APPENDIX B

NATIVE AND INTRODUCED FISHES OF THE SAN JOAQUIN RIVER SUMMARY OF DISTRIBUTION, LIFE HISTORY, AND HABITAT REQUIREMENTS

Preface

The San Joaquin River was historically inhabited by a unique and diverse native fish community, and more recently by numerous non-native (introduced) species. A thorough description of all fish species is beyond the scope of this Background Report; however, we nevertheless felt it important to include many of the non-salmonid fish species that are frequently overlooked or de-emphasized in other restoration and management programs.

This appendix summarizes key aspects of 46 fish species that were historically present in the San Joaquin River study area, and potentially can be maintained in or restored to the San Joaquin River, as well as those non-native species presently in the San Joaquin River study area that will influence restoration strategies. This summary provides readers with an abbreviated description (generally one page) of the species' common and scientific names, legal status, historical and present distributions, life history, habitat requirements, ecological interactions, and key uncertainties. Some of this information was paraphrased, by generous permission of the author, from the recently revised and expanded book: *Inland Fishes of California* (Moyle 2002; University of California Press, Berkeley). Readers interested in more information than is provided in this appendix should consult this book. We also included information from other literature sources, particularly for the anadromous salmonid species, for which more expanded descriptions are provided.

Common Name	Scientific Name (family)
White sturgeon	*Acipenser transmontanus (*Acipenseridae)

Legal Status:

Federal None
State None

Distribution

White sturgeon have a marine distribution spanning from the Gulf of Alaska south to Ensenada, Mexico, but a spawning distribution ranging only from the Sacramento-San Joaquin basin northward. Currently, self-sustaining spawning populations are only known to occur in the Sacramento, Fraser, and Columbia Rivers. In California, primary abundance is in the San Francisco estuary with spawning occurring mainly in the Sacramento and Feather rivers. Spawning may occur in the San Joaquin River when flows and water quality permit. Landlocked populations are located above major dams in the Columbia River basin, and residual non-reproducing fish above the Shasta Dam can occasionally be found. In the ocean, white sturgeon have been known to migrate broad distances, but spend most of their life in brackish portions of large river estuaries.

Life History

Reports of maximum size and age of white sturgeon are as great as 6 m fork length (820 kg) and >100 yr, although they generally do not exceed 2 m fork length or 27 years of age. Males mature in 10-12 years (75-105 cm FL) and females in 12-16 years (95-135 cm FL). Maturation depends largely on temperature and photoperiod. Sturgeon migrates upstream when they are ready to spawn in response to increases of flow. Only a portion of the adult population spawns each year and is dependent on favorable conditions such as pulses of high flows, which appears to stimulate sizeable numbers of sturgeon to spawn. Because of this, successful year classes tend to occur at irregular intervals and therefore numbers of adult fish within a population can fluctuate significantly. Females are highly fecund, and average roughly 200,000 eggs each. Eggs become adhesive subsequent to fertilization, and adhere to the substrate until they hatch 4-12 days later depending on temperature. The yolk sac is absorbed within 7-10 days, at which time they are free to move about the estuary. White sturgeon are benthic feeders and juveniles consume mainly crustaceans, especially amphipods and opossum shrimp. Adult diets encompass mainly fish and estuarine invertebrates, the bulk of which is clams, crabs, and shrimps.

Habitat Requirements

White sturgeon primarily live in brackish portions of estuaries where they tend to concentrate in deep sections having soft substrate. They move according to salinity changes, and may swim into intertidal zones to feed at high tide. Juvenile sturgeon are often found in upper reaches of estuaries in comparison to adults, which suggests that there is a correlation between size and salinity tolerance. Spawning occurs over deep gravel riffles or in deep pools with swift currents and rock bottoms between late February and early June when temperatures are between 8-19°C.

Ecological Interactions

There are valuable commercial, sport, and Native American fisheries for white sturgeon in California. Although they may be vulnerable to overfishing, current management of this species is thought to allow for sustainable yield, and in addition white sturgeon are being cultured successfully. One other consequence of their life history is heightened bioaccumulation potential of toxic substances such as PCBs as well as selenium, which is thought to be passed on from the introduced overbite clam which is a favorite food of the sturgeon. Another possible hazard to these fish is alteration of estuary habitat, such as in the Sacramento-San Joaquin Delta, which may decrease successful spawning and rearing.

Key Uncertainties

The potential to restore white sturgeon populations using cultured juvenile white sturgeon is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Green sturgeon (Acipenseridae)	*Acipenser medirostris*

Legal Status:

Federal The status review by NMFS to determine whether or not *Acipenser medirostris* should be listed as a threatened or endangered species under the ESA is due June 2002. Upon completion of the review, NMFS is to publish its findings and make a ruling on the listing.

State Species of Special Concern

Distribution

Green sturgeon have been found from Mexico north to Canada, Russia (Commonwealth of Independent States), Korea, and Japan, although Asian populations are thought to belong to a separate species. In North America, green sturgeon reside in oceanic waters from the Bering Sea south to Ensenada, Mexico, and in rivers from British Columbia south to the Sacramento River. Historically spawning rivers included the San Joaquin, Fraser, Columbia, Umpqua, Eel, and South Fork Trinity Rivers, although they are currently only confirmed to spawn in the Sacramento, Klamath, Trinity, and Rogue Rivers.

Life History

Green sturgeon is anadromous, migrating from the ocean between March and July to spawn when temperatures are 8-14°C. Females produce 60,000-140,000 eggs that are broadcast in swift water and are then fertilized externally. Eggs hatch in about 8 days (at 12.7°C). Juveniles generally outmigrate in spring or autumn between years 1 and 3. At this time, they remain in close proximity to estuaries, and subsequently migrate far distances as they grow. Males tend to grow less and mature more rapidly than females, and consequently spend only 3 to 9 years at sea before returning whereas females spend 3 to 13 years. Mature fish are typically 15–20 years old. Juveniles are known to consume prey items including small fish and amphipods, while adults tend to eat sand lances, callianassid shrimp, anchovies, and clams.

Habitat Requirements

Green sturgeon probably have similar spawning and larval habitat requirements as white sturgeon. Green sturgeon have larger egg sizes and thinner chorions than white sturgeon eggs, suggesting that green sturgeon may require colder, cleaner water for spawning than white sturgeon. Spawning occurs in fast, deep (>3 m), water in substrates ranging from clean sand to bedrock, although large cobble is preferred. Small amounts of silt appear to increase egg survival by preventing eggs from adhering to each other.

Ecological Interactions

Green sturgeon in the Sacramento-San Joaquin are caught by anglers that are targeting white sturgeon. Green sturgeon are caught less frequently than white sturgeon and are therefore considered to be more rare.

Key Uncertainties

Due to low abundance, limited spawning distribution, and low sport and commercial fishing value, the ecology, population dynamics and life history of green sturgeon has not been well studied. Green sturgeon appear to be diminishing throughout their range. Effects of fisheries targeting this species are not understood, particularly in the Sacramento-San Joaquin and Klamath River drainages.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento sucker (Catostomidae)	*Catostomus occidentalis*

Legal Status:

Federal None
State None

Distribution

Sacramento suckers are common and have a wide distribution within central and northern California including streams and reservoirs of the Sacramento-San Joaquin drainage; on the coast in the Mad, Bear, Eel, Navarro, Russian, Pajaro, and Salinas Rivers, and in Lagunitas Creeks; and watercourses within and surrounding the Morro Bay drainage from water transfers. They are also likely to be distributed within southern California reservoirs that receive water from the California Aqueduct. Sacramento suckers can inhabit a wide array of habitats ranging from cool, high-velocity streams to warm sloughs to low-salinity portions of estuaries.

Life History

Sacramento suckers typically feed at nighttime on such items as algae, detritus, and small benthic invertebrates. Sucker growth is highly variable, and includes one specimen from Crystal Springs measuring 560 mm FL and 30 years of age. First spawning takes place during years 4-6, and typically takes place over gravel riffles during the months of February through June when temperatures are approximately 12-18°C. Females can spawn up to 7 years, and may produce between roughly 5,000-32,000 eggs/spawning period that adhere to gravel bits or pieces of detritus upon fertilization. After embryos hatch in 2-4 weeks, larvae remain in association with the substrate until they are swept into warm shallows or among flooded vegetation.

Habitat Requirements

Sacramento suckers are most commonly found in cold, clear streams and moderate elevation lakes and reservoirs. They chose microhabitat according to size, and typically move from shallow, low-velocity peripheral zones to areas of deeper water as they grow. They can tolerate a wide range of temperature fluctuations from streams that rarely exceed 15-16°C to those that reach up to 29-30°C. They have also been observed to have high salinity tolerances, and have been found living in reaches where salinities surpass 13 ppt. Due to their relatively high tolerances, Sacramento suckers have the ability to colonize new habitats readily.

Ecological Interactions

Sacramento suckers are generally associated with other native minnows such as Sacramento pikeminnows, hardhead, and California roach, but can also be common in watercourses dominated by nonnative fishes.

Key Uncertainties

The ecology of Sacramento suckers is poorly understood. They may play major ecological roles that include keystone species with impacts on invertebrate communities, and high-energy food resources for juvenile salmonids and trout.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento perch (Centrarchidae)	*Archoplites interruptus*

Legal Status:

Federal None
State Species of Special Concern

Distribution

The native range for the endemic Sacramento perch was throughout the Central Valley, the Pajaro and Salinas Rivers, and Clear Lake. Currently, they only reside in Clear Lake and Alameda Creek within their historical native distribution. Populations that presently occur outside of their native distribution within California include those in the upper Klamath basin and in the Cedar Creek, Mono Lake, Owens River and Walker River watersheds. They are typically found in reservoirs and farm ponds, and are frequently associated with beds of rooted, submerged, and emergent vegetation, but may also be abundant in shallow, highly turbid environments with no aquatic vegetation.

Life History

Growth rates are highly variable and are influenced by both biotic and abiotic factors. They can live over nine years, and in California have been known to exceed 1.5 kg. Breeding begins during their second or third year from March through early August. Fecundity varies with size, and can exceed 120,000 eggs/female. Males create nests out of shallow pits in substrate ranging from silt to gravel which they defend both prior and subsequent to fertilization, until larvae are able to leave the nest. After living for 1-2 weeks as planktonic larvae, young-of-the-year descend into aquatic vegetation or shallow areas. The type of prey consumed by Sacramento perch is dependant upon size, food availability, and time of year. Prey items include small crustaceans, copepods, insect pupae and larvae, other fish including their own young-of-the-year, planktonic and surface organisms, and aquatic insects.

Habitat Requirements

Sacramento perch can tolerate environmental conditions including high turbidity, temperatures up to 30°C, and elevated salinity and alkalinity concentrations. They can survive and also reproduce in salinities up to 17 ppt and in sodium-potassium carbonate concentrations of over 0.8 ppt. Young-of-the-year tend to inhabit shallow areas, and require moderately clear water containing aquatic plants.

Ecological Interactions

Sacramento perch are thought to be able to persist in their chosen habitats due to the absence of other centrarchids, especially black crappie and bluegill, which are usually excluded from these habitats due to high alkalinities or lack of introduction. When present, these nonnative species can successfully compete for food and space, and possibly prey on perch embryos and larvae. Decline of this species within their native range is assumed to be caused by such factors as interspecific competition, embryo predation, and habitat destruction, especially draining of lakes and sloughs and reduction of aquatic plant beds.

Key Uncertainties

Limited genetic lineage of populations may restrict their long-term survival potential. Reviews of their distribution and status are needed in order to be certain that they are being protected.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Prickly sculpin	*Cottus asper* (Cottidae)

Legal Status:

Federal None
State None

Distribution

Prickly sculpins residing on the coast can be found from the Kenai Peninsula, Alaska, down to the Ventura River in southern California. Within California, there are also inland Central Valley populations in low elevations of most streams up to Keswick Dam on the Sacramento River, and in the San Joaquin Valley south to the Kings River. They have also been spread to reservoirs and associated streams within southern California that receive water from the California Aqueduct. A separate form is also located in Clear Lake. Prickly sculpin can live in a multitude of environments that include fresh, brackish, and seawater, streams that range from small and cold to clear to large and warm and turbid, and lakes and reservoirs from small to large, and eutrophic to mesotrophic.

Life History

Growth of prickly sculpins can vary greatly, and it is possible they can exceed 200 cm SL and live >7 years. Maturity occurs during years 2-4, and spawning can last from February through June when water temperatures reach 8-13°C. During this period, sculpins will move into freshwater or intertidal reaches where males will dig nests by forming small hollows in the substrate underneath a rock. Depending on size, females will produce somewhere between about 300-11,000 eggs, and since males will mate with more than one female, up to 30,000 embryos can be found in one nest. Males protect the nest until embryos hatch. After hatching, larvae move down into large pools, lakes, and estuaries where they spend 3-5 weeks as planktonic fry. At this time, they begin to settle to the bottom, and start to move upstream or into shallow water of lakes or pools. The primary food items for prickly sculpins are large benthic invertebrates, but other aquatic insects, mollusks, isopods, amphipods, and small fish and frogs are also consumed.

Habitat Requirements

In the Central Valley, prickly sculpins are generally found in medium-sized, low-elevation streams with clear water and bottoms of mixed substrate and dispersed woody debris. The most vital habitat characteristic for sculpin residing in streams is probably the presence of cover such as rocks, logs, and overhanging vegetation. In the San Joaquin Valley, they are absent from warm, polluted areas, which suggests their distribution is regulated by water quality. In the area near Friant, prickly sculpins have been found in abundance in the cool flowing San Joaquin River, in the large, warm water Millerton Reservoir, and in the small, shallow Lost Lake where bottom temperatures exceed 26°C in the summer.

Ecological Interactions

Prickly sculpin have highly migratory life cycles, and because of this many populations have been eradicated or diminished due to the construction of barriers on streams.

Key Uncertainties

The degree of genetic isolation of prickly sculpin populations due to the effects of barriers is unknown.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Riffle sculpin	*Cottus gulosus* (Cottidae)

Legal Status:

Federal	None
State	None

Distribution

Riffle sculpin have a scattered distribution pattern throughout California that includes parts of the Sacramento-San Joaquin drainage, the San Francisco Bay Region, and coastal streams having historical connections to the Central Valley. They are also found in coastal streams from Puget Sound in Washington south to the Coquille River in Oregon. Their distribution indicates that they may have difficulties dispersing from one drainage to the next. They are most plentiful in undisturbed streams, especially headwaters or just below dams, where there are cold, permanent flows and an abundance of riffles and rocky substrates.

Life History

Riffle sculpins are benthic, opportunistic feeders. They grow mostly during the warmer months, and rarely exceed 100 mm total length. Maximum age is not well studied, but is probably no more that four years. Maturity takes place in their second year, and spawning occurs between February and April. Females can spawn >1000 eggs, which they deposit on the underside of rocks in swift riffles or inside cavities of submerged logs. Males guard the embryos, which hatch in 11-24 days, as well as yolk-sac fry. When fry reach approximately 6 mm total length, they begin a benthic existence.

Habitat Requirements

Riffle sculpin prefer habitats that are fairly shallow and have moderately swift water velocities. They can also live in small pools as long as they are cool and contain adequate cover. They select for areas where water temperatures do not surpass 25-26°C, as temperatures over 30°C are generally lethal. Riffle sculpin are restricted to flowing water due to their requirement of oxygen levels near saturation.

Ecological Interactions

Although they cannot easily disband to new locales, populations reductions through drought and toxic substance exposure can recover, albeit not quickly. Sculpin numbers can also be reduced when gold dredging practices destroy riffle habitats and loosen gravel utilized by the sculpin. Because they are so sensitive to degradation of water and habitat quality, their presence is generally a sign of a healthy salmonid habitat. Although they generally do not interact with salmonids due to niche separation, they will occasionally prey upon one another. Sculpin can be fairly aggressive toward other benthic fishes, such as speckled dace, and may feed upon or even displace them.

Key Uncertainties

Little is known about the effects of populations' isolation and the potential for local extirpation.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
California roach	*Lavinia symmetricus* (Cyprinidae)

Legal Status:

Federal None
State Species of Special Concern (Sacramento-San Joaquin roach subspecies)

Distribution

California roach were first described from a specimen found in the San Joaquin River near Friant. They are endemic to the Sacramento-San Joaquin Province and have distributions spanning the Sacramento-San Joaquin River drainage, including the Pit River and tributaries to Goose Lake. They also occur in coastal streams including the Navarro, Gualala, and Russian rivers, tributaries to Tomales Bay, Pescadero Creek, and several rivers within the Monterey Bay drainage. Introduced populations have been described in the Eel River, Soquel Creek, and the Cuyama River (although this population may be native). California roach are typically found in small tepid streams, and are most plentiful in mid-elevation streams in the foothills of the Sierras and lower portions of coastal streams.

Life History

California roach as old as 6 years have been reported but they usually seldom live longer than three years, and growth within this period is highly variable based on season and stream characteristics. Most growth occurs in early summer, and 120 mm standard length is rarely exceeded for these fish. Maturity occurs when these fish attain 45-60 mm standard length (2-3 years). Spawning is regulated by water temperatures, and occurs from March to July when 16°C is exceeded. Roach spawn in large aggregations in shallow areas where the dominant substrate is 3-5 cm gravel. Depending on their size, females will deposit from 250-2000 adhesive eggs within interstices of the substrate. Hatching takes place in 2-3 days, and fry remain in crevices until they are able to actively swim. Roach are omnivores and will digest such items as terrestrial insects, filamentous algae, aquatic insect larvae and adults, crustaceans, and detritus.

Habitat Requirements

California roach are found in a broad variety of habitats within their wide distribution. They can be found in extreme conditions such as those with high temperatures (30-35°C) and low dissolved oxygen (1-2 ppm) as well as cold, clear, and well–aerated conditions. They have been noted from headwaters to lower reaches, including the main channel and highly modified reaches. Roach are unable to tolerate high salinities; mortality has been noted in the Navarro River when tidal influence increased salinity to 9-10 ppm.

Ecological Interactions

The presence of predatory pikeminnow can force roach from the open waters of sizeable pools to shallow areas at the periphery of pools and riffles, and nonnative green sunfish and largemouth bass have the ability to totally exclude them from streams. Though the Sacramento-San Joaquin roach subspecies is abundant, it has been eliminated from certain areas where it traditionally occurred. Currently populations are often confined to reaches below barriers such as dams, diversions, and polluted waters containing predatory fishes, and are becoming increasingly more isolated. Additionally, much of their habitat is located within private lands where activities such as heightened grazing pressure leads to diminished stream flow and degraded habitat. Predatory fish are often introduced into remaining deep pools where roach can easily be eliminated.

Key Uncertainties

Although this subspecies is still abundant, has disappeared from a portion of its range, and has not had a comprehensive study of its status, systematics, and distribution. The suitability of streams in the Pit and San Joaquin River drainages that can be managed as refuges for local populations is not known.

Key References

Moyle (2002)

Common Name	Scientific Name (family)
Hardhead	*Mylopharodon conocephalus* (Cyprinidae)

Legal Status:

Federal none
State none

Distribution

Hardhead is endemic to the Sacramento-San Joaquin Province and occurs in sections of the larger low and mid-elevation streams of the Sacramento-San Joaquin drainage. They are largely absent from the lower Central Valley reaches. Hardhead are widely distributed in foothill streams and may be found in a few reservoirs such as the Redinger and Kerkhoff Reservoirs on the San Joaquin River, which are used for hydroelectric power generation. Their range extends from the Pit River system south to the Kern River. Hardhead also occur in the Russian River drainage.

Life History

Hardhead begin spawning at three years of age during the months of April and May. Spawning may continue through August. Fish in larger rivers or impoundments may migrate as far as 75 km to tributary streams for spawning. Spawning behavior is not known, however observed large aggregations during spawning season indicate behavior similar to hitch or pikeminnows. Females lay 7,000-24,000 eggs on gravel in riffles, runs or the heads of pools. The early life history of hardhead is not well known. Hardheads can reach 30 cm SL in 4-6 years in the larger rivers but rarely exceed 28 cm SL in the smaller streams. The maximum size for hardheads is believed to be around 1 meter TL and they may live more than 10 years. Adult hardhead are bottom-feeding omnivores in deep pools. Juveniles may take insects from the surface. Prey items may include insect larvae, snails, algae and aquatic plants, crayfish, and other large invertebrates.

Habitat Requirements

In the Central Valley, hardhead occupy the relatively undisturbed reaches of low and mid-elevation streams in the Sacramento-San Joaquin system. They also are known to occur in the mainstem Sacramento. Hardhead prefer water temperatures of above 20º C with optimal temperatures around 24-28º C. In the colder Pit River system they prefer the warmest available water where temperatures peak at 17-21ºC. Their distribution is limited to well-oxygenated streams and the surface water of impoundments. They are often found in clear deep pools (>80 cm) and runs with slower water velocities of 20-40 cm/s. Hardhead distribution in streams appears to be limited by their poor swimming ability in colder waters. Larvae and post larvae may occupy river edges or flooded habitat prior to seeking deeper low velocity habitat once they have grown larger.

Ecological Interactions

Hardhead are often absent from streams where introduced species such as centrarchids are established. They are also usually absent from streams that have been heavily altered by human activity. Hardhead decline appears to be associated with habitat loss and predation by non-native fishes. When present, hardhead are often found in association with Sacramento pikeminnow and Sacramento suckers which both have similar ecological requirements. Hardheads closely resemble the Sacramento pikeminnow but differ in the following in their morphology: the head is not as pointed and the body is deeper and heavier, the maxillary does not reach past the front margin of the eye, and a frenum, or small bridge of skin, connects the premaxillary bone, or upper lip, to the head.

