coastal cutthroat trout, but production is “relatively poor” (Gerstung 1993). Abundance in Stone Lagoon has increased since the late 1980s, due to plantings of hatchery-reared fish. Prior to the stocking program and restrictive angling regulations, catch rates during 1980-1986 were 0.04 fish per hour (creel census data), which increased following plantings in 1990 and 1991 to 1.1 fish per hour (Gerstung 1993). Over 2,200 spawning fish were observed in the tributaries in 1992, compared to a few dozen fish observed spawning before the stocking program (E. Gerstung, pers. comm.).

The exact status of coastal cutthroat populationsis hard to determine, because juveniles (<50 mm SL) are very difficult to distinguish from the more abundant rainbow trout (steelhead) in the field. Migrating adult cutthroat also are probably sometimes mistaken for steelhead at some localities (Giger

1972). Nevertheless, there is little doubt that cutthroat populations have declined in recent years, because they depend on small streams which have been damaged by logging and other human activities.

In Oregon, coastal cutthroat trout have declined due to habitat loss and degradation, and their populations are classified as "sensitive-critical" (Weeks 1992). An analysis by The Wilderness Society (1993) indicates that coastal cutthroat could qualify as a threatened species throughout Washington, Oregon, and California.

Nature and Degree of Threat: The greatest threat to coastal cutthroat trout populations in California is habitat alteration and destruction, particularly for the developing embryos and fry in small streams. The most significant cause of habitat loss is logging and its negative effects on stream environments, including increased temperatures, loss of cover, reduction in food supply and increases in turbidity and siltation (Pauley et al. 1989, CDFG, unpubl. report). For example, severe damage has been caused by tractor logging on steep and unstable slopes in the Klamath River drainage, where habitat recovery could take many decades in some places (CDFG, unpubl. report). Within the Smith River drainage, numerous streams have been degraded. Gerstung (1981, unpubl.) reported that out of 321 miles (516 km) of river and streams surveyed in that drainage, 15% were severely degraded, 29% moderately degraded, 35% slightly degraded, and 21% were relatively pristine; however, some habitat recovery may have occurred since the survey (Gerstung 1993).

Cutthroat trout also spend a relatively substantial part of their lives in the estuaries of coastal streams, and threats to estuarine areas by dredging and filling can significantly impact the populations. Northern California estuaries have been severely altered by human activities (Gerstung 1993).

Management: There has been little direct management of coastal cutthroat trout populations in California. Most management efforts have been directed toward other anadromous salmonids, but programs focusing on habitat improvement or preservation have indirectly benefited coastal cutthroat trout (Gerstung 1993). Plantings of fingerling and yearling hatchery-produced cutthroat trout into streams have not been successful, due to poor survival, while plantings of catchable-sized fish in streams have failed to produce sea-run returns (Gerstung 1993). Hatchery fish have also have been planted into coastal lagoons and estuaries in northern California, but the fishery benefits of these efforts generally have not been assessed. However, a stocking program for yearling coastal cutthroat trout into Stone Lagoon currently is being evaluated (Gerstung 1993). Produced from wild broodstock from streams near Arcata, 14,000 hatchery-reared yearlings were planted in 1990 and another 29,000 in 1991 (Gerstung 1993). These plantings have supported a new and highly popular fishery for coastal cutthroat trout (E. Gerstung, pers. comm.).

Periodic surveys of coastal cutthroat populations need to be performed and the results compared to those of Dewitt (1954) and Gerstung (1981, 1993, and unpubl.). Special attention should be paid to the location and status of non-anadromous populations. Once populations have been located, a status survey of key populations should be conducted every two to five years. Streams that are important for cutthroat spawning should be given special management designation by state and federal agencies in order to enhance production of cutthroat. Because the Smith River drainage appears to have the largest population of coastal cutthroat in California, special attention should be given to enhancing cutthroat populations in this system. Restoration of known coastal cutthroat streams that have been degraded should be a high priority. Non-anadromous populations of cutthroat such as in Little Jones Creek, a tributary to the Smith River, require special management to preserve their genetic integrity and to ensure their long-term survival. Efforts to enhance coastal cutthroat populations by artificial propagation should be designed to ensure that the genetic integrity of wild stocks is not disrupted.

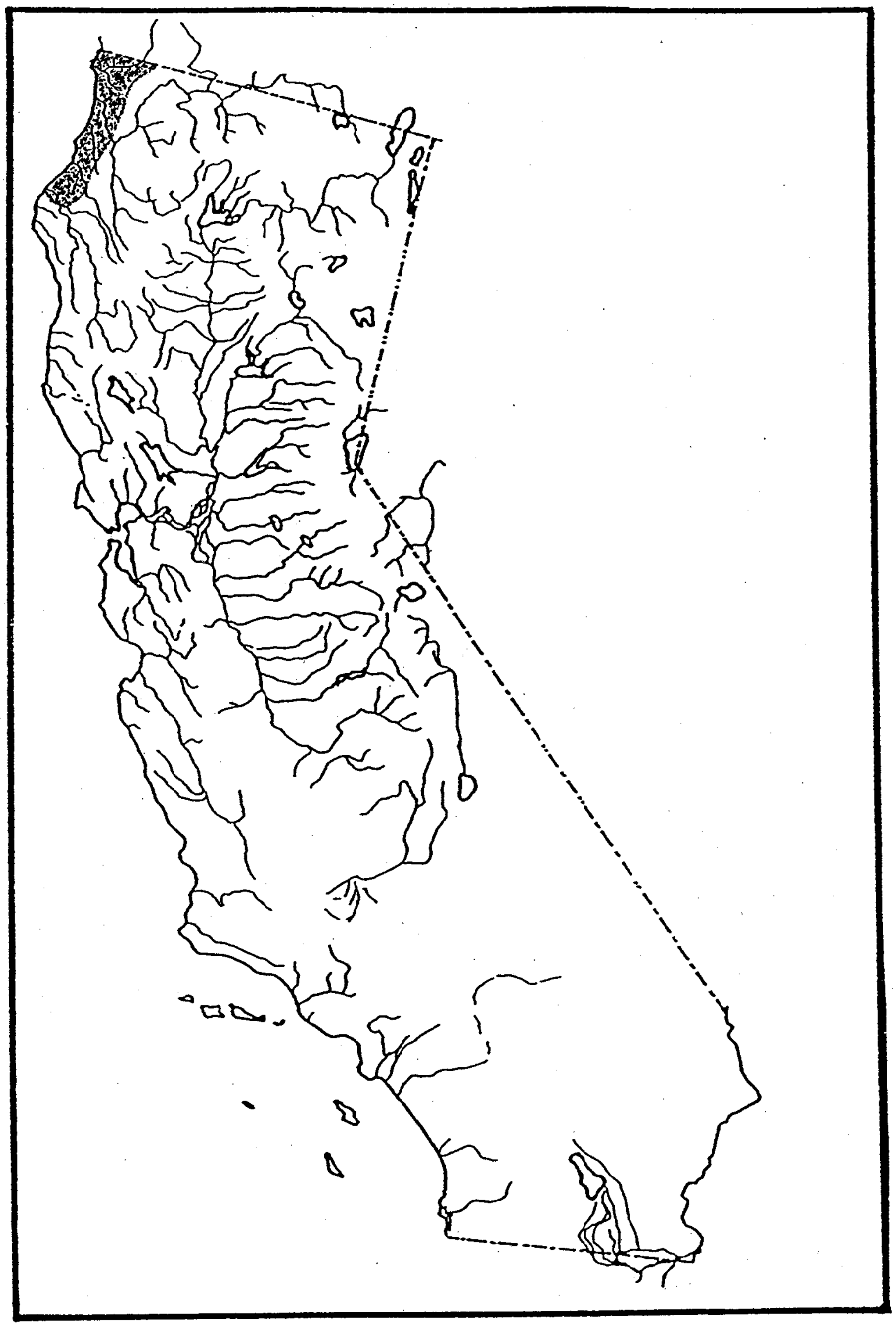


FIGURE 19. Distribution of coastal cutthroat trout, *Oncorhynchus clarki clarki*, in California.

LONGFIN SMELT
Spirinchus thaleichthys (Ayres)

Status: Class 1. Endangered in California.

Description: Longfin smelt can be distinguished from other California smelts by their long pectoral fins (which reach or nearly reach the base of the pelvic tins), incomplete lateral line; weak or absent striations on the opercular bones, low number of scales in the lateral series (54-65), and long maxillary bones (which in adults extend just short of the posterior margin of the eye). The lower jaw projects forward of the upper jaw when the mouth is closed. Small, fine teeth are present on both jaws, tongue, vomer and palatines. The number of dorsal rays is 8-10; anal rays, 15-22; pectoral rays, 10-12; gill rakers, 38-47; and pyloric caeca, 4-6. The orbit width goes into the head length 3.6-4.5 times, and the longest anal rays 1.4-2.2 times into the head length (McAllister 1963, Miller and Lea 1972, Morrow 1980). The lining of the gut cavity is silvery with a few scattered speckles. The sides of living fish appear translucent silver while the back has an olive to iridescent pinkish hue. Mature males are usually darker than females, with enlarged and stiffened dorsal and anal fins, a dilated lateral line region, and breeding tubercles on the paired fins and scales (McAllister 1963).

Taxonomic Relationships: The longfin smelt belongs to the true smelt family Osmeridae. Its closest relative in California is the night smelt, *Spirinchus starksi.* A third *Spirinchus* species, *S. lanceolatus,* occurs in northern Japanese waters and differs from *S. thaleichthys* in several morphological characters and in timing of spawning (McAllister 1963). The longfin smelt was at one time considered to be two species: the Sacramento smelt *(S. thaleichthys)* in the Sacramento-San Joaquin estuary, and the longfin smelt *(S. dilatus)* for the rest of the populations. McAllister (1963) merged the two species because he thought the meristic characters separating the Sacramento smelt from the other populations represented the southern end of a north-south cline in the characters, rather than a discrete set. This analysis was confirmed by the electrophoretic study of Stanley et al. (1995), which showed only minor differences in allele frequencies between smelt populations in Lake Washington (Washington) and those in San Francisco Bay. The differences were sufficient, however, to demonstrate no recent gene flow between the two populations. The longfin smelt population in the Sacramento-San Joaquin estuary is very isolated from other populations, the closest occurring in the Eel River estuary ca. 300 km away by sea. Also this population is the southernmost of the species. Both factors clearly qualify, it for consideration for listing as a "species" under the federal Endangered Species Act. It is similar in this respect to a recognized run of chinook salmon (e.g., winter-run chinook) and fits the definition of an Evolutionarily Significant Unit established by the National Marine Fisheries Service (Waples 1991).[12/]

[12/] [A stock of fish] "will be considered 'distinct' (and hence a 'species') for the purposes of the ESA if it represents an evolutionarily significant unit (ESU) of the biological species. A population must satisfy two criteria to be considered an ESU:

1) It must be substantially reproductively isolated from other conspecific population units, and
2) It must represent an important component in the evolutionary legacy of the species.

[The first criterion, reproductive isolation] does not have to be absolute, but it must be strong enough to permit evolutionarily important differences to accrue in different population units... The second criterion would be met if the population contributed substantially to the ecological/genetic diversity of the species as a whole."

Life History: Longfin smelt generally are euryhaline and anadromous. In the Sacramento-San Joaquin estuary adults and juveniles can be found in water ranging from nearly pure sea water to completely fresh water. The preference of larval smelt for the upper part of the water column is an adaptation that allows them to be swept quickly into food-rich nursery areas downstream, mainly Suisun and San Pablo bays. During years when periods of high outflows coincide with the presence of the larval smelt (e.g., 1980, 1982, 1983, 1984, 1986), the larvae are mostly transported to Suisun and San Pablo bays while in years of lower outflow, they are transported to the western Delta and Suisun Bay (R. Baxter, unpub. data). The distribution of young-of-year smelt largely coincides with that of the larvae. In the winter months, yearling smelt become more widely distributed downstream, with some even colonizing South Bay, although they remain most abundant in San Pablo and Suisun bays.

In late summer (August, September), the distribution of yearling smelt gradually shifts upstream, a change which coincides with development of the gonads in preparation for spawning. They congregate for spawning at the upper end of Suisun Bay and in the lower and middle Delta, especially in the Sacramento River channel and adjacent sloughs. Larval longfin smelt are generally collected below Medford Island in the San Joaquin River and below Rio Vista on the Sacramento River (Wang 1991), indicating that spawning rarely occurs above these locations. The lower end of the spawning habitat seems to be upper Suisun Bay around Pittsburg and Montezuma Slough, in Suisun Marsh (Wang 1986).

The Sacramento longfin smelt has a rather protracted spawning period. Adult movements indicate that some spawning may take place as early as November (R. Baxter, unpubl. data) while larval surveys indicate spawning may occur into June (Wang 1986, 1991). Most spawning takes place from February through April, because larval smelt are most abundant in this period and large smelt become rare after this time. Wang (1986) indicates that older and larger smelt spawn later in the season than smaller ones. Males evidently precede the females in the spawning run upriver (Wydoski and Whitney 1979), and spawning occurs at night. The eggs are adhesive (Dryfoos 1965) and are deposited either on rocks or on aquatic plants in the freshwater sections of the Delta. Each female lays 5,000-24,000 eggs (Dryfoos 1965, Moyle 1976.). However, the mean number for ten females from Lake Washington was 18,104 (Dryfoos 1965), which is higher than recorded for California populations (mean=9752, Moyle, unpublished data). The eggs hatch in 40 days at 7°C (Dryfoos 1965). Apparently, most longfin smelt die after spawning. A few smelt, mostly females, live another year, although it is not certain whether or not they have spawned previously.

Newly hatched larvae are 5-8 mm long (Wang 1991). They can spend considerable time in fresh water; young fish up to 7.2 cm long have been caught in the Fraser River, British Columbia (Morrow 1980). Metamorphosis into the juvenile form probably begins 30-60 days after hatching, depending on temperature (Emmett et al. 1991). Growth in California populations is similar to that of more intensively studied Washington populations (Dryfoos 1965). Most growth in length takes place in the first nine to ten months of life, when they typically reach 6-7 cm SL. Growth rate levels off during the first winter, but there is another period of growth during the second summer and fall, when the smelt reach 9-11 cm SL. Weight gains may be considerable during this latter period as the gonads develop. The largest smelt are 12-14 cm SL, presumably females in their third year of life.

The main food of longfin smelt is the opossum shrimp, *Neomysis mercedis,* although copepods and other crustaceans are important at times, especially to small fish (Moyle 1976). This is similar to their feeding habits in Lake Washington, Washington (Dryfoos 1965). Longfin smelt, in turn, are eaten by a variety of predatory fishes, birds and marine mammals. They are a major prey of harbor seals, *Phoca vitulina,* in the Columbia River (Emmett et al. 1991).

In the landlocked Lake Washington population in Washington, adult longfin smelt show daily vertical migrations, moving into deep water during. the day and in the upper water column at night (Wydoski and Whitney 1979, Emmett et al. 1991). This may explain why juvenile and adult longfin smelt are usually captured in trawls in the lower half of the water column in the Sacramento-San Joaquin estuary (R. Baxter, unpubl. data), where most sampling takes place during the day.

Longfin smelt are caught and marketed incidentally with other smelt species (Wang 1986). They are of only minor commercial importance, evidently because the supply is sporadic and the amounts caught are relatively small. However, it is likely that they were an important component of the smelt fishery that existed in the estuary in the late 19th century.

Habitat Requirements: Adult and juvenile longfin smelt occupy mostly the middle or bottom of the water column in the salt or brackish water portions of the estuary, although larval smelt are concentrated in near-surface brackish waters (R. Baxter, pers. comm.). Spawning takes place in fresh water, over sandy-gravel substrates, rocks, and aquatic plants (Wang 1986; Emmett et al. 1991). Spawning in the Sacramento-San Joaquin estuary occurs at water temperatures of 7.0-14.5°C (Wang 1986), although spawning occurs at lower temperatures in other areas, such as Lake Washington (Emmett et al. 1991). There is a strong positive correlation between winter and spring Delta outflow and longfin smelt abundance the following year. There is also a strong correlation between juvenile survival in the Sacramento-San Joaquin estuary and Delta outflow (Stevens and Miller 1983). The reason for this seems to be that the flows increase the rate of transport into the rearing habitat in Suisun and San Pablo bays and reduce the probability of the larvae being retained in the Delta, where they are exposed to greater likelihood of entrainment, exposure to pesticides, and other factors. However, the positive relationship between smelt abundance and outflow may have broken down in recent years, or dropped to a lower level (as occurred for striped bass). The fall midwater trawl abundance index predicted by the regression equation has consistently been higher than the actual index for 1989-1992; the index for 1992 occured outside the 95% confidence interval (L. Meng, pers. comm.).

High freshwater outflows also increase the volume of brackish water (2-18 ppt salinity) rearing habitat required by larval and juvenile smelt (R. Baxter, unpubl. data). Because the life history of longfin smelt is similar in many respects to that of striped bass *(Morone saxatilis),* it is likely that longfin smelt larvae, like striped bass larvae, have higher survival rates in brackish water (Hall 1991). Adults occur in the open waters of the estuary at salinities ranging from fresh water to full sea water. In most years, adults are found primarily in Suisun, San Pablo, and San Francisco bays. However, they are most abundant in San Pablo and Suisun bays, although in low outflow years they concentrated in Suisun Bay and the Delta. Average summertime salinities in Suisun Bay normally were < 8 ppt even in dry years prior to the smelt decline. In San Pablo Bay salinities are typically < 25 ppt.

Distribution: Historically, populations of longfin smelt in California have been present in the Sacramento-San Joaquin estuary, Humboldt Bay, the Eel River estuary, and the Klamath River estuary (Monaco et al. 1990). Spawning longfin smelt have been recorded from the Van Duzen River in the Eel River drainage, and a sample from there is in the fish collection at Humboldt State University. A 1994 study of the Eel River estuary found that longfin smelt were still present there (S. Cannata, pers. comm.). There are also recent records from the mouth of the Klamath River, so presumably a small population still exists there. In the Sacramento-San Joaquin estuary, longfin smelt are rarely found upstream of Rio Vista or Medford Island in the Delta. Adults occur seasonally as far downstream as South Bay but they are concentrated in Suisun, San Pablo, and North San Francisco bays. They are rarely collected outside the estuary. The southernmost record of the species range is a single fish from Monterey Bay (Eschmeyer et al. 1983, Wang 1986), but probably only individuals flushed out of the Sacramento-San Joaquin estuary occur that far south (W. Eschmeyer, pers. comm.).

Outside of California, longfin smelt are found from Coos Bay, Oregon, to Prince William Sound, Alaska. Emmett et al. (1991) inferred longfin smelt to be common in Skagit Bay, Grays Harbor and Willapa Bay in Washington, highly abundant in the Columbia River, and common in Yaquina and Coos bays, Oregon. However, most of the Oregon and Washington inferences were not based on actual sampling and so the smelt may be absent from some locations. For example, longfin smelt have rarely been collected from Coos Bay, Oregon, despite 20 years of intensive sampling (D. Varoujean, pers.comm.). Landlocked populations occur in Lake Washington, Washington, and Harrison Lake, British Columbia.

Abundance: Longfin smelt populations have declined dramatically in the Sacramento-San Joaquin estuary and have apparently disappeared from Humboldt Bay (USFWS 1994). In the Sacramento-San Joaquin estuary, longfin smelt were once one of the most abundant fish. For example, the CDFG fall midwater trawl survey of the upper estuary, the CDFG otter and midwater trawl Bay surveys, and the UCD Suisun Marsh surveys consistently caught longfin smelt in large numbers until the early 1980s (Herbold et al. 1992). The numbers of longfin smelt fluctuated widely, reaching their lowest levels during drought years but quickly recovering when adequate winter and spring flows were once again present. Since 1983, longfin smelt numbers have plummeted and have remained at record low numbers (Herbold et al. 1992). For example, in 1982, the fall midwater abundance index was 62,929, the second highest on record, while in 1992 it was 73, the lowest on record. In 1993, the index increased to 792 in response to increased outflows and then dropped to 523 in 1994 (CDFG, unpubl. data). Both of these latter numbers were below numbers that would have been predicted based on the outflow-abundance relationship estalbished in previous years (R. Baxter, pers. comm.). This decline in longfin smelt abundance parallels that of other fishes in the estuary, such as delta smelt, but it has been; if anything, even more precipitous. Longfin smelt have declined in rank abundance from first or second in most trawl surveys during the 1960s and 1970s to seventh or eighth at present (B. Herbold, pers. comm.).

In Humboldt Bay, Barnhart et al. (1992) noted that in the early 1970s longfin smelt were the third most abundant species in larval fish surveys and fourth most abundant fish in trawl surveys. On the basis of these studies they listed the smelt as "abundant" in the bay and important as forage fishes. Monaco et al. (1990) listed longfin smelt as common in Humboldt Bay and in the Klamath River and Eel River estuaries. However, no longfin smelt have been collected from Humboldt Bay in recent years despite extensive sampling of the estuary (R. Fritzsche, pers. comm.). However, in 1994 and 1995 small numbers of smelt were collected from the Eel River estuary (S. Cannata, pers. comm.). Longfin smelt are still present in the Klamath River estuary, but confirmed records are few; two apparently spent males were collected in November 1992 (R. Baxter, pers. comm.).

Because of the severe decline in abundance of longfin smelt in California, The Natural Heritage Institute petitioned the USFWS in 1992 to list the smelt as an endangered species. The petition was denied in 1993, largely on the basis of taxonomy and the fact the smelt is not in trouble throughout its range.

Nature and Degree of Threat: The longfin smelt clearly has undergone a severe decline in the Sacramento-San Joaquin estuary, while the Humboldt Bay smelt population has either gone extinct or become very rare. The only other populations in the state, in the Eel and Klamath estuaries, are small and of uncertain status. The causes of the decline of the smelt in the northern estuaries are not known but they are probably similar to the causes, of the decline of the smelt in the Sacramento-San Joaquin estuary, which are multiple and synergystic. They include the following, in approximate order of importance:

1. <u>Reduction in outlfows</u>

Reduction in outflow through water exports is probably the single biggest factor affecting longfin smelt abundance in the Sacramento-San Joaquin estuary. To demonstrate the effects of the SWP and CVP on the smelt, a regression equation has been calculated relating smelt numbers to Delta outflow ($p< .01$, B. Herbold, pers. comm.). This equation predicts that mean spring (March-May) outflows much less than

3400 cfs will result in reproductive failure of the smelt. Such flows for two or three years in a row would probably result in extinction of the longfin smelt in the estuary. Between 1987 and 1993, outflows were perilously close to that number, pushed there by the increase in diversions. This has resulted in abnormally low numbers of longfin smelt being produced. The strong correlation between average monthly outflow and the CDFG longlin abundance index, and the mechanisms explaining that close relationship, are further documented in CDFG testimony presented during 1992 to the State Water Resources Control Board in the Interim Water Rights Proceedings for the Bay-Delta Estuary (Exhibit WRINT-DFG-6, "Estuary Dependent Species", at pp. 50-61).

Since 1989, however, the abundance of smelt has been consistently lower than would be predicted by the past relationship between smelt abundance and outflow. This highlights the increasing impact of water exports on this species. Analysis of the decline over the last ten years shows that the increasing quantity of water exported during a time when the quantity of water in the state was low has resulted in a continuous decline in longfin smelt capture rates. In earlier, wetter years the quantity of exports was a small fraction of the total Delta inflow and outflow. In most recent years the amount of water exported has exceeded the amount flowing into the Bay and capture rates of longfin smelt have declined largely due to the impacts of exports on total Delta outflow. This amplification of normal drought effects has been compounded by the ability of upstream reservoirs to retain more of the winter-spring runoff because the reservoirs have been below flood control limits. The later release of this water for export may have exacerbated the normal drought year decline of this species even beyond the impacts of the annual totals, contributing to the breakdown of the outflow-abundance relationship.

2. Entrainment losses to water diversions.

One of the effects of decreased outflows in the estuary is increased vulnerability of longfin smelt of all sizes to entrainment in the pumping plants of CVP and SWP, in agricultural diversions within the Delta, and in power plants.

The effects of direct entrainment of longfin smelt in the two pumping plants is not well understood because of the limited information on what proportion of the population at each life stage is entrained and the survival rates of the fish that are salvaged and returned to the Delta. Although large numbers of adult longfin smelt are captured at the pumping plants, it is unlikely many individuals of this species survive the experience (actual survival rates have not been documented). If they do, they are probably consumed by piscine and avian predators attracted to the predictable commotion of trucks releasing fish, In any case, the fact that rates of capture at the pumping plants have increased when populations have been decreasing make it likely that direct entrainment in the pumping plants has been a significant source of mortality.

Entrainment of larvae in agricultural diversions within the estuary is largely unquantified. Presumably, entrainment in Delta agricultural diversion was a fairly constant source of mortality for 50-100 years, until flows across the Delta increased as the result of the changed hydraulics of the Delta caused by increased pumping by the SWP and CVP. These pumps not only remove more water than formerly but they pump water earlier in the year, when longfin smelt are spawning and larval fish are present. The changed hydraulics increase the exposure of larval, juvenile, and adult smelt to in-Delta entrainment, predation, and other factors. In their 1992 testimony to the State Water Resources Control Board, the USBR stated "...the negative impact of Delta diversions on the fisheries and food chain is largely a consequence of the flow patterns (hydrodynamics) resulting from Delta inflow and CVP/SWP exports. Consequently, any proposed solution must address this important issue if it is to be effective in the long term (WRINT-USBR-Exhibit 10, p. 8)."

The importance of entrainment of longfin smelt, especially larval smelt, in the cooling water of power plants is not well known. The potential for entraining significant numbers of larvae is considerable, however, especially now that smelt populations are low.

3. Climatic variation

The climatic conditions the estuary has experienced since 1982 have been among the most extreme occurring since the arrival of Europeans. The years 1985-1992 were ones of continuous drought, broken only by the record outflows of February 1986. The 1986 flood occurred during the peak spawning season of longfin smelt and quite likely washed a high percentage of the spawning fish and/or their offspring far downstream, perhaps beyond the Golden Gate. This event was particularly unfortunate because the smelt were already showing signs of precipitous decline and the washout may have exacerbated the problem. The prolonged drought had two major interacting effects: a natural decrease in outflow and an increase in the proportion of inflowing water being diverted. A natural decline in smelt numbers would be expected from the reduced outflow, because of the reduced availability of brackish water habitat for larvae and juveniles. However, the increase in diversions most likely exacerbated the decline in smelt survival through a combination of further reduction in brackish water habitat and increased entrainment of larvae, juveniles and adults. It is important to recognize that extreme floods and droughts have occurred in the past and smelt have managed to persist. However, unlike today, the smelt historically did not experience the extreme conditions caused by increased diversion of water.

4. Toxic substances

Pollution is an insidious problem in the estuary because toxic compounds, especially pesticides, can come from many sources, may be episodic in nature (and therefore hard to detect), and may affect mainly early life history stages of fish, where mortality is hard to observe. For longfin smelt, there is no evidence that toxic compounds have affected their populations over the long term. This is not surprising because smelt spawn early in the season when few agricultural chemicals are being applied and flows for dilution may be high. However, many agricultural and domestic pesticides are applied during the winter (mainly dormant sprays). Elevated concentrations of these pesticides have been detected in the estuary following rainfall events. For example, in February 1993, a pulse of diazinon (a water soluble dormant spray) was followed down the Sacramento River and through Suisun and San Pablo bays (Kuikila 1993). It is possible that episodic high concentrations of chemicals may have negative effects on smelt if the episodes coincide with major spawning times. The short life span and plankton feeding habits (short food chain) of longfin smelt reduce the probability of accumulation of toxic materials in tissues.

5. Predation

Predation is a poorly understood but potentially important factor affecting longfin smelt abundance. The principal piscivore in the estuary is the striped bass. This species was introduced over 100 years ago, replacing native piscivores such as Sacramento perch and various salmonids. The longfin smelt remained abundant despite the explosion of striped bass numbers and in recent years the smelt decline has coincided with the decline of striped bass. Therefore, it is unlikely that striped bass predation per se is responsible for the decline of the longfin smelt. It is possible that concentrated striped bass predation in Clifton Court Forebay may be having some effect on longfin smelt populations. Smelt are drawn into this forebay by SWP pumps and both predators and prey are concentrated as a consequence.

6. Introduced species

Invasions by exotic species are a perpetual problem in the Sacramento-San Joaquin estuary, especially those that are introduced into the system from the ballast water of ships. The most recent problem introductions have been several species of planktonic copepods and an Asiatic clam, *Potamocorbula amurensis.* The copepods are regarded as a problem because they seem to be replacing *Eurytemora affinis,* a native copepod that has been the favored food of larval fish. Although one of the introduced copepod species *(Sinocalanus doerri)* seems to be more difficult for larval fish to capture, it occurs mostly upstream of the concentrations of longfin smelt larvae. It may only be a problem if diversions keep the smelt larvae in upstream, freshwater conditions. Other introduced copepod species probably do not present the capture problems of *S. doerri* (e.g., Meng and Orsi 1991). The Asiatic clam, in contrast, may have a direct effect on smelt populations because it has become extremely abundant in San Pablo and Suisun bays, from which it appears to be filtering out most of the planktonic algae, the base of the food web on which smelt depend (Nichols et al. 1990, Alpine and Cloem 1992).

The clam is not, however, a direct cause of the initial decline of longfin smelt because it did not invade until after February 1986, when the estuary's biota had been devastated by immense outflows (Nichols et al. 1990). Its present abundance may make the recovery of longfin smelt more difficult but it is quite likely that the Asiatic clam will become less abundant in response to (1) increased freshwater outflows, and (2) discovery of it as a food source by fishes such as sturgeon, by invertebrates such as the invading mitten crab, and by diving ducks. A typical pattern for invading species is to increase explosively in response to optimal conditions at the time of invasion (due to the absence of their predators, parasites, etc.) and then to decline as the local ecosystem adjusts to its presence.

Management: The longfin smelt is currently an unmanaged species. In the Sacramento-San Joaquin estuary, the longfin smelt will persist only if adequate standards for Delta outflows and/or salinity are set that provide adequate habitat for all stages of its life history. The geographic extent of this critical habitat includes all of the Delta (up to Sacramento on the Sacramento River, up to Mossdale on the San Joaquin River), Suisun Bay, Suisun Marsh, San Pablo Bay, and San Francisco Bay. More important than geographic area, however, is the need to have appropriate ecological conditions in the estuary available to smelt. In particular, adequate flows through the Delta are needed while the smelt are spawning in February through April. Thus, critical habitat should include components such as the following:

1. Net positive flows down the Sacramento and San Joaquin rivers when adult smelt are moving up for spawning (November-February).

2. Net positive flows down the two rivers when larval Smelt are present (mainly February-April).

3 . Late-spring (April-June) outflows of 12,000-14,000 cfs to keep juvenile and larval smelt out of the Delta, to prevent entrainment and exposure to toxic materials, and to maintain salinities below 2 ppt at Roe Island.

4. Salinities in San Pablo Bay at less than 25 ppt through September in most years.

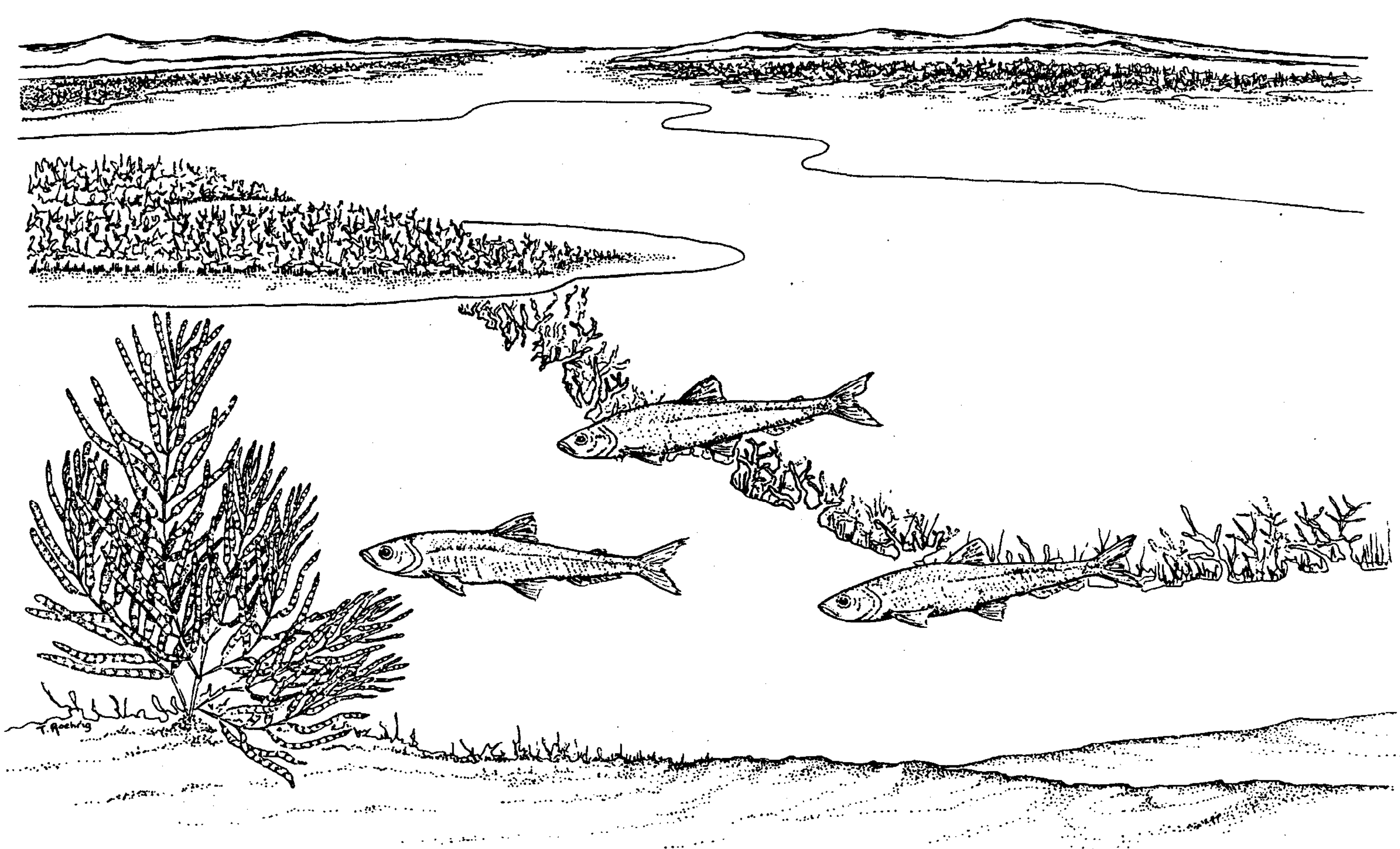
These standards would help to provide general protection for the estuarine ecosystem of which the longfin smelt is part and they are consistent with the recommendations of agencies concerned with estuarine protection. For example, in testimony before the California State Water Resources Control Board in 1992, the National Marine Fisheries Service recommended similar measures to protect an array of jeopardized species, including the longfin smelt:

> "To implement . . . interim, protective standards, the Board should rely on habitat protection measures that will reduce reverse flows, increase Delta outflow, reduce fish entrainment in diversions, and provide adequate reservoir carryover storage. In other words, the Board should focus primarily on changes to system management, such as changes to Delta export restrictions, Delta outflow requirements, cross-channel closures, reverse-flow limits, and carryover storage requirements. In addition, all diversions and export facilities should be managed to provide the best possible fish protections and minimal effects on natural migration pathways. These actions

could provide immediate benefits to the ecosystem." (Testimony of Roger S. C. Wolcott, for NMFS, July 9, 1992).

The Delta Native Fishes Recovery Team, appointed by the USFWS, has developed recovery criteria and recommendations for longfin smelt, along with those for other native fishes in the estuary. Basically, the Team noted that longfin smelt can be regarded as recovered when their population dynamics and distribution pattern within the estuary are similar to those that existed in the 1967-1984 period. During this period, numbers were generally high, based on the CDFG fall midwater trawl surveys. It is quite possible that this goal will be achieved if the Bay-Delta Agreement of December 15, 1994, is adhered to by the agencies that signed it.

For Humboldt Bay, studies need to be conducted to determine if a longfin smelt population still exists there. If one is present, the conditions required for survival of the species need to be determined. The nature and extent of the smelt populations in the Eel and Klamath estuaries should be determined, as well as factors that limit smelt abundance in these estuaries.



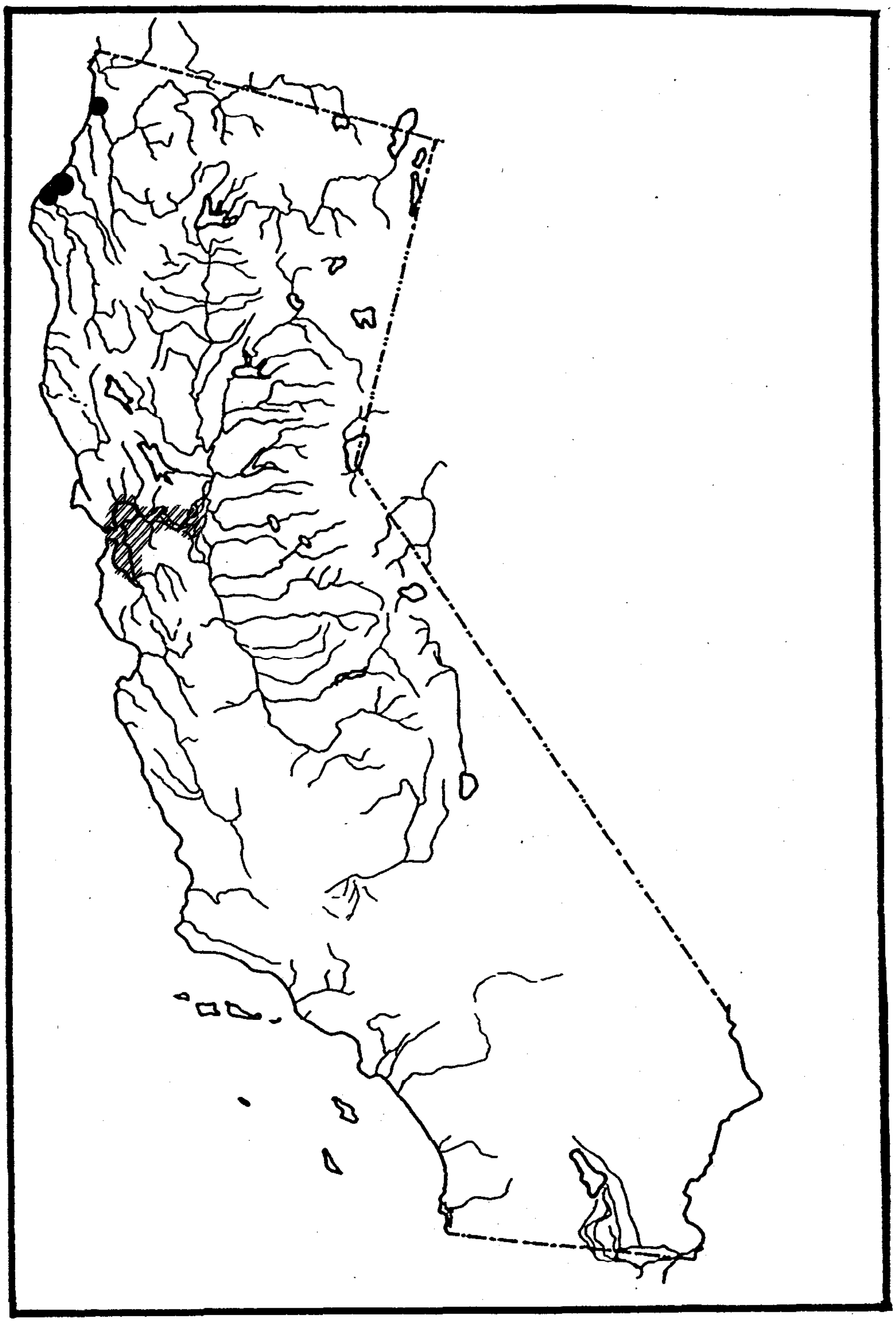


FIGURE 20. Distribution of longfin smelt, *Spirinchus thaleichthys*, in California.

EULACHON
Thaleichtys pacificus (Richardson)

Status: Class 3. Watch List.

Description: Eulachon, also called candlefish or hooligan, are the largest of the Pacific North American smelts. They can reach 30 cm TL, but fish over 20 cm TL are uncommon. Eulachon have compressed, elongate bodies and large, oblique mouths; the maxilla usually reaches just past the middle of the eye but can extend beyond the posterior margin of the eye in adults. The gill covers possess strong concentric striations and the pectoral fins, when pressed against the body, reach about two-thirds of the way to the bases of the pelvic fins. Body depth is 15-20% of standard length (SL); head length is 20-26% of SL. The lateral line is complete, with 70-78 scales. There are 8-12 pyloric caeca, 10-13 dorsal rays, 8 pelvic rays, 10-12 pectoral rays, 18-23 anal rays, 17-23 slender gill rakers on the first arch, and 7-8 branchiostegal rays. The jaws have small, pointed teeth which may be missing from spawning fish, especially males. There are small teeth also present on the tongue and palatines, and a pair of moderately large canines on the vomer. The lining of the gut cavity (peritoneum) is pale with dark speckles. In life, eulachon are brown to dark blue on the back and head with a silvery white belly and unmarked tins. Spawning males develop a distinct midlateral ridge and numerous distinct tubercles on the head, body and fins. Females may also have tubercles but they are poorly developed. The flesh is very oily.

Taxonomic Relationships: The eulachon is the only species in the genus *Thaleichthys* and is one of the true smelts (Osmeridae). Although there are signficant differences in meristic characters (e.g., number of vertebrae) between fishes from different rivers (Hart and McHugh 1944), there have been no genetic studies documenting the discreteness of the disparate stocks. The seemingly wide dispersal of the larvae might argue against significant genetic separation of stocks, but this may be countered by high fidelity of individuals to their natal streams, as is true of salmon and steelhead (but not demonstrated for eulachon).

Habitat Requirements: Eulachon are anadromous, with spawning usually occuring in the lower reaches of rivers or tributaries. However, some spawning areas in the Columbia River are located upriver of Vancouver, Washington, more than 160 km from the sea. Spawning runs commence when river temperatures are above 4°C, but the runs slow or stop if the temperature drops below 4°C or exceeds 8°C (Morrow 1980, Emmett et al. 1991). Spawning occurs in freshwater at moderate water velocities and 4-10°C water temperatures; spawning substrate is pea-sized gravel or semi-sandy areas with woody and other debris (Emmett et al. 1991). Hatching occurs in 19 days at 8.5-11.5°C, and in 30-40 days at 4.4-7.2°C (Emmett et al. 1991).

Life History: Eulachon spend most of their life in salt water, moving up rivers to spawn in large numbers in the spring. The spawning migration occurs sometime between December and May, depending on locality (Wydoski and Whitney 1979, Emmett et al. 1991), usually peaking in February-March. It typically begins in mid-March in the southern part of the species range and extends into May at the northern end (Morrow 1980). In the Klamath River, most eulachon migration takes place in March and April and the fish seldom penetrate more than 10 to 12 km upstream. Males arrive at the spawning grounds first and remain there longer than the females; hence, more males are taken by the sport and commercial fisheries. Spawning takes place en masse at night. Fertilization is external and females produce an average of 25,000 eggs. Range in fecundity has been variously reported as 17,300-60,000

(Wydoski and Whitney 1979) and 7,000-31,000 (Emmett et al. 1991), but depends on female size. Each egg is surrounded by two membranes. The outer membrane ruptures when the egg hits the bottom and its adhesive edges stick to the substrate. The outer membrane is attached by a short stalk to the inner membrane, which still surrounds the egg, so that the egg is anchored to the bottom until it hatches in two to three weeks (Carl and Clemens 1953). The feeble, transparent larvae (4-7 mm TL) stay near the bottom of the water column and are quickly washed to sea by river currents.

At sea the larvae evidently are widely distributed by ocean currents. Transformation to the juvenile stage likely occurs during the second year at 50-80 mm fork length (Barraclough 1964), and juveniles are 30-140 mm long. For the next two to three years the immature fish form part of the deep echo-scattering layers of coastal waters, where they feed on euphausiids, copepods and other crustaceans (Barraclough 1964, Emmett et al. 1991). Eulachon also occur in shallow inshore waters, where they feed heavily on euphausiids. Details of their ocean movements are unknown.

Most eulachon mature during their third year, move upstream to spawn, then die, although a fraction live to spawn once again the following year (Barraclough 1964). A few fish may live to 5 years (Emmett et al. 1991). Spawning adult length averages 17.0 cm, with range 14.0-20.0 cm. During the spawning migration, the adults evidently travel along the bottom of estuarine and river channels (Emmett et al. 1991) and also in shallows at the waters edge (T. Kisanuki, pers. comm.). There is some indication, based on meristic characteristics, that eulachon return to their natal streams (Morrow 1980, citing Hart and McHugh 1944). They do not feed while in fresh water.

Eulachon constitute an important food source for marine and anadromous sport fishes. At times they are heavily preyed upon by halibut, cod, salmon and sturgeon, as well as by a variety of marine mammals, including finback whales, porpoises, killer whales, seals and sea lions (Emmett et al. 1991).

In more northern regions, especially British Columbia, eulachon support a small but valuable commercial fishery, despite their oily flesh (Moyle 1976). Rated highly as a gourmet food fish by some (Morrow 1980), it has been described as “unsurpassed by any fish whatsoever in delicacy of the flesh, which is far superior to that of the trout” (Jordan and Evermann 1896). In California, eulachon have never been particularly important as a commercially harvested fish. In 1963, however, heavy runs in the Klamath and Mad rivers and Redwood Creek resulted in a commercial catch of 56,000 pounds (Odemar 1964). In the past, eulachon were important to the local Native Americans for food, who also had used them for fuel and oil. The oil (described as having “a very attractive flavor” by Jordan and Evermann, 1896) can be rendered down to a fatty substance that was highly valued by the Pacific Northwest tribes. Dried eulachon were burned as candles, after insertion of a wick, hence the name “candlefish”. Their only use in recent times has been as food, and eulachon evidently are less preferred by native American fishermen to salmon and lampreys (T. Kisanuki, pers. comm.) Although the range of uses is now less than before, this species clearly has been an important component of the cultural legacy of Native American fishing tribes.

Distribution: The main eulachon population in California is in the Klamath River, Del Norte County, with runs also in the Mad River and Redwood Creek, Humboldt County. The California populations are the southernmost of the species. To the north, eulachon have been found spawning in coastal streams from Oregon to Bristol Bay, Alaska. Oceanic distribution parallels the coastal distribution but eulachon have been collected westward in the Bering Sea to the Pribilof Islands (Emmett et al. 1991) and as far south as Bodega Head, Sonoma County (Odemar 1964) and Point Buchon, San Luis Obispo County (R. Lea, pers. comm.). Most eulachon runs occur in the larger rivers, such as the Fraser and Columbia, although smaller streams also may have runs. Rivers in Washington that have (or had) large spawning runs are the Columbia, Cowlitz, Grays, Kalama, Lewis, Sandy and Nooksack (Wydoski and Whitney 1979). In Oregon, eulachon apparently spawn only in the Umpqua River (Emmett et al. 1991).

Abundance: Among the 32 U. S. Pacific coast estuaries included in the survey by Emmett et al. (1991), eulachon are listed as abundant in two (Columbia and Klamath rivers) and common in three (Grays Harbor and Willapa Bay, Washington, and the Umpqua River, Oregon). The Columbia River run has remained large and for the most part stable, with 1990 commercial landings surpassing 2,780,000 pounds and recreational catches in some years equalling the commercial catch (ODFW 1991). In California, however, there are indications that eulachon abundance has decreased considerably in recent years, compared to previous decades. Records and quantitative data unfortunately are lacking, and our assessment of past and present population status must rely on the recollections of fishery biologists and fishermen.

Eulachon spawning runs in the Klamath River and other streams at one time provided the basis of a sport dipnet fishery and, until recently, a Native American subsistence fishery. Heavy runs also occurred in both the Mad River and Redwood Creek up to the mid-1970's (T. Kisanuki and J. Waldvogel, pers. comm.), and there were incidental reports of fish but no regular large runs in the Smith River (J. Waldvogel, pers. comm.). In the Mad River, spring runs of eulachon would occur in spurts, each lasting a few days, with runs occurring perhaps two weeks apart. The fish would "pour" by, and at times several (2-5) pounds of fish could be taken in a single dipnet haul (J. Waldvogel, pers. comm.). In Redwood Creek, "massive runs" of eulachon occurred during the spring in the three years 1972-1974; the fish would form a "black mass" so thick they could be caught by hand (S. Saunders, pers. comm.). Studies by Donald La Faunce (CDFG) at that time indicated that spawning occurred primarily between the ocean and mouth of tributary Prairie Creek, and up Prairie Creek about 1/2 km (pers. comm. from La Faunce to S. Saunders). Since the 1970s, eulachon have not been seen in Prairie Creek. There have been no occurrences of eulachon in Redwood Creek and the Mad River reported by fishery biologists since at least the mid-1980s (T. Kisanuki, J. Waldvogel, S. Saunders, pers. comm.).

Native American fishermen reportedly have been catching eulachon in recent years, but in much reduced numbers. As recounted by Ms. Sue Masten (Yurok Tribe, pers. comm.), the runs are down now, but in former times they could be gotten "all the time" (during the spring). Eulachon were exceptionally plentiful in the Klamath River in 1988, as were *surf* smelt *(Hypomesus pretiosus),* night smelt *(Spirinchus starksi)* and anchovy *(Engraulis mordax).* The abundance of fish in that year apparently was unmatched in recent years (S. Masten, pers. comm.). The eulachon were "everywhere" and "thick", "throughout the estuary, from the mouth to the [Klamath] Glen area". These fishes also were abundant in 1989, but less than in the previous year. Since 1988, the runs have been larger in Redwood Creek (at the "lagoon" and upstream toward Fern Canyon in the National Park) than in the Klamath River, and fishing effort has been directed there (S. Masten, pers. comm.).

Accounts by Native American fishermen interviewed by USFWS personnel in 1992 likewise attest to a recent decline. Mr. Tom William, Sr., a Yurok tribal elder, recalls selling eulachon commercially in 1960, when "they were very abundant" and had last seen them in 1986 - "caught them all the time and then they just quit." He reported catching eulachon in the Klamath River, Orick Beach "for years", and the Mad and Eel rivers. Mr. Larry Hendrix, another Yurok fisherman, stated that the last time he caught eulachon by the "washtubs full" was 1988, at the mouth of the Klamath and that they definitely were "much more abundant" before 1988. He also has heard reports of a "few" eulachon caught in 1990 and 1991 (T. Kisanuki, pers. comm.).

The factors responsible for the decline of California eulachon populations are unknown. In Redwood Creek, extensive modification of the creek mouth and lagoon area due to levee construction rendered much of that estuary unsuitable for juvenile salmon and steelhead trout (Larson et al. 1983), and it is likely that eulachon were likewise affected. Given the extensive ocean life-phase of the species and the apparently sporadic nature of its abundance in recent years, it is likely that oceanic conditions may be important determinants of the sizes of spawning runs. Yet, it is known that all life stages are sensitive to temperature changes and probably to industrial pollutants. The disappearance of the Cowlitz River run (tributary to the Columbia River) in 1949-1952 may have been due to pollution (Emmett et al. 1991). Furthermore, the 1977 drought conditions apparently caused the eulachon to bypass the Cowlitz River and spawn in other tributaries (Emmett et al. 1991). Thus, eulachon are evidently sensitive to a number of environmental factors, and their recent decline in California streams may be a manifestation of changes in water quality or spawning habitat in the lower reaches of the rivers they occupy.

Management: Given the lack of quantitative data on eulachon populations, an important first step is to monitor the year-to-year abundance of eulachon in the Klamath River, Mad River and Redwood Creek. It is not clear whether eulachon populations in California would be amenable to, or benefit from, active management. However, perhaps "rehabilitation" of selected streams (e.g., the lower reaches of Redwood Creek) to previous levels of environmental quality could improve spawning success and early life-stage survival.

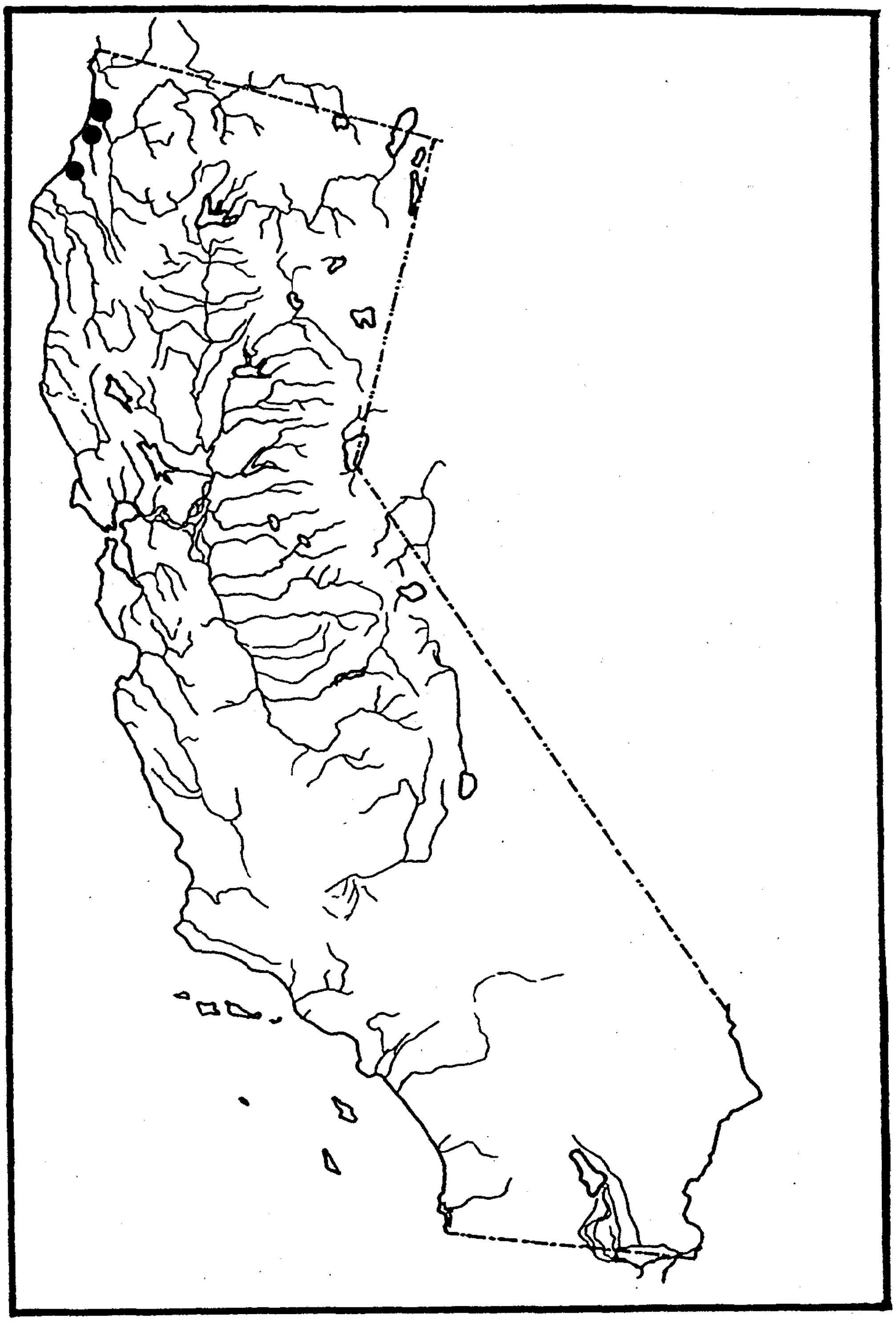


FIGURE 21. Spawning runs of the eulachon, *Thaleichthys pacificus*, in California.

LAHONTAN LAKE TUI CHUB
Gila bicolor pectinifer (Snyder)

Status: Class 3. Watch List.

Description: Lahontan Lake tui chubs can reach lengths of 35 to 41 cm FL. The mouth is small, terminal, and oblique. There is a single row of hooked, pharyngeal teeth (5-5, 5-4, or 4-4) with narrow grinding surfaces. This subspecies is characterized by numerous (29-40), long, slender gill rakers, the primary characteristic that serves to differentiate it from sympatric *G. b. obesa* (Miller 1951, Moyle 1976, Vigg 1985). The inter-gill raker distances are usually less than the width of the gill rakers themselves. Other morphological characteristics that differentiate *pectinifer* from *obesa* are the oblique mouth, the slightly concave profile of the head, and a uniform blackish or silvery body coloration (Miller 1951). Dorsal and anal fin rays usually number 8, but may range from 7-9. Fins are short and rounded. Scales are large and there are 44-60 along the lateral line. Spawning males have reddish fins and develop small, white breeding tubercles on their body surfaces. Females have reddish fins, slightly enlarged anal regions, protruding genital papilla, and deeper bodies.

Taxonomic Relationships: The taxonomy of tui chubs is confusing because there are many isolated populations that are morphologically similar. Compounding the confusion is the lack of phenetic and genetic studies and information on life histories and habitat requirements. Presently there are ten subspecies of *Gila bicolor* recognized in California, although three lack formal taxonomic descriptions: Lahontan lake tui chub *(Gila bicolor pectinifer),* Eagle Lake tui chub, *(G. b.* ssp.), Cowhead Lake tui chub *(G. b. vaccaceps),* High Rock Spring tui chub *(G. b.* ssp,), Goose Lake tui chub *(G. b. thalassina),* Owens tui chub *(G. b. snyderi),* Mohave tui chub *(G. b. mohavensis),* Lahontan creek tui chub *(G. b. obseus),* Klamath tui chub *(G. b. bicolor),* and Pit River tui chub *(G. b.* ssp.). The first five subspecies are included in this report; the Owens and Mohave tui chubs are already listed as endangered species by both state and federal governments.

Gila b. pectinifer has a complex taxonomic history. It was first described as *Leuciscus pectinifer* by Snyder (1917) who simultaneously described the sympatric form as *Siphateles obesus.* Hubbs and Miller (1943), however, considered *L. pectinifer* to be a subspecies of *Siphateles obesus* and thus called it *Siphateles obesus pectinifer.* Shapovalov and Dill (1950) recognized that both forms were part of the *Siphateles bicolor* complex and renamed them *S. b. pectinifer* and S. *b. obesus,* respectively. Bailey and Uyeno (1964) designated *Siphateles* as a subgenus of *Gila* and designated the fine gill raker tui chub as *Gila bicolor pectinifer.*

Because the zoogeographic range of *G. b. pectinifer* is contained within that of *G. bicolor obesa,* its subspecific status is controversial (Moyle 1976). However, studies in both Lake Tahoe and Pyramid Lake, Nevada, indicate that the two forms segregate ecologically (Miller 1951, Galat and Vucinich 1983) and do not interbreed, which may argue for species status for the fine gill raker form. Hubbs and Miller (1943), Kimsey (1954) and Hubbs et, al. (1974) suggested that tui chubs in Eagle Lake, Lassen County, are a hybrid swarm between *G. b. obesa* and *G. b. pectinifer,* based on bimodal gill raker counts. However, the lack of other hybrid characters and the isolation of this lake from other parts of the Lahontan Basin indicate that a separate evolutionary origin is more likely.

Life History: Lahontan Lake tui chub feed mostly on zooplankton, especially cladocerans and copepods, but also consume benthic insects such as chironomid larvae, annelid worms, and winged insects such as ants and beetles (Miller 1951, Marrin and Erman 1982). *Gila b. pectinifer* is primarily a mid-water feeder with a gill-raker structure adapted to feeding on plankton. In contrast, the co-occurring subspecies *obesus* is primarily a benthic feeder (Miller 1951). A comparison of stomach contents, of both subspecies captured together in bottom-set gillnets indicated *obesa* had fed on benthic insects such as chironomids and trichopterans, while *pectinifer* had fed on planktonic microcrustacea (Miller 1951). There is no significant ontogenetic niche shift in diet for *pectinifer,* it feeds on plankton throughout its life (Miller 1951). In Pyramid Lake, tui chubs of both subspecies feed primarily on zooplankton (mostly microcrustaceans) when 125 mm FL, but the *obesa* subspecies feed increasingly on benthic and terrestrial macroinvertebrates as they become larger (Galat and Vucinich 1983). There is an ontogenetic change in gill-raker numbers in the two forms that accompanies the differentiation of diets. When 125 mm FL, the *pectinifer* form and the *obesa* form were indistinguishable based on gill-raker count, but the gill-raker count increased in *pectinifer* until the two forms were readily distinguishable by 250 mm FL.

Tui chubs fall prey to large trout and, to a lesser extent, to birds and snakes. Examination of stomachs of rainbow trout and mackinaw trout in Lake Tahoe revealed that 10% and 7%, respectively, of their stomach contents consisted of *G. b. pectinifer* (Miller 1951).

In Lake Tahoe, spawning apparently occurs at night during May and June, and possibly later (Miller 1951). By early August, females do not have mature ova. Lahontan Lake tui chubs spawn by 11 cm SL (Miller 1951). They are probably serial spawners, capable of reproducing several times during a season (Moyle 1976). Snyder (1917) documented that reproductive adults spawned in near-shore shallow areas over beds of aquatic vegetation and found eggs adhering to the aquatic vegetation. He noted that young remained in the near-shore environment until winter when they were 1-2 cm in length and then migrated into deeper water offshore.

Growth (length increments) of tui chubs is linear until about age 4, when weight increases more rapidly and length increments decrease. The largest Lahontan Lake tui chub caught in Lake Tahoe was 13.7 cm SL (Miller 1951). These fish are considerably smaller than the tui chubs in Walker Lake, Nevada, where they grow to 21 cm SL (Miller 1951). It is likely that the largest Lahontan lake tui chubs are in excess of 20 years old (Scoppetone 1988).

Habitat Requirements: Lahontan Lake tui chub are schooling fish and inhabit large, deep lakes (Moyle 1976). They seem to be able to tolerate a wide range of physicochemical water conditions because they are found in oligotrophic Lake Tahoe as well as in Pyramid Lake, a mesotrophic and highly alkaline lake, and (presumably) in fluctuating reservoirs. In Lake Tahoe, the larger fish (>16 cm TL) exhibit a diel horizontal migration by moving into deeper water (>50 m) during the day and back into shallower habitat at night (Miller 1951). However, they always remain high in the water column. The smaller individuals occupy shallower water. Additionally, there is also a seasonal vertical migration, with fishes located deeper in the water column during winter and moving back into the upper water column during summer (Snyder 1917, Miller 1951). Algal beds in shallow, inshore areas seem necessary for successful spawning, egg hatching, and larval survival.

Distribution: *Gila b. pectinifer* are found in Lake Tahoe and Pyramid Lake, Nevada, which are connected to each other by the Truckee River (Fig. 22), and in nearby Walker Lake, Nevada. Plankton-feeding populations of chubs in Stampede, Boca and Prosser reservoirs on the Little Truckee River may also be *G. b. pectinifer* because they have a superior oblique mouth, fine gill rakers and are never found in tributary streams (Marrin and Erman 1982, D. Erman, pers. comm.). Tui chub populations of uncertain affinities also occur in Topaz Lake on the California-Nevada border and in Honey Lake, Lassen County.