Key Uncertainties

The decline of hardhead populations is similar to the decline of other native California fishes. Habitat alteration and predation by introduced species has adversely effected hardhead populations throughout their range. It is not known if hardhead populations can be stabilized. There are many information gaps in the life history and habitat requirements of hardheads. Spawning behavior has not been documented and early life history is poorly known.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Hitch	*Lavinia exilicauda exilicauda* (Cyprinidae)

Legal Status:

Federal None

State *L. exilicauda chi (*Clear Lake subspecies) is a Species of Special Concern.

Distribution

Hitch are endemic to the Sacramento – San Joaquin Province. There are three subspecies within this species: *L.e. chi* from Clear Lake, *L.e. harengus* from the Pajaro and Salinas drainages, and *L.e. exilicauda* from the Sacramento-San Joaquin drainage (Lee et al. 1980). In addition to these regions, hitch are native to the Russian River, and are also found in the San Francisco Bay region and the Monterey Bay region. Additionally, they have been introduced into reservoirs within their native range, and have subsequently been carried via the California Aqueduct to several other reservoirs.

Life History

Hitch generally live for 4-6 years, reaching an ultimate size of up to 350 mm fork length. Females grow larger and more rapidly than males, and growth is correlated with productivity and summer temperatures. Maturation can occur from years 1-3 for both sexes. Mass spawning migrations typically take place when flows increase from spring rains in locales such as rivers, sloughs, ponds, reservoirs, drainage ditches, and riffles of lake tributaries. Females will lay anywhere from 3,000-63,000 eggs which sink to gravel interstices where they swell to approximately four times their preliminary size and remain lodged within the substrate. Hatching occurs in 3-7 days (15-22°C) and larvae take another 3-4 days to emerge. When they reach adequate size, they move into perennial water bodies where they will shoal for several months in association with aquatic vegetation or other complex vegetation before moving into open water. Hitch are omnivorous and feed in open waters on filamentous algae, aquatic and terrestrial insects, zooplankton, aquatic insect pupae and larvae, and small planktonic crustaceans.

Habitat Requirements

Hitch occur in warm, low elevation lakes, sloughs, and slow-moving stretches of river, and in clear, low-gradient streams. Among native fishes, hitch have the highest temperature tolerances in the Central Valley. They can withstand high temperatures of up to 38°C, although they prefer temperatures of 27-29°C. Hitch also have moderate salinity tolerances, and can be found in environments with salinities up to 7-9 ppt. For spawning, hitch require clean, fine to medium gravel and temperatures of 14-18°C. When larvae and small juveniles move into shallow areas to shoal, they require vegetative refugia such as tule beds to avoid predators. Larger fish are often found in deep pools containing an abundance of aquatic and terrestrial cover.

Ecological Interactions

Hitch are declining in numbers, and some populations in streams of the San Joaquin Valley have recently become extirpated. Factors for decline include loss of adequate spawning flows due to dams and diversions, loss of summer rearing habitat, and predation by nonnative fishes. Besides piscine predators, hitch are preyed upon by avian predators, raccoons, mink, otter, and bears, especially during mass spawning migrations. In disturbed habitats, hitch are associated with introduced species such as catfish, centrarchids, and mosquitofish whereas they are linked with Sacramento perch, Sacramento blackfish, thicktail chub, and splittail in less disturbed locales. When Sacramento blackfish share their same habitat, the two species often hybridize as a consequence of having to share spawning areas.

Key Uncertainties

Little is known about the abundance, distribution, status and systematics of hitch

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento blackfish	*Orthodon microlepidotus*
(Cyprinidae)	

Legal Status:

Federal None
State None

Distribution

Sacramento blackfish are endemic to the Sacramento-San Joaquin Province. They are found primarily in central and southern California, being native to major tributaries and low elevation reaches of the San Joaquin and Sacramento Rivers, the Pajaro and Salinas Rivers, and Clear Lake. Although they were abundant in the (now exhausted) sizeable lakes of the San Joaquin Valley, they are currently common in sloughs and oxbow lakes of the Sacramento-San Joaquin Delta. They have also been identified in the Russian River, but it is currently unknown if they are native there. They occur in a few central California reservoirs (including Shasta, Alameda, and Lagoon Valley), the San Francisco Bay Delta, and several creeks within the Bay region. Additionally, they have been transported via the California Aqueduct to reservoirs receiving water from this source. They have also been introduced into the Lahontan Reservoir, and have consequently spread to lakes of Stillwater Marsh and the Humboldt River drainage.

Life History

Scale samples suggest that Sacramento blackfish live up to five years, although 7-9 years may be a better estimate based on inaccuracies associated with using scale samples to date cyprinids. They grow rapidly within their first and second years, in the third year females tend to fractionally surpass the males, and each year after growth rates diminish and seldom exceed 50 mm FL and 1.5 kg. Depending on environmental conditions, blackfish will mature within years 1-4, although males tend to mature sooner. Fecundity is correlated with size, and a single female can produce anywhere from about 14,700 to 346,500 eggs at lengths of 171 to 466 mm FL, respectively. Spawning occurs in shallow areas with dense aquatic vegetation between May and July when water temperatures range between 12-24°C. Fertilized eggs attach to substrate within this aquatic vegetation, and larvae are frequently found in similar shallow areas, although they have been noted in open water. Juvenile blackfish are often found in large schools within shallow areas associated with cover. Sacramento blackfish are generally suspension feeders on planktonic algae and zooplankton.

Habitat Requirements

Sacramento blackfish are frequently abundant in warm, typically turbid, and often highly modified habitats. They have been found in locations ranging from deep turbid pools with clay bottoms such as the Pajaro River to warm, shallow, seasonally highly alkaline, and greatly turbid environments such as the Lagoon Valley Reservoir. Blackfish have a remarkable ability to adapt to extreme environments such as high temperatures and low dissolved oxygen. Although optimal temperatures range from 22-28°C, adults can regularly be found in waters exceeding 30°C, and laboratory experiments have shown juveniles can survive in temperatures up to 37°C. Their ability to tolerate extreme conditions affords them survival during periods of drought or low flow.

Ecological Interactions

Through introductions and aqueduct linkage, blackfish have been and are continuing to be spread to a number of reservoirs and streams. At this time, consequences and possible impacts of this spread on other organisms is generally not known. In the Lahontan Reservoir, blackfish have replaced native tui chub as the most abundant species. When blackfish densities are elevated, algae blooms, increased nutrient levels, and other various lake ecosystem changes may occur as a result of selective consumption of algae-grazing zooplankton.

Key Uncertainties

Through introductions, Sacramento blackfish have spread to a number of water bodies within California, and their complete distribution is not currently known. In turn, their impact on organisms within these areas is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento pikeminnow	*Ptychocheilus grandis* (Cyprinidae)

Legal Status:

Federal none
State none

Distribution

Sacramento pikeminnow are endemic to the Sacramento-San-Joaquin Province and are native to creeks and rivers in the Sacramento-San Joaquin Rivers, the Pajaro and Salinas Rivers, the Russian River, the Clear Lake basin, and the upper Pit River. In the 1970s Sacramento pikeminnow were spread throughout the state through introductions and via the aqueduct system. They are now found in Chorro and Los Osos Creeks (tributaries to Morro Bay, San Luis Obispo County), southern California reservoirs, and Pillsbury Reservoir and the Eel River (Mendocino and Humboldt Counties).

Life History

Sacramento pikeminnow become sexually mature when they are 3-4 years old when they are 22-25 cm SL. Males mature before females. Sexually mature fish move upstream in April and May when water temperatures are 15-20ºC. Spawning occurs over gravel riffles or the base of pools in smaller tributaries. Spawning occurs at night and has not been well documented but is probably similar to the closely related northern pikeminnow (P. oregonensis). Males congregate and await females who swim by and attract a number of males. The female releases a small number of eggs close to the bottom during a number of passes and the males fertilize the eggs. Fertilized eggs sink and adhere to the gravel. The number of eggs a female carries is related to size. A female 31-65 cm SL can spawn 15,000-40,000 eggs. Eggs probably hatch in 4-7 days at 18ºC. In approximately one week, larvae form shoals and occupy shallow areas before moving to deeper water and dispersing. Pikeminnow are slow growing and may live longer than 12 years. The largest known specimen was 115 cm SL and weighed 14.5 kg and was captured near the Kings River, Fresno County. Prior to the introduction of larger predatory fish such as basses, pikeminnows may have been the apex predator in the Central Valley. Pikeminnow prey includes insects, crayfish, larval fish and fish, amphibians, lamprey ammocoetes, and occasionally small rodents. Pikeminnow larger than 150 mm SL are primarily piscivorous.

Habitat Requirements

Sacramento pikeminnow prefer intermittent and permanent rivers and streams in low to mid-elevation areas with clear water, deep pools, slow runs, undercut banks, and vegetation. They do not prefer turbid or polluted water or areas where centrarchids have become established. Sacramento pikeminnow prefer summer water temperatures above 15ºC with a maximum of 26ºC. Temperatures above 38ºC are usually lethal. Pikeminnow can tolerate salinities as high as 8 ppt but are rarely found in waters above 5 ppt.

Ecological Interactions

Sacramento pikeminnow prefer vegetated reaches of streams that are relatively undisturbed. In these types of habitats they are usually associated with other native fish species such as hardhead and Sacramento sucker. They are usually absent where centrarchid basses have become established. Pikeminnow may have adverse impacts on salmonids under some conditions. They opportunistically prey on juvenile salmonids in the Eel River, where pikeminnow were introduced, and in locations in the Sacramento River, where dams and diversions have altered natural habitat conditions, including flows. Sacramento pikeminnow have gained an undeservedly bad reputation due to their predatory nature. Pikeminnow have been implicated for predation on juvenile salmon and affecting their population numbers in the Central Valley system. Both species naturally occur there. Where habitat has been altered, such as the Red Bluff Diversion dam, both salmon and pikeminnow migrations have been delayed, which resulted in large pikeminnow adults preying on outmigrating juvenile salmonids. Efforts to improve fish passage reduced predation and improved the situation. In many instances, pikeminnow populations have suffered due to introduced predator species and adverse affects from altered habitat.

Key Uncertainties

Sacramento pikeminnow spawning behavior and early life history has not been well documented.

Key References

Moyle 2002; Lee et al. 1980

Common Name	Scientific Name (family)
Speckled dace	*Rhinichthys osculus* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Speckled dace are native to all major western drainage systems from Canada south to Sonora, Mexico. They are widely distributed throughout many portions of California, though do not occur in most small coastal drainages and various other drainages and watercourses including the San Joaquin drainage, Clear Lake basin, Russian River, and Cosumnes River drainage. Dace are typically considered second or third order stream specialists, although they are known to occupy a variety of habitats such as springs, high velocity brooks, pools in intermittent streams, higher order streams, and deep lakes. In some watersheds, however, speckled dace are potentially limited to small areas of suitable habitat, which may lead to extinction of these isolated populations.

Life History

Speckled dace generally live no longer than three years, and seldom exceed 85 mm FL. Depending on environmental factors, population density, and food availability, speckled dace tend to grow 20-30 mm FL in their first year, and 10-15 mm in years thereafter; females growing marginally faster than males. Maturation generally occurs in their second summer, and spawning generally occurs in the months of June and July. Females have been documented to spawn between roughly 200-800 eggs within crevices of gravel substrate where they adhere. Hatching occurs in about 6 days (at 18-19°C), after which larval fish will remain in the interstices for 7-8 days. Upon emergence, fry tend to seek warm shallow reaches associated with cover. Speckled dace are specialized to feed on small, benthic invertebrates living in riffles, but will also consume zooplankton and large terrestrial insects.

Habitat Requirements

Though speckled dace can occupy a wide variety of habitats, they each tend to have similar characteristics including clear, moving, well-oxygenated water, and plentiful deep cover such as submerged and overhanging vegetation, woody debris, and rocks. They prefer shallow (<60 cm) and rocky riffles and runs, and may actually be more abundant in channelized streams or those with reduced flows due to an increased quantity of preferred habitat. Certain populations of dace are tolerant of periodic extreme temperatures ranging from 0 to >31°C, and dissolved oxygen levels as low as 1 ppm. If threshold levels are exceeded and local populations are eliminated or seriously depressed, dace have an extraordinary ability to recolonize and repopulate areas.

Ecological Interactions

Speckled dace tend to be more abundant in reaches where sculpin are absent due to overlapping food niches. They also display avoidance behavior in response to avian predators, oftentimes being more nocturnally active. When avian predators are scarce, populations may be active during the day as well. Dace may also not be able to persist when there is an overabundance of nonnative predators. During spawning, dace may hybridize with Lahontan redside because they can spawn at the same time and place.

Key Uncertainties

Speckled dace may be present in headwaters of tributaries on the west side of the San Joaquin Valley but their presence has not been confirmed.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Sacramento splittail	*Pogonichthys macrolepidotus* (Cyprinidae)

Legal Status:

Federal Threatened (listed February 1999)
State Species of Special Concern

Distribution

Sacramento splittail are endemic to the Sacramento and San Joaquin river systems of California, including the waters of the Sacramento-San Joaquin Delta and the San Francisco Estuary. Historically, splittail were found in the Sacramento River as far upstream as Redding, in the Feather River to Oroville, and in the American River upstream to Folsom. In the San Joaquin River they were once documented as far upstream as Friant (Rutter 1908, as cited in Moyle 2002). Splittail are thought to have originally ranged throughout the San Francisco Estuary, with catches reported by Snyder (1905, as cited in Moyle 2002) from southern San Francisco Bay and at the mouth of Coyote Creek.

In wet years Sacramento splittail have been found in the San Joaquin River as far upstream as Salt Slough (Baxter 2000, Baxter 1999, Brown and Moyle 1993, all as cited in Moyle 2002, Saiki 1984) and in the Tuolumne River as far upstream as Modesto (T. Ford, Turlock Irrigation District, pers. comm. 1998, as cited in Moyle 2002), where the presence of both adults and juveniles during wet years in the 1980s and 1990s indicated successful spawning.

When spawning, splittail can be found in the lower reaches of rivers and flooded areas. Otherwise they are primarily confined to the Delta, Suisun Bay, Suisun Marsh, the lower Napa River, the lower Petaluma River, and other parts of the San Francisco Estuary (Meng and Moyle 1995, Meng et al. 1994, as cited in Moyle 2002). In general, splittail are most abundant in Suisun Marsh, especially in drier years (Meng and Moyle 1995), and reportedly rare in southern San Francisco Bay (Leidy 1984). Splittail abundance appears to be highest in the northern and western Delta when population levels are low, and they are somewhat more evenly distributed throughout the Delta during successful year classes (Sommer et al. 1997, Turner 1966, both as cited in Moyle 2002).

Splittail are largely absent from the upper river reaches where they formerly occurred, residing primarily in the lower parts of the Sacramento and San Joaquin rivers and tributaries and in some Central Valley lakes and sloughs (Moyle 2002, Moyle et al. 2001). In wet years, however, they have been known to ascend the Sacramento River as far as Red Bluff Diversion Dam and into the lower Feather and American rivers (Baxter 2000, Baxter 1999, Baxter et al.1996, Sommer et al. 1997, all as cited in Moyle 2002). Currently the Sutter and Yolo bypasses along the lower Sacramento River appear to be important splittail spawning areas (Sommer et al. 1997). Splittail now migrate into the San Joaquin River only during wet years, and use of the Sacramento River and its tributaries is likely more important (Moyle 2002).

Accounts of early fisheries suggested that splittail had large seasonal migrations (Walford 1931, as cited in Moyle et al. 2001). Splittail migration now appears closely tied to river outflow. In wet years with increased river flow, adult splittail will still move long distances upstream to spawn, allowing juvenile rearing in upstream habitats. The upstream migration is smaller during dry years, although larvae and juveniles are often found upstream of the city of Sacramento to Colusa or Ord Bend on the Sacramento River (Moyle et al. 2001). Currently the tidal upper estuary, including Suisun Bay, provides most juvenile rearing habitat, although young-of-the-year may rear over a broader area, including the lower Sacramento River. Brackish water apparently provides optimal rearing habitat for splittail.

Life History

Adult splittail move upstream beginning in late November to late January, foraging in flooded areas along the main rivers, bypasses, and tidal freshwater marsh areas of Montezuma and Suisun sloughs and San Pablo Bay prior to the onset of spawning (Moyle et al. 2001). Feeding in flooded riparian areas prior to spawning may contribute to spawning success and survival of adults after spawning (Moyle et al. 2001). Splittail are adapted to the wet-dry climatic cycles of northern California, and thus appear to concentrate their reproductive effort in wet years when potential success is greatly enhanced by the availability of inundated floodplain (Meng and Moyle 1995, Sommer et al. 1997). Splittail are thought to be fractional spawners, with individuals spawning over a protracted period—often as long as several months (Wang 1995, as cited in Moyle 2002). Older fish are believed to begin spawning first (Caywood 1974, as cited in Moyle 2002).

Larger females may lay 100,000 eggs. Splittail eggs, which are 0.4–0.6 inches (1.0–1.6 mm) in diameter (Wang 1986, Feyrer and Baxter 1998, both as cited in Moyle 2002), begin to hatch within 3–7 days, depending on temperature (Bailey et al. 2000, as cited in Moyle 2002). Eggs laid in clumps hatch more quickly than individual eggs (Moyle et al. 2001). Within 5–7 days after hatching, swim bladder inflation occurs and larvae begin active swimming and feeding (Moyle 2002). Larval splittail reared in captivity reach 0.4 inches (10–11 mm) within 15 days following hatching (Bailey et al. 1999, as cited in Moyle et al. 2001).

The adhesive eggs are released by the female, fertilized by one or more attendant males, and adhere to vegetation until hatching (Moyle 2002). Females are typically highly fecund, with the largest individuals potentially producing 100,000 or more eggs (Daniels and Moyle 1983, Feyrer and Baxter 1998, both as cited in Moyle 2002). Fecundity has been found to be highly variable, however, and may be influenced by food supplies in the year prior to spawning (Moyle et al. 2001). Little is known regarding the tolerance of splittail eggs and developing larvae to dissolved oxygen, temperature, pH, or other water quality parameters, or to other factors such as physical disturbance or desiccation.

After emergence, most larval splittail remain in flooded riparian areas for 10–14 days, most likely feeding among submerged vegetation before moving off floodplains into deeper water as they become stronger swimmers (Sommer et al. 1997, Wang 1986, both as cited in Moyle 2002). Although juvenile splittail are known to rear in upstream areas for a year or more (Baxter 1999, as cited in Moyle et al. 2001), most move to tidal waters after only a few weeks, often in response to flow pulses (Moyle et al. 2001). The majority of juveniles apparently move downstream into shallow, productive bay and estuarine waters from April–August (Meng and Moyle 1995, as cited in Moyle 2002). Growth is likely dependent on the availability of high-quality food, especially in the first year of life (Moyle et al. 2001).

Non-breeding splittail are found in temperatures ranging from 5 to 24°C (41–75° F), depending on the season, and acclimated fish can survive temperatures up to 33°C (91° F) for short periods (Young and Cech 1996, as cited in Moyle 2002). Juveniles and adult splittail demonstrate optimal growth at 20º C (68° F), and signs of physiological distress only above 29ºC (84° F) (Young and Cech 1995 as cited in Winternitz and Wadsworth 1997).

Because splittail are adapted for living in brackish waters with fluctuating conditions, they are quite tolerant of high salinities and low dissolved oxygen levels. Splittail are often found in salinities of 10–18 ppt, although lower salinities may be preferred (Meng and Moyle 1995, as cited in Moyle 2002), and can survive low dissolved oxygen levels (0.6–1.2 mg/L for young-of-the-year, juveniles, and subadults) (Young and Cech 1995, 1996). Because splittail have a high tolerance for variable environmental conditions (Young and Cech 1996), and are generally opportunistic feeders (prey includes mysid shrimp, clams, copepods, amphipods, and some terrestrial invertebrates), reduced prey abundance will not likely have major population-level impacts. Year class success appears dependent on access and availability of floodplain spawning and rearing habitats, high outflow, and wet years (Sommer et al. 1997).

Habitat Requirements

Rising flows appear to be the major trigger for splittail spawning, but increases in water temperature and day length may also be factors (Moyle et al. 2001). Spawning typically takes place on inundated floodplains from February through June, with peak spawning in March and April. Available information indicates that splittail spawn in open areas with moving, turbid water less than 5 feet (1.5 meters) deep, amongst dense annual vegetation and where water temperatures are less than about 59°F (15°C) (Moyle et al. 2001). Perhaps the most important spawning habitat in the eastern Delta is the Cosumnes River floodplain, where ripe splittail have been observed in flooded fields with cool temperatures (<59° F [15° C]), turbid water, and submerged terrestrial vegetation (Moyle, Crain, and Whitener, unpublished data, as cited in Moyle et al. 2001).

Splittail eggs are deposited in flooded areas amongst submerged vegetation, to which they adhere until hatching. Juveniles are strong swimmers and are usually found in shallow (<2 m [6.6 ft] deep), turbid water (Young and Cech 1996). As their swimming ability increases, juveniles move away from the shallow areas near spawning sites into faster, deeper water (Moyle 2002). Floodplain habitat offers high food quality and production and low predator densities to increase juvenile growth.

The following is a review of the scientific literature to select habitat criteria for each Sacramento splittail life history stage, focusing as much as possible on relevance to the Sacramento River.

Table 1. Life history stage criteria for splittail.

Criteria	Adult Up-Migration and Spawning	Egg/Alevin Rearing	Juvenile Rearing	Adult
Water Temperature (°C)	Increase to 14–19°C may trigger spawning[(a)]; spawn where water is < 15°C[(c)]	≤ 18.5°C[(c,e)]	7–28°C; but 21–25°C preferred[(d)]	7–24°C[(a,d)]; but 19°C preferred[(d)]
Water Salinity (ppt)	≤ 18 ppt[(b)]		< 16 ppt[(d)]	10–18 ppt, but prefer lower[(b)]; can briefly tolerate up to 29 ppt[(d)]
Water Depth (cm)	50–200 cm for spawning[(a)]		< 200 cm[(a)]	<400 cm[(c)]
Water Velocity			tidal currents[(a)]	slow moving[(a)]
Substrate	spawn on floodplains with flooded vegetation[(a)]	floodplains with flooded vegetation	variable—may prefer soft bottoms with fine substrate and emergent vegetation[(a,b)]	variable—may prefer soft bottoms with fine substrate and emergent vegetation[(a,b)]

Sources:

a Moyle 2002
b Meng and Moyle 1995
c Moyle et al. 2001
d Young and Cech 1996
e Bailey et al. 2000, as cited in Moyle 2002

Ecological Interactions

Human activities, such as extensive dam construction, water diversions, channelization, and agricultural drainage, have resulted in splittail disappearing as permanent residents from portions of the Sacramento and San Joaquin valleys. Much of the lowland habitat that they once occupied has been altered so that it is now inaccessible except during wet years.

The USFWS listed Sacramento splittail as a threatened species in February 1999 because of the reduction in its historical range and because of the large population decline during the drought of 1987–1993 (Moyle et al. 1995, USFWS 1996, USFWS 1999, all as cited in Moyle 2002). The CDFG (1992) estimates that splittail during most years are only 35–60 percent as abundant as they were in 1940. CDFG midwater trawl data indicate considerable fluctuations in splittail numbers since the mid-1960s, with abundance often tracking river and Delta outflow conditions. The overall trends include a decline from the mid-1960s to the late 1970s, somewhat of a resurgence through the mid-1980s, and another decline from the mid-1980s through 1994 (Moyle 2002). In 1995 and 1998 the population increased dramatically, demonstrating the extreme short-term and long-term variability of splittail recruitment success and the apparent correlation with river outflow (Sommer et al. 1997). Outflow in February–May can explain between 55 percent and 69 percent of the variability in abundance of splittail young, depending on the abundance measure. Age-0 abundance of splittail declined in the estuary during most dry years, particularly in the drought that began in 1987 (Sommer et al. 1997). Not all wet years result in high splittail recruitment, however, since recruitment success is largely dependent on the availability of flooded spawning habitat. In 1996, for example, most high river flows occurred in December and January, prior to the onset of the splittail spawning season (Moyle 2002). Splittail are preyed upon by striped bass and other piscivores.

In summary, the long-term decline of splittail is due to the following factors, in order of importance: 1) reduction in valley floor habitats, 2) modification of spawning habitat, 3) changed estuarine hydraulics, especially reduced outflows, 4) climatic variation, 5) toxic substances, 6) introduced species, 7) fishing exploitation.

Key Uncertainties

A variety of surveys have compiled splittail abundance data. None of these, however, was specifically designed to systematically sample splittail abundance, and definitive conclusions are therefore not possible (Moyle et al. 2001). Combined, the survey data indicate that some successful reproduction occurs on a yearly basis, but large numbers of juvenile splittail are produced only when outflow is relatively high. Thus the majority of adult fish in the population probably result from spawning in wet years (Moyle et al. 2001). The stock-recruitment relationship in splittail is apparently weak, indicating that given the right environmental conditions a small number of large females can produce many young (Sommer et al. 1997, Meng and Moyle 1995, both as cited in Moyle 2002).

The effects of pesticides and other toxics on splittail are not known but are considered to be potentially negative. The effects of introduced species on splittail are poorly understood, although it is recognized that changes in the food web are likely to have negative consequences.

Key References

Bailey, H. C., E. Hallen, T. Hampson, M. Emanuel and B.S. Washburn. 2000. Characterization of reproductive status and spawning and rearing conditions for splittail *Pogonichthys macrolpeidotus*, a cyprinid of Special Concern, endemic to the Sacramento-San Joaquin estuary. Unpublished manuscript, University of California, Davis.

Common Name	**Scientific Name (family)**
Thicktail chub	*Gila crassicauda* (Cyprinidae)

Legal Status:

Federal	None
State	SE 01-10-74. Delisted 10-02-80 (EXTINCT)

Distribution

Thicktail chub are endemic to the Sacramento-San Joaquin Province. Historical distribution was in lowland areas of the Central Valley, Clear Lake, the Pajaro and Salinas Rivers, and in tributaries to the San Francisco Bay. The species is now extinct. It is assumed that thicktail chub became extinct due to their inability to adapt to extreme modifications of valley floor habitats, especially removal of tule beds, drainage of large shallow lakes, reduction in stream flows, and modification of stream channels. Another important source of their demise was the introduction of exotic predators, especially striped and largemouth bass.

Life History

Based on morphology, it is likely that thicktail chubs were carnivorous and probably fed on small fish and large aquatic invertebrates.

Habitat Requirements

Thicktail chubs were abundant in lowland lakes, sloughs, and slow-moving sections of rivers.

Ecological Interactions

Thicktail chubs were able to hybridize with hitch, and were part of the original valley floor fish assemblage that included hitch, Sacramento sucker, Sacramento blackfish, Sacramento perch, and tule perch.

Key Uncertainties

Little is known about this extinct species.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Tule perch	*Hysterocarpus traski traski* (Embiotocidae)

Legal Status:

Federal None

State Russian River Tule Perch (Hysterocarpus traski pomo) is listed as a Species of Special Concern.

Distribution

Historically the endemic Sacramento-San Joaquin subspecies of tule perch was widespread throughout the lowland rivers and creeks in the Central Valley. Currently in the San Joaquin drainage they occur in the Stanislaus River, occasionally in the San Joaquin River near the Delta, and the lower Tuolumne River. The other subspecies are *H. t. pomo* in the Russian River and its lower tributaries and *H. t. lagunae* in Clear Lake. In addition, tule perch have been carried via the California Aqueduct to Silverwood and Pyramid Reservoirs in southern California. They can be found in a number of lowland habitats including lakes, estuarine sloughs, and clear streams and rivers.

Life History

Tule perch generally search on the bottom or within aquatic plants for food items, but will also feed midwater. They are primarily adapted to feed on small invertebrates and zooplankton and have been observed to ingest small amphipods, midge and mayfly larvae, small clams, brachyuran crabs, mysid shrimp. Principal growth occurs within the first year, and a maximum length of 20 cm standard length is rarely exceeded. They can live for up to 7-8 years, but more often do not survive past 5 years. Age at first maturity varies with environment, and number of young produced varies with size of the female. Females mate multiple times between July and September, and sperm is stored until January when fertilization occurs. Young develop within the female, and are born in June or July when food is most abundant. Juveniles begin to school soon after birth.

Habitat Requirements

Tule perch inhabiting rivers can usually be found within beds of emergent plants, in deep pools, and near banks with complex cover. They require cool, well-oxygenated water for their persistence, and tend not to be found in water exceeding 25°C for extended periods. They have a remarkable capability to tolerate high salinities, and can even persist at salinities of >30 ppt.

Ecological Interactions

Tule perch that reside in lakes are commonly associated with bluegill and other alien centrarchids, but in streams they are associated primarily with other native fishes. They tend to not be found in environments dominated by exotic fishes, but this appears to be a result of poor water quality. The fact that they are viviparous lowers their vulnerability to competition and predation by nonnative fishes. Poor water quality and toxic chemical exposure seem to be responsible for their extirpation from the Pajaro and Salinas Rivers, a majority of the San Joaquin basin, and various other smaller streams. They are rare in areas that have been greatly anthropogenically modified.

Key Uncertainties

Tule perch appear to have been extirpated from most of the San Joaquin basin, but the exact causes are not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Threespine stickleback	*Gasterosteus aculeatus* (Gasterosteidae)

Legal Status:

Federal *G. a. williamsoni* is listed as endangered (10-13-70), *G. a. aculeatus* and *G.a. microcephalus* have no federal listing. Critical habitat was proposed for *G.a. williamsoni* 11-17-80.

State *G. a. williamsoni* is listed as endangered (06-27-71), *G. a. aculeatus* and *G.a. microcephalus* have no state listing.

Distribution

Threespine stickleback populations are distributed in North America from the East Coast southward to Chesapeake Bay, and from the West Coast southward as far as Baja California. They have resident, anadromous, and unarmored subspecies, and are found in coastal streams, estuaries, and bays. In California, anadromous populations are present from the Oregon border south to Monterey Bay, while fully plated nonmigratory populations can occur southward as far as San Luis Obispo Creek. In the Central Valley, populations may be found from the lower Kings River to approximately Redding in the Sacramento River drainage, including the San Joaquin River where they are present below Friant Dam as well as a small stream above Kerckoff Reservoir. Unarmored threespine sticklebacks are presently only found naturally in the upper Santa Clara River, San Antonio Creek, and Whitewater River.

Life History

Though the majority of threespine sticklebacks complete their life cycle within one year, there is evidence that they have the potential to survive for up to two or three years. In California, resident populations rarely exceed 50 mm TL whereas anadromous populations typically reach 80 mm TL. Often females are larger than males. All forms of threespine stickleback breed in freshwater from April through July when daylight hours and water temperature increase, although anadromous forms tend to spawn earlier. Males construct nests out of algae, aquatic vegetation, and a sticky kidney secretion in which females will lay 50-300 eggs over several spawning periods. Males are responsible for protection and maintenance of the embryos, which hatch in 6-8 days at 18-20°C. Upon hatch, fry remain in the nest for several days while being cared for by the male, until they begin to swim in shoals.

Habitat Requirements

Preferred habitat for threespine sticklebacks includes calm-water shallow pools and backwaters containing vegetation, or associated with emergent plants at stream edges located above gravel, sand, and mud. A major requirement for this species is water clarity that is great enough to allow growth of aquatic plants used for building nests. Water clarity is also important due to the fact that they are visual feeders. Anadromous forms are typically pelagic, and tend to stay close to shore. This species generally requires cool water (<23-24°C) for long-term survival, and have broad salinity tolerances. Unless breeding, they shoal to more readily locate prey that consists of bottom-dwelling organisms, or those living in aquatic vegetation.

Ecological Interactions

Although these fish have spines and bony plates for armor and protection, the combination of small size, sluggish motion, and shallow-water preference make them an ideal prey for both avian and piscine predators. The distribution of this species is largely determined by predation pressure; when predation is high, they will most likely be found in association with dense aquatic vegetation. They are considered an important prey item of salmonids, and it has been suggested that within Central Valley river systems, pikeminnow predation can eliminate sticklebacks. They act as a host for intermediate stages of bird tapeworm that causes the infected fish to turn white and swim slowly at the surface, increasing vulnerability to kingfishers and herons that then become the final hosts.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Kern brook lamprey	*Lampetra hubbsi* (Petromyzontidae)

Legal Status

Federal None
State Species of Special Concern

Distribution

Kern brook lamprey are endemic to the east portion of the San Joaquin Valley, and were first collected in the Friant-Kern Canal. They have subsequently been found in the lower Merced, Kaweah, Kings, and San Joaquin Rivers. They are generally found in silty backwaters of rivers stemming from the Sierra foothills.

Life History

It is thought that this species undergoes metamorphosis in autumn, spawns in spring, and dies thereafter. Not much else is known about Kern brook lamprey, but they presumably have similar life histories to western brook lamprey.

Habitat Requirements

Ammocoetes are typically found in low-velocity portions of shallow pools and along edges of runs. They prefer habitats with substrates of mud and sand, depths of 30-110 cm, and summer temperatures that do not exceed 25°C. Ammocoetes are often intermittently abundant in the siphons of the Friant-Kern Canal because this area meets the majority of habitat requirements. Adults tend to prefer riffles containing gravel for spawning, and rubble for cover.

Key Uncertainties

There is uncertainty about the potential for extirpation of populations within the San Joaquin drainage because they are largely isolated with most populations found below dams where flow regulation typically does not address lamprey needs. The effects of channelization, work on banks, and elimination or compaction of gravel beds from various management practices on habitats required by Kern brook lamprey are not well understood.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Pacific lamprey (Petromyzontidae)	*Lampetra tridentata*

Legal Status:

Federal None
State None

Distribution

Pacific lampreys are anadromous fish that have Pacific coast distributions in streams from Hokkaido, Japan, through Alaska, and down to Rio Santo Domingo in Baja, California, although their distribution south of San Luis Obispo is intermittent. There are also landlocked populations from the Upper Klamath River, Goose Lake, and Clair Engle Reservoir on the Trinity River. Anadromous forms spend the predatory portion of their life in the ocean, and move into streams to spawn, while resident forms will spend this portion of their life in lakes and reservoirs before moving into spawning streams.

Life History

Depending on their location, lamprey will begin upstream migrations anywhere between January and September, and may spend up to a year maturing in freshwater until they are ready to spawn. Upstream migration seems to largely take place in response to high flows, and adults can move substantial distances unless blocked by major barriers such as the Friant Dam on the San Joaquin River. When they are ready to spawn both sexes will work together to build a nest. Females can produce 20,000-200,000 eggs that are released onto the gravel where they will adhere upon fertilization. Lamprey will typically die soon after spawning, though this is not always the case. Hatching occurs in approximately 19 days (at 15°C), and after spending a short period in the gravel, ammocoetes will move up into the current where they are swept downstream to an area with soft substrate where they bury themselves and filter feed on organic materials covering the substrate. Ammocoetes will move about, but will remain in this state for 5-7 years before beginning morphological changes enabling them to move into the ocean. When transformation is complete, downstream migration will take place during high flow events.

Habitat Requirements

Nests are typically built in gravel-sized substrate, where water velocity is fairly rapid, depths are 30-150 cm, and water temperatures are generally 12-18°C. Ammocoetes occur in areas with soft substrate.

Ecological Interactions

While in their predatory phase, lamprey attack a multitude of fishes, including salmon and flatfishes in the ocean, and tui chub, suckers, and redband trout in lakes and reservoirs. Overall, their effect on fish populations is considered to be minimal. They are at times, prey of other organisms such as sharks and sea lions. Highly altered or polluted streams will often exclude Pacific lamprey from inhabiting an area.

Key Uncertainties

Little is known about the status and biology of this species, in particular if multiple spawning runs exist in some rivers as well as where landlocked forms exist.

Key References

Moyle (2002)

Common Name	Scientific Name (family)
River lamprey	*Lampetra ayresi* (Petromyzontidae)

Legal Status:

Federal None
State Species of Special Concern

Distribution

River lampreys can be found in large coastal streams from roughly Juneau, Alaska to the San Francisco Bay. From what is known about this species, the region of primary abundance in California is in the lower Sacramento-San Joaquin drainage, especially the Stanislaus and Tuolumne Rivers. They are additionally present in Sonoma, Salmon, and Alameda Creeks, the Napa River, tributaries to the lower Russian River, and possibly the Eel River. Outside of California, their distributions are isolated and greatly scattered.

Life History

Spawning migrations occur in autumn, and spawning takes place in streams from February through May. One study in Cache Creek found females with fecundities of 11,400 to 37,300 eggs. After spawning, adults will die. After hatching, ammocoetes are hypothesized to spend 3-5 years in this stage before metamorphosis into adults. This transformation begins in the summer, and takes 9-10 months to complete. These lampreys will then enter the ocean at the end of spring where they spend 3-4 months. During this period, they will display rapid growth while feeding on a variety of fishes such as herring and salmon.

Habitat Requirements

Nests are created by formation of depressions in gravel riffles. Ammocoates occur in silty backwaters and eddies.

Ecological Interactions

River lamprey can have a substantial impact on prey populations, and in certain locations have been identified as a major source of salmon mortality. In laboratory studies, river lampreys are able to hybridize with western brook lamprey, though this has not been observed to occur in the wild.

Key Uncertainties

River lamprey population trends are unknown in the southern portion of its range, but it is probable they have declined in response to degradation of adequate spawning and rearing habitat in lower sections of large rivers. In California, the extent and timing of spawning migrations is not well known.

Key References

Moyle (2002

Common Name	**Scientific Name (family)**
Western brook lamprey	*Lampetra richardsoni* (Petromyzontidae)

Legal Status:

Federal none
State none

Distribution

The western brook lamprey is distributed from southeast Alaska to California including the Sacramento San Joaquin system. They may occur further south in California in larger streams and rivers.

Life History

Western brook lamprey spawn in late April to early June when water temperatures exceed 10º C. They construct nests in gravel riffles, which are occupied by 2-4 and as many as 12 individuals. Egg number varies from 1,100 to 3,700. Eggs are adhesive and hatch in approximately 10 days at 10-15.6ºC. In approximately 30 days ammocoetes burrow into the silt. Survival is apparently high as this species is one of the more abundant life forms in the lower courses of streams in the northwestern United States. Density can be as high as 170 per square meter. Western brook lamprey live 3-4 years in California and reach 13-18 cm in size. From August until November the largest ammocoetes metamorphose into adults. These individuals overwinter without feeding, sexually mature in the spring, then spawn and die.

The western brook lamprey is non-anadromous and is non-parasitic, consuming algae, including diatoms, and other organic matter.

Habitat Requirements

The species is abundant in freshwater streams and occupies backwaters and pools where silt and sand substrates exist. They may be restricted to the less disturbed sections of rivers and intolerant of high pollution levels.

Ecological Interactions

The species is probably more abundant than reported. Sculpin, salmonids, and even ravens may eat western brook lamprey eggs, spawning adults, and smaller ammocoetes. Some species may demonstrate an aversion to eating larger ammocoetes, which may be due to secretion of granular cells in the skin.

Western brook lamprey may compete with the Pacific lamprey, *E. tridentatus*, and river lamprey, *L. ayresi*, for nesting space. However, brook lamprey usually nest in smaller streams and further upstream.

Key Uncertainties

Little work has been done on the biology of western brook lamprey in California. The more isolated populations of this species may have unique characteristics and may be distinct species.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973.

Common Name	**Scientific Name (family)**
Chinook salmon	*Oncorhynchus tshawytscha* (Salmonidae)

Legal Status:

Federal Candidate/not warranted (Central Valley Fall and Late Fall ESU)

Distribution and Population Trends

Chinook salmon are distributed in the Pacific Ocean throughout the northern temperate latitudes in North America and northeast Asia. In North America, they spawn in rivers from Kotzebue Sound, Alaska south to the San Joaquin River in California's Central Valley (Healey 1991). In California, large populations are found in the Sacramento River and its major tributaries. Chinook salmon are also widely distributed in smaller California coastal streams north of San Francisco Bay (Allen and Hassler 1986). Fall Chinook occurring in the San Joaquin river belong to the Central Valley Fall and Late Fall Evolutionary Significant Unit (ESU). The ESU includes all naturally spawned populations of fall-run Chinook salmon in the Sacramento and San Joaquin River Basins and their tributaries, east of Carquinez Strait, California. NMFS (1999) determined that listing was not warranted for this ESU, but subsequently designated the ESU as a candidate for listing. Spring Chinook are extirpated from the San Joaquin basin, and are not included in an ESU.

Four runs of Chinook salmon occur in California fall, late fall, winter, and spring (Leet et al. 1992, Allen et al. 1986, Mills et al. 1997). Fall-run populations (or "fall Chinook") occur throughout the species' range and are currently the most abundant and widespread salmon runs in California (Mills et al. 1997). Winter-run populations are limited to the Sacramento River basin and were listed as endangered under the federal Endangered Species Act in 1994. Two apparently distinct stocks of spring-run Chinook (or "spring Chinook") occur in California: a Sacramento-San Joaquin population and a Klamath-Trinity population (Moyle et al. 1995). Moyle et al. (1995) state that although other spring Chinook populations may have existed in smaller coastal streams between these two basins, such as the Eel River, they have since been extirpated and there is no evidence of recent spawning in these streams.

The San Joaquin River system once supported large runs of both spring and fall Chinook salmon. In the San Joaquin River and its tributaries historic production is estimated to have approached 300,000 fish (Reynolds et al. 1993, as cited in Yoshiyama et al. 1998). The last large run observed in the San Joaquin River was over 56,000 fish in 1945 (Fry 1961, as cited in Moyle et al. 1995). Adult spring Chinook salmon entered the system during periods of high spring snowmelt, held over in deep pools during the summer, then spawned in the upper reaches of the San Joaquin River and its major tributaries—the Stanislaus, Tuolumne, and Merced rivers—in the early fall. Locals living on the San Joaquin River mainstem before dam construction observed spring Chinook holding in the summer in pools near Friant, and moving upstream into the gorge of the San Joaquin River to spawn (currently inundated by Millerton Lake) (CFGC 1921). Dam construction and irrigation diversions, which eliminated access to upstream spawning and holding areas, extirpated the spring run from the basin by the late 1940s (Skinner 1962).

Fall Chinook salmon are currently the most abundant race of salmon in California (Mills et al. 1997). In the San Joaquin Basin, fall Chinook historically spawned in the mainstem San Joaquin River upstream of the Merced River confluence and in the mainstem channels of the major tributaries. Dam construction and water diversion dewatered much of the mainstem San Joaquin River, limiting fall Chinook to the three major tributaries where they spawn and rear downstream of mainstem dams.