Abundance: The Lake Tahoe population is the only confirmed population in California, but the chubs in Stampede, Boca, and Prosser reservoirs probably also belong to this subspecies. It has not been studied in Lake Tahoe since Miller (1951). Since then, the zooplankton in. the lake have changed.

Daphnia, an important prey of adult chubs, have been nearly eliminated (Richards et al. 1975) by the introduced kokanee salmon *(Oncorhynchus nerka)* and opossum shrimp *(Mysis relicta),* both of which feed on zooplankton. The population may also have been stressed by the elimination of marshlands along the lake that may have been used for spawning and nursery areas. Small numbers have been collected from Lake Tahoe in recent years (P. Budry, unpubl. data), but their actual abundance is not known. Populations in Pyramid and Walker lakes are large and healthy, but both these lakes are becoming increasingly alkaline due to diversions of inflowing water. If diversions continue at present levels, the lakes could eventually become too alkaline for tui chubs.

Chubs are abundant in the three reservoirs but are continually threatened by reservoir operations that take little account of resident fish populations.

Management: Surveys of Lake Tahoe and other waters are needed to determine the distribution and abundance of *G. b. pectinifer* in California. Equally important, a taxonomic study is needed of all potential populations this subspecies, as well as of other subspecies and isolated populations of tui chub throughout the range of the species, but especially in California. Until taxonomic studies are completed, all potential populations of this form should be managed in ways to as to not reduce their numbers.

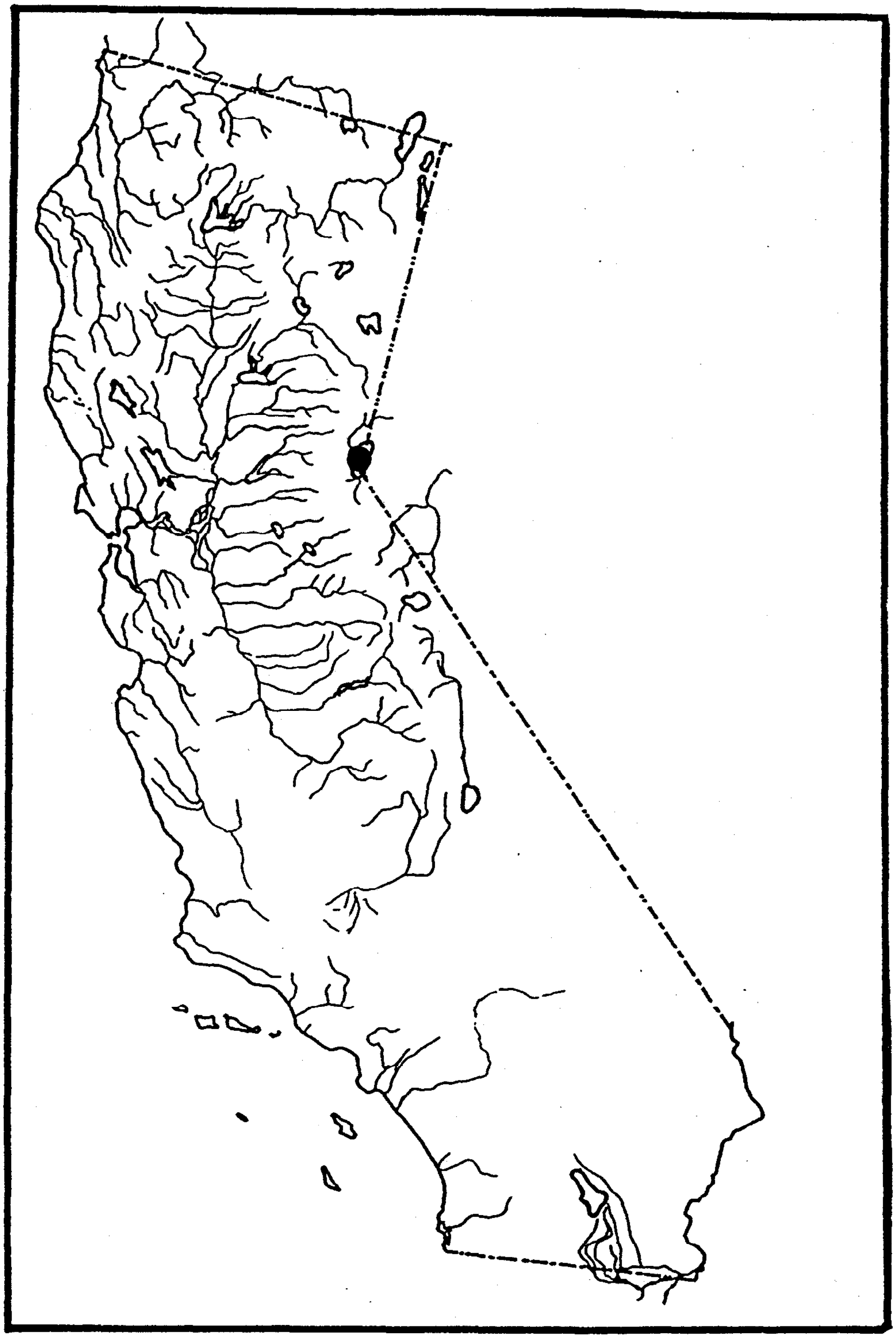


FIGURE 22. Distribution of the Lahontan Lake tui chub, *Gila bicolor pectinifer*, in California.

COWHEAD LAKE TUI CHUB
Gila bicolor vaccaceps Bills and Bond

Status: Class 1. Endangered.

Description: The Cowhead Lake tui chub is similar to the Klamath tui chub, *Gila b. bicolor,* but is differentiated primarily on the basis of more gill rakers (Bills and Bond 1980). The Cowhead Lake tui chub has 19-25 (mean=22.49) short, "bluntly rounded" gill rakers, compared with 10-15 gill rakers in *G. b. bicolor.* Other morphological features that characterize this subspecies are: the head is not as deep as in other chubs, is relatively longer, and is convex in profile with a rounded interorbital; a nuchal hump is present, but low; the lower jaw is not overhung by the upper jaw and the caudal peduncle is relatively deep. Predorsal scales number from 26-35 (mean=31) and there are approximately 57 lateral line scales. The pectoral fin has 15-17 rays, and the pelvic fin, 8-9 rays. Pharyngeal tooth counts are 0,5-4,0; 0,4-4,0; 0,5-5,0. Coloration is similar to other subspecies, except there is a dark lateral stripe with speckles on the head region, especially the cheek and operculum, and on the lower body. Reproductive males and females develop breeding tubercles, especially on the anterior rays of the pectoral fins. Smaller tubercles develop in rows on the edges of the breast scales. In males, tubercles also develop on the scales above the pectorals and across the nape. The largest individual collected measured 11.6 cm SL (Bills and Bond 1980)

Taxonomic Relationships: This subspecies was first recognized as a distinct form by Hubbs and Miller (1948) and formally described by Bills and Bond (1980). Hubbs and Miller (1948) postulated a possible relationship between Cowhead Lake tui chub and chubs from the lakes in Warner Valley, Oregon, because of the connection that existed between Cowhead Lake and the Warner Valley drainage. Bills and Bond (1980) disputed this hypothesis on the basis of differences in gill-raker length and tin and head shapes between the two populations. For a more detailed discussion of tui chub taxonomy, see the account of *G. b. pectinifer.*

Life History: The life history of this subspecies has not been well documented, although Moyle (unpubl. data) found that they reached 40-50 mm SL in their first year and 60-80 mm in their second year. They live to at least age 3+, at which time they are about 80 mm SL. The maximum size recorded is 101 mm SL (Sato 1992b).

Habitat Requirements: Cowhead Lake slough is a small, muddy creek - in the summer consisting of a series of pools (95%) and riffles (5%) - that meanders through a lava canyon approximately 50 m wide. The pools are fairly large, approximately 50 m^2, and are interconnected by shallow trickles. In 1974, the average depth of the pools was 0.5 m and maximum depth was at least 1.2 m. Flow was 0.5 cfs. There was considerable vertical stratification of water temperature: 18-19°C on the bottom and 32°C at the surface. Substrate was mostly mud (80%), with some sand (5%) and boulder/bedrock (15%). There was abundant rooted and floating vegetation *(Sagittaria sp., Ranunculus aquatilis),* but little canopy cover (Moyle, unpubl. data). Speckled dace *(Rhinichthys osculus)* have been found in the slough and in the feeder streams, as have been a few rainbow trout.

During drought conditions, the slough dries up to a few isolated pools (Sato 1992b). The source of water for the slough is described by Sato (1992b):

> “Cowhead Slough, which drains Cowhead Lake, receives water mostly from snowmelt run-off in spring, running naturally only about two weeks a year. With the current irrigation system of the Schadler’s ranch, which includes run-off and spring capture in the reservoir on Eightmile Creek and eventual release to the ditches that reach the slough, flowing water in the slough is probably prolonged by another two weeks. The upper end of the slough may also receive subsurface flow from several faults that are in the area.”

Distribution: Under non-drought conditions, the Cowhead Lake tui chub is confined to about 4 km of slough below Cowhead Lake in the extreme northeastern comer of Modoc Country, California. Small numbers may also exist in an irrigation ditch above the slough. Water in the slough is maintained by flows from Eight Mile, Ten Mile, and Twelve Mile creeks, which drain the Warner Mountains. Formerly, the chubs probably also occupied Cowhead Lake during wet years, but the lake is now drained annually to create pasture. About half the slough is on private land and the rest is on BLM land. The lower reaches of the creeks are also largely on private land. In 1992, during severe drought conditions, fish were confined to turbid pools in the upper end of Cowhead Slough (Sato 1992b).

Abundance: The Cowhead Lake tui chub was presumably much more abundant in the past, when Cowhead Lake contained water. However, the lake probably dried up naturally on occasion, confining the chub to inflowing streams and springs. In 1992, much of the chub’s remaining habitat dried up as a consequence of prolonged drought, and it is likely that only a small number of fish survived the summer. The fish in the few remaining pools were highly vulnerable to garter snake predation (Sato 1992b).

Nature and Degree of Threat: The main threat to the continued existence of Cowhead Lake tui chub is diversion of the water that flows into Cowhead Slough, especially during periods of drought. In 1992, chubs were largely confined to a short section of slough that was entirely on private land with a water supply that depended in part on inflow from an irrigation ditch. Livestock grazing in the area has removed most riparian vegetation, reducing cover available to the fish and making them more vulnerable to predation by garter snakes and birds. In addition, an illegal introduction of another fish species could happen very easily and threaten the chub’s survival, as could pest control programs that introduce pesticides into the drainage (e.g., USDA-APHIS Grasshopper Control Program).

Management: The likelihood is high that Cowhead Lake tui chubs will soon become extinct if active management is not undertaken. There is no formal management of the Cowhead Lake tui chub at the present time, although there is considerable interest in finding ways to improve its status (G. Sato, pers. comm.). We recommend that the following steps be taken to protect the slough and its fish.

- A cooperative agreement should be developed among interested agencies (CDFG, BLM, USFWS) and private landowners to find ways to assure a permanent water supply to Cowhead Lake Slough and to improve the habitat in the refuge area in the upper end of the slough.

- The Bureau of Land Management should declare the slough reaches on land it manages to be an Area of Critical Environmental Concern and find ways to establish a permanent refuge for the chub on public land. The slough should be fenced to reduce or eliminate cattle grazing in the riparian area.

- Establish a monitoring program whereby the fish are sampled at least once a year. A study of the environmental requirements of these tui chubs is also needed.

- Until the future of the Cowhead Lake tui chub is regarded as reasonably secure in its natural habitat, establish at least one refuge population outside the drainage, in artificial pools if necessary.

- For the long run, develop a management plan for the waters of the Cowhead Lake drainage that will assure not only protection of the Cowhead Lake tui chub, but of the local speckled dace and trout populations as well.

- Require that range improvement or pest control programs (e.g., the USDA-APHIS Grasshopper Control Program) stay out of the Cowhead Lake slough drainage.

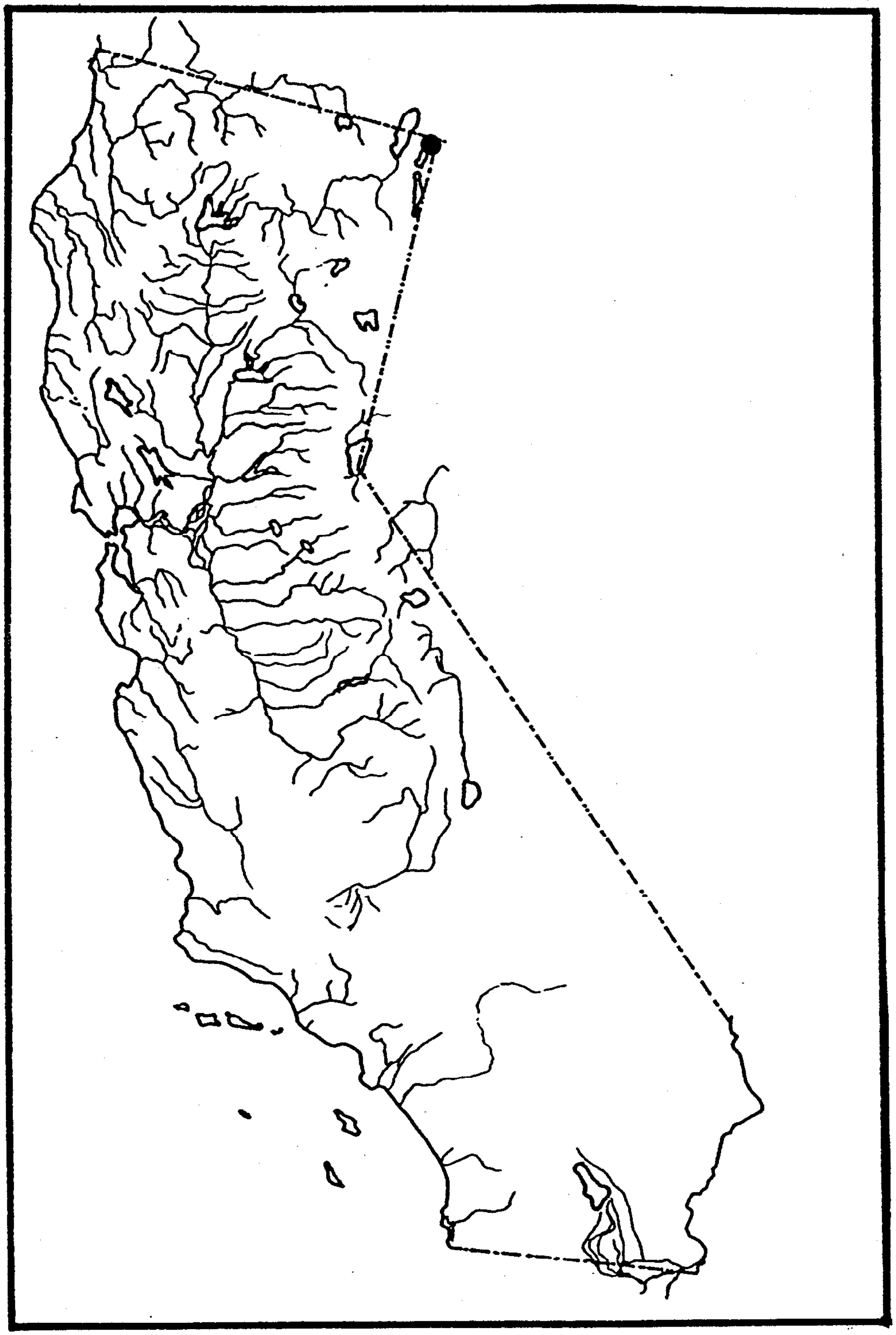


FIGURE 23. Distribution of the Cowhead Lake tui chub, *Gila bicolor vaccaceps*, in California.

EAGLE LAKE TUI CHUB
Gila bicolor ssp.

Status: Class 3. Watch List.

Description: A thorough description of the Eagle Lake tui chub is lacking, but it seems to be similar in most respects to *Gila bicolor pectinifer.* The most notable difference between the two forms is the number of gill rakers: Eagle Lake tui chubs have 12-28 gill rakers on the first arch, *G. b. pectinifer* has 27-40 (Galat and Vucinich 1983, Kennedy 1983). In addition, Eagle Lake chubs have a bimodal distribution of gill rakers, with a low point at 20-21 rakers (Kimsey 1954, B. Martin, unpubl. data). The chubs can grow to 40 cm SL.

Taxonomic Relationships: This form has been regarded as a hybrid between *G. b. pectinifer* and *G. b. obesa* (Kimsey 1954, Hubbs and Miller 1943, Hubbs et al. 1974). However, the lack of other hybrid characters and the isolation of this lake from other parts of the Lahontan Basin indicate a separate evolutionary origin. For a detailed discussion of tui chub taxonomy, see the *G. b. pectinifer* account.

Life History: Kimsey (1954) conducted the most comprehensive study of the natural history of this subspecies. The fish school in open waters of the lake, with schools consisting of fish from similar size-classes. During the spawning season, schools break up and mature adults congregate in near-shore, shallow areas with dense algal beds. At this time the immature fish remain scattered throughout the lake.

Spawning occurs from mid-May through the beginning of July. Adults in spawning aggregations mill around dense algal beds in about l-m deep water and deposit adhesive eggs which stick to aquatic plants *(Myriophyllum spicatum, Ceratophyllum demersum, Potamogeton* sp.). The newly laid eggs are a pale orange-yellow, but color fades to a lighter straw-yellow after some time. Kimsey (1954) estimated the fecundity of a 27-cm female tui chub at 11,200 mature eggs but considered this a conservative estimate because not all eggs mature simultaneously. Thus, tui chubs are probably serial spawners capable of reproducing several times during a season (Moyle 1976).

Newly hatched larvae are well developed and immediately begin to feed on rotifers, diatoms, desmids and other microscopic material. Juveniles aggregate along the lake shore in huge schools until about December, when they move into the deeper waters of the lake. The young-of-year feed on zooplankton and terrestrial insects blown into the lake from the surrounding forest. Adult Eagle Lake tui chubs are opportunistic omnivores. The bulk of their stomach contents usually consists of detritus, with small quantities of benthic and planktonic invertebrates, algae, and aquatic macrophytes (Kimsey 1954, Martin, unpubl. data).

Kimsey (1954) aged Eagle Lake tui chubs at 6-7 years using scales; however, Davis and Moyle (unpubl.) found that if opercular bones are used instead, the ages of adult tui chubs (30-40 cm SL) range from 12-33 years. Such ages appear to be typical of tui chubs and suckers (Catostomidae) of terminal lakes of the Great Basin (Scoppettone 1988).

Habitat Requirements: Eagle Lake is a large (22,000 ha) lake at an elevation of 1,557 m. It consists of three distinct basins. Most of the water enters the lake from flows of Pine Creek and a number of smaller creeks, all of which flow only during the winter. Most water loss is through evaporation. There is no outflow from Eagle Lake, except for Bly Tunnel (constructed in the 1920s), which releases several cfs of water into Willow Creek. The lake is highly alkaline (pH about 9 in most years), clear (secchi depth typically 4-6 m) and cool (summer temperatures rarely >20°C at the surface). Average depth is 5-7 m, with the maximum depth at 30 m (in the lower basin). Eagle Lake tui chubs are found throughout the lake. They require beds of aquatic vegetation in shallow, inshore areas for successful spawning, egg hatching and larval survival (Kimsey 1954).

Distribution: This form is confined to Eagle Lake, Lassen County, California (Fig. 24).

Abundance: Eagle Lake tui chubs are included in this report because of their restricted distribution. At present, they are the most abundant fish in Eagle Lake and support large populations of fish-eating birds.

Nature and Degree of Threat: Despite the long life span and abundance of these tui chubs, introductions of other species into the lake could cause them problems. In 1986, BLM (with financial assistance of CDFG) blocked the Bly Tunnel that was keeping the lake water levels low. However, because of downstream water rights in Willow Creek, an eight inch pipe through the barrier allows a flow of about 12 cfs to the creek. Although some of the water emanating from the tunnel may originate in springs, the chemistry of the water is nearly identical to that of Eagle Lake water (Moyle et al. 1991). If the lake level does rise as predicted, the lake will become considerably less alkaline and will be able to support introduced fishes, as it did in the early 1900s when largemouth bass and catfish were common. These introduced fishes died out when the lake level dropped during the drought of the 1930s, and the impact these fishes had on the chub populations is not known. However, the effects of introduced diseases, predators, parasites or competitors from future fish introductions could be disastrous to the lake ecosystem. Although CDFG and other agencies are strongly opposed to introducing species into Eagle Lake, illegal introductions by ignorant anglers are easily accomplished.

Another potential problem is that the lake could actually become too alkaline to support tui chubs during an extended period (10+ years) of drought. Because of the Bly Tunnel, the lake cannot hold as much water for as long as it formerly did, so low, possibly lethal, lake levels are now more likely to occur.

Management: Eagle Lake should have special recognition as a refuge for native fishes, including the endemic Eagle Lake trout which feeds in part on tui chubs. An informational program should be initiated to reduce the likelihood of unauthorized introductions. The possibility of acquiring the rights to the 12 cfs release of water from the tunnel should be investigated to eliminate the diversion and allow the lake to maintain more natural levels.

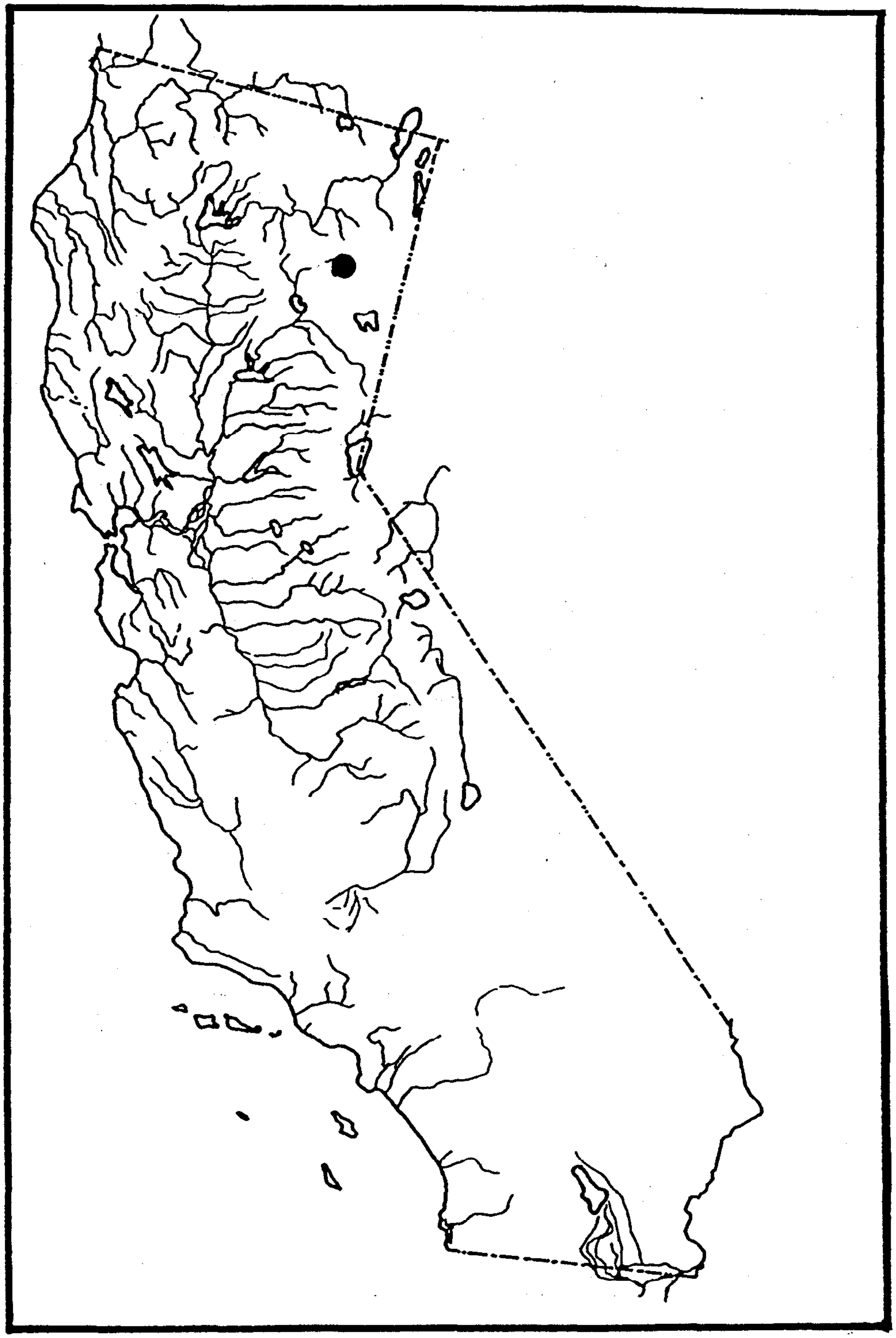


FIGURE 24. Distribution of the Eagle Lake tui chub, *Gila bicolor* ssp., in California.

GOOSE LAKE TUI CHUB
Gila bicolor thalassina (Cope)

Status: Class 1. Threatened.

Description: The Goose Lake tui chub is differentiated from other subspecies of *Gila bicolor* by its longer fins, more posterior dorsal fin, longer head, and larger number of dorsal rays, usually 9 (Snyder 1908c). Coloration is similar to other subspecies. Larger specimens from Goose Lake (up to 30 cm FL) are uniformly silver except for a white belly.

Taxonomic Relationships: The Goose Lake tui chub was first described by Cope (1883) as *Myloleucus thalassinus,* but he simultaneously described a second species of tui chub from the lake as well. Snyder (1908c) noted that Cope collected numerous fresh and dried chubs that had been dropped by fish-eating birds along the shoreline, and hypothesized that the second species recognized by Cope was based on these poorly preserved specimens. However, there are apparently two morphological types of tui chub in Goose Lake, a "standard" heavy-bodied tui chub and another form with a less robust body and more pointed head (R. White and P. Moyle, unpubl. obs.). Snyder (1908) placed *thalassinus* in the genus *Rutilus* because Jordan and Evermann (1896) synonymized *Myloleucus* with *Rutilus.* North American cyprinids placed in the European genus *Rutilus* eventually were referred to generic names of New World minnows, including *Gila.* Snyder (1908c) considered *thalassinus* to be native to Goose Lake and the upper Pit River from Big Valley upstream to Goose Lake. Hubbs et al. (1979), however, considered the form in the Pit River to be distinct from the Goose Lake form and used *thalassina* as the grammatically correct name.

Life History: The life history of this subspecies has been little studied. Chubs commonly reach 250 mm FL in the lake and fish as large as 3 16 mm FL have been collected, indicating that this form may be very long-lived in lake habitats. In streams, however, they rarely exceed 120 mm FL. The size distribution of tui chubs sampled from Goose Lake in 1989 showed two modes. The great majority (>90%) of fish were less than 120 mm SL, while the remainder were 200-300 mm SL (R. White, unpubl. data). Most tui chubs are opportunistic omnivores and consume a wide variety of aquatic invertebrates (Moyle 1976). Tui chubs are a major prey of Goose Lake lamprey; depending on the length class, 20-70% of the tui chubs >200 mm SL sampled in 1989 had lamprey scars (R. White, unpubl. data)

Habitat Requirements: Goose Lake is a massive, natural akaline lake covering approximately 39,000 surface hectares along the Oregon-California border. The lake is shallow, averaging 2.5 m deep, and is hypereutrophic and very turbid (Johnson et al. 1985). Physical limnological measurements taken by R. White (unpubl. data) reveal the following. A thermocline may be present, depending on wind conditions. On a calm September day, water temperature at one sampling locality was 17°C from the surface to 40 cm depth, with a sharp drop at 40-50 cm, and 14-15°C at 50-200 cm depths. At a second locality, temperature decreased from 23°C at the surface to 15°C at 35 cm, remaining at about 15°C between 35-265 cm depths. At those two localities, dissolved oxygen concentration held at about 8-10 mg $O_2\, l^{-1}$ from the surface down through the water column, but dropped abruptly to <1 mg $O_2\, l^{-1}$ in deeper water, depending on locality. The drop in O_2 occurred at about 150 cm depth at one locality, and between 260-270 cm depths at the second locality. On a windy September day, the water temperature was 15°C throughout the water column (surface to 185 cm depth) measured at one locality. Dissolved O_2 was constant (slightly <10 mg O_2 l^{-1}) from the surface to 170 cm depth, but dropped abruptly to <4 mg O_2 l^{-1} at about 175-180 cm.

The surface elevation of Goose Lake fluctuates seasonally, but averages 1,433 m. In California, no tui chubs have been found in streams above 1,441 m in elevation, although tui chubs have been found above 1550 m in Oregon streams (J. Williams, unpubl. data). Chubs prefer pools and are generally not found in swift water, although they have been collected from runs in Battle Creek near the west shore of Goose Lake (J. Williams, unpubl. data). Goose Lake tui chubs have been collected in habitats ranging in temperature from 9-29°C. In July 1992, large numbers of chubs were observed in the lower reaches of Thomas, Willow, and Lassen creeks (G. Sato, pers. comm.), where they may have been attempting to escape from the increasing alkalinity of the drying lake.

Goose Lake tui chubs also occur in several small reservoirs in the Thomas Creek drainage, Oregon, but the limnological characteristics of those reservoirs are not known.

Distribution: This tui chub is confined to the Goose Lake basin of Oregon and California. In addition to Goose Lake itself, the chub also occurs in low-elevation sections of streams tributary to the lake and Everly Reservoir in California, as well as in Cottonwood, Dog and Drews reservoirs in Oregon (Sato 1992a).

Abundance: This tui chub has been extremely abundant in the lake. During 1966 gillnetting surveys of Goose Lake, it constituted 88% of fishes collected (King and Hanson 1966). In 1984 it constituted nearly 96% of gillnet collections (J. Williams, unpubl. data), and in 1989 was 96% of fishes sampled by trawls, gillnets, and seines (R. White, unpubl. data). Large numbers of chubs could be caught with comparatively little sampling effort (e.g., 100+ in a 5-minute haul with a small trawl). In 1992, the chubs were eliminated from the lake as it became progressively more shallow and alkaline and then dried up. As lake levels dropped, fish crowded into the inflowing streams where they were extremely vulnerable to predation from white pelicans and other fish-eating birds. Apparently the tui chubs survived in greatly reduced numbers in stream pools and in some upstream reservoirs. When the lake was dry in late June of 1994, chubs were abundant in a small portion of lower Willow and Lassen creeks (CDFG unpubl. data).

Nature and Degree of Threat: The principal threat to the Goose Lake tui chub is the loss of water in its principal habitat, Goose Lake, accompanied by loss of refuge habitat in tributary streams and reservoirs in the drainage. Although the lake has dried up in the past, diversions for irrigation and loss of natural water storage areas (e.g., wet meadows) presumably caused it to dry up more rapidly during the recent period of prolonged drought. Even in the absence of complete drying of the lake, reduction of inflows would-increase the likelihood that the lake will periodically become too alkaline to support freshwater fishes such as the tui chub. High alkalinity may be particularly a problem to early life-history stages. The key to the survival of Goose Lake tui chubs in the past presumably was the presence of refuges in the springs and pools of the lower reaches of tributary streams. A number of these refuges still exist but probably in a degraded condition as the result of road building, agricultural activity, reduced streamflow, and other factors. On the other hand, reservoirs created for storage of irrigation water apparently now serve as major refuges for the tui chubs because they have fairly large minimum pools.

When water levels rise in the lake again and alkalinity levels decline, attempts may be made, both officially and unofficially, to introduce exotic game fishes to the lake, as has been done in the past. If such introductions are successful, they could cause a major shift in the Goose Lake ecosystem, away from native fishes such as the tui chub.

Management: A Goose Lake Fishes Working Group has been formed with representatives from federal and state agencies, as well as private individuals with interest in the lake, to explore management measures for all the fishes (Sato 1992a). The involvement of private landowners is particularly critical because much of the key refuge habitat for the fishes occurs on private land. Some possibilities for management include:

- Determine the suitability of all reservoirs in the drainage as refuges for the native fishes and negotiate, if necessary, for minimum pools during periods of drought.

-- Undertake, with the leadership of U.S. Soil Conservation Service, major watershed restoration projects to assure adequate habitat for the native fishes in the lower reaches of Goose Lake tributaries.

-- Prohibit introduction of nonnative fishes into Goose Lake.

-- Prohibit use of live baitfish in the entire Goose Lake basin, including Oregon.

-- Establish instream flow protection for the longer streams in the basin (Oregon; Thomas, Drews, and Cottonwood creeks; California: Lassen and Willow creeks) to assure adequate flows into the lake and adequate flows into refuge areas during periods of drought.

-- Conduct a thorough study of the Goose Lake ecosystem, including a systematic survey of the invertebrates present.

-- Establish refuge populations of the chub in regional farm ponds.

-- Investigate life-history and habitat requirements of the tui chub to determine what additional species-specific management measures are required.

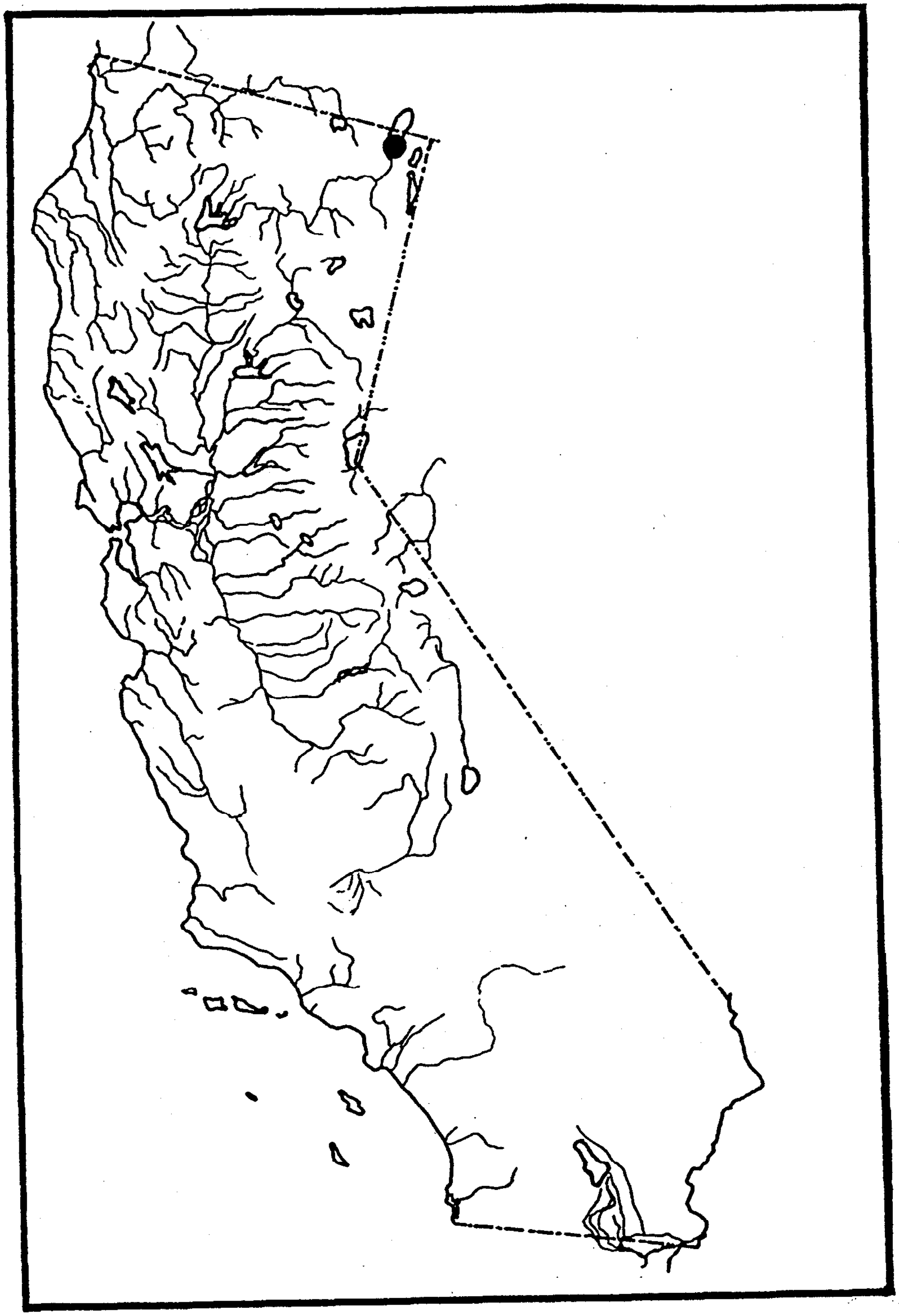


FIGURE 25. Distribution of the Goose Lake tui chub, *Gila bicolor thalassina*.

HIGH ROCK SPRING TUI CHUB
Gila bicolor ssp.

Status: Class 1. Endangered, but probably extinct.

Description: This tui chub is undescribed and in need of taxonomic study. Mills (1979) regarded it as a dwarf form, with adults achieving a maximum standard length of about 100 mm. The largest adult in a CDFG collection (#0559) of 54 tui chubs from High Rock Spring is 91 mm SL. Most adults in this collection range from 53-75 mm SL. In comparison with tui chubs from Clear Lake Reservoir, Goose Lake, and Hat Creek, Mills (1979) found High Rock Spring chubs had longer, deeper heads, thicker caudal peduncles, and fewer pectoral rays. He reported the following average meristic characters for 5 specimens: 53 lateral line scales; 13.4 scales above the lateral line; 9 scales below the lateral line; 27.5 predorsal scales; 9 dorsal rays; 8.4 anal rays; and 13.8 pectoral rays. Our measurements (made by JW) of selected mensural characters are given in Table 8. Robert R. Miller provided the following gill-raker counts from 15 specimens: 11(3), 12(7), 13(5). Coloration of live fish is similar to other subspecies.

TABLE 8. Standard lengths (SL) and relative measurements (in thousandths of SL) of 15 specimens of *Gila bicolor* collected from High Rock Spring, Lassen County, on 24 July 1977 (CDFG collection #0559).

Measurement	Range	Mean	SD
Standard length (mm)	56.3 - 90.0	67.3	9.8
Predorsal length	518 - 567	539.7	14.8
Greatest body depth	257 - 329	294.1	21.5
Least caudal peduncle depth	114 - 132	125.7	5.1
Head length	283 - 386	306.0	25.6
Head depth	86 - 103	94.3	4.8

Taxonomic Relationships: The taxonomic relationships of this form are uncertain and in need of study. Its status as a separate subspecies is made provisionally on the basis of the isolated nature of the habitat, unusually deep body and long head, and observations of Mills (1979). The High Rock Spring tui chub is probably allied to other Lahontan Basin tui chubs, particularly those of nearby Honey and Eagle lakes.

Life History: The life history of this form was not studied, and we can only assume that it was somewhat similar to other tui chubs. For a general description of tui chub life histories, see Moyle (1976).

Habitat Requirements: The High Rock Spring tui chub was present in the spring pool, its outflow, irrigation ditches, and artificial ponds. The main spring pool is a rockbound pool of clear water, approximately 6 x 12 m and 1 m deep. On 23 October 1979, water temperature at the spring was 28.3°C and pH was 6.0. The only other fish species known from the spring is speckled dace (M. Coots, pers. comm.)

Distribution: High Rock Spring is located in eastern Lassen County, T28N, R17E, Section 25. The chub was restricted to High Rock Spring and its outflow (Fig. 26). According to Mills (1979) and an April 1983 letter from L. Hans to A.E. Naylor (CDFG), the chub was found throughout an irrigation system fed by the spring. The system includes approximately 4.8 km of ditches and 4 irrigation ponds. All of the habitat is on a privately-owned ranch.

Abundance: Despite extensive physical modification of the spring habitat, the chub was abundant when surveyed in 1979 (Mills 1979). In 1989 and 1990, the chub was absent from the spring and its outflow (P. Chappell, pers. comm.). A remote possibility exists that High Rock Spring-type tui chubs occur in isolated water bodies along the California-Nevada border. A survey of Modoc and Lassen counties is being planned jointly by CDFG and BLM (P. Chappell, pers. comm.). If remnants, or related forms, of this tui chub are found, perhaps a population could be established in the High Rock Spring system.

Nature and Degree of Threat: In December 1982, Mr. Louie Hans, manager of the ranch surrounding High Rock Spring, filed an application to use the water from the springs for aquaculture. The CDFG issued an aquaculture permit to Mr. Hans for rearing Mozambique tilapia, *Oreochromis mossambica,* in a screened rearing area 100 m downstream from the spring source. On 27 January 1983, 1,000 tilapia were stocked into Mr. Hans's rearing facility. One specimen in the shipment, identified as redbelly tilapia, *O. zilli,* was removed. On 17 June 1983, Larry Eng (pers. comm.) reported observations of another shipment of tilapia and freshwater prawns into the rearing facility. He observed tilapia and chubs throughout the spring system. Inadequate screening apparently allowed the tilapia access to the entire system. Channel catfish, *Ictalurus punctatus,* were reported to have been introduced into the spring system, but their occurrence has not been documented. By 1989, the High Rock Spring tui chub was apparently extirpated, evidently as the result of competition and/or predation from tilapia (P. Chappell, pers. comm.). The aquaculture operation had been discontinued, and the facility abandoned. The only fish presently in the Spring and irrigation system reportedly are *O. mossambica* and possibly *O. zilli,* which are widespread and numerous. The speckled dace, once present, presumably are also gone, as may be various undescribed and perhaps forever unknown invertebrates.

Overall, the presumed extinction of the High Rock Spring tui chub was the result of a combination of factors:

1. High Rock Spring is located entirely on private land, limiting the ability of agencies to regulate its use and to monitor its biota.

2. The tui chub had not been formally described as a taxon, making its protection a relatively low priority. It had not been described because of the general lack of funding available for taxonomic studies, especially for large and complex groups such as the *Gila bicolor* complex.

3. An aquaculture permit was issued without adequately considering the potential effects of the inevitable escape of the exotic fish on the spring ecosystem. Presumably, the permit would not have been issued if more information had been available on the uniqueness of the chub and the High Rock Spring system.

The fate of this chub demonstrates how quickly the extinction of isolated fish populations can occur. The apparent extinction represents not only the loss of a unique gene pool of tui chubs but the probable disruption of an entire miniature ecosystem. We can only hope that the loss of the chub will serve as an example to help prevent similar events in the future.

Management: At this stage, the main thing to be done is to look for other populations of tui chubs in remote springs of the region for possible introduction into High Rock Spring. The following measures were recommended to protect High Rock Spring and its tui chub in the 1989 edition of this report. Most may no longer have any relevance.

-- A taxonomic and electrophoretic analysis of this population should be conducted and compared with other isolated populations in the region.

-- High Rock Spring should be surveyed and mapped to determine the status of the tui chub, introduced fishes and invertebrates, and recent habitat modifications.

-- CDFG should develop a management plan with the landowner that would ensure continued survival of the tui chub.

-- Aquaculture permits should be removed for the entire system. A conservation easement, lease, or purchase should then be negotiated for the spring system.

-- The U.S. Geological Survey should be requested to determine the effects of groundwater mining on quality and quantity of water in High Rock Spring.

-- A Groundwater Management District should be created for the Honey Lake Basin to regulate the use of groundwater. This could help prevent excessive water withdrawals that might reduce the outflow of High Rock Spring.

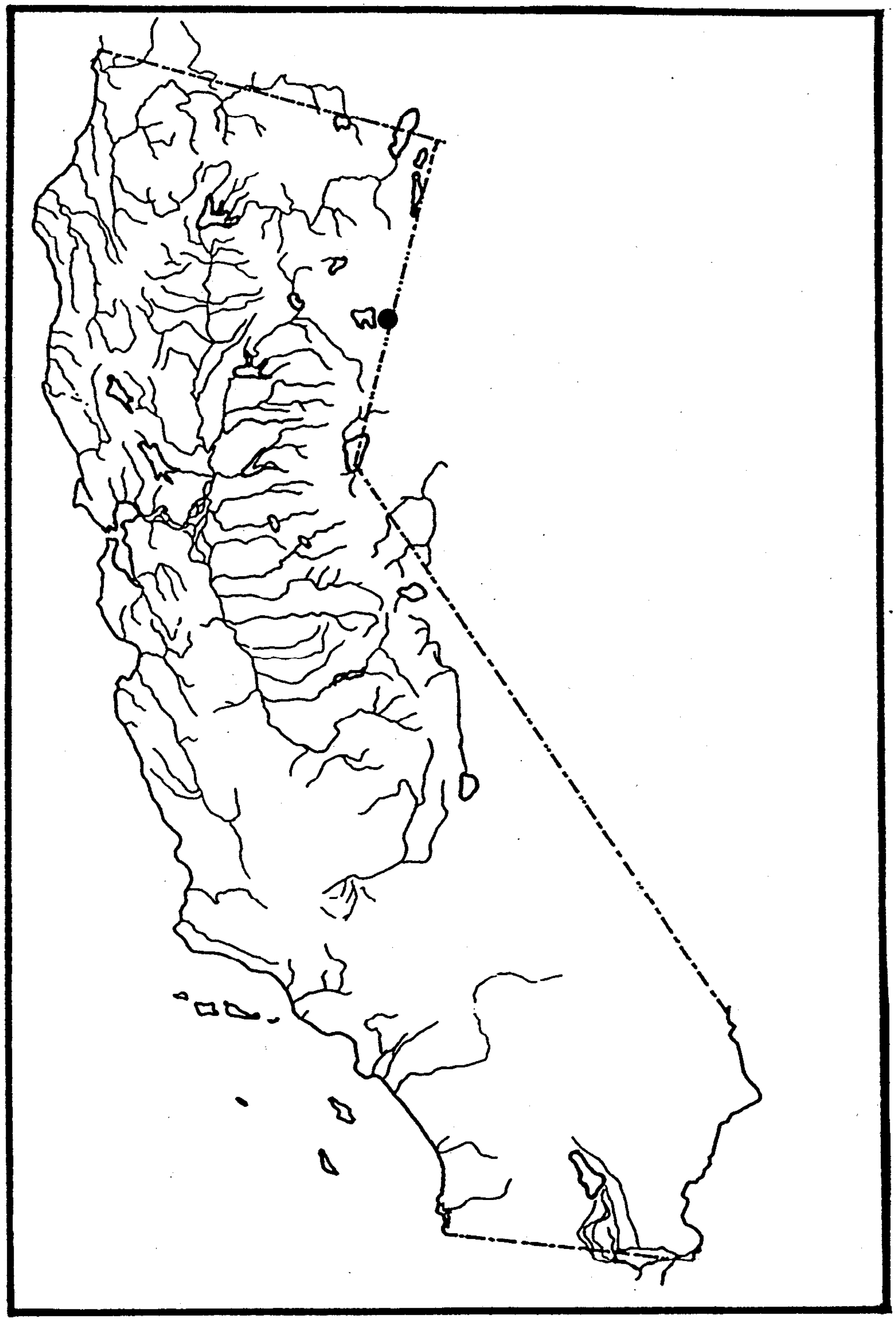


FIGURE 26. Distribution of the High Rock Spring tui chub, *Gila bicolor* ssp.

BLUE CHUB
Gila coerulea (Girard)

Status: Class 2. Special Concern.

Description: Blue chubs resemble Klamath tui chubs, with which they are usually associated, except that they have finer scales (58-71 in the lateral line), are not as deep bodied, have longer fins, and have pointed heads with larger mouths, the maxillary reaching the eye. There are 9 dorsal rays, 8-9 anal rays, and 14-17 rays in each pectoral fin. The two-rowed pharyngeal teeth (2, 5-5, 2) are sharp and slightly hooked. The lateral line is decurved. Blue chubs seldom exceed 40 cm SL and, when alive, tend to be silvery blue on the sides and dusky on the back. Spawning males have blue snouts and are brightly tinged with orange on the sides and tins.

Taxonomic Relationships: This species has been taxonomically stable since Charles Girard described it in 1857. The confusion that once existed over its scientific name was cleared up by Bailey and Uyeno (1964).

Life History: Blue chubs are omnivorous, as indicated by the generalized body shape and tooth structure. Twenty chubs collected from Willow Creek, Modoc County, in August 1972 (all age I, 29-59 mm SL) had fed mostly (66% by volume) on chironomid midge larvae and pupae and on small numbers of water boatmen, water fleas, other aquatic insect larvae, and various flying insects. Sixteen 2-year-old chubs (61-109 mm SL) from the same place had fed heavily on filamentous algae (68%) and aquatic and terrestrial insects. A similar diet was recorded for an Oregon population (Lee et al. 1980).

Spawning occurs in May and June over shallow rocky areas at temperatures of 15-18°C. Spawning behavior was witnessed by C. R. Hazel (pers. comm.) in Upper Klamath Lake, Oregon: "On the afternoon of May 4, 1966, I observed an estimated 200-300 blue chubs spawning at the shoreline on the northern end of Eagle Ridge. Spawning was taking place from near the surface to a depth of 0.3 to 0.5 m. The bottom was composed of large gravel and rubble of volcanic origin. The water was clear with a low concentration of blue-green algae (Aphanizomenon) . . .[and] . . . the water temperature was 17°C. Two to several males would approach a female and exhibit rapid and violent agitations of the water, making it impossible to see exactly what was taking place. In some instances the female was pushed from the water onto dry land and in a few situations, eggs were spawned outside the water. After these activities, egg masses were found attached to [submerged] rocks either on the sides or near the bottom edge. Many of the depositions were found along rocky edges at depths to 0.5 m."

Nothing has been published on age and growth of blue chubs or on its early life history.

Habitat Requirements: Blue chubs are most abundant in warm (summer temperatures >20°C), quiet waters with mixed substrates (Bond et al. 1988). They are especially abundant in lakes but school conspicuously in a variety of habitats, from small streams and rivers to shallow reservoirs and deep lakes. In upper Klamath Lake Oregon, they are (or were) most numerous along rocky shores or out in the open water (Vincent 1968). They seem to avoid marshy shore areas. Apparently, only the complete lack of oxygen in the lower layers of Klamath Lake prevents them from occupying the deep areas of the lake in summer, because they have been gillnetted in waters with dissolved oxygen concentration <0.1 mg l^{-1} (Vincent 1968). As winter sets in and oxygen levels rise in the deep areas, the chubs generally move into the greater depths.

Distribution: Blue chubs are widely distributed in the lower elevations of the upper Klamath and Lost River systems of Oregon and California. In California, they are found in Clear Lake Reservoir, Lost River, Lower Klamath Lake, and Tule Lake, as well the canals and tributaries feeding them.

Abundance: Although the blue chub has historically been an extremely abundant fish within its limited range, its populations have apparently plummetted in the 1980s and early 1990s. However, no systematic estimates of its past or present abundance have been made.

Nature and Degree of Threat: The blue chub has declined through a combination of factors: drought, water diversions, pollution, and introduced species. The drought created additional stress to a system already stressed by the other factors. Diversions of water from the rivers and reservoirs has dried up the lowland habitats preferred by the chubs or allowed organic pollutants to become so concentrated that lakes such as upper and lower Klamath lakes and Tule Lake become difficult for the native fishes to inhabit, even though they are tolerant of fairly extreme environmental conditions. The lakes of the upper Klamath drainage have become sumps for agricultural runoff, which carry fertilizers and animal waste, so they have become increasingly eutrophic and decreasingly favorabable to fish life, even when lake levels are high. In addition, the introduced fathead minnow *(Pimephales promelas)* has proliferated in the lakes and canals in recent years, with unknown effects on blue chubs and other native fishes. The fathead minnow is a particular concern because it is ecologically similar to the blue chub (Moyle 1976).

Management: A survey of the present distribution and abundance of blue chub is urgently needed in both California and Oregon. As an interim measure, at least one refuge population should be established in a farm pond or special refuge facility. Basic studies of its life history and habitat requirements are also needed to determine the best management practices.

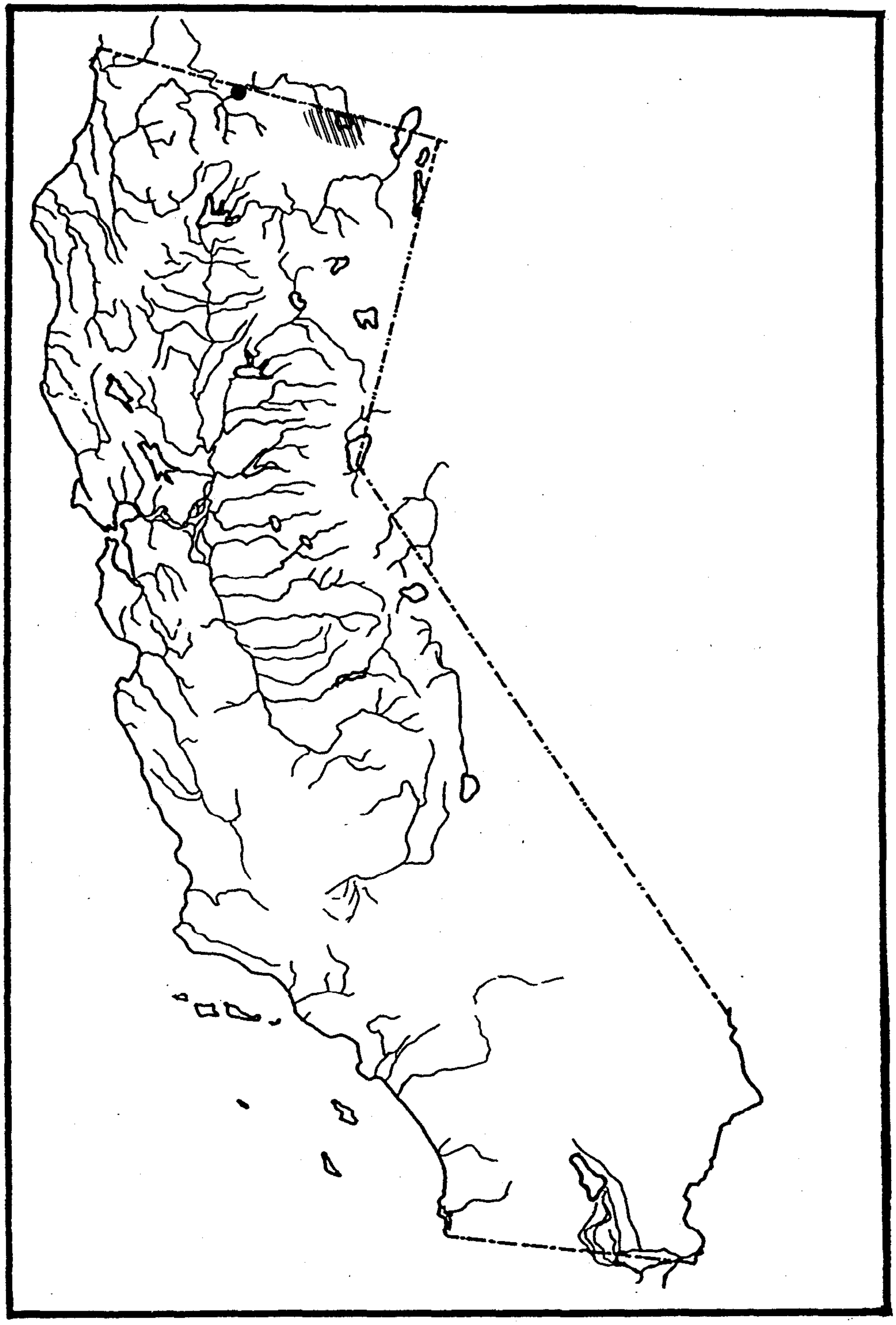


FIGURE 27. Distribution of the blue chub, *Gila coerulea*, in California.

ARROYO CHUB
Gila orcutti (Eigenmann and Eigenmann)

Status: Class 2. Special Concern (Class 1, Threatened in native range).

Description: These are small fish that can reach lengths of 120 mm SL but typical adult lengths are 70-100 mm. Males can be distinguished from females by their larger tins and, when breeding, by the prominent patch of tubercles on the upper surface of the pectoral fins (Tres 1992). Both sexes have chunky bodies, fairly large eyes, and small mouths. The pharyngeal teeth are hooked and closely spaced with a formula of 2,5-4,2, but may be variable. They have 7 anal fin rays and 8 dorsal rays. Gill rakers number 5-9. The lateral line is complete with 48-62 scales, extends to the caudal peduncle, and is not decurved. Body color is silver or grey to olive-green dorsally, white ventrally, and there usually is a dull grey lateral band (Moyle 1976).

Taxonomic Relationships: Miller (1945) placed both *Gila orcutti* and closely related *G. purpurea* in the subgenus *Temeculina.* The arroyo chub hybridizes readily with the Mohave tui chub and with the California roach *(Lavinia symmetricus)* (Hubbs and Miller 1943, Greenfield and Greenfield 1972, Greenfield and Deckert 1973).

Life History: Arroyo chubs are fractional spawners that breed more or less continuously from February through August, although most spawning takes place in June and July (Tres 1992). Most spawning occurs in pools or in quiet edge water, at temperatures of 14- 22°C. During spawning, males follow a ripe female while actively rubbing the upper part of their snouts against the area below the female's pelvic fins. The rubbing and chasing leads to egg release and the eggs may be fertilized by more than one male (Tres 1992). The embryos adhere to the bottom and hatch in 4 days at 24°C. The fry spend their first few days after hatching clinging to the substrate but rise to the surface once the yolk sac has been absorbed (Tres 1992). The next 3-4 months are spent in quiet water, in the water column and usually among vegetation or other flooded cover.

Arroyo chubs in the Santa Clara River reach about 60 mm SL in their first year, 70-75 mm SL in their second year, 75-80 mm SL in their third year, and 80-90 mm SL in their fourth year (Tres 1992). Females first reproduce after reaching one year of age. After their second year, females generally grow larger than males. Arroyo chubs rarely live beyond four years.

Laboratory studies indicate that the arroyo chub is physiologically adapted to survive hypoxic conditions and the wide temperature fluctuations common in south coastal streams (Castleberry and Cech 1986). They are omnivorous, feeding on algae, insects, and small crustaceans. However, most (60-80%) of the stomach contents consist of algae (Greenfield and Deckert 1973). They are also known to feed extensively on the roots of a floating water fern *(Azolla)* infested with nematodes (Moyle 1976).

Habitat Requirements: Arroyo chubs are found in slow-moving or backwater sections of warm to cool (10-24°C) streams with mud or sand substrates. Depths are typically greater than 40 cm. Wells and Diana (1975) described physical characteristics of the streams sites where the arroyo chubs were collected.

Distribution: Arroyo chubs are native to the Los Angeles, San Gabriel, San Luis Rey, Santa Ana, and Santa Margarita rivers and to Malibu and San Juan creeks (Wells and Diana 1975) (Fig. 28). They have been successfully introduced into the Santa Ynez, Santa Maria, Cuyama, and Mojave river systems and other smaller coastal streams (e.g., Arroyo Grande Creek) (Miller 1968, Moyle 1976). The most northern introduced population is in Chorro Creek, San Luis Obispo County (T. Taylor, pers. comm.). They are now absent from much of their native range and are abundant only in the upper Santa Margarita River and its tributary De Luz Creek, Trabuco Creek below O'Neill Park and San Juan Creek (San Juan Creek drainage), Malibu Creek (Swift et al. 1993) and the West Fork of the upper San Gabriel River below Cogswell Reservoir as of 1991 (CDFG, unpubl. data). They also occur, but are scarce, in: Big Tujunga Canyon, Pacoima Creek above Pacoima Reservoir, and in the Sepulveda Flood Control Basin, Los Angeles River drainage; and middle Santa Ana River tributaries between Riverside and the Orange County line (Swift et al. 1993).

Abundance: There is little information available on the actual numbers of chubs at various localities. Presently, arroyo chubs are common at only four places within their native range: upper Santa Margarita River and its tributary, De Luz Creek; Trabuco Creek below O'Neill Park and San Juan Creek; Malibu Creek (Swift et al. 1993); and West Fork San Gabriel River below Cogswell Reservoir (J. Deinstadt, unpubl. data). According to Swift et al. (1993), arroyo chubs are scarce within their native range because the low-gradient streams in which they do best have largely disappeared. During 1986-1990, low-water conditions in the West Fork of the San Gabriel River were favorable to the chub, causing a temporary increase in numbers. They became scarce again after the 1991-1992 rains but were common in 1993. Arroyo chubs appear to be common in some of the streams into which they have been introduced, especially the Santa Clara River. Many such introduced populations have a history of hybridization with other cyprinids (although not in the Santa Clara River; T. Haglund, pers. comm.) and cannot be regarded as secure (or genetically pure) (Swift et al. 1993).

Nature and Degree of Threat: If arroyo chubs had not been introduced into a number of waters outside their native range and had they not thrived in those waters, they would qualify for listing as a threatened species. Their native range, like that of the sympatric Santa Ana sucker, is largely coincident with the Los Angeles metropolitan area where most streams are degraded and populations reduced and fragmented-especially the low-gradient stream reaches which formerly contained optimal habitat (Swift et al. 1993). Those in the Cuyama River and Mojave River have hybridized with California roach and Mohave tui chub, respectively (Hubbs and Miller 1943, Greenfield and Deckert 1972). Recently, red shiner *(Cyprinella lutrensis)* have been introduced into arroyo chub streams and may competitively exclude chubs from many areas (C. Swift, pers. comm.). Chubs generally decline when the shiners become abundant (T. Haglund, pers. comm.). The potential effects of introduced species, combined with the continued degradation of the urbanized streams that constitute much of its habitat, mean that this species is not secure despite its wide range.

Management: Status surveys should be done annually in this species' native range and every five years at all known sites. Within its native range, streams should be selected to be managed to favor the chub's survival, along with that of the other native fishes of the region. The strongest candidate for a native fish refuge is the West Fork of the San Gabriel River.