Run estimates are available from 1940, but systematic counts of salmon in the San Joaquin Basin began in 1953, long after construction of large dams on the major San Joaquin basin rivers. Comparable estimates of population size prior to 1940 are not available. Since population estimates began, the number of fall Chinook returning to the San Joaquin Basin annually has fluctuated widely. Most recently, escapement in the Tuolumne River dropped from a high of 40,300 in 1985 to a low about 100 resulting from the 1987–1992 dry period (EA 1997). With increased precipitation and improved flow conditions, escapement has increased to 3,300 in 1996 (EA 1997). Since 1991 hatchery production is estimated to compose about 30–60% of the fall Chinook run in the San Joaquin River (PFMC 1998, as cited in Yoshiyama et al. 1998). Figure 1 provides a summary of estimated escapement from 1953–2000 in the Stanislaus, Tuolumne, and Merced rivers.

Due to extensive hatchery introductions, most spring Chinook currently in Sacramento mainstem have hybridized with fall-run fish, and are heavily introgressed with fall Chinook characteristics, particularly with regard to run timing (Yoshiyama et al. 1998). Deer, Mill, and Butte Creek stocks appear to have minimal to no hatchery influence.

Life History

Overview

Chinook salmon vary in length of fresh and salt-water residency, and in upstream and downstream migration timing (Healey 1991). Chinook salmon are the largest of the Pacific salmon species, reaching weights of up to 45 kg (99 lb), although most adults in Oregon weigh 4.5–18 kg (10–40 lbs) (Healey 1991, Kostow 1995). Chinook salmon have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989).

Spring Chinook typically spend up to one year rearing in fresh water before migrating to sea, perform extensive offshore migrations, and return to their natal river in the spring or summer, several months prior to spawning (these are also referred to as “stream-type” Chinook). Fall (or “ocean-type”) Chinook migrate to sea during their first year of life-typically within three months after their emergence from spawning gravels, spend most of their ocean life in coastal waters, and return to their natal river in the fall, a few days or weeks before spawning (Moyle et al. 1989, Healey 1991). The following information focuses on the life history and habitat requirements of spring Chinook salmon although information on fall Chinook is also included. Information specific to the San Joaquin River has been included where possible. Table 1 displays the timing of specific life history events for spring Chinook salmon in the San Joaquin River basin based on historical information, and recent information from similar stocks (e.g., Sacramento River basin stocks), and Table 2 displays the general timing of life history events of fall chinook in the Central Valley.

Adult upstream migration and spawning

Adult Chinook salmon migrate upstream from the ocean to spawn in their natal streams, although a small percentage may stray into other streams, especially during high water years (Moyle et al. 1989). In California rivers, adult spring Chinook typically return to fresh water between March and May while still sexually immature (Marcotte 1984). Upstream migration in the San Joaquin River historically occurred from March through June (CFGC 1921, Hatton and Clark 1942), and holding occurred from April though mid-July (Table 1). There are differences in run timing between basins within the Sacramento/San Joaquin Rivers, which have been attributed to the timing of fall decreases in water temperature. Spring Chinook salmon tend to move up into the cooler reaches of rivers earlier in the season to spawn, and spawn in warmer reaches later (after seasonal changes decrease water temperatures) (Parker and Hanson 1944, as cited in Moyle et al. 1995). Migration timing also appears to be based in part on snow-melt flows (NMFS 1999). Therefore it is likely that current run timing in the San Joaquin River would differ from both historical timing, and the timing in tributaries to the Sacramento River. Fall Chinook salmon in the San Joaquin system typically enter spawning streams from October through December (Table 2). The age of returning Chinook adults in California ranges from 2 to 5 years.

Adult Chinook salmon appear to be less capable of negotiating fish ladders, culverts, and waterfalls during upstream migration than coho salmon or steelhead (Nicholas and Hankin 1989), due in part to slower swimming speeds and inferior jumping ability compared to steelhead (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds, which are used primarily for long-distance travel, range from 0 to 1 m/s (0 to 3.3 ft/s) (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 1 to 3.3 m/s (3.3 to 10.8 ft/s) (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 3.3 to 6.8 m/s (10.8 to 22.3 ft/s) (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 2.4 m (7.9 ft) (Bjornn and Reiser 1991).

Spring Chinook spawning in the San Joaquin River historically occurred from late August to October, with peak spawning occurring in September and October (Clark 1942). Fall Chinook in the San Joaquin system typically spawn from October through December, with spawning activity peaking in early to mid-November. Upon arrival at the spawning grounds, adult females dig shallow depressions or pits in suitably-sized gravels, deposit eggs in the bottom during the act of spawning, and cover them with additional gravel. Over a period of one to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Healey 1991). Redds are typically 10–17 m^2 (108–183 ft^2) in size, although they can range from 0.5 to 45 m^2 (5.4–484 ft^2) (Healey 1991). Spring Chinook redds in Deer Creek average 4 m^2 (42 ft^2) (Cramer and Hammack 1952, as cited in Moyle et al. 1995).

Spring Chinook spawners tend to congregate in high densities where stream reaches offer appropriate spawning habitat (Nicholas and Hankin 1989). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Briggs (1953) observed that the defended area could extend up to 6 m (20 ft) in all directions from the redd. Redds may be defended by the female for up to a month (Hobbs 1937). Males do not defend the redd but may exhibit aggressive behavior toward other males while defending spawning females (Shapovalov and Taft 1954). Both male and female adults die within two weeks after spawning (Kostow 1995), with females defending the redd until they become too weak to maintain position over the redd or die.

Spawning gravel availability and redd superimposition

Dams have reduced the supply of spawning gravels in the many rivers in the Sacramento-San Joaquin River basin. Limitations on spawning gravels often result in redd superimposition, whereby later arriving females dig redds on top of existing redds, causing substantial mortality of the previously-deposited eggs (McNeil 1964, Hayes 1987). This has been found to be an important factor affecting Chinook populations in the Tuolumne River, and other rivers where gravel supplies may be limited by dams (EA Engineering 1992).

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel. 417,000 ft^2 of suitable spawning gravel were found in 26 miles of channel between Lanes Bridge and the Kerchoff Powerhouse (upstream of Friant Dam). The Friant Dam inundated 36% of this area, leaving about 266,800 ft^2 of suitable spawning gravel in the channel below the dam, though it is not clear what criteria were used to determine suitability.

Egg incubation, alevin development, and fry emergence

In the Sacramento River, the egg incubation period for spring Chinook extends from August to March (Fisher 1994, Ward and McReynolds 2001). Egg incubation generally lasts between 40–90 days at water temperatures of 6–12°C (42.8°F to 53.6°F) (Vernier 1969, Bams 1970, Heming 1982, all as cited in Bjornn and Reiser 1991). At temperatures of 2.7°C (37°F), time to 50% hatching can take up to 159 days (Alderdice and Velsen 1978, as cited by Healey 1991). The alevins remain in the gravel for two to three weeks after hatching and absorb their yolk sac before emerging from the gravels into the water column during November to March in the Sacramento River basin (Fisher 1994, Ward and McReynolds 2001).

Juvenile freshwater rearing

The length of time spent rearing in freshwater varies greatly among spring Chinook juveniles. Chinook may disperse downstream as fry soon after emergence; early in their first summer as fingerlings; in the fall as flows increase; or after overwintering in freshwater as yearlings (Healey 1991). Even in rivers such as the Sacramento River where many juveniles rear until they are yearlings, some juveniles probably migrate downstream throughout the year (Nicholas and Hankin 1989). Although fry typically drift downstream following emergence (Healey 1991), movement upstream or into cooler tributaries following emergence has been observed in some systems (Lindsay et al. 1986, Taylor and Larkin 1986).

Juveniles feed voraciously during summer, and display territoriality in feeding areas and are aggressive towards other juvenile Chinook (Taylor and Larkin 1986, Reimers 1968). Experiments conducted in artificial streams suggest that aggressive behavior among juvenile Chinook results in formation of territories in riffles and size hierarchies in pools having abundant food resources and relatively dense groupings of fish (Reimers 1968). Territorial individuals have been observed to stay closer to the substrate, while other individuals may school in hierarchical groups (Everest and Chapman 1972). At night, juvenile Chinook may move toward stream margins with low velocities and finer substrates or into pool bottoms, returning to their previous riffle/glide territories during the day (Edmundson et al. 1968; Don Chapman Consultants 1989, as cited in Healey 1991). Reimers (1968) speculated that intraspecific interactions or density-dependent mechanisms may cause downstream displacement of fry.

During winter, juvenile Chinook typically reduce feeding activity and hide in cover, conserving energy and avoiding predation and displacement by high flows (Chapman and Bjornn 1969, Meehan and Bjornn 1991). Juvenile Chinook that overwinter in fresh water either migrate downstream in the fall to larger streams that have suitable winter habitat or enter interstitial spaces among cobbles and boulders whereupon growth is suspended for the winter (Chapman and Bjornn 1969, Bjornn 1971, Everest and Chapman 1972, Carl and Healey 1984). Reductions in stream temperatures to 4–6°C (39–43°F) typically cause downstream migration and/or movement into the interstices of the substrate (Morgan and Hinojosa 1996). In some areas, such as the mainstem Fraser River, juveniles have been observed to continue feeding in the winter (Levings and Lauzier 1991, as cited in Morgan and Hinojosa 1996). Morgan and Hinojosa (1996) suggested that juvenile Chinook may maintain territories in winter as well.

Rearing densities

Juvenile Chinook densities vary widely according to habitat conditions, presence of competitors, and life history strategies. Lister and Genoe (1970) reported maximum densities of fall Chinook emergent fry in stream margin habitats as 7.2 fish/m^2 (0.65 fish/ft^2) and in mid-channel habitats as 7.0 fish/m^2 (0.63 fish/ft^2). In the Red River, Idaho, densities of age 0+ Chinook in August averaged approximately 0.6 fish/m^2 (0.05 fish/ft^2) and declined to approximately 0.13 fish/m^2 (0.01 fish/ft^2) in November in low-gradient (1–2%) reaches (Hillman et al. 1987). Bjornn (1978, as cited in Bjornn and Reiser 1991) recorded late-summer age-0+ Chinook densities of up to 1.35 fish/m^2 (0.12 fish/ft^2) in a productive Idaho stream, and fewer than 0.8 fish/m^2 (0.07 fish/ft^2) in less productive third- and fourth-order streams. Densities in low-gradient (0.5%) reaches of Johnson Creek, Idaho were over 1.8/m^2 (0.16 fish/ft^2) (maximum recorded density was 6.5 fish/m^2 [0.59 fish/ft^2]) in early July, whereas densities in a higher gradient (1.3%) reach averaged 0.5 fish/m^2 (0.05 fish/ft^2) (maximum recorded density was 1.4 fish/m^2 [0.13 fish/ft^2]) in late July (Everest and Chapman 1972).

Smolt outmigration and estuarine rearing

In the mainstem San Joaquin River outmigrating trapping at Mossdale in 1939, 1940, and 1941 showed that spring Chinook smolt outmigration historically occurred from January until mid-June, with a peak in February (Hatton and Clark 1942). Data from Hatton and Clark (1942) show that the average total length of age 0+ spring Chinook fry in January was 35 mm, by March fry averaged 40 mm total length, and by the middle of April most fry were between 60 and 70 mm total length. By the end of migration (June) most fish were greater than 80 mm total length. Hatton and Clark (1942) compared fish sizes from the San Joaquin with fry captured in the Sacramento River during the same time period. The January captures from the San Joaquin averaged slightly less in length than fry captured in the Sacramento River, while fry captured later in the migration period were slightly larger.

Most age 0+ outmigrants in Butte Creek move downstream at sizes of 30 to 110 mm (1.18–4.33 inches) (Hill and Weber 1999), while age 1+ outmigrants are generally larger than 120 mm (4.7 inches), and can reach 150 mm (5.91 inches) or more in Butte Creek (Hill and Weber 1999). Trapping records from the Sacramento River basin show that three stages of downstream migration occur among spring Chinook. Some age-0+ juveniles are observed moving downstream from spring to early summer (Hill and Weber 1999, Ward and McReynolds 2001, Fisher 1994). Another group of juveniles are observed migrating downstream as age 1+ from October to January (Hill and Weber 1999, Ward and McReynolds 2001), and a third wave of migrants leave the river as age 1+ yearlings the following spring (Fisher 1994). In many river systems yearling smolts typically outmigrate to the ocean in early spring, either before or during the outmigration of fry and fingerlings (Healey 1991).

In general, fall Chinook fry (length <50 mm) and juveniles (length >50 mm) outmigrate from the spawning areas between January and May. Outmigration of larger juveniles generally occurs from April though June with smolts entering the ocean between April and July (Leet et al 1992).

Juvenile Chinook feed and grow as they move downstream in spring and summer; larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not outmigrate (Bradford et al. 2001). Juveniles that do not disperse downstream in their first spring may display high fidelity to their rearing areas throughout the summer rearing period (Edmundson et al. 1968). Nicholas and Hankin (1989) suggested that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures. Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Kjelson et al. (1981) observed peak seine catches of Chinook fry in the Sacramento-San Joaquin Delta correlated with increases in flow associated with storm runoff. Flow accounted for approximately 30 percent of the variability in the fry catch. Photoperiod may also be important, although the relative importance of various outmigration cues remains unclear (Bjornn 1971, Healey 1991).

Ocean phase

When fall Chinook salmon produced from the Sacramento-San Joaquin system enter the ocean they appear to head north, and rear off the northern California-southern Oregon coast (Cramer 1987, as cited in Maragni 2001). Fall Chinook typically rear in coastal waters early in their ocean life. Ocean conditions are likely an important cause of density-independent mortality and interannual fluctuations in escapement sizes.

Habitat Requirements

Adult upstream migration and spawning

Adult spring Chinook require large, deep pools with moderate flows for summer holding during their upstream migration. Marcotte (1984) reported that suitability of pools declines at depths less than 2.4 m (7.9 ft) and that optimal water velocities range from 15 to 37 cm/s (0.5 to 1.2 ft/s). In the John Day River, Oregon, adults usually hold in pools deeper than 1.5 m (4.9 ft) that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986). Adult

Chinook salmon require water deeper than 24 cm (0.8 ft) and water velocities less than 2.4 m/s (8 ft/s) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). Water temperatures for adult Chinook holding and spawning are reportedly best when <16ºC (60.8ºF), and lethal when >27ºC (80.6ºF) (Moyle et al. 1995). Spring Chinook in the Sacramento River typically hold in pools below 21–25ºC (69.8–77ºF). Table 3 provides a summary of spring Chinook holding temperature criteria.

In July of 1942 Clark (1942) observed an estimated 5,000-spring Chinook holding in two large pools directly downstream of the Friant Dam. These fish appeared to be in good condition, and held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 22.2ºC (72ºF) in July. Fewer fish were seen in each subsequent visit in August, September, and October, and it was assumed they had moved downstream in search of spawning riffles. A seasonal sand dam was installed in late summer in the San Joaquin, blocking the migration of additional spring Chinook into the upper river. By September fish were observed spawning 10 miles downstream of the Friant Dam. Although some fish may have held in pools downstream of Lanes bridge, Clark (1942) concluded that the abundant spawning he observed in September and October on riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam and dropped back downstream to spawn.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 2–3 m (6.6–9.8 ft) in width (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook prefer low-gradient (<3%) reaches for spawning and rearing, but will occasionally use higher-gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Redds are typically located near pool tailouts (i.e., heads of riffles) where high concentrations of intragravel dissolved oxygen are available.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over Chinook redds range from 10 to 200 cm (3.9 to 78 in) and velocities from 15 to 100 cm/s (0.5 to 3.3 ft/s), although criteria may vary between races and stream basins. Fall Chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring Chinook tend to dig smaller redds and use finer gravels than fall Chinook (Burner 1951).

Substrate particle size composition has been shown to have a significant influence on intragravel flow dynamics (Platts et al. 1979). Chinook salmon may therefore have evolved to select redd sites with specific particle size criteria that will ensure adequate delivery of dissolved oxygen to their incubating eggs and developing alevins. In addition, salmon are limited by the size of substrate that they can physically move during the redd building process. Substrates selected likely reflect a balance between water depth and velocity, substrate composition and angularity, and fish size. As depth, velocity, and fish size increase, Chinook are able to displace larger substrate particles. D_{50} values (the median diameter of substrate particles found within a redd) for Chinook have been found to range from 10.8 mm (0.43 in) to 78.0 mm (3.12 in) (Kondolf and Wolman 1993). Chinook in the Central Valley have been observed to use substrate ranging from 31–66 mm (1.22–2.60 in) (Van Woert and Smith, unpublished data 1962, as cited in Kondolf and Wolman 1993; and Kondolf and Wolman 1993).

Egg incubation, alevin development, and fry emergence

Suitable water temperatures, dissolved oxygen delivery, and substrate characteristics are required for proper embryo development and emergence. Review of the literature suggests that 5.8–14.2°C (42.5–57.5°F) is the optimum temperature range for incubating Chinook salmon (Donaldson 1955, Combs and Burrows 1957, Combs 1965, Eddy 1972, Bell 1973, Healey 1979, Reiser and Bjornn 1979, Garling and Masterson 1985). Sublethal stress and/or mortality of incubating eggs resulting from elevated temperatures would be expected to begin at temperatures of about 14.4°C (58°F) for constant exposures (Combs and Burrows 1957, Combs 1965, Healey 1979).

Delivery of dissolved oxygen to the egg pocket is the major factor affecting survival-to-emergence that is impacted by the deposition of fines in the spawning substrate. Several studies have correlated reduced dissolved oxygen levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Silver et al. (1963) found that low dissolved oxygen concentrations were related to mortality and reduced size in Chinook salmon and steelhead embryos. Data suggest that growth may be restricted day at oxygen levels below saturation (Silver et al. 1963). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976).

Juvenile freshwater rearing

Juvenile Chinook salmon tend to use mainstem reaches and estuaries as rearing habitat more extensively than juvenile coho salmon, steelhead, and sea-run coastal cutthroat trout do. Spring Chinook typically rear in low gradient reaches of mainstem rivers areas and large tributaries (Nicholas and Hankin 1989).

Following emergence, fry occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Everest and Chapman (1972) observed at least small numbers of Chinook fry in virtually all habitats sampled in early summer. Because Chinook fry tend to be larger than coho fry upon emergence, they may tend to use areas with higher water velocities than coho (Murphy et al. 1989, Healey 1991). Most researchers have not addressed fry habitat requirements separately from juvenile summer habitat requirements, but there seems to be consensus that Chinook fry prefer quiet, shallow water with cover. Everest and Chapman (1972) investigated habitat use of emergent Chinook fry; they found fry using depths less than 60 cm (24 in) and water velocities less than 15 cm/s (0.5 ft/s).

Substantial variability in the depth and velocity preferences of juvenile Chinook has been reported. Juvenile Chinook have been observed in virtually all depths and velocities where researchers have sampled (Hillman et al. 1987, Murphy et al. 1989). Lister and Genoe (1970) found that juvenile Chinook preferred slow water adjacent to faster water (40 cm/s [1.3 ft/s]).

Summer rearing habitat

Juvenile Chinook salmon appear to prefer pools that have cover provided by banks, overhanging vegetation, large substrates, or LWD. Juvenile densities in pools have been found to increase with increasing amounts of cover (Steward and Bjornn, unpublished data, as cited in Bjornn and Reiser 1991). Water temperature may also influence juvenile habitat use. In the South Umpqua River basin, Roper et al. (1994) observed lower densities of juvenile Chinook where water temperatures were higher. In areas where more suitable water temperatures were available, juvenile Chinook salmon abundance appeared to be tied to pool availability.

Temperatures also have a significant effect on juvenile Chinook growth rates. On maximum daily rations, growth rate increases with temperature to a certain point and then declines with further increases. Reduced rations can also result in reduced growth rates; therefore, declines in juvenile salmonid growth rates are a function of both temperature and food availability. Laboratory studies indicate that juvenile Chinook salmon growth rates are highest at rearing temperatures from 18.3° to

21.1°C (65° to 70°F) in the presence of unlimited food (Clarke and Shelbourn 1985, Banks et al. 1971, Brett et al. 1982, Rich 1987), but decrease at higher temperatures, with temperatures >23.3° C (74° F) being potentially lethal (Hanson 1990).

Nicholas and Hankin (1989) suggest that the duration of freshwater rearing is tied to water temperatures, with juveniles remaining longer in rivers with cool water temperatures.

Winter rearing habitat

Juvenile Chinook salmon rearing in tributaries may disperse downstream into mainstem reaches in the fall and take up residence in deep pools with LWD, interstitial habitat provided by boulder and rubble substrates, or along river margins (Swales et al. 1986, Healey 1991, Levings and Lauzier 1991). During high flow events, juveniles have been observed to move to deeper areas in pools and they may also move laterally in search of slow water (Shirvell 1994, Steward and Bjornn 1987). Hillman et al. (1987) found that individuals remaining in tributaries to overwinter chose areas with cover and low water velocities, such as areas along well-vegetated, undercut banks. Lakes may occasionally be used by overwintering Chinook, but they appear to avoid beaver ponds and off-channel slough habitats (Healey 1991). In the winter in the Sacramento/San Joaquin system juveniles rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook juveniles that reared on the Yolo Bypass floodplain than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. On the Yolo Bypass bioenergetic modeling suggested that increased prey availability on the floodplain was sufficient to offset increased metabolic demands from higher water temperatures (5ºC higher than mainstem). Sommer et al. (2001) believe that the well-drained topography may help reduce stranding risks when flood waters recede.