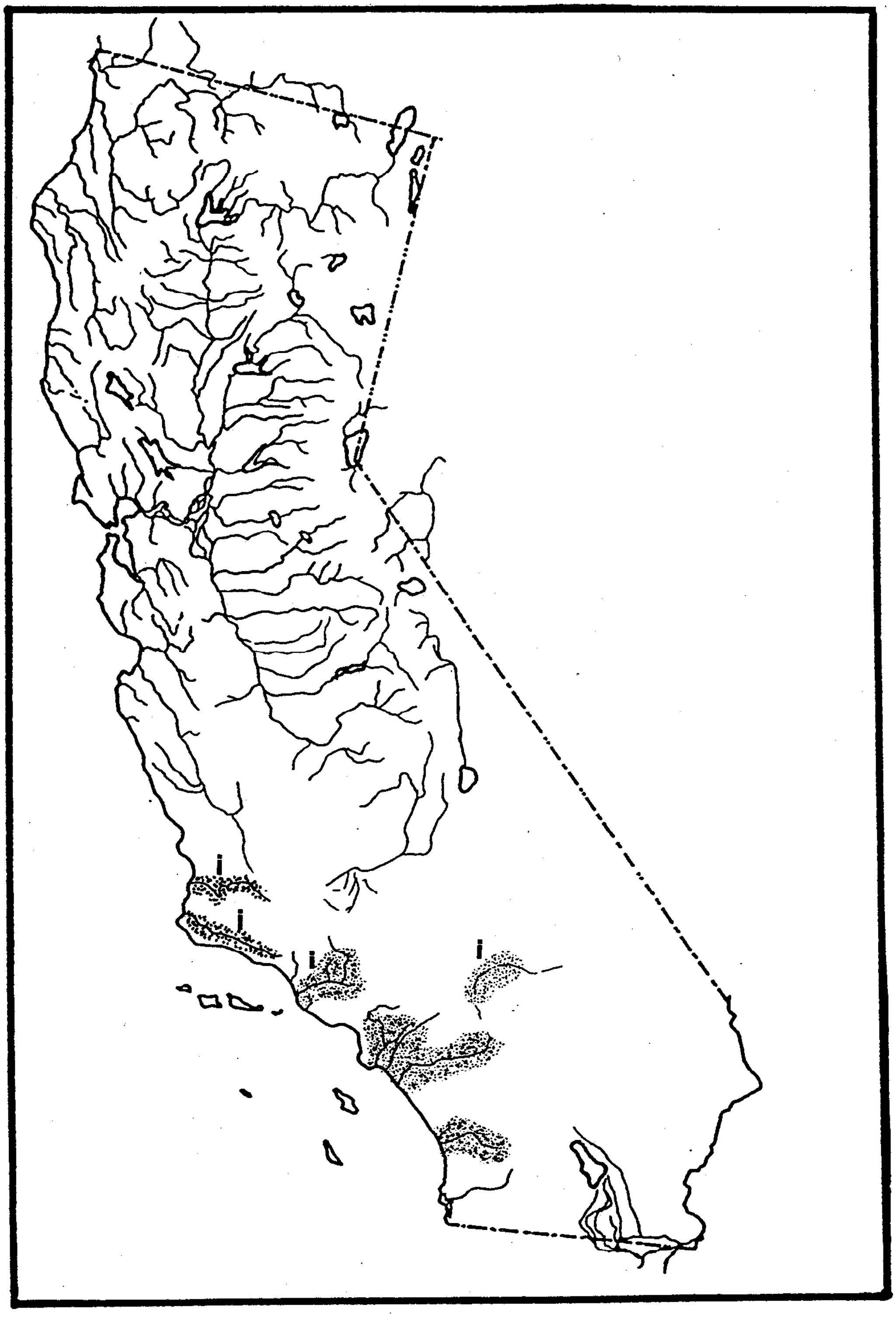


FIGURE 28. Distribution of the Arroyo chub, *Gila orcutti*, in California. (i = introduced population.)

CLEAR LAKE HITCH
Lavinia exilicauda chi Hopkirk

Status: Class 2. Special Concern.

Description: Hitch are cyprinids that can grow to over 350 mm SL. The body is moderately elongated and thick, almost oval shaped in cross section (Hopkirk 1973, Moyle 1976). The head is relatively small and conical. The caudal peduncle is narrow, this feature being responsible for the specific etymology. Clear Lake hitch are distinguished from the type subspecies by a deeper body, larger eyes and more gill rakers. Scales are also larger, with 55-64 along the complete, decurved lateral line (Hopkirk 1973). Clear Lake hitch have 10-12 dorsal fin rays, 11-14 anal fin rays, and 26-32 gill rakers. The pharyngeal teeth are long, narrow, and slightly hooked, but the surfaces are relatively broad and adapted for grinding (Moyle 1976). Young fish are silver and have a dark, triangular blotch on the caudal peduncle extending anteriorly as a black stripe that gradually fades (Hopkirk 1973). As fish age, they become duller in color, with the dorsal area turning brownish-yellow (Moyle 1976).

Taxonomic Relationships: Hitch are most closely related to the California roach *(Lavinia symmetricus),* with which they can hybridize to produce either fertile or infertile hybrids, depending on the population. (Avise et al. 1975). Hitch also hybridize with Sacramento blackfish, but the hybrids are sterile (Moyle and Massingill 1981). The Clear Lake subspecies, *L. e. chi,* was first described by Hopkirk (1973) as a lake-adapted form. Another subspecies *Lavinia exilicauda harengus* from the Pajaro and Salinas rivers was described by Miller (1945), based solely on deeper body depth compared to the type species *Lavinia exilicauda exilicauda.* However, Hopkirk (1973) disputed the validity of *harengus* because *L. e. exilicauda* (the Central Valley subspecies) exhibits sexual dimorphism based on body depth, and there is considerable body size and proportional variability among populations.

Life History: The deep, compressed body, small upturned mouth and long slender gill rakers reflect the zooplankton-feeding strategy of this open-water feeder (Moyle 1976). Hitch >50 mm SL feed almost exclusively on *Daphnia* (Geary 1978, Geary and Moyle 1980). Juveniles (<50 mm SL) in the shallower, nearshore environment feed primarily on the larvae and pupae of chironomid midges, planktonic crustaceans including *Bosmina* and *Daphnia* (Geary 1978), and the eggs, larvae, and adults of the Clear Lake gnat *(Chaoborus astictopus)* (Lindquist et al. 1943). The hitch switch to feeding on *Daphnia* after moving into the offshore limnetic habitat. Geary (1978) found that stomachs of hitch caught early in the morning were empty, while fish caught in the afternoon had fed, indicating that hitch feed primarily during the daylight hours.

Clear Lake hitch grow much more rapidly than lacustrine Sacramento hitch from high-elevation Beardsley Reservoir (Murphy 1948, Geary 1978). In Clear Lake, hitch reach 44 mm SL within three months and are 80-120 mm SL by the end of their first year (Geary 1978). Hitch in Beardsley Reservoir, in contrast, are only 40-50 mm by the end of the first year (Nicola 1974). Geary (1978) attributes this rapid growth rate in Clear Lake hitch to the high productivity and warm water temperatures of the lake.

Females become mature by their second or third year, whereas males tend to mature in their first or second year (Kimsey 1960). Mature females are also larger than males (Geary 1978). Females are quite fecund, producing up to 26,000 eggs (Moyle 1976). Spawning occurs in tributary streams, and the spawning migrations, which resemble salmon runs on a miniature scale, usually take place from mid-March through May and occasionally into June (S. Hill and R. Macedo, pers comm.). In 1992, the hitch runs started in mid-February and persisted until the streams dried in May-June (R. Macedo, pers. comm.).

The current major spawning streams are, in roughly decreasing order of importance, Kelsey, Adobe, Seigler Canyon, and Middle and Scotts creeks (R. Macedo, pers. comm.). Seigler Canyon Creek in Anderson Marsh Historic Park, is one of the better places to observe the still spectacular spawning runs (S. Hill, pers. comm.). Other streams used for spawning are Manning and Cole creeks. The hitch also will opportunistically ascend and spawn in various unnamed tributaries and drainage ditches, as they have done during the current wet year (1993) when R. Macedo (pers. comm.) observed 4-6 pairs spawning in a small ditch. In one year, they even were observed spawning in a flooded meadow adjacent to the former State Park headquarters, after swimming up a small ditch and across a flooded parking lot (S. Hill, pers. comm.). Some hitch in the past evidently spawned along the shores of Clear Lake, over clean gravel where there was wave action (Kimsey 1960); however, the contribution to recruitment by such shore-spawners may have been minimal because of potentially heavy predation on eggs and larvae by carp and other introduced fishes (Kimsey 1960).

Clear Lake hitch usually spawn after heavy rains. They require clean, fine-to-medium gravel, and water temperatures from 14-18°C for spawning (Murphy 1948, Kimsey 1960). When spawning, each female is pursued by 1-5 males that fertilize the eggs as they are released (Moyle 1976). Eggs sink to the bottom after fertilization, where they become lodged among the interstices in the gravel. At times, the white eggs, which resemble silica aquarium sand, can be see piled up on the gravel beds "by the millions" (S. Hill, pers. comm.). The eggs hatch after approximately seven days and the larvae become free-swimming after another seven days (Swift 1965). They then move downstream quickly before the streams dry up (Moyle 1976).

Clear Lake hitch are preyed upon by herons, bald eagles, white pelicans and other birds, by largemouth bass and other introduced fishes (especially centrarchids), and opportunistically (during spawning runs) by racoons, skunks and-black bear (R. Macedo and S. Hill, pers. comm.). The commercial fishery on the lake for blackfish and carp harvests some hitch as well. Clear Lake hitch had been an important component in the diet and culture of the local Native Americans (Pomo tribe). Although hitch presently are used by them less than before, renewed interest in traditional foods has led to a recent increase in requests by Native Americans to harvest hitch from State Park areas (S. Hill, pers. comm.). There is an annual gathering to smoke and dry the hitch, but Native American harvests are low (R. Macedo, pers. comm.).

Habitat Requirements: Adult Clear Lake hitch are usually found in the limnetic zone of Clear Lake. Juveniles are found in the nearshore shallow-water habitat and move into the deeper offshore areas after approximately 80 days, when they are between 40-50 mm SL (Geary 1978). While in the nearshore environment, juveniles require vegetation for refuge from predators. During the reproductive season, adults migrate into low gradient tributary streams where they spawn in the lower reaches, mostly in gravel-bottomed sections that dry up during the summer (Geary 1978, Moyle 1976). Because hitch are not aggressive swimmers, their runs are easily blocked by small dams and other structures that impede upstream migration.

Distribution: This subspecies is confined to Clear Lake, Lake County, California (Fig. 29) and to associated lakes and ponds such as Thurston Lake and Lampson Pond. It spawns in intermittent tributary streams to Clear Lake, mainly Kelsey, Seigler Canyon, Adobe, Middle, Scotts, Cole and Manning creeks, and occasionally in other, unnamed tributaries.

Abundance: The Clear Lake hitch still seems to be common in Clear Lake. The hitch spawning run in Kelsey Creek in 1990 was "excellent" (R. Macedo, pers. comm.), and although the run in 1991 was weaker, numbers still were substantial (R. Macedo and S. Hill, pers. comm.). Compared to past abundances, however, the population undoubtedly is diminished. In 1992, surveys of the three main hitch spawning streams - Seigler Canyon, Kelsey and Adobe creeks - indicated “good” runs of hitch (R. Macedo, pets. comm.). The population status in 1993 was not clear; runs appeared, to be smaller in the three main spawning streams than in 1992, but it is not known whether this was due to a decreased population or to greater dispersal of the hitch into the numerous small tributaries and drainage ditches that the hitch can also utilize during wet years (R. Macedo, pers. comm.).

Nature and Degree of Threat: The principal threats to Clear Lake hitch are loss of spawning habitat and loss of nursery areas, factors which contributed strongly to the extinction of the Clear Lake splittail, *Pogonichthys ciscoides* (Moyle 1976). The lower reaches of all their spawning streams dry up annually and probably did so naturally. However, these streams now go dry earlier in the season due to stream diversions, resulting in spawning failures, especially during dry years. The Clear Lake splittail formerly spawned somewhat later than did the hitch, and the drying up of streams undoubtedly contributed to its demise. Continuation of this progressively earlier drying of streams may seriously affect the hitch population as well, because its spawning period already is relatively limited.

In streams such as Adobe and Kelsey creeks, upstream areas that were once used for spawning are now blocked by roads and other obstructions. Gravel mining on Kelsey, Scotts and Middle creeks has lowered the level of stream beds and the water table as much as 15 feet in some places. Construction of structures (mainly on Kelsey Creek) intended to aggrade gravel and raise the streambed present partial barriers to fish migration, especially during periods of low flow (R. Macedo, pers. comm.). Fish that reach their spawning areas are vulnerable in shallow water to the local “sport” of “hitching”, whereby the fish are clubbed and thrown on the shore. Recent increased protection by CDFG wardens and some educational activities for school children hopefully will lessen this destruction. An additional problem is that many of the marshy areas that once ringed the lake are now gone, limiting the habitat available to larval hitch. This habitat loss is ongoing.

A recent problem has been the introduction and proliferation of planktivorous threadfin shad *(Dorosoma petenense)* in the lake, which may compete with hitch for food. In 1988, threadfin shad constituted 70% of the fish caught in beach seine samples by the Lake County Mosquito Abatement District (N. Anderson, unpubl. data). The shad population was severely reduced during the cold winter of 1990-91 and they have been rare since then. However, a small school was observed in early 1992, and it is expected that the shad again will reach high abundance (R. Macedo, pers. comm.). Introduced game fishes also may have an added impact on the hitch population. Two record largemouth bass from the lake both contained large hitch, and several channel catfish captured by CDFG were observed to have eaten hitch (R. Macedo, pers. comm.). Finally, in 1991 the water in Clear Lake was unusually clear due to the agglomeration of the suspended microscopic algae, which in normal years is dispersed in the water (S. Hill, pers. comm.). Clearer water conditions facilitates predation on the fishes by birds, mainly terns and hundreds of white pelicans.

Management: Annual surveys of spawning runs should be done to determine fish abundance. Critical areas that require protection should be identified and designated. Human-made barriers across spawning streams that are presently insurmountable to hitch should be modified to facilitate the passage of hitch during spawning migrations. On Kelsey Creek, for example, these barriers include the retention dam 2-3 miles upstream of the lake, a small concrete bridge further upstream with culverts which tend to clog with debris, the base of the Main Street bridge in Kelseyville, and a number of “drop-structures” intended for gravel aggradation. Also, rock riprap situated below the retention dam seems to have impeded the upstream migration of the hitch and should be modified to provide a clear channel for fish transit. Seigler Canyon Creek has two barriers to hitch migration (an exposed sewer pipe and one road crossing) and Adobe Creek has one (R. Macedo, pers. comm.). While many of these structures do not present complete barriers, they retard migration to varying degrees. Work by CDFG to improve fish passage has been implemented (R. Macedo, pers. comm.), and such efforts should be continued.

Clear Lake hitch are competing against time, because all spawning streams become dry. Barriers, along with water diversions, can delay spawning to the point where the adults and/or developing young become stranded in the drying streams. Proposed dams on Scotts and Adobe creeks also pose potential barriers to spawning runs. On Adobe Creek, the proposed dam would block access to approximately 20% of the spawning habitat (R. Macedo, pers. comm.). It is imperative that potential barriers on the important spawning streams be built with fish passageways of proven efffectiveness. Water diversions should be controlled such that they do not threaten the spawning runs. Marshy areas near the mouths of streams also should receive special protection as hitch nursery areas.

In general, any water diversions or manipulation of tributary streams should be carefully evaluated with regard to their potential ecological effects on hitch and other aquatic organisms. This would require close coordination by the Flood Control and Water Conservation District, the Lake County Planning Commission and state resource agencies. Efforts should be made to educate the local people about hitch, their importance as a California native and Clear Lake endemic, their role in local food chains (such as their probable importance as forage for breeding osprey), and their niche in the traditional culture of the local Native Americans. The commercial harvest of hitch is minor because demand is low. However, there presently are no restrictions on taking of hitch, so harvesting regulations may need to be formulated if the demand for hitch increases in the future.

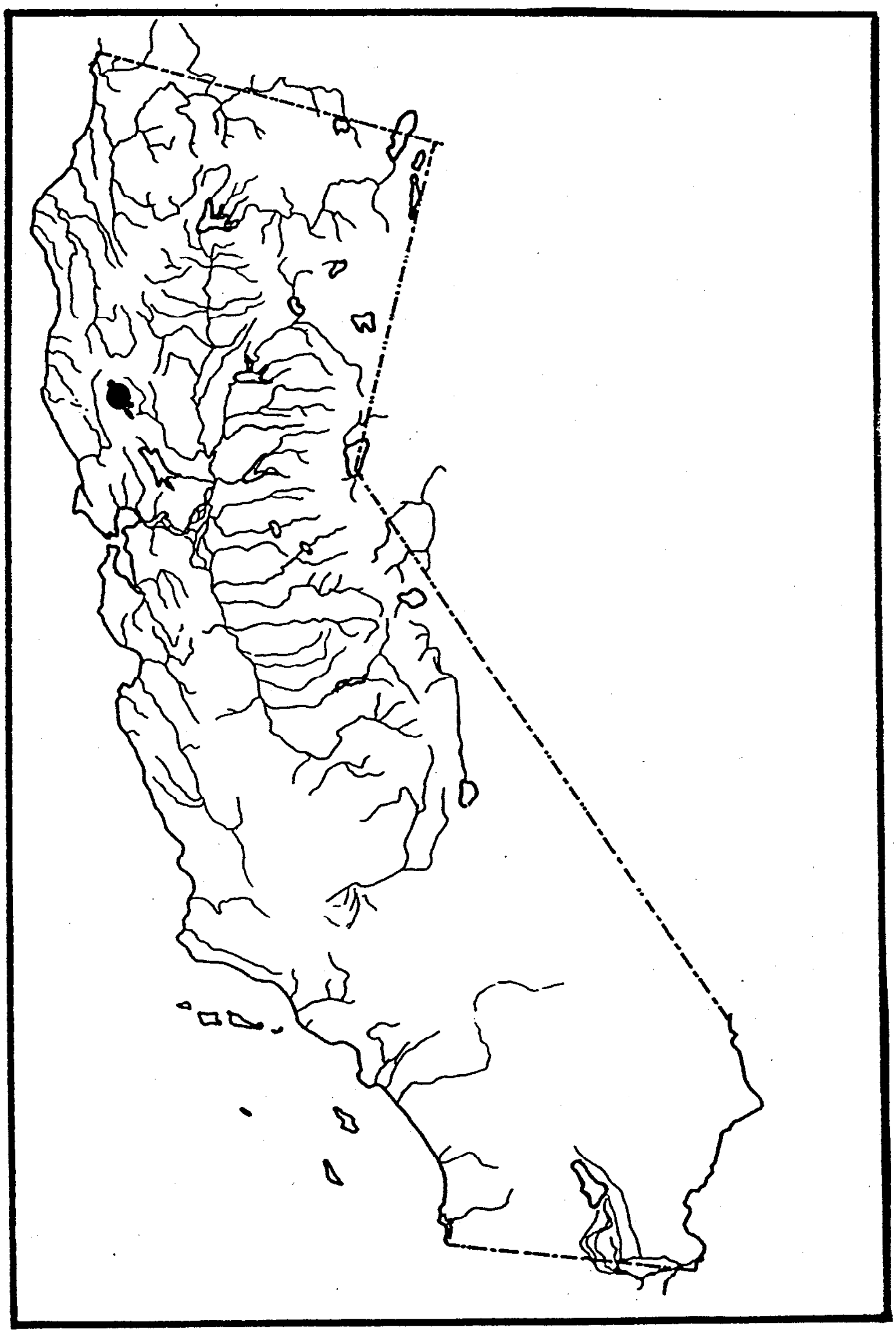


FIGURE 29. Distribution of the Clear Lake hitch, *Lavinia exilicauda chi,* in California.

CALIFORNIA ROACH
Lavinia symmetricus (Baird and Girard)

Status: Class 1. Endangered: Red Hills roach
Class 2. Special Concern: Pit roach
Class 3. Watch List: San Joaquin roach; Monterey roach; Tomales roach; Gualala roach.

Description: Adult California roach are usually <10 cm SL. The body of a typical roach is elongate and rounded in cross section. The head is relatively large and conical. The mouth is small and subterminal. Some populations develop a distinctive "chisel lip," with a cartilaginous plate on the lower jaw. The short dorsal fin has 7-10 rays, and the anal fin, 6-9 rays. Scales are small, with 47-63 along the lateral line, 32-38 of these being anterior to the dorsal fin. Roach have 4-5 pharyngeal teeth adapted for grinding. Coloration is grey-steel blue dorsally and dull silver ventrally. Red-orange patches appear on the chin, opercula, and at the bases of the paired and anal fins of reproductive adults. Like most minnows, reproductive males develop breeding tubercles on the head. Subspecies are distinguished by various distinctive subsets of these characters. Probably the most distinctive is the Red Hills roach, which has a somewhat flattened body, small fins and a chisel lip (Brown et al. 1992).

Taxonomic Relationships: The California roach was first described as *Rutilus symmetricus* (Baird and Girard) and collected from the San Joaquin River near Friant. It was subsequently reassigned to the genus *Hesperoleucus* by Snyder (1913) who described the following six species based on locality and morphological differences:

1. *Hesperoleucus symmetricus* from the Sacramento-San Joaquin Valley.
2. *Hesperoleucus subditus* from the Pajaro River system.
3. *Hesperoleucus venustus* from the San Francisco Bay system and the Russian River and Tomales Bay drainages.
4. *Hesperoleucus parvipinnis* from the Gualala River system in Mendocino County.
5. *Hesperoleucus navarroensis* from the Navarro River system, Sonoma County.
6. *Hesperoleucus mitrulus* from the Pit River system and Goose Lake, Modoc County.

Murphy (1948a) reanalyzed Snyder's data along with his own from coastal streams and concluded that the species should be relegated to subspecies. This diagnosis was accepted by the American Fisheries Society even though Murphy's study was never formally published. It has also been accepted by most subsequent workers (e.g., Moyle 1976, Hubbs et al. 1979), mostly as a matter of convenience. Hopkirk (1973) also examined roach from coastal drainages and concluded that Murphy was correct in placing all roach species together. However, he differed in his conclusions as to what populations should be recognized as subspecies. Hopkirk (1973) considered *H. s. symmetricus, H. s. subditis,* and *H. s. parvipinnis* to be morphologically distinct subspecies, whereas *H. s. venustus* was not different from *H. s. symmetricus*. *Hesperoleucus s. navarroensis* was considered distinct, but also included roach from the Russian River and perhaps the tributaries to Tomales Bay. The Tomales roach populations may, however, be distinct enough to be recognized as a separate subspecies. Hopkirk (1973) warned that his own *H. s. symmetricus* possibly consisted of several subspecies, noting that a collection he examined from the Cosumnes River was quite distinct. Brown et al. (1992) examined roach populations from throughout the San Joaquin River drainage and found that populations from the more isolated tributary basins (e.g., Kaweah and Tule rivers) could be distinguished by multivariate analyses of morphometric data. The Kaweah River population was particularly distinctive because a high percentage had a "chisel lip," with the lower jaw having a projecting cartilaginous plate. One population that was originally discovered by B. Quelvog (CDFG) in small creeks near Sonora is so different from the others that it undoubtedly merits subspecies status (Brown et al. 1992). The California roach "complex" needs to be taxonomically reevaluated. Such an evaluation may turn up new subspecies or even species and perhaps merge presently recognized forms. For the present, we recognize the following forms:

1. Sacramento roach, *L. s. symmetricus.* Sacramento River drainage, except the Pit River, as well as tributaries to San Francisco Bay.
2. San Joaquin Roach, *L. s.* ssp. This form is either several subspecies or part of *L. s. symmetricus.* Tributaries to the San Joaquin River from the Cosumnes River south.
3. Monterey roach, *L. s. subditus.* Tributaries to Monterey Bay, specifically the Salinas, Pajaro, and San Lorenzo drainages.
4. Navarro roach, *L. s. navarroensis.* From the Russian and Navarro Rivers.
5. Tomales roach, *L. s.* ssp. From Walker Creek and other tributaries to Tomales Bay.
6. Gualala roach, *L. s. parvipinnis.* Gualala River.
7. Pit Roach, *L. s. mitrulus.* From the upper Pit River and tributaries, and tributaries to Goose Lake. The roach found in Oregon presumably belongs to this subspecies.
8. Red Hills roach, *L. s.* ssp., from Horton Creek and other small streams near Sonora.

The generic name *Lavinia* is preferred to *Hesperoleucus* because studies have shown little basis for separation of the two genera (Hopkirk 1973, Avise et al. 1975, Moyle and Massingill 1981).

Life History: California roach are omnivores. They feed primarily on filamentous algae, but ingest lesser quantities of crustaceans and aquatic insects (Greenfield and.Deckert 1973, Moyle 1976). They have also been observed feeding on larval lampreys (Moyle, unpubl. data). During the winter their diet consists largely of diatoms and other unicellular algae. Being feeders on soft bottoms, their intestines also contained a high proportion of detritus. However, in the Tuolume River (below Preston Falls) and in the Clavey River large roach have been observed feeding on drift organisms in fairly fast current (Moyle, unpubl. obs.).

Growth is seasonal, with rapid growth during the early summer (Fry 1936). This could be related to food abundance and availability during this time. Roach reach sexual maturity by about the second year (approximately 45 mm SL). Studies also indicate that roach in the Russian and Navarro rivers grow much faster and attain in excess of 45 mm SL by the first year, 69-70 mm by the second year, and 80-90 mm by the third (Moyle 1976).

Reproduction occurs from March to June, but may be extended through late July (Moyle 1976). Murphy (1943) states that spawning is determined by water temperature, which must be approximately 16°C (60°F) for spawning to be initiated. During the spawning season, schools of fish move into shallow areas with moderate flow and gravel/rubble substrate (Moyle 1976). Females deposit adhesive eggs in the substrate interstices and the eggs are fertilized by attendant males. Typically, 250-900 eggs are produced by a female and the eggs hatch within two to three days. The fry remain in the substrate interstices until they are free-swimming.

Habitat Requirements: California roach are generally found in small, warm intermittent streams, and dense populations are frequently found in isolated pools (Moyle 1976, Moyle et al. 1982). They are most abundant in mid-elevation streams in the Sierra foothills and in the lower reaches of some coastal streams (Moyle 1976). Roach are tolerant of relatively high temperatures (30-35°C) and low oxygen levels (1-2 ppm) (Taylor et al. 1982). However, they are habitat generalists, also being found in cold, well-aerated clear "trout" streams (Taylor et al. 1982), in human-modified habitats (Moyle 1976, Moyle and Daniels 1982) and in the main channels of rivers, such as the Russian and Tuolumne.

In the Clear Lake region, roach are found in a wide variety of habitats, from cool headwater streams to the warmwater lower reaches (Taylor et al. 1982). Their abundance in this drainage is positively correlated with such environmental variables as temperature, conductivity, gradient and coarse substrates. Abundance is negatively correlated with depth, cover, canopy, and fast-water habitat (Taylor et al. 1982). They are most numerous in the low-mid elevational streams with high pH, conductivity, and temperature and little cover or canopy. Stream width and depth, however, have little influence on abundance, although roach prefer pools or slow-water sections in the streams.

In the Pit River system, however, Pit roach are found in deep mud/rock-bottomed pools in second or third order streams and in the Pit River itself (Moyle and Daniels 1982). Most such habitat is characterized by low flows, moderate gradients, warm temperatures, and edge mats of duckweed and water ferns. Furthermore, unlike in the Sierra foothill streams where roach abundance is negatively correlated with other species (Moyle and Nichols 1974), in the Pit River there is a positive correlation between the abundance of roach and that of other native fishes. However, Brown and Moyle (1992) demonstrated that habitat use by roach is severely restricted when predatory Sacramento squawfish are present.

Distribution: The overall distribution of California roach and of the various subspecies reflects the geographic isolation of the subspecies (Figure 30). At least two additional populations have resulted from introductions: the Eel (Fite 1973) and Cuyama rivers, San Luis Obispo and Santa Barbara counties, respectively (Moyle 1976). The sources of the introductions are not known.

Abundance: There is little quantitative information available on the abundances of the various subspecies, so the following assessments are highly subjective.

<u>Sacramento roach.</u> Assuming this widely distributed form is indeed just one subspecies, it appears to be abundant in a large number of streams. Nevertheless, it is now absent from many streams and stream reaches where it once occurred (e.g., Leidy 1984), and most populations are probably isolated by downstream barriers such as dams, diversions or polluted water containing predatory introduced fishes. Extinctions without recolonization can therefore be expected.

<u>San Joaquin roach.</u> Surveys by Moyle and Nichols (1973) repeated by Brown and Moyle (1987, 1993) indicate that this form is abundant in many areas, yet it has been eliminated from many others since 1970.

<u>Red Hills roach.</u> This highly distinctive form occurs in a few small streams in an area administered by the BLM and characterized by serpentine soils and stunted vegetation. The largest population, of several hundred individuals, exists in Horton Creek, and smaller numbers occur in Amber and Roach creeks (B. Quelvog, pers. comm.).

<u>Monterey roach.</u> Smith (1982) found this roach to be widespread in the Pajaro and San Benito drainages, but probably less widely distributed than formerly. Since Snyder's (1913) collections in 1908, they have disappeared from four sites.

<u>Navarro roach.</u> This form appears to be abundant in both the Russian and Navarro rivers. The roach have been reported recently to be "extremely numerous in the warmer reaches of the Navarro River, where they may be displacing salmonids" (CDFG 1991b). Although apparently not in trouble, given the effects of

dams on the Russian River and the logging and agricultural practices in the Navarro River drainage, the populations of this subspecies should be monitored.

Tomales roach. Most of the streams in the Tomales drainage have been heavily modified by dams and by erosion due to livestock grazing. The roach nevertheless are abundant in many areas such as the middle reaches of Walker Creek (P. Moyle, unpubl. data).

Gualala roach. This form is common in the Gualala River (CDFG 1991b) and is the dominant fish in some headwater areas (P. Moyle, unpubl. observations). Its numbers may actually have increased temporarily as the result of warmer water associated with habitat degradation (E. Gerstung, pers. comm.).

Pit roach. This roach has apparently disappeared from much of its former range in the upper Pit River drainage (Moyle and Daniels 1982) and is confined to a few scattered populations such as Willow Creek, tributary to Goose Lake. Oregon stocks are classified as "sensitive-peripheral"; the only known Oregon population seems to be in Drews Creek, a tributary to Goose Lake (G. Sato, pers. comm.).

Nature and Degree of Threat: Most populations of California roach are threatened to some degree because they tend to be located in small streams vulnerable to human disturbance (especially diversions) and to introduced predatory fishes (such as green sunfish), to which roach seem exceptionally vulnerable (Brown et al. 1992). The following threats to the subspecies presently in the most trouble often apply to other subspecies as well.

San Joaquin Roach. The problems of conserving the many distinct evolutionary units represented by this form are discussed by Brown et al. (1992). Populations of this subspecies are increasingly being isolated from one another by dams, diversions, and artificial barriers. Much of their habitat is on private land, which is subject to development and/or intense grazing pressure. As a result, many of the streams dry up more frequently or more completely than usual due to diversions and to pumping from the aquifers that feed them. Predators such as largemouth bass and green sunfish are often introduced into the remaining deep pools to provide recreational fishing, often eliminating roach from these pools as a result.

Monterey Roach. Smith (1982) attributes the disappearance of this form from some streams to habitat alteration, including lowered water quality (increased alkalinity, low dissolved oxygen). The streams in the Monterey Bay drainages have been channelized, polluted, diverted, and otherwise altered from a combination of intensive agriculture and grazing, housing developments, road building and other human activities. Dams have reduced flood flows, resulting in the upstream expansion of hitch populations; hybridization and competition with hitch have subsequently eliminated some roach populations. Recent losses of roach populations have occurred when droughts eliminated isolated populations and dams or other human-made barriers have prevented recolonization (J. Smith, pers. comm.). Most of the original habitats of Monterey roach are on private land, where there is little protection for aquatic organisms.

Tomales Roach. This form has a rather restricted distribution in small Marin County streams that are largely on heavily grazed private lands. Thus siltation, bank erosion and loss of riparian cover are constant problems. Equally important, the streams (e.g., Walker Creek) are dammed and diverted, regulating and reducing flows, as well as creating conditions in which nonnative species are more likely to invade.

Gualala Roach. Like the Tomales roach, this form has a rather restricted distribution within a watershed subjected to many insults in recent years (logging, roadbuilding, etc.). While the population seems to be holding its own at the present time, it nonetheless should be monitored and quantitative data obtained so that the population status and effects of droughts and floods can be determined.

Pit Roach. This form apparently was once common and widely distributed in the upper Pit River drainage. Currently, its populations are few and scattered, occuring either in small, isolated streams or in some of the regulated sections of the Pit River. They also occur in some of the tributaries to Goose Lake, notably Willow Creek, where they are locally abundant. Presumably, each population is threatened by different factors, but the principal ones seem to be habitat loss (from heavy grazing in riparian areas, road and housing construction, water diversions, etc.) and introduced predators, such as largemouth bass and green sunfish. Because the populations are now widely scattered, local extinctions due to natural factors can also occur, but without hope of natural recolonization. As a result, the number of populations of this subspecies can be expected to dwindle over the years.

Red Hills roach. The limited serpentine-soil area in which this form occurs is subjected to intense recreational use by off-road vehicles and to grazing and mining, which together are significantly degrading the habitat. Activities causing streamside soil disturbance at the site of the main Horton Creek population pose a particularly serious threat (B. Quelvog, pers. comm.). These activities cause the limited pool habitat to become shallower and warmer and reduces the riparian cover.

Management: The California roach needs a comprehensive study that looks at both systematics and distribution. An analysis of their systematics is especially needed because the recent discovery of the Red Hills roach and the study by Brown et al. (1992) indicate that a number of undescribed forms of this fish may exist around the state. Immediate needs are to find streams in the Pit River and San Joaquin River drainages that can be managed as refuges for Pit roach and San Joaquin roach, respectively. The Red Hills roach needs to have all its known stream habitats protected and managed to its benefit (and other native organisms in this unusual area). Measures would include restrictions on mining, off-road vehicle use and grazing. The Tomales and Gualala roach would benefit from watershed management practices that improve instream and riparian habitats. In absolute terms, most subspecies of California roach still are abundant, but there is growing evidence that local populations are disappearing one at a time (Moyle and Nichols 1973, Moyle and Daniels 1982, Brown and Moyle 1992, Brown et al. 1992). It would be prudent to at least stabilize populations of all subspecies at their present level of abundances. As a minimum measure, Moyle and Yoshiyama (1992) suggest that a system of Aquatic Diversity Management Areas (ADMAs) be established that would include special ADMAs for each subspecies of roach. Because California roach are often a good indicator species of relatively undisturbed conditions, a system of such preserves would not only protect the species, but its entire biotic community. In the meantime, populations should be monitored to ascertain the status of each subspecies.

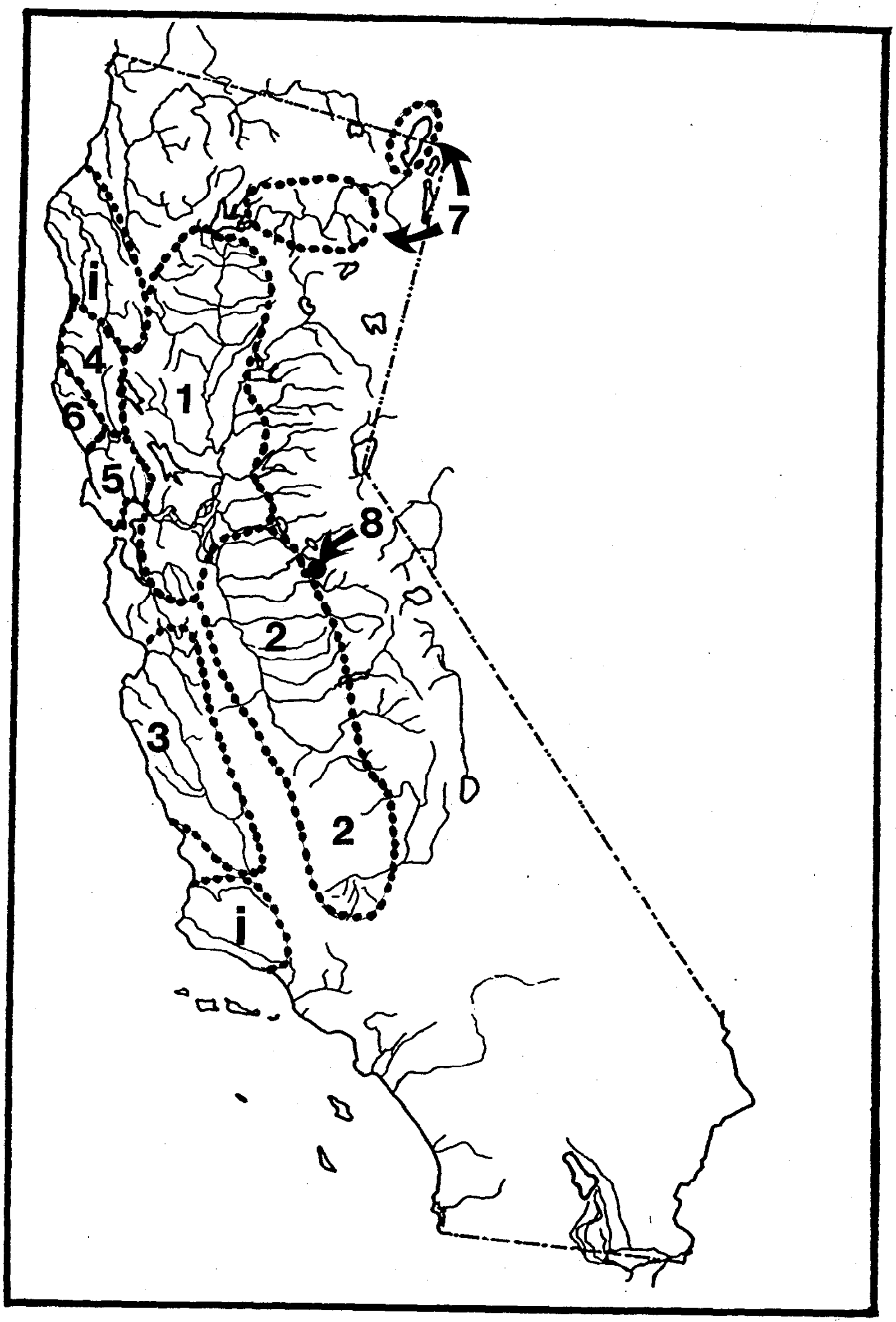


FIGURE 30. Distribution of the California roach, *Lavinia symmetricus*. The numbers correspond to the distributions of the following subspecies: 1 = Sacramento roach, 2 = San Joaquin roach, 3 = Monterey roach, 4 = Navarro roach, 5 = Tomales roach, 6 = Gualala roach, 7 = Pit roach, 8 = Red Hills roach, i = introduced populations.

SACRAMENTO SPLITTAIL
Pogonichthys macrolepidotus (Ayres)

Status: Class 1. Threatened. Proposed for threatened status by the USFWS in December 1993 but listing was deferred in 1995.

Description: Splittail are large cyprinids, growing in excess of 30 cm SL, and are distinctive in having the upper lobe of the caudal fin larger than the lower lobe. The body shape is elongate with a blunt head. Small barbels may be present on either side of the subterminal mouth. They possess 14-18 gill rakers. Pharyngeal teeth are hooked and have narrow grinding surfaces. Dorsal rays number 9-10, pectoral rays 16-19, pelvic rays 8-9, and anal rays 7-9. The lateral line usually has 60-62 scales, but ranges from 57 to 64. The fish are silver on the sides and olive grey dorsally. Adults develop a nuchal hump. During the breeding season, the caudal, pectoral, and pelvic fins take on a red-orange hue and males develop small white nuptial tubercles in the head region.

Taxonomic Relationships: This species was first described in 1854 by W. O. Ayres as *Leuciscus macrolepidotus* and by S. F. Baird and C. Girard as *Pogonichthys inaeqilobus.* Ayres' species description is accepted as the official one, but *Pogonichthys* was accepted as the genus name in recognition of its distinctive characteristics (Hopkirk 1973). The splittail is considered by some taxonomists to be allied to cyprinids of Asia (Howes 1984). The genus *Pogonichthys* consists of two species, *P. ciscoides* Hopkirk and *P. macrolepidotus* (Hopkirk 1973). *P. ciscoides* from Clear Lake, Lake County, became extinct in the early 1970s.

Life History: Splittail are relatively long-lived (about five to seven years) and are highly fecund (up to 100,000 eggs per female). Their populations fluctuate on an annual basis depending on spawning success and strength of the year class (Daniels and Moyle 1983). Both male and female splittail mature by the end of their second year (Daniels and Moyle 1983), although occasionally males may mature by the end of their first year and females by the end of their third year (Caywood 1974). Fish are about 180-200 mm SL when they attain sexual maturity (Daniels and Moyle 1983), and the sex ratio among mature individuals is 1:1 (Caywood 1974).

There is some variability in the reproductive period, with older fish reproducing first, followed by younger fish which tend to reproduce later in the season (Caywood 1974). Generally, gonadal development is initiated by fall, with a concomitant decrease in somatic growth (Daniels and Moyle 1983). By April, ovaries reach peak maturity and account for approximately 18% of body weight. Spawning onset seems to be associated with increasing water temperature and day length and occurs between early March and May in the upper Delta (Caywood 1974). However, Wang (1986) found that in the tidal freshwater and euryhaline habitats of the Sacramento-San Joaquin estuary, spawning occurs by late January/early February and continues through July. Spawning times are also indicated by the salvage records from SWP pumps. Adults are captured most frequently in December through May, when they are presumably engaged in spawning movements, while young-of-year are captured most abundantly in May through September (Meng and Moyle, in press). These records indicate most spawning takes place from February through April, following an upstream migration by the adults.

Splittail probably spawn on submerged vegetation in flooded areas, and spawning occurs in the lower reaches of rivers (Caywood 1974), dead-end sloughs (Moyle 1976) and in the larger sloughs such as Montezuma Slough (Wang 1986). Larvae remain in the shallow, weedy areas inshore in close proximity to the spawning sites and move into the deeper offshore habitat as they mature (Wang 1986).

The stock-recruitment relationship in splittail is weak (r^2 = .22, N = 14, Meng and Moyle, in press), because strong year classes can be associated with relatively low adult numbers in years with high outflow in early spring (1982, 1986). Also, in most years since 1983, recruitment has been lower than expected, given the strong positive relationship between outflow and abundance of splittail young-of-year (Meng and Moyle, in press).

Splittail are benthic foragers that feed extensively on opossum shrimp *(Neomysis mercedis)*. However, detrital material typically makes up a high percentage of their stomach contents. They will feed opportunistically on earthworms, clams, insect larvae, and other invertebrates. They are preyed upon by striped bass and other predatory fishes. The preference for splittail by striped bass has long been recognized by anglers, who fish for splittail to use them for bait.

Habitat Requirements: Splittail are primarily freshwater fish, but are tolerant of moderate salinities and can live in water with salinities of 10-18 ppt (Moyle 1976, unpubl. obs.). In the 1950s, they were commonly caught by striped bass anglers in Suisun Bay during periods of fast tides (D. Stevens, pers. comm.). During the past 20 years, however, they have been found mostly in slow-moving sections of rivers and sloughs, and in the Delta and Suisun Marsh they seemed to congregate in dead-end sloughs (Moyle 1976, Moyle et al. 1982, Daniels and Moyle 1983). Overall, they seem to have a preference for low-salinity, shallow-water habitat (Meng and Moyle, in press). Young-of-year and age-1 splittail were common in beach seine sampling by CDFG during 1992 along the Sacramento River between Rio Vista and Chipps Island (R. Baxter, pers. comm.) indicating that in some years juvenile splittail may favor the more riverine habitats in the Delta, downstream from the areas where they were spawned. Splittail apparently require flooded vegetation for spawning and as foraging areas for young, hence are found in habitat subject to periodic flooding during the breeding season (Caywood 1974). Currently, the place where splittail are most abundant is Suisun Marsh, although they are also common in and around the marshy areas of Shennan Island and Big Break (Meng and Moyle, in press). They are year-round residents of the Marsh, concentrating in the dead-end sloughs that typically have small streams feeding into them (Moyle et al. 1985). They tend to be most abundant where other native fishes, as well as striped bass, are abundant. In Suisun Marsh, trawl catches are highest in summer when salinities are 6-10 ppt and temperatures are 15-23°C (Moyle et al. 1985), reflecting an influx of young-of-year fish.

Daniels and Moyle (1983) found that year-class success of splittail was positively correlated with Delta outflow, and Caywood (1974) found that a successful year class was associated with winter runoff sufficiently high to flood the peripheral areas of the Delta. These observations were confirmed by a CDFG analysis (CDFG 1992b). Meng and Moyle (in press) indicated that there was a negative relationship between the amount of water diverted from the Delta and abundance of young splittail, and noted that the effect of the diversions was particularly strong during periods of prolonged drought.

Distribution: The Sacramento splittail is a California Central Valley endemic that was once distributed in lakes and rivers throughout the Central Valley. They were found as far north as Redding by Rutter (1908), who collected them at the Battle Creek Fish Hatchery in Shasta County. Splittail are no longer found in this area and are limited by the Red Bluff Diversion Dam in Tehama County to the downstream reaches of the Sacramento River. They also enter the lower reaches of the Feather River on occasion, but records indicate that Rutter (1908) had collected them as far upstream as Oroville. Splittail are also known from the American River and have been collected at the Highway 160 bridge in Sacramento, although in the past Rutter (1908) collected them as far upstream as Folsom. He also collected them from the Merced River at Livingston and from the San Joaquin River at Fort Miller (where Friant Dam is today). Gobalet and Fenenga (1993) found that splittail were consumed by the Indians that lived around the now-dry Tulare Lake in the southern San Joaquin Valley, so it is likely their native range included most of the San Joaquin Valley. Snyder (1905) reported catches of splittail from southern San Francisco

Bay and at the mouth of Coyote Creek in Santa Clara County, but recent surveys indicate that splittail are no longer present at these locations (Leidy 1984).

Splittail are now largely confined to the Delta, Suisun Bay, Suisun Marsh, Napa River, Petaluma River, and other parts of the Sacramento-San Joaquin estuary (Caywood 1974, Moyle 1976 and unpubl. data). In the Delta, they are most abundant in the north and west portions, although other areas may be used for spawning (CDFG 1987). This may reflect a shrinking of their Delta habitat because Turner (1966a) found a more even distribution throughout the Delta. Recent surveys of San Joaquin Valley streams found splittail in the San Joaquin River below its confluence with the Merced River (Saiki 1984, Brown and Moyle 1993); large numbers of juveniles were caught in 1986 in the San Joaquin River 10-12 km above the junction with Tuolumne River (T. Ford, pers. comm.). Successful spawning has been recorded in the lower Tuolumne River during wet years in the 1980s, with both adults and juveniles observed at Modesto, 11 km upriver from the river mouth (T. Ford, pers. comm.). Further surveys are needed to determine how far up the San Joaquin River splittail presently occur, and if they are present in the Merced River and other tributaries. Occasionally, splittail are caught in San Luis Reservoir (Caywood 1974) which stores water that has been pumped from the Delta. In the Sacramento River system, splittail are rare in the main river channel upstream of the Delta, although large individuals are caught in the lower river during spring in large fyke traps set to catch striped bass migrating upstream to spawn (CDFG unpubl. data). Presumably, the splittail are also on a spawning migration and it is likely that in many years spawning concentrates in the reach of the Sacramento River below the confluence with the Feather River (J. Wang, pers. comm.). During wet years, the shallow flooded areas of the Yolo and Sutter bypasses may also be important for spawning (Meng and Moyle in press).

Abundance: Splittail have disappeared from much of their native range because dams, diversions, and agricultural development have eliminated or drastically altered much of the lowland habitat these fish once occupied. Access to spawning areas or upstream habitats is now blocked by dams on the large rivers because splittail seem incapable of negotiating existing fishways. As a result they are restricted to water below Red Bluff Diversion Dam on the Sacramento River, below Nimbus Dam on the American River and below Oroville Dam on the Feather River. They are rare, however, more than 10-20 km above the upstream boundaries of the Delta. Caywood (1974) found a consensus among splittail anglers that the fishery has declined since the completion of Folsom and Oroville dams. In the San Joaquin River, their distribution may be limited in good part by water quality (high temperature, pollutants) because they seem to move up the river only during wet years.

Today the principal habitat of splittail is the Sacramento-San Joaquin estuary, especially the western Delta and Suisun Marsh. Their abundance in this system is strongly tied to outflows, presumably because spawning occurs over flooded vegetation. Thus, when outflows are high, reproductive success is high, but when outflows are low, reproduction tends to fail (Daniels and Moyle 1983). The CDFG confirms this observation:

> "[S]uccessful reproduction is strongly associated with high outflows preceding, during and following spawning as demonstrated by high correlations between abundance of splittail in the fall midwater trawl survey and various monthly combinations of Delta outflow from the previous winter through early summer:" (CDFG 1992b, p. 2)

Even within their constricted range in the Delta, splittail populations are estimated to be only 35 to 60 percent as abundant as they were in 1940 (CDFG 1992b), and considered over their historic range, the percentage decline is much greater. Since 1980, splittail numbers in the Delta have declined steadily (Moyle et al. 1986), and in 1992 numbers declined to the lowest on record (Meng and Moyle, in press).

Population levels appear to fluctuate widely from year to year; CDFG midwater trawl data for 1967-1990 indicate a decline from the mid-1960s to the late 1970s, a resurgence (with fluctuations) through the mid-1980s, and a decline since 1986. Survey data for Suisun Marsh (Meng and Moyle, in press) show a substantial decline in numbers during the period 1979-1991 (catch per trawl of 7 adults and 15 young-of-year in 1979; 2 adults and 1 young-of-year per trawl in 1991; mean catch in 1979-1983, ca. 188 fish per month; mean catch in 1987-1990, ca. 25 fish per month; 1990-1992, 3-5 fish per month). Data from the CDFG Bay survey and fish salvage operations for the SWP and CVP south Delta indicate that splittail recruitment success is highly variable from year to year. Large pulses of young fish were observed in 1982, 1983 and 1986, but recruitment was low in 1980, 1984, 1985 and 1987-1990. Since 1985, splittail have been rare in San Pablo Bay, reflecting a constriction of their distribution to the upper Bay-Delta areas and to isolated areas such as the Petaluma and Napa rivers.

Nature and Degree of Threat: Since the start of the massive influx of non-native peoples into California in the 1850s, the range and abundance of splittail has steadily declined. It is now largely confined to the Sacramento-San Joaquin estuary, except for occasional forays upstream to spawn. This means that its long-term survival depends upon conditions in the estuary and having adequate spawning habitat. The continuing decline in splittail numbers can be attributed to a variety of interacting factors. Approximate order of importance is: (1) changed estuarine hydraulics, especially reduced outflows, (2) modification of spawning habitat, (3) climatic variation, (4) toxic substances, (5) introduced species, (6) predation, and (7) exploitation.

Changed estuarine hydraulics. For Sacramento splittail, the preeminent factor in their decline appears to have been habitat constriction associated with the reduction of water flows and changed hydraulics in the Sacramento-San Joaquin Delta. CDFG (1992b) indicates that such changes are probably the largest factor contributing to the decline of splittail because of the strong positive correlation between splittail year class success and outflows. The USBR has acknowledged the adverse effects of the delta export facilities on the estuarine fishes in its testimony to the State Water Resources Control Board in the interim water rights proceeding for the Bay-Delta Estuary (1992):

> ". . . Reclamation believes the negative impact of Delta diversions on the fisheries and food chain is largely a consequence of the flow patterns (hydrodynamics) resulting from Delta inflow and CVP/SWP exports. Consequently, any proposed solution must address this important issue if it is to be effective in the long-term." (WRINT-USBR-Exhibit Number 10, p. 8.)

While the exact mechanism that reduces splittail survival during low outflow-high diversion years is not well understood, direct entrainment in the CVP and SWP pumps and shifting of splittail populations to the presumably less favorable conditions of the south Delta are likely contributors to low survival. During the period of decline, exceptionally high numbers of splittail have been salvaged from the pumping plants in some years (1982, 1986, 1993), with no apparent relationship to actual abundance. In addition, since 1983 catches of splittail in the fall midwater trawl survey have become more frequent in the south Delta and the Sacramento River and less frequent in Suisun Bay (Meng and Moyle 1995). This may expose larval or young of year splittail to increased probability of within-delta entrainment, as well as placing them in conditions less favorable for growth and survival.

Modification of spawning habitat. While the spawning habitat and habitat of larval splittail have not been well characterized, the best evidence indicates that they spawn on flooded vegetation in the lower reaches of rivers and perhaps in the Delta as well. It is probable that the early larval stages also live in the flooded vegetation, where rotifer and microcrustacean populations are likely to be high. The increase in flooded vegetation is presumably one of the factors contributing to splittail year-class success in wet years. The decrease in riparian marshlands (floodable areas) in recent decades is consequently likely to be a major contributor to the general decline in splittail numbers. When the Yolo and Sutter bypasses are covered with flood waters, splittail apparently will use them for spawning although both adults and young may be stranded when the water to the bypasses is suddenly shut off (Jones and Stokes Associates, unpubl. data).

Climatic fluctuations. The past 15 years have seen some of the most extreme environmental conditions the estuary has experienced since the arrival of Europeans. The past eight years have been ones of continuous drought, broken only by the record outflows of February 1986. The prolonged drought has had two major interacting effects: a natural decrease in outflow and an increase in the proportion of inflowing water being diverted. A natural decline in splittail numbers would be expected from the reduced outflow, presumably because of the reduced availability of spawning and larval rearing habitat. However, the increase in diversions has decreased the survival of splittail through a combination of further reduction in habitat, especially in the lower Delta and Suisun Marsh, and increased entrainment of larvae, juveniles, and adults. It is important to recognize that extreme floods and droughts have occurred in the past and splittail have managed to persist. However, the splittail historically did not experience the extreme conditions caused by increased diversion of water nor did they have the reduced populations that make recovery from natural disasters much more difficult.

Toxic substances. The effects of pesticides and other toxic substances on splittail is not known, but there is considerable potential for negative interactions, especially when larvae are in riverine areas or near wastewater discharge areas. This area needs investigation.

Introduced species. Introduced species are a perpetual problem in the Sacramento-San Joaquin estuary, especially those that are introduced “accidentally” from the ballast water of ships. The most recent problem introductions have been several species of planktonic copepods and an Asiatic clam, *Potamocorbula amurensis.* The copepods are regarded as a problem because they seem to be replacing *Eurytemora affinis,* a native copepod that has been the favored food of larval fish and of opossum shrimp, the favored prey of splittail. Although one of the introduced copepod species *(Sinocalanus doerri)* seems to be harder for larval fish (and perhaps opossum shrimp, L. Meng, USFWS, unpubl. data) to capture, other introduced copepod species probably do not present the capture problems of *S. doerri* (e.g., Meng and Orsi 1991). The Asiatic clam, in contrast, may have a direct effect on splittail populations because it has become extremely abundant in Suisun Bay, from which it appears to be filtering out much of the planktonic algae, the base of the food web that leads to splittail through opossum shrimp (Nichols et al. 1990). The splittail occurs in many areas where the clam is not abundant. The clam, however, is not a direct cause of the initial decline of splittail because it did not invade until after February 1986, when the estuary's biota had been devastated by immense outflows (Nichols et al. 1990). The clam’s present abundance may make the recovery of splittail more difficult but it is quite likely that the Asiatic clam will become less abundant in response to increased freshwater outflows and to its discovery as a food source by fishes such as sturgeon, by invertebrates such as the invading mitten and green crabs, and by diving ducks. A typical pattern for invading species is to have a population explosion in response to optimal conditions at the time of invasion (due to the absence of their predators, parasites, etc.) and then a decline to lower levels as the local ecosystem adjusts to their presence.

Predation. Splittail are preyed upon by introduced striped bass but they have successfully coexisted with them since their introduction in the 1870s. However, it is possible that increased predation by bass and other predators on splittail drawn into Clifton Court Forebay by the changed hydraulics of the Delta may be a contributing factor in their decline. In addition, the artificial enhancement of striped bass populations with hatchery fish (until 1992, when it was halted by CDFG) may have artificially increased predation rates on splittail.

Exploitation. Although splittail have been harvested as food and bait by sport anglers, there is no evidence that this exploitation has contributed to their decline. However, the Asian sport fishery concentrates on presumably spawning fish, which could inhibit recovery of the species.

Management: Principal spawning areas of splittail need to be identified so they can be protected and/or managed for proper conditions. Habitat requirements of young-of-year splittail, especially for the first month of life, need to be identified to determine special protective measures. Because successful reproduction is strongly associated with high Delta outflows preceding, during and following spawning (CDFG 1992b), additional measures are necessary to limit diversion of water from the Delta and to ensure adequate inflow from the lower reaches of the rivers during spring months.

Survival of the Sacramento splittail is dependent upon protection of the habitat it needs in all stages of its life. The geographic extent of this critical habitat encompasses all of the Delta including the Sacramento River up to and including the lower mile of the American River, and the San Joaquin River as far as Modesto and including the lower mile of the Tuolumne River; Suisun Bay, including Suisun Marsh; Napa Marsh; and all areas fed by Petaluma Creek. As is the case with several other fish species that share this geographical habitat, physical and biological conditions are related to adequate Delta outflows are critical. Thus, recovery of the Sacramento splittail will require the following conditions:

1. Adequate fresh water (<1 ppt) and flooded vegetation in spawning areas during March and April to ensure successful reproduction.

2. Adequate flows down the rivers when splittail are spawning to facilitate rapid transport of juveniles to Suisun and San Pablo Bays.

3. High enough late-spring (April-June) outflows and/or other measures to keep juvenile and larval splittail out of the southern Delta in order to reduce entrainment.

The Delta Native Fishes Recovery Plan (USFWS 1994) provides specific criteria with which to measure splittail recovery, based on catches in three monitoring programs: CDFG Bay survey and fall midwater trawl survey, and UCD's Suisun Marsh sampling. Essentially, the recovery plan recommends that splittail populations be maintained in the estuary at levels no lower than those present in the early 1980s, even though these numbers are presumably significantly lower than they were historically.

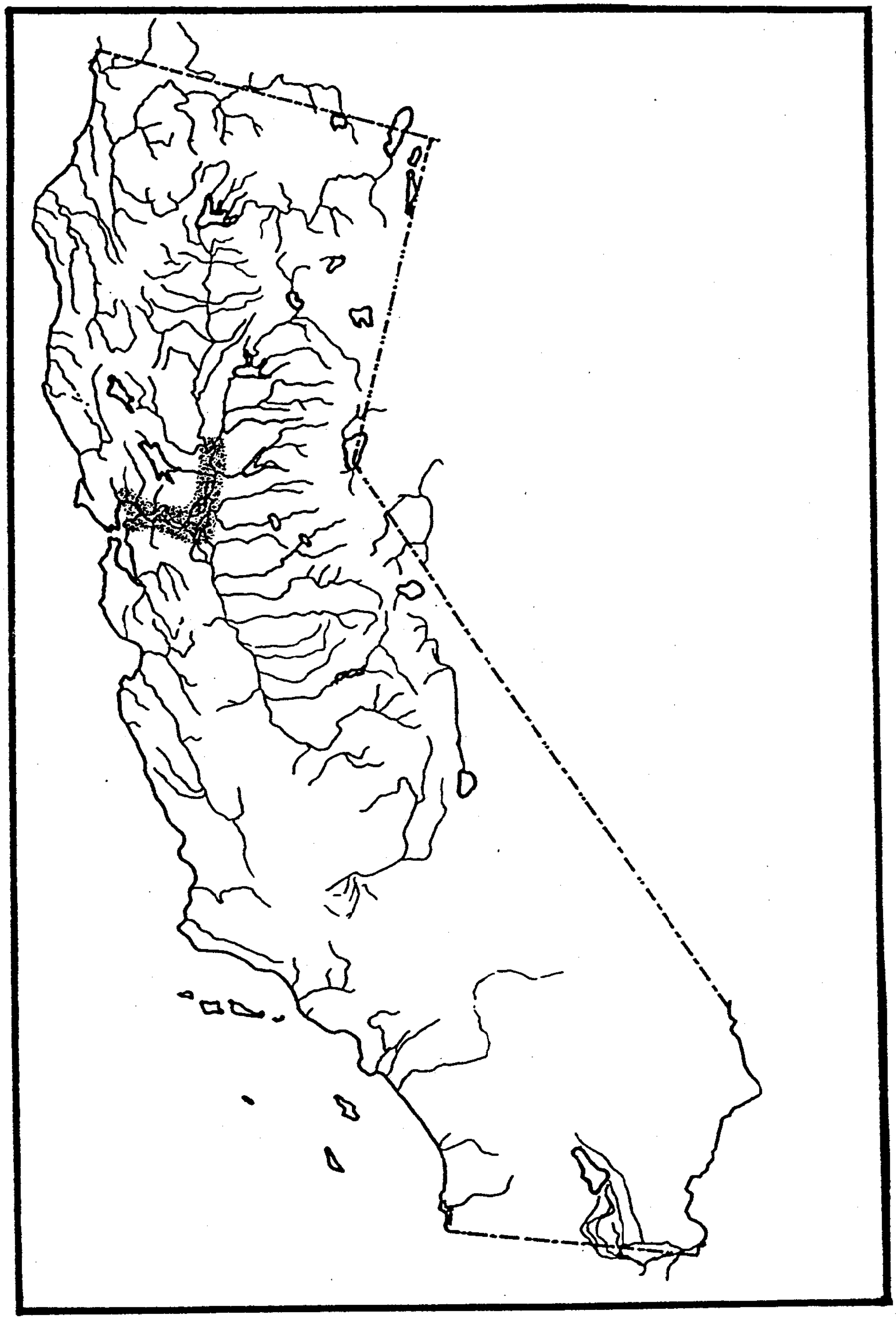


FIGURE 31. Distribution of Sacramento splittail, *Pogonichthys macrolepidotus*, in California.

HARDHEAD
Mylopharodon conocephalus (Baird and Girard)

Status: Class 3. Watch List.

Description: Hardhead are large cyprinids, reaching lengths in excess of 60 cm SL. Body shape is similar to that of Sacramento squawfish, with which they co-occur, but the body is deeper and heavier and the head is less pointed. Hardhead also differ from squawfish in that their maxilla do not extend beyond the anterior margin of the eye and they possess a frenum connecting the premaxilla to the head. Hardhead have 8 dorsal rays, 8-9 anal rays, and 69-81 lateral line scales. Adults have large molariform pharyngeal teeth, but juvenile teeth are hooklike. Juveniles are silver; adults are brown-bronze dorsally. During the spawning season adult males develop fine nuptial tubercles in the head region (Moyle 1976).

Taxonomic Relationships: *Mylopharodon conocephalus* was first described as *Gila conocephala* Baird and Girard (Girard 1854b) from one specimen collected from the "Rio San Joaquin." Ayres (1854a) redescribed the species as *Mylopharodon robustus.* Girard (1856a) recognized the generic designation and reclassified *G. conocephala* as *Mylopharodon conocephalus* and recognized *M. robustus* as a closely allied species. Jordan (1879), however, considered the genus monotypic and united both forms as *Mylopharodon conocephalus* (Jordan and Gilbert 1882) and attributed the generic nomenclature to Ayres and the specific nomenclature to Girard and Baird. Electrophoretic studies by Avise and Ayala (1976) and morphometric analysis by Mayden et al. (1991) indicate it to be closely allied to Sacramento squawfish in the California fauna but different enough to be retained in a separate genus.