Hillman et al. (1987) found that the addition of cobble substrate to heavily-sedimented glides in the fall substantially increased winter rearing densities, with Chinook using the interstitial spaces between the cobbles as cover. Fine sediment can act to reduce the value of gravel and cobble substrate as winter cover by filling interstitial spaces between substrate particles. This may cause juvenile Chinook to avoid these embedded areas and move elsewhere in search of suitable winter cover (Stuehrenberg 1975, Hillman et al. 1987).

Tables

Figures

Table 1. Life history timing of spring Chinook in the California Central Valley

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration													Geographic area: Sacramento River basin March through July, peaking in May–June (Fisher 1994). Source of data not stated.
Upstream Migration													Jones and Stokes, Foundation Runs Report 2002 Geographic area: not stated Migrate to natal streams March through September (USFWS 1995). Source of data not stated.
Adult Holding													Geographic area: San Joaquin River Congregate in large pools near Friant from May through mid-July (CFGC 1921), and then spawn in gorge upstream. Source of data is personal observation. Fish observed holding on May 23, 1942 in the pool directly below the Friant Dam (Clark 1942). No visits were made prior to this date. Fish were continued to be observed in subsequent visits in August and September in pools downstream of the dam, and directly below the dam. It appeared that fish moved as much as 10 miles downstream from holding pools to spawn.
Adult Holding													Geographic area: Sacramento River basin, Mill Creek Holding as early as late April and early May in Mill Creek. However, no observations conducted before late April, so fish could be holding earlier. Most fish holding by July. (C. Harvey, CFG, pers. comm. 2002). Based on walking and dive surveys. General comment: Many spring Chinook migrate from holding pools to spawning areas further upstream in the watershed, while the rest remain to spawn in the tails of the holding pools (Moyle et al. 1995). No source or location of data stated.
Adult Holding													Jones and Stokes Foundations Runs Report Geographic area: San Joaquin River Congregate in pools after upstream migration during May to early July (Yoshiyama et al. 1998).
Spawning													Geographic area: San Joaquin River The San Joaquin River below Friant dam was surveyed for one day in late August, late September, early October, and early November of 1942. The first spawning was observed on September 21, and large numbers of fish were spawning on all the riffles observed between Friant Dam and Lanes Bridge on November 4 (Clark 1942). Clark also reports that in detailed surveys prior to dam construction 417,000 ft^2 of spawning gravel were observed between Lanes Bridge and the Kerchoff Powerhouse. He reports that 36% of this area was eliminated by construction of the Friant Dam.

Table 1. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spawning													Geographic area: San Joaquin River Spawning took place in September and early October near Friant (Hallock and Van Woert 1959). Source of data not stated.
Spawning													Geographic area: Sacramento River basin Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning													Geographic area: Sacramento River basin Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning													Geographic area: Sacramento River basin, Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).
Spawning													Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Spawning August through October, depending on water temperatures (USFWS 1995). Source of data not stated.
Incubation													Embryos hatch after 5-6 month incubation. Alevins remain in gravel an additional 2-3 weeks (Moyle et al. 1995). No source or location of data stated.
Emergence													Geographic area: Sacramento River basin Emergence November to March in the Sacramento River basin (Fisher 1994). Source of data not stated. Emergence in Butte Creek from November to March (Ward and McReynolds 2001). Based on outmigrant trapping of recently emerged fry.

Table 1. cont.

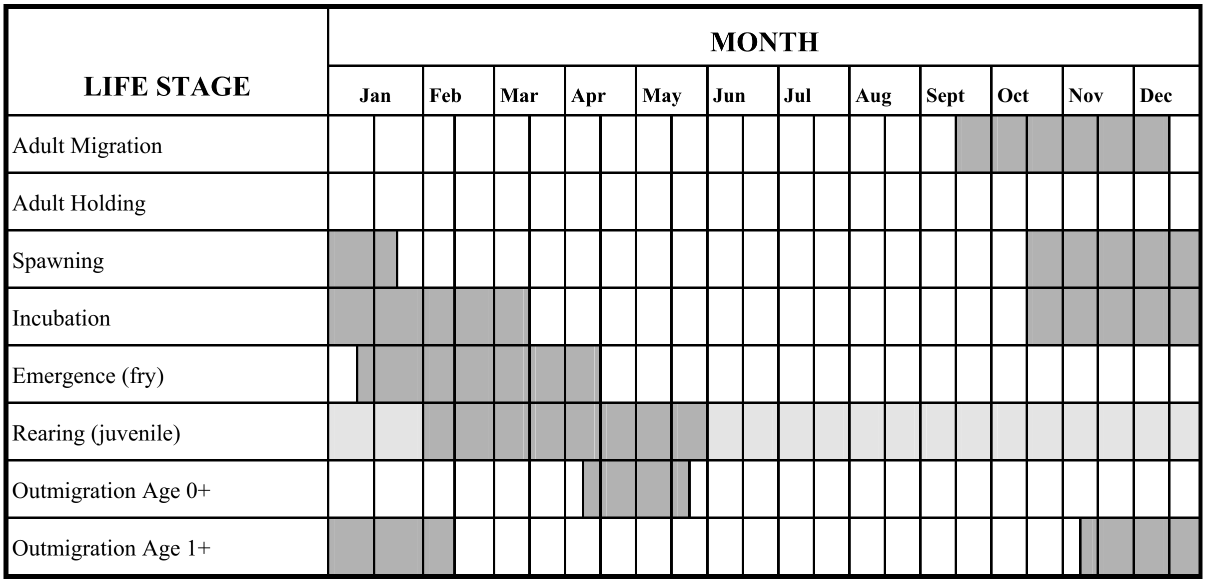
LIFE STAGE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
Rearing													Geographic area: Sacramento River basin Rear 3 to 15 months in the Sacramento River basin (Fisher 1994). Source of data not stated. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. Some juveniles outmigrate after hatching, and others move downstream during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.
Fry Dispersal													Geographic area: San Joaquin River Before construction of Friant Dam outmigration occurred during major seasonal runoff. Fish and Game fyke netting in 1939 and 1940 at Mossdale demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with a peak in February (Hallock and Van Woert 1959).
Fry Dispersal													Geographic area: San Joaquin River After construction of Friant Dam outmigration it appeared that the elimination of flood flows altered migration patterns. In 1948 fyke trapping at Mendota there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 peaks were recorded in early March and again in mid-May (Hallock and Van Woert 1959).
Fry Dispersal													Geographic area: Sacramento River basin Juveniles typically outmigrate during November through Jan. during the first high flows as subyearlings, though some stay as late as March (F. Fisher, pers. comm., as cited in USFWS 1994). Source of data not stated. Juveniles typically outmigrate as fry from Butte Creek between mid-November and mid-February, with a peak in December and January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. In the Sacramento River most downstream movement takes place December to February as parr (Vogel and Marine 1991, as cited in USFWS 1994). Source of data not stated.

Table 1. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spring Smolts (subyearling)													Geographic area: Sacramento River basin Some YOY remain in Butte Creek and outmigrate in late spring or early summer (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In the Sacramento River basin ocean entry during March to June (Fisher 1994). Source of data not stated
Fall Smolts (yearling)													Geographic area: Sacramento River basin Most yearlings outmigrate from Butte Creek in October to January (Hill and Weber 1999, Ward and McReynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Mill Creek some juveniles outmigrate during the following fall as yearlings (C. Harvey, pers. comm., as cited in Moyle et al. 1995). Source of data not stated.
Fall and Spring Smolts (yearling)													Geographic area: Sacramento River basin Ocean entry from November to April (Fisher 1994). Source of data not stated.
Spring Smolts (subyearling)													Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated May rear in freshwater for 3 to 8 months, migrating to the ocean during spring (Raleigh et al. 1986, Moyle 1976).
Fall Smolts (yearlings)													Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Frequently rear over the summer and migrate to the ocean from October to December, after 12-14 months in freshwater (no source cited).
Juveniles enter the ocean													Moyle et al. (1995) "presumes" that all fish have left the Sacramento basin by mid-may. No source of data stated.

	Span of Life History Activity
	Peak of Life History Activity

Table 2. Life history timing of Fall Chinook in the California Central Valley.



(source: Reavis 1995)

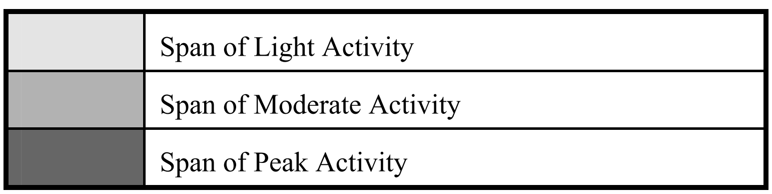


Table 3. Holding temperature criteria for spring Chinook salmon.

Temperature Criteria						Source and Notes
Average		Preferred		Maximum		
°C	°F	°C	°F	°C	°F	
20.3	68.5					Average temperature at mouth of Willamette River, OR, during the 1966 Chinook run (Alabaster 1988)
		3.3–13.3	37.9–55.9			Spring Chinook (Bell 1986). Source not specified.
				17.5–19.0	63.5–66.2	Egg viability and alevin survival may be reduced at temperatures between 17.5–19.0°C (Berman 1990). Yakima River, Washington.
				14.4–19.4	57.9–66.9	Egg mortalities of 50% or more of adults held at 14.4–19.4°C (B. Ready, pers. comm., as cited in Berman 1990).
				22.2	72.0	Adults holding below the Friant Dam on the San Joaquin River appeared in good condition, despite a maximum-recorded July temperature of 72°C (Clark 1942).
				24	76	Adults in the Klamath River apparently unaffected by temperatures as high as 76°F (Dunham 1968, as cited in Boles et al. 1988).
				18.3	65	Sonically tagged San Joaquin River spring Chinook were not observed migrating until temperatures dropped below 65°F (Hallock et al. 1970).
				23.0	73.4	Adult spring Chinook salmon can survive in deep pools with surface temperatures as high as 23.0°C (Hodges and Gharrett 1949, as cited in Beauchamp et al. 1983).
				13.3	56	Eggs will not develop normally if held in constant temperatures exceeding 13.3°C (Leitritz and Lewis 1976). Race or source of data not specified.
				21	70	Migrations blocked at temperatures exceeding 21°C (Major and Mighell 1967, as cited in Armour 1991). Source of data not stated.
11.7–21.1	53–70					Range used by spring Chinook salmon in Deer and Mill Creeks, Sacramento River basin (Moyle et al. 1995). Source of data not given.
		5.6–18.3	42.0–65.0	23.9	75	Maximum for survival (Brett 1959, as cited in Marcotte 1984).
				17–19	63–66	Acute mortality of Chinook salmon broodstock (R. Ducy, Pers. Comm, as cited in Marine 1992).
				18–21	64–70	Considerable pre-spawn mortality of spring Chinook observed in the Rogue River, Or when temperatures were in the range of 18–21°C (M. Everson, pers. comm., as cited in Marine 1992).
				21–25	70–77	Spring Chinook salmon in the Sacramento-San Joaquin system tributaries hold in pools that seldom exceeded 21–25°C (70–77°F) (Moyle 1976, as cited in Moyle et al. 1995).
				21.1	70	Thermal barrier to spring Chinook on the Tucannon River, Wa. (Bumgarner et al. 1997, as cited in McCullough 1999).
		10–14	50–57			Piper et al. (1982). Race not stated, source of data not stated.
20	68					Spring Chinook often hold in pools in Butte Creek, Sacramento River basin, where average daily temperatures exceed 20°C (Williams et al. 2002), though pre-spawn mortality can be high.

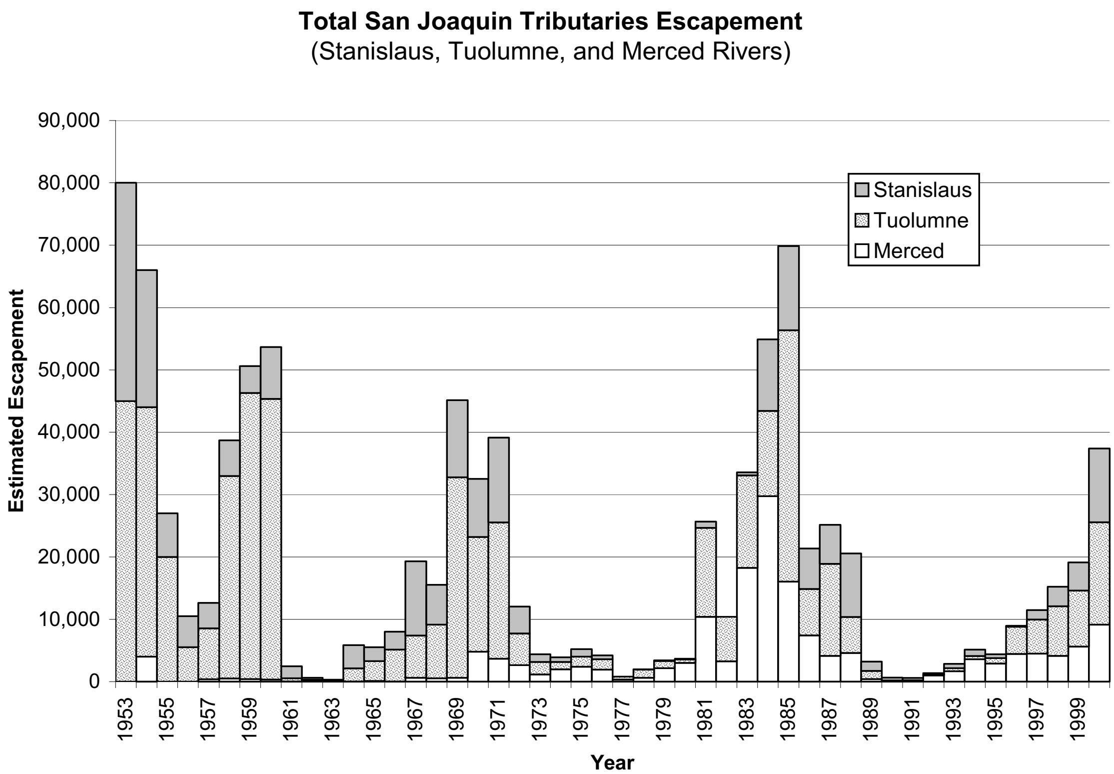


Figure 1. Chinook salmon escapement into San Joaquin basin tributaries 1953 to 2000.

Common Name	**Scientific Name (family)**
Steelhead	*Oncorhynchus mykiss* (Salmonidae)

Status

The Central Valley steelhead ESU includes naturally spawned steelhead occurring in the Sacramento and San Joaquin rivers and their tributaries and extends into the San Francisco estuary to San Pablo Bay. Steelhead is the term commonly used for the anadromous life history form of rainbow trout *(Oncorhynchus mykiss)*. Only winter-run steelhead stocks are currently present in Central Valley streams (McEwan and Jackson 1996).

The National Marine Fisheries Service (NMFS) considered including resident *O. mykiss* in listed steelhead ESUs in certain cases, including (1) where resident *O. mykiss* have the opportunity to interbreed with anadromous fish below natural or artificial barriers or (2) where resident fish of native lineage once had the ability to interbreed with anadromous fish but no longer do because they are currently above artificial barriers and are considered essential for the recovery of the ESU (NMFS 1998, p. 13350). The U.S. Fish and Wildlife Service (USFWS), which has authority under the Endangered Species Act (ESA) over resident fish, however, concluded that behavioral forms of *O. mykiss* can be regarded as separate Distinct Population Segments (the USFWS version of an ESU) and that lacking evidence that resident rainbow trout need ESA protection, only anadromous forms should be included in the ESU and listed under the ESA (NMFS 1998, p. 13351). The USFWS also did not believe that steelhead recovery would rely on the intermittent exchange of genetic material between resident and anadromous forms (NMFS 1998, p. 13351). In the final rule, the listing includes only the anadromous life history form of *O. mykiss* (NMFS 1998, p. 13369).

From this information, it seems that resident rainbow trout are not protected under the ESA and are not included in the ESU. NMFS, however, considers all *O. mykiss* that have physical access to the ocean (including resident rainbow trout) to potentially be steelhead (Chris Mobley, Dennis Smith, and Steven Edmundson, NMFS, personal communication) and will treat these fish as steelhead because (1) resident fish can produce anadromous offspring, and (2) it is difficult or impossible to distinguish between juveniles of the different life history forms. NMFS considers juvenile *O. mykiss* smaller than 8 inches (203 mm) and adult *O. mykiss* larger than 16 inches (406 mm) to be steelhead (Dennis Smith, NMFS, personal communication). NMFS does not yet have a written policy regarding this position or clarifying their relationship with the USFWS in protecting resident rainbow trout and anadromous steelhead.

Adult resident rainbow trout occurring in Central Valley Rivers are often larger than Central Valley steelhead. Several sources indicate resident trout in the Central Valley commonly exceed 16 inches (406 mm) in length. Cramer et al. (1995) reported that resident rainbow trout in Central Valley rivers grow to sizes of more than 20 inches (508 mm). Hallock et al. (1961) noted that resident trout observed in the Upper Sacramento River upstream of the Feather River were 14–20 inches (356–508 mm) in length. Also, at Coleman National Fish Hatchery, the USFWS found about 15 percent overlap in size distribution between resident and anadromous fish at a length of 22.8 inches (579 mm) (Cramer et al. 1995). NMFS's size criterion for steelhead, therefore, has significant overlap with resident rainbow trout occurring in Central Valley rivers, and many resident adult trout will be considered to be steelhead.

Geographic Distribution
Steelhead are distributed throughout the North Pacific Ocean and historically spawned in streams along the west coast of North America from Alaska to northern Baja California. The species is currently known to spawn only as far south as Malibu Creek in southern California (Barnhart 1991, NMFS 1996a). Two major genetic groups exist in the Pacific Northwest, consisting of a coastal and an inland group separated by the Cascade Range crest (Schreck et al. 1986, Reisenbichler et al. 1992). Historic steelhead distribution in the upper San Joaquin River is not known, but in rivers where they still occur they are normally more widely distributed than Chinook (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996), and are typically tributary spawners. Therefore it can be assumed steelhead would have been as least as far upstream as Mammoth Pool in the San Joaquin River, and probably in many smaller tributaries.

Population Trends

The National Marine Fisheries Service (NMFS 1996a) has concluded that populations of naturally reproducing steelhead have been experiencing a long-term decline in abundance throughout their range. Populations in the southern portion of the range have experienced the most severe declines, particularly in streams from California's Central Valley and south, where many stocks have been extirpated (NMFS 1996a). During this century, 23 naturally reproducing populations of steelhead are believed to have been extirpated in the western United States. Many more are thought to be in decline in Washington, Oregon, Idaho, and California. Based on analyses of dam and weir counts, stream surveys, and angler catches, NMFS (1997) concluded that, of the 160 west coast steelhead stocks for which adequate data were available, 118 (74 percent) exhibited declining trends in abundance, while the remaining 42 (26 percent) exhibited increasing trends. From this analysis, the NMFS concluded that naturally reproducing populations of steelhead have exhibited long-term declines in abundance across their range. Steelhead stocks in California, however, have declined precipitously. The current population of steelhead in California is roughly 250,000 adults, which is nearly half the adult population that existed 30 years ago (McEwan and Jackson 1996). Current estimates of all steelhead adults in San Francisco Bay tributaries combined are well below 10,000 fish (Leidy 2001). Steelhead in the San Joaquin River were historically very abundant, though data on their population levels is lacking (McEwan 2001). Currently the steelhead population in the San Joaquin River is drastically reduced from historic levels, and considered extinct by some researchers (Reynolds et al. 1990, as cited in McEwan 2001). However, there is evidence that small populations of steelhead persist in some lower San Joaquin River tributaries (e.g., Stanislaus River) (McEwan 2001). In a review of factors affecting steelhead declines in the Central Valley McEwan and Jackson (1996) concluded that all were related to water development and water management. Impassible dams have blocked historic habitat, forcing steelhead to spawn and rear in lower river reaches, where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001).

Life History

Steelhead is the term used for the anadromous life history form of rainbow trout, *Oncorhynchus mykiss*. Steelhead exhibit highly variable life history patterns throughout their range, but are broadly categorized into winter- and summer-run reproductive ecotypes. Only winter steelhead are believed to have occurred in the San Joaquin River. Winter steelhead, the most widespread reproductive ecotype, become sexually mature in the ocean, enter spawning streams in fall or winter, and spawn a few months later in winter or late spring (Meehan and Bjornn 1991, Behnke 1992). The general timing of winter steelhead life history in California is shown in Table 1. In the Sacramento River, steelhead generally emigrate as 1-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6 - 8 inches being the size of most downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Adult upstream migration and spawning

In the Central Valley adult winter steelhead migrate upstream during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954, both as cited in McEwan and Jackson 1996) (Table 1). Spawning occurs primarily from January through March, but may begin as early as late December and may extend through April (Hallock et al. 1961, as cited in McEwan and Jackson 1996). No information on the run timing or life history of steelhead that occurred in the San Joaquin basin is available apart from the observation of 66 adults seen at Dennett Dam on the Tuolumne River from October 1 through November 30 in 1940 and five in late October of 1942 (CDFG unpublished data). In the Central Valley ESU, adult winter steelhead generally return at ages 2 and 3 and range in size from 2 to 12 pounds (0.9–5.4 kg) (Reynolds et al. 1993).