Life History: Hardhead are bottom feeders that forage for benthic invertebrates and aquatic plant material in quiet water. Occasionally they will also feed on plankton and surface insects, and in Shasta Reservoir they were known to feed on cladocerans (Wales 1946). Smaller fish (<20 cm SL) feed primarily on mayfly larvae, caddisfly larvae, and small snails (Reeves 1964), whereas the larger fish feed more on aquatic plants (especially filamentous algae), as well as crayfish and other large invertebrates (Moyle, unpubl. data). The ontogenetic changes in teeth structure seems to fit this dietary switch. Reeves (1964) stressed that no fish remains have been found in the stomachs of large hardhead.

In Britton Reservoir, Shasta County, adult hardhead concentrated in the surface waters (<1 m) and could often be seen motionless close to the surface (Vondracek et al. 1988). This behavior made them an important prey for bald eagles that nested in the area.

Hardhead reach 7-8 cm by their first year, but growth slows in subsequent years. In the American River, hardhead reach 30 cm SL in 4 years; in the Pit and Feather rivers, it typically takes six years to reach that length (Moyle et al. 1983, PG&E 1985). The Feather River fish in the 44-46 cm SL range were aged at 9-10 years, but older and larger fish probably exist in the Sacramento River.

Hardhead mature following their second year and presumably spawn in the spring (Reeves 1964), judging by the upstream migrations of adults into smaller tributary streams during this time of the year (Wales 1946, Murphy 1947, Bell and Kimsey 1955, Rowley 1955). Shapovalov (1932) reported the presence of mature eggs in females during March, but gonads of males and females caught in July and August were spent (Reeves 1964). Estimates based on juvenile recruitment suggest that hardhead spawn by May-June in Central Valley streams and that the spawning season may extend into August in the foothill streams of the Sacramento-San Joaquin drainage (Wang 1986).

Spawning activity has not been documented, but reproductive behavior presumably involves mass spawning in upstream gravel riffles (Moyle 1976). Females are highly fecund, producing over 20,000 eggs (Bums 1966) although Reeves (1964) reported fewer (9,500-10,700) eggs.

Habitat Requirements: Hardhead are typically found in undisturbed areas of larger middle- and low-elevation streams (Moyle and Nichols 1973, Daniels and Moyle 1982). Elevational range of hardhead is 10-1,450 m (Reeves 1964). Most streams in which they occur have summer temperatures in excess of 20°C, and optimal temperatures for hardhead (as determined by laboratory choice experiments) appear to be 24-28°C (Knight 1985). However, in a natural thermal plume, hardhead generally selected temperatures of 17-21°C (cooler, but usually not warmer, temperatures were available). Cech et al. (1990) demonstrated that hardhead are relatively intolerant of low oxygen levels, especially at higher temperatures, a factor which may limit their distribution to well oxygenated streams and the surface water of reservoirs. Hardhead prefer clear, deep (> 1 m) pools with sand-gravel-boulder substrates and slow water velocities (<25 cm sec^{-1}) (Moyle and Nichols 1973, Knight 1985, Moyle and Baltz 1985). In streams, adult hardhead tend to remain in the lower half of the water column, rarely moving into the upper water column (Knight 1985), while juveniles concentrate in shallow water close to the stream edges (Moyle and Baltz 1985). However, in Britton Reservoir (Vondracek et al. 1988) and in large pools of the Pit River downstream from the reservoir (Hunt et al. 1988), they were found close to the surface. Hardhead are always found in association with Sacramento squawfish and usually with Sacramento suckers. They tend to be absent from streams where introduced species, especially centrarchids, predominate (Moyle and Nichols 1973, Moyle and Daniels 1982) or streams that have been severely altered by human activity (Baltz and Moyle 1993).

Hardhead populations are well established in mid-elevation reservoirs used exclusively for hydroelectric power generation, such as the Redinger and Kerkhoff Reservoirs on the San Joaquin River, Fresno County, and Britton Reservoir on the Pit River, Shasta County. In the Pit River, hardhead are most abundant in Upper Lake Britton where habitat is more riverine and less abundant in the lacustrine habitat of Lower Lake Britton, where centrarchids are more abundant (PG&E 1985). The initial establishment of hardhead in recently impounded reservoirs is probably the result of residual populations of juvenile fish growing to large sizes before populations of predatory centrarchid basses are established.

Distribution: Hardhead are widely distributed in low to mid-elevation streams in the main Sacramento-San Joaquin drainage as well as in the Russian River drainage. Their range extends from the Kern River, Kern County, in the south to the Pit River (south of the Goose Lake drainage), Modoc County, in the north. In the San Joaquin drainage, populations are scattered in the tributary streams, but are absent from the valley reaches of the San Joaquin River (Moyle and Nichols 1973, Saiki 1984, Brown and Moyle 1987). In the Sacramento River drainage, hardhead are present in most of the larger tributary streams as well as in the Sacramento River. They are present in the Russian River and in the Napa River, although the Napa River population is very restricted in its distribution (R. Leidy, pers. comm.). They are widely, if spottily, distributed in the Pit River drainage (Cooper 1983, Moyle and Daniels 1982), including the main Pit River and its series of hydroelectric reservoirs.

Abundance: Historically, hardhead have been regarded as a widespread and locally abundant species (Ayres 1854b, Jordan and Evermann 1896, Evermann 1905, Rutter 1908, Follett 1937, Murphy 1947, Soule 1951, Reeves 1964). Hardhead are still widespread in the foothill streams, but their specialized habitat requirements, combined with widespread alteration of downstream habitats, has resulted in localized, isolated populations. This makes them vulnerable to localized extinctions. Consequently, hardhead are much less abundant than they once were, especially in the southern half of their range. Reeves (1964) summarized the historical records and noted they were found in most streams in the San Joaquin drainage, but Moyle and Nichols (1973) found them in only 9% of the streams they sampled. Brown and Moyle (1987, 1993) resampled most of the sites of Moyle and Nichols (1973) and found that a number of hardhead populations had disappeared during the 15-year period.

Hardhead have been abundant enough in reservoirs in the past to be regarded as a problem species, under the assumption they competed with trout and other gamefishes for food. However, most of these reservoir populations proved to be temporary, presumably the result of colonization of the reservoir by juvenile hardhead before introduced predators became established. Populations in Shasta Reservoir, Shasta County, declined dramatically within two years (Reeves 1964), although hardhead are still present there in small numbers (J. Hayes, pers. comm.). Similar crashes of large reservoir populations have been reported from: Pardee Reservoir on the Mokelumne River, Amador/Calaveras County (Kimsey et al. 1956); Millerton Reservoir on the San Joaquin River, Fresno County (Bell and Kimsey 1955); Berryessa Reservoir, Napa County (Moyle 1976); Don Pedro Reservoir, Tuolumne County; and Folsom Reservoir, El Dorado County (Kimsey et al. 1956).

Nature and Degree of Threat: Hardhead require large to medium-sized, cool to warm-water streams with natural flow regimes for their long-term survival. Because such streams are increasingly dammed and diverted, thus eliminating habitat, isolating upstream areas, or creating temperature and flow regimes unsuitable for hardhead, populations are declining or disappearing gradually throughout its range. A particular problem seems to be predation by smallmouth bass. Brown and Moyle (1993) observed that hardhead disappeared from the upper Kings River when the reach was invaded by the bass; a similar situation exists in the South Fork Yuba River (Gard 1994). Hardhead can colonize reservoirs but will persist only if exotic species, especially centrarchid basses, are not abundant. The few reservoirs in which they are abundant today are those in which water-level fluctuations (such as for power-generating flows) prevent exotic species from reproducing. However, either stabilization of water levels or increasing the amount of seasonal fluctuation of these reservoirs can result in increased populations of centrarchid basses and decreased hardhead populations.

Management: In absolute terms, hardhead still are abundant, but their recent downward population trend matches the declines shown by other California native fishes. It would be prudent to stabilize hardhead populations while they still are at moderate levels. The best way to protect hardhead is to have a number Aquatic Diversity Management Areas established in mid-elevation canyon areas in which normal flow regimes and high water quality are maintained (Moyle and Yoshiyama 1992, Baltz and Moyle 1993). Because hardhead are good indicator species of relatively undisturbed conditions, a system of such preserves would protect not only the species, but their entire biotic community. In the meantime, stream populations should be monitored to ascertain species' status. Particular attention should be paid to the Russian River population which may have declined in recent years and to populations in the San Joaquin drainage, which seem to be disappearing rapidly.

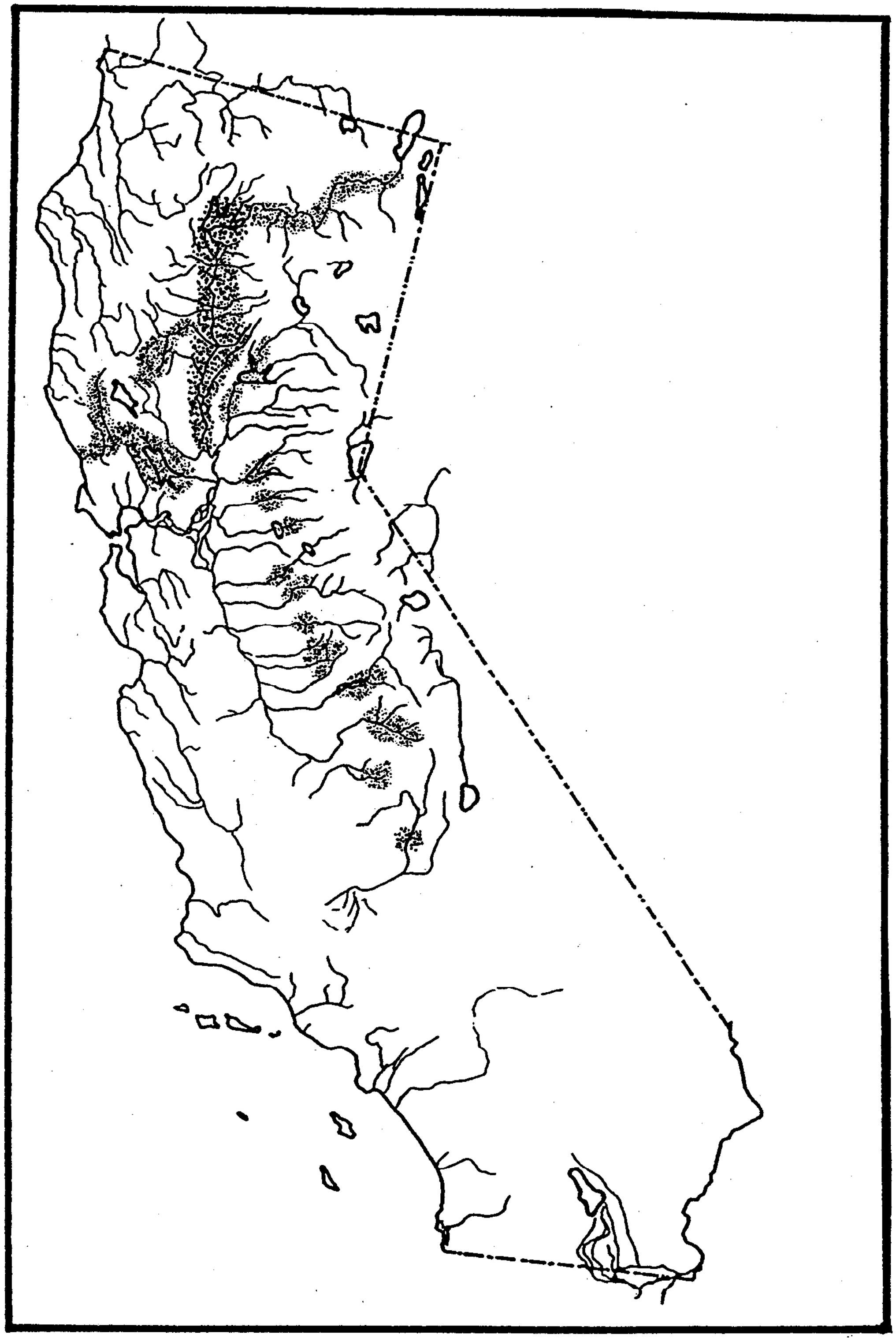


FIGURE 32. Distribution of hardhead, *Mylopharodon conocephalus*, in California.

AMARGOSA CANYON SPECKLED DACE
***Rhinichthys osculus* ssp.**

Status: Class 1. Threatened.

Description: Speckled dace are small cyprinids, usually <90 mm TL, but Amargosa dace are small even for this species, rarely reaching 60 mm TL. They have a small, subterminal mouth, a pointed snout, thick caudal peduncle and slender body. The dorsal fin is set posterior to the origin of the pelvic fins. There are 6-9 dorsal fin rays (usually 8) and 6-7 anal fin rays (occasionally 8). Scales are small and there are 47-89 along the lateral line. The pharyngeal teeth are hooked with slight grinding surfaces. The dental formula is 1,4-4,1 or 2,4-4,2. They possess small barbels and a frenum that may or may not be attached to the premaxilla. Coloration is highly variable, but consists of a series of dark blotches on a lighter background. In reproductive individuals of both sexes, the bases of the fins become orange to red and males may develop tubercles on the pectoral tins.

Taxonomic Relationships: The speckled dace is the most widely distributed species in the western United States and has been isolated in many small streams and springs. Its taxonomy is poorly understood and highly confusing because the species is naturally so variable, and no one has attempted a taxonomic analysis over its entire range. Nevertheless, a number of forms are recognized as separate taxa by ichthyologists because of their distinctive morphology and habitat and, usually, their isolation from other dace populations. Three such forms are present in the Death Valley region: the Owens speckled dace, the Amargosa Canyon speckled dace, and the Ash Meadows speckled dace. Gilbert (1893) described *Rhinichthys nevadensis* from Ash Meadows, Nevada, but the subspecific name *R. o. nevadensis* has been assigned to speckled dace in the Amargosa River canyon and Owens Valley as well (La Rivers 1962, Moyle 1976). Williams et al. (1982) compared speckled dace from the Amargosa Canyon region in California with speckled dace from Ash Meadows and found that the two populations were morphologically distinct. The former were characterized by a comparatively smaller head depth, shorter snout-to-nostril length, longer anal-to-caudal length, more pectoral fin rays, and fewer vertebrae. As a consequence Williams et al. (1982) and Deacon and Williams (1984) recommended that the populations from the three areas be placed in separate subspecies.

Nevertheless, Amargosa Canyon and Ash Meadows populations have generally been listed as *R. o. nevadensis* and considered to be related to dace from the lower Colorado River, while the Owens Basin populations have been thought to be derived from *R. o. robustus,* a pluvial (stream-dwelling) Lahontan form (Sada 1989). Morphological and electrophoretic studies by Sada et al. (1993) suggest that the dace populations in the Owens River may be most closely related to Lahontan speckled dace but that other populations in the Owens Basin seem may be closely related to the Amargosa Canyon speckled dace. In a way, the taxonomic confusion generated by this plastic species is of little consequence because all the populations in the Amargosa River drainage and Owens River drainage are in need of protection to prevent their extinction.

Life History: Speckled dace typically form small feeding aggregations. They are omnivorous; diet includes aquatic and terrestrial insects, other invertebrates such as snails and microcrustaceans and filamentous algae (Moyle 1976). In stream systems they may be active throughout the year, including the winter months. As a consequence, they are difficult to age by scale analysis because growth is continuous throughout the year. However, length-frequency analysis of dace from various localities suggests that they may live for 5-6 years (Moyle 1976). In Amargosa Canyon, the most frequent size class in May was 52-54 mm TL, but in July smaller fish averaging 31-33 mm were more common (Williams et al. 1982). However, in May there were many small fish (<30 mm TL), suggesting that peak spawning occurs in early spring (March) and that spawning activity is reduced or absent in late spring and summer. Speckled dace are reproductive in their second year (Costantz 1981), and the 52-54 mm TL size class (common in May) are probably first-year fish (Williams et al. 1982).

Habitat Requirements: Unlike other speckled dace, which usually prefer running water, the Amargosa Canyon form prefers pool-like habitat with deep (0.45-0.75 m), slow (<0.01 m^3 sec^{-1}) water. They are rare in the Amargosa River itself (Williams et al. 1982), but have probably never been very abundant there (Soltz and Naiman 1978). Dace are, however; abundant in Willow Creek and Willow Creek Reservoir (Williams et al. 1982). Willow Creek is a small, clear stream with low flow (1 cfs) and fine sand/silt substrates. It is characterized by a pH of 7.7, dissolved oxygen of 5-6 mg l^{-1}, total dissolved solids of 700 ppm, and water temperatures of 21-28°C. The reservoir, however, is turbid, with a substrate of easily roiled fines. The periphery of the reservoir has dense stands of salt-cedar and cattails (Williams et al. 1982).

Distribution: This population is confined to the Amargosa River in Amargosa Canyon and tributaries to it, especially Willow Creek and Willow Creek Reservoir (Williams et al. 1982). It was found in 1937 in a warm spring just north of Tecopa (Miller 1938), but that population is no longer present. Overall, its range has probably been reduced somewhat, but the exact extent is not known.

Abundance: During a 1981 survey of the Amargosa Canyon that included the river and Willow Creek, speckled dace comprised 1% of the fishes collected (Williams et al. 1982). Introduced mosquitofish comprised 40% of the fish fauna. This indicates that the dace are much less abundant than they used to be and are probably declining. There are, however, no historic estimates of abundance.

Nature and Degree of Threat: The major threat to the Amargosa Canyon speckled dace is the potential dewatering of its unique habitats, the Amargosa River and tributaries, by water withdrawals from both distant and near points on the aquifer that feeds the system and by local stream diversions. The Amargosa River apparently receives much of its permanent flow from springs fed by a large, ancient aquifer that extends into western Utah and central Nevada. The Las Vegas Valley Water District has proposed mining this water in large quantities to supply its ever-growing human population (E. L. Rothfuss, Superintendent of Death Valley National Park, letter to B. Bolster of CDFG, May 27, 1992). At the present time, farming operations and human settlements in the Amargosa region are withdrawing increasing amounts of water from the aquifer, which has already caused the water level of Devil's Hole in nearby Nevada (habitat of the endangered Devil's Hole pupfish, *Cyprinodon diabolis*) to drop (L. L. Lehman and R. G. Atkins, 1991, unpubl. report). If the Amargosa region withdrawals continue to increase and if Las Vegas proceeds with its planned withdrawals, it is highly likely that the Amargosa River could have its flows greatly reduced or even dry up completely during dry years. Already, diversions of springs and outflows on private land in the Tecopa area have probably reduced local flows in the river and local pupfish populations as well. With an increasing human population in Tecopa and the upper Amargosa Valley, demand for water and flood protection is increasing.

Although most of the land in the Amargosa Canyon is owned by The Nature Conservancy or the BLM, critical habitat for the dace includes a large tract of privately owned land, China Ranch. This ranch contains the headwater area of Willow Creek. Diversion of water from the creek or other alterations affecting water quality could cause dace populations to decline further.

A more immediate threat to the dace seems to be the introduced species present in the quiet-water habitat it prefers. In particular, mosquitofish may be reducing its numbers through competition and predation. Because much of its habitat is on public land, additional introductions of undesirable species that may affect dace populations are also possible.

Management: Populations should be monitored annually. Efforts should be made to ensure a natural flow of water in Willow Creek and the Amargosa River, including flood flows that reduce populations of introduced fishes. Fortunately, most of the canyon area is now owned by The Nature Conservancy and the BLM. Amargosa Canyon is part of an Area of Critical Environmental Concern and is closed to off-road vehicle use. Fences and barriers need to be properly maintained, however, because vehicle trespass is a common problem.

In Willow Creek, an evaluation should be conducted to see if permanent eradication of exotic species from speckled dace habitat is possible. If it is not, invasion-proof refuges for the dace (and Amargosa pupfish) should be created in the drainage.

The small population of dace in the Amargosa River may be dependent upon recruitment of dace from Willow Creek. If this is so, maintenance of adequate flows from China Ranch are critical to the survival of this fish. Efforts also should be made to locate the spring occupied by dace in 1937 (Miller 1938) to determine if this spring, or another nearby spring, could again support a dace population. As discussed for the Amargosa pupfish, frequent surveys of the Amargosa Canyon are necessary to monitor habitat conditions and the presence of introduced fishes.

The most difficult problem is dealing with the results of water removal from the aquifer that apparently feeds the river. The U.S. Supreme Court decision that protected the Devil's Hole pupfish from water withdrawals may be some help here, but its application on a larger, regional basis is uncertain. Listing of the dace and other regional fishes as threatened might forestall massive groundwater pumping by Las Vegas Valley Water District until it can be determined for certain whether or not the Amargosa River depends on the aquifer and would be threatened by the pumping. Protection of the fishes thus could protect an entire unique desert ecosystem.

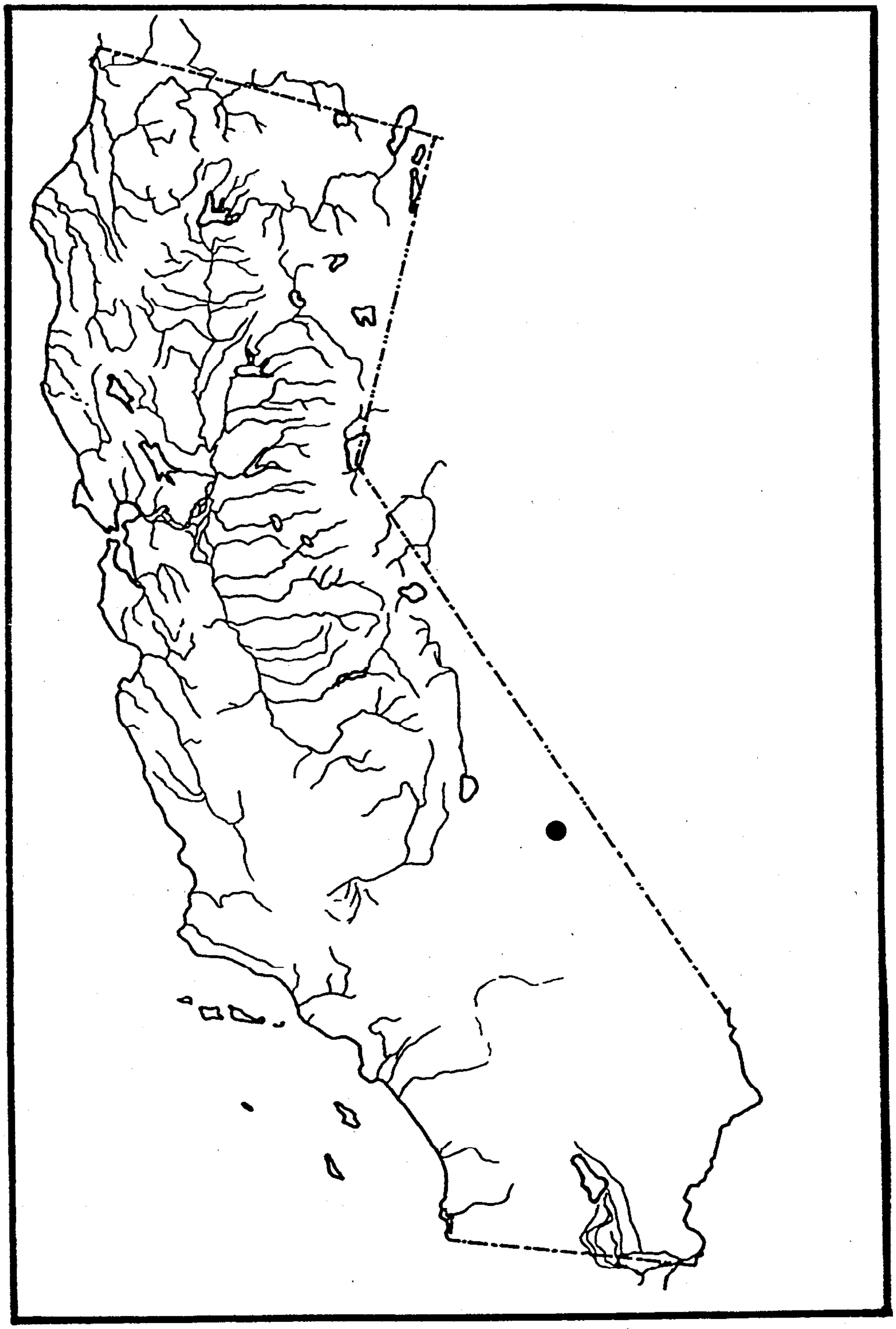


FIGURE 33. Distribution of Amargosa Canyon speckled dace, *Rhinichthys osculus* ssp., in the Amargosa Canyon area of the Amargosa River, California.

SANTA ANA SPECKLED DACE
Rhinichthys osculus ssp.

Status: Class 1. Endangered.

Description: This is a small (<80 mm SL) cyprinid, with basic characteristics similar to those of Amargosa Canyon speckled dace. Cornelius (1969) presented evidence that the Santa Ana dace differs from other speckled dace in some of its meristic and morphometric characteristics. Santa Ana speckled dace have finer scales (69-82 scales in lateral line), a better developed frenum on the upper lip, a longer head, and smaller eggs than other California dace.

Taxonomic Relationships: The Santa Ana speckled dace has not been formally described as a subspecies, but the data of Cornelius (1969) suggest that it warrants this status. Hubbs et al. (1979) listed it as an undescribed subspecies. Preliminary electrophoretic data seem to confirm that Santa Ana speckled dace are distinctive and deserve taxonomic recognition (T. R. Haglund, pers. comm.). The data also support the contention of Cornelius (1969) that this dace appears to be more closely related to dace of the Colorado River drainage than to populations to the north.

Life History: No specific information is available on the life history of this subspecies, although length data in Deinstadt et al. (1990) indicate that it probably lives for three years. Other aspects of its life history are presumably similar to those described for other stream dwelling speckled dace, summarized by Minckley (1973) and Moyle (1976).

Habitat Requirements: The Santa Ana speckled dace requires permanent flowing streams with summer water temperatures of 17-20°C. Typically, these streams are maintained by outflows of cool springs. The dace inhabits shallow cobble and gravel riffles (Wells and Diana 1975). The best description of its habitat is provided by Deinstadt et al. (1990) for the West Fork of the San Gabriel River. The West Fork is a small (typical summer flow of 4 cfs, 5-8 m wide, depths mostly 15-30 cm), permanent stream that flows through a steep, rocky canyon with chaparral-covered walls. Overhanging riparian plants, mainly alders and sedges, provide cover for fish. Even though Deinstadt et al. (1990) found dace throughout the 14 km of stream they sampled, the dace were common only in the lower reaches of the stream where the dominant habitat types were runs and riffles with gravel and cobble substrates. In the West Fork, Santa Ana speckled dace are most common where other native fishes (rainbow trout and Santa Ana sucker) are common as well. Introduced species (largemouth bass, green sunfish) may be present, but only in low numbers so far. Brown trout are more piscivorous and are believed to prey on native cyprinids such as the dace. Brown trout are very rare or absent from the San Gabriel system, but flourish in the Santa Ana River and its major tributary, Bear Creek, where speckled dace have been absent for a long time.

Distribution: The Santa Ana speckled dace was once distributed throughout the upland portions of the Santa Ana, San Gabriel, and Los Angeles river systems of southern California (Los Angeles and Orange counties), but was rare in the lowlands. In all three drainages, the species occurred in the mountains and was scattered in the foothills. It was not noted among other freshwater fishes that occurred farther down on the Los Angeles Plain (Culver and Hubbs 1917). Later, a few widely scattered local populations were documented, but they all disappeared by about 1950 (Swift et al. 1993). Today the dace has a very limited distribution in the headwaters of only the Santa Ana and San Gabriel rivers. It seems to have been recently extirpated from the Los Angeles River drainage (T. R. Haglund, pers. comm.).

Santa Ana speckled dace also have been reported from the South Fork of the San Jacinto River, Riverside County, and they were introduced into the Santa Clara and Cuyama rivers and River Springs on the east side of Adobe Valley, Mono County (Miller 1968, Swift et al. 1993). The status of the introduced populations is not known, although the Santa Clara introduction apparently failed. This subspecies has been reported from Pismo and Arroyo Grande creeks south of San Luis Obispo Creek. Populations in San Luis Obispo Creek probably are more closely related to those farther north rather than to the southern California form (Cornelius 1969; Swift et al. 1993), based on electrophoretic data (T. R. Haglund, pers. comm.).

Abundance: Numbers of dace have been reduced in all cases because of reductions in range. It is now so diminished in numbers that it is in danger of extinction. The Lytle Creek situation is documented in the section that follows. The situation is repeated for Big Tujunga Canyon and the San Gabriel River as shown by comparing collections from the 1960s at California State University, Fullerton (now in the Natural History Museum of Los Angeles County [LACM]), from the 1970s (at LACM), and the 1980s (at LACM, University of California, Los Angeles, and the U.S. Forest Service).

Nature and Degree of Threat: The Santa Ana speckled dace occupies only remnants of its native range because of water diversions, urbanization of watersheds, introduction of nonnative species, and a myriad other factors associated with expanding human populations in the Los Angeles region. It is considered to be one of the rarest native fishes in coastal southern California. Its possible remaining populations, and the threats to them, are (from Swift et al. 1993):

- Big Tujunga Creek. Fish inhabited the stream for 10-20 km below Big Tujunga Dam. Stream flows and temperatures vary so much that a trout population cannot maintain itself. During drought years, these unstable conditions, in combination with the establishment of red shiners *(Cyprinella lutrensis),* apparently led to the extinction of the dace. The shiners became established around 1985 and may have competed with dace for food and space and preyed on dace eggs. In any case, surveys of the creek in 1991-92 failed to find any dace (T. R. Haglund, pers. comm.)

- Fish Canyon (lower tributary of the San Gabriel River). The population is this tiny stream was very small on February 15, 1988; only 6-7 fish were seen, despite a thorough search, and it may now (1994) be gone. The best habitat in the lower canyon is being actively encroached upon by a rock quarry operation. The population is isolated from other San Gabriel River fish by Morris Dam.

- The contiguous West, North and East Forks San Gabriel River. These streams together are the best remaining habitat for the dace. They consist of about 40 km of stream below Cogswell Reservoir and 1-2 km each in Devil's Canyon and the West Fork, all tributaries to the reservoir. The population estimates of Deinstadt et al. (1990) indicate that probably less than 2,000 dace exist in the West Fork. The West Fork is constantly threatened by accidental high releases of water and sediment from Cogswell Reservoir that have devastated this stream section several times in the past. There were major releases of sediments from Cogswell Dam in 1981 and again in 1991, from which the stream is now recovering. These sediments smothered most of the dace's habitat and were not flushed out until 1988 through a combination of high rainfall and releases from the dam. Cogswell Dam was constructed for flood control, so the water stored in it is normally released after storms have passed. Often there is little water in the reservoir during the summer, and the stream is maintained only by seepage from below the dam and from springs. This water is reliable enough, however, for the CDFG to manage much of the stream below the dam as a wild trout fishery (Deinstadt et al. 1990). Dace were present in "fair numbers" in 1993; in a 68 m section of stream 29 dace were captured with three passes of an electrofisher (J. Deinstadt, pers.

comm.). Sampling by CDFG in 1993 also indicated that the dace was abundant in the 1 km of stream immediately above the reservoir. Mining has increased on the Cattle Canyon tributary of the East Fork, and at times the population has been much smaller or nonexistent in Cattle Canyon.

- Cajon Creek has a large population, but much of the watershed has not burned in a long time; thus, a large fire (and subsequent catastrophic flood scouring) could eliminate the population (S. Loe, pers. comm.). Recently most of the fish have been within 2 km above and below the crossing of Interstate 15.

- **North Fork of Lytle Creek.** A CDFG survey crew noted one fish on June 30, 1977, the only recent record from the Lytle Creek drainage. This population has been very small since 1975 and may no longer exist. Fish were abundant in 1967 (Cornelius' collection, LACM), but none were found in 1992 (T. R. Haglund, pers. comm.).

- **The West Folk of City Creek** had dace in 1982; a small but stable population apparently still exists, but it has not be examined recently.

- **Strawberry Creek** (tributary of the Santa Ana River. A small population was discovered in the fall of 1992 by R. Robinson (U.S. Forest Service; C. Swift, pers. comm.). The viability of this population is undetermined.

- **Siverado Canyon at Shrewsberry Springs.** A small population maintained itself here through 1987. During the fall of 1990 none were found in the few areas in which they had been seen previously.

- **Mill Creek** (tributary to the Santa Ana River) held speckled dace into the late 1980s, but they could not be found after 1990. The dace probably no longer occur in this creek.

- **The San Jacinto River** has about 15-30 km of stream where fish had been recorded in the 1970s. However, Dr. Thomas Haglund had difficulties finding any native fishes in the middle 1980s. He is completing a survey of the area. This should be the second largest and best locality for the speckled dace after the San Gabriel River. In particular, the North Fork, South Fork, Herkey Creek, and Strawberry Creek are desirable *Rhinichthys* and trout habitat. Dr. Haglund and the U.S. Forest Service note that large portions of the main river and lower creeks become dry in the summer, and the minimum habitat in the fall has not been documented.

The populations of Cajon Creek, North Fork of Lytle Creek, West Fork of City Creek, Silverado Canyon, and the San Jacinto River represent isolated headwater stocks separated by vast areas of dry washes most of the year, so that repopulation among them is not possible. The Lytle Creek population already has apparently become extirpated. The localities suffer variously from (1) severe reduction in size of habitat, (2) inability of populations to intermix, even during the (wetter) winter, because of dams, (3) erratic water flows from upstream control devices, (4) introductions of nonnative species, (5) heavy human recreational use of areas that can alter stream habitats and disturb spawning and feeding behavior, (6) degradation of water quality, and (7) historically record-breaking low water levels during the 1986-1992 drought.

Overall, it appears that the remaining populations of Santa Ana speckled dace in the Los Angeles River were extirpated during the past ten years and that dace in the Santa Ana River system are in imminent danger of extinction. Populations in the San Gabriel River are less threatened, but their very limited range means that they could be eliminated from either or both forks by major floods, debris torrents, or landslides. Such events can occur if heavy rains follow a season of heavy fires that eliminate stabilizing vegetation on the slopes of the drainages. The problems with Cogswell Dam in the past indicate that its presence is no guarantee for the safety of the fish that live in the stream below it.

Management: Immediate steps should then be taken to protect the remaining habitats in all the San Gabriel and Santa Ana drainages, including measures to secure enough water for the fish to live in. Studies of their life history should be undertaken to establish the parameters needed for survival.

As an immediate conservation measure, the East and West Forks of the San Gabriel River should be given the status of Aquatic Diversity Management Areas (Moyle and Ellison 1991, Moyle and Yoshiyama 1992) or refuges to protect the dace as well as other native fishes. Jonathan Baskin and Thomas Haglund completed a thorough survey of the San Gabriel River system in the summer of 1991, so there is adequate information to establish a refuge.

For the Los Angeles River system, thorough surveys should be made of all habitats where the dace have been recorded as existing. If any populations are rediscovered then immediate conservation actions should be taken. If the dace is found to be extirpated from the drainage, rehabilitation of potential habitats should begin and dace reintroduced as soon as possible.

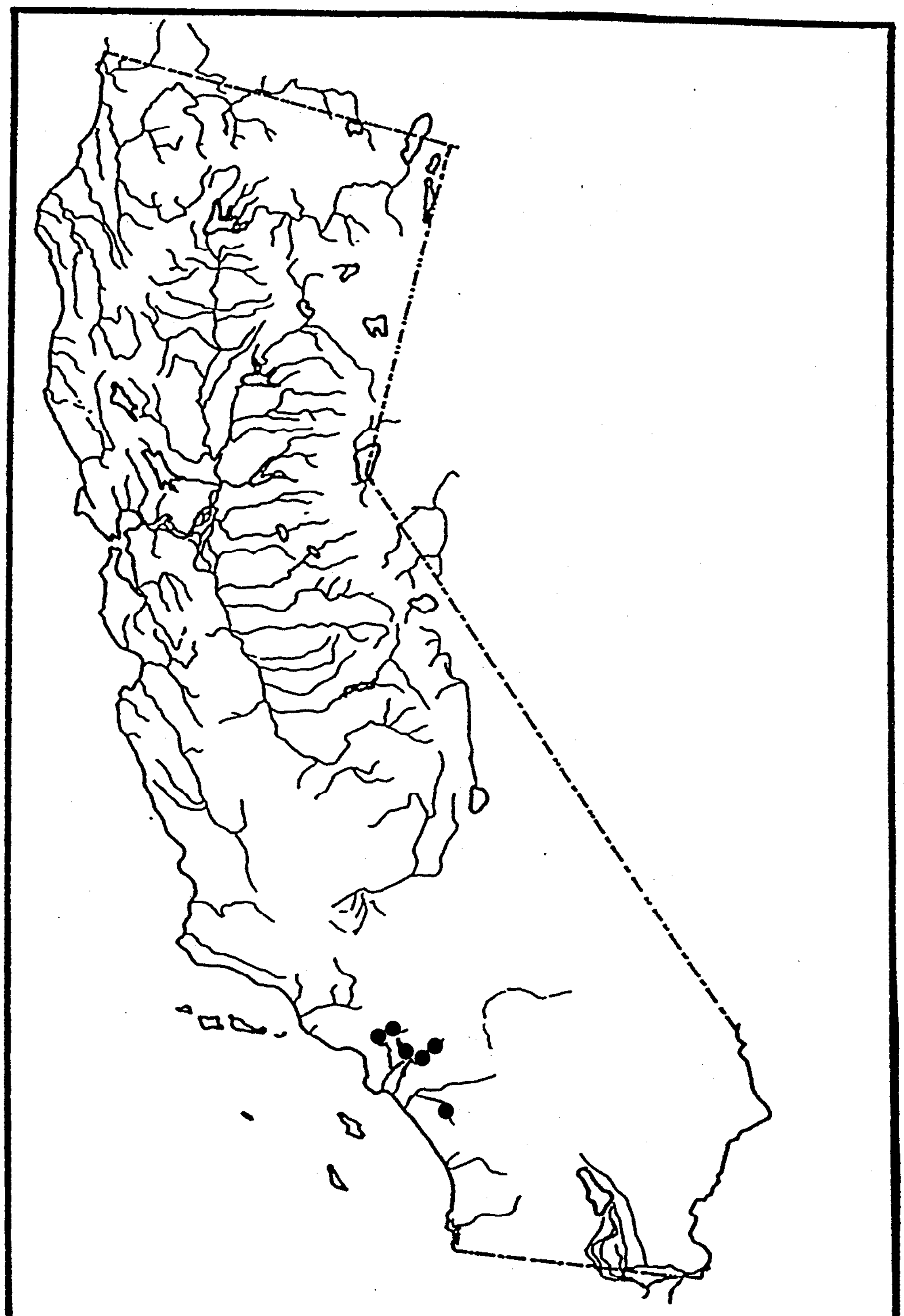


FIGURE 34. Distribution of the Santa Ana speckled dace, *Rhinichthys osculus* ssp., in California.

OWENS SPECKLED DACE
Rhinichthys osculus ssp.

Status: Class 1. Threatened.

Description: The following general description of speckled dace is from Moyle (1976), with notes on a presumably related form, *Rhinichthys osculus nevadensis.* Speckled dace are highly variable in morphology but are generally distinguished by: small, subterminal mouths; pointed snout; small, irregularly placed scales; and torpedo-shaped body. Total body length is usually less than 90 mm. Typically, dorsal fin rays number 8 (range 6-9) and anal fin rays number 7 (range 6-8). As their common name indicates, numerous black speckles cover the body, except in fish from turbid waters which may lack them. Gilbert's (1893) description of *Rhinichthys nevadensis* generally fits the above details, with these additional characteristics: (1) lateral line incomplete and with 65 scales, (2) mouth terminal (rather than subterminal), and (3) well-developed maxillary barbel.

Owens speckled dace are highly variable; populations differ significantly for many morphological characteristics, and they also are distinct from *R. o. robustus* of the Lahontan basin (Sada 1989). The high variability in characteristics, however, results in high morphological overlap between populations. The following characteristics are based on Sada (1989): the pharyngeal teeth, development of the supratemporal canal, and presence and location of tubercles are similar among Owens drainage populations and are characteristic of *R. osculus.* The frenum is well developed only in the now extirpated Little Lake population; barbels occur in most populations but are poorly developed in Long Valley populations and absent from Walker River fish. The following ranges in mean counts are for four populations in the Owens River drainage and one in the Walker River: lateral line scales 59.3-70.7; lateral line pores 11.6-61.7; dorsal rays 7.8-8.0; anal rays 7.0-7.1; pectoral rays 12.0-13.9; pelvic rays 7.0-7.6; total vertebrae 36.9-38.1.

Taxonomic Relationships: The taxonomic history of the genus *Rhinichthys* is reviewed by Hubbs et al. (1974) and Matthews et al. (1982). A history of Owens River speckled dace is given by Sada (1989) and Sada et al. (1993). Gilbert (1893) described *Rhinichthys nevadensis* from Ash Meadows, Nevada, but the subspecific name *R. o. nevadensis* has been assigned to speckled dace in both the Amargosa River system and Owens Valley (La Rivers 1962, Moyle 1976). However, some investigators have placed speckled dace from Ash Meadows, Amargosa River, and Owens Basin in separate subspecies (Williams et al. 1982, Deacon and Williams 1984). Amargosa River populations are generally listed as *R. o. nevadensis* and considered to be related to dace from the lower Colorado River, while the Owens Basin populations have been thought to be derived from *R. o. robustus,* a pluvial (stream-dwelling) Lahontan form (Sada 1989). Morphological and electrophoretic studies by Sada et al. (1993) suggest the following:

1. All the various isolated populations in the Owens Valley that were examined show genetic and morphological differences from each other, but, with one exception, not enough for them to be regarded as separate taxa.

2. The exception is the Long Valley speckled dace populations in Whitemore Spring and Little Alkalai Lake which together differ enough from other dace populations to be regarded as a separate subspecies. Genetically, these fish have a fixed allele not found in other dace populations.

3. The dace populations in the Owens River seem to be most closely related to Lahontan speckled dace *(R. o. robustus)* and may be partially the result of an introduction of that form. This result is uncertain, however.

4. With the exception of the Long Valley and Owens River populations, the speckled dace of the Owens Basin are closely related to the Amargosa speckled dace *(R. o. nevadensis)* of Death Valley and probably should be placed within the same subspecies.

Because of the confusing nature of these results, the Owens speckled dace should not be formally named until further analysis is completed (e.g., mitochondrial DNA). However, each population should be recognized as a distinct evolutionary unit for management purposes.

Life History: Particular life-history adaptations of speckled dace from the Owens Basin have yet to be determined. In general, speckled dace feed on small aquatic insects and algae (Moyle 1976). They typically live three years and attain a maximum size of 80 mm SL in inland basins (Moyle 1976). Owens speckled dace, however, rarely exceed 50 mm SL in length.

Habitat Requirements: Speckled dace from the Owens Basin are known to occupy a variety of habitats ranging from small coldwater streams and hot-spring systems, although they are rarely found in water exceeding 29°C. They also have been found in irrigation ditches near Bishop. Despite the large variety of habitats apparently suitable to speckled dace of the Owens Basin, their disappearance from numerous localities since the 1930s and 1940s suggests their vulnerability to habitat modifications or to invasion by exotic fishes.

Distribution: Museum records from the 1930s and 1940s indicate that speckled dace occupied most small streams and springs in the Owens Valley. The Mojave River is the only river system in the Owens Basin that has not been occupied at some time by speckled dace (Sada 1989). Sada (1989) reported that 17 different sites are represented in collections at the University of Michigan Museum of Zoology, California Academy of Sciences and files of CDFG. Speckled dace no longer occur at many of the sites they were collected from during the 1930s-1960s such as the Hot Creek system, or springs near Benton Crossing in Long Valley (Mono Co.) or Little Lake (Inyo Co.). Only one small population remains in one of three springs near Benton that were historically occupied (Sada 1989). A survey of 166 sites in 1988-1990 found speckled dace extirpated from most historic localities (Sada 1989). They currently persist at two Long Valley sites (Whitmore Hot Springs and Little Alkali Lake), one East Fork Owens River site near Benton (a spring on Mathieu Ranch/Lower Marble Creek), and live sites in the northern Owens Valley (North McNally Ditch, North Fork Bishop Creek, irrigation ditch in north Bishop, Lower Horton Creek, and Lower Pine and Rock creeks). In the northern Owens Valley, speckled dace no longer are found in Fish Slough, in irrigation canals between Bishop and Big Pine, or in the Owens River. They also were not found at Warm Springs, where CDFG biologists had planted 75 speckled dace in 1983 (Sada 1989). In the southern Owens Valley, speckled dace have been collected only from Little Lake but no longer occur there. Speckled dace now occur primarily in streams and irrigation ditches around Bishop, but the populations are scattered, mostly small and fluctuate widely in size. Some of these populations are ephemeral (Sada 1989).

Abundance: There are little data available on the historic abundance of this dace. Given its greatly diminished range due to extirpation of many populations, it is undoubtedly much less numerous than it once was and is continuing to decline. Even in the streams and irrigation ditches around Bishop, where they are widespread, speckled dace now occur at low densities (Sada 1989).

Nature and Degree of Threat: A detailed account of the extant populations of Owens speckled dace, including human impacts and current threats, is given by Sada (1989). Sada (1989) includes among the causes of the decline of Owens speckled dace the diversion of waters from the streams (which may dry up on occasion), destruction of stream and riparian habitat by livestock, and predation by introduced fishes such as brown trout and green sunfish. The most significant threats are the increasing diversion of streams and associated habitat alterations, especially grazing and trampling of streambanks by cattle. Populations in springs and pools are under continued threat from illegal introductions of predatory fishes, such as largemouth bass. Other introduced fishes that may be competitors or predators of speckled dace are mosquitofish *(Gambusia affinis)* throughout Long Valley, and channel cattish *(Ictalurus punctatus)* and Sacramento perch *(Archoplites interruptus)* in Benton Valley springs. The two remnant populations in Long Valley and the one in the East Fork Owens River are small, occur in extremely small springs and are therefore vulnerable to extirpation. The single East Fork Owens River population is restricted to poor-quality habitat that is "frequently altered and occupied by introduced predators" (Sada 1989).

Management: The most critical needs for Owens speckled dace are formal protection of existing habitat and creation of artificial refugia for populations in immediate danger of extinction. Sada (1989) recommends formal listing of the populations in Long Valley and near Benton as endangered, and populations in the northern Owens Valley as threatened. The Long Valley populations are especially in need of attention because of the high probability that they represent a distinct subspecies by themselves (Sada et al. 1993). However, all isolated populations of dace are susceptible to habitat changes and to the establishment of exotic fishes (Williams and Sada 1985). Establishment of speckled dace at additional sites in the Owens River drainage, as recommended by Sada (1989), would reduce the chance that they would be completely extirpated from this area. Remnant populations of Owens speckled dace should be monitored annually, particularly those in springs.

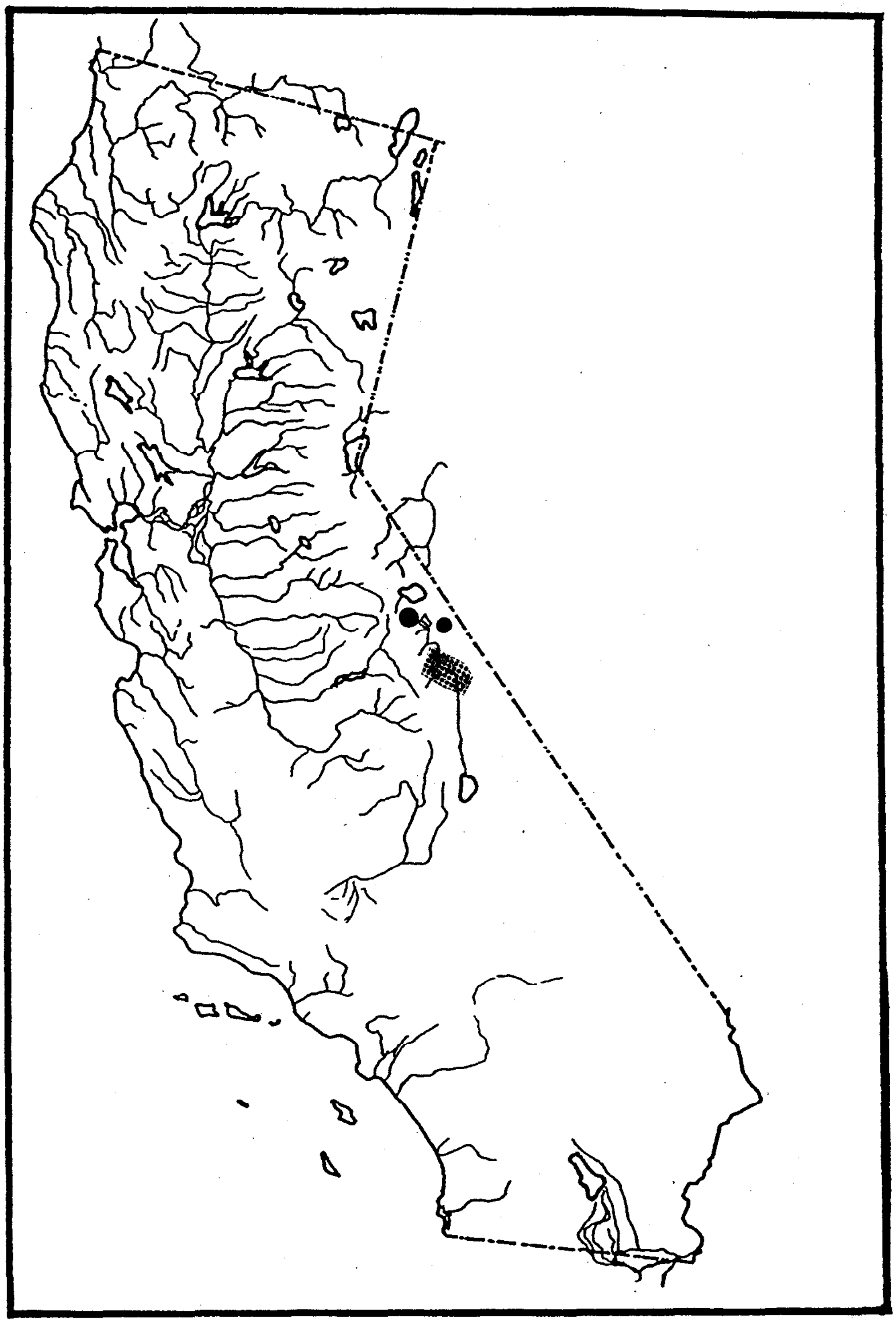


FIGURE 35. Distribution of Owens Speckled Dace, *Rhinichthys osculus* ssp., in California.

GOOSE LAKE SUCKER
Catostomus occidentalis lacusanserinus (Fowler)

Status: Class 1. Threatened.

Description: This is a large catostomid that reaches 350 mm SL. It is similar to other subspecies of Sacramento sucker, with the following combination of characters (Ward and Fritzche 1987): lateral line scales, 64-73; scales above lateral line, 12-16; scales below lateral line,. 8-12; scale rows before dorsal fin, 27-36; dorsal rays, 11-13; anal rays, 7; pectoral rays, 16-18; pelvic rays, 9-10; upper lip papillae, 5-6; lower lip papillae, 5; gill rakers, 21-27. The number of post-Weberian vertebrae ranges from 42 to 44. The caudal peduncle is 8-10% of SL. There are no pelvic axillary processes. The peritoneum is black. External body coloration is dark grey to black dorsally and light grey to dull brown ventrally. The head is steel-grey to brown dorsally, but is lighter ventrally. A darker lateral streak is present in larger fish. The caudal, pelvic, and pectoral fins are light grey to cream. Males develop sexual tubercles on branched and unbranched anal rays and on lower caudal rays. Females have no tubercles (Martin 1967). In reproductive males, the pelvic fins become extremely enlarged, elongated, and cupped, presumably to aid in dispersal of sperm during reproduction (Martin 1967).

Taxonomic Relationships: The Goose Lake sucker was first described as a subspecies of *Catostomus occidentalis* by Fowler (1913) from a single specimen. Since then, the original subspecific name, *lacus-anserinus,* has been modified to eliminate the hyphen, resulting in the present name (Shapovalov et al. 1959, Kimsey and Fisk 1960, Hubbs et al. 1979). Martin (1967) compared Goose Lake suckers with Sacramento suckers from the Pit River. He concluded that the two forms belonged to different subspecies but that the differences were minor. Ward and Fritsche (1987), using standard meristic and morphological measurements, looked at Sacramento suckers from a number of localities, including Goose Lake. Although their multivariate analysis could separate the suckers of Goose Lake from other populations, they concluded that the morphological differences were too small for the Goose Lake form to merit subspecies status. Both Martin (1967) and Ward and Fritsche (1987) indicated that the Sacramento sucker is a highly variable species morphologically. Therefore, the conservative course of action is to retain the various subspecies names until a thorough genetic study is done on the Sacramento sucker throughout its range.

Life History: Little is known about the life history of the Goose Lake sucker, except that they spawn during spring in the streams that are tributary to Goose Lake (Martin 1967). Adults can be found in the streams and lake throughout the year. Young suckers 40-70 mm SL are very abundant in shallow water during summer in the lake, “packed” in among aquatic macrophytes (R. White, unpubl. data). Fish become sexually mature by the second year when they are 80-90 mm SL. Martin (1967) found several fish (141-216 mm SL), both male and female, with mature gonads at the beginning of April and concluded that *C. o. lacusanserinus* breeds during April or May, depending on water temperature. J. Williams (BLM, unpubl. observ.) observed 246-430 mm FL fish on a spawning migration in Willow Creek during May 14-16, 1984. Goose Lake suckers feed primarily on algae and diatoms (Martin 1967). Like other suckers, it has a long intestine and ventral mouth adaptive to this diet.

Habitat Requirements: Little information is available on this subspecies. In streams, *C. o. lacusanserinus* is typically found in water depths of 15-150 cm of moderate to slow velocity (Martin 1967). Streams they inhabit are up to 4.5 m wide, with summer water temperatures of 15-19°C. Little vegetation is present in the streams. Substrates consist primarily of rock and gravel in headwater sections and mud, silt and gravel in lower sections. Goose Lake, the principal habitat of the fish, is shallow, muddy and alkaline; it is described in the Goose Lake tui chub account. Gillnetting and trawling indicate that the sucker is found throughout the lake (R. White, unpubl. data). Populations of Goose Lake suckers are apparently also present in small reservoirs in the Cottonwood and Thomas creek drainages, Oregon, but the characteristics of these reservoirs are not known. Juvenile fish have been observed in shallow water among emergent vegetation.

Distribution: The Goose Lake sucker is restricted to the Goose Lake basin and has been reported from Goose Lake and Willow, Lassen, Branch, and Corral creeks, Modoc County, California; and from Dog, Drews, Cottonwood, Dry, Thomas, Cox, and Warner creeks, Lake County, Oregon (Sato 1992a). It is also known from Drews and Cottonwood reservoirs in Oregon, but it is not certain. if permanent populations are established in these reservoirs. Apparent spawning runs from them, however, have been recorded (J. Williams, unpubl. obs.)

Abundance: Until 1992, the species was presumably common in its limited range. It was collected in brief surveys of the lake by CDFG (King and Hanson 1966), by USFWS (J. Williams, 1984, unpubl. data), and by the University of California, Davis (R. White, 1989, unpubl. data). In 1994, suckers were common in a small portion of Lassen Creek and throughout most of Willow Creek (CDFG, unpubl. data).

Nature and Degree of Threat: The principal threat to the Goose Lake sucker is destruction of its habitat in Goose Lake and its tributaries. Diversions for irrigation, combined with the loss of natural water-storage areas (e.g., wet meadows lost to bank erosion and downcutting of streams) presumably caused the lake to dry up rapidly during a period of prolonged drought. While the lake has dried up naturally in the past, it may do so more quickly now or more frequently become too alkaline to support freshwater fishes such as the sucker. Diversions, dams, culverts, and other obstructions also presumably prevent migrating adults from reaching spawning areas in tributary streams and reduce stream habitat required for persistence of the fishes during long-term droughts. In addition, most of the streams have experienced some habitat loss due to the effects of logging, grazing and other factors that can degrade watersheds. The presumed populations in Drews and Cottonwood reservoirs may help keep this sucker from becoming extinct, provided that the reservoirs are not drawn down too low as well.

Management: Currently, plans to protect the sucker and other Goose Lake fishes are being developed by the Goose Lake Fishes Working Group, which includes representatives from federal and state agencies, private landowners and interested citizen groups (Sato 1992a). If it can be established that populations exist in Drews and Cottonwood reservoirs in Oregon, then a cooperative agreement should be established with local water rights holders to maintain a minimum pool in the reservoirs sufficent to protect the fish. Additional short-term refuge populations should be established in farm ponds and other sites in the drainage. Stream improvement programs now underway or proposed in many areas should done as expediently as possible, especially measures that create large pools with plenty of riparian vegetation as cover. Improving access and flows in streams in California and Oregon, especially Lassen, Willow, and Thomas creeks, would benefit the sucker as well as all other fish species in the drainage. As soon as possible, an investigation of the sucker's life history and habitat requirements should be conducted to determine what additional management measures are required.

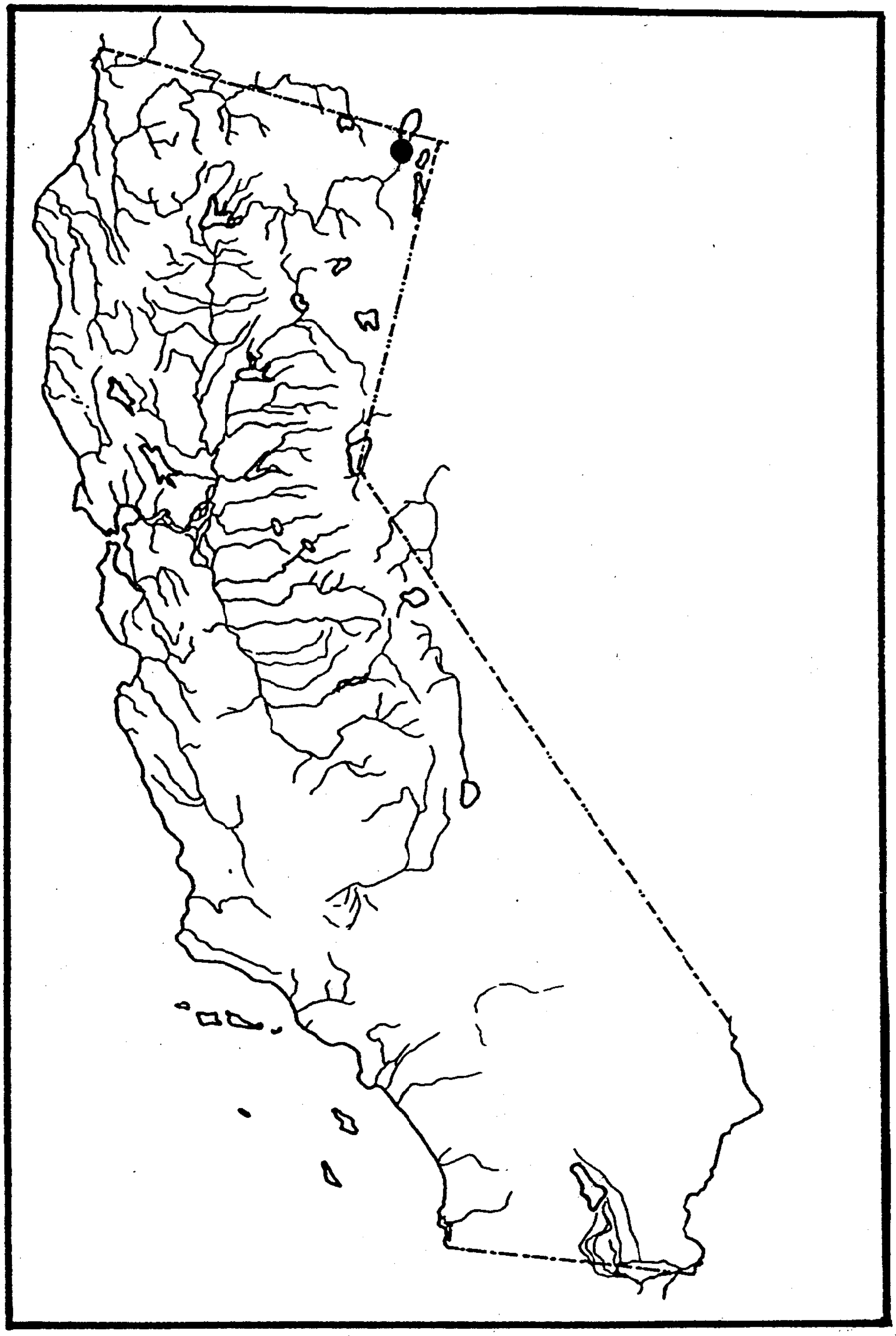


FIGURE 36. Distribution of the Goose Lake sucker, *Catostomus occidentalis lacusanserinus*, in California.

OWENS SUCKER
Catostomus fumeiventris (Miller)

Status: Class 3. Watch List

Description: The Owens sucker is most closely related to the Tahoe sucker *(Catostomus tahoensis)* and the external morphology of the two species is quite similar (Miller 1973). Adults are 20-40 cm SL. They have large heads, long snouts, and coarse scales (Moyle 1976). The subterminal mouth is large and the papillose lower lip is deeply incised. The cephalic fontanelle is well developed. The caudal peduncle is thick. There are 75-78 lateral line scales, with usually 13-16 scale rows above and 9-11 scale rows below the lateral line. Pectoral fins have 16-19 rays, dorsal fin 10 rays, and pelvic fins 9-10 rays.

Adults are slate-colored dorsally, which occasionally becomes very dark, and can have weak, blue iridescence on their sides. The ventrum is a dusky/smoky color, giving rise to the specific name. Unlike most other species of sucker, reproductive adults of this species do not develop the characteristic red lateral stripe, and thus may be distinguished from the Tahoe sucker *(C. tahoensis)*. However, the paired fins may be faintly tinged with a dull reddish-amber.

Taxonomic Relationships: *Catostomus fumeiventris* was first diagnosed by Snyder (1919) as *Catostomus arenaris,* but it was later included with *Catostomus tahoensis*. However, *Catostomus fumeiventris* was subsequently recognized as distinct and described by Miller (1973).