Adult steelhead migrate upstream on both the rising and falling limbs of high flows, but do not appear to move during flood peaks. Some authors have suggested that increased water temperatures trigger movement, but some steelhead ascend into freshwater without any apparent environmental cues (Barnhart 1991). Peak upstream movement appears to occur in the morning and evening, although steelhead have been observed to move at all hours (Barnhart 1991).

Steelhead are among the strongest swimmers of freshwater fishes. Cruising speeds, which are used for long-distance travel, are up to 1.5 m/s (5 ft/s); sustained speeds, which may last several minutes and are used to surpass rapids or other barriers, range from 1.5 to 4.6 m/s (5 to 15 ft/s), and darting speeds, which are brief bursts used in feeding and escape, range from 4.3 to 8.2 m/s (14 to 27 ft/s) (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 5.2 m (17 feet) over falls (W. Trush pers. comm., as cited in Roelofs 1987).

During spawning, female steelhead create a depression in streambed gravels by vigorously pumping their body and tail horizontally near the streambed. Steelhead redds are approximately 10–30 cm (4–12 in) deep, 38-cm (15-in) in diameter, and oval in shape (Needham and Taft 1934, Shapovalov and Taft 1954). Males do not assist with redd construction, but may fight with other males to defend spawning females (Shapovalov and Taft 1954). Males fertilize the female's eggs as they are deposited in the redd, after which the female moves to the upstream end of the nest and stirs up additional gravel, covering the egg pocket (Orcutt et al. 1968). Females then move two to three feet upstream and dig another pit, enlarging the redd. Females may dig six to seven egg pockets, moving progressively upstream, and spawning may continue for several days to over a week (Needham and Taft 1934). A female approximately 85 cm (33 in) in length may lay 5,000 to 10,000 eggs, with fecundity being related to age and length of the adult female and varying between populations (Meehan and Bjornn 1991). A range of 1,000 to 4,500 eggs per female has been observed within the Sacramento Drainage (Mills and Fisher 1994, as cited in Leidy 2001). In cases where spawning habitat is limited, late-arriving spawners may superimpose their redds atop existing nests (Orcutt et al. 1968).

Although most steelhead die after spawning, adults are capable of returning to the ocean and migrating back upstream to spawn in subsequent years, unlike most other Pacific salmon. Runs may include from 10 to 30% repeat spawners, the majority of which are females (Ward and Slaney 1988, Meehan and Bjornn 1991, Behnke 1992). Repeat spawning is more common in smaller coastal streams than in large drainages requiring a lengthy migration (Meehan and Bjornn 1991). Hatchery steelhead are typically less likely than wild fish to survive to spawn a second time (Leider et al. 1986). In the Sacramento River, California, Hallock (1989) reported that 14 percent of the steelhead were returning to spawn a second time.

Whereas females spawn only once before returning to the sea, males may spend two or more months in spawning areas and may mate with multiple females, incurring higher mortality and reducing their chances of repeat spawning (Shapovalov and Taft 1954). Steelhead may migrate downstream to the ocean immediately following spawning or may spend several weeks holding in pools before outmigrating (Shapovalov and Taft 1954).

Egg incubation, alevin development, and fry emergence

Hatching of eggs follows a 20- to 100-day incubation period, the length of which depends on water temperature (Shapovalov and Taft 1954, Barnhart 1991). In Waddell Creek (San Mareo County), Shapovalov and Taft (1954) found incubation times between 25 and 30 days. Newly-hatched steelhead alevins remain in the gravel for an additional 14–35 days while being nourished by their yolk sac (Barnhart 1991). Fry emerge from the substrate just before total yolk absorption under optimal conditions; later-emerging fry that have already absorbed their yolk supply are likely to be weaker (Barnhart 1991). Upon emergence, fry inhale air at the stream surface to fill their air bladder, absorb the remains of their yolk, and start to feed actively, often in schools (Barnhart 1991, NMFS 1996b). Survival from egg to emergent fry is typically less than 50% (Meehan and Bjornn 1991), but may be quite variable depending upon local conditions.

Juvenile freshwater rearing

Juvenile steelhead (parr) rear in freshwater before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

Juveniles typically remain in their natal streams for at least their first summer, dispersing from fry schools and establishing feeding territories (Barnhart 1991). Peak feeding and freshwater growth rates occur in late spring and early summer. In Steamboat Creek, a major steelhead spawning tributary in the North Umpqua River watershed, juveniles typically rest in the interstices of rocky substrate in the morning and evening, and rise into the water column and orient themselves into the flow to feed during the day when water temperatures are higher (Dambacher 1991). In the Smith River of Oregon, Reedy (1995) suggested that rising stream temperatures and reduced food availability occurring in late summer may lead to a decline in steelhead feeding activity and growth rates.

Juveniles either overwinter in their natal streams if adequate cover exists or disperse as pre-smolts to other streams to find more suitable winter habitat (Bjornn 1971, Dambacher 1991). As stream temperatures fall below approximately 7°C (44.6°F) in the late fall to early winter, steelhead enter a period of winter inactivity spent hiding in the substrate or closely associated with instream cover, during which time growth ceases (Everest and Chapman 1972). Age 0+ steelhead appear to remain active later into the fall than 1+ steelhead (Everest et al. 1986). Winter hiding behavior of juveniles reduces their metabolism and food requirements and reduces their exposure to predation and high flows (Bustard and Narver 1975), although substantial mortality appears to occur in winter, nonetheless. Winter mortalities ranging from 60 to 86% for 0+ steelhead and from 18 to 60% for 1+ steelhead were reported in Fish Creek in the Clackamas River basin, Oregon (Everest et al. 1988, as cited in Dambacher 1991).

Juveniles appear to compete for food and rearing habitat with other steelhead. Age 0+ and 1+ steelhead exhibit territorial behavior (Everest and Chapman 1972), although this behavior may dissipate in winter as fish reduce feeding activity and congregate in suitable cover habitat (Meehan and Bjornn 1991). Reedy (1995) found that steelhead in the tails of pools did not exhibit territorialism or form dominance hierarchies.

Parr outmigration appears to be more significant in smaller basins, when compared to larger basins (Dambacher 1991). In some areas juveniles migrate out of tributaries despite the fact that downstream rearing habitat may be limited and survival rates low in these areas, suggesting that migrants are responding to density-related competition for food and space, or to reduction in habitat quality in tributaries as flows decline (Dambacher 1991, Peven et al. 1994, Reedy 1995). In relatively small tributaries with good rearing habitat located downstream, early outmigration may represent an adaptation to improve survival and may not be driven by environment- or competition-related limitations (Dambacher 1991). Steelhead may overwinter in mainstem reaches, particularly if coarse substrates in which to seek cover from high flows are available (Reedy 1995), or they may return to tributaries for the winter (Everest 1973, as cited in Dambacher 1991).

Rearing densities for juvenile steelhead overwintering in high-quality habitats with cobble-boulder substrates are estimated to range from approximately 2.7 fish/m^2 (0.24 fish/ft^2) (W. Trush, pers. comm., 1997) to 5.7 fish/m^2 (0.53 fish/ft^2) (Meyer and Griffith 1997). Reedy (1995) observed higher densities of juvenile steelhead in the Middle Fork Smith River, California, than in the Steamboat Creek basin; he suggests that this may be due to the greater availability of large bed particles used for overwintering cover and velocity refuge in the Middle Fork Smith River than in Steamboat Creek. Everest and Chapman (1972) report age 0+ densities of 1.3 to 1.5 fish/m^2 (0.12 to 0.14 fish/ft^2) in preferred habitat in Idaho.

Smolt outmigration and estuarine rearing

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 15 to 20 cm (5.85 to 7.80 in) (Meehan and Bjornn 1991). A length of 14 cm (5.46 in) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year olds during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6–8 inches (152–203 mm) being most common for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Evidence suggests that photoperiod is the most important environmental variable stimulating the physiological transformation from parr to smolt (Wagner 1974). During smoltification, the spots and parr marks characteristic of juvenile coloration are replaced by a silver and blue-green iridescent body color (Barnhart 1991) and physiological transformations occur that allow them to survive in salt water.

Less is known regarding the use of estuaries by steelhead than for other anadromous salmonid species; however, the available evidence shows that steelhead in many systems use estuaries as rearing habitat. Smith (1990) concluded that even tiny lagoons unsuitable for summer rearing can contribute to the maintenance of steelhead populations by providing feeding areas during winter or spring smolt outmigration.

Estuarine rearing may be more important to steelhead populations in the southern half of the species' range due to greater variability in ocean conditions and paucity of high quality near-shore habitats in this portion of their range (NMFS 1996a). Estuaries may also be more important to populations spawning in smaller coastal tributaries due to the more limited availability of rearing habitat in the headwaters of smaller stream systems (McEwan and Jackson 1996). Most marine mortality of steelhead occurs soon after they enter the ocean and predation is believed to be the primary cause of this mortality (Pearcy 1992, as cited in McEwan and Jackson 1996). Because predation mortality and fish size are likely to be inversely related (Pearcy 1992, as cited in McEwan and Jackson 1996), the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Pearcy 1992 [as cited in McEwan and Jackson 1996], Simenstad et al. 1982 [as cited in NMFS 1996a], Shapovalov and Taft 1954).

Steelhead have variable life histories and may migrate downstream to estuaries as age 0+ juveniles or may rear in streams up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Steelhead migrating downstream as juveniles may rear for one to six months in the estuary before entering the ocean (Barnhart 1991). Shapovalov and Taft (1954) conducted exhaustive life history studies of steelhead and coho salmon in Waddell Creek (Santa Cruz County, California) and found that coho salmon went to sea almost immediately after migrating downstream, but that some of the steelhead remained for a whole season in Waddell Creek lagoon or the lower portions of the stream before moving out to sea. Some steelhead individuals remained in the lagoon rather than moving out to sea and migrated back upstream and underwent a second downstream migration the following year. In Scott Creek lagoon (Santa Cruz County), Marston (1992, as cited in McEwan and Jackson 1996) found that half of the steelhead rearing in the lagoon in June and July of 1992 were less than 90 mm and appeared to be pre-smolts. Coots (1973, as cited in McEwan and Jackson 1996) found that 34% of juvenile steelhead in San Gregorio Creek lagoon captured in summer were juveniles less than 100 mm [3.9 in] in length. From these studies and others, it has been shown estuaries provide valuable rearing habitat to juvenile and yearling steelhead and not merely a corridor for smolts outmigrating to the ocean.

Ocean phase

The majority of steelhead spend one to three years in the ocean, with smaller smolts tending to remain in salt water for a longer period than larger smolts (Chapman 1958, Behnke 1992). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988). Steelhead grow rapidly in the ocean compared to in freshwater rearing habitats, with growth rates potentially exceeding 2.5 cm (0.98 in) per month (Shapovalov and Taft 1954, Barnhart 1991). Steelhead staying in the ocean for two years typically weigh 3.15 to 4.50 kg (7 to10 lbs) upon return to fresh water (Roelofs 1985). Unlike other salmonids, steelhead do not appear to form schools in the ocean. Steelhead in the southern part of the species' range appear to migrate close to the continental shelf, while more northern populations of steelhead may migrate throughout the northern Pacific Ocean (Barnhart 1991).

Habitat Requirements

Adult upstream migration and spawning

During their upstream migration, adult steelhead require deep pools for resting and holding (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989). Deep pool habitat (>1.5 m) (>4.88 ft) is preferred by summer steelhead during the summer holding period.

Because adult winter steelhead generally do not feed during their upstream migration, delays experienced during migration may affect reproductive success. A minimum depth of about 7 inches (18 cm) is required for adult upstream migration (Thompson 1972, as cited by Barnhart 1986); however, high water velocity and natural or artificial barriers are more likely to affect adult movements than depth (Barnhart 1986, as cited in McEwan and Jackson 1996). Velocities over 8 ft/s (2.4 m/s) may hinder upstream movement (Thompson 1972, as cited in Everest et al. 1985). Steelhead are capable of ascending high barriers under suitable flow conditions and have been observed to make vertical leaps of up to 17 feet (5.1 m) over waterfalls (W. Trush, pers. comm., as cited in Roelofs 1987). Deep pools provide important resting and holding habitat during the upstream migration (Puckett 1975, Roelofs 1983, as cited in Moyle et al. 1989).

Temperature thresholds for the adult migration and spawning life stages are shown in Table 2. These temperatures, however, are from the general literature and may not represent preferred or suitable temperature ranges for Central Valley steelhead stocks. No Central Valley-specific temperature evaluations or criteria were identified by our review. For adult migration, temperatures ranging from 46 to 52°F (8 to 11°C) are considered to be preferred (McEwan and Jackson 1996), while temperatures exceeding 70°F (21°C) are stressful (Lantz 1971, as cited in Beschta et al. 1987). Preferred spawning temperatures range from 39–52°F (4–11°C) (McEwan and Jackson 1996, Bell 1973, 1991), with 68°F (20°C) being considered stressful and 72°F (22°C) considered lethal.

Areas of the stream with water depths from about 18 to 137 cm (7.02 to 53.43 in) and velocities from 0.6 to 1.15 m/s (1.97 to 3.77 ft/s) are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). The average area encompassed by a redd is 4.4–5.9 m2 (47–65.56 ft2) (Orcutt et al. 1968, Hunter 1973, as cited in Bjornn and Reiser 1991). D_{50} values (the median diameter of substrate particles found within a redd) for steelhead have been found to range from 10.4 mm (0.41 in) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 46.0 mm (1.81 in) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Steelhead pairs have been observed spawning within 1.2 m (3.94 ft) of each other (Orcutt et al. 1968). Bell (1986) indicates that preferred temperatures for steelhead spawning range from 3.9º to 9.4ºC (39.0º to 48.9ºF). Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). In the Rogue River drainage, summer steelhead are more likely to spawn in intermittent streams, while winter steelhead typically spawn in permanent streams (Roelofs 1985).

Egg incubation, alevin development, and fry emergence

Incubating eggs require dissolved oxygen concentrations, with optimal concentrations at or near saturation. Low dissolved oxygen increases the length of the incubation period and cause emergent fry to be smaller and weaker. Dissolved oxygen levels remaining below 2 ppm result in egg mortality (Barnhart 1991). Temperature thresholds for the incubation, rearing, and outmigration life history stages are shown in Table 3. Information available in the literature indicates preferred incubation temperatures ranging from 48 to 52°F (9 to 11°C) (McEwan and Jackson 1996, FERC 1993),

Juvenile freshwater rearing

Age 0+

After emergence from spawning gravels in spring or early summer, steelhead fry move to shallow-water, low-velocity habitats such as stream margins and low-gradient riffles and will forage in open areas lacking instream cover (Hartman 1965, Everest et al. 1986, Fontaine 1988). As fry increase in size in late summer and fall, they increasingly use areas with cover and show a preference for higher-velocity, deeper mid-channel waters near the thalweg (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). In general, age 0+ steelhead occur in a wide range of hydraulic conditions (Bisson et al. 1988), appearing to prefer water less than 50 cm (19.5 in) deep with velocities below 0.3 m/s (0.98 ft/s) (Everest and Chapman 1972). Age 0+ steelhead have been found to be relatively abundant in backwater pools and often live in the downstream ends of pools in late summer (Bisson et al. 1988, Fontaine 1988).

Age 1+ and older juveniles

Older age classes of juvenile steelhead (age 1+ and older) occupy a wide range of hydraulic conditions. They prefer deeper water during the summer and have been observed to use deep pools near the thalweg with ample cover as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, Bisson et al. 1988). Age 1+ fish typically feed in pools, especially scour and plunge pools, resting and finding escape cover in the interstices of boulders and boulder-log clusters (Fontaine 1988, Bisson et al. 1988). During summer, steelhead parr appear to prefer habitats with rocky substrates, overhead cover, and low light intensities (Hartman 1965, Facchin and Slaney 1977, Ward and Slaney 1979, Fausch 1993). Age 1+ steelhead appear to avoid secondary channel and dammed pools, glides, and low-gradient riffles with mean depths less than 20 cm (7.8 in) (Fontaine 1988, Bisson et al. 1988, Dambacher 1991).

As steelhead grow larger, they tend to prefer microhabitats with deeper water and higher velocity as locations for focal points, attempting to find areas with an optimal balance of food supply versus energy expenditure, such as velocity refuge positions associated with boulders or other large roughness elements close to swift current with high macroinvertebrate drift rates (Everest and Chapman 1972, Bisson et al. 1988, Fausch 1993). Reedy (1995) indicates that 1+ steelhead especially prefer high-velocity pool heads, where food resources are abundant, and pool tails, which provide optimal feeding conditions in summer due to lower energy expenditure requirements than the more turbulent pool heads. Fast, deep water, in addition to optimizing feeding versus energy expenditure, provides greater protection from avian and terrestrial predators (Everest and Chapman 1972).

Age 1+ steelhead appear to prefer rearing habitats with velocities ranging from 10–30 cm/s (0.33–0.98 ft/s) and depths ranging from 50–75 cm (19.5–29.3 in) (Everest and Chapman 1972, Hanson 1977, as cited in Bjornn and Reiser 1991). During the juvenile rearing period, steelhead are often observed using habitats with swifter water velocities and shallower depths than coho salmon (Sullivan 1986, Bisson et al. 1988), a species they are often sympatric with. In comparison with juvenile coho, steelhead have a fusiform body shape that is better adapted to holding and feeding in swifter currents (Bisson et al. 1988). Where the two species coexist, this generally results in spatial segregation of rearing habitat that becomes most apparent during the summer months. While juvenile coho salmon are strongly associated with low-velocity habitats such as pools throughout the rearing period (Shirvell 1990), steelhead will use riffles (age 0+) and higher velocity pool habitats (age 1+) such as scour and plunge pools in the summer (Sullivan 1986, Bisson et al. 1982).

Preferred rearing temperatures range from 48 to 58°F (9 to 20°C), and preferred outmigration temperatures of <57°F (<13°C) (McEwan and Jackson 1996) (Table 3). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments used steelhead that were reared at the Mokelumne River State Fish Hatchery from eggs were collected at the Nimbus Fish Hatchery (American River). These experiments indicate that Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures ranging from 62.6 to 68°F (17 to 20°C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80°F (27°C).

Winter habitat

Steelhead overwinter in pools, especially low-velocity deep pools with large rocky substrate or woody debris for cover, including backwater and dammed pools (Hartman 1965, Swales et al. 1986, Raleigh et al. 1984, Fontaine 1988). Juveniles are known to use the interstices between substrate particles as overwintering cover. Bustard and Narver (1975) typically found age 0+ steelhead using 10–25 cm (3.9–9.7 in) diameter cobble substrates in shallow, low-velocity areas near the stream margin. Everest et al. (1986) observed age 1+ steelhead using logs, rootwads, and interstices between assemblages of large boulders (>100 cm [39.00 in] diameter) surrounded by small boulder to cobble size (50–100 cm [19.7–39.0 in] diameter) materials as winter cover. Age 1+ fish typically stay within the area of the streambed that remains inundated at summer low flows, while age 0+ fish frequently overwinter beyond the summer low flow perimeter along the stream margins (Everest et al. 1986).

In winter, 1+ steelhead prefer water deeper than 45 cm (17.5 in), while age 0+ steelhead often occupy water less than 15 cm (5.8 in) deep and are rarely found at depths over about 60 cm (23.4 in) (Bustard and Narver 1975). Below 7°C (44.6oF), juvenile steelhead prefer water velocities <15 cm/s (0.5 ft/s) (Bustard and Narver 1975). Spatial segregation of stream habitat by juvenile coho salmon and steelhead is less pronounced in winter than in summer, although older juvenile steelhead may prefer deeper pools than coho salmon (Bustard and Narver 1975).

Ocean phase

Little is known about steelhead use of ocean habitat, although changes in ocean conditions are important for explaining trends among Oregon coastal steelhead populations (Kostow 1995). Evidence suggests that increased ocean temperatures associated with El Niño events may increase ocean survival as much as two-fold (Ward and Slaney 1988). The magnitude of upwelling, which determines the amount of nutrients brought to the ocean surface and which is related to wind patterns, influences ocean productivity with significant effects on steelhead growth and survival (Barnhart 1991). Steelhead appear to prefer ocean temperatures of 9º–11.5ºC (48.2º–52.7ºF) and typically swim in the upper 9–12 m (29.52–39.36 ft) of the ocean's surface (Barnhart 1991).

List of Tables

Table 1. Central Valley winter steelhead life history timing.

LIFE STAGE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Notes
Adult Migration													Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration													Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration													Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration													Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning													Mills and Fisher 1994
Spawning													Peak spawning in California streams (McEwan 2001).
Spawning													Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea													Mills and Fisher 1994
Incubation													Reynolds et al. 1993
Emergence													Eggs hatch in 30 days at 51°F (Leitritz and Lewis 1980, as cited in McEwan 2001).
Emergence													Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).

Table 1. cont.

LIFE STAGE	MONTH												Notes
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Emergence													Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River Based on the results of emergence analysis for water temperature in SJR, Jones and Stokes estimated that emergence may occur between March 15 and August 30.
Rearing													In California scale analysis showed 70% Reared for two years, 29% for one year, and 1% for three years (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration													Geographic area: Sacramento River Migrate downstream in every month of the year, with a peak in the spring, and a smaller peak in the fall (Hallock et al. 1961, as cited in McEwan 2001).
Outmigration													Geographic area: lower Sacramento Migrated past Knights landing in 1998 from late December through early May, and peaked in mid-March (DFG unpublished data, as cited in McEwan 2001).
Outmigration													Reynolds et al. 1993
Outmigration													Jones and Stokes 2002 Foundation Runs Report Geographic area: Woodbridge Dam Outmigrating yearling and older steelhead detected January through July, and young of year detected April through July (Natural Resource Scientist 1998b, as cited in Jones and Stokes 2000).

	Span of Light Activity
	Span of Moderate Activity
	Span of Peak Activity

Table 2. Temperature thresholds for steelhead adult migration and spawning

Life History Stage	Temperature	Comments	Source
Adult Migration	46–52°F (8–11°C)	preferred	McEwan and Jackson 1996
	>70°F (21°C)	stressful (Columbia River)	Lantz 1971, as cited in Beschta et al. 1987
Spawning	39–49°F (4–9°C)	preferred	Bell 1973, 1991
	39–52°F (4–11°C)	preferred	McEwan and Jackson 1996
	68°F (20°C)	stressful	FERC 1993
	>72 °F (>22°C)	lethal	FERC 1993
	75°F (24°C)	upper lethal	Bell 1991

Table 3. Temperature thresholds for incubation, rearing, and outmigration of steelhead

Life History Stage	Temperature °F (°C)	Comments	Source
Incubation	50°F (10°C)	preferred (hatching)	Bell 1991
	48–52°F (9–11°C)	preferred □incubation and emergence□	McEwan and Jackson 1996 FERC 1993
	>55°F (>12.8°C)	stressful	FERC 1993
	60°F (15.6°C)	lethal	FERC 1993
Juvenile Rearing	48–52°F (9–11°C)	preferred □fry and juvenile rearing□	McEwan and Jackson 1996
	55–65°F (12.8–18.3°C)	optimal	FERC 1993
	62.6–68°F (17–20°C)	preferred □Central Valley Steelhead□	Myrick (1998) p. 134
	50–59°F (10–15°C)	preferred	Moyle et al. 1995
	68°F (20°C)	sustained upper limit	Moyle et al. 1995
	77°F (25°C)	lethal	FERC 1993
	80°F (27°C)	lethal critical thermal maximum □Central Valley Steelhead□ □absolute maximum temperature tolerated□	Myrick (1998)
Smolt Outmigration	<57°F (14°C)	preferred	McEwan and Jackson 1996
	>55°F (13°C)	stressful (inhibit gill ATPase activity)	Zaugg and Wagneer 1973, Adams et al., 1975, both as cited in ODEQ 1995

Common Name	**Scientific Name (family)**
Inland silverside	*Menidia beryllina* (Atherinopsidae)

Legal Status:

Federal none
State none

Distribution

Inland silversides appear to be native to estuaries and lower reaches of coastal rivers from Maine to Florida and along the Gulf Coast from Florida to Veracruz, Mexico. They occur in the Mississippi River from southern Illinois to the coast including Texas and Oklahoma. Inland silversides were introduced from Oklahoma to Blue Lakes and Clear Lake, Lake County, California in 1967. The species rapidly spread through introductions, both illegal and those authorized by CDFG. It was well established in the San Francisco Bay area by 1975 and spread further to the San Joaquin River, and then, via the aqueduct and reservoir system, to southern California.

Life History

Silversides grow fast and have a short lifespan. Most fish reach 8-10cm TL in their first year and spawn and die during their first or second summer of life. Females grow faster and larger than males and may live a third year. Silversides are fractional spawners, meaning they can spawn using a fraction of their gonads on nearly a daily basis when temperatures reach 15-30°C. Females can produce 200-2,000 eggs per day during the California spawning season that runs from April-September. Fertilized eggs are adhesive and attach to substrate. Larvae hatch in 4-30 days depending on water temperature. Due to their reproductive capacity, silversides are now the most abundant fish throughout much of their range in California, including the San Francisco Estuary.

Habitat Requirements

Silversides are most abundant in shallow areas of warm water lakes, reservoirs, and estuaries. Silversides typically shoal in large numbers, in or near protected areas with sand or gravel bottoms. They apparently move into open waters to feed on zooplankton and move into shallow water to avoid predation at night. They occur in waters of 8-34°C with optimal temperatures of 20-25°C. Optimal salinities appear to be 10-15 ppt, but they can survive salinities as high as 33 ppt. Larval survival is highest around 15 ppt.

Ecological Interactions

The rapid expansion of the silverside population has resulted in their becoming the most abundant fish throughout much of their range in California, including the San Francisco Estuary and the San Joaquin River. They occupy the same shallow water habitat that is important for rearing of juvenile salmon, splittail, and other fishes. Silversides have the potential to deplete zooplankton populations in these habitats that may influence growth and survival of juveniles of other species. Silversides may also prey on eggs and larvae of other species of fishes. Although other factors may also be important, delta smelt populations declined shortly after the introduction of silversides to the estuary.

Key Uncertainties

The ecological interactions between the introduced silversides and other species have not been well studied. Silversides may have adverse affects on native species through predation on their larvae and eggs or competition for food.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Black crappie	*Pomoxis nigromaculatus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

The natural range of the black crappie is in the fresh (and rarely brackish) waters of eastern and central North America from Quebec south to the Gulf coast and from Virginia south to Florida and from Manitoba south to central Texas. Black crappies were probably introduced into California in 1908 when white crappies were also introduced. They were introduced to the Central Valley around 1916-1919 and are now well established throughout the state in reservoirs or where there is warm quiet water.

Life History

Black Crappies mature in their second year at around 10-20 cm TL. Spawning begins when water temperatures reach 14-17ºC in March or April and may continue through July. Males construct 20-23 cm diameter nests in shallow water (<1 m) near cover such as overhanging banks or aquatic vegetation. Females can produce up to 188,000 eggs depending on the size of the fish. Males defend the nest and fry for a short period. Fry leave the nest and spend the next few weeks in the plankton before settling around structures. Young-of-the-year crappie grow rapidly and can reach 4-8 cm their first year. Black crappie can live 13 years and reach 2.2 kg in weight.

Black crappie prey in midwater on zooplankton, dipteran larvae, aquatic insects, planktonic crustaceans, and on fish such as threadfin shad, inland silversides, and juvenile striped bass. They may be somewhat less piscivorous than white crappie.

Habitat Requirements

Black Crappie prefer large warm water lakes and reservoirs and are usually associated with abundant aquatic vegetation and sandy/muddy bottoms. They prefer water that is less turbid than that preferred by white crappie. Preferred summer water temperatures are around 27-29ºC and temperatures over 37-38ºC are usually lethal. They can survive greater temperature extremes than the white crappie. Although their salinity (<10 ppt) and dissolved oxygen (>1-2 mg/liter) tolerances are similar to white crappie they are more abundant in the tidal sloughs of the San Francisco estuary.

Ecological Interactions

Black crappie can show population fluctuations in relation to abundance of competing and prey species. Black crappie are ecologically similar to Sacramento perch, a native species. Once black crappie become established, they may displace Sacramento perch from breeding sites, and through predation and competition for food.

Key Uncertainties

When black crappie first became established in the Sacramento – San Joaquin delta region in the 1920s the numbers of Sacramento perch declined. It is unclear why black crappie may displace the Sacramento perch.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	Scientific Name (family)
Bluegill	*Lepomis macrochirus*
(Centrarchidae)	

Legal Status:

Federal none
State none

Distribution

Bluegill are native to the freshwaters of eastern and southern North America from the St. Lawrence and Mississippi drainages south to Florida and northeastern Mexico. Bluegill were introduced to California in 1908 and became widely distributed throughout the state. They are probably the most widely distributed freshwater fish in California.

Life History

Spawning begins in spring when water temperatures reach 18-21ºC and may continue through the summer into September. Males construct nests in shallow waters that are approximately 20-30 cm in diameter. Females approach the male and deposit eggs in the nest as the male fertilizes them. Fertilized eggs adhere to debris at the bottom of the nest. Males and females spawn with multiple partners. Sunfish in general have a complex mating system. Females lay 2,000-50,000 eggs that hatch in 3-5 days. The nesting male may guard the newly hatched larvae for a short period until the next breeding cycle. Fry seek shelter in aquatic plants but may forage in the plankton before settling in plant beds near shore at 21-25 mm TL. Bluegill are opportunistic feeders, but because their mouths are relatively small they prey on a variety of smaller organisms including aquatic insects, fish, fish eggs, snails, zooplankton, and crayfish.

Habitat Requirements

Bluegill prefer warm, shallow lakes, reservoirs, ponds, streams, and sloughs but can survive as slow growing populations in colder systems. They are often associated with rooted plants and aquatic vegetation where they can hide and feed. Bluegill spend most of their lives in a small area where they become are able to find food and avoid predators. Bluegill prefer temperatures of 27-32ºC but can tolerate temperatures as low as 2-5ºC and as high as 40-41ºC. Preferred salinities are below 1-2 ppt but bluegill have been recorded in salinities up to 5 ppt in the San Francisco estuary. Salinities of 12 ppt are lethal to bluegill. Maximum growth and reproduction occur in clear waters and dissolved oxygen of 4-8 mg/liter.

Ecological Interactions

This species is known to hybridize with warmouth, green sunfish, and pumpkinseed sunfish. Bluegills are often associated with assemblages of other non-native fishes such as largemouth bass, green sunfish, redear sunfish, catfish, golden and red shiners, carp, inland silverside, and western mosquitofish. Bluegill also sometimes serve as cleaner fish for other fishes (i.e. smallmouth bass). Because bluegill are so adaptive, aggressive, and prolific, they are an alien fish that limit native fish populations through predation on larvae and indirect effects that may make native fish more vulnerable to predators.

Key Uncertainties

The long-term effects of bluegill on native fishes are not known.

Key References

Moyle 2002; Scott and Crossman 1973

Common Name	Scientific Name (family)
Green sunfish	*Lepomis cyanellus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

The green sunfish is native to the fresh waters of east-central North America including the great Lakes and most of the Mississippi drainage. They now occur in every state in the United States including California due to introductions. They were first introduced to California in 1891 and have been spread throughout the state since then.

Life History

Spawning begins when water temperatures reach around 19°C. Males dig 15-38 cm diameter nests in 4-50 cm deep water. Females hover around the nests while males court and spawn with them. Males and females spawn with multiple partners. Females carry 2,000-10,000 eggs which when fertilized, adhere to the nest substrate, and are guarded by males. Eggs hatch in 5-7 days. Larvae feed on zooplankton for several days before seeking cover in vegetation. Green sunfish are opportunistic predators and feed on a wider spectrum of benthic invertebrates, zooplankton, and small fish than other species of sunfish. Green sunfish rarely grow larger than 15 cm SL although they can reach 30 cm SL and live 10 years. They often form stunted populations since they can reproduce at a small size (5-7 cm SL). Green sunfish are very aggressive and older fish can be territorial forming dominance hierarchies. This aggressiveness makes green sunfish susceptible to angling. They feed on invertebrates and small fish including insects, zooplankton, benthic invertebrates, crayfish, and fish larvae including their own.

Habitat Requirements

Green sunfish can survive temperatures greater than 38°C but prefer 26-30°C. They can withstand low oxygen levels (<1 mg/L) but avoid salinities higher than 1-2 ppt. They are good colonizers and can reoccupy dewatered stream reaches by surviving in intermittent pools. Green sunfish are found in small, warm, streams, ponds and lake edges. They usually are found associated with dense growths of emergent vegetation and brush piles. They are often the sole species in warm isolated pools in intermittent streams that have been affected by human disturbance. Green sunfish are capable of surviving where other species cannot.

Ecological Interactions

Water withdrawals may be enhancing intermittent pool-type habitat that this species prefers. They are part of the introduced predator species complex in California, and they are aggressive and form stunted populations that compete with or prey on native species such as the California roach, sticklebacks, and minnows. They prevent the reestablishment of native species if their habitat requirements are similar. They are known to hybridize with bluegill and pumpkinseed sunfish.

Key Uncertainties

It is not known how to prevent further spread or creation of habitat beneficial to this species, or how to eradicate this species where it does the most harm.

Key References

Moyle 2002; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Largemouth bass	*Micropterus salmoides*
(Centrarchidae)	

Legal Status:

Federal none
State none

Distribution

The native range of largemouth bass is from northeastern Mexico east to Florida, and north including the Mississippi River to Ontario and Quebec, and along the Atlantic seaboard to South Carolina. Largemouth bass were first introduced to California in 1891 from Illinois and were quickly distributed throughout California. A second introduction of Florida largemouth bass occurred in 1959 that also became widely distributed and promptly hybridized with the northern strain. Largemouth bass now occur throughout California in streams, lakes, and reservoirs.

Life History

Largemouth bass become sexually mature during their second or third year when they reach approximately 18-21 cm TL in males and 20-25 cm in females. Males construct nests in gravel or among aquatic vegetation in approximately 1-2 m of water when water temperatures reach 15-16º C. Females may lay eggs in multiple nests and may lay a total of 2,000-94,000 eggs. Eggs adhere to the substrate and hatch in 2-7 days depending on water temperature. Males guard the eggs and then the fry for up to four weeks. Fry form large schools that feed on zooplankton and patrol along vegetation and cover in shallower waters. Fry are vulnerable to predation at this time. Growth rates appear to be more variable for largemouth than for smallmouth bass. Many variables including genetics, food availability, water temperature, and competition may influence growth. Largemouth bass live to be more than 4 years old and exceed 45 cm TL. The largest largemouth on record weighed 9.9 kg and was caught in Castaic Reservoir, Los Angeles County. The Florida strain of bass, or hybrid, appears to grow larger than the northern strain. Largemouth bass eat zooplankton and insects when they are fry and then aquatic insects, fish fry, and small crustaceans as they grow. Adult largemouth bass are adaptable predators and can feed on a variety of prey including larger invertebrates, amphibians, small mammals, and fish. Largemouth bass may also cannibalize young of their own species, including when they are fry and swim in large schools.

Habitat Requirements

Largemouth bass prefer warm, quiet water lakes, ponds, sloughs, abandoned gravel mine pits, and backwaters of low gradient streams, with relatively low turbidity, and with vegetative cover. Largemouth bass are frequently found in disturbed areas and in association with other non-native species especially other centrarchids. Areas with current velocities ≤ 6 cm/s (0.2 ft/s) would constitute optimal habitat and velocities over 10 cm/s (0.34 ft/s) would likely be avoided. Adults prefer water temperatures of 25-30º C but can tolerate water temperatures of 37ºC. Juveniles may prefer slightly warmer waters (30-32ºC). Largemouth bass can tolerate dissolved oxygen as low as 1mg/liter and salinities as high as 16 ppt but they tend to avoid salinities over 5 ppt. Their adaptability to habitat extremes enables largemouth bass to survive in intermittent pools caused by drought or diversions. As a result they can persist in an area and their populations can quickly recover once flows resume. Habitat suitability for largemouth bass is not likely determined by depth as much as by velocity, temperature, and prey availability. In the Sacramento-San Joaquin Delta, largemouth bass and other centrarchid populations appear to be responding positively to increased habitat provided by an introduced aquatic plant, *Egeria densa*.

Ecological Interactions

Wherever largemouth bass are present they generally have adverse impacts on native species due to predation. In isolated water bodies they are capable of causing native species extirpations, and in larger systems they can effectively extirpate native species from certain areas. Largemouth bass can selectively feed on certain species to the point where they influence those populations. The reduction in a population of a native species, such a planktivore, by largemouth bass can result in a cascade effect that may cause changes to not only species composition in a water body but water quality parameters as well.

Key Uncertainties

The predation dynamics associated with increased bass and other centrarchid populations on salmonids and other native species is poorly understood.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	Scientific Name (family)
Pumpkinseed	*Lepomis gibbosus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

Pumpkinseeds are native to eastern North America from Canada to Georgia and in the upper Mississippi drainage west to South Dakota. They were apparently introduced to California in the early 1900s and have been reported from the Klamath basin, Susan River, Sacramento-San Joaquin rivers and southern California. Due to illegal introductions, pumpkinseed can be expected throughout the state in cool, quiet waters.

Life History

Pumpkinseeds mature in approximately 2 years. Spawning occurs when temperatures reach 13-17ºC from April through June. Males build nests on the bottom in less than one meter of water and defend the nest. Males and females spawn with multiple partners. Females lay 600-7,00 eggs that hatch in 3-5 days. Males defend the larvae for a short period before the young swim into open waters and feed on zooplankton. After several weeks the young settle out and associate with vegetation and structures.

Pumpkinseeds grow slowly but live relatively long: they rarely exceed 30 cm FL but can live 12 years. Pumpkinseeds feed on hard-shelled invertebrates such as insects, snails, and bivalves that they pick from the bottom or from vegetation.

Habitat Requirements

Pumpkinseeds prefer quiet, cool, clear or slightly turbid waters in lakes, ponds, sloughs, and sluggish streams. They are usually associated with aquatic vegetation or other structure. Ecologically they are similar to redear sunfish, but can withstand cooler water temperatures. They prefer water temperatures of 24-32ºC but can withstand high temperatures of up to 38ºC and lows down to 3-4º C. They can survive higher salinities up to 17 ppt and can withstand dissolved oxygen levels as low as 4 mg/L.

Ecological Interactions

Pumpkinseeds have the potential to compete with and prey on native species. They have the potential to populate cooler waters including middle to higher elevation reservoirs and compete with native fishes there.

Key Uncertainties

Pumkinseed population dynamics are not known, but they appear to be spreading in Sacramento-San Joaquin rivers.

Key References

Moyle 2002; Scott and Crossman 1973; Lee et al. 1973

Common Name	**Scientific Name (family)**
Redear sunfish	*Lepomis microlophus*
(Centrarchidae)	

Legal Status:

Federal none
State none

Distribution

Redear sunfish are native to the southeastern United States and from Florida to the Rio Grande including the lower Mississippi drainage. The were first recorded in California in 1951 and have since been introduced to southern California, the Central Valley, the Russian River, and likely farm ponds and other waters throughout the state.

Life History

Redear sunfish usually mature by the second year and spawning occurs throughout the summer months when temperatures reach 21-24ºC. Males construct nests 25-62 cm in diameter, attract females and spawn much like other sunfishes. Females lay 9,000-80,000 eggs. Larvae appear to be planktonic before settling into aquatic vegetation. Redear sunfish feed on aquatic snails and hard-shelled invertebrates from the bottom and aquatic plants, and are known to feed on introduced mollusk species. They also feed on insect larvae and cladocerans.

Habitat Requirements

Redear sunfish prefer to inhabit deeper clear warm waters (> 2 m) of ponds, lakes, backwaters, and sloughs. They are most often found in aquatic vegetation, brush, stumps, logs and other cover. They are rarely found in the brackish waters of the San Francisco estuary but can tolerate salinities up to 20 ppt, which makes them one of the more saline tolerant sunfishes. Turbid waters can inhibit redear sunfish reproduction. Turbid waters reduce light penetration to deeper water and decreases plant growth at depth, which forces redear sunfish into shallower waters where they are forced to compete with other species such as bluegill.

Ecological Interactions

Redear sunfish compete with bluegill, green sunfish, and pumpkinseed especially where turbid waters force them into the shallows where vegetation can grow. Other introduced sunfishes may have a greater impact on native fish species than redear sunfish do. Redear are not as common as bluegill and green sunfishes and their preferred diet of snails and bivalves often includes introduced species as well.

Key Uncertainties

Little is known about the ecology and dynamics of California populations of redear sunfish. Because of their relatively recent introduction in California, their role in the decline of native fishes is poorly understood.

Key References

Moyle 2002; Lee et al. 1980

Common Name	**Scientific Name (family)**
Smallmouth bass (Centrarchidae)	*Micropterus dolomieu*

Legal Status:

Federal none
State none

Distribution

The native range of smallmouth bass is the eastern waters of North America from Minnesota and Quebec south to Alabama and west to Oklahoma. Smallmouth bass were first introduced to California in 1874 and are now widely distributed in rivers and reservoirs throughout California. Smallmouth bass now occur in most streams and reservoirs in the Central Valley, the Pit River, Russian River, Mad River, Freshwater Lagoon, Trinity River, Carmel River, Colorado River, Lake Tahoe, and other streams in southern California.

Life History

Smallmouth bass become mature in their third or fourth year and begin to spawn when water temperatures reach 13-16ºC in May and June. Males construct nests in gravel in approximately 1-2 m of water with nests containing 2,000-21,000 eggs. Males and females are apparently monogamous. Males defend eggs and fry for up to four weeks when the fry reach 20-30 mm TL and disperse into shallower waters. Growth rates appear to be less variable for smallmouth than for largemouth bass because the parameters (temperature, salinity, DO) of their occupied habitats appear to be more uniform. Smallmouth bass live to be more than 4 years old and may exceed 40 cm TL. Smallmouth bass eat zooplankton and insects when they are fry and then aquatic insects and small crustaceans as they grow. Adult smallmouth bass are predators on larger invertebrates, amphibians, small mammals, and fish. Adult smallmouth bass often feed on crayfish, which are frequently also introduced species. Smallmouth bass may also cannibalize young of their own species.

Habitat Requirements

Smallmouth bass prefer cool (20-27ºC), large, clear-water lakes and streams of moderate gradient with riffle-pool morphology, relatively low turbidity, and rocky substrates. Optimal stream reaches for adult smallmouth contain large pools, slow runs, eddies, or backwaters with abundant cover (e.g., boulders, rock ledges, undercut banks, and LWD) and prey (especially small fish and crayfish) and cobble-boulder substrates. In streams, larger adult smallmouth bass have been described variously as pool guild members, run or pool inhabitants, and habitat generalists. The biology of the smallmouth bass is quite similar to that of the largemouth bass; however, the smallmouth bass shows a somewhat greater preference for cooler streams with areas of swifter velocities. Water temperatures above 38ºC can be lethal. Smallmouth bass can tolerate dissolved oxygen as low as 1-3 mg/L but prefer oxygen levels above 6 mg/L.