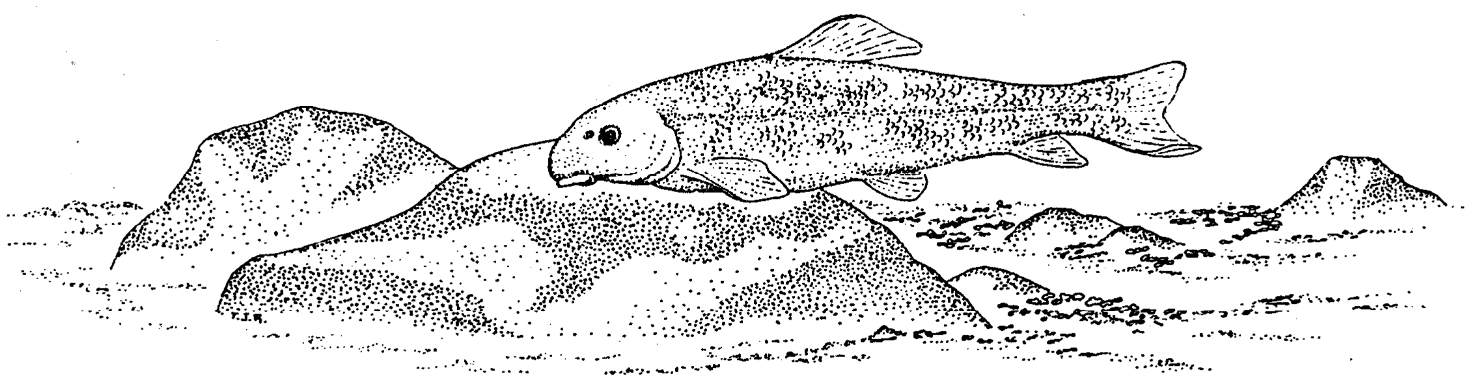
Life History: The life history of Owens suckers is thought to be similar to the closely related Tahoe sucker (Miller 1973); they are probably nocturnal feeders that ingest aquatic insects, algae, detritus and inorganic matter picked off the bottom. They spawn from. late May to early July. The population in Crowley Reservoir on the Owens River spawns in tributary streams. Larval and juvenile suckers have been collected in late June near the mouth of Whiskey Creek, a tributary to the southwestern arm of reservoir (Miller 1973). Larvae transform into juveniles at 19-22 mm and are usually found in quiet, sedge-dominated margins and backwater areas (Miller 1973).

Habitat Requirements: In the lower Owens River and two of its tributaries, lower Rock Creek and lower Hot Creek, Owens suckers are most abundant in sections with long runs and few riffles (Deinstadt et al. 1986). The substrate in these sections consists mostly of line material, with lesser amounts of gravel and rubble. Water temperature is 7-13°C and pH 7.9-8.0. Adults can thrive in lakes and reservoirs, but presumably need gravelly riffles in tributary streams for spawning.

Distribution: The Owens sucker is endemic to the Owens River drainage (Fig. 37) and is widely distributed throughout the Owens Valley. It is most abundant in Crowley Reservoir in Mono County (P. Pister, pers. comm.). Other populations exist in Convict Lake in Mono County and Lake Sabrina in Inyo County (P. Pister, pers. comm.). There is also an introduced population in June Lake of the Mono Lake Basin. A population is apparently established in the Santa Clara River, Los Angeles County, presumably via the Owens Aqueduct. Although Bell (1978) did not record it from the Santa Clara River during his survey, Wells and Diana (1975) found it in Sespe Creek of this drainage. Adults have been observed spawning in the outflow of Fillmore Trout Hatchery on the Santa Clara River in large numbers, although the numbers seems to have declined in recent years (T. R. Haglund, pers. comm.). In 1992, large suckers were observed in Piru Creek (S. Sweet, pers. comm.) above Piru Reservoir, which were probably Owens suckers (C. Swift, pers. comm.).

Abundance and Nature and Degree of Threat: Owens suckers have adapted well to the damming of the Owens River and creation of Crowley Reservoir, so they still have large populations in a good portion of their native range. A successful introduction of Owens suckers into June Lake, outside their native range, has also been made. However, their total range is limited and the bulk of their population seems to depend on reservoirs that are dominated by introduced game fishes.

Management: No special management is needed at this time, but their status should be assessed every five to ten years to see if their numbers are declining.



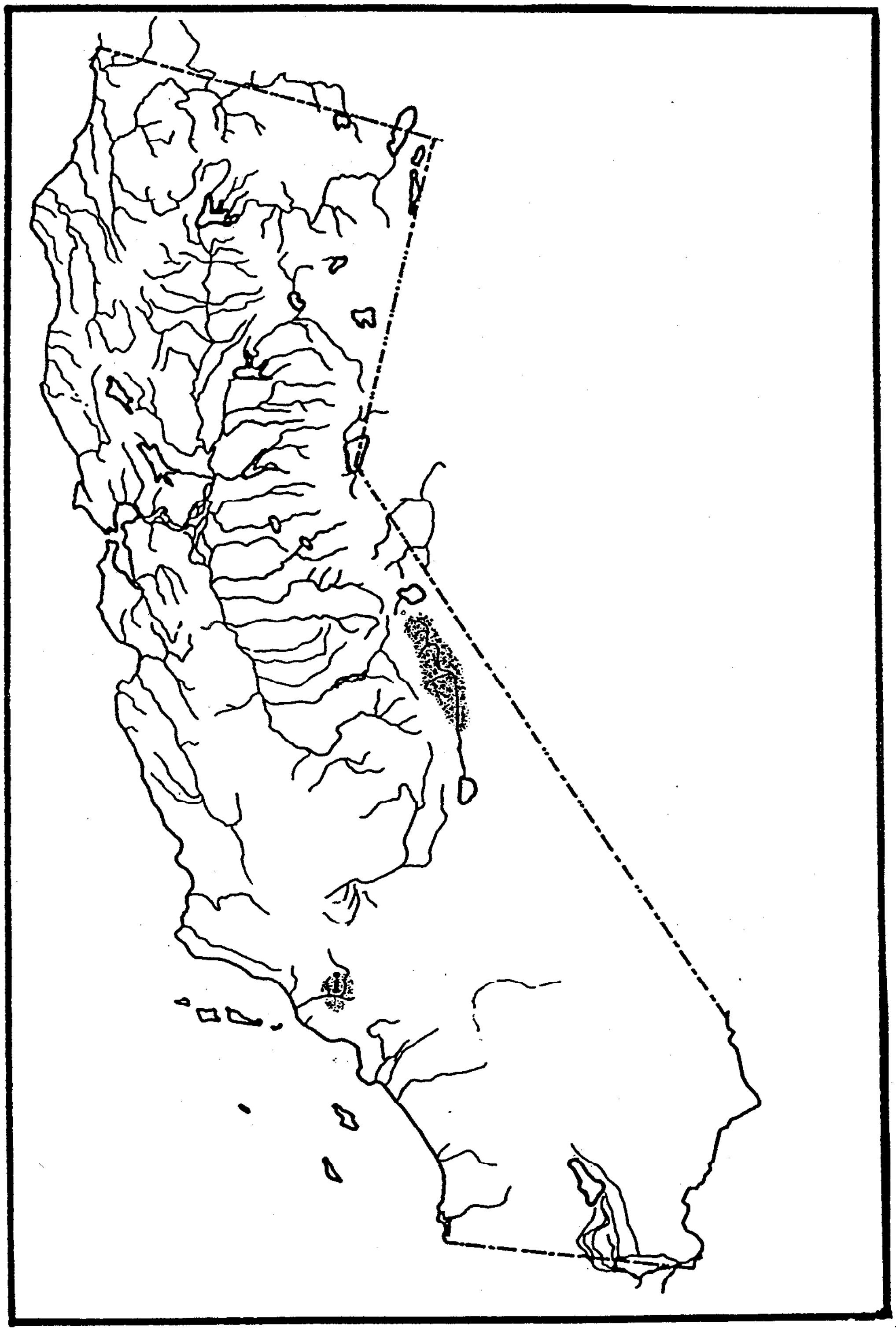


FIGURE 37. Distribution of the Owens sucker, *Catostomus fumeiventris*, in California. An introduced population (i) is shown in the Santa Clara basin.

KLAMATH LARGESCALE SUCKER
Catostomus snyderi Gilbert

Status: Class 2. Special Concern.

Description: The Klamath largescale sucker is similar to the Sacramento sucker *(Catostomus occidentalis)* in gross morphology. Andreasen (1975) described this species as being a generalized sucker, intermediate in most morphological characteristics, especially between *Deltistes luxatus* and *Chasmistes brevirostris* with which it co-occurs. The inferior mouth of this sucker is smaller than that of the Sacramento sucker. The lips are papillose and there is a medial incision on the lower lip resulting in only one row of papillae extending across the lip. The upper lip is narrow and has 4-5 complete rows of papillae. It also differs from the Sacramento sucker in having a shorter dorsal fin, with a basal length equal or shorter than the longest dorsal ray. The dorsal fin insertion is closer to the snout than to the caudal fin. There are 11 dorsal fin rays (may range from 11 to 12) and 7 anal fin rays. Scales are large and there are 69-77 along the lateral line, with 13-14 scale rows above and 10-11 rows below. Gill rakers number 31-33, but usually there are 32. Adult body coloration is similar to the Sacramento sucker. The dorsal surface is greenish and ventral surface is yellow-gold (Moyle 1976). The coloration of reproductive adults has not been described.

Taxonomic Relationships: *Catostomus snyderi* from Upper Klamath Lake was first described by Gilbert (1897). It is presumably closely related to *C. macrocheilus* of the Columbia River drainage to the north and to *C. occidentalis* of the Sacramento drainage to the south.

Life History: Detailed information is scant on the biology and life history of this species. Mature.suckers collected during a spawning migration were aged at 5-8 yr (Andreasen 1975), but this is probably an underestimate. In Upper Klamath Lake, the spawning migrations occurred during March and peaked by the end of March when ripe individuals of both sexes were migrating in large numbers. Earlier in the month, Andreasen (1975) found lesser numbers migrating; although most of the males were ripe, the few females observed were not. Initiation of reproduction was attributed to temperature. Fecundity was estimated for three females at 39,697 (353 mm SL), 64,477 (405 mm SL), and 63,905 eggs (421 mm SL).

Extensive hybridization and introgression with *Chasmistes brevirostris* has been reported, especially in the Clear Lake and Lost Rive; populations (Andreasen 1975). Although the Klamath largescale sucker presumably has also hybridized with *Deltistes luxatus* and *Chasmistes brevirostris* in Upper Klamath Lake, no introgression has occurred and distinct species are still present (W. Berg, unpubl. data).

Habitat Requirements: Although the largescale sucker is known to inhabit both lentic and lotic habitats, it is primarily adapted to a riverine existence (Andreasen 1975). However, little additional information on its ecology is available.

Distribution: The Klamath largescale sucker is native to the Klamath River and Lost River-Clear Lake systems of Oregon and California (Fig. 38). Although it is found in the Klamath River below Klamath Falls, most are found in the river above the falls. Andreasen (1975) reported them from Upper Klamath Lake, the Clear Lake-Lost River system, the entire Sprague River, the lower 20 km of the Sycan River, the lower Williamson River, and the Williamson River above Klamath Marsh. However, Contreras (1973) failed to find any in the Lost River drainage. This may be because Klamath largescale suckers have never been very abundant anywhere. In California they are found mainly in the Lost River drainage and in the Klamath River above Irongate Reservoir.

Abundance and Nature and Degree of Threat: The Klamath largescale sucker is a poorly known species native to waters highly modified by dams, diversions, and pollution. California populations are on the edge of its range, but its range is rather limited in any case. The Lost River drainage in California has been especially altered by human activity and contains large populations of introduced predatory fishes, such as yellow perch *(Perca flavescens)* and Sacramento perch *(Archoplites interruptus)*. The largescale sucker occurs with and occasionally hybridizes with two other native catostomids, the Lost River sucker, *Deltistes luxatus,* and the shortnose sucker, *Chasmistes brevirostris,* both of which have been formally listed as endangered by both the USFWS and CDFG. All this evidence indicates that the Klamath largescale sucker may be on its way to becoming a threatened species.

Management: The first step is to find out more about the distribution, habitat requirements, and life history of this species in both Oregon and California. There is also a need to find ways to manage at least part of the Klamath River drainage as a refuge for the largescale sucker and other native fishes. It is quite likely that steps taken to benefit the two endangered suckers of the upper Klamath basin will also benefit Klamath largescale sucker, but several measures such as protection of spawning grounds may also be needed to specifically protect it.

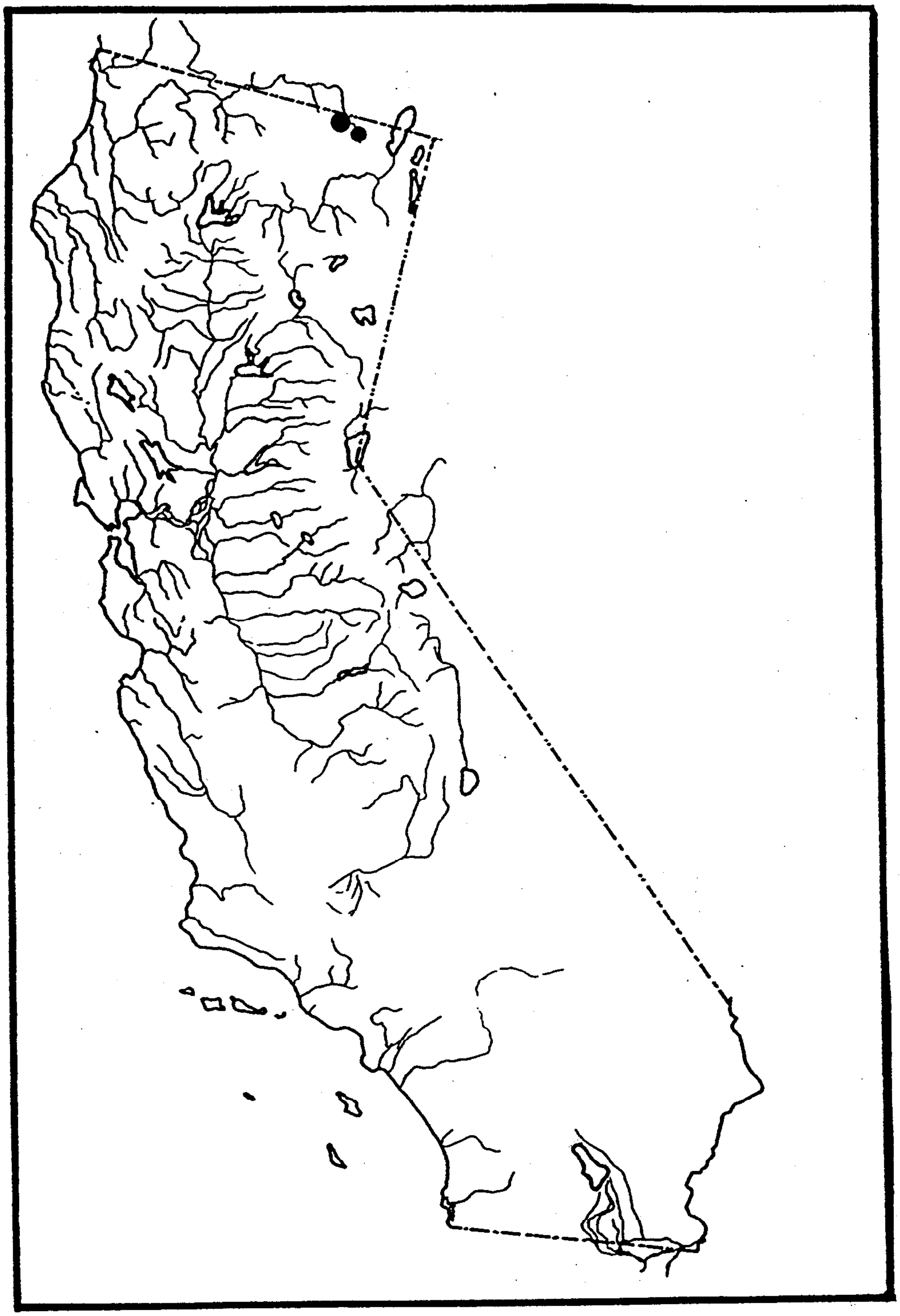


FIGURE 38. Distribution of the Klamath largescale sucker, *Catostomus snyderi*, in the Lost and Klamath rivers in California.

MOUNTAIN SUCKER
Catostomus platyrhynchus (Cope)

Status: Class 3. Watch List.

Description: Mountain suckers are small catostomids that are typically 80-120 mm TL when adults and seldom exceed 180 mm TL (Smith 1966, Moyle 1976). Like other catostomids, they have subterminal mouths with prominent, fleshy, protrusible lips. Adult and juvenile mountain suckers, however, have deep lateral notches at the juncture of the upper and lower lips and a shallow, median cleft on the lower lip; these serve to distinguish mountain suckers from other species. The lips have numerous large papillae, except on the anterolateral comers of the lower lip and the anterior area of the upper lip. Jaws are modified with cartilaginous plates for scraping food from rocks. Mountain suckers have 23-37 gill rakers on the external row and 31-51 gill rakers on the internal row of the first gill arch. Lateral line scales typically number 75-92. The dorsal fin has 8-13 rays (mean = 10). Pelvic fins have 9 rays. The intestine is long (4.5 to 6 times body length), reflecting its herbivorous trophic status. The peritoneum is black. Fish are brown to olive-green dorsally and laterally, and white to yellow ventrally. A lateral band, or a series of blotches, along the sides is usually present. Reproductively mature fish have a dark, red-orange lateral band. The fins also take on a red-orange color in reproductive specimens. Reproductive adults exhibit secondary sexually dimorphic characteristics (Hauser 1969). In mature males, large conical tubercles are present on rays of the enlarged anal fin, and smaller tubercles are present in the lower caudal fin. Males develop breeding tubercles over the entire body and all tins, except for the dorsal. In females, tubercles are restricted to the dorsal and lateral areas of the head and body.

Taxonomic Relationships: *Catostomus (Pantosteus) platyrhynchus* was first described by Cope (1874) as *Minomus platyrhynchus* from specimens collected from Provo, Utah. The generic designation was subsequently changed to *Pantosteus* by Cope and Yarrow (1875). However, Smith (1966), in an extensive review of the taxonomy of Catostomidae, combined *Pantosteus platyrhynchus* with two other species, *Pantosteus lahontan* (Rutter 1903) and *Pantosteus jordani* (Evermann 1893), and reclassified all three as one species under the genus *Catostomus* while retaining *platyrhynchus* as the specific name. The former genus *Pantosteus* was reduced to a subgeneric status. The three former species, however, may deserve subspecific recognition. California populations were originally part of *P. lahontan.*

Life History: Mountain suckers feed mostly on algae and diatoms as well as small quantities of aquatic insects and other invertebrates (Smith 1966). Their feeding mode of scraping food off the substrate also results in a high proportion of sand and grit being ingested. The diet of juveniles (<30 mm TL) contains a higher proportion of insects (Hauser 1969).

Hauser (1969) documented growth rates of mountain suckers from streams in Montana and found that by the first year they reached 60-65 mm TL and by the second year, 90-100 mm TL. Average growth rates are greatest during the first year and decrease gradually through the third year, after which growth is slow and constant. This pattern is probably true of the California population as well.

Males mature earlier than females (Hauser 1969). However, females are larger than males and seem to live longer (7 yrs for males and 7-9 yrs for females). Males become reproductive by the third year when approximately 127 mm TL, whereas females mature by the fourth year at approximately 175 mm TL (Smith 1966). Fecundity is variable, females producing between 990 (for a 131-mm TL specimen) and 3,710 (for a 184-mm TL specimen) eggs.

Upstream migrations during summer have been associated with spawning (Decker 1989). Spawning is usually thought to occur between the last week of June and the first two weeks of July when water temperature is between 11-19°C (Snyder 1983, Smith 1966, Hauser 1969), and takes place in gravel riffles (Moyle 1976). However, Decker (1989) noted that mountain suckers with breeding tubercles were most abundant in Sagehen Creek in late July and early August, when water temperatures were 9-12°C.

Habitat Requirements: In the Little Truckee stream system, Olson and Erman (1987) found that most mountain suckers were in stream sections above the reservoirs. Within this distribution, there was some spatial separation between adults and juveniles, with juveniles in stream habitat closer to the reservoirs.

Contrary to descriptions of habitat requirements elsewhere (Snyder 1983, Smith 1966), mountain suckers in California streams generally occupy pool-like habitats. Olson and Erman (1987) found that mountain sucker abundance was positively correlated with pools, but negatively correlated with riffles. Decker (1989) observed that mountain suckers were never found in riffles and swift currents despite presumed morphological adaptations for inhabiting fast water. She found that the suckers selected areas with mean water-column velocities of 0.1-0.5 m sec^{-1} and depths of 0.5-1.8 m. Decker (1989) also found that mountain sucker abundance was greatest in areas with dense cover, especially where abundant instream rootwads were present. Suckers presumably require such cover as refuge, and fish were often observed resting on the bottom in close proximity to cover during daylight hours.

Mountain suckers in Montana streams tended to form exclusive schools and thus were separated from other catostomids (Hauser 1969). However, in California streams they form mixed schools with Tahoe suckers *(Catostomus tahoensis)* (Decker 1989). There is a positive correlation between mountain sucker abundance, Tahoe sucker abundance and speckled dace abundance (Olson and Erman 1987).

Distribution: Although this species is widely distributed in the western United States (Smith 1966, Snyder 1983), in California it is restricted to the Lahontan drainage system (Fig. 39) and the North Fork of the Feather River (Smith 1966). They are common in Red Clover Creek, a tributary to the North Fork of the Feather River (R. Hinton, unpubl. data). The Feather River population presumably resulted from an irrigation diversion into the basin from the Little Truckee River (D. Erman, pers. comm.). Scattered populations are found in the Truckee, Walker, and Carson River drainages (Decker 1989, Moyle unpubl. data). In the Truckee drainage of California, it has been found in the Little Truckee River and associated streams such as Alder, Prosser, and Sagehen creeks (Flittner 1953, Gard and Flittner 1974, Decker 1984, Olson and Erman 1987), as well as in the Truckee River and Martis Creek (Moyle and Vondracek 1985).

Abundance and Nature and Degree of Threat: Although the mountain sucker is still present in scattered populations in California and Nevada, its populations in California seem to be in a general decline (Olson and Erman 1987, Decker 1989), with the exception of the introduced population in Red Clover Creek and the population in the East Fork of the Carson River and its tributary, Hot Springs Creek (J. Deinstadt, unpubl. data). The decline is tied to stream alterations and modifications, especially the construction of dams and reservoirs, that isolate populations. Mountain sucker populations apparently cannot persist in reservoirs, and so they become confined to tributary streams. Furthermore, because their favored habitats are the lower reaches of streams now flooded by reservoirs, remaining habitat supports only small populations that are vulnerable to extirpation. In the East Fork of the Carson River, a stream without a major reservoir on the mainstem, sucker populations in 1988 were estimated to range from 1,000 to 44,000 per kilometer of stream, although variances on the estimates were high (J. Deinstadt, unpubl. data).

Management: Olson (1988) noted that streams in which mountain suckers had sharp declines were also characterized by declines of Lahontan speckled dace and mountain whitefish. Thus, the decline of mountain suckers is probably a good indicator that native fish and invertebrate assemblages of the Lahontan drainage of California are in some trouble. It is therefore important that a number of streams in the basin are identified in order to manage them specifically for maintaining the integrity of the native biotic community, which includes the mountain sucker.

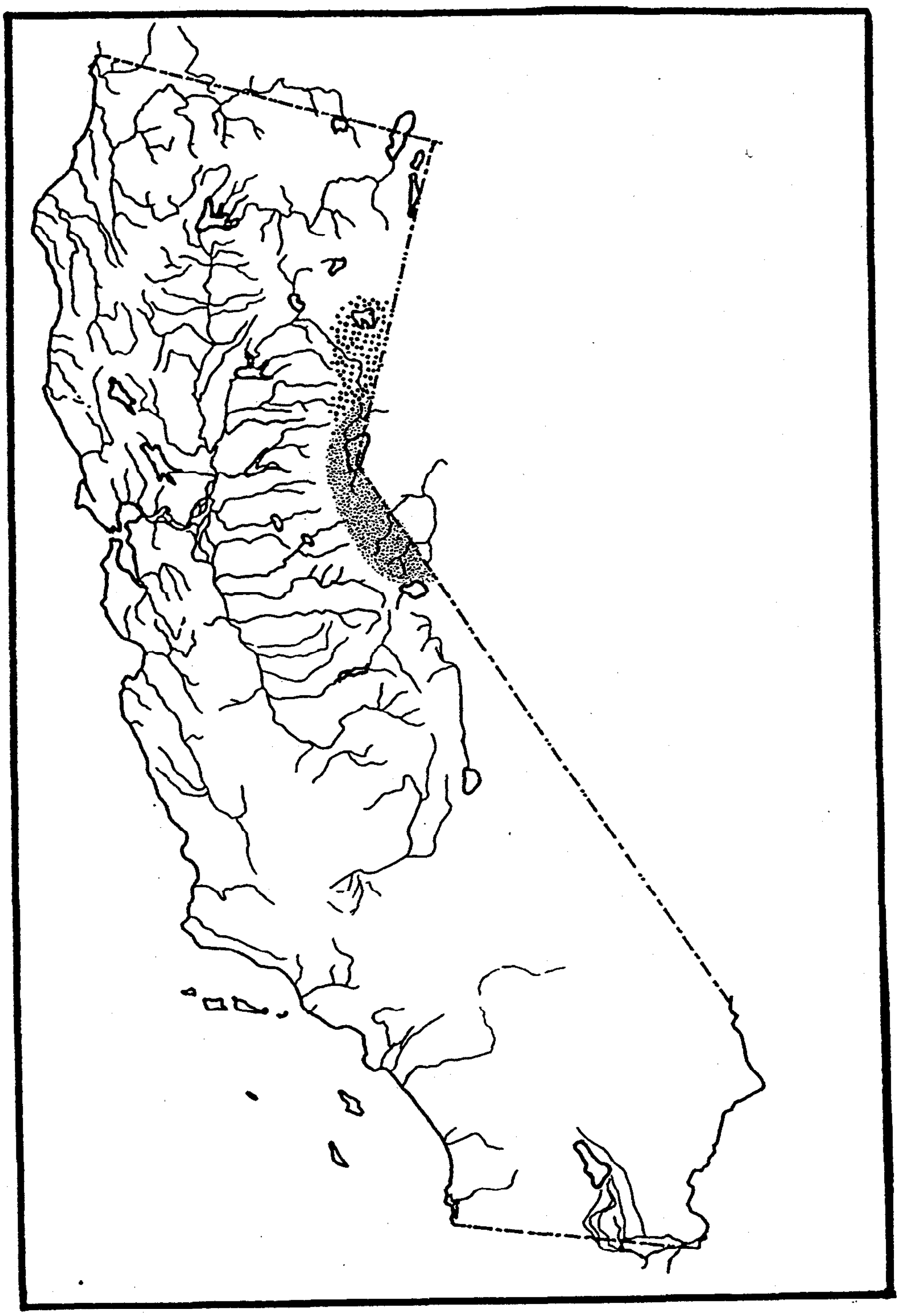


FIGURE 39. Distribution of the mountain sucker, *Catostomus platyrhynchus*, in California. Fine stippling indicates recent distributions and larger stippling indicates past records.

SANTA ANA SUCKER
Catostomus santaanae (Snyder)

Status: Class 1. Threatened.

Description: Adult Santa Ana suckers are usually less than 200 mm SL and resemble mountain suckers *(Catostomus platyrhynchus)* in gross morphology. Santa Ana suckers also possess a broad mouth with notches at the junctions of upper and lower lips (as do mountain suckers). The median notch on the lower. lip is less well defined. Large papillae are distributed in a convex arc on the anterior lower lip. Papillae are poorly developed on the upper lip. Cartilaginous plates are present on the inside of the lips. In fish >70 mm SL, the fontanelle on the head is closed. There are 21-28 gill rakers on the external row of the first gill arch and 27-36 gill rakers on the internal row. The lateral line has 67-86 scales and there are 27-41 predorsal scales. The short dorsal fin has 10 fin rays (may range from 9-11) and the pelvic fins have 8-10 rays. The axillary process at the base of the pelvic fins is a simple fold. The caudal peduncle is deep, being 8-11 percent of SL. The intestine is long, with up to 8 coils, adapting Santa Ana suckers to a herbivorous trophic habit. The peritoneum is black.

Body coloration is silver on the ventral surface and darker with irregular blotches on the dorsal surface. The melanophore pattern of the scales resembles longitudinal lateral striping. The interradial membrane of the caudal fin is pigmented, and the anal and pelvic fins usually lack pigment. Reproductive males develop breeding tubercles over most of the body, but tubercles are densest on the caudal and anal fins and the caudal peduncle. Reproductive females possess tubercles only on the caudal fin and peduncle.

Taxonomic Relationships: *Catostomus santaanae* was originally described as *Pantosteus santa-anae* by Snyder (1908b), who collected the fish from the Santa Ana River, Riverside County, California. In a subsequent revision of the nomenclature (Smith 1966), the hyphen was omitted from the specific name and the genus reduced to a subgenus of *Catostomus.* Santa Ana suckers exhibit variability in certain anatomical characteristics that are more homogeneous among other members of the subgenus *Pantosteus* (Smith 1966). The characters that commonly show variability are the degree of papillation of the anterolateral corners of the lower lip, the degree of pigmentation of the caudal interradial membrane, and the development of the pelvic axillary process. Within the species, however, there is little differentiation among populations from the four adjacent but isolated rivers (Smith 1966).

Life History: The only extensive study documenting the life history of the Santa Ana sucker is Greenfield et al. (1970). They found that 97% of the stomach contents of Santa Ana sucker consisted of detritus, algae, and diatoms; aquatic insect larvae, fish scales, and fish eggs constituted 3%. They also found that larger fish usually had a higher percentage of insect material in their diets. Growth studies indicate that by the first year Santa Ana suckers are 61 mm; by the second year, 77-83 mm; and by the third, 141-153 mm SL. Santa Ana suckers are relatively short-lived. They become reproductively mature by the first year and spawn during the first and second years. Most suckers do not survive beyond the second year, although a few live three to four years. There is no sexual dimorphism and the sex ratio is 1:1. Females are highly fecund and produce between 4,423 (for a 78-mm SL female) and 16,151 (for a 158amm SL female) eggs. Santa Ana suckers are more fecund than most other catostomids. There is also a linear relationship between size and number of eggs produced. Eggs hatch within 360 hours (at 13°C) and are demersal and adhesive. Spawning can occur from March until early July, but peaks from late May through early June (Moyle 1976), except in the Santa Clara River where it occurs mostly in March-April (Greenfield et al. 1970).

Streams in which Santa Ana suckers are found are subject to periodic, severe flooding that results in drastic decreases in sucker population densities. Greenfield et al. (1970) sampled the Santa Clara River one week following a flood in late January 1969 and collected only 120 Santa Ana suckers, compared to 225 collected the previous December. Santa Ana suckers, however, are adapted for living in such unpredictable environments and are able to repopulate the rivers following floods. Such adaptations include short generation time (early maturity), high fecundity, and relatively prolonged spawning period. These characteristics enable Santa Ana suckers to rapidly recolonize rivers following a flood by producing more young over a longer time span. The short generation time allows Santa Ana suckers to reproduce early in life, as the probability of adult mortality is high. The small size also probably enables individuals to utilize a greater range of instream refuges that would be unavailable to larger fish during high flows. The greater dependence on detritus, algae, and diatoms by juveniles has been viewed as another adaptation for survival in highly variable environments (Greenfield et al. 1970). Nonetheless, with the continual loss of habitat, local population reductions may prove to be permanent.

Habitat Requirements: Santa Ana suckers are generally found in small to medium-sized (<7 m wide) permanent streams in water ranging in depth from a few centimeters to a meter or more (Smith 1966, Deinstadt et al. 1990). Flow is described as ranging from slight to swift. Although Santa Ana suckers are usually found in clear water, they can tolerate seasonal turbidity. Preferred substrates are generally coarse and consist of gravel, rubble, and boulder, but occasionally Santa Ana suckers are found on sand/mud substrates. Santa Ana suckers often are associated with algae but not with macrophytes.

The best description of Santa Ana sucker habitat is provided by Deinstadt et al. (1990) for the West Fork of the San Gabriel River. The West Fork is a small (typical summer flow of 4 cfs, 5-8 m wide, depths mostly 15-30 cm), permanent stream that flows through a steep, rocky canyon with chapparal-covered walls. Overhanging riparian plants, mainly alders and sedges, provide cover for the fish. Santa Ana suckers utilize all areas and do not require streamside cover when larger, deeper holes and riffles are present for refuge, particularly for adult fish. Greenfield et al. (1970) recorded that Santa Ana suckers were washed into the Santa Clara River from a recreational lake. However, Santa Ana suckers probably do not successfully inhabit reservoirs, as they are not known to occur in Pint, Morris and San Gabriel reservoirs, or Hansen Dam (C. Swift, pers. comm.). Even though Santa Ana suckers seem to be quite generalized in their stream habitat requirements, they are intolerant of polluted or highly modified streams.

Distribution: The distribution of Santa Ana suckers was recorded by Swift (1980) and Swift et al. (1993). In two drainages (Los Angeles, San Gabriel) the species once occurred well downstream (to Los Angeles and Whittier, respectively) but are now restricted to the larger stream sections that still exist in headwater areas. In the Santa Ana River they survive only in the lower portions, mainly in reaches with flows enhanced by waste water (Mt. Roubidoux downstream to a few km below Imperial Highway). They have been extirpated from the upper Santa Ana River drainage where they were once present in Fish and Santiago canyons and in Cajon and City creeks. The historic Los Angeles Basin records are mostly at the California Academy of Sciences, University of Michigan, and the University of California, Los Angeles (UCLA). In the Santa Clara River to the north of the Los Angeles Basin, Santa Ana suckers were first collected in the 1930s and are considered to be introduced (Smith 1966, Bell 1978). They hybridize with another introduced species, *C. fumeiventris,* in the vicinity of Fillmore (Swift et al. 1993). Fish upstream in the Soledad Canyon area are pure Santa Ana suckers (Buth and Crabtree 1982). This stream and the San Gabriel River have the largest populations of Santa Ana suckers.

Abundance: The native range of the Santa Ana sucker is largely coincident with the Los Angeles metropolitan area, so it is not surprising that most populations in its native range have declined or been extirpated in recent years. The introduced population in Soledad Canyon still appears to be viable, although numbers were greatly reduced during the 1985-1992 drought. The status of the Santa Ana sucker in the three river drainages to which it is native is as follows:

- Los Angeles River. Once widespread in this drainage, Santa Ana suckers have been found in recent years only in Big Tujunga Creek, where they inhabit(ed) 10-20 km of stream below Big Tujunga Dam. Suckers could not be found here in the fall of 1990, but "3 or 4 juveniles" were caught during fall 1992 in Big Tujunga Creek just above Hansen Dam (C. Swift, pers. comm.).

- San Gabriel River. This is the only drainage in which the Santa Ana sucker is still fairly common, although it is likely that the population consists of less than 5,000 fish. The sucker now inhabits about 40 km of the contiguous West, North and East Forks of the San Gabriel River. The West Fork population exists mainly below Cogswell Reservoir where it is subject to the vagaries of regulated flows.

- Santa Ana River. Several hundred fish were observed in the river below Prado Dam (a flood control basin dam) in 1986 and 1987 by Robert Fisher (UCD, pers. comm.). Sampling below Prado Dam in the area of Imperial Highway during 1990-1991 produced only four adults (T. R. Haglund, pers. comm.). Considerable sampling effort above the dam from Norco to about 5 km upstream in April 1987 produced only five large individuals; definite evidence of reproduction was not obtained. However, additional surveys in 1987-1988 by Chadwick and Associates (Oregon) found moderate numbers upstream of Prado to about the town of Riverside (C. Swift, pers. comm.). Water quality is constantly threatened by many and various local sources (L. Courtois, pers. comm.). The apparent fluctuation in sucker numbers in this river, combined with water quality problems, indicate that the Santa Ana River population is not secure.

Nature and Degree of Threat: The Santa Ana sucker is threatened by elimination or alteration of its stream habitats, reduction or alteration of stream flows, pollution, and introduced species. The Santa Ana sucker is adapted for surviving extreme environmental perturbations, so populations can recover from disasters, provided there is a source of colonists for whatever suitable habitat exists. The fact that this fish is in such trouble is indicative of the poor state of the streams in the Los Angeles Basin, which suffer from multiple and cumulative effects of many agents of change.

Alteration of stream habitats. In lowland areas, virtually all of the habitats once used by this species have been channelized, frozen in concrete, dewatered, or otherwise altered. In upland areas, most streams either have been dammed and diverted, or are continually threatened by mass erosion of destabilized hillsides (from roadbuilding, off-road vehicle use, gravel extraction, forest fires, development, etc.), by gold dredging and other mining activities and by grazing and other heavy uses of riparian areas. For example, mining activity has increased in recent years on Cattle Canyon, a tributary of the East Fork of the San Gabriel River, resulting in the apparent elimination of sucker populations in Cattle Canyon.

Flow alterations. A number of the remaining populations of Santa Ana sucker live below dams or live in sections of stream dependent on waste water from sewage treatment plants (Santa Ana River). The flows of Big Tujunga Creek below Big Tunjunga Dam vary so much that an artificially enhanced trout population cannot maintain itself and all the native fishes are subject to extirpation, as almost happened to the sucker around 1989 or 1990. The population in the West Fork of the San Gabriel River is constantly threatened by accidental high-water releases (with heavy sediment loads) from Cogswell Reservoir, which have devastated this stream several times in the past. In the Santa Ana River, the main population depends on adequate releases of water from Prado Dam. In earlier years, water diversions for power generation probably often dried up the lower reaches of the Santa Ana River during the summer (C. Swift, pers. comm.).

Introduced species. Introduced species are a constant threat to Santa Ana sucker populations. For example, the sucker formerly inhabited the upper Santa Ana River in the San Bernardino Mountains but seems to have been eliminated by introduced predatory brown trout, because it has not been taken there for many years. Large numbers of genetically pure Santa Ana suckers exist in the Soledad Canyon area of the upper Santa Clara River, but the potential exists for hybridization with introduced Owens suckers that inhabit the lower river (Swift et al. 1993). Other populations are continually threatened by introduced species such as red shiner, *Cyprinella lutrensis,* (a potential competitor and egg predator) and green sunfish, *Lepomis cyanellus* (a potential predator).

Management: Thorough surveys are needed annually of all reaches of stream known to contain the sucker to determine population sizes and factors threatening their continued existence. Immediate steps should then be taken to protect their habitats in all three native drainages, including assurance of enough water for them to live in. Studies on their life history requirements also should be undertaken. As an immediate conservation measure, the East and West Forks of the San Gabriel River should be given the status of native fish management areas or refuges to protect not only the sucker but other native fishes as well, Protection of native fishes should have priority over management of the stream for other purposes, including maintanence of the wild trout fishery.

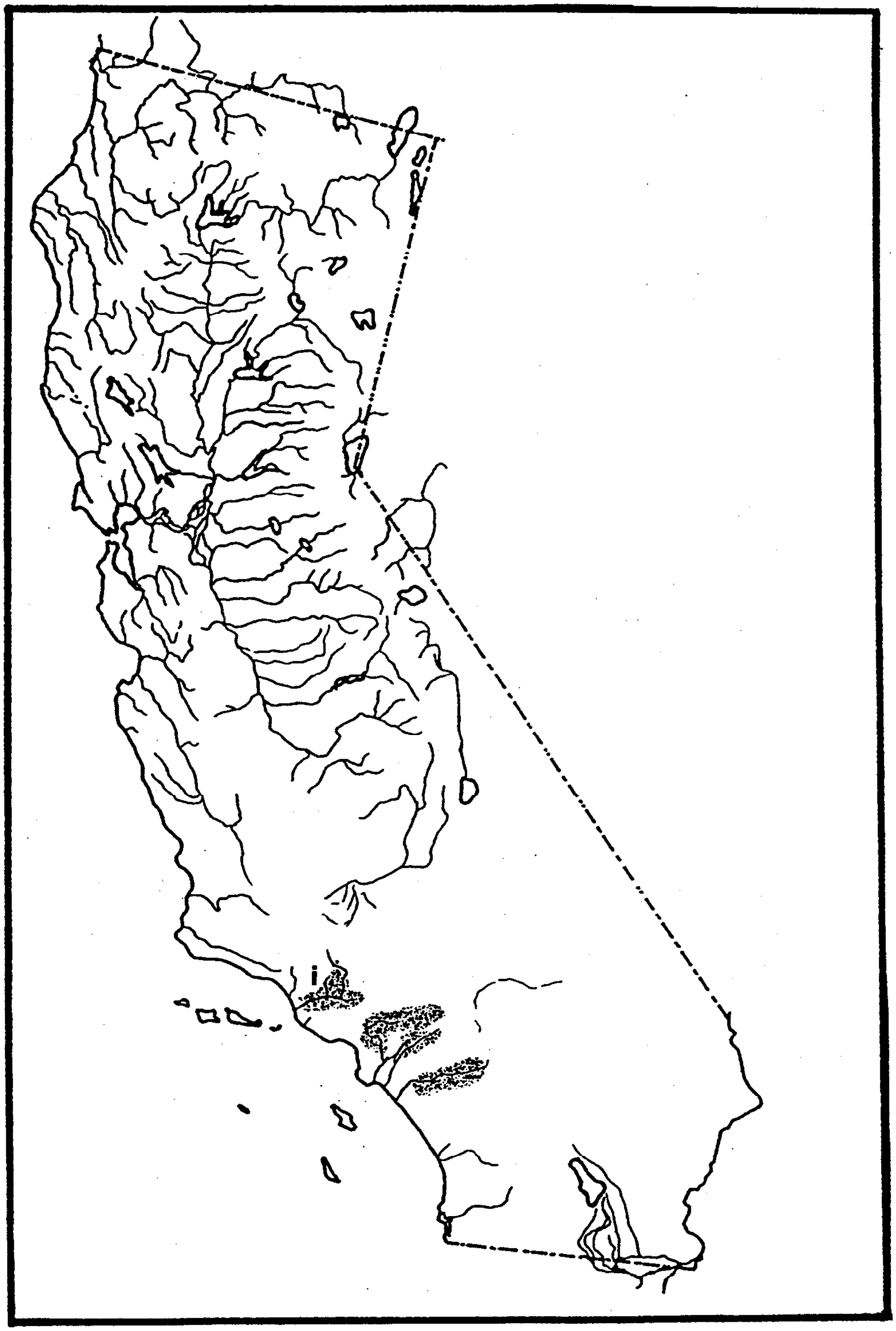


FIGURE 40. Distribution of the Santa Ana sucker, *Catostomus santaanae*, in California. (i = introduced population.)

SARATOGA SPRINGS PUPFISH
Cyprinodon nevadensis nevadensis Miller

Status: Class 1. Threatened.

Description: These are small fish that rarely exceed 50 mm TL. The body is deep, especially in reproductive males. The head is blunt and slopes steeply in front to a small, terminal, oblique mouth. There is one row of tricuspid teeth on each jaw, with the central cusps being truncated or pointed. *Cyprinodon nevadensis* is a variable species, but it can be distinguished from other pupfish by the following characteristics: (1) the scales are large, the circuli lack spine-like projections, and the interspaces are reticulated; (2) there are 23-28 scales (usually 25-26) along the lateral line and 15-24 scales (usually 16-18) anterior to the dorsal fin; (3) the pelvic fins are reduced and may even be absent; (4) there are 8-11 anal fin rays (usually 10), 11-18 pectoral fin rays (usually 15-17), 0-9 pelvic fin rays (usually 6), and 14-22 caudal fin rays (usually 16-19); gill rakers range from 14-22 (usually 15-17) and preopercular pores from 7-17 (usually 12-14). Reproductive males in nuptial coloration are bright blue with a black band at the posterior edge of the caudal fin. Reproductive females are drab olive-brown and develop 6-10 lateral vertical bars which may be distinct or faint. An ocellus is typically present on the posterior base of the dorsal fin of females.

Cyprinodon n. nevadensis can be distinguished from the other subspecies by the deeper, broader body, anteriorly placed pelvic fins, and a greater average number of scales (Table 9). Scales are narrow and larger, with very dense and extensive reticulations and a high number of scale radii. Males of this subspecies have an intense blue coloration (Soltz and Naiman 1978).

Taxonomic Relationships: The fossil record and past geologic events suggest that the *Cyprinodon* species differentiated relatively recently, with most differentiation occurring during the pluvial-interpluvial fluctuations of the early to mid-Pleistocene (Miller 1981). Some differentiation may have even occurred in the last 10,000 years, following the final recession of the pluvial waters. As the numerous scattered lakes and streams throughout the Great Basin shrank during the Pleistocene, remnant populations of pupfish survived in isolation, leading to speciation of *C. nevadensis.*

Cyprinodon nevadensis was first described from Saratoga Springs by Eigenmann and Eigenmann (1889). Following the initial description, the species was lumped with *Cyprinodon macularius* until Miller (1943) resurrected the species by extensive analysis of collections. In subsequent studies, Miller (1948) recognized and described six subspecies of *C. nevadensis,* four of which occur in California (C. n *nevadensis, C. n. amargosae, C. n. shoshone,* and C. *n. calidae)* and two in Nevada (C. *n. mionectes* and *C. n. pectoralis). Cyprinodon n. calidae* is now extinct (Moyle 1976).

Life History: These pupfish exhibit many adaptations that allow them to live in habitat with thermal and osmotic extremes (Miller 1981). Their growth is extremely rapid and they become sexually mature within four to six weeks (Miller 1948). Such a short generation time enables the pupfish to maintain small but viable populations. Among the subspecies, however, there are minor differences in generation times, with pupfish in habitats with widely fluctuating environmental conditions exhibiting shorter generation times (Moyle 1976). Young adults (15-30 mm SL) of *C. nevadensis* usually contribute most of the biomass throughout the year (Naiman 1976). Highest densities and peak breeding season occur during summer when water temperatures are higher and food is abundant (Kodric-Brown 1977). However, in the thermally stable habitat of Saratoga Springs, the breeding season is continuous the year around.

TABLE 9. Comparative morphometrics and meristics of *Cyprinodon nevadensis* subspecies. Adapted from Miller (1948).

Measure/Count	*C. n. amargosae*		*C. n. nevadensis*		*C. n. shoshone*	
	male	female	male	female	male	female
Standard length (mm)	36		40		34	
*Body width	256	265	274	269	231	229
*Head length	305		312		307	
*Head depth	330	304	367	343	331	311
*Head width	240	259	257	256	233	231
*Snout length	101		97		89	
*Mouth width	117		115		114	
*Mandible length	98		95		93	
*Anal origin to caudal base	338	346	394	362	371	355
*Caudal peduncle length	264	237	277	253	263	251
*Anal fin base length	116	105	111	105	108	101
*Anal fin length	233	199	227	195	217	190
*Pelvic tin length	98	89	95	87	90	77
Anal tin ray count	10		10		10	
Dorsal fin ray count	10		10		10	
Pelvic fin ray count	6		6		4	
Pectoral fin ray count	16		16		16	
Caudal fin ray count	18		17		18	
Lateral line scales	26		26		26	
Predorsal scale count	19		18		18	
Dorsal fin to pelvic fin scale count	11		10		9	
Caudal peduncle circum-ference scale count	16		16		15	
Body circumference scale count	27		25		23	

* Expressed as percent of standard length x 1000.

Cyprinodon n. nevadensis, like other spring-dwelling subspecies, exhibits a different reproductive behavior than riverine forms (Kodric-Brown 1981). The males of spring-dwelling subspecies establish territories over substrate with a topographic complexity suited for oviposition. Both sexes are promiscuous, and a single female may lay eggs in a number of different territories. The demersal eggs are sticky and thus adhere to the substrate. Females may lay a few eggs each day (not necessarily on consecutive days) throughout the year. Territorial defense by the males confers some protection of the eggs from predators, but otherwise parental investment is limited to gamete production (Kodric-Brown 1981). However, such territorial behavior is dependent on space availability and substrate complexity.

Pupfishes are capable of precise thermoregulation and usually exploit habitat close to their thermal maxima (Gerking 1981). The most sensitive phase of the life history of pupfishes to thermal stress is during reproduction (Gerking 1981). Although the adults have wide temperature tolerances (2-44°C), their reproductive tolerance limits are narrow, ranging from only 24-30°C. Extreme temperatures affect egg production and egg viability (Shrode and Gerking 1977, Gerking 1981). Furthermore, reproductive performance does not improve despite generation-long acclimation to suboptimal temperatures (Gerking et al. 1979). Thus, any alterations to their habitat that would result in temperature changes outside the range of their reproductive temperature optima would be potentially deleterious. Eggs, however, become resistant to environmental stresses within hours of being laid.

Pupfishes feed primarily on blue-green cyanobacteria. They feed seasonally on small invertebrates, mostly chironomid larvae, ostracods, and copepods (Naiman 1975, 1976). They forage continuously from sunrise to sunset and become inactive during the night. Their guts are extremely long and convoluted, an adaptation that enables them to digest cyanobacteria. Their teeth are also adapted for feeding behavior which involves nipping (Moyle 1976).

Habitat Requirements: Saratoga Springs is circular in shape, approximately 10 m in diameter and 1-2 m deep (Miller 1948). The water is clear with some algal material and detritus on the soft bottom. Water temperature is rather constant at 28-29°C. The spring overflows to the north into a larger pond that, in turn, drains into a number of shallow lakes 4-6 ha in area. Lake bottoms are grassy and the substrate consists of mud and sand. Water temperatures fluctuate considerably with ambient temperature and may vary from 10 to 49°C on a seasonal basis. Depth along the shores ranges up to 50 cm. Fish remain along the shores but move into the marshy meadows when disturbed. Juvenile fish abound in the lakes but are absent from the main spring, suggesting that spawning occurs only in the lakes.

Distribution: *Cyprinodon n. nevadensis* is and has been found only in Saratoga Springs and its outflow in Death Valley National Park, San Bernardino County, California. This spring is one of four adjacent springs that are among the largest in the California deserts. They are located at an elevation of 70 m and are tributary to the Amargosa River (Miller 1948). The overflow from the springs forms a series of marshes and shallow lakes. *Cyprinodon n. nevadensis* was introduced into and became established in "Lake" Tuendae, San Bernardino County, an artificial, spring-fed pond (Turner and Liu 1976). However, it appears to have died out there.

Abundance: Periodic surveys have found the population to be stable and occupying all available habitat, as it probably has for thousands of years.

Nature and Degree of Threat: The major threat to the Saratoga Springs pupfish is the potential destruction of its unique habitat, Saratoga Springs. Saratoga Springs is apparently recharged by water from a large, ancient aquifer that extends into western Utah and central Nevada. The Las Vegas Valley Water District proposes to mine this water in large quantities to supply the ever-growing human population of Las Vegas in southern Nevada (E. L. Rothfuss, Superintendent of Death Valley National Park, letter to B. Bolster of CDFG, 27 May 1992). The amount of groundwater that would be pumped out would be immense, in order to meet the city's demand. Author John McPhee writes (The New Yorker, April 26, 1993):

> "Around Las Vegas, well casings stand in the air like contemporary sculpture, and so much water has been mined from below that the surface of the earth has subsided six feet. While new wells are no longer permissible, Las Vegas desperately needs water for its lakes. They are not glacial lakes. If you want a lake in Las Vegas, you dig a hole and pour water into it. In one new subdivision are eight lakes. Las Vegas has twenty-two golf courses, at sixteen hundred gallons a divot. Green lawn runs down the median of the Strip. Here is the Wet 'N Wild park, there the new M-G-M water rides. Outside the Mirage, a stratovolcano is in a state of perpetual eruption. It erupts water."

If the proposed large-scale removal of groundwater happens, it is quite possible that Saratoga Springs will stop flowing or have greatly reduced flows. A comparable situation existed for Devil's Hole in Nevada, which had dropping water levels as a result of water being pumped from its aquifer for irrigation. It took an order from the U.S. Supreme Court to protect Devil's Hole and the Devil's Hole pupfish *(Cyprinodon diabolis),* by stopping the pumping (Deacon and Williams 1991). After rising and then stabilizing for a number of years, the water level in Devil's Hole is now dropping again, most likely as the result of groundwater pumping a considerable distance away (L. L. Lehman and R. G. Atkins, unpublished report, 1991). As a consequence of the proposed pumping, the Superintendent of Death Valley National Park (Rothfuss letter to Bolster, op. cit., above) has recommended the Saratoga Springs pupfish be listed as threatened. This recommendation is endorsed by the Desert Fishes Council (P. Pister, pers. comm.).

An additional threat to the pupfish is introduced species. Although Saratoga Springs is in Death Valley National Park, it is accessible to the public. Therefore, it always has the threat of someone introducing exotic fishes or invertebrates into the spring which may compete with or prey on the pupfish, or bring in disease to which the pupfish is not resistant.

Management: Saratoga Springs and the habitat created by the outflow are protected by the National Park Service and are in near-pristine condition. They will only remain that way if the water continues to flow at its present constant level. A listing of the subspecies as threatened might forestall massive groundwater pumping by the Las Vegas Valley Water District until it can be determined for certain whether or not Saratoga Springs (and other springs in the region) are connected to the aquifer and would be threatened by the pumping. A contingency plan should be developed that includes the identification of habitats or of facilities to temporarily hold pupfish from Saratoga Springs in the event population loss appears imminent.

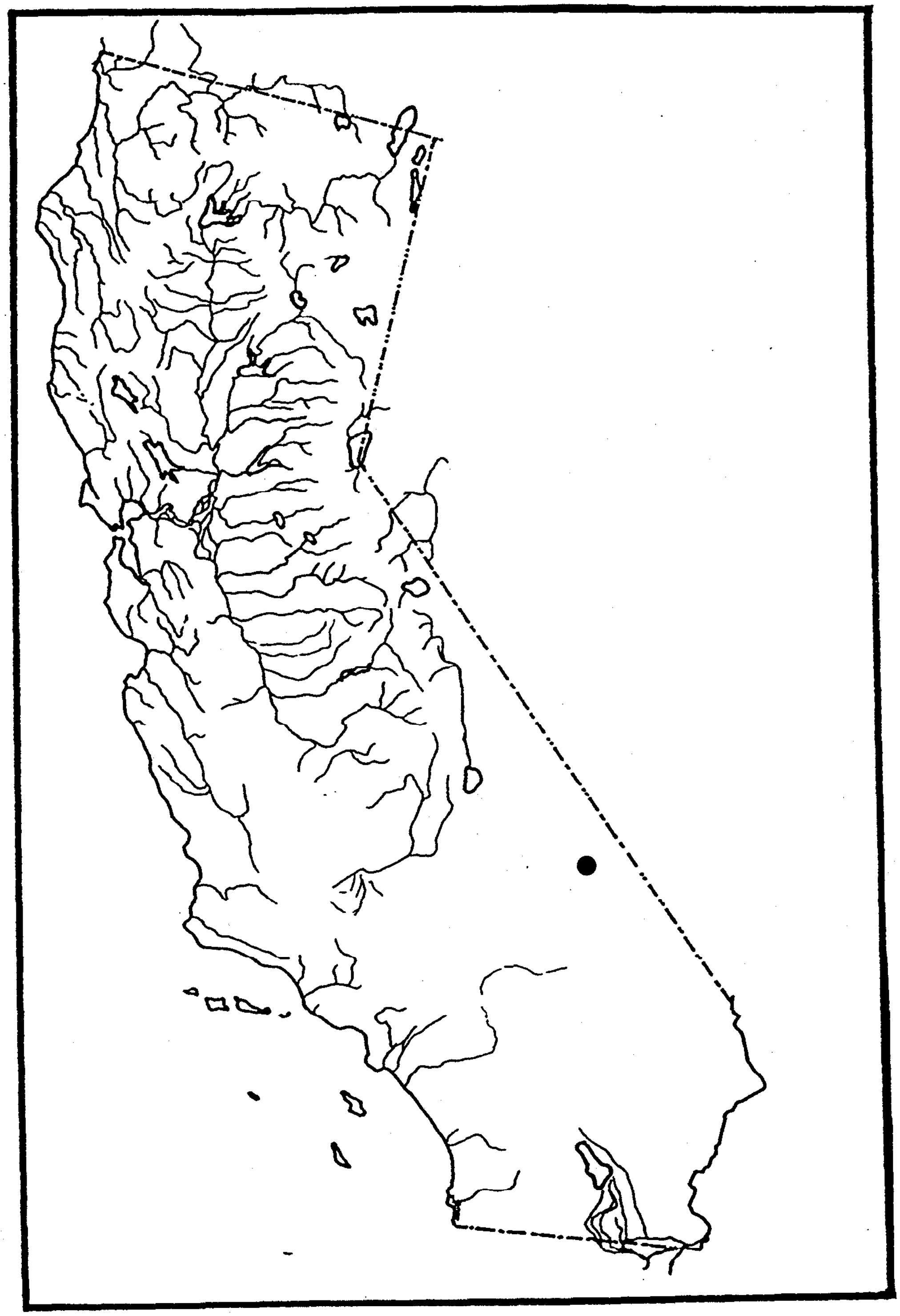


FIGURE 41. Distribution of the Saratoga Springs pupfish, *Cyprinodon nevadensis nevadensis*, in Saratoga Springs, San Bernardino County, California.

AMARGOSA PUPFISH
Cyprinodon nevadensis amargosae Miller

Status: Class 1. Threatened.

Description: This subspecies is similar to *Cyprinodon n. nevadensis* but has more scales around the body and fewer scale radii than other subspecies (see Table 9 in the Saratoga Springs pupfish account).

Taxonomic Relationships: *Cyprinodon nevadensis amargosae* is one of three extant subspecies of C. *nevadensis* found in California. Their relationships are discussed in the account of the Shoshone pupfish.

Life History: The life history of this subspecies is similar to the Saratoga Springs pupfish. Being a riverine fish, however, its reproductive strategies differ from many spring-dwelling pupfishes. *Cyprinodon n. amargosae* is a group spawner (Kodric-Brown 1981). Males do not establish and defend territories as do males of spring-dwelling subspecies. Instead, a reproductive male usually directs a receptive female to the periphery of the group where spawning occurs, although spawning may even take place in the center of the group.

The pupfish feed primarily on blue-green cyanobacteria, but they also ingest lesser quantities of small invertebrates (mostly chironomid larvae, ostracods, and copepods) (Naiman 1975, 1976). They forage continuously during the day but become inactive during the night.

Habitat Requirements: The upper section of the lower Amargosa River is divided into two distinct areas. The upstream area near Tecopa is characterized by broad marshes fed by hot springs. The second area is immediately downstream where the river flows through a narrow, steep-sided canyon. The river there is less than 2 m wide and up to 2.5 m deep. The flows are swift in the runs between pools and the substrate consists mostly of gravel and sand, with some boulder and rubble (Miller 1948, Williams et al. 1982). The water is clear and saline, with pH ranging from 8.2-8.7. Total dissolved solids are fairly high and variable at 1,390-3,890 ppm and dissolved oxygen is 7.3-11.6 mg l^{-1}. Shoreline vegetation is abundant. Pools are numerous, both in the river and on the flood plain, the largest being about 8 x 5 m. Substrate in the pools is mostly mud and clay. Water temperature in habitat where fish are found is 20-21°C (Miller 1948) and the preferred depth range is 10-35 cm (Williams et al. 1982). In the Tecopa area, this subspecies also inhabits torrid outflows of hot springs, habitats formerly occupied by *C. n. calidae.*

The downstream section in Death Valley National Park is at an elevation of 33 m (Miller 1948). The river bottom consists of fine silt, clay, mud, and sand and there is no instream macrovegetation. The current is moderate to swift between pools that are 0.75-1.25 m deep. Water temperature varies seasonally from 10-38°C. During severe winters, temperatures may approach freezing. Diel variation in water temperature is also present and there is a tendency for longitudinal and vertical temperature stratification. Younger fish tolerate higher water temperatures than adults (Shrode 1975) and are commonly found in warmer water (Miller 1948), which may serve as a refuge from predation or competition for food.

Distribution: *Cyprinodon n. amargosae* is the most widely distributed subspecies of this species, inhabiting two sections with permanent flows of the lower Amargosa River, Inyo County. The upper section begins above Tecopa and flows through Amargosa Canyon for about 11 km until it approaches Sperry. The second, lower section flows through Death Valley northwest of Saratoga Springs and approximately 32 km below Sperry and continues for about 3 km. Differences in meristic characteristics between the two populations suggest that they are effectively isolated from each other (Miller 1948), except perhaps in times of floods. In 1940, R. R. Miller planted 350 Amargosa pupfish in River Springs, Adobe Valley, Mono County. This population is extant and flourishing (P. Pister, pers. comm.). However, because *C. s. salinus* was planted at the same time but apparently died out (E. Pister, CDFG, pers. comm.), studies are needed to determine whether and to what extent hybridization between the two subspecies may have occurred. CDFG funded a mtDNA study of Death Valley system pupfishes; results from Dr. Bruce Turner (Virginia Polytechnic Univ.) are expected in 1996.

Abundance: This pupfish is the most widespread of any *Cyprinodon nevadensis* subspecies and is fairly common in the lower Amargosa River, particularly around Tecopa and in Amargosa Canyon. It also occurs in an isolated downstream reach of river in Death Valley National Park. Historic records of its abundance are lacking, but it is presumably less abundant than formerly because water diversions have reduced the flows of the Amargosa River in places.

Nature and Degree of Threat: The major threat to the Amargosa pupfish is the potential dewatering of its unique habitat, the Amargosa River, by a combination of water withdrawals at both distant and near points from the aquifer that feeds it and from local water diversions. The Amargosa River apparently receives much of its permanent flow from springs fed by a large, ancient aquifer that extends into western Utah and central Nevada. The Las Vegas Valley Water District proposes to mine this water in large quantities to supply its ever-growing human population (E. L. Rothfuss, Superintendent of Death Valley National Monument, letter to B. Bolster of CDFG, May 27, 1992). At the present time, farming operations and human settlements in the Amargosa region are withdrawing increasing amounts of water from the aquifer, which has already caused a drop in the water level at Devil's Hole (habitat of the endangered Devil's Hole pupfish, *Cyprinodon diabolis,* in nearby Nevada) (L. L. Lehman and R. G. Atkins, 1991, unpubl. report). If the Amargosa region withdrawals continue to increase and if Las Vegas proceeds with its planned withdrawals, it is highly likely that the Amargosa River will have its flows greatly reduced or dry up completely during dry years. Already, diversions of springs and outflows on private land in the Tecopa area have probably reduced local flows in the river and local pupfish populations as well. With an increasing human population in Tecopa and the upper Amargosa Valley, demand for water and protection from floods is increasing.

An additional threat is the introduction of potential competitors and predators, as the Amargosa River is highly accessible to the public. Mosquitofish that are associated with declines of other pupfish species often are abundant in Amargosa Canyon, yet Amargosa pupfish appear able to coexist with them (Williams et al. 1982). Flash floods periodically reduce mosquitofish populations, to the advantage of pupfish. The possibility of additional introductions of exotic fishes into the Amargosa River exists, however. A catfish farm located upstream in Shoshone will require careful management to prevent escape and subsequent establishment of unwanted species in the river.

As a consequence of these threats, the Superintendent of Death Valley National Monument has recommended that the Amargosa pupfish be listed as a threatened species (E. L. Rothfuss, Superintendent of Death Valley National Monument, letter to B. Bolster, CDFG, May 27, 1992). This recommendation is endorsed by the Desert Fishes Council (E. P. Pister, pers. comm.).

Management: Populations should be monitored annually. Efforts should be made to ensure a natural flow of water in the Amargosa River, including flood flows that reduce populations of introduced fishes. Management strategies should protect populations in both the upstream segment (Tecopa area and Amargosa Canyon) and the downstream segment (Death Valley) to maintain genetic diversity. Fortunately, most of the canyon area is now owned by The Nature Conservancy and the BLM. Amargosa Canyon is part of an Area of Critical Environmental Concern and is closed to off-road vehicle use. Fences and barriers need to be properly maintained, however, as vehicle trespass is a common problem.

The downstream section in Death Valley is managed by the National Park Service but is dependent on water availability from upstream, unprotected areas.

The most difficult problem is dealing with the results of water removal from the aquifer that apparently feeds the river. The U.S. Supreme Court decision that protected the Devil's Hole pupfish from water withdrawals may be some help here, but its application on a regional basis is uncertain. The proposed, massive groundwater pumping by Las Vegas should be forestalled until it can be determined for certain whether or not the Amargosa River depends on the aquifer and would be threatened by pumping. Protection of the pupfish could thus help to protect an entire unique desert ecosystem.

Given the uncertainties of continued flow in the Amargosa River, a contingency plan should be developed that would include the identification of habitats or of facilities to temporarily hold pupfish from both upstream and downstream populations in the event population loss appears imminent.

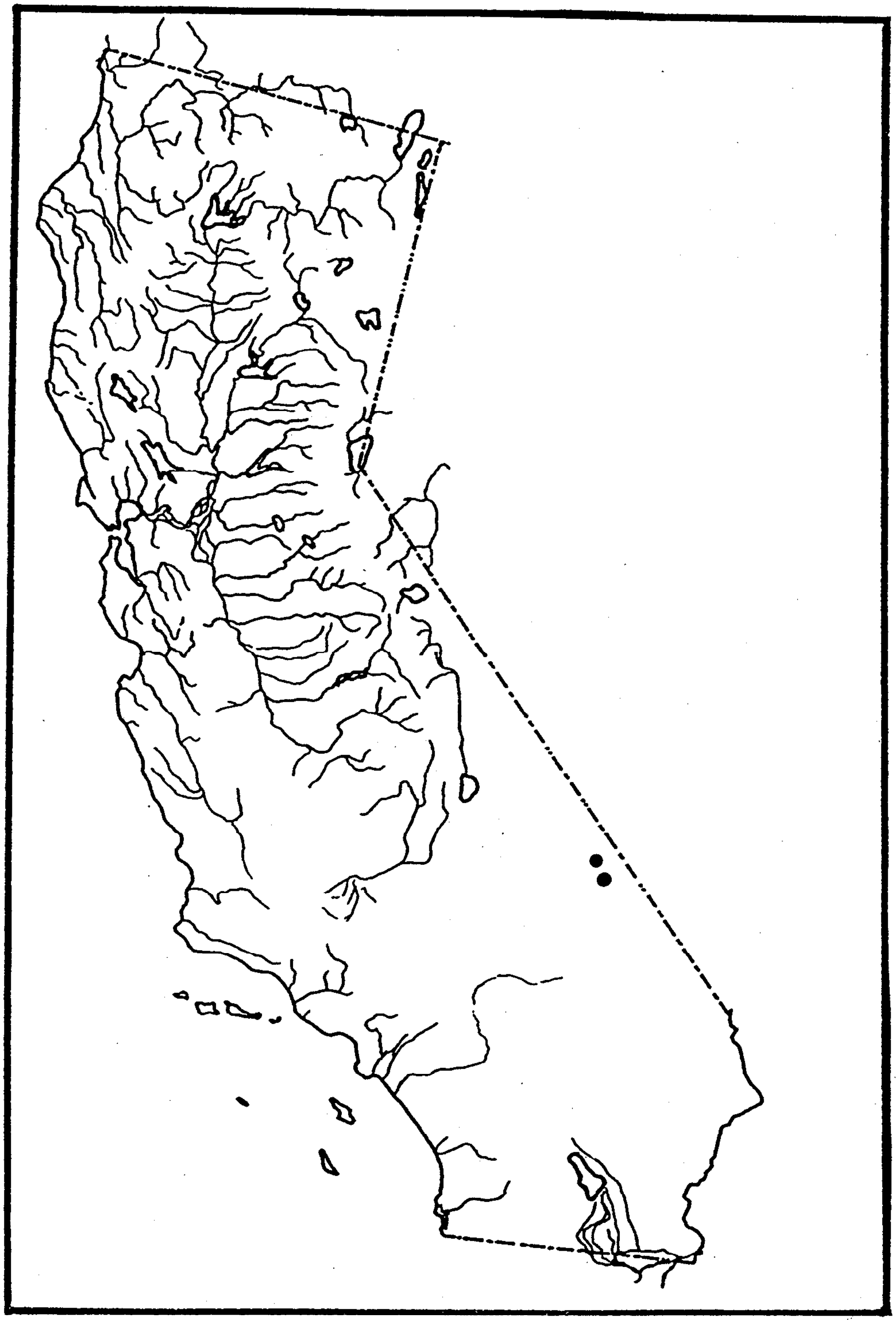


FIGURE 42. Distribution of the Amargosa pupfish, *Cyprinodon nevadensis amargosae*, in the lower Amargosa River, California.

SHOSHONE PUPFISH
Cyprinodon nevadensis shoshone Miller

Status: Class 1. Endangered.

Description: The morphology of this subspecies is similar to *Cyprinodon n. nevadensis.* However, it is characterized by large scales and a "slab-sided," narrow, slender body, with the arch of the ventral contour much less pronounced than the dorsal. It also has fewer pelvic fin rays and scales than the other subspecies.

Taxonomic Relationships: The fossil record and past geologic events suggest that at least some of the western *Cyprinodon* species differentiated relatively recently, with most of this differentiation occurring during the pluvial-interpluvial fluctuations of the early to mid-Pleistocene (Miller 1981). Speciation of the Devil's Hole pupfish *(Cyprinodon diabolis),* which together with *C. radiosus, C. nevadensis* and *C. salinus,* constitutes the *Cyprinodon nevadensis* species complex, possibly occurred less than 20,000 years ago (Echelle and Echelle 1993). Further differentiation may have occurred in the last 10,000 years, following the final recession of the pluvial waters. As the numerous scattered lakes and streams throughout the Great Basin shrank after the Pleistocene, remnant populations of pupfish survived in isolation, leading to subspecific differentiation within *C. nevadensis.*

Cyprinodon nevadensis was first described from Saratoga Springs by Eigenmann and Eigenmann (1889). Following the initial description, the species was lumped with *Cyprinodon macularius* until Miller (1943) resurrected the species by extensive analysis of collections. In subsequent studies, Miller (1948). recognized and described six subspecies of *C. nevadensis,* four of which occur in California (C. n. *nevadensis, C. n. amargosae, C. n. shoshone,* and *C. n. calidae)* and two in Nevada *(C. n. mionectes* and *C. n. pectoralis). Cyprinodon n. calidae* is now extinct (Moyle 1976). The taxonomic status of pupfish in the Amargosa River near Shoshone is uncertain. They may be pure *C. n. shoshone,* as hypothesized by Taylor et al. (1988), or *C. n. amargosae* from downstream sources, or hybrids between them.

Life History: The life-history characteristics of this subspecies have not been studied in detail but are undoubtedly similar to *C. n. nevadensis.* Pupfish, such as the Shoshone pupfish, exhibit many characteristics that adapt them to live in habitat with thermal and osmotic extremes (Miller 1981). Their growth is extremely rapid and they become sexually mature within four to six weeks (Miller 1948). Such short a generation time enables pupfish to maintain small but viable populations. Among the subspecies, however, there are minor differences in generation times, with pupfish in habitats with widely fluctuating environmental conditions exhibiting shorter generation times (Moyle 1976).

Young adults (15-30 mm SL) of *C. nevadensis* usually contribute to most of the biomass throughout the year (Naiman 1976). Highest densities and the peak breeding season occur during summer when water temperatures are highest and food is abundant (Kodric-Brown 1977), although the Shoshone pupfish presumably once bred year-round, like the Saratoga Spring pupfish. In the river and outflow ditch, where thermal conditions are highly variable, the probable breeding season extends throughout spring and summer. The males of spring-dwelling subspecies establish territories over substrate with a topographic complexity suited for oviposition. Both sexes are promiscuous, and a single female may lay eggs in a number of different territories. The demersal eggs are sticky and thus adhere to the substrate. Females may lay a few eggs each day (not necessarily on consecutive days) throughout the year. Territorial defense by the males confers some protection of the eggs from predators, but otherwise parental investment is limited to gamete production (Kodric-Brown 1981). However, such territorial behavior is dependent on space availability and substrate complexity.

Shoshone pupfish presumably are like other *C. newdensis* subspecies in that adults have wide temperature tolerances (2-44°C); however, their reproductive tolerance limits are narrow, ranging from only 24-30°C. Extreme temperatures affect egg production and egg viability (Shrode and Gerking 1977, Gerking 1981). Thus, any alterations to their habitat that would result in temperature changes outside the range of their reproductive temperature optima would be potentially deleterious. Eggs, however, become resistant to environmental stresses within hours of being laid.

Shoshone pupfish, like other pupfishes, feed primarily on blue-green cyanobacteria but also consume small invertebrates like chironomid larvae, ostracods, and copepods (Naiman 1975, 1976). They forage continuously from sunrise to sunset and become inactive at night. Their guts are extremely long and convoluted, an adaptation that enables them to digest cyanobacteria.

Habitat Requirements: In Shoshone Spring and its outlet creek there were two holes located well above the Old State Highway that provided refuge to the Shoshone pupfish from the swifter flows in the main channel (Miller 1948). The larger, upper hole (known as Squaw Hole) was about 1 m in diameter and 0.75 m deep. The water was clear and the bottom muddy. There were overhanging banks. Shoshone Spring was less saline than the other springs and had less boron content but more calcium. Since then, the habitat has been completely altered (Taylor et al. 1988, Castleberry et al. 1990). The spring source has been enclosed by a series of concrete boxes for the past 45 years or so. These boxes direct the water supply to the town of Shoshone, a swimming pool and a catfish rearing pond. Some water escapes the diversion and flows toward Old State Highway, but is then joined by chlorinated outflow water from the swimming pool. After passing under Old State Highway, most of the water is piped into the large catfish pond, and the rest flows down a cement ditch, in which remnants of the spring pupfish populations managed to survive. Outflow from the pond enters the cement ditch downstream. Water then flows through a dense cattail marsh and an impenetrable tamarisk thicket prior to becoming confluent with the Amargosa River. The depth of the channel during the 1986 collections of Taylor et al. (1988) varied from 8 - 50 cm, and the width from 1.5 - 8 m. Conductivity was 2,959 $\mu m\ cm^{-1}$, pH 8.2, and water temperature varied from 28-34°C.

Distribution: *Cyprinodon n. shoshone* was formerly found in the Shoshone Spring and throughout its outlet creek (Miller 1948, Taylor et al. 1988). Taylor et al. (1988) also considered pupfish in the Amargosa River near the Shoshone Spring outlet creek to be *C. n. shoshone,* but this finding remains tentative pending a detailed examination of the fish. The spring is located in Shoshone, Inyo County, California. The spring source is at an elevation of 5 18 m, about 170 m above State Highway 127 on the east slope of a rocky lava hill. The outlet creek flows under the Old State Highway and becomes confluent with the Amargosa River approximately 400-500 m downstream. Today, the Shoshone pupfish exists primarily in a pond constructed near the spring.

Abundance: The Shoshone pupfish was recently considered to be extinct (Selby 1977, CDFG 1980) but was rediscovered in 1986 (Taylor et al. 1988). Although the pupfish was found in "large numbers" through the outflow creek in the summer of 1986 (Taylor et al. 1988), its numbers had dwindled to perhaps less than about 20 individuals by 1988 (J. Williams, unpubl. data). The decline may have been precipitated by the vast numbers of mosquitofish *(Gambusia affinis)* in the outflow creek. Taylor et al. (1988) hypothesized that the Shoshone pupfish survived in very low numbers until conditions became more favorable, when the population expanded. The pupfish apparently passed through a genetic bottleneck during the period of reduced population size.

Because of the lack of suitable habitat and the abundance of mosquitofish, most Shoshone pupfish were removed from the wild and small stocks of approximately 12 fish each were kept at the University of Nevada, Las Vegas, and UCD. Recently, captive-raised individuals from both UCD and UNLV were introduced into a refuge pond constructed at the headspring of this system (Swift et al. 1993, D. Castleberry and F. Taylor, pers. comm.) and their numbers appear to have increased (D. Castleberry, pers. comm.). However, no recent abundance estimates are available.

Nature and Degree of Threat: The existence of Shoshone pupfish is entirely dependent on the maintenance of artificial habitats because the original Shoshone Spring and its outflow have been virtually destroyed. The spring is privately owned and is used as a water supply for the town of Shoshone and a catfish farm, as well as for the pupfish refuge, so the survival of the pupfish depends almost entirely on the good will of the owners. The fact that Shoshone pupfish are now largely confined to a small artificial habitat means that they are extremely vulnerable to random acts of vandalism and to the introduction of other fishes into their habitat.

Introduced mosquitofish undoubtedly preyed on the eggs and young and were the immediate factor threatening the pupfish with extinction before they were rescued. They now would prevent the re-establishment of pupfish in the outflow ditch, even if water quality were high (e.g, no chlorinated water from the swimming pool, etc.).

Management: Two artificial pools were created in the headsprings area of Shoshone Spring during 1988 and stocked with Shoshone pupfish. The pools were subsequently enlarged into a single pool that serves as the principal refuge for the pupfish. The headsprings area should be managed as a preserve and the refuge pool monitored to establish baseline water conditions and to check for presence of introduced fishes.

The cement ditch between the Old State Highway and State Highway 127 should be managed to enhance conditions for the pupfish. This would include maintaining a slight to moderate flow through the channel because a slight flow will be unfavorable to mosquitofish. However, the mosquitofish must be eradicated from the ditch before any reintroduction attempt is made. At least two fish kills in the cement ditch, due to concentrated chlorinated outflow from weekly swimming pool cleanings, have been noted (D. Castleberry and B. Bolster, pers. comms.). Undiluted chlorinated discharges therefore need to be halted. Conditions in the outflow creek between State Highway 127 and the Amargosa River will have to be monitored to determine if desirable habitat can be restored.

Several studies are needed to enable proper management of this subspecies. For example, tamarisk is now the dominant riparian plant in the system, in contrast to the predominance of cattails and mesquite in earlier years (Castleberry et al. 1990). A number of large tamarisk trees were removed in 1988 but additional studies are needed on more permanent methods of tamarisk control. A hydrologic study is also needed to establish the amount of available water and of water losses through evaporation from open water and for municipal uses. A taxonomic evaluation of pupfish in the Amargosa River is also needed to determine the presence of *C. n. shoshone* and *C. n. amargosae* genotypes. Both meristic (Taylor et al. 1988) and morphometric (Taylor and Pedretti 1994) comparisons of Amargosa River and Shoshone Spring pupfish populations found them to be different. The genetic history of the Death Valley pupfishes is complex (Echelle and Dowling 1992). A molecular genetic study of all California pupfish populations is currently underway, with results expected in 1996 (B. Bolster, pers. comm.). The study includes attempting to discriminate between *C. nevadensis* subspecies in Shoshone Spring and the Amargosa River.

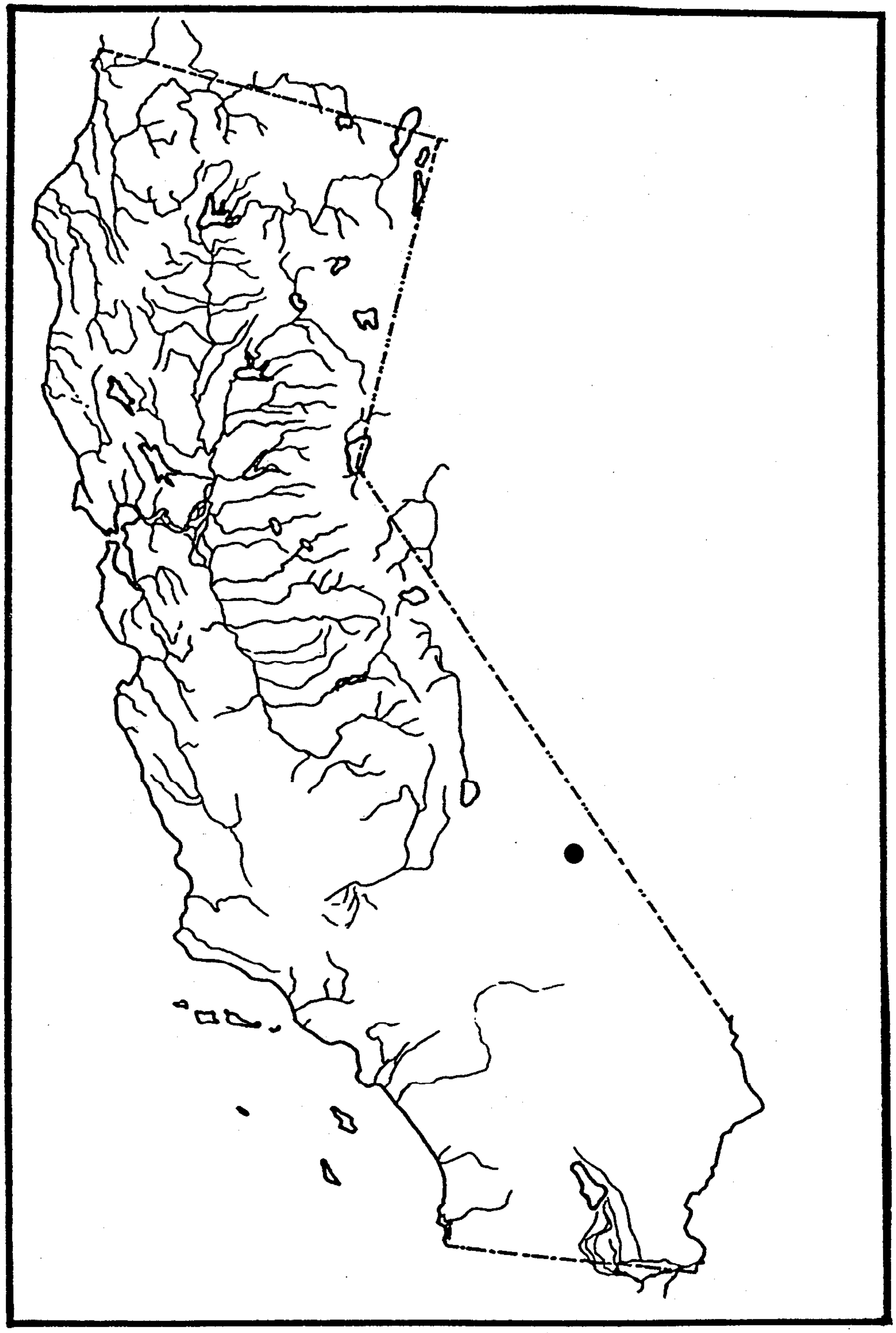


FIGURE 43. Distribution of the Shoshone pupfish, *Cyprinodon nevadensis shoshone*, in Shoshone, Inyo County, California.

SALT CREEK PUPFISH
Cyprinodon salinus salinus Miller

Status: Class 1. Threatened.

Description: These small fish reach approximately 6.5 cm TL and, of all the species of Death Valley pupfishes, they are the most slender bodied. They have small scales, crowded together, with reticulated interspaces between the circuli. Scales are oval to nearly circular in outline, being intermediate to *Cyprinodon nevadensis* and *C. macularius* in the number of radii (15-22, usually 18). There are 28-29 scales along the lateral line and a high number of predorsal scales, serving to distinguish this species from other western *Cyprinodon* species. The preorbital region of the head lacks scales. Lateral line pores, especially the preopercular pores, are well developed. The mouth is slightly supraterminal and has tricuspid teeth with prominent median ridges. The dorsal fin is set behind the midpoint of the body. The pelvic fins are reduced and may even be absent. There are 8-11 dorsal fin rays (usually 9-10); 9-11 anal fin rays (usually 10); 14-17 pectoral fin rays (usually 15-16); 15-19 caudal fin rays (usually 16-17); and 6 (or no) pelvic fin rays. Gill rakers number 18-22 (usually 19-21) and are shorter and more compressed than in other pupfishes.

Reproductive males are deep blue on the sides and iridescent purple dorsally (Miller 1943). Caudal fins of males have a prominent black terminal band. The sides have 5-8 broad black bands that may be continuous or interrupted ventrally. Females are a less conspicuous brown with a silvery sheen (Miller 1943a,b). Females have 4-8 vertical lateral bars less striking than those of males, except during spawning. Females are also more slender than males, the latter being more deep bodied, with a noticeable arch to their profile anteriorly.

Taxonomic Relationships: *Cyprinodon salinus* was first described by Miller (1943) from Salt Creek in Death Valley. In scale structure, *C. salinus* agrees with the other species of *Cyprinodon* in the Death Valley system. However, other characteristics such as reduced or absent pelvic tins, posterior position of the dorsal fin, short head, small eyes, low mean fin-ray counts, and inconspicuous humeral process suggest that it is closely related to *C. nevadensis* (Miller 1943). Thus, *C. salinus* probably either shared a common ancestral stock with *C. nevadensis* or became differentiated from *C. nevadensis* during the late Pleistocene when most of Lake Manly (which was contiguous with the Amargosa River) receded and dried up, isolating *C. salinus* in its present habitat (Miller 1981). *Cyprinodon salinus* has subsequently been divided into two subspecies, *C. s. salinus* from Salt Creek and *C. s. milleri* from Cottonball Marsh, into which Salt Creek overflows.

Life History: Salt Creek pupfish usually live one year or less (Sigler and Sigler 1987), and have generation times of 2-3 months, enabling them to reproduce several times a year. Thus, large populations are built up during favorable conditions of high water, and colonization of areas beyond the permanent water occurs. During these periods their numbers have been estimated to be in the millions (Miller 1943). However, when the waters recede, most of these fish are trapped in side pools and on the flood plain and perish. Also, the habitat is vulnerable to flash flooding, which may result in population losses as young fish are washed downstream and adults are isolated in pools that eventually dry (Williams and Bolster 1989). Reproductive behavior and other aspects of their life history are similar to Amargosa pupfish.

Habitat Requirements: Salt Creek begins from seepages that collect to form the meandering, mud-bottomed creek. The upper reaches of the creek contain surface water only during the winter and spring.

This section, which originates at 60 m below sea level, traverses Mesquite Flat for 1-2 km before abruptly entering a narrow, shallow canyon. The flow within the canyon is permanent and provides year-round habitat for the pupfish. The stream channel in the canyon is carved 3-7 m deep into the alkaline mud and has a series of large (10 x 25 x 2 m deep) interconnected pools. These pools provide shelter and refuge for the pupfish. Overhanging salt grass, pickleweed, and saltbush form a protective canopy over the pool edges. The pools also contain heavy growths of aquatic plants that provide instream refuge for the fish. Below the pool area, the stream is shallow and exposed. Shortly afterward, it emerges from the canyon and disappears into the floor of Death Valley. When flows are high, pupfish may also inhabit this stream section.

Water temperatures in Salt Creek fluctuate from near freezing during the winter to >40°C during the summer. However, the deeper water in the pools seldom exceeds 28°C and may provide temperature refuges, especially for reproduction. Salinity is also high, approaching that of sea water, but the levels of boron (39 ppm) and total dissolved solids (23,600 ppm) are considerably higher.

Given the extreme conditions found in Salt Creek, it is not surprising that these fish are physiologically adapted to tolerate wide temperature and salinity fluctuations. Brown and Feldmeth (1971) found that under experimental conditions *C. salinus* survived temperatures up to 42°C and tolerated a wide temperature range. They also survived salinities of up to 67 ppt, but died at 79 ppt (LaBounty and Deacon 1972).

Distribution: Salt Creek pupfish are restricted to Salt Creek, Inyo County, in Death Valley National Park. However, Salt Creek pupfish were introduced into Soda Lake, San Bernardino County, and into River Springs, Mono County (Miller 1968). The Soda Lake population no longer exists and the pupfish in River Springs have been mixed with *Cyprinodon nevadensis amargosae,* and few *C. salinus* genes remain (R. Miller, pers. comm.). Thus, genetically pure *C. s. salinus* apparently are restricted to Salt Creek and its associated marshes about 1.5-6 km below McLean Springs, the range varying with rainfall (Swift et al. 1993).

Abundance: The numbers of Salt Creek pupfish fluctuate widely on an annual basis, but there is no reason to think they are less abundant now than they were in the past.

Nature and Degree of Threat: E. L. Rothfuss, Superintendent of Death Valley National Park, recommended that the Salt Creek pupfish be listed as a threatened species for the following reasons: "During spring the population expands and disperses throughout the braided stream system, but by mid-summer habitat has contracted due to seasonal evaporation of water, and the fish are confined to several source pools south of MacLean Spring. We believe listing is warranted in light of the restricted areal extent of the habitat during this portion of the year. While restricted to these pools, the fish are vulnerable to intentional contamination, introduction of exotic competitors, and stochastic events" (letter to B. Bolster, CDFG, June 1, 1992).

Management: Present management by the National Park Service is sufficient to maintain the pupfish populations, as well as the entire unique Salt Creek ecosystem. However, listing is warranted to help protect the species and the ecosystem from unexpected events. Potential refuge sites need to be located and contingency plans developed in case of a sudden change in the Salt Creek populations below minimum viable levels.

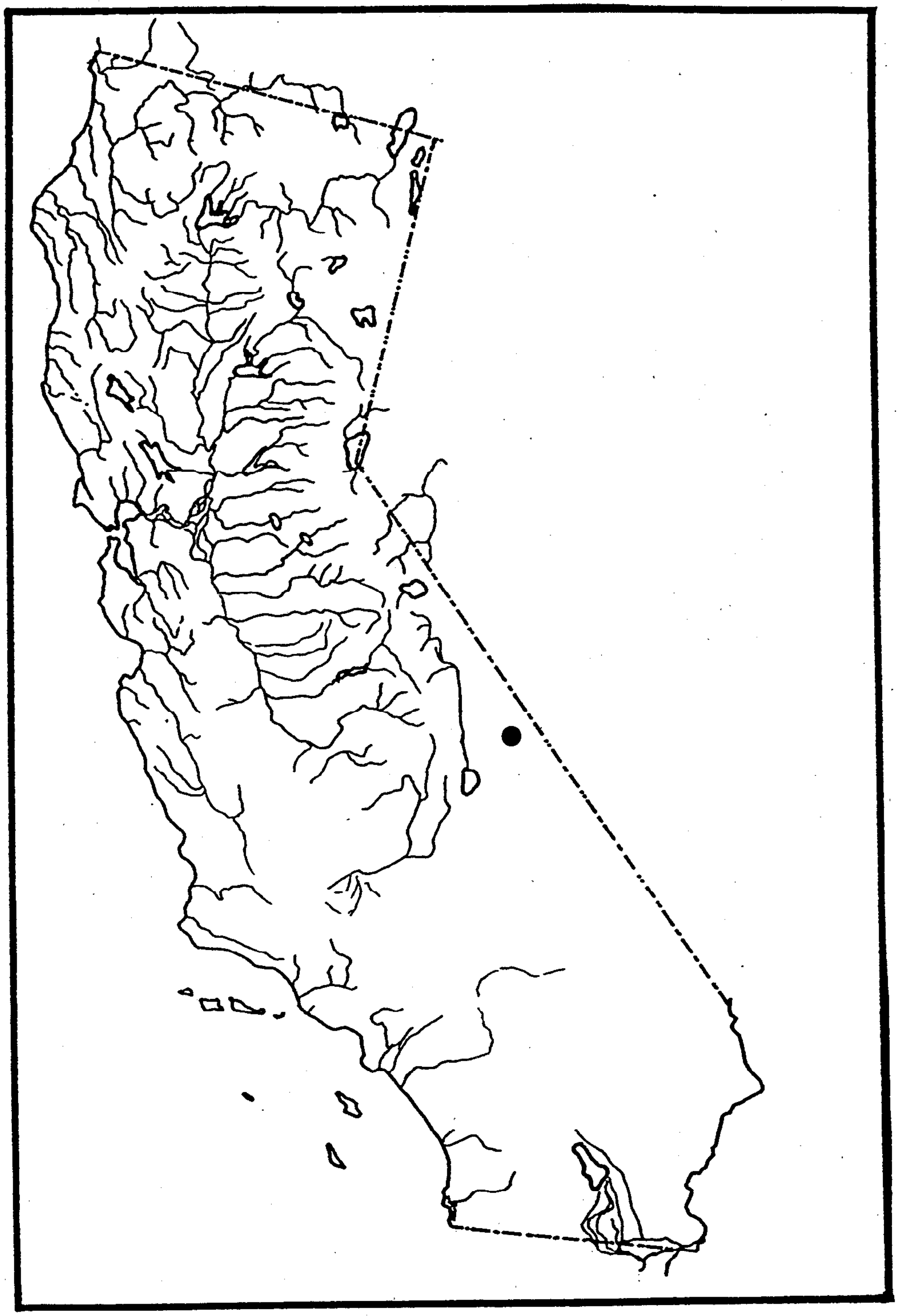


FIGURE 44. Distribution of the Salt Creek pupfish, *Cyprinodon salinus salinus*, in Salt Creek, Inyo County, California.

SHAY CREEK THREESPINE STICKLEBACK
Gasterosteus aculeatus ssp.

Status: Class 1. Endangered.

Description: The Shay Creek threespine stickleback is morphologically similar to the unarmored stickleback, *G. a. williamsoni* (Haglund and Buth 1988, T. Haglund pers. comm). The Shay Creek stickleback often lacks lateral plates, but the presence of plates is highly variable. Fish from Shay Creek itself frequently lack lateral plates (80-90% of individuals collected; Malcolm 1992), while individuals collected from Baldwin Lake more frequently possess plates (present in 40-65% of individuals examined; Malcolm 1992). Preliminary data suggest that fish from larger bodies of open water have higher plate counts (Malcolm 1992). Shay Creek sticklebacks are small (maximum size is about 80 mm TL) and have three sharp dorsal spines anterior to the dorsal fin and a short, stout spine derived from modified pelvic fins on each side. The rounded body and short spines are typical of southern California *G. aculeatus;* however, the ascending member of the pelvic girdle is broad and fan-shaped compared to other southern California sticklebacks (Malcolm 1992). The mouth is terminal and oblique and the eyes are large. The caudal peduncle is narrow. Gill rakers number 17-26, dorsal fin rays 10-24, anal fin rays 6-10, and pectoral tin rays 9-11. There is only one pelvic tin ray.

Adult coloration is usually olive to dark green on the sides and back, and white to golden ventrally. The fins are colorless. Reproductive males acquire an intense, shiny black nuptial coloration on their sides and back, iridescent blue eyes, and a characteristic bright red color on the throat and anterior ventral area. Almost all males have the red extending to the anal fin; in many individuals it extends to the caudal peduncle. The extent of red coloration in males is greater than in other populations in southern California. Females are generally larger than males at maturity.

Taxonomic Relationships: Regan (1909) described *Gasterosteus santa-annae,* an unplated stickleback from the Santa Ana River, near Riverside, but the original lowland populations of *G. santa-annae* are now extinct. Miller (1960) considered all unarmored sticklebacks to be *G. a williamsoni.* However, electrophoretic studies by T. Haglund and D. Buth (1988 and pers. comm.) indicate that even though the Shay Creek population is phenotypically similar to *G. a. williamsoni,* the genetic differences are great enough to warrant subspecies or perhaps even species status. In an electrophoretic comparison, sticklebacks from the rest of southern California were more similar to sticklebacks from Scotland than to ones from Shay Creek (T. R. Haglund, unpubl. data). Taxonomic recognition of the Shay Creek stickleback is also warranted by its unusual habitat requirements, the distinctive breeding coloration of males (especially the large amount of red on the body), and its unusual nest-building behavior (see below). It is possible that the Shay Creek population represents the remnants of the original lowland, southern California form. Alternatively, it may be a relict form surviving in isolation since the last glaciation or perhaps longer (Malcolm 1992).

Life History: There is limited information available on the life history of the Shay Creek population, but much information exists for other sticklebacks whose life history is presumably similar (Wooton 1976, 1984). Freshwater sticklebacks feed primarily on benthic organisms and organisms found on the surfaces of aquatic plants (Hynes 1950, Hagen 1967). Anadromous populations also feed on pelagic, free-swimming microcrustaceans. Except during the breeding season, they form loose schools, especially while feeding (Moyle 1976). The small size and slow movements of stickleback make them susceptible to piscine predators, but the spines and lateral plates provide some protection against predation (Hoogland et al. 1957, Moodie 1972, Moodie and Reimchen 1976).

During the breeding season male sticklebacks assume nuptial coloration, move away from the schools, and set up territories among beds of aquatic plants. Shay Creek males in nuptial colors have been caught in January, March, July, October and December, and it is possible that they breed year-round. Gravid female Shay Creek sticklebacks have been found in January, February, April, June and September. The exact duration of the female breeding season has not been determined, but it appears to be relatively extended during drought years (Malcolm 1992). In captivity, males were observed to build nests through the fall, but eggs were not laid in the nests until mid-November (Malcolm 1992). In general, male sticklebacks construct nests by excavating shallow pits in the substrate and placing strands of algae, pieces of aquatic plants, and other material in it. These are then glued together with sticky kidney secretions. When the pile is large enough, the male wriggles through it to create a tunnel. He then approaches the females, engages in the characteristic zig-zag courtship dances of sticklebacks, and leads a responding female into the nest. The female lays her eggs in the nest and the male fertilizes them. After spawning in aquaria, male Shay Creek sticklebacks cover the nest with small pebbles until only the entrance is visible, a highly unusual behavior (Malcolm 1992). Males aerate and guard the eggs, which hatch in four days at room temperature. A day before the eggs hatch, the male tears the nest open, and he guards the young for 7-10 days. Males will repeat the nesting cycle (Malcolm 1992).

Variation in clutch size has not been determined, but Malcolm (1992) reported that 56 young were produced from the eggs of one female. Captive-hatched fish raised in lo-gallon aquaria grew to an average length of 35 mm in 7 months and were 40-55 mm long in their second year when they bred. No growth data are available for wild stocks, except for the observation that 9 months after the establishment of a transplanted population (Sugarloaf Meadow), most of the young fish (evidently the first spawn of the transplanted fish) were 30-40 mm long (Malcolm 1992). This growth rate is similar to that seen for captive fish. Mean lengths of fish from 14 collections (n=803) of wild fish ranged from 38.9 mm to 46.8 mm. Fish from Weibe's Pond (on the shore of Baldwin Lake) were larger on average (45 mm) than those from Shay Creek (41 mm), and the largest fish caught was 65 mm (Malcolm 1992). Shay Creek sticklebacks may start to breed at age 5-6 months. Large fish may experience a regular die-off in Shay Creek; only a fraction survive past their first winter.

Limited stomach content analysis showed that small snails and crustaceans had been consumed by Shay Creek sticklebacks, and some fish observed on one occasion appeared to bite algae off a rock (Malcolm 1992). No other fish species occur with Shay Creek sticklebacks. Great blue herons, common mergansers and garter snakes *(Thamnophis couchii)* frequent the Baldwin Lake area and probably prey upon the sticklebacks. Shay Creek sticklebacks have been observed infested with the monogeneic trematode *Gyrodactylus alexanderi* (Malcolm 1992).

Habitat Requirements: Sticklebacks prefer quiet-water habitat like pools with abundant aquatic vegetation, backwater areas and stream margins where water velocity is low. They presumably require water temperatures below 23-24°C and clear water. The two ponds in which Shay Creek sticklebacks currently occur have a depth range of 0.3-4 m, fine bottom sediments and extensive submergent and emergent vegetation. Although the sticklebacks hide in the vegetation, males with nests can occur in open areas (Malcom 1992). Shay Creek, where sticklebacks were abundant prior to 1985, is ephemeral. When flowing, it no more than 1 m wide and flows slowly through marshy areas with emergent tussocks of grass. Sticklebacks are found among the tussocks. Baldwin Lake, which the sticklebacks also occupied in wet years, can cover about 1,400 acres after a series of wet years and has a maximum depth of 4.5 m. There is no outflow from the lake, therefore, it usually becomes highly saline. As the water evaporates, total dissolved solids can rise above 7,000 mg l^{-1} and pH over 10.0 before the lake dries up.

The environmental tolerances of this stickleback are broad, but the fundamental habitat requirements are (1) sufficient water depth and flows to prevent anoxic conditions in summer and complete freezing of the water in the winter, (2) aquatic vegetation to provide cover and nest materials and (3) small invertebrates for food.

Distribution: When first identified as a potentially distinct and threatened form, the Shay Creek threespine stickleback occurred only in Baldwin Lake (a reservoir) and its tributary, Shay Creek, in San Bernardino County, California (Fig. 45). This basin is closed and not part of the Santa Ana River drainage. The area is situated at 2,000 m elevation, 1,200 m higher than other native stickleback populations. The Shay Creek stickleback currently survives in two ponds which are ice-covered for long periods in winter. One pond is an artificially maintained pool in Shay Creek, the other two ponds had sticklebacks introduced. The introduced population is in Sugarloaf Meadows in the upper Santa Ana drainage. The remaining native habitat represents less than 1% of the original range when the sticklebacks were first discovered (Malcolm 1992).

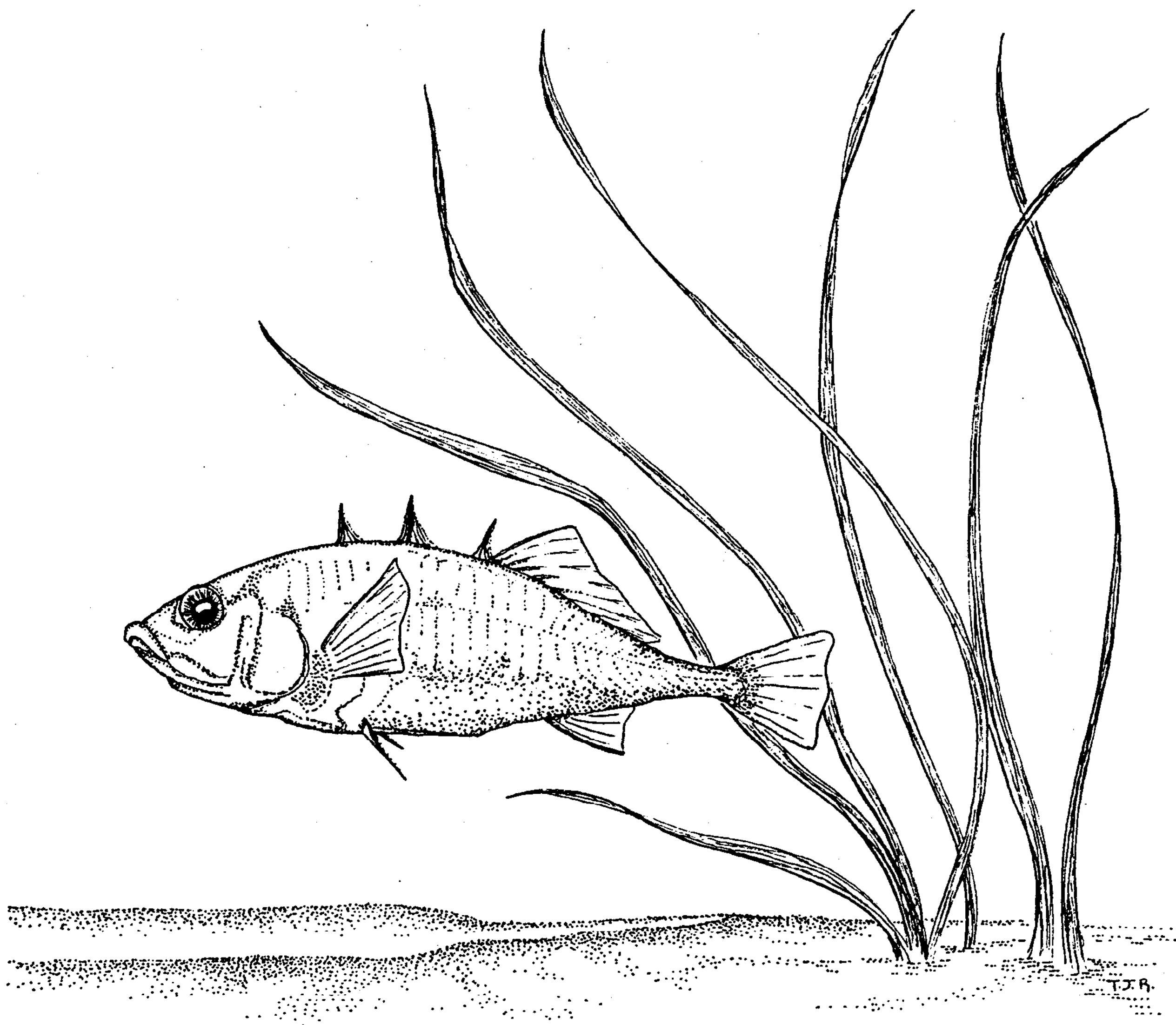
Abundance: Shay Creek threespine sticklebacks clearly undergo major population fluctuations as their pond and stream habitats wax and wane. Catastrophic mortality of the sticklebacks was observed in 1985 and 1986 as their habitat dried up. Most fish in Shay Creek died of desiccation, and hundreds were observed dying in Baldwin Lake, evidently of temperature and salinity-related stress. Low rainfall, coupled with water removals for human use, caused most of Shay Creek to dry up during 1985. Two deep pools with fish persisted, one of which received water pumped in by the Community Services District (the water company) starting in August 1985. Drought conditions caused Baldwin Lake to evaporate and most of Shay Creek to remain dry. In 1989, the pool that did not receive pumped water was reduced to a low level and its sticklebacks died off. A population accidentally established in Weibe's pond when aquatic plants were moved from Shay Creek also disappeared during the drought (T. Haglund, pers. comm.). In October 1988, about 400 sticklebacks from Shay Creek were introduced into a pond in Sugarloaf Meadow, about 11 km southeast of Baldwin Lake in the San Bernardino Mountains (Malcolm 1992, Swift et al. 1993). Mark-and-release estimates of population size indicate that there are at least 5,000-6,000 sticklebacks in the Shay Creek pool and at least 6,000-7,000 in the Sugarloaf Meadow pond (Malcolm 1992).

Nature and Degree of Threat: The most immediate threat to the Shay Creek population is the drying up of the remaining natural pool. The Shay Creek pool remained stable for five years, but decreased in size in 1991-1992. Future droughts will make it necessary but increasingly difficult to maintain artificial water flows into the pool. Excessive growth of aquatic vegetation has been a problem, and the pool has been cleared out several times. The pool also is near a populated area and 6 m from a road. Eutrophication resulting from run-off water contaminated with horse manure is a possibility, as is roadside dumping of toxic substances and the introduction of exotic fish species. Continued development of the properties surrounding the pool will most likely result in loss of the former creek bed, which is now usually dry.

Management: The immediate management requirements are continuous inflow (at 45 gal min^{-1}) into the remaining pool in upper Shay Creek and periodic removal of aquatic vegetation as it tills the pool. Potentially threatening human activities should be diverted away from the pools (by fencing), as should run-off water laden with horse manure. For the longer term, restoration of stream flows in at least part of Shay Creek would be desirable, mainly to increase habitat and, thus, stickleback abundance. Recycled waste water is a potential water source. Utilization of the Baldwin Lake bed as a natural waste-water treatment area is also possible;. Resultant shallow pools might provide habitat for the sticklebacks if water quality were high enough (Malcolm 1992). The feasibility of these restoration activities needs to be determined and options for restoring the original habitat should be pursued.

Given the success of the two transplants to date, additional transplants of fish into ponds near Shay Creek and Baldwin Lake are a feasible measure for ensuring the continued existence of Shay Creek sticklebacks. The Shay Creek Stickleback working group, part of the Unarmored Threespine Stickleback Recovery Team, has set a goal of establishing 6-10 additional populations that would persist at least five years; somewhere around 300-500 probably would be used for each transplant effort (Malcolm 1992). A study is presently underway to examine the genetic success of the Sugarloaf Meadows population (T. Haglund, pers. comm.).

Shay Creek sticklebacks have been raised extensively in the laboratory at the University of Redlands (Malcolm 1992). Breeding in aquaria of first, second, and third-generation fish has successfully occurred, but fourth-generation fish failed to breed. The sticklebacks survive well in captivity, but the costs of cultivating enough fish to preserve the genetic diversity of the population would be high. Captive breeding, therefore, is a measure of last resort (Malcolm 1992).



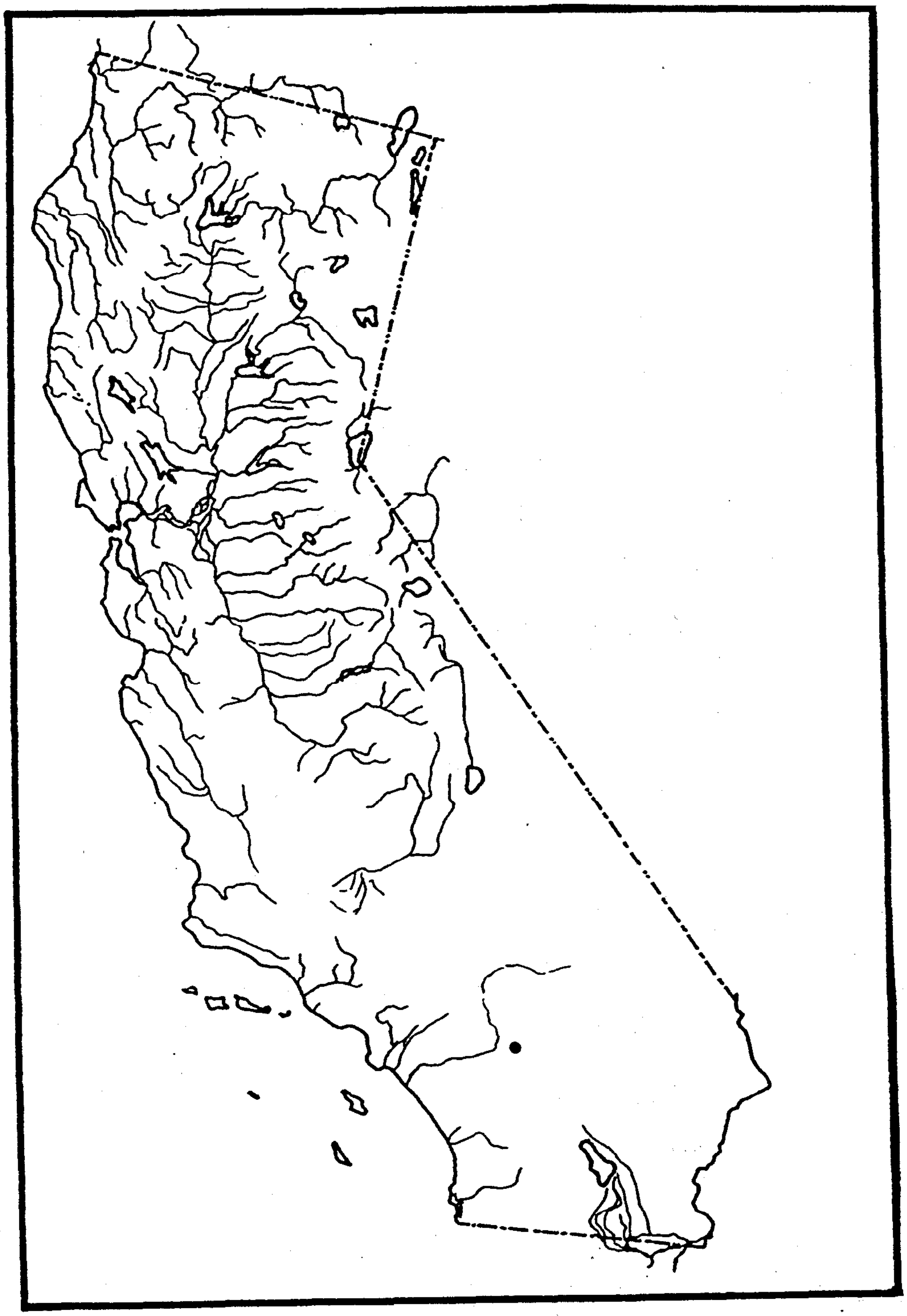


FIGURE 45. Distribution of the Shay Creek threespine stickleback, *Gasterosteus aculeatus ssp.*, in California.

SACRAMENTO PERCH
Archoplites interruptus (Girard)

Status: Class 3. Watch List for the species.
Class 2. Special Concern for Clear Lake population.

Description: Sacramento perch are deep-bodied (depth is up to 2.5 times the body length), laterally compressed centrarchids known to attain lengths of 30-61 cm FL (Aceituno and Vanicek 1976). Adult males are usually smaller than adult females at a given age (Mathews 1965). The mouth is large and oblique, with the maxilla extending to the plane of the middle of the eye. Numerous small teeth are present on the jaws, tongue, and the roof of the mouth. There are 25-30 long gill rakers. The dorsal fin has 12-13 spines and 10 rays; the anal fin, 6-7 spines and 10 rays. The spinous portion of the dorsal fin is continuous with the soft-rayed portion. There are 38-48 scales along the lateral line. Live fish are brown laterally and dorsally and have a metallic green to purplish sheen on the sides, but the ventral surface is white. There are 6-7 darker, irregular vertical bars on the sides. The operculae have black spots. Reproductive males become darker, especially on the operculae, which turn purple (Mathews 1965). Males also develop a distinct silvery spotting which shows through the darker sides, but in females the color is more uniform (Moyle 1976).

Taxonomic Relationships: *Archoplites interruptus* is the only native centrarchid west of the Rocky Mountains and is believed to have been isolated since the Miocene period (Miller 1958). Due to its isolation and lack of competition from closely related species, it has retained many ancestral structural and behavioral characteristics (Moyle 1976). The species was first collected and described by Girard (1854) as *Centrarchus interruptus.* The collections were made from an unspecified site on the lower Sacramento River. Gill (1861) assigned this species to the monotypic genus *Archoplites,* recognizing that it was very distinct from all other members of the family. Hopkirk (1973) examined meristic variation in Sacramento perch and failed to find differences among populations from various areas, although he did note some differences in color patterns. However, the Clear Lake population probably is genetically distinct, given its long isolation from other populations.

Life History: Growth rates in Sacramento perch are variable and are affected by both biotic and abiotic environmental factors (Mathews 1962, McCarraher and Gregory 1970, Moyle et al. 1974, Aceituno and Vanicek 1976, Vanicek 1980). The largest recorded Sacramento perch was 61 cm TL (Jordan and Evermann 1896). More recent records indicate that Sacramento perch reach approximately 30 cm TL in about four years. Length increments typically decrease as fish get older, but weight tends to increase more rapidly (McCarraher and Gregory 1970, Moyle 1976). Recent longevity records in California for Sacramento perch indicate life spans of 4-5 yrs, but Mathews (1962) reported 9-year-old Sacramento perch from Pyramid Lake, Nevada, that ranged from 35-42 cm total length. Growth of Sacramento perch in Clear Lake appears to be slower than in other populations (Moyle, unpubl. data). Vanicek (1980) monitored the Sacramento perch populations in Greenhaven Lake (=Brickyard Pond) each year between 1973-1978 and found that the population underwent a decline during this period. In addition to a decrease in fish abundance, he also reported a decrease in growth rates. These declines coincided with the establishment of a large housing development on the shores of the lake.

The diet of Sacramento perch consists primarily of benthic insect larvae (especially chironomid midge larvae), snails, mid-water insects, zooplankton and fish (Moyle et al. 1974). There is a tendency for the diet to vary with size of the fish as well as with season, but no diel variation was observed (Moyle et al. 1974). Usually, larger Sacramento perch included more fish in their diet (McCarraher and Gregory

1970). Sacramento perch in Clear Lake ate a high proportion of zooplankton, especially the freshwater amphipod *Hyelella azteca* (McCarraher and Gregory 1970).

Fecundity is greater in this species than in other centrarchids and increases with size (Moyle 1976). Females in Lake Anza (12-15.7 cm TL) and Pyramid Lake (19.6-33.7 cm TL) produced between 8,370-16,219 and 9,666-124,720 eggs, respectively (Mathews 1962). Sacramento perch can become reproductive by the first year (Murphy 1948b), but second-year and older females spawn earlier than the first-year females (McCarraher and Gregory 1970). Spawning occurs during spring and early summer and usually begins by the end of March, continuing through the first week of August (Mathews 1965, Moyle 1976). Timing of the spawning period is thought to be dependent on the water temperatures usually between 21.7-23.9°C (Murphy 1948b, Mathews 1965). Specifically, Mathews (1965) observed spawning Sacramento perch in Kingfish Lake, San Joaquin County, in April 1962 and in Lake Anza, Contra Costa County, in early May. Gravid females were also observed during mid-May in the latter lake. Murphy (1948b) observed spawning Sacramento perch in Clear Lake, Lake County, during May-June. In Pyramid Lake, however, spawning begins much later in mid-June and August (Johnson 1958, cited in Mathews 1965). This lake is much deeper and presumably takes longer to warm up to the required temperature.

Spawning behavior has, been extensively described by Murphy (1948b) and Mathews (1965). Murphy reports that Sacramento perch school prior to spawning and maintain the aggregations during spawning. Such aggregations are unique to this species within the family. Furthermore, unlike other centrarchids, Sacramento perch do not build distinctive nests. However, the male establishes and guards a territory during the spawning period (Murphy 1948b, Mathews 1965). The territories are approximately 40 cm in diameter (Aceituno and Vanicek 1976) and are located in a wide variety of substrate types ranging from clay and mud to rocks (Murphy 1948b, Mathews 1965, Aceituno and Vanicek 1976). Depth of the nests ranges from 20-75 cm (Murphy 1948b, Mathews 1965).

Females indicate reproductive readiness by increased activity and approaching the territory. During the first few approaches she is chased away by the male, but after repeated attempts she is accepted. Both fish then spend about 30 minutes at the nest prior to spawning. Once the eggs are laid and fertilized, the female leaves. The male remains at the nest until the eggs hatch following an incubation period of approximately 50 hours (at 21.7°C) and for about two more days following hatching (i.e. during the initial period of larval development). Observations in Clear Lake indicate that the larvae remain in the shallow areas among aquatic and emergent vegetation and move into the offshore environments when 5 cm in length (Murphy 1948b).

Habitat Requirements: Sacramento perch are warm-water, lacustrine fish. They formerly inhabited sloughs, slow-moving rivers, and lakes of the Central Valley, but are now mostly found in reservoirs and farm ponds. They are often associated with beds of rooted, submerged, and emergent vegetation and other submerged objects. Aquatic vegetation is especially essential for the young-of-year which remain close to it and/or in shallow areas. Sacramento perch are able to tolerate a wide range of physicochemical water conditions. This tolerance is thought to be an adaptation to fluctuating environmental conditions resulting from floods and droughts. Thus, they do well in highly alkaline water with salinities of up to 17,000 ppm (McCarraher and Gregory 1970, Moyle 1976). Most populations today are established in warm (summer temperatures >25°C), turbid, moderately alkaline reservoirs or farm ponds.

Distribution: After the first collections of Girard, collections from Clear Lake in Lake County (Jordan and Gilbert 1895), the Pajaro River (Snyder 1913), and the Salinas River (Hubbs 1947) helped to establish the original distribution of Sacramento perch. Historically, they were found throughout the Sacramento-San Joaquin, the Pajaro, and the Salinas River systems and in Clear Lake, Lake County (Fig. 46). Today, Sacramento perch in their native range are restricted to Clear Lake, plus a few disjunct localities consisting primarily of reservoirs and farm ponds into which they were introduced. Even in 1947, Murphy

(1948b) reported the population in Clear Lake to be depleted. Another small population from Lake Greenhaven (Brickyard Pond), an original habitat, is also now extinct (Vanicek 1980). Fortunately, Sacramento perch have been widely introduced in Nevada, Colorado, North Dakota, and Utah outside their native range (McCarraher and Gregory 1970), as well as in numerous other localities in California (Table 10).

Abundance: Very little is known about the abundance of Sacramento perch within their native range, except that virtually all populations occur in reservoirs or ponds in which extinction can occur quickly. The principal exception is the population in Clear Lake, which has maintained itself as a minor part of the fish fauna and whose continued existence must be regarded as tenuous. A 15 cm Sacramento perch was captured in the Sacramento-San Joaquin delta in 1992, about 330 m above the junction of Little Potato slough and South Fork Mokolumne River (I. Paulsen, pers. comm.), but it is unlikely that an established population exists there. Sacramento perch are often extremely abundant in alkaline reservoirs, such as Crowley Reservoir or West Valley Reservoir, but little is known about what regulates their populations there. Eventually, all reservoir populations are doomed to extinction since reservoirs have a finite lifespan.

Nature and Degree of Threat: The Sacramento perch is tolerant of a wide range of water quality and probably would be abundant throughout its native range in the absence of introduced centrarchids, especially crappie *(Pomoxis* spp.) and sunfishes *(Lepomis* spp.). In Clear Lake, the perch usually has been very rare in the lake, apparently because it may only be able to reproduce successfully when black crappie populations are low (P. Moyle, unpubl. observ.) and there is less competition for breeding sites. Sacramento perch in Clear Lake may have increased somewhat in recent years, with the decline in crappie numbers (R. Macedo, pers. comm.). However, plantings of Florida-strain crappie and largemouth bass by the Lake County Planning Department occur on a regular basis, and whatever depressive effect the introduced centrarchids have on the Sacramento perch population may be expected to continue. Clear Lake Sacramento perch recently were transplanted to Sonoma Reservoir, Sonoma County, by CDFG to provide a "reserve" stock, and there are plans to stock an additional small pond (R. Macedo, pers. comm.). Other populations are scattered throughout California and the western United States, but most are in isolated reservoirs or ponds. The isolated nature of these populations and their occurrence in human-created habitats makes them vulnerable to extinction, although the perch are now the most abundant fish in a number of reservoirs.

Management: Continued attempts should be made to propagate the Clear Lake Sacramento perch in ponds in the Clear Lake Basin. Once pond populations are established, Clear Lake could be stocked with Sacramento Perch on a regular basis. This would add a native fish to a fishery dominated by introduced species. Outside the Clear Lake Basin, efforts should be made to establish this fish in as many suitable habitats as possible, promote its value as a sport and food fish and encourage its use in farm ponds.

There is also a need to conduct a genetic investigation of Sacramento perch to see if the Clear Lake population actually is distinct (and therefore needs separate management) and if other populations within the native range are distinctive in any way. Most reservoir populations are apparently derived from the population that once existed in Brickyard Pond, Sacramento, because it was accessible and easy to sample. However, the population in Calaveras Reservoir (built in 1925) probably has a separate origin, as do a few other long-established populations. Future management should take into account the maintenance of the genetic diversity of this species.

TABLE 10. Major localities of Sacramento perch in California. Data mostly from Aceituno and Nicola (1976), based on CDFG and Moyle (unpubl. data). This record is by no means comprehensive in that it does not take into account small farm ponds, etc.

Location	County	Source
Alamo River	Imperial	Introduced
Lake Greenhaven (Brickyard Pond)	Sacramento	Native**
Calaveras Reservoir	Alameda/Contra Costa	Introduced(?)
Clear Lake	Lake	Native
Duncan Pond	Mendocino	Introduced
Gravel Pit Ponds near Niles	Alameda	Introduced
Lake Anza, Jewel Lake*	Contra Costa	Introduced
Lassotovich Pond	Fresno	Introduced
Hume Lake	Fresno	Introduced
Sequoia Lake	Fresno	Introduced
Middle Lake	San Francisco	Introduced
Ramer Lake	Imperial	Introduced
Tevis Ponds	Marin	Introduced
Abbott's Lagoon	Marin	Introduced
Van Vleck Ponds	Sacramento	Introduced
Washington Lake	Yolo	Native**
West Valley Reservoir*	Modoc	Introduced
Moon Reservoir*	Lassen	Introduced
Clear Lake Reservoir*	Modoc	Introduced
Lost River	Modoc	Introduced
Crowley Reservoir*	Mono	Introduced
Almanor Reservoir	Plumas	Introduced
Owens River	Inyo	Introduced
Gull Lake	Mono	Introduced
Bridgeport Reservoir	Mono	Introduced
East Walker River	Mono	Introduced
West Walker River	Mono	Introduced
Topaz Lake	Mono	Introduced
Lagoon Valley Lake	Solano	Introduced
Willow Creek Ponds	Sacramento	Introduced
Elkhorn Wildlife	Sacramento	Introduced
Mitigation Area Ponds	Sacramento	Introduced

* Major population (i.e., Sacramento perch are one of the most abundant species). ** Probably extirpated in recent years.

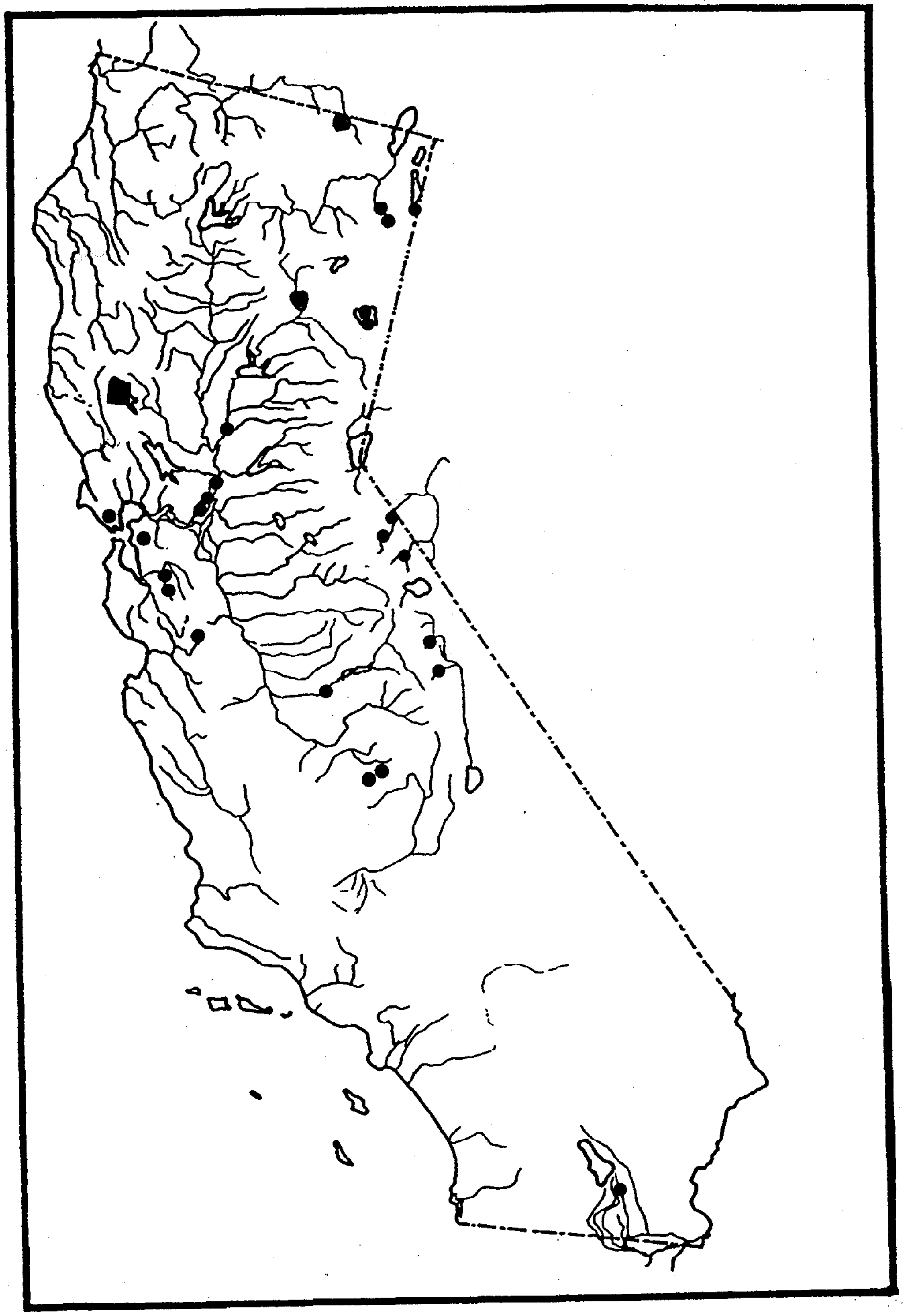


FIGURE 46. Distribution of Sacramento perch, *Archoplites interruptus*, in California. All populations except that in Clear Lake (solid square) are introduced.

RUSSIAN RIVER TULE PERCH
Hysterocarpus traskii pomo Hopkirk

Status: Class 2. Special Concern.

Description: Tule perch are small (up to 150 mm SL), deep-bodied fish, bluish to purple dorsally, and white to yellow ventrally. Three color variants are described, based on their lateral barring patterns: wide-barred, narrow-barred, and bars absent. Adults have a pronounced hump (nuchal concavity) immediately anterior to the dorsal fin. The dorsal tin has 15-19 spines and 9-15 rays; the anal fin, 3 spines and 20-26 rays; the pectoral fins, 17-19 rays. There are 34-43 scales along the lateral line (Moyle 1976). Body proportions and gill-raker morphology of the Russian River subspecies, *Hysterocarpus traskii pomo,* differ from the other two subspecies, *H. t. traskii* and *H. t. lagunae* (Hopkirk 1973). The narrow-barred color variant predominates (98.7%) in the Russian River population, with few broad-barred (1.3%) fish (Hopkirk 1973). The unbarred variant is absent from this system.

Taxonomic Relationships: The tule perch is the only freshwater species in the marine family Embiotocidae. *Hysterocarpus traskii pomo* was described by Hopkirk (1973) as one of three subspecies. Although this designation was disputed by Hubbs (1974), morphometric analyses by Baltz and Moyle (1981) showed that *H. t. pomo* is different from *H. t. lagunae* (from the Clear Lake drainage basin) and from *H. t. traskii* (from the main Sacramento-San Joaquin drainage), thus supporting Hopkirk's contention. The three subspecies also show some genetic divergence (Baltz and Loudenslager 1984), as well as striking differences in life-history patterns (Baltz and Moyle 1982).

Life History: The life history of Russian River tule perch is adapted to the unpredictable flow conditions of the Russian River system (Baltz and Moyle 1982). Flow variations in streams and rivers affect aquatic macrophytes, riparian vegetation (Westlake 1975) and water-column turbidity. Because these tule perch require cover provided by aquatic vegetation and are intolerant of turbid conditions, they are susceptible to extreme flow variations and suffer high annual mortality. Baltz and Moyle (1982) found that these perch are relatively short-lived (maximum 3-4 yr) compared with the two other subspecies.

The reproductive strategy of Russian River tule perch reflects its adaptations to this unpredictable environment (Baltz and Moyle 1982). The viviparous females produce more young per brood and reproduce at smaller sizes than those of other subspecies. Mating occurs from July through September and sperm is stored within the female until January, when fertilization takes place. Young are born during May-June when food is abundant (Moyle 1976). During the mating season, males apparently hold and defend territories, usually under overhanging branches and among plants close to shore. Courtship and mating can, however, occur away from territories (Moyle 1976).

Except when breeding, tule perch are gregarious, feeding and swimming in schools. The terminal mouth of Russian River tule perch, with its protrusible upper jaw, and the number and length of gill rakers are adaptations for feeding on benthic and plant-dwelling aquatic invertebrates (Moyle 1976, Baltz and Moyle 1981). The number and length of gill rakers of this subspecies are intermediate to the two other subspecies. The lake-dwelling *H. t. lagunae* has a greater number of longer gill rakers and feeds on zooplankton, while *H. t. traskii* feeds on larger benthic invertebrates (Baltz and Moyle 1981).

Habitat Requirements: This subspecies requires clear, flowing water and abundant cover, such as beds of aquatic macrophytes, submerged tree branches, and overhanging plants (Moyle 1976). Cover is especially essential for near-term females and young because it serves as refuge from predators. Although

Russian River tule perch sometimes feed in riffles, they require deep (>1 m) pool habitat and will use rip-rapped habitat in deep water. For a number of years, a population of tule perch maintained itself in a pond on the campus of Sonoma State University, but this population is now gone (J. Hopkirk, pers. comm.) They are usually absent from polluted water with reduced flows, high turbidity and lack of cover (Moyle 1976).

Distribution: This subspecies is confined to the Russian River and its tributaries in Sonoma and Mendocino Counties, California (Hopkirk 1973, Fig. 47). A. Phelps (unpubl. data) found them in the Russian River from Ukiah downstream to Monte Rio.

Abundance: Russian River tule perch seem to be less abundant then they were in the early 1970s when they were the subject of studies by students in UCD field courses. A seine survey of the river during June-October 1988 yielded 52 adults, most of which were taken between Hopland and Cloverdale, and 427 young-of-year, taken mainly between Hopland and Geyserville (A. Phelps, unpubl. ms.). They are uncommon compared to other native and introduced fishes in the river.

Abundance and Nature and Degree of Threat: The limited distribution, short life span, and low numbers of this subspecies makes it susceptible to extinction from a variety of causes, but probably most important are alterations of habitat and water quality in the Russian River. Tule perch are extremely sensitive and susceptible to stream pollution and tend to disappear from polluted, low-flow, turbid streams. The Coyote and Warm Springs dams now control flows in the Russian River, resulting in increased turbidity and decreased water quality. Other pond and dam construction has also resulted in habitat alterations detrimental to *H. t. pomo.* Introduced fish predators such as smallmouth bass *(Micropterus dolomieui)* also may contribute to population declines of this tule perch.

Management: The following actions are recommended:

- A thorough survey should be conducted to accurately determine the status and range of *H. t. pomo* and to identity critical and suitable habitat. Such habitat should then be managed for conservation of *H. t. pomo.* If higher water quality is needed (e.g., increased clarity), alternate flow regimes may be needed from the dams on the river.

- A survey should also be conducted of the Mendocino Reservoir to determine whether *H. t. pomo* is present there and, if it is, the status of the population should be evaluated.

- Populations of Russian River tule perch should be restored to the Sonoma State University ponds or a similar refuge should be constructed for them.

-A regular monitoring program should be established to determine the status and trends of the native fishes of the Russian River, including the tule perch.

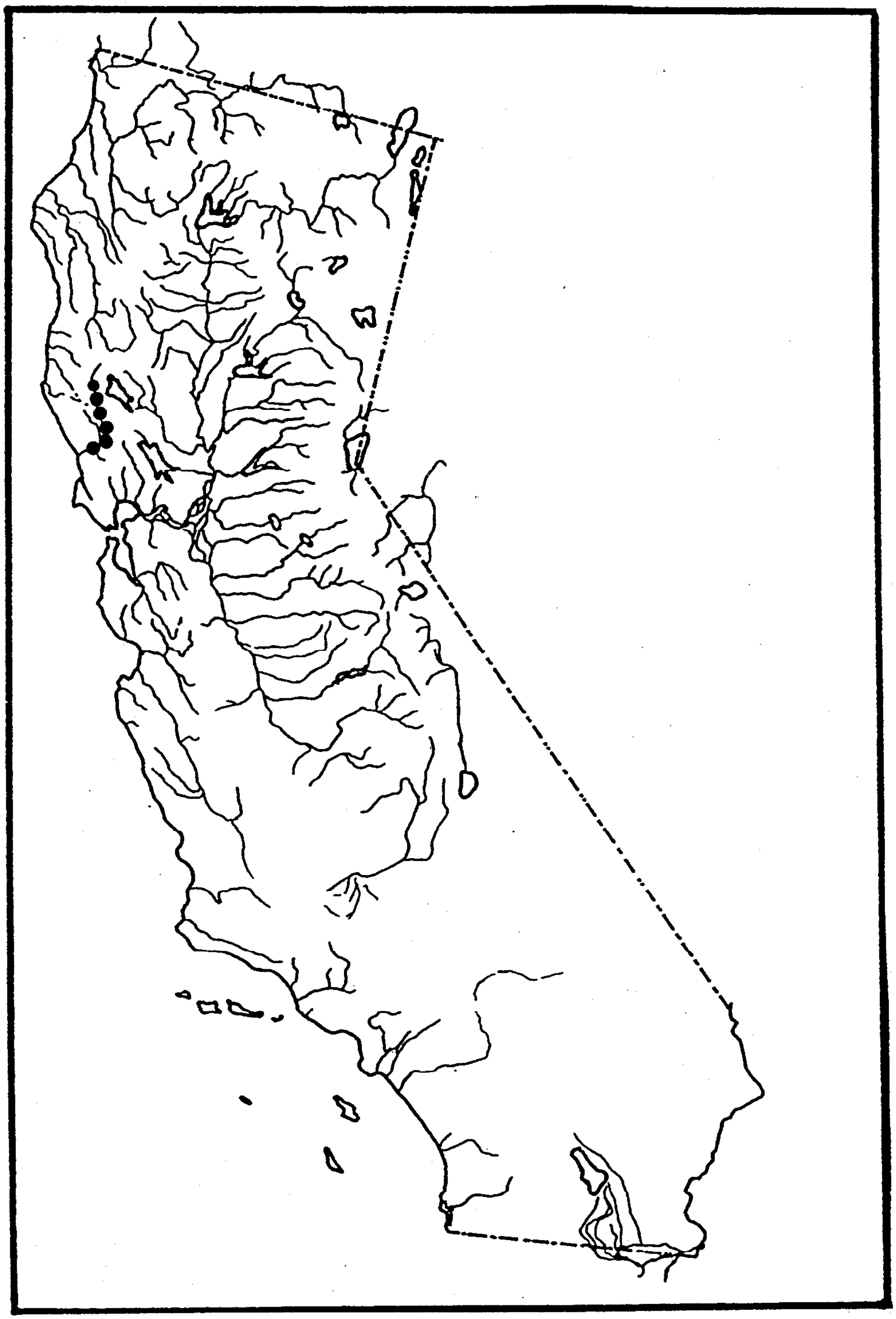


FIGURE 47. Distribution of Russian River tule perch, *Hysterocarpus traskii pomo*, in California.

TIDEWATER GOBY
Eucyclogobius newberryi (Girard)

Status: Class 1. Endangered. Listed as endangered by USFWS in 1994.

Description: This is a relatively small goby that rarely exceeds 50 mm SL. Its body shape is typical of species in the family Gobiidae, being elongate and somewhat dorso-ventrally flattened, especially anteriorly. The head is blunt and the mouth terminal, oblique, and large, with the maxillary extending to the posterior margin of the eye. Eyes are near-dorsal in location. Pelvic fins are fused to form a ventral disc, another characteristic of gobiid species. Pectoral fins are large and the caudal fin elongate and rounded. There are 6-7 spines in the first dorsal fin and 9-13 rays in the second dorsal fin; 99% of individuals have 11-12 dorsal fin rays (C. Swift, pers. comm.). The anal fin usually has 10-11 elements, rarely 9 or 12. Gill rakers number from 8-10. Scales are small and cycloid and are absent on the head; the chest, belly and nape are usually naked. Scales are often lacking on the anterior 20-25% of the body, even mid-laterally (C. Swift, pers. comm.). There are 65-80 lateral scales. Body coloration is a dark olive, with darker mottling along the sides, back, and dorsal fin. Fish of all sizes have the first dorsal fin distinctively colored a prominent cream or orange,with the distal one-third to one-half transparent (C. Swift, pers. comm.). The pelvic fins are yellow or dusky, and the anal fin is dusky.

Taxonomic Relationships: This is the only species in the genus *Eucyclogobius.* It was first described by Girard (1856b) as *Gobius newberryi* from specimens collected in the San Francisco Bay area. T. Gill, in 1862, then reassigned the species to the newly described genus *Eucyclogobius* (Eschmeyer 1990). The closest relatives of the tidewater goby are estuarine and marine species.

Life History: The tidewater goby is a benthic species that inhabits shallow lagoons and the lower reaches of coastal streams, and "is almost unique among fishes along the U.S. Pacific coast in its restriction to low-salinity waters in California's coastal wetlands" (Federal Register Vol. 57, No. 239, Dec. 11, 1992). It differs from other species of gobies in California in that it is able to complete its entire life cycle in fresh or brackish water (Wang 1982, Irwin and Soltz 1984, Swift et al. 1989). This goby appears to be mainly an annual species (Swift 1980b, Wang 1982, 1986, Irwin and Soltz 1984, Swift et al. 1989), although according to Swift (1980b), individuals in the northern part of the range live up to 3 years. Irwin and Soltz (1984) found that there is a marked decrease in the number of adults in the population during winter.

The diet consists mostly of small crustaceans (i.e., mysid shrimp, ostracods, amphipods), aquatic insects (i.e., chironomid larvae, diptera larvae), and molluscs (Swift 1980b, Wang 1982, 1986, Irwin and Soltz 1984, Swift et al. 1989). Inorganic material consistently found in the guts indicates a benthic foraging mode, complementing its benthic life-style.

Goldberg (1977) found that in tidewater gobies of southern California, ovarian maturation is asynchronous; i.e., females with various stages of ovarian development are found throughout the year. The occurrence of larvae throughout the year, albeit in small numbers, supports the theory for year-round reproduction. However, there are definite peak spawning periods when most recruitment takes place. In southern California, peak spawning occurs during April-June when water temperature is 18-22°C (Swift 1980b, Swift et al. 1989). In San Francisco Bay area streams, peak spawning occurs from late August to November when water temperature ranges from 13.5-21°C (Wang 1982). In Santa Barbara County, gravid females were collected from February to October, but there was a distinct peak in spawning in the fall and most recruitment took place during winter (Irwin and Soltz 1984). Fecundity is fairly low in this species; females 43-47 mm TL produce 640-800 eggs (Wang 1982). Wang (1982) observed adults in spawning condition (identified by darker color) in shallow ditches and along the inshore areas of lagoons. Swift et al. (1989) reported that during spawning, the male digs a vertical burrow approximately 10-20 cm into the sandy substrate, usually in water 25-50 cm deep, in which the female deposits her eggs. The male then guards the nest. The proximal ends of the elongate, pear-shaped eggs bear adhesive filaments with which they are attached to the burrow walls (Wang 1982). Larvae emerge in 9-10 days when they are 5-7 mm SL and live in the water column among vegetation until they are 15-18 SL, at which time they become benthic.

Habitat Requirements: Tidewater gobies are found in shallow lagoons and lower stream reaches where the water is brackish (salinities usually <10 ppt) to fresh (Miller and Lea 1972, Moyle 1976, Swift 1980b, Wang 1982, Irwin and Soltz 1984) and slow-moving or fairly still, but not stagnant (Irwin and Soltz 1984). They avoid open areas were there is strong wave action or strong currents. Particularly important for their persistence in the lagoons is the presence of backwater, marshy habitats where they can avoid winter flood flows (J. Smith, pers. comm.). Thus, many small lagoons with backwater areas have maintained goby populations, while larger lagoons with no backwater areas have lost their populations (J. Smith, pers. comm.).

Tidewater gobies are capable of living in saline water ranging from 0 to over 50 ppt salinity and at temperatures of 8-23°C (Swift et al. 1989, K. Worchester, pers. comm.). Suitable water conditions for nesting have been reported as 5-10 ppt salinities and 18-22°C temperatures (Federal Register 1992, op. cit.). Water depth in tidewater goby habitat ranges from 25-100 cm and dissolved oxygen is fairly high (Irwin and Soltz 1984). Gobies sometimes can persist, however, under anoxic conditions that eliminate other fish species. They have been observed to come up and gulp air at the water surface, and they probably breathe air like *Gillichthys mirabilis (C.* Swift, pers. comm.). The substrate usually consists of sand and mud, with abundant emergent and submerged vegetation (Moyle 1976). Severe salinity changes and tidal or flow fluctuations have a detrimental effect on the survival of tidewater gobies, resulting in population declines (Irwin and Soltz 1984).

Distribution: The tidewater goby is endemic to California and is distributed in brackish-water habitats along the California coast (Fig. 48), from the Agua Hedionda Lagoon, San Diego County, in the south to the mouth of the Smith River (Tillas Slough), Del Norte County, in the north (Swift 1980b, Swift et al. 1989). Three sections of coastline in California, characterized by precipitous topography, lack lagoons at stream mouths and therefore form gaps in the distribution of the tidewater goby. These areas are (1) Humboldt Bay to Ten Mile River, (2) Point Arena to Salmon Creek, and (3) Monterey Bay to Arroyo del Oso (Federal Register 1992, op. cit.). Tidewater gobies normally are found in lagoons, but they have been reported from ponded freshwater habitats up to 8 km upstream from San Antonio lagoon in Santa Barbara County (Irwin and Stoltz 1984).

Abundance: Swift et al. (1989) estimated that of 94 localities from which specimens of tidewater gobies have been collected, the gobies have been extirpated from, or are likely to be extirpated from soon, 53 (56%) of the localites. They probably also occurred at, but are now gone from, a minimum of 46 other localties that once had suitable habitat. They were presumably once common in formerly brackish habitats in San Francisco Bay, Monterey Bay, Santa Monica Bay, the Los Angeles Harbor area, Anaheim Bay, the mouth of the Santa Ana River, and Newport Bay (C. Swift, pers. comm.). Swift et al. (1989) recorded their presence at 63 localities in 1984, only 11 of them north of San Francisco Bay. However, their populations are now declining, especially since 1950, and since 1900 they have disappeared from 74% of the coastal lagoons south of Morro Bay. They are known to have occurred in Morro Bay, but populations there have not been seen for several years (C. Swift, pers. comm.). In San Francisco Bay and its associated streams, nine of ten previously identified populations have disappeared (Wang 1982), and a survey of streams of the Bay drainage by Leidy (1984) failed to record any populations. There are 15 remaining populations south of Point Conception (Swift et al. 1989). Only three populations currently exist south of Ventura County (Federal Register 1992, op. cit.).

According to the Federal Register (1992, op. cit.), only six populations are large enough and relatively free from habitat degradation to be considered safe for the immediate future. This may be an underestimate. On the central coast, Pescadero and San Gregorio Creek lagoons (San Mateo County) appear to have large and secure populations, as do the lagoons of Baldwin, Wilder, Moore's and Scott creeks and the Pajaro River (Santa Cruz County)(J. Smith, pers. comm.). Most of these populations are located in state parks.

On the south coast, most extant populations are small and are threatened by a variety of human-related and natural factors. In San Luis Obispo County, for example, several populations are so small that they were believed to have been (or actually were) extirpated, but subsequent sampling revealed the existence of gobies (see below). In San Luis Obispo County, there presently are healthy tidewater goby populations in San Simeon, Little Pica and Pismo creeks, plus a few other stable, but small, populations (K. Worchester, pers. comm.). However, the population in San Simeon Creek is smaller than formerly (Federal Register 1992, op. cit.).

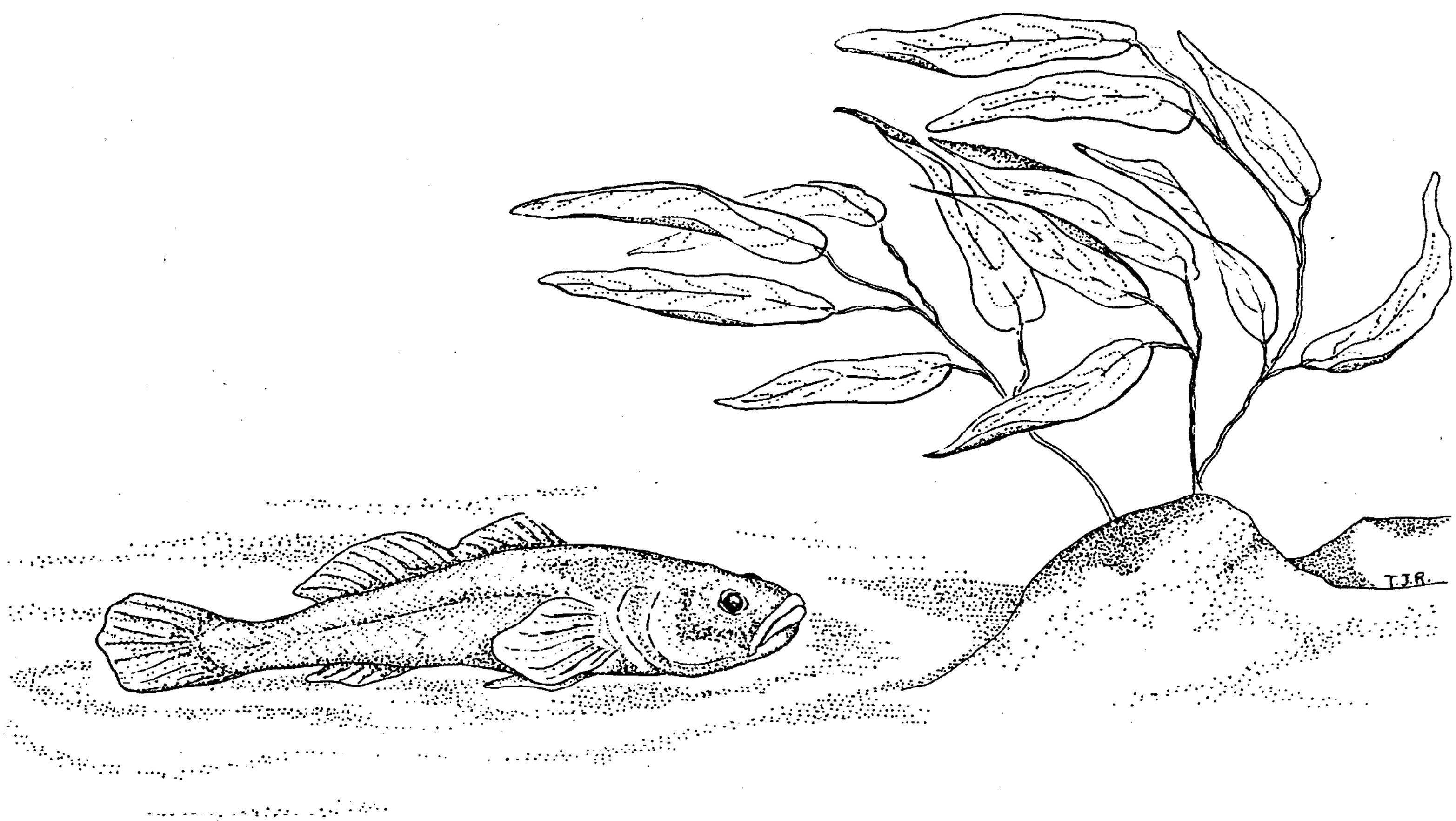
Nature and Degree of Threat: Dr. Camm Swift (Loyola Marymount University) submitted a petition for listing this species as endangered to the USFWS in October 1990. The USFWS decided in October 1991 that the petition had merit, and subsequently listed the tidewater goby as endangered (Federal Register Vol. 59, No. 24, February 4, 1994). Threats to the tidewater goby are described in detail in the listing proposal.

Despite the fact that tidewater gobies still are found in many lagoons along the California coast, their potential for going extinct is considerable because (1) each of the populations is relatively small and isolated and (2) most estuaries or lagoons along the coast have been, and continue to be, highly altered by human activity. Crabtree (1985) noted that populations had differentiated genetically, indicating long isolation. Because they are a small, nondescript species, local extinctions are likely to go unnoticed: A number of populations have already disappeared during the past 20 years, especially in southern California and the San Francisco Bay area. Population extinctions can occur rapidly, given the goby's short life cycle and specialized habitat requirements.

The loss or degradation of coastal saltmarsh habitat due to coastal development projects is currently the major factor affecting tidewater goby populations (Federal Register 1992, op. cit.). Coastal lagoons are highly susceptible to degradation through diversion of their freshwater supplies, pollution, siltation, bridge construction, and urban development of surrounding lands, and to invasion by non-native species of fish and frogs which are potential predators of tidewater gobies. When environmental degradation is severe, tidewater gobies disappear. Thus, of 20 known populations of gobies in San Luis Obispo County, six were believed to have been extirpated between 1984 and 1989 due to drought coupled with water diversions and pollution (K. Worchester, pers. comm.). In one of these populations (Bull Creek), the principal cause of extirpation seems to have been predation by smallmouth bass and bullfrogs (K. Worchester, pers. comm.). Three populations have "reappeared" since then but are in precarious condition. Since 1989, at least 5 more populations were lost due to water diversions or to the drought conditions in 1990 (K. Worchester, pers. comm.). In addition, channelization of streams above the lagoons results in heavy scouring during winter floods. Such an event was responsible for the disappearance of the population in Waddell Creek lagoon during the winter of 1972-1973 (C. Swift, pers. comm., cited in Federal Register 1992, op. cit.). Because the tidewater goby is sensitive to environmental changes, it is a good indicator species of the health of small coastal lagoon ecosystems that are important to many other species as well.

The extirpation of many tidewater goby populations has increasingly isolated the remaining populations from one another, thus making it even more difficult for them to recolonize areas from which they have been lost.

Management: Coastal lagoons should be surveyed at least once every five years to determine the status of each population, and steps should be taken to protect declining populations. Because coastal lagoons are considered to be threatened habitats in general, especially in southern California, a major effort needs to be made to protect the integrity of the remaining lagoons and to restore those that have been severely degraded. Once restored, lagoons from which tidewater gobies have been eliminated should have gobies reintroduced from nearby locations, in order to reconstitute as closely as possible the genetic makeup of the extirpated populations. This procedure has already been tried successfully, when gobies from the Scott Creek lagoon were successfully transplanted to the nearby Waddell Creek lagoon (J. Smith, pers. comm.). A similar transplant could probably me made successfully to the lagoon on the Salinas River mouth (J. Smith, pers. comm.). An effort should be made to maintain a number of tidewater goby populations within different areas of the geographical range to preserve the overall genetic diversity of the species. Other suggestions for management are provided by Swift et al. (1989).



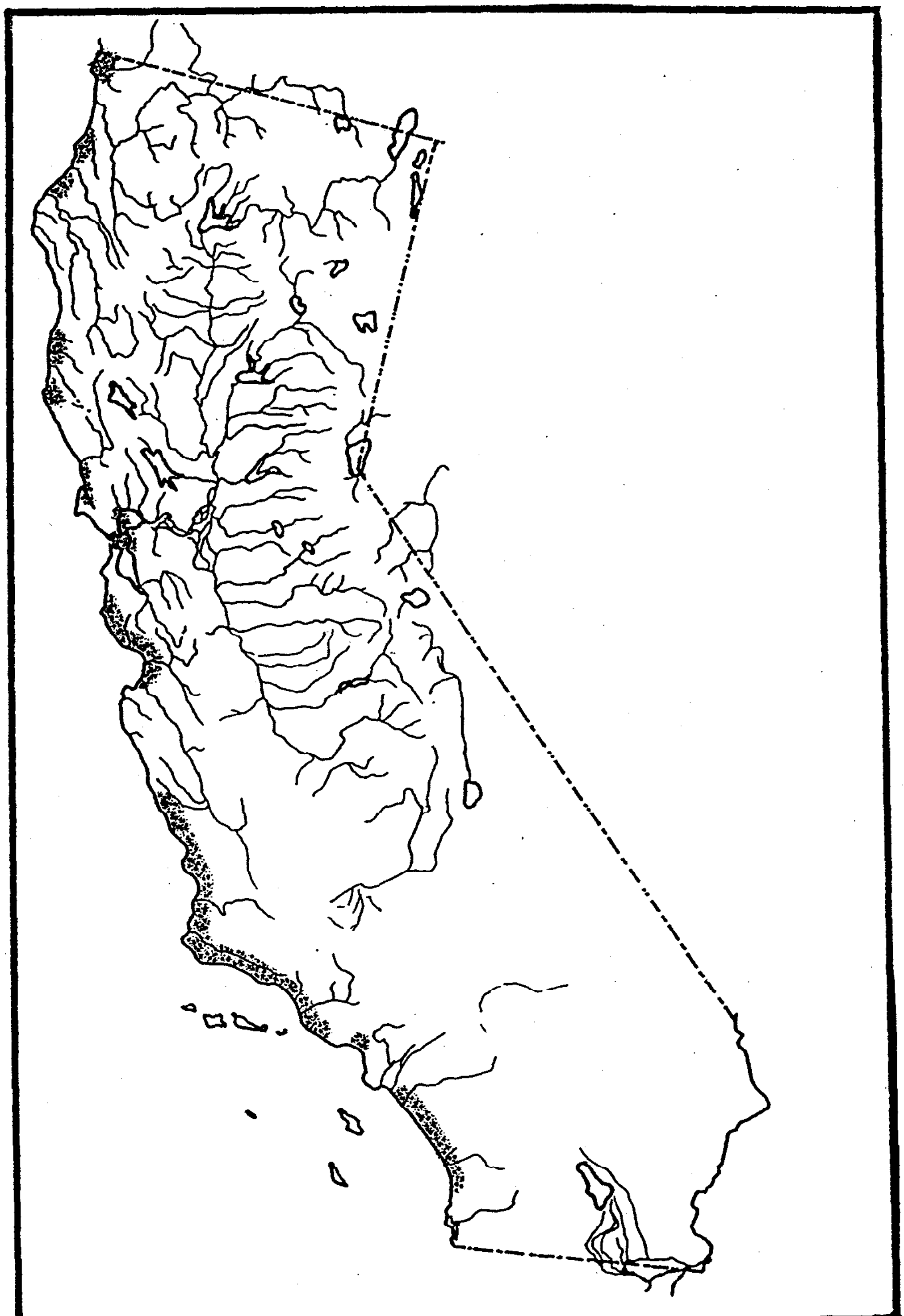


FIGURE 48. Distribution of the tidewater goby, *Eucyclogobius newberryi*, in California.

BIGEYE MARBLED SCULPIN
Cottus klamathensis macrops (Rutter)

Status: Class 3. Watch List.

Description: Gross morphology of the marbled sculpin is typical of the genus *Cottus.* The head is large and dorsally flattened, pectoral tins are large and fan-like, and the small pelvic tins are positioned ventrally between the pectorals. *Cottus klamathensis* is distinguished from other species of *Cottus* in that it usually has fewer than 7 dorsal fin spines, the dorsal fins are joined, the lateral line is incomplete, and the skin is relatively smooth (Daniels and Moyle 1984). All other species in California possess a split dorsal fin and more than 7 dorsal spines. The pectoral fins of *C. klamathensis* have four elements. The incomplete lateral line has 16-18 pores. The smooth skin has few prickles, which are usually below the lateral line. Fish have a green hue and possess a dark circular spot at the posterior end of the spinous dorsal fin. Marbled sculpins also lack palatine teeth and have only one preopercular spine (Moyle 1976). Other characteristics of *C. klamathensis* include a wide interorbital region, a wide head and blunt snout, a maxillary rarely extending beyond the anterior half of the eye, and unjoined preoperculomandibular canals, but these characteristics are shared with one or more other species (Daniels and Moyle 1984). The subspecies *C. klamathensis macrops* is distinguished from other subspecies by: few (if any) axillary prickles, a short preopercular spine (<1 percent of SL), a large orbit diameter, and a long predorsal length (Daniels and Moyle 1984). It is also ecologically distinct (Daniels 1987).

Taxonomic Relationships: *Cottus klamathensis* was first described by Gilbert (1897) from the Klamath River system. Rutter (1908) then described *Cottus macrops* from the Fall River, a large tributary to the Pit River, and noted that it closely resembled *C. klamathensis.* Robins and Miller (1957), upon review of specimens and recent collections, concluded that the two species were not sufficiently different to warrant separate species designations and considered *C. macrops* synomymous with *C. klamathensis.* Daniels and Moyle (1984), however, on the basis of meristic and mensural differences in fish from the Pit River and Klamath River systems, concluded that *C. klamathensis* could be divided into three subspecies: (1) *C. k. klamathensis,* the nominate subspecies found in the Upper Klamath River drainage; *(2) C. k. polyporus,* found in the lower Klamath River, in some of its larger tributaries, and possibly in the Trinity River system; and (3) *C. k. macrops,* found in the Pit River system downstream from the confluence of the Fall River to the Pit 7 Reservoir, and in three tributaries, Hat Creek (downstream of the Rising River system), Burney Creek (downstream of Burney Falls), and the Fall River system (with the exception of Bear Creek).

Life History: Bigeye marbled sculpins live about 5 years, attaining 35% of their maximum length during their first year (Daniels 1987). The growing season begins in spring and lasts until early autumn. Fish attain sexual maturity after 2 years. Males and females begin to mature reproductively during the winter, and spawning occurs from late February to March. Fecundity is low; females produce from 139-650 large ova per fish. Adhesive eggs are deposited in nests under flat rocks. More than one clutch of eggs may be present in a nest. Nests are generally guarded by males (Daniels 1987). The low fecundity, late reproductive maturation, and relatively long life span reflect this subspecies' adaption to an environment with relatively few fluctuations (Daniels 1987).

Habitat Requirements: *Cottus k. macrops* is adapted for life in large, clear, cool, spring-fed streams but has also managed to adjust to the conditions in some reservoirs. Brown (1988) found that the acute preferred temperature was about 13°C for fish acclimated at 10°, 15°, and 20°C. They are usually found in water with moderate flows (mean bottom velocity = 9.7 ±3.0 (1 S.E.) cm sec^{-1}; mean water column velocity = 23.1 ±4.5 cm sec^{-1}) and depths (mean 64.3 ±7.3 cm). Habitat use does not differ between adults and juveniles with respect to water velocity, but juveniles are found in shallower water. Typically, these sculpins are associated with abundant aquatic vegetation and coarse substrates, especially cobble, boulder, and gravel (Daniels 1987). In artificial streams, when given a choice of cobble and sand, they always selected cobble (Brown 1988).

Distribution: The bigeye marbled sculpin is distributed throughout the middle reach of the Pit River system (Fig. 49) (Moyle and Daniels 1982). In this region, it is found in the main river below Britton Reservoir, in Britton Reservoir, Tunnel Reservoir, lower Hat Creek, Sucker Springs Creek, and Clark Creek. It is the dominant sculpin in the sections of Lower Hat Creek and Burney Creek just above Britton Reservoir. The bigeye marbled sculpin also is found in the lower reaches of streams flowing into reservoirs of the lower Pit River and in the lower Pit River itself. They are present in the Fall River, but seem to be less abundant today than when Rutter (1908) first collected them there.

Abundance: This sculpin is the least abundant of the three sculpins endemic to the Pit River drainage, but it still remains fairly common in much of its limited range. It co-occurs with the rough sculpin, *Cottus asperrimus,* which is listed by the state as a threatened species, although the rough sculpin probably is more abundant than the bigeye marbled sculpin.

Nature and Degree of Threat: As long as rough sculpin are protected, bigeye marbled sculpin presumably will be as well. However, its apparent decline in the Fall River may indicate that long-term, subtle changes in its native habitats may be occurring, such as changes in water quality caused by agricultural effluent and watershed degradation (Fall River) or changes in flow created by variable operation of hydroelectric projects (Pit River). The streams in which marbled sculpin occur are largely managed for their fisheries for wild rainbow trout *(Oncorhynchus mykiss)* and brown trout *(Salmo trutta)*. For the most part, the native rainbow trout have dominated the streams and the introduced brown trout have been relatively uncommon. Changes in water quality or management that favor brown trout might have negative effects on marbled sculpin, through increased predation by brown trout.

Management. Periodic status surveys (about every 5 years) of the endemic fishes and invertebrates of Fall River and Hat Creek should be done to determine if the unique fauna is maintaining itself. Changes in the management of hydroelectric projects in the region or of the fisheries should take into account the needs of the native fauna, including the bigeye marbled sculpin.

FIGURE 49. Distribution of the bigeye marbled sculpin, *Cottus klamathensis macrops*, in California.

RETICULATE SCULPIN
Cottus perplexus Gilbert and Evermann

Status: Class 3. Watch List.

Description: This species is similar to the marbled sculpin in overall shape, but it is considerably smaller, reaching no more than 85 mm TL. It is distinguished from other sculpins by a complex of characters that consist of: a mouth that is narrower than the body posterior to the pectoral tins; absence of palatine teeth; a maxilla that extends to the anterior margin of the eye; broadly joined dorsal fins with 7-8 spines on the anterior dorsal tin and 18-20 rays on the posterior dorsal fin; 14-15 unbranched pectoral fin rays (range 13-16); 13-16 anal fin rays; 22-23 pores along the lateral line that may or may not be complete; 1-2 median chin pores; 1-4 preopercular spines, of which only 2 are usually visible; and variable body prickling, although axillary prickling is always present. Body coloration of live fish consists of faint vermiculate markings and some darker mottling. The pectoral fins have a checkerboard pattern that is similar to the marbled sculpin. A dark blotch is present on the posterior margin of the anterior dorsal fin.

Taxonomic Relationships: The reticulate sculpin was first described by Gilbert and Evermann (1894), but was synonymized with *Cottus gulosus* by Shultz (1930). However, in a subsequent reanalysis of the type material, Robins and Miller (1957) redesignated *Cottus perplexus* as a species based on morphological characteristics. They found it is more closely allied to *Cottus klamathensis* than to *C. gulosus.*

Life History: Reticulate sculpins spawn from March to May when water temperature exceeds 6-7°C (Moyle 1976). Eggs are laid on the underside of rocks (10-45 cm in diameter), with numerous females contributing to the nest. When other sculpins are rare or absent, *C. perplexus* spawn in riffle habitat; however, in the presence of other sculpins, they spawn in areas of slower water. Fecundity is low and increases with size. In Oregon, fecundity has been determined to be 35-315 eggs for fish ranging from 30-69 mm SL (Bond 1963) and in Washington state 84-432 eggs for fish ranging from 60-97 mm TL (Patten 1971). Mean fecundity in these latter fish was 172 eggs for 2-year old fish and 283 eggs for 3-year-old fish. Males guard the nest and fry from predators. Fry assume a benthic life style in quiet water immediately after leaving the nest (Bond 1963).

Growth is slow, with fish reaching only 27 mm SL by age one, 42 mm by age two, 56 mm by age three and 64 mm by age four. They live for about six years and are sexually mature by their second year. The fish feed mostly on aquatic insect larvae, especially mayfly, stonefly, chironomid and caddisfly larvae (Moyle 1976).

Habitat Requirements: This species has been extensively studied in Oregon where it primarily occupies slower-water habitat in small coastal and headwater streams. It seems to be excluded by *C. gulosus* from fast water. In sympatry, *C. perplexus* is found in quiet water; in allopatry it tends to occupy faster water with rubble and gravel substrates (Bond 1963). It is tolerant of fairly high fluctuations of water temperature and is able to withstand temperatures up to 30°C and salinities up to 18 ppt (Bond 1963).

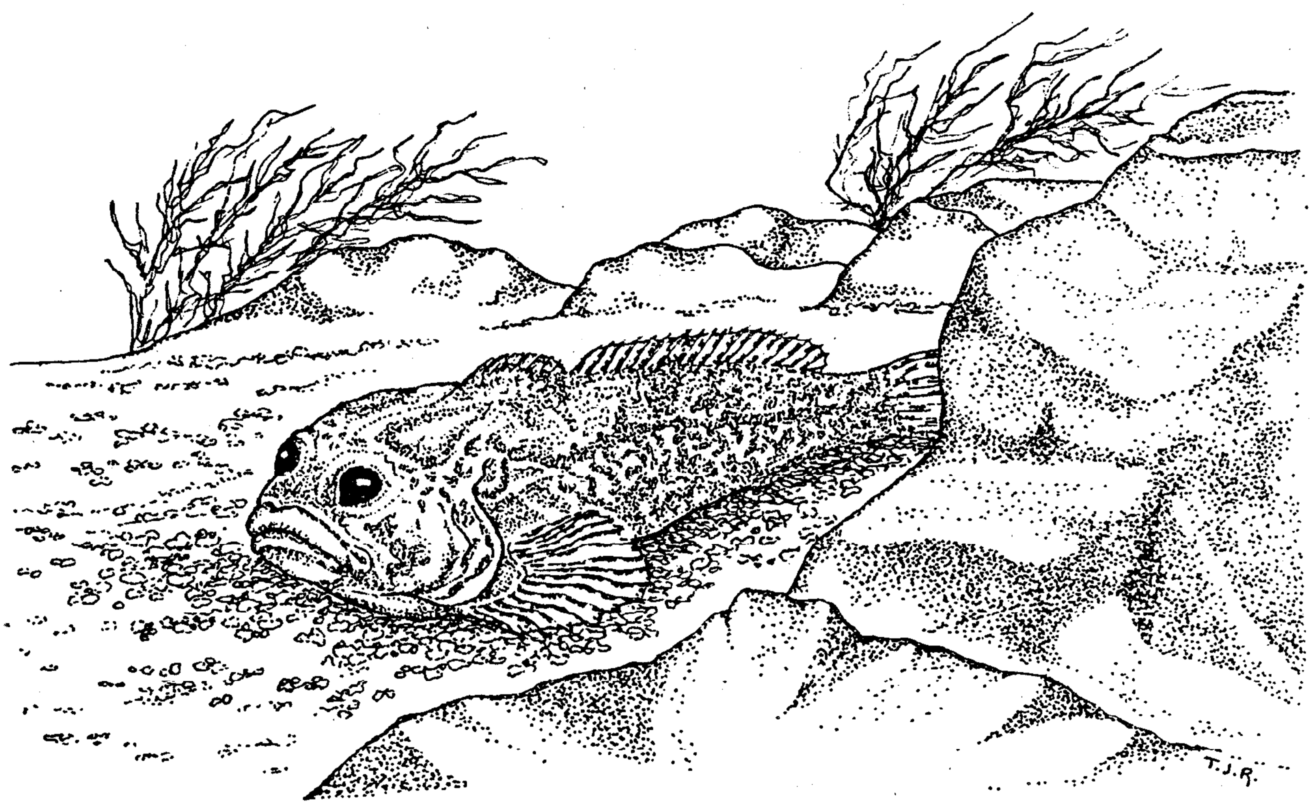
Distribution: This sculpin is common in Oregon and Washington. Its range extends from the Columbia River drainage, Washington, south to the Rogue River drainage, Oregon, and includes the Williamette and Upper Deschutes River drainages in between (Bond 1963, Reimers and Bond 1967). Only a few populations have been recorded in California, from the Middle Fork of the Applegate River on the

California side of the border (Bond 1973) and from creeks that drain north into the Rogue River, especially Elliot Creek (Moyle 1976) (Fig. 50).

Abundance. Nothing is known about the abundance of this sculpin in California, although the populations seem to be small (i.e., probably only a few hundred individuals in each of the streams from which it is known in the state).

Nature and Degree of Threat: California populations of reticulate sculpins are on the periphery of the species range. As a species, it is not threatened, but the California populations could disappear if the water quality and habitats of the few California streams in which they occur should be degraded through logging and road-building. The presence of dams on the streams indicates that the California populations are now isolated from other populations downstream, so natural recolonization cannot take place should extinction occur.

Management: A survey of all California tributaries to the Rogue River is needed to determine the extent of the distribution of this sculpin. Agencies that administer reticulate sculpin habitat should be alerted to the fish's presence so streams can be managed to maintain populations in California. This management probably also would benefit landlocked populations of cutthroat trout present in some of the tributaries.



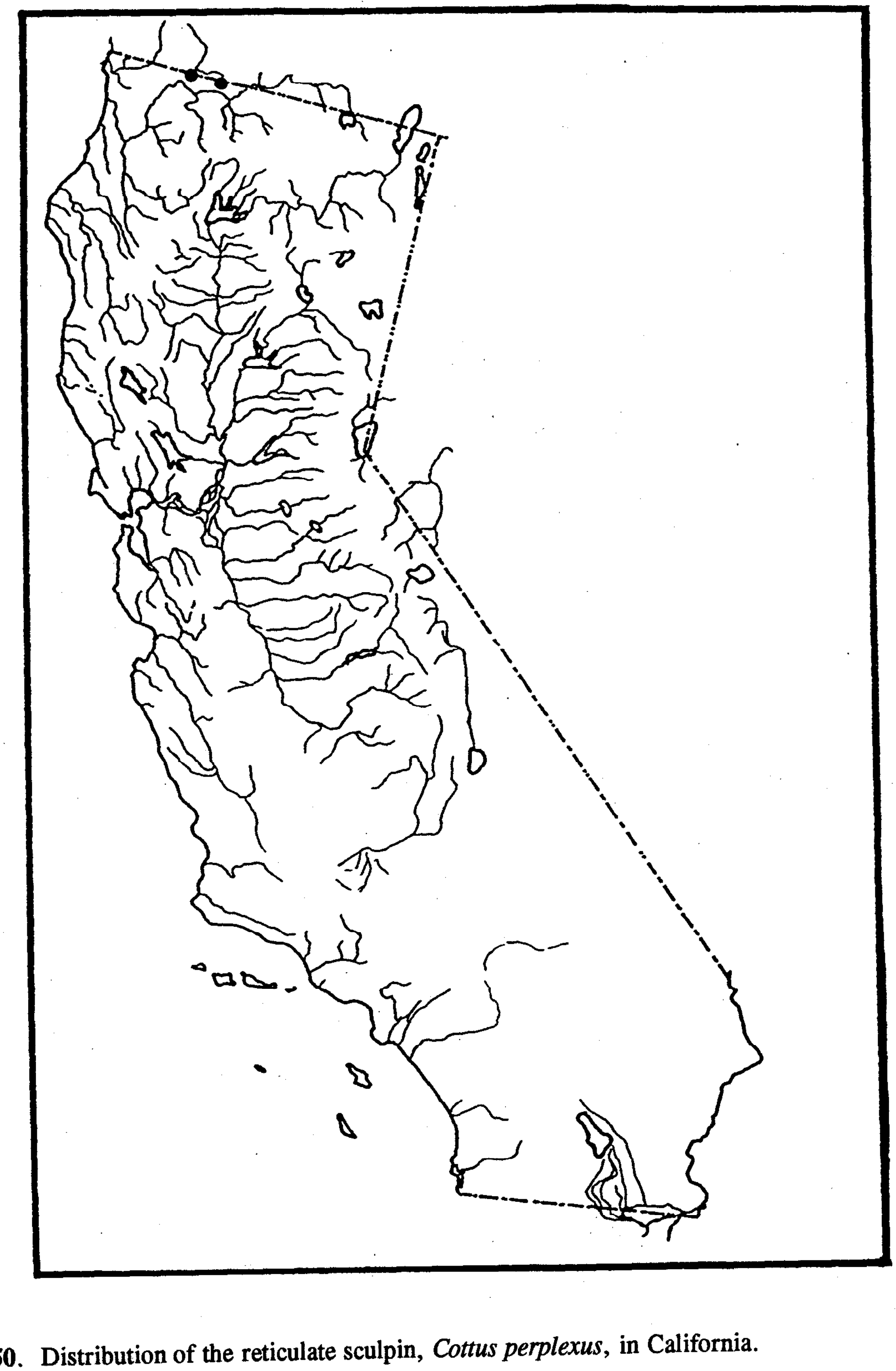


FIGURE 50. Distribution of the reticulate sculpin, *Cottus perplexus*, in California.

LITERATURE CITED

Aceituno, M.E. and S.J. Nicola. 1976. Distribution and status of the Sacramento perch, *Archoplites interruptus* (Girard), in California. Calif. Fish Game 62:246-254.

Aceituno, M.E. and C.D. Vanicek. 1976. Life history studies of the Sacramento perch, *Archoplites interruptus* (Girard), in California. Calif. Fish Game 62:5-20.

Airola, D.A. 1983. A survey of spring-run chinook salmon and habitat in Antelope Creek, Tehama County, California. Unpubl. Rept., Lassen National Forest, Chester, CA. 11 pp.

Airola, D.A. and B.D. Marcotte. 1985. A survey of holding pools for spring-run chinook salmon in Deer and Mill Creeks, 1985. Unpubl. Rept., Lassen National Forest, Chester, CA.

Alpine, A.E. and J.E. Cloem. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol Oceanogr. 37:946-955.

Andreasen, J.K. 1975. Systematics and status of the family Catostomidae in southern Oregon. Unpubl. Ph.D. Diss., Oregon State University. 76 pp.

Avise, J.C. and F.J. Ayala. 1976. Genetic differentiation in speciose versus depauperate phylads: Evidence from the California minnows. Evolution 30:46-58.

Avise, J.C., J.J. Smith, and F.J. Ayala. 1975. Adaptive differentiation with little genic change between two native California minnows. Evolution 29:411-426.

Ayres, W.O. 1854a. [Descriptions of three new species of sturgeon from San Francisco.] The Pacific 4(1):2. Reprinted in Proc. Calif. Acad. Sci. 1:15-16.

Ayres, W.O. 1854b. Remarks on some fish of the cyprinoid family. Daily Placer Times and Transcripts, 30 May 1854:1

Bailey, R.M. and T. Uyeno. 1964. Nomenclature of the blue chub and the tui chub, cyprinid fishes from Western United States. Copeia 1964:238-239.

Baker, P. and F. Reynolds. 1986. Life history, habitat requirements, and status of coho salmon in California. Report to California Fish and Game Commission, Calif. Dept. of Fish and Game. 37 pp.

Baltz, D.M. and E.J. Loudenslager. 1984. Electrophoretic variation among subspecies of tule perch *(Hysterocarpus traski)*. Copeia 1984:223-227.

Baltz, D.M. and P.B. Moyle. 1981. Morphometric analysis of the tule perch *(Hysterocarpus traski)* populations in three isolated drainages. Copeia 1981:305-311

Baltz, D.M. and P.B. Moyle. 1982. Life history characteristics of tule perch *(Hysterocarpus traski)* populations in contrasting environments. Environ. Biol. Fishes 7:229-242.

Baltz, D.M. and P.B. Moyle. 1993. Invasion resistance by an assemblage of native California stream fishes. Ecol. Applic.3:246-255.

Baltz, D.M., B. Vondracek, L.R. Brown, and P.B. Moyle. 1987. Influence of temperature on microhabitat choice by fishes in a California stream. Trans. Amer. Fish. Soc. 116: 12-20.

Bamhart, R.A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)-- steelhead. U.S. Fish and Wildl. Serv. Biol. Rep. 82(11.60).

Bamhart, R.A., M.J. Boyd, and J.E. Pequenat. 1992. The ecology of Humboldt Bay, California, an estuarine profile. U.S. Fish and Wildlife Service Biological Report 1. 121 pp.

Barraclough, W.E. 1964. Contribution to the marine life history of the eulachon, *Thaleichthys pacificus.* J. Fish. Res. Bd. Canada 21:1333-1337.

Bartley, D. M., B. Bentley, P. G. Olin and G. A. E. Gall. 1992. Population genetic structure of coho salmon *(Oncorhynchus kisutch)* in California. Calif. Fish and Game 78:88-104.

Bartley, D.M. and G.A.E. Gall. 1990. Genetic structure and gene flow in chinook salmon populations of California. Trans. Am. Fish. Soc. 119:55-71.

Beamish, R.J. 1980. Adult biology of the river lamprey *(Lampetra ayersi)* and the Pacific lamprey *(Lampetra tridentata)* from the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 37:1906-1923.

Beamish, R.J. and CM. Neville. 1992. The importance of size as an isolating mechanism in lampreys. Copeia 1992:191-196.

Beamish, R.J. and N.E. Williams. 1976. A preliminary report on the effects of river lamprey *(Lampetra ayresii)* predation on salmon and herring stocks. Tech. Rep. No. 611, Fisheries and Marine Service, Canada.

Beamish, R.J. and J.H. Youson. 1987. Life history and abundance of young adult *Lampetra ayresi* in the Fraser River and their possible impact on salmon and herring stocks in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 44:525-537.

Behnke, R.J. 1960. Taxonomy of the cutthroat trout of the Great Basin. Unpubl. M.S. Thesis, University of California, Berkeley.

Behnke, R.J. 1965. A systematic study of the family Salmonidae with special reference to the genus *Salmo.* Unpubl. Ph.D. Diss., University of California, Berkeley.

Behnke, R.J. 1972. The systematics of salmonid fishes of recently glaciated lakes. J. Fish. Res. Board Can. 29:639-671.

Behnke, R.J. 1981. Systematic and zoogeographical interpretation of Great Basin trouts. Pages 95-125, In: R.S. Naiman and D.L. Soltz, eds., Fishes in North American Deserts. John Wiley and Sons, NJ.

Behnke, R.J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6. Bethesda, Maryland. 275 pp.

Bell, M.A. 1978. Fishes of the Santa Clara River system, southern California. Contrib. Sci. Nat. Hist. Mus. Los Angeles Co. 295:1-20.

Bell, R.R. and J.B. Kimsey. 1955. Some considerations of the chemical treatment of the Monticello Reservoir basin, Napa County. Calif. Dept. of Fish and Game, Inland Fish. Admin. Rep. No. 55. 7 pp.

Berg, W.J. 1987. Evolutionary genetics of rainbow trout, *Parasalmo gairdnerii* (Richardson). Unpubl. Ph.D. Diss., University of California, Davis.

Berg, W.J. and G.A.E. Gall. 1988. Gene flow and genetic differentiation among California coastal rainbow trout populations. Can. J. Fish. Aquat. Sci. 45:122-132.

Bills, F.T. and C.E. Bond. 1980. A new subspecies of tui chub (Pisces: Cyprinidae) from Cowhead Lake, California. Copeia 1980:320-322.

Birstein, V.J. 1993. Is *Acipenser medirostris* one or two species? The Sturgeon Quarterly 1(2): 8

Blunt, C.E. 1980. Atlas of California coastal marine resources. Sacramento, Calif. Dept. Fish and Game. 134 pp.

Bond, C.E. 1963. Distribution and ecology of freshwater sculpins, genus *Cottus,* in Oregon. Ph.D. Diss., University of Michigan. 198 pp.

Bond, C.E. 1973. Occurrence of the reticulate sculpin, *Cottus perplexus,* in California, with distributional notes on *Cottus gulosus* in Oregon and Washington. Calif. Fish Game 59:93-94.

Bond, C.E. and T.T. Kan. 1973. *Lampetra (Entosphenus) minima* sp., a dwarfed parasitic lamprey from Oregon. Copeia 1973:568-574.

Bond, C.E., E. Rexstad, and R.M. Hughes. 1988. Habitat use of twenty-five common species of Oregon freshwater fishes. Northwest Science 62:223-232.

Borodin, A.L. 1984. The red book of USSR: species of animals and plants in danger of extinction. Vol. 1. Moscow: Forest Industry. Second edition.

Brown, J.H. and C.R. Feldmeth. 197 1. Evolution in constant and fluctuating environments: thermal tolerances of desert pupfish, *Cyprinodon.* Evolution 25:390-398.

Brown, L.R. 1987. The fishes of the Eel River Drainage: A review and annotated bibliography. Unpubl. Rep., Dept. Wildlife and Fisheries Biology, University of California, Davis.

Brown, L.R. 1988. Factors determining the distribution of three species of sculpin *(Cottus)* from the Pit River drainage, California. Unpubl. Ph.D. Diss., University of California, Davis.

Brown, L.R. and P.B. Moyle. 1987. Survey of fishes of mid-elevation streams of the San Joaquin Valley. Unpubl. Rep., Calif. Dept. of Fish and Game. 220 pp.

Brown, L.R. and P.B. Moyle. 199 1. Status of coho salmon in California. Report to the National Marine Fisheries Service. University of California, Davis. 95 pp.

Brown, L.R. and P.B. Moyle. 1992. Native fishes of the San Joaquin Valley drainage: status of a remnant fauna and its habitats. Pages 89-98, In: D.F. Williams, T.A. RAdo and S. Byrde, eds., Proceedings of the Conference on Endangered and Sensitive Species of the San Joaquin Valley, California. California Energy Commission, Sacramento. 388 pp.

Brown, L.R. and P.B. Moyle. 1993. Distribution, ecology, and status of the fishes of the San Joaquin River drainage, California. Calif. Fish Game 79:96-114.

Brown, L.R., P.B. Moyle, W.A. Bennett and B.D. Quelvog. 1992. Implications of morphological variation among populations of California roach (Cyprinidae: *Lavinia symmetricus)* for conservation policy. Biol. Conserv. 62:1-10.

Brown, L.R. , P.B. Moyle, R.M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. N. Amer. J. Fish. Mgmt. 14: 237-261.

Burns, J. W. 1966. Hardhead. Pp. 518-519 in A. Calhoun, ed. Inland Fisheries Management. Sacramento: Calif. Dept. Fish, Game.

Busack, CA., G.H. Thorgaard, M.P. Bannon, and G.A.E Gall. 1980. An electrophoretic, karyotypic and meristic characterization of the Eagle Lake trout, *Salmo gairdneri aquilarum.* Copeia 1980:418-424.

Buth, D.G. and C.B. Crabtree. 1982. Genetic variability and population structure of *Catostomus santaanae* in the Santa Clara drainage. Copeia 1982:439-444.

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the Balance. 1988 Annual Report, 84 pp. Sausalito, California.

California Department of Fish and Game (CDFG). 1955. Fish and Game water problems of the upper San Joaquin River: potential values and needs. Statement for Division of Water Resources hearings, Fresno, April 5, 1955. 21 pp.

California Department of Fish and Game. 1980. At the crossroads 1980. A Report on California's endangered and rare fish and wildlife. State of California Resources Agency.

California Department of Fish and Game. 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin River System. DFG exhibit 25, State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. 149 pp.

California Department of Fish and Game. 1990a. Status and management of spring-run chinook salmon. Report by Inland Fisheries Division, May 1990. 33 pp.

California Department of Fish and Game. 1990b. Status and management of steelhead rainbow trout. Report by Inland Fisheries Division. 27 pp.

California Department of Fish and Game. 1991a. Timberlands Task Force Report to the Legislature. December, 1991.

California Department of Fish and Game. 1991b. Attachment to comments on northern spotted owl recovery plan appendix C. Consideration of, other species and ecosystem concerns. Submitted to the Secretary for Resources, State of California, November 26, 1991.

California Department of Fish and Game. 1992a. Status report: California salmon. A report to the Fish and Game Commission, Sacramento, February 1992. 72 pp.

California Department of Fish and Game. 1992b. Impact of water management on splittail in the Sacramento-San Joaquin estuary. State Water Resources Control Board Hearing for setting interim standards for the Delta. WRINT-DFG-Exhibit 5. 7 pp.

California Fish and Game Commission. 1885. Biennial report of the Fish and Game Commission, 1883-1884. Calif. Dept. Fish and Game, Sacramento.

Campbell, E.A. and P.B. Moyle. 1991. Historical and recent population sizes of spring-run chinook salmon in California. Pages 155-216, In: T.J. Hassler, ed., Proceedings of the 1990 Northeast Pacific Chinook and Coho Salmon Workshop. American Fisheries Society, Humboldt State University, Arcata, California.

Carl, G.C. and W.A. Clemens. 1953. The freshwater fishes of British Columbia. 2nd ed. B. C. Provi. Museum Handbook 5: 136 pp.

Castleberry, D.T. and J.J. Cech, Jr. 1986. Physiological responses of a native and an introduced desert fish to environmental stressors. Ecology 67:912-918.

Castleberry, D.T., J.E. Williams, G.M. Sato, T.E. Hopkins, A.M. Brasher, and M.S. Parker. 1990. Status and management of Shoshone pupfish, *Cyprinodon nevadensis shoshone* (Cyprinodontidae), at Shoshone Spring, Inyo County, California. Bull. Southern California Acad. Sci. 89: 19-25.

Caywood, M.L. 1974. Contributions to the life history of the splittail *Pogonichthys macrolepidotus* (Ayres). M.S. Thesis. California State University, Sacramento. 77 pp.

Chadwick, H.K. 1959. California sturgeon tagging studies. Calif. Fish Game 45:297-301.

Cech, J.J., S.J. Mitchell, D.T. Castleberry, and M. McEnroe. 1990. Distribution of California stream fishes: influence of environmental temperature and hypoxia. Env. Biol. Fish. 29:95-105.

Chapman, D.W. and T.C. Bjomn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176, In: T.G. Northcote, ed., Symposium on Salmon and Trout in Streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia.

Clark, G.H. 1929. Sacramento-San Joaquin salmon *(Oncorhynchus tschawytscha)* fishery of California. Calif. Dept. Fish Game Fish Bull. 17:38-39.

Cochran, P.A. 1986. Attachment sites of parasitic lampreys: comparisons among species. Environ. Biol. Fishes 17:71-79.

Comstock, R. 1992. Santa Clara River steelhead restoration assessment. Unpubl. report by U.S. Fish and Wildlife Service, July 1992. 10 pp.

Constantz, G.D. 1981. Life history patterns of desert fishes. Pages 237-290, In: R.J. Naiman and D.L. Soltz, eds., Fishes in North American Deserts. John Wiley, N.Y.

Contreras, G.P. 1973. Distribution of the fishes of the Lost River system, California-Oregon, with a key to the species present. Unpubl. M.S. Thesis, University of Nevada, Reno. 61 pp.

Cooper, J.J. 1983. Distributional ecology of native and introduced fishes in the Pit River system, northeastern California, with notes on the Modoc sucker. Calif. Fish Game 69:39-53.

Coots, M. 1955. The Pacific lamprey, *Entosphenus tridentatus,* above Copco Dam, Siskiyou County, California. Calif. Fish Game 41:118-119

Cope, E.D. 1874. On the Plagopterinae and the ichthyology of Utah. Proc. Am. Philos. Soc. 14:129-139.

Cope, E.D. 1883. On the fishes of the recent and Pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene lake. Proc. Phila. Acad. Nat. Sci., 35:134-166.

Cope, E.D. and H.C. Yarrow. 1875. Report upon the collections of fishes made in portions of Nevada, Utah, Colorado, New Mexico, and Arizona during the years 1871, 1872, 1873, and 1874. Rep. Geog. and Geol. Expl. and Sruv., N 100th Mer. (Wheeler Survey) 5:635-703.

Cornelius, R.H. 1969. The systematics and zoogeography of *Rhinichthys osculus* (Girard) in Southern California. M.A. Thesis, California State University, Fullerton. 194 pp.

Crabtree, C.B. 1985. Allozyme variability in the tidewater goby, *Encyclogobius newberryi,* (Pisces, Gobiidae). Isozyme Bull. 18:70.

Cramer, F.K. and D.F. Hammack. 1952. Salmon research at Deer Creek, California. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. Fisheries 67. 16 pp.

Culver, G. B. and C. L. Hubbs. 1917. The fishes of the Santa Ana system streams in southern California. Lorquina 1: 82-83.

Curtis, B. 1934. The golden trout of Cottonwood Lakes *(Salmo agua-bonita* Jordan). Trans. Am. Fish. Soc. 64:259-265.

Daniels, R.A. 1987. Comparative life histories and microhabitat use in three sympatric sculpins (Cottidae:*Cottus*) in northeastern California. Environ. Biol. Fishes 19:93-110.

Daniels, R.A. and P.B. Moyle. 1983. Life history of splittail (Cyprinidae:*Pogonichthys macrolepidotus)* in the Sacramento-San Joaquin estuary. Fish. Bull. 84:105-117.

Daniels, R.A. and P.B. Moyle. 1984. Geographic variation and a taxonomic reappraisal of the marbled sculpin, *Cottus klamathensis.* Copeia 1984:949-959.

Dawley, E.M., R.D. Ledgerwood, T.H. Blahm, C.W. Sims, J.T. Durkin, R.A. Kim, A.E. Rankis, G.E. Monan, and F.J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. Final Rept. to Bonneville Power Admin., Contract DE-A179-84BP39652. 256 pp. Available from Northwest and Alaska Fish. Center, 2725 Montlake Blvd. E., Seattle, Washington.

Deacon, J.E. and C.D. Williams. 1991. Ash Meadows and the legacy of the Devil's Hole pupfish. Pages 69-87, In: W. L. Minckley and J. E. Deacon, eds. Battle against extinction: native fish management in the American West. Tucson, Univ. of Arizona Press.

Deacon, J.E. and J.E. Williams. 1984. Annotated list of the fishes of Nevada. Proc. Biol. Soc. Wash. 97:103-118.

Decker, L.M. 1984. Distribution, abundance, and coexistence of two species of sucker *(Catostomus)* in Sagehen Creek, California and their status in the Western Lahontan Basin. Unpubl. M.S. Thesis, University of California, Berkeley. 40 pp.

Decker, L.M. 1989. Coexistence of two species of sucker, *Catostomus,* in Sagehen Creek, California, and notes on their status in the western Lahontan Basin. Great Basin Natur. 49:540-551.

Deinstadt, J.M., E.J. Pert, F.G. Hoover, and S. Sasaki. 1990. Survey of fish populations in southern California streams: 1987. Calif. Fish and Game Inland Fish. Div. Admin. Rep. 90-1

Deinstadt, J.M., G.F. Sibbald, J.D. Knarr, and D.M. Wang. 1986. Survey of fish populations in streams of the Owens River drainage: 1985. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. No. 86-3. 71 pp.

DesLaurier, G.C. and J.R. West. 1990. 1990 adult spring chinook and summer steelhead census, Salmon River, Calif. Report by U.S.D.A.-Forest Service, Klamath National Forest. 11 pp.

Dewitt, J. W. 1954. A survey of the coast cutthroat trout, *Salmo clarki clarki* Richardson in California. Calif. Fish, Game 40: 329-335.

Dryfoos, R.L. 1965. The life history and ecology of longfin smelt in Lake Washington. Unpubl. Ph.D. dissertation, Univ. of Washington. 229 pp.

Dunn, P.L. 1981. Migration behavior and holding habitat of adult summer steelhead in Wooley Creek, California. M.S. Thesis, Humboldt State University, CA. 83 pp.

Easthouse, K.B. 1985. A biological survey of summer steelhead, Middle Fork Eel River, 1985. Calif. Dept. Fish and Game, Unpubl. Rep.

Echelle, A.A. and T.E. Dowling. 1992. Mitochodrial DNA variation and evolution of the Death Valley pupfishes *(Cyprinodon,* Cyprinodontidae). Evolution 46(1):193-206.

Echelle, A.A. and A.F. Echelle. 1993. Allozyme perspective on mitochondrial DNA variation and evolution of the Death Valley pupfishes (Cyprinodontidae: *Cyprinodon).* Copeia 1993:275-387.

Eigemnann, C.H. 1890. The food fishes of California fresh waters. Biennial Report California Fish Comm. 1888-1890:53-65.

Eigenmann, C.H. and R.S. Eigenmann. 1889. Description of a new species of *Cyprinodon.* Proc. Calif. Acad. Sci. 1:270.

Ekman, E. 1987. Report on adult spring-run salmon surveys, 1986 and 1987. Unpubl. Rep., U.S. Forest Service, Lassen National Forest.

Emmett, R.L., S.L. Stone, S.A. Hinton and M.E. Monaco. 1991. Distribution and abundances of fishes and invertebrates in west coast estuaries, Volume 2: Species life histories summaries. ELMR Rep. No. 8. NOS/NOAA Strategic Environmental Assessment Division, Rockville, MD, 329 pp.

Emig, J., P. Baker, and F. Reynolds. 1988. Coho salmon on the comeback trail. Outdoor California 49:1-4.

Eschmeyer, W.N. 1990. Catalog of the genera of recent fishes. Calif. Acad. Sci., San Francisco. 697 pp.

Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin, Boston. 336 pp.

Everest, F.H. 1973. Ecology and management of summer steelhead in the Rogue River. Oregon St. Game Comm., Fish. Res. Rep. No. 7, Proj. AFS-31. 48 pp.

Evermann, B.W. 1893. Description of a new sucker, *Pantosteus jordani,* from the upper Missouri basin. Bull. U.S. Fish. Comm. 12:51-56.

Evermann, B.W. 1905. The golden trout of the southern High Sierras. Bull. U.S. Bur. Fish. 25:1-51.

Evermann, B.W. and H.W. Clark. 1931. A distributional list of the species of freshwater fishes known to occur in California. Fish Bull. No. 35. California State Printing Office, Sacramento.

Fitch, J.E. and R.J. Lavenberg. 1971. Marine food and game fishes of California. Berkeley, University of California Press. 179 pp.

Fitch, J.E. and S.A. Schultz. 1978. Some rare and unusual occurences of fishes off California and Baja California. Calif. Fish Game 64:74-92.

Fite, K.R. 1973. Feeding overlap between juvenile steelhead and California roach in the Eel River. M.S. Thesis, California State University, Humboldt. 38 pp.

Flittner, G.A. 1953. The composition and distribution of the fish populations in Sagehen Creek, Nevada-Sierra Counties, California. M.S. Thesis, University of California, Berkeley. 150 pp.

Follett, W.I. 1937. Prey of the weasel and mink. J. Mammal. 18:365.

Fowler, H.W. 1913. Notes on catostomid fishes. Proc. Acad. Nat. Sci. Phila. 65:45-71

Fry, D.H. 1936. Life history of *Hesperoleucus venustus* Snyder. Calif. Fish Game 22:65-98.

Fry, D.H., Jr. 1961. King salmon spawning stocks of the California Central Valley, 1940-1959. Calif. Fish and Game 47:55-71.

Fry, D.H., Jr. 1967. A 1955 record of pink salmon, *Oncorhynchus gorbuscha,* spawning in the Russian River. Calif. Fish Game 53:210-211.

Fry, D.H., Jr. 1973. Anadromous fishes of California. CDFG, Sacramento. 111 pp.

Fry, D.H., Jr. 1979. Anadromous fishes of California, revised edition. CDFG, Sacramento, California. 112 pp.

Galat, D.L. and N. Vucinich. 1983. Food partitioning between young of the year of two sympatric tui chub morphs. Trans. Am. Fish. Soc. 112:486-497.

Gall, G.A.E., M. Bannon, R.C. Smith, and B. Bentley. 1981. Native trout of California (progress report). Unpubl. Rep. to Calif. Dept. Fish and Game Threatened Trout Committee.

Garcia, A. 1986. A study of the Eagle Lake rainbow trout *(Salmo gairdneri aquiliarum).* Dept. Wildlife and Fisheries Biology, Unpubl. Rep., University of California, Davis. 28 pp.

Gard, M.F. 1994. Biotic and abiotic factors affecting native stream fishes in the South Yuba River, Nevada County, California. Ph.D. Dissertation. University of California, Davis.

Gard, R. and G.A. Flittner. 1974. Distribution and abundance of fishes in Sagehen Creek, California. J. Wildl. Manage. 38:347-358.

Geary, R.E. 1978. Life history of the Clear Lake hitch *(Lavinia exilicauda chi).* Unpubl. MS. Thesis, University of California, Davis. 27 pp.

Geary, R.E. and P.B. Moyle. 1980. Aspects of the ecology of the hitch, *Lavinia exilicauda* (Cyprinidae), a persistent native cyprinid in Clear Lake, California. Southwest. Nat. 25:385-390.

Gerking, S.D. 1981. The contribution of the desert pupfish *(Cyprinodon nevadensis)* to fish reproduction in stressful environments. Pages 335-356, In: R.J. Naiman and D.L. Soltz, eds., Fishes in North American Deserts. John Wiley, NY.

Gerking, S.D., R. Lee, and J.B. Shrode. 1979. Effects of generation-long temperature acclimation on reproductive performance of the desert pupfish, *Cyprinodon n. nevadensis.* Physiol. Zool. 52: 113-121.

Gerstung, E.R. 1980. 1979 annual report of the Threatened Salmonids Project. Unpubl. Rep., Calif. Dept. Fish and Game, Sacramento.

Gerstung, E.R. 1981. Status and management of the coast cutthroat trout *(Salmo clarki clarki)* in California. Cal-Neva Wildlife Trans. 1981:25-32.

Gerstung, E.R. 1993. Status and management of coastal cutthroat trout in California. Unpubl. file report, Inland Fisheries Division, California Dept. of Fish and Game. 26 pp.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Research reports of the Fish Commission of Oregon 6.

Gilbert, C.H. 1893. Pages 229-234, In: Report on the fishes of the Death Valley expedition collected in southern California and Nevada in 1891, with descriptions of new species. North Am. Fauna No. 7.

Gilbert, C.H. 1897. The fishes of the Klamath Basin. Bull. U.S. Fish Comm. 17:1-13.

Gilbert, C. and B.W. Evermann. 1894. A report upon investigations in the Columbia River basin, with descriptions of four new species of fishes. Bull. U.S. Fish Comm. 14:169-204.

Gill, T.N. 1861. Notes on some genera of fishes of the western coast of North America. Proc. Acad. Nat. Sci. Phila. 13:164-168.

Girard, C. 1854a. Descriptions of new fishes, collected by Dr. A.L. Heermann, naturalist attached to the survey of the Pacific Railroad Route, under Lt. R.S. Williamson, U.S.A., Proc, Acad. Nat. Sci. Phila. 7:129-140.

Girard, C. 1854b. Description of *Sebastes* ruber, Sebastes ruber var. *parvus,* Sebastes *variabilis,* and *Centrarchus maculosus.* The Pacific 3:182.

Girard, C. 1856a. Researches upon the cyprinid fishes inhabiting the fresh waters of the United States of America west of the Mississippi Valley, from specimens in the Museum of the Smithsonian Institution. Proc. Acad. Nat. Sci. 1856:165-209.

Girard, C. 1856b. Contributions to the Ichthyology of the western coast of the United States, from specimens in the museum of the Smithsonian Institution. Proc. Acad. Nat. Sci. Philadelphia 8:131-137.

Gobalet, K.W. and G.L. Fenenga. 1993. Terminal Pleistocene-Early Holocene fishes from Tulare Lake, San Joaquin Valley, California with comments on the evolution of Sacramento squawfish *(Ptychocheilus grandis:* Cyprinidae). PaleoBios 15(1):1-8.

Gold, J.R. 1977. Systematics of western North American trout *(Salmo),* with notes on the redband trout of Sheepheaven Creek, California. Can. J. Zool. 55:1858-1873.

Gold, J.R. and G.A.E. Gall. 1975. The taxonomic structure of six California high Sierra golden trout *(Salmo aquabonita)* populations. Proc. Calif. Acad. Sci. 40:243-263.

Goldberg, S.R. 1977. Seasonal ovarian cycle of the tidewater goby, *Eucyclogobius newberryi* (Gobiidae). Southwest. Nat. 22:557-559.

Greenfield, D.W. and G.D. Deckert. 1973. Introgressive hybridization between *Gila orcutti* and *Hesperoleucus symmetricus* (Pisces:Cyprinidae) in the Cuyama River Basin, California: II. Ecological aspects. Copeia 1973:417-427.

Greenfield, D.W. and T. Greenfield. 1972. Introgressive hybridization between *Gila orcutti* and *Hesperoleucus symmetricus* (Pisces:Cyprinidae) in the Cuyama River Basin, California: I. Meristics, morphometrics and breeding. Copeia 1972:849-859.

Greenfield, D.W., S.T. Ross, and G.D. Deckert. 1970. Some aspects of the life history of the Santa Ana sucker, *Catostomus (Pantosteus) santaunae* (Snyder). Calif. Fish Game 56:166-179.

Hagen, D.W. 1967. Isolating mechanisms in threespine sticklebacks *(Gasterosteus).* J. Fish. Res. Board Can. 24:1637-1692.

Haglund, T.R. and D.G. Buth. 1988. Allozymes of the unarmored threespine stickleback *(Gasterosteus aculeatus williamsoni)* and identification of the Shay Creek population. Isozyme Bull. 21:196.

Hall, L.W., Jr. 1991. A synthesis of water quality and contaminants data on early life history stages of striped bass, *Morone saxatilis.* Reviews in Aquat. Sci. 4: 261-288.

Hallock, R.J. and D.H. Fry. 1967. Five species of salmon, *Oncorhynchus,* in the Sacramento River, California. Calif. Fish Game 53:5-22.

Hart, J.L. and J.L. McHugh. 1944. The smelts (Osmeridae) of British Columbia. Fish Res. Bd. Can., Bull. No. 64: 27 pp.

Hartman, G.F. and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout *(Salmo gairdneri* and *S. clarki clarki)* within streams in southwestern British Columbia. J. Fish. Res. Board Can. 14:687-691.

Hassler, T.J. 1987. Coho salmon. U.S. Fish Wildl. Ser. Biol. Rep. 82 (11.70):19 pp.

Hauser, W.J. 1969. Life history of the mountain sucker, *Catostomus platyrhynchus* in Montana. Trans. Am. Fish. Soc. 98:209-224.

Healy, M.C. 1991. Life history of chinook salmon *(Oncorhynchus tshawytscha).* Pages 311-393, In: C. Groot and L. Margolis, eds., Pacific Salmon Life Histories. University of British Columbia Press, Vancouver.

Healey, T.P., Jr. 1973. Studies of steelhead and salmon emigration in the Trinity River. Calif. Dept. Fish Game, Anad. Fish. Rept. 73-1. 37 pp.

Heard, W.R. 1991. Life history of pink salmon *(Oncorhynchus gorbuscha).* Pages 110-230, In: C. Groot and L. Margolis, eds., Pacific Salmon Life Histories. University of British Columbia Press, Vancouver.

Herbold, B., A. Jassby, and P.B. Moyle. 1992. Status and trends of aquatic resources of the San Francisco Bay Estuary. U.S. Environmental Protection Agency San Francisco Estuary Project. 257 pp.

Higgins, P. 1991. Southern California steelhead recovery assessment: San Mateo Creek, Santa Margarita River. A wider role for TU in Protection and Recovery. Report to South Coast Chapter of Trout Unlimited. 26 pp.

Higgins, P. 1992. Northern California stocks of salmon, steelhead, and cutthroat trout: at risk of extinction, Pages 11-16, In: J. Waldvogel, ed., Proceedings fo the Tenth Annual California Salmon, Steelhead, and Trout Restoration Conference. University of California Sea Grant, Eureka, California.

Hoogland, R.D., D. Morris, and N. Tinbergen. 1957. The spines of sticklebacks *(Gasterosteus* and *Pygosteus)* as means of defense against predators *(Perca* and *Esox).* Behaviour 10:205-236.

Hoopaugh, D.A. 1974. Status of redband trout *(Salmo* sp.) in California. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 74. 11 pp.

Hopkirk, J.D. 1962. Morphological variation in the freshwater embiotocid, *Hysterocarpus traski* Gibbons. M.A. Thesis, University of California, Berkeley. 159 pp.

Hopkirk, J.D. 1973. Endemism in fishes of the Clear Lake region of central California. University of California Publ. Zool. 96: 160 pp.

Houston, J.J. 1988. Status of the green sturgeon, *Acipenser medirostris,* in Canada. Can. Field Naturalist 102:286-290.

Howes, G. 1984. Phyletics and biogeography of the aspinine cyprinid fishes. Bull. Brit. Mus. Nat. Hist. (Zool.) 47:283-303.

Hubbs. C. 1947. Mixture of marine and freshwater fishes in the lower Salinas River, California. Copeia 1947:147-149.

Hubbs, C.L. 1925. The life-cycle and growth of lampreys. Pap. Mich. Acad. Sci., Arts Letters 4:587-603.

Hubbs, C.L. 1946. Wandering of pink salmon and other salmonid fishes into southern California. Calif. Fish Game 32:81-86.

Hubbs, C.L. 1971. *Lampetra (Entosphenus) lethophaga,* new species, the nonparasitic derivative of the Pacific lamprey. San Diego Soc. Nat. Hist. Trans. 16:125-164

Hubbs, C.L. 1974. Review of J.D. Hopkirk (1973). Endemism in fishes of the Clear Lake region of central California. Copeia 1974:808-809.

Hubbs, C.L., W.I. Follett, and L.J. Dempster. 1979. List of the fishes of California. Occas. Pap. Calif. Acad. Sci., 133:1-51.

Hubbs, C.L. and R.R. Miller. 1943. Mass hybridization between two genera of cyprinid fishes in the Mohave Desert, California. Pap. Mich. Acad. Sci. Arts Lett. 28:343-378.

Hubbs, C.L. and R.R. Miller. 1948. The Great Basin with emphasis on glacial and postglacial times. II. The zoological evidence. Bull. Univ. Utah 38:17-166.

Hubbs, C.L., R.R. Miller, and L.C. Hubbs. 1974. Hydrographic history and relict fishes of the northcentral Great basin. Calif. Acad. Sci. Mem. 7:1-259.

Hunt, W.G., J.M. Jenkins, R.E. Jackman, and E.G. Thelander. 1988. Foraging ecology of Bald Eagles on a regulated river. J. Raptor Res. 26: 243-256.

Hynes, H.B.N. 1950. The food of freshwater sticklebacks *(Gasterosteus aculeatus* and *Pygosteus pungitius),* with a review of methods used in studies of the food of fishes. J. Anim. Ecol. 19:36-58.

Irwin, J.F. and D.L. Soltz. 1984. The natural history of the tidewater goby, *Eucyclogobius newberryi,* in the San Antonio and Shuman creek systems, Santa Barbara County, California. U.S. Fish and Wildl. Serv. Rep., Sacramento Endangered Species Off. Contract Order No. 11310-0215-2.

Johnson, D.M., R.R. Peterson, D.R. Lycan, J.W. Sweet, M.E. Neuhaus, and A.L. Schaedel. 1985. Atlas of Oregon lakes. Oregon State University Press, Corvallis.

Johnson, V.K. 1958. Fisheries management report, Pyramid Lake. Lakes Pyramid, Walker, and Tahoe investigations, Dingell-Johnson Project FAF-4-R, Nev. Fish and Game Dept.

Jones, W.E. 1980. Summer steelhead *(Salmo gairdneri)* in the Middle Fork Eel River and their relationship to environmental changes, 1966 through 1978. Calif. Dept. Fish and Game, Anad. Fish. Br., Admin. Rep. No. 80-2. 25 pp.

Jones, W.E. and E. Ekman. 1980. Summer steelhead management plan-Middle Fork of the Eel River. Rep. to Calif. Dept. Fish and Game and U.S. Forest Serv. 48 pp.

Jordan, D.S. 1879. Notes on a collection of fishes from Clackamus River, Oregon. Proc. U.S. Nat. Mus. 1:69-85.

Jordan, D.S. and B.W. Evermann. 1896. Fishes of North and Middle America. Bull. U.S. Nat. Mus. 47:1-3705.

Jordan, D.S. and C.H. Gilbert. 1881. Notes on the fishes of the Pacific coast of the United States. Proc. U.S. Nat. Mus., IV, 1881:29-70.

Jordan, D.S. and C.H. Gilbert. 1882. Synopsis of the fishes of North America. Bull. U.S. Nat. Mus. 16:1-1018.

Jordan, D.S. and C.H. Gilbert. 1883.. Synopsis of fishes of North America. Bull. U.S. Nat. Nus. 1882, 16:1-1018.

Jordan, D.S. and C.H. Gilbert. 1895. List of the fishes inhabiting Clear Lake, California. U.S. Fish Comm. Bull. 16 (1894):139-140.

Jordon, D.S. and J.O. Snyder. 1906. A synopsis of the sturgeons (Acipenseridae) of Japan. Proc. U.S. Nat. Mus. 30:397-398.

Kennedy, J.L. 1983. Seasonal growth of the tui chub, *Gila bicolor,* in Pyramid Lake, Nevada. Great Basin Nat. 43:713-716.

Kimsey, J.B. 1954. The life history of the tui chub, *Siphatales bicolor* (Girard), from Eagle Lake, California. Calif. Fish Game 40:395-410.

Kimsey, J.B. 1960. Observations on the spawning of Sacramento hitch in a lacustrine environment. Calif. Fish Game 46:211-215.

Kimsey, J.B. and L.O. Fisk. 1960. Keys to the freshwater and anadromous fishes of California. Calif. Fish Game 46:453-79.

Kimsey, J.B., D.W. Kelley, R. Hagy, and G. McCammon. 1956. A survey of the fish populations of Pardee Reservoir, Amador/Calaveras counties. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 56. 13 pp.

King, V.L. 1963. First progress report of the Eagle Lake rainbow trout fishery. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep., No. 63-9:18 pp.

King, V.L. and R.J. Hanson. 1966. A preliminary investigation of the fish fauna of Goose Lake and their relative abundance. Unpubl. Rep., Calif. Dept. Fish and Game. 7 pp.

Knapp, R.A. and T.L. Dudley. 1990. Growth and longevity of golden trout, *Oncorhynchus aquabonita,* in their native streams. Calif. Fish, Game 76:161-173.

Knight, N.J. 1985. Microhabitats and temperature requirements of hardhead *(Mylopharadon conocephalus)* and Sacramento squawfish *(Ptychocheilus grandis),* with notes for some other native California stream fishes. Unpubl. Ph.D. Diss., University of California, Davis. 161 pp.

Kodric-Brown, A. 1977. Reproductive success and the evolution of breeding territories in pupfish *(Cyprinodon).* Evolution 31:750-766.

Kodric-Brown, A. 1981. Variable breeding systems in pupfishes (Genus *Cyprinodon):* adaptations to changing environments. Pages 205-236, In: R.J. Naiman and D.L. Soltz, eds., Fishes in North American Deserts. John Wiley, NY.

Kohlhorst, D.W., L.W. Botsford, J.S. Brennan, and G.M. Cailliett. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon *(Acipenser transmontanus).* Pages 227-293, In: P. Williot, ed., Acipenser. Bordeaux:CEMAGREF

Kope, R.G. and L.W. Botsford. 1990. Determination of factors affecting recruitment of chinook salmon *Oncorhynchus tshawytscha.* U.S. Fishery Bulletin 28:257-269.

Kuikila, K. 1993. Diazinon concentrations in the Sacramento and San Joaquin rivers and San Francisco Bay, California. U. S. Geological Survey Open File Report 93-440. Sacramento Ca.

LaBounty, J.F. and J.E. Deacon. 1972. *Cyprinodon milleri,* a new species of pupfish (family Cyprinodontidae) from Death Valley, California. Copeia 1972:769-780.

LaFaunce, D.A. 1967. A king salmon spawning survey of the South Fork Trinity River, 1964. California Department of Fish and Game, Marine Resources Branch Administrative Report No. 67-10.

La Rivers, I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Comm. 782 pp.

Larson, J., J. McKeon, T. Salamunovich and T.D. Hofstra. 1983. Water quality and productivity of the Redwood Creek Estuary. Pages 190-199, In: C. van Riper III, L. D. Whittig and M. L. Murphy, eds., Proceedings of the First Biennial Conference of Research in California's National Parks. University of California, Davis.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, J.R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. N. Carolina Mus. Nat. Hist., Raleigh. 854 pp.

Legendre, P., C.B. Schreck, and R.J. Behnke. 1972. Taximetric analysis of selected groups of western North American *Salmo* with respect to phylogenetic divergences. Syst. Zool. 21:292-307.

Leidy, R.A. 1984. Distribution and ecology of stream fishes in the San Francisco Bay drainage. Hilgardia 52:1-175.

Lindquist, A.W., C.D. Deonier, and J.E. Hanley. 1943. The relationship of fish to the Clear Lake gnat, in Clear Lake, California. Calif. Fish Game 29:196-202.

Malcolm, J.R. 1992. Supporting information for a petition to list as endangered or threatened: Shay Creek stickleback, *Gasterosteus* sp. Pages 213-222, In: P. B. Moyle and R. M. Yoshiyama, eds., Fishes, Aquatic Diversity Management Areas, and Endangered Species: A Plan to Protect California's Native Aquatic Biota. CPS Report, the California Policy Seminar, University of California.

Marcotte, B.D. 1984. Life history, status and habitat requirements of spring-run chinook salmon in California. Unpubl. Report., Lassen National Forest, Chester, Calif. 34 pp.

Marrin, D.L. and D.C. Erman. 1982. Evidence against competition between trout and nongamefish in Stampede Reservoir, California. N. Amer. J. Fish. Mgmt. 2:262-269.

Martin, M. 1967. The distribution and morphology of the North American catostomid fishes of the Pit River system, California. Unpubl. M.S. Thesis, Sacramento State College.

Mathews, S.B. 1962. The ecology of the Sacramento perch, *Archoplites interruptus,* from selected areas of California and Nevada. M.A. Thesis, University of California, Berkeley. 93 pp.

Mathews, S.B. 1965. Reproductive behavior of the Sacramento perch. Copeia 1965:224-228.

Matthews, W.J., R.E. Jenkins, and J.T. Syron, Jr. 1982. Systematics of two forms of blacknose dace, *Rhinichthys atratulus* (Pisces: Cyprinidae) in a zone of syntopy, with a reivew of the species group. Copeia 1982: 902-920.

Mayden, R.L., W.J. Ra inboth, and D.G. Buth. 1991. Phylogenetic systematics of the cyprinid genera *Mylopharodon* and *Ptychocheilus:* comparative morphometry. Copeia 1991:819-834.

McAfee, W.R. 1966. Eagle Lake rainbow trout. Pages 221-224, In: A.E. Calhoun, ed., Inland Fisheries Management. Calif. Dept. Fish and Game, Sacramento.

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. Bull. Natl. Mus. Canada. 191:53 pp.

McCarraher, D.B. and R.W. Gregory. 1970. Adaptability and current status of introductions of Sacramento perch, *Archoplites interruptus,* in North America. Trans. Am. Fish. Soc. 99:700-707.

McPhail, J.O. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can. Bull. 173: 381 pp.

Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. Fisheries 11:14-23.

Meng, L., B. Herbold and P.B. Moyle. 1991. Trends in fish populations of Suisun Marsh. Annual Report to Calif. Dept. Water Resources, 16 pp.

Meng, L. and P. B. Moyle. 1995. Status of splittail in the Sacramento-San Joaquin estuary. Trans. Amer. Fish Soc. 124: (in press).

Meng, L., P. B. Moyle, and B. Herbold. 1994. Changes in abundance and distribution of native and introduced fishes in Suisun Marsh. Trans. Amer. Fish. Soc. 123: 498-507.

Meng, L. and J.J. Orsi. 1991. Selective predation by larval striped bass on native and introduced copepods. Trans. Am. Fish. Soc. 120:187-192.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish Game Fish. Bull. 157:235 pp.

Miller, L.W. 1972. Migrations of sturgeon tagged in the Sacramento-San Joaquin Estuary. Calif. Fish Game 58: 102-106.

Miller, R.G. 1951. The natural history of Lake Tahoe fishes. Unpubl. Ph.D. Diss., Stanford University. 160 pp.

Miller, R.R. 1938. Record of the fresh-water minnow *Apocope nevadensis* from southeastern California. Copeia 1938:147.

Miller, R.R. 1943a. *Cyprinodon salinus,* a new species of fish from Death Valley, California. Copeia 1943:69-78.

Miller, R.R. 1943b. The status of *Cyprinodon macularius* and *Cyprinodon nevadensis,* two desert fishes of western North America. Occas. Pap. Mus. Zool., University of Michigan 473:1-25.

Miller, R.R. 1945. A new cyprinid fish from Southern Arizona, and Sonora, Mexico, with description of a new subgenus of *Gila* and a review of related species. Copeia 1945:104-110.

Miller, R.R. 1948. The cyprinodont fishes of the Death Valley system of eastern California and southwestern Nevada. Misc. Publ. Mus. Zool., University of Michigan 68:1-155.

Miller, R.R. 1950. Notes on the cutthroat and rainbow trouts with the description of a new species from the Gila River, New Mexico. Occas. Pap. Mus. Zool., University of Michigan 529:1-42.

Miller, R.R. 1958. Origin and affinities of the fish fauna of western North America. Pages 187-222, In: C.L. Hubbs, ed., Zoogeography. AAAS, Washington, D.C.

Miller, R.R. 1960. The type locality of *Gasterosteus aculeatus williamsoni* and its significance in the taxonomy of Californian sticklebacks. Copeia 1960:348-350.

Miller, R.R. 1968. Records of some native freshwater fishes transplanted into various waters of California, Baja California, and Nevada. Calif. Fish Game 54:170-179.

Miller, R.R. 1972. Classification of the native trouts of Arizona with the description of a new species, *Salmo apache.* Copeia 1972:401-422.

Miller, R.R. 1973. Two new fishes, *Gila bicolor snyderi* and *Catostomus fumeiventris,* from the Owens River Basin, California. Occas. Pap. Mus. Zool., University of Michigan 667:1-19.

Miller, R.R. 1981. Coevolution of deserts and pupfishes (Genus *Cyprinodon)* in the American southwest. Pages 39-94, In: R.J. Naiman and D.L. Soltz, eds., Fishes in North American Deserts. John Wiley, NY.

Mills, T.J. 1979. High Rock Spring, Lassen County, with notes *on the* species comprising *Gila bicolor,* in California. Unpubl. Rep., Calif. Dept. Fish and Game.

Mills, T.J. 1983. Utilization of the Eel River tributary streams by anadromous salmonids, Appendix H. In: F.L. Reynolds, ed., 1983 Status Report of California Wild and Scenic Rivers: Salmon and Steelhead Fisheries. Calif. Dept. Fish and Game. 57 pp.

Minckley, W.L. 1973. Fishes of Arizona. Phoenix: Ariz. Dept. Fish, Game.

Moffett, J.W. and S.H. Smith: 1950. Biological investigations of the fishery resources of Trinity River, California. USFWS Spec. Sci. Rept. Fisheries 12:1-71.

Monaco, M.E., D.M. Nelson, R.L. Emmett and S.A. Hinton. 1990. Distribution and abundance of fishes and invertebrates in West Coast estuaries, Vol. 1: Data summaries. ELMR Rep. No. 4, Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 pp.

Monroe, G.M., B.J. Mapes, and P.L. McLaughlin. 1975. Natural resources of Lake Earl and the Smith River Delta. Calif. Dept. Fish and Game, Coastal Wetland Series 10. 114 pp.

Monroe, G.M. and T. Reynolds. 1974. Natural resources of the Eel River Delta. Calif. Dept. Fish and Game, Coastal Wetland Series 9. 108 pp.

Moodie, G.E.E. 1972. Predation, natural selection and adaptation in an unusual threespine stickleback. Heredity 28: 155-167.

Moodie, G.E.E. and T.E. Reimchen. 1976. Phenetic variation and habitat differences in *Gasterosteus* populations of the Queen Charlotte Islands. Syst. Zool. 25:49-61.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northw. Pub. Co., Anchorage. 248 pp.

Moyle, P.B. 1976. Inland Fishes of California. University of California Press, Berkeley. 405 pp.

Moyle, P.B. and D.M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow recommendations. Trans. Amer. Fish. Soc. 114: 695-704.

Moyle, P.B. and R.A. Daniels. 1982. Fishes of the Pit River system, and Surprise Valley region. University of Calif. Publ. Zool. 115:1-82.

Moyle, P.B., R.A. Daniels, B. Herbold, and D.M. Baltz. 1985. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. Fish. Bull. 84: 105-117.

Moyle, P.B. and J.P. Ellison. 1991. A conservation-oriented classification system for the inland waters of California. California Fish and Game 77:161-180.

Moyle, P.B., T. Kennedy, D. Kuda, L. Martin and G. Grant. 1991. Fishes of Bly Tunnel, Lassen County, California. Great Basin Naturalist 51: 267-270.

Moyle, P.B. and M. Massingill. 1981. Hybridization between hitch, *Lavinia exilicauda,* and Sacramento blackfish, *Orthodon microlepidotus,* in San Luis Reservoir, California. Calif. Fish Game 67:196-198.

Moyle, P. B., S. B. Mathews, and N. Bonderson. 1974. Feeding habits of the Sacramento perch, Archoplites interruptus. Trans. Amer. Fish. Soc. 103: 399-402.

Moyle, P.B. and R.D. Nichols. 1973. Ecology of some native and introduced fishes of the Sierra Nevada foothills in central California. Copeia 1973:478-490.

Moyle, P.B. and R.D. Nichols. 1974. Decline of the native fish fauna of the Sierra-Nevada foothills, central California. Amer. Midl. Nat. 92:72-83.

Moyle, P.B., J.J. Smith, R.A. Daniels, and D.M. Baltz. 1982. Distribution and ecology of stream fishes of the Sacramento-San Joaquin Drainage System, California: a review. University of Calif. Publ. Zool. 115:225-256.

Moyle, P.B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage of a small California stream. Ecology 66:1-13.

Moyle, P.B., B. Vondracek and G.D. Grossman. 1983. Response of fish populations in the North Fork of the Feather River, California to treatment with fish toxicants: N. Amer. J. Fish. Mangmt. 3:48-60.

Moyle, P.B. and J.E. Williams. 1989. Loss of biodiversity in the temperate zone: decline of the native fish fauna of California. Conserv. Biol. 4:275-284.

Moyle, P.B., J.E. Williams, and E. Wikramanayake. 1989. Fish species of special concern of California. California Department of Fish and Game, Sacramento. 222 pp.

Moyle, P.B., and R.M. Yoshiyama. 1992. Fishes, Aquatic Diversity Management Areas, and Endangered Species: A Plan to Protect California's Native Biota. CPS Report, The California Policy Seminar, University of California.

Moyle, P.B., and R.M. Yoshiyama. 1994. Protection of aquatic biodiversity in California: a live-tiered approach. Fisheries 19:6-18

Murphy, G. 1943. Sexual dimorphism in the minnows *Hesperoleucus* and *Rhinichthys.* Copeia 1943:101-111.

Murphy, G. 1948. Distribution and variation of the roach *(Hesperoleucus)* in the coastal region of California. M.A. Thesis, University of California. 55 pp.

Murphy, G.I. 1947. Notes on hardhead control in the East Fork of the Russian River, Mendocino County, California. Calif. Dept. Fish and Game, Inland Fish Admin. Rep. 47.

Murphy, G.I. 1948a. Notes on the biology of the Sacramento hitch *(Lavinia e. exilicauda)* of Clear Lake, Lake County, California. Calif. Fish Game 34:101-110.

Murphy, G.I. 1948b. A contribution to the life history of the Sacramento perch *(Archoplites interruptus)* in Clear Lake, Lake County, California. Calif. Fish Game 34:93-100.

Murphy, G.I. and J.W. Dewitt. 1951. Notes on the fishes and fisheries of the lower Eel River, Humboldt County, California. Calif. Dept. Fish and Game, Admin. Rept. 51-9. 28 pp.

Naiman, R.J. 1975. Food habits of the Amargosa pupfish in a thermal stream. Trans. Am. Fish. Soc. 104:536-538.

Naiman, R.J. 1976. Productivity of a herbivorous pupfish population *(Cyprinodon nevadensis)* in a warm desert stream. J. Fish. Biol. 9:125-137.

Needham, P.R. and R. Gard. 1959. Rainbow trout in Mexico and California, with notes on the cutthroat trout series. Univ. Calif. Publ., Zool. 67:123 pp.

Nehlsen, W., J.E. Williams and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: west coast stocks of salmon, steelhead, and sea-run cutthroat trout at risk. Fisheries (Bethesda) 16:4-21.

Nichols, F.H. , J.K. Thompson, and L.R. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, U.S.A.) by the Asian clam, *Potamocorbula amurensis.* II. Displacement of a former community. Mar. Ecol. Prog. Series 66:95-101.

Nicola, S.J. 1974. The life history of the hitch, *Lavinia exilicauda* Baird and Girard, in Beardsley Reservoir, California. Inland Fish. Admin. Rep. 74-6:1-16.

Odemar, M.W. 1964. Southern range extension of the eulachon, *Thaleichthys pacificus.* Calif. Fish Game 50:305-307.

Odion, D.C., T. L. Dudley, and CM. D'Antonio. 1988. Cattle grazing in southeastern sierran meadows: ecosystem change and prospects for recovery. Pages 277-292, In C. A. Hall and V. Doyle-Jones, eds., Plant biology of eastern California. White Mountain Res. Station, Univ. Calif. Los Angeles.

Olson, M.D. 1988. Upstream changes in native fish abundance after reservoir impoundment in California streams of the Lahontan Basin. Unpubl. M.S. Thesis, University of California, Berkeley. 34 pp.

Olson, M.D. and D.C. Erman. 1987. Distribution and abundance of mountain sucker, *Catostomus platyrhynchus,* in five California streams of the Western Lahontan Basin. Calif. Dept. Fish and Game Rep. Contract C-2057.

Omel'chenko, V.T. and G.P. Vyalova. 1990. Population structure of pink salmon. Soviet J. Marine Biology 16:1-10.

Oregon Department of Fish and Wildlife (and Washington Department of Fisheries). 1991. Status report. Columbia River fish runs and fisheries, 1960-1990. 154 pp.

Otaki, K. 1907. The common sturgeon of Hokkaido. Trans. Sapporo Nat. Hist. Soc. 2(1):79-84.

Pacific Gas and Electric (PG&E). 1985. Bald Eagle and Fish Study. Pit 3, 4 and 5 Project. Biosystems Analysis, Inc. and University of California, Davis.

Parker, L.P. and H.A. Hanson. 1944. Experiments on transfer of adult salmon into Deer Creek, California. J. Wildl. Manage. 8:192-198.

Patten, B.G. 1971. Spawning and fecundity of seven species of northwest American *Cottus.* Am. Midl. Nat. 85:493-506.

Pauley, G.B., K. Oshima, K.L. Bowers, and G.L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)-- sea-run cutthroat trout. U.S. Fish and Wildlife Serv. Biol. Rep. 82(11.86).

Pearcy, W. G. 1992. Ocean ecology of North Pacific salmonids. University of Washington Press, Seattle. 179 pp.

Platts, W.S. and S. Jensen. 1991. Pine Creek assessment, Eagle Lake watershed, Lassen County, California. Unpubl. Report, Lassen National Forest. 74 pp.

Platts, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environ. Prot. Agency, Corvallis, OR. EPA-600/3-79-C43. 32 pp.

Puckett, L.E. 1975. The status of spring-run steelhead *(Salmo gairderi)* of the Eel River system. Calif. Dept. Fish and Game Memo. Rep. 22 pp.

Puckett, L.K. 1976. Observations on the downstream migrations of anadromous fishes within the Eel River system. Calif. Dept. Fish and Game Memorandum Report. 34 pp.

Purdy, T.I. 1988. Purdy's Eagle Lake. Lahontan Images, Susanville. 136 pp.

Radtke, L.D. 1966. Distribution of smelt, juvenile sturgeon and starry flounder in the Sacramento-San Joaquin Delta. Pages 115-119, In: S.L. Turner and D.W. Kelley, eds., Ecological Studies of the Sacramento-San Joaquin Estuary, Pt. 2. Calif. Dept. Fish Game Fish Bull. 136.

Reeves, J.G. 1964. Age and growth of the hardhead minnow *Mylopharodon conocephalus* in the American River basin of California, with notes on its ecology. M.S. Thesis. University of California, Berkeley. 90 pp.

Regan, C.T. 1909. The species of threespine sticklebacks, *Gasterosteus.* Ann. Mag. Nat. Hist., Ser. 8, 4:435-437.

Reimers, P.E. and C.E. Bond. 1967. Distribution of fishes in tributaries of the lower Columbia River. Copeia 1967:541-550.

Reisenbichler, R. R., J. D. McIntyre, M. F. Solazzi, and S. W. Landino. 1992. Genetic variation in steelhead of Oregon and northern California. Trans. Amer. Fish. Soc. 121:158-169.

Reiser, D.W. and T.C. Bjornn. 1979, Habitat requirements of anadromous salmonids. Pages 54-58, In: W. R. Meehan, ed., Influence of Forest and Range Management on Anadromous Fish Habitat in Western North America. Pacific N.W. Forest Range Exp. Stn. USDA Forest Serv., Portland. Gen. Tech. Rep. PNW-96.

Richards, J.E., R.J. Beamish and F.W.H. Beamish. 1982. Description and keys for ammocoetes of lampreys from British Columbia, Canada. Can. J. Fish. Aquat. Sci. 39:1484-1495.

Richards, R.C., C.R. Goldman, T.C. Frantz, and R. Wickwire. 1975. Where have all the *Daphnia* gone? The decline of a major cladoceran in Lake Tahoe, California-Nevada. Verh. Internat. Verein. Limnol. 19:835-842.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea and W.B. Scott. 1991. Common and scientific names of fishes from the United States and Canada (4th Ed.). Am. Fish. Soc. Spec. Publ. No. 20.

Robins, C.R. and R.R. Miller. 1957. Classification, variation, and distribution of the sculpins, genus *Cottus,* inhabiting Pacific slope waters in California and southern Oregon, with a key to the species. Calif. Fish Game 43:213-233.

Rochard, E., G. Castelnaud and M. Lepage. 1990. Sturgeons (Pisces: Acipenseridae): threats and prospects. J. Fish Biol. 37 (Suppl. A):123-132.

Roedel, P.M. 1953. Common ocean fishes of the California coast. Calif. Dept. Fish Game Fish Bull. 91: 184 p.

Roelofs, T.D. 1983. Current status of California summer steelhead *(Salmo gairdneri)* stocks and habitat, and recommendations for their management. Report to USDA Forest Service Region 5. 77 pp.

Roos, J.F., P. Gilhousen, S.R. Killick, and R. Zyblut. 1973. Parasitism on juvenile Pacific salmon *(Oncorhynchus)* and Pacific herring *(Clupea harengeus pallasi)* in the Strait of Georgia by the river lamprey *(Lampetra ayresi).* J. Fish. Res. Board Can. 30:565-568.

Rowley, W. 1955. 1954 creel census, North Fork, Feather River. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 55. 17 pp.

Rutter, C. 1903. Notes on fishes from streams and lakes of northeastern California not tributary to the Sacramento Basin. Bull. U.S. Fish Comm. 22:143-48.

Rutter, C. 1908. The fishes of the Sacramento-San Joaquin basin, with a study of their distribution and variation. U.S. Bur. Fish. Bull. 27:103-152.

Rybock, J.T., H.F. Horton, and J.L. Fessler. 1975. Use of otoliths to separate juvenile steelhead trout from juvenile rainbow trout. Fish. Bull. 73:654-659.

Sada, D.W. 1989. Status, distribution and morphological variation of speckled dace in the Owens River system. Report to Calif, Dept. of Fish and Game, Inland Fisheries Division, Rancho Cordova, Contract No. FG7343. 77 pp.

Sada, D.W., H.B. Britten, and P.F. Brussard. 1993. Morphometric and genetic differentiation among Death Valley system *Rhinichthys osculus.* Report to Calif. Dept. of Fish and Game, Inland Fisheries Division, Rancho Cordova, Contract No. FG0524. 51 pp.

Saiki, M.K. 1984. Environmental conditions and fish faunas in low elevation rivers on the irrigated San Joaquin Valley floor, California. Calif. Fish Game 70: 145-157.

Salo, E.O. 1991. Life history of chum salmon *(Oncorhynchus keta).* Pages 231-309, In: C. Groot and L. Margolis, eds., Pacific Salmon Life Histories. University of British Columbia Press, Vancouver.

Samuelson, C.E. 1973. Fishes of South Humboldt Bay, Humboldt County, California. Unpubl. M.S. thesis, Humboldt State University, Arcata, California. 94 pp.

Sandercock, F.K. 1991. Life history of coho salmon, *Oncorhynchus kisutch.* Pages 397-445 In C. Groot and L. Margolis, eds., Pacific salmon life histories. University of British Columbia Press, Vancouver, B.C.

Santa Ana Daily Register. 1916. Trout larger than 1915 is verdict. May 18, 1916.

Sato, G.M. 1992a. Minutes of the Goose Lake Fishes Working Group meeting, June 26, 1992, Lakeview, Oregon. Bureau of Land Management, Susanville, CA. 20 pp.

Sato, G.M. 1992b. Survey report on Cowhead Lake tui chub. Bureau of Land Management, Susanville, CA. 5 pp.

Sato, G.M. and P.B. Moyle. 1988. Stream surveys of Deer and Mill Creek, Tehama County, California, 1986 and 1987, with recommendations for the protection of their drainages and their spring-run chinook salmon. Rep. submitted to U.S.D.I. Nat. Park Serv. and Calif. Dept. Water Resourses. 77 pp.

Sato, G.M. and P.B. Moyle. 1989. Ecology and conservation of spring-run chinook salmon. Annual Report, Water Resources Center Project W-719, July 30, 1988 - June 30, 1989.

Schlichting, D.L. 1988. Annual report, Feather River Hatchery, 1986-87. Calif. Dept. Fish and Game Inland Fish. Admin. Rep. 88-10. 12 pp.

Schmidt, P.Yu. 1950. Fishes of the Sea of Okhotsk. [1965 English translation. Israel Program for Scientific Translations, Jerusalem, and Smithsonian Institution, Washington, D.C. 392 pp.]

Schreck, C.B. and R.J. Behnke. 1971. Trouts of the upper Kern River Basin, California with reference to systematics and evolution of western North American *Salmo.* J. Fish. Res. Board Can. 28:987-998.

Scofield, N.B. 1916. The humpback and dog salmon taken in the San Lorenzo River. Calif. Fish Game 2:41.

Scoppettone, G.G. 1988. Growth and longevity of the cui-ui and longevity of other catostomids and cyprinids in western North America. Trans. Am. Fish. Soc. 117:301-307.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184:966 pp.

Selby, D.A. 1977. Report on the aquatic systems of the Tecopa-Shoshone area of the Death Valley system: fish, invertebrates, and habitat status. Unpubl. Rep., Calif. Dept. Fish and Game.

Shapovalov, L. 1932. Report on a survey of the streams in the vicinity of Cloverdale, California. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 32.

Shapovalov, L. 1940. Report on planting of marked steelhead trout in the lagoon of Santa Ynez River, Santa Barbara County, California. Unpubl. report, Calif. Div. Fish and Game. 8 pp.

Shapovalov, L. and W.A. Dill. 1950. A check list of the freshwater and anadromous fishes of California. Calif. Fish Game 36:382-391.

Shapovalov, L., W.A. Dill, and A.J. Cordone. 1959. A revised checklist of the freshwater and anadromous fishes of California. Calif. Fish and Game 45:159-180.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead rainbow trout *(Salmo gairdneri gairdneri)* and silver salmon *(Oncorhynchus kisutch).* Calif. Dept. Fish and Game Fish Bull. 98. 275 pp.

Shepherd, B.G., ed. 1989. Proceedings of the 1988 Northeast Pacific chinook and, coho workshop. Am. Fish. Soc., North Pacific International Chapter, Penticton, B.C. 284 pp.

Sheppard, D. 1972. The present status of the steelhead trout stocks along the Pacific Coast. M.S. Thesis, University of Washington, Seattle.

Shrode, J.B. 1975. Developmental temperature tolerance of a Death Valley pupfish *(Cyprinodon nevadensis).* Physiol. Zool. 48:378-389.

Shrode, J.B. and Gerking, S.D. 1977. Effects of constant and fluctuating temperatures on reproductive performance of a desert pupfish, *Cyprinodon n. nevadensis.* Physiol. Zool. 50:1-10.

Shultz, L.P. 1930. Notes on the species of *Cottus* in western Washington. Copeia 1930: 14-15.

Sigler, W.F. and J.W. Sigler. 1987. Fishes of the Great Basin: A Natural History. University of Nevada Press, Reno. 425 pp.

Skinner, J.E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Calif. Dept. Fish and Game. 226 pp.

Smedley, S.C. 1952. Pink salmon in Prairie Creek, California. Calif. Fish and Game 38:272.

Smith, E.J., Jr. and R.F. Elwell. 1961. The effects of the Spencer-Franciscan, Jarbow, and DOS Rios alternative projects on the fisheries of the Middle Fork Eel River. Calif. Dept. Fish and Game, Memo. Rep. 96 pp.

Smith, G.R. 1966. Distribution and evolution of the North American catostomid fishes of the subgenus *Pantosteus,* genus *Catostomus.* University of Michigan Mus. Zool. Misc. Publ. 129:1-33.

Smith, G.R. and R.F. Stearley. 1989. The classification and scientific names of rainbow and cutthroat trouts. Fisheries (Bethesda) 14(1):4-10

Smith, J.J. 1982. Fishes of the Pajaro River system. University of Calif. Publ. Zool. 115:83-170.

Smith, J.J. 1987. Aquatic habitat and fish utilization of Pescadero, San Gregorio, Waddell, and Pomponio Creek estuary/lagoon systems. Report to Dept. of Biology, San Jose State University, San Jose, California, under Interagency Agreement 4-823-6004 with California Dept. of Parks and Recreation. 30 pp + figures.

Smith, S.B. 1960. A note on two stocks of steelhead trout *(Salmo gairdneri)* in Capilano River, British Columbia. J. Fish. Res. Board Can. 17:739-742.

Snyder, D.E. 1983. Identification of catostomid larvae in Pyramid Lake and the Truckee River, Nevada. Trans. Am. Fish. Soc. 112:333-348.

Snyder, J.O. 1905. Notes on the fishes of the streams flowing into San Francisco Bay. Rep. U.S. Bur. Fish. for 1904:327-338.

Snyder, J.O. 1908a. The fishes of the coastal streams of Oregon and northern California. Bull. U. S. Bur. Fish. 1907, 27:153-189.

Snyder, J.O. 1908b. Description of *Pantosteus santa-anae,* a new species of fish from the Santa Ana River, California. Proc. U.S. Natl. Mus. 59:23-28.

Snyder, J.O. 1908c. Relationships of the fish fauna of the lakes of southeastern Oregon, Bull. U.S. Bur. Fish. 27 (1907):69-102.

Snyder, J.O. 1908d. The fauna of the Russian River, California, and its relation to that of the Sacramento. Science, n.s., 27:269-271.

Snyder, J.O. 1913. The fishes of the streams tributary to Monterey Bay, California. Bull. U.S. Bur. Fish. 32 (1912):47-72.

Snyder, J.O. 1916. The fishes of the streams tributary to Tomales Bay, California. Bull. U.S. Bur. Fish. 34:375-381.

Snyder, J.O. 1917. Fishes of the Lahontan system of Nevada and northeastern California. Bull. U.S. Bur. Fish. 35:31-86.

Snyder, J.O. 1919. An account of some fishes from the Owens River, California. Proc. U.S. Nat. Hist. Mus. 54:297-299.

Snyder, J.O. 1931. Salmon of the Klamath River, California. Calif. Div. Fish and Game Fish Bull. 34: 130 pp.

Soltz, D.L. and R.J. Naiman. 1978. The natural history of native fishes in the Death Valley system. Nat. Hist. Mus., Los Angeles Co. Sci. Ser. 30:1-76.

Sopher, T.R. 1974. A trawl survey of the fishes of Arcata Bay, California. M.S. thesis. Humboldt State University, Arcata, California. 103 pp.

Soulé M. 1951. Power development of the Kings River drainage, Fresno County, California. Rep. No. 3., Junction development of the Kings River and its Middle and South Forks. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 51. 17 pp.

Stanley, S. E., P. B. Moyle, and H. B. Shaffer. 1995. Allozyme analysis of delta smelt, *Hypomesus transpacifcus,* and longfin smelt, *Spirinchus thaleichthys,* in the Sacramento-San Joaquin estuary, California. Copeia 1995: 390-396.

Stephens, S., D. Christensen, M. Lechner and H. Werner. 1995. Upper Kern Basin fishery management plan. California Department of Fish and Game, Sequoia National Forest and Sequoia National Park. 56 pp.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and Delta smelt in the Sacramento-San Joaquin river system. N. Am. J. Fish. Manage. 3:425-437.

Swift, C. 1965. Early development of the hitch, *Lavinia exilicauda,* of Clear Lake, California. Calif. Fish Game 51:74-80.

Swift, C.C. 1980. *Eucyclogobius newbrryi* (Girard), Tidewater goby. Page 788, In: D.S. Lee et al., eds., Atlas of North American Fishes. N. Carolina State Mus. Nat. Hist., Raleigh.

Swift, C.C., T. Haglund and M. Ruiz. 1990. Status of freshwater fishes of southern California with recommendations for preserves to maintain their existence. Report to Calif. Dept. Fish and Game, 217 p.

Swift, C.C., T. Haglund, M. Ruiz and R. Fisher. 1993. The status and distribution of the freshwater fishes of southern California. Bull. So. Calif. Acad. Sci. 92: 101-167.

Swift, C.C., J.L. Nelson, C. Maslow, and T. Stein. 1989. Biology and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces: Gobiidae) of California. Los Angeles Co. Museum of Nat. Hist. Contribs. in Science 404:1-19.

Taft, A.C. 1938. Pink salmon in California. Calif. Fish Game 24:197-198.

Taylor, F.R., R.R. Miller, J.W. Pedretti, and J.E. Deacon. 1988. Rediscovery of the Shoshone pupfish, *Cyprinodon nevadensis shoshone* (Cyprinodontidae), at Shoshone Springs, Inyo County, California. Bull. So. Calif. Acad. Sci. 87:67-73.

Taylor, F.R. and J.W. Pedretti. 1994. Morphometric comparison of pupfish populations, *(Cyprinodon nevadensis),* at Shoshone and Tecopa, California. Southwestern Naturalist 39(3):300-303.

Taylor, T.L., P.B. Moyle, and D.G. Price. 1982. Fishes of the Clear Lake Basin. University of California Publ. Zool. 115:171-224.

The Wilderness Society. 1993. The Living Landscape. Vol. 2. Pacific Salmon and Federal Lands. Washington, D.C. 111 pp.

Tres, J. 1992. Breeding biology of the arroyo chub, *Gila orcutti* (Pisces: Cyrpindae). Unpubl. M.S. Thesis, Calif. State Polytechnic Univ., Pomona. 73 pp.

Turner, B.J. and R.K. Liu. 1976. The subspecific identity of the introduced pupfish population at Zzyzx Spring, California. Copeia 1976:211-212.

Turner, J.L. 1966. Distribution of cyprinid fishes in the Sacramento-San Joaquin Delta. Pages 154-158, In: J.L. Turner and D.W. Kelley, eds., Ecological Studies of the Sacramento-San Joaquin Delta. Calif. Dept. Fish Game Fish Bull. 136.

U.S. Commission of Fish and Fisheries. 1892. Report to the Commissioner for 1888, Part XVI. Government Printing Office, Washington, D.C.

U.S. Department of the Interior. 1985. Klamath River Basin Fisheries Resource Plan. Prepared by CH2M Hill, Redding, California.

U.S. Fish and Wildlife Service. 1979. Klamath River fisheries investigations: Progress, problems and prospects. Annual Report, Arcata, California, Nov. 21, 1979, 49 p.

U.S. Fish and Wildlife Service. 1980-1991. Klamath River fisheries investigations, Annual Reports. Arcata, California.

U.S. Fish and Wildlife Service. 1991. Minutes of Southern California Steelhead Meeting, USFWS Office, Ventura, California, January 22, 1991. 9 pp.

U.S. Fish and Wildlife Service. 1992. Annual Report Fiscal Year 1992. Northern Central Valley Fishery Resource Office, Red Bluff, California. 19 pp.

U. S. Fish and Wildlife Service. 1994. Recovery plan for the Sacramento-San Joaquin native fishes. Technical draft. Portland, Or. 142 pp.

U.S. Heritage Conservation and Recreation Service. 1980. Final environmental impact statement. Proposed designation of five California rivers in the national wild and scenic rivers system. Vol. 1. 322 pp.

Vanicek, C.D. 1980. Decline of the Lake Greenhaven Sacramento perch population. Calif. Fish Game 66: 178-183.

Vigg, S. 1985. Gill-raker differentiation of the tui-chub in remnant Lahonton waters. In: E. Pister, Ed., Abst. Proc. Desert Fishes Council. Vol 13-25B.

Vincent, D.T. 1968. The influence of some environmental factors on the distribution of fishes in upper Klamath Lake, Oregon. Unpubl. M.S. thesis, Oregon State Univ., Corvallis.

Vladykov, V.D. 1973. *Lampetra pacifica,* a new nonparasitic species of lamprey (Petromyzontidae) from Oregon and California. J. Fish. Res. Board Can. 30:205-213.

Vladykov, V.D. and W.I. Follett. 1958. Redescription of *Lumpetra ayresii* (Gunther) of western North America, a species of lamprey (Petromyzonidae) distinct from *Lampetra fluviatilis* (Linnaeus) of Europe. J. Fish. Res. Board Can. 15:47-77.

Vladykov, V.D. and W.I. Follett. 1965. *Lampetra richardsoni,* a new nonparasitic species of lamprey (Petromyzontidae) from western North America. J. Fish. Res. Board Can. 22: 139-158.

Vladykov, V.D. and E. Kott. 1976a. A new nonparasitic species of lamprey of the Genus *Entosphenus* Gill, 1862, (Petromyzonidae) from south central California. Bull. South. Calif. Acad. Sci. 75:60-67.

Vladykov, V.D. and E. Kott. 1976b. A second nonparasitic species of *Entosphenus* Gill, 1862 (Petromyzonidae) from Klamath River System, California. Can. J. Zool. 54:974-989.

Vladykov, V.D. and E. Kott. 1979. A new parasitic species of the holarctic lamprey genus *Entosphenus* Gill, 1862 (Petromyzonidae) from Klamath River, in California and Oregon. Can. J. Zool. 57:808-823.

Vladykov, V.D. and E. Kott. 1984. A second record for California and additional morphological information on *Entosphenus hubbsi* Vladykov and Kott 1976 (Petromyzonidae). Calif. Fish Game 70:121-127.

Vogel, D.A. 1987a. Estimation of the 1986 spring chinook salmon run in Deer Creek, California. U.S. Fish and Wildl. Serv. Rep. No. FR1/FAO-87-3.

Vogel, D.A. 1987b. Estimation of the 1986 spring chinook salmon run in Mill Creek, California. U.S. Fish and Wildl. Serv. Rep. No. FR1/FAO-87-12.

Vogel, D.A. and K.R. Marine. 1991. Guide to upper Sacramento River chinook salmon life history. Report to U.S. Bureau of Reclamation, Central Valley Project. CH2M Hill, Inc., Redding, California. 55 pp.

Vondracek, B., D.M. Baltz, L.R. Brown, and P.B. Moyle. 1988. Spatial, seasonal, and diel distribution of fishes in a California reservoir dominated by native fishes. Fish. Res. 7:31-53.

Wainwright, D.L. 1965. The fisheries of Humboldt County from 1854 to 1892. [Excerpts from the Humboldt Times]. Humboldt Room Collection, Humboldt State University.

Waldvogel, J. 1988. Fall chinook salmon spawning escapement estimate for a tributary of the Smith River, California. Second Interim Report (1980-1989). University of California Cooperative Extension. USCGEP 88-5. 22 pp.

Wales, J.H. 1946. The hardhead problem in the Sacramento River above Shasta Lake, California. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 46. 4 pp.

Wang, J.C.S. 1982. Early life history and protection of the tidewater goby *Eucyclogobius newberryi:*(Girard) in the Rodeo Lagoon of the Golden Gate National Recreation Area. Tech. Rep. #7: National Park Service. Contribution No. CPSU/UCD 022/3.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Tech. Rep. 9.

Waples, R.S. 1991. Definition of "species" under the Endangered Species Act: application to Pacific salmon. NOAA Technical Memorandum NMFS F/NWC-194. March 1991. 29 pp.

Ward, D.L. and R.L. Fritzche. 1987. Comparison of meristic and morphometric characters among and within subspecies of the Sacramento sucker *(Catostomus occidentalis* Ayres). Calif. Fish, Game 73: 175-187.

Warner, G. 1991. Remember the San Joaquin. Pages 61-69, In: A. Lufkin, ed., California's salmon and steelhead: The struggle to restore an imperiled resource. University of California Press, Berkeley.

Weeks, H. 1992. Oregon sensitive, threatened and endangered fishes. Oregon Dept. Fish and Wildlife, Portland, 16 pp.

Wells, A.W., and J.S. Diana. 1975. Survey of the freshwater fishes and their habitats in the coastal drainages of southern California. Rep. submitted to Calif. Dept. Fish and Game, Inland Fish. Branch from the L.A. County Mus. Nat. Hist. 360 pp.

West, J.R. 1991. A proposed strategy to recover endemic spring-run chinook salmon populations and their habitats in the Klamath River Basin. Report submitted to U.S.D.A.-Forest Service Pacific Southwest Region, October, 1991. 25 pp.

Westlake, D.F. 1975. Macrophytes. Pages 106-128, In: B.A. Whitton, ed., River Ecology. University of California Press, Berkeley.

Williams, C.D., T.P. Hardy, and J.E. Deacon. 1982. Distribution and status of fishes of the Amargosa River Canyon, California. Unpubl. Rep. submitted to U.S. Fish and Wildl. Ser., Endangered Species Off., Sacramento, California. 115 pp.

Williams, J.E. and B.C. Bolster. 1989. Observation on Salt Creek pupfish mortality during a flash flood. Calif. Fish Game 75:57-59.

Williams, J.E. and D.W. Sada. 1985. Status of two endangered fishes, *Cyprinodon nevadensis mionectes* and *Rhinichthys osculus nevadensis,* from two springs in Ash Meadows, Nevada. Southwest. Nat. 30:475-484.

Williams, J.E. and CD. Williams. 1991. The Endangered Species Act and the Sacramento River winter chinook salmon. In: Lufkin, J.A.L., ed., California Salmon and Steelhead in the Environmental Age. University of Calif. Press, Berkeley.

Winter, B.D. 1987. Racial identification of juvenile summer and winter steelhead and resident rainbow trout *(Salmo gairdneri* Richardson). Calif. Dept. of Fish and Game, Inland Fish. Admin. Rep. No. 87-1.

Woefel, D. 1991. Steelhead of San Mateo Creek: reasons for decline and possibilities for recovery. MS. these at Calif. State University, Fullerton.

Wootton, R.J. 1976. The biology of sticklebacks. Academic Press, NY.

Wooton, R.J. 1984. A functional biology of sticklebacks. Croom Helm, London.

Wydoski, R.S. and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press, Seattle. 220 pp.