Ecological Interactions

Smallmouth bass often exist with native species that have similar habitat requirements but their interactions are not well understood. Smallmouth bass may compete with hardheads for crayfish since they are a major component in the diet of both species. Smallmouth bass may also prey on juvenile Sacramento pikeminnow and hardhead and may adversely impact native frog populations. Under certain conditions, such as drought and warmer water conditions, smallmouth bass may have a reproductive advantage and have a greater impact on native fishes. Conversely, during cool years native fishes may spawn earlier and their juveniles may prey on smallmouth fry.

Key Uncertainties

Impacts on native fishes by smallmouth bass are not well known. However, impacts in water supply reservoirs may not be too severe where native fish are not very abundant. Methods to enhance native fish populations in relatively undisturbed areas where smallmouth bass coexist have not been established.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
Spotted bass	*Micropterus punctulatus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

The native range of spotted bass was the central and lower Mississippi River and along the Gulf coast from Texas to northwestern Florida. Spotted bass were introduced from Ohio to California in 1933. Spotted bass were introduced throughout southern California and the Central Valley after 1974. They are now widely distributed in rivers and reservoirs throughout California, including those in the Central Valley.

Life History

Spotted bass become mature in their second year and begin to spawn when water temperatures reach 15-18ºC in late spring. Males construct nests in gravel in 0.5-4.6 m of water. Spawning continues until water temperatures reach 22-23ºC. Males and females are apparently monogamous but males may have more than one nest. Each nest contains 2,000-14,000 young, which are vigorously defended by the male for up to four weeks until the fry disperse when they are 30 mm TL. Growth rates are higher in warm-water reservoirs and slower in cool streams. Spotted bass can live to be 4-5 years old and may reach approximately 40 cm TL. Spotted bass are predators on larger invertebrates and fish, and larger fish eat larger prey. Fry eat zooplankton and insects and juveniles up to 75 mm eat aquatic insects and crustaceans. Fish over 75 mm eat fish, crustaceans and aquatic and terrestrial insects. The most common fish prey species are sunfishes, crappie, and threadfin shad. Spotted bass may also cannibalize young of their own species.

Habitat Requirements

Spotted bass prefer clear, low gradient waters in rivers and reservoirs. They inhabit slower more turbid water than smallmouth bass prefer, and faster water than largemouth bass. In rivers they occupy pools and avoid riffles and backwaters with heavy cover. In reservoirs they are found along steep, rocky underwater slopes, in the end where streams enter. Spotted bass prefer summer temperatures of 24-31ºC with adults just above the thermocline in moderate depths. Juveniles remain near shore in shallow water. They have a low salinity tolerance although they have been found in 10 ppt waters.

Ecological Interactions

Bluegills are common predators of spotted bass embryos and fry. Spotted bass may hybridize with smallmouth bass and redeye bass. Spotted bass may compete with, and prey on native fishes under certain circumstances.

Key Uncertainties

Impacts on native fishes by spotted bass are unknown. However impacts may not be too severe in water supply reservoirs where native fish are not very abundant. Spotted bass are capable of swimming up reservoir tributary streams on a seasonal basis where they may compete with and prey on native fishes.

The affects of hybridization with other species of bass are unknown.

Key References

Moyle 2002; Lee et al. 1980

Common Name	Scientific Name (family)
Warmouth	*Lepomis gulosus* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

Warmouth are native to the Mississippi River drainage, the Rio Grande, Florida and much of the Atlantic seaboard. Warmouth were introduced to California and were first mentioned in the 1930s. They are now found throughout the Central Valley and associated reservoirs. Although warmouth are established in California, they are relatively uncommon when compared to other sunfishes.

Life History

Warmouth live fairly long (6-8 years) but grow slowly. A 28 cm fish would be considered very large. They are known to have stunted populations where fish 10 cm TL are 4-6 years old. Warmouth mature in their second summer, and spawning occurs in late spring and early summer when water temperatures reach 21ºC. Males build nests near dense cover in 0.5-1.5 m deep water. Spawning behavior is similar to other sunfishes. Females produce 4,500-63,000 eggs depending on the size of the fish. Warmouth feed mainly on insects, snails, crayfish, and fish.

Habitat Requirements

Warmouth prefer abundant vegetation and cover in warm turbid, muddy bottom sloughs of the Central Valley, and they also do well in reservoirs. They are uncommon in tidal portions of the estuary. The preferred habitat parameters include summer water temperatures 22-28°C, salinities under 4 ppt, and oxygen levels above 4 mg/L although they can withstand lower levels.

Ecological Interactions

Warmouth may hybridize with bluegill.

Key Uncertainties

The ecological role of warmouth in the sloughs and reservoirs of the Central Valley is poorly understood. Their interactions with other fish species are not well known.

Key References

Moyle 2002; Lee et al. 1980

Common Name	Scientific Name (family)
White Crappie	*Pomoxis annularis* (Centrarchidae)

Legal Status:

Federal none
State none

Distribution

White crappie naturally occurred in the freshwaters of east central North America from southern Ontario and New York west of the Appalachian Mountains, south to the Gulf coast, and west to Texas and South Dakota. White crappie were apparently introduced to southern California around 1908. They were not planted north of the Tehachapi Mountains until 1951 when they were also were introduced in the north from Oregon. They are now well established in all major river systems and reservoirs in California.

Life History

White crappie become mature in 2-3 years at 10-20 cm TL, and spawning usually begins in April and May when water temperatures reach 17-20ºC. Males construct either isolated nests or nests in colonies in waters that are usually less than less than 1 m deep but sometimes as deep as 6-7 m. Females may spawn in the nests of several different males. Eggs adhere to substrate in the nest, which is defended by the male. Females may have 27,000 to 68,000 eggs that hatch into planktonic larvae. Small juveniles feed in the plankton but return to protected areas near shore. White Crappie can live longer than 7-8 years and reach a size greater than 35 cm FL.

Habitat Requirements

White crappie occur in warm, turbid, streams, lakes, ponds and slow moving rivers. They are apparently more tolerant of high turbidity, higher salinity, higher currents, and higher temperatures than the black crappie but have a lower tolerance of low dissolved oxygen levels. Black crappies displace white crappie in reservoirs that have oxygen levels less than 2-4 mg/liter. White crappies also appear to tolerate a lack of aquatic vegetation and cover better than black crappie. Nests are constructed in hard clay bottoms close to bushes or overhanging branches. Optimal temperatures for white crappie range from 27-29º C with a maximum tolerance of around 31º C. White crappie are rare in estuaries but have been reported in salinities as high as 10 ppt. White crappie are shoaling fishes that congregate around structure during the day but move into open water to feed during evening and morning periods. White crappie eat a variety of prey including planktonic crustaceans, small fish, and aquatic insects. Fish and larger invertebrates are the preferred diet of fish larger than 140 mm FL. Threadfin shad are an important prey item.

Ecological Interactions

White crappie populations may interact with native and non-native populations of fish through predation and competition. Inland silversides may compete for plankton with white crappie larvae and juveniles. Some populations of white crappie have demonstrated a boom and crash cycle in some locations (Clear Lake).

Key Uncertainties

How white crappie populations affect native fishes is not known. Effects may be minimal since most crappie populations are located in reservoirs or other highly disturbed areas where native fishes may not be present.

Key References

Moyle 2002; Lee et al. 1980; Scott and Crossman 1973

Common Name	**Scientific Name (family)**
American shad	*Alosa sapidissima*
(Clupeidae)	

Legal Status:

Federal none
State none

Distribution

American shad are anadromous and native to the Atlantic Coast from Labrador to Florida. They were introduced into the Sacramento River in 1871-1881. Once established, American shad spread quickly along the West Coast. Their current distribution is from Todos Santos Bay, Baja California, to Alaska and Kamchatka, USSR. In California, American shad are found in the Sacramento River system, the Delta, and the San Joaquin River system, the Klamath River, the Eel River, and the Russian River. A unique and successfully reproducing landlocked population exists in Millerton Lake, Madera County.

Life History

The anadromous American shad enter fresh water to spawn in the spring when water temperatures exceed 14º C although mature fish may occupy the estuary since the previous autumn. Males mature at 3-5 years and females at 4-5 years. Peak spawning occurs at temperatures around 18º C. The largest runs in the Sacramento are not seen until late May and early June. Fish spawn repeatedly over several days and eggs are fertilized in open water. Females can produce 20,000-150,000 eggs. Shad do not always die after spawning and surviving adults return downstream. Fertilized eggs are slightly negative buoyant, are not adhesive, and drift in the current. Eggs hatch in 8-12 days at 11-15º C but can hatch as quickly as 3 days at 24º C. Hatching success may be lower at higher temperatures. Larvae are 6-10 mm when they hatch and are planktonic for about 4 weeks. Juvenile shad can tolerate salinities of up to 20 ppt, and leave the estuary at 5-15 cm FL in September through November. However, some juveniles may use the estuary as a nursery for one to two years.

Growth may be related to water temperature and the availability of prey. Shad are reported to live up to seven years in California and males may reach 42 cm FL and females may reach 48 cm FL during that time. Young shad in the San Francisco estuary feed on zooplankton, bottom organisms, and surface insects. Little is known about shad during their 3-5 years at sea, although emigrating fish tagged in the Sacramento River have been recaptured from Monterey to Eureka. Shad may live to be 7 years old.

Habitat Requirements

American shad spend most of their adult life at sea and may make extensive migrations along the coast. American shad are anadromous and need larger rivers for reproduction and juvenile rearing. They require spring water temperatures of 14-24º C for spawning to occur. Shad ascend freshwater rivers in the spring and migrate upstream, sometimes for considerable distances. Mass spawning occurs in the main channels of rivers in 1-10 m of water over a variety of substrates. Water velocity ranges from 31-91 cm/sec.

Ecological Interactions

Shad populations have been declining and are approximately one third the number that they were 60 years ago. Dams and other obstructions impede juvenile and adult shad migration in many areas. Pollution, pesticides, and water diversions may also affect adult and juvenile shad populations.

Key Uncertainties

The affect of pesticides on larval shad and shad populations is not clear. The effects of changing ocean conditions on adult populations are not understood.

Key References

Moyle 2002; Lee et al. 1980; Scott Crossman 1973

Common Name	**Scientific Name (family)**
Threadfin shad	*Dorosoma petenense* (Clupeidae)

Legal Status:

Federal none
State none

Distribution

The native range of threadfin shad is from the Ohio River of Kentucky and southern Indiana, south to Texas and Florida including streams and rivers that flow into the Gulf of Mexico. Their range extends south to Guatemala and Belize. Threadfin shad were first introduced into California in San Diego County in 1953 and then were planted in reservoirs throughout the state and in the Sacramento-San Joaquin drainage in 1959. Threadfin shad are now well established in the Sacramento and San Joaquin rivers and the Delta and San Francisco Estuary. They also occur in the marine environment and have been recorded from Long Beach to Yaquina Bay, Oregon.

Life History

Spawning occurs in open water during spring when water temperatures exceed 21ºC. Eggs adhere to plants, floating or submerged objects, or under brush or logs. Threadfin shad may spawn at less than one year old. Females may release 900-21,000 eggs depending on the size of the female. Eggs hatch in 3-6 days and larvae immediately become planktonic. Larvae become juveniles in 2-3 weeks and form dense schools of similar size and age class. Threadfin shad grow fast and have short life spans, rarely living past 2 years and 10 cm TL. The largest California specimen was 22 cm TL. Like all clupeids, threadfin shad are planktivores and feed on zooplankton, phytoplankton, and detritus. They can strain food with their gill rakers or pick off individual organisms.

Habitat Requirements

Threadfin shad are found in lakes, ponds, larger rivers, estuaries, and reservoirs. They can also be found in the swifter waters of tailraces, near stream inlets and along dam faces, usually no deeper than 18 m. They prefer summer water temperatures of 22-24ºC and waters that do not become colder than 7-14ºC in winter. Threadfin shad cannot endure temperatures below 4ºC for long periods. The Sacramento-San Joaquin populations experience die offs when temperatures drop to 6-8ºC. Threadfin shad can survive and grow in seawater but apparently prefer fresh water and require it for successful reproduction.

Ecological Interactions

Threadfin shad were intentionally introduced into California as a forage fish for game fish. Their populations have the ability to rapidly increase when they are introduced into suitable habitat. At some locations the introduction has been a success with increased game fish growth rates. However, in some locations, threadfin shad proved to be unavailable as prey items to small warm water game fish due to their open water preference. In addition, threadfin shad may compete with and consume the planktonic larval stages of many warm water game fish, such as centrarchids (including the basses). The growth and survival of larval centrarchids in some reservoirs may decrease when threadfin shad are present.

Key Uncertainties

The effect of threadfin shad on native species, especially those with planktonic larvae, is poorly understood. Threadfin shad numbers have slowly declined in the Sacramento- San Joaquin Delta in the last 20 years. This may indicate a general decline of planktonic fishes in the estuary. The ecological role of threadfin shad in this ecosystem is not well known.

Key References

Moyle 2002; Lee et al 1980

Common Name	Scientific Name (family)
Common carp (Cyprinidae)	*Cyprinus carpio*

Legal Status:

Federal None
State None

Distribution

It is likely that carp evolved in the Caspian-Black Sea region. The Romans already cultured carp, which is now found in suitable waters worldwide. Due to their status as favorite food and sports fish in Europe, they were brought to California in 1872. By 1896, they were widely distributed. In California they are found in the Sacramento-San Joaquin drainage, the Salinas and Pajaro basins, the Russian River, Clear Lake, the Colorado River, some Lahontan drainage reservoirs and rivers, the Owens River, and along coastal southern California.

Life History

Common carp live in the wild rarely longer than 12–15 years. Growth varies depending on environmental conditions, and they reach approximately 7–36 cm SL. During their second year they double in length, growth slows down after the fourth year. Spawning occurs during any time of the day or night in spring and summer as soon as temperatures exceed 15°C, but especially when temperatures reach 19 –23°C. The adhesive eggs attach to plants, roots, and bottom debris. Embryos hatch in 3-6 days and drop to the bottom or attach to vegetation where they stay until they have consumed the content of their yolk sac. After a few days they start feeding on zooplankton. Most carp fry move into protective beds of emergent and submerged vegetation by the end of the first week, which they will rarely leave until reaching 7–10 cm TL.

Habitat Requirements

Common carp are most abundant in warm, eutrophic lakes, reservoirs, and sloughs with silty bottoms and growths of submergent and emergent aquatic vegetation. They can also inhabit some trout streams and coldwater reservoirs. In streams they are found in deep pools with higher turbidity and soft bottoms. Carp are active between 2–24°C, can survive high turbidities, high temperatures (31–36°C), and low oxygen concentrations (0.5–3.0 ppm). They can survive salinities up to 16 ppt.

Ecological Interactions

Common carp are probably responsible for the reduction and displacement of native fish. Due to their foraging behavior, they may increase turbidity and prevent the growth of dense beds of aquatic vegetation. Young carp are preyed upon by game fish such as largemouth bass.

Key Uncertainties

It is uncertain how to prevent carp from spreading into watersheds that have not been populated.

Key References

Moyle 2002

Common Name	**Scientific Name (family)**
Fathead minnow	*Pimephales promelas* (Cyprinidae)

Legal Status:

Federal	None
State	None

Distribution

Fathead minnow are native to much of the eastern and midwestern portions of the United States and Canada, as well as parts of northern Mexico. They were introduced into much of the western United States as a bait and forage fish, including California (in the early 1950's) where they have been reared by both commercial breeders and CDFG. This has lead to their establishment in the Sacramento-San Joaquin and Klamath basins, the Colorado drainage, a number of coastal drainages, portions of southern California, and potentially in any watersheds with adequate conditions for their survival. They can be found in an array of habitats, but appear to be most adapted to pools of small, turbid streams and in ponds where other fish are sparse.

Life History

Fathead minnow are opportunistic feeders who browse for filamentous algae, diatoms, small invertebrates, and organic matter located on the bottom, midwater, or amongst aquatic vegetation. Growth rates are extremely variable, and are largely dependent on temperature, availability of food, and population size. Maximum recorded length is 109 mm total length. First spawning can occur between a few months to two years of age, and the majority of fish die 1-2 months after the onset of spawning. Females can spawn throughout the summer season when temperatures are above 15-16°C and below 32°C, and can produce >4000 eggs. Males form nests by creating hollows in the substrate around some type of item such as a flat stone, branch, or root mass at a depth of 30-90 cm that the sticky eggs will adhere to. Males defend the nest and care for the embryos that hatch in 4-6 days (at 25°C).

Habitat Requirements

Fathead minnows are capable of surviving under extreme conditions such as, dissolved oxygen levels <1 mg/L, temperatures up to 33°C, high alkalinities, and high levels of organic pollution and turbidity. They are considered pioneer species because their ability to withstand environmental extremes allows them to inhabit and dominate temporary aquatic environments when they arise.

Ecological Interactions

When fathead minnows inhabit perennial environments, they are often poor interspecific competitors, especially with other cyprinids, but this is not always the case. In areas where they have become exceedingly abundant, such as the Upper and Lower Klamath Lakes and in Tule Lake, they have been known to displace native cyprinids such as the blue chub in these locations.

Key Uncertainties

Fathead minnows are legal baitfish within California, and are easily moved to new locations where they have the potential to establish populations. It is unknown if this practice should be eliminated to safeguard native fishes that have similar habitat preferences, such as the California roach.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Goldfish	*Carrasius auratus* (Cyprinidae)

Legal Status:

Federal None
State None

Distribution

Goldfish naturally occur in eastern Europe and China. They have been spread by aquarists and bait fishermen throughout the world. Established in California since the 1860s, goldfish occur in large populations in southern California reservoirs, in Clear Lake, as well as sloughs and reservoirs in the Central Valley. However, individuals and smaller populations can be found throughout the state where the water temperature is sufficiently warm.

Life History

Goldfish in the wild rarely live longer than 6-8 years, and growth during that time is variable, depending on environmental conditions. In California they usually reach 50-90 mm in their first year and can reach up to 20 cm TL. Females grow larger and live longer than males. Males mature during their second or third year. Goldfish are serial spawners and require temperatures of 16–26°C. Spawning takes place in May and April during sunrise on sunny days, over aquatic vegetation or flooded and emergent objects, such as leaves, roots, and grass. Eggs are adhesive and hatch within a week. Larvae and small juveniles seek cover among aquatic vegetation. Goldfish are omnivores feeding on algae, zooplankton, mollusks, crustaceans, organic detritus, and macrophytes. In the San Joaquin River, goldfish feed mostly on planktonic diatoms and strands of filamentous algae.

Habitat Requirements

Goldfish can survive in temperatures between 0 and 41°C, however populations generally establish in water with temperatures between 27 and 37°C. They prefer standing or slow moving water with heavy growth of aquatic vegetation but they can become established in colder lakes if there is a littoral area warm enough for breeding. They do well in disturbed and polluted areas, and can be found below reservoirs and in deep pools with dense cover in streams.

Ecological Interactions

In some areas their feeding behavior may lead to the elimination of aquatic plants and increase turbidity, especially in mud-bottomed ponds. They are often found in association with other non-native fish, especially in disturbed and polluted areas.

Key Uncertainties

Goldfish occur widely throughout California, however, their ecological role is not well understood.

Key References

Moyle 2002; Scott and Crossman 1985

Common Name	**Scientific Name (family)**
Golden shiner	*Notemingonus crysoleucas*
(Cyprinidae)	

Legal Status:

Federal None
State None

Distribution

Golden shiners are native throughout the majority of eastern North America form Quebec southward to Texas and Florida. In the late 1800s, they were introduced to California as a forage species, but did not have a large distribution until after 1955 when they were established as a legal baitfish. They are currently ubiquitous throughout the state. They generally inhabit warm, shallow ponds, lakes, and sloughs where they can be found in association with aquatic vegetation.

Life History

Golden shiners can obtain an ultimate length of up to 260 mm standard length, and a maximum age of nine years. They are sight feeders, and typically feed during the day on prey items such as mollusks, terrestrial and aquatic insects, small fish, aquatic insect larvae, filamentous algae, and large zooplankters such as *Daphnia sp.* Breeding season in California lasts from March through September when water temperatures are in the region of 20°C. Females are fractional spawners, with initial fecundities of 2,700-4,700+ eggs. The adhesive eggs are deposited on submerged vegetation or bottom debris where males subsequently fertilize them. Hatching occurs in 4-5 days (at 24-27°C), upon which time emergent fry begin to shoal in large numbers, generally in association with nearshore aquatic vegetation.

Habitat Requirements

Golden shiners are most abundant in low-velocity, turbid environments with muddy bottoms such as low-elevation reservoirs and sloughs, but can also be present in coldwater lakes as long as there are warm, shallow areas for breeding and rearing their young. They can endure temperatures of up to 36-37°C, and dissolved oxygen concentrations <1 mg/L.

Ecological Interactions

Golden shiners can most often be found in areas having other introduced species such as largemouth bass, various sunfish species, and mosquitofish. In some locales, piscivorous fishes may limit their abundance. They shoal in littoral or pelagic areas to avoid predators, and if predation pressure is high, may become nocturnal feeders. In coldwater lakes, golden shiners have been known to reduce growth and survival of trout by reducing zooplankton populations.

Key Uncertainties

Golden shiners are one of three legal baitfish in California, and it is challenging to predict where populations could become established, and what problems could occur as a result of their colonization.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Red shiner	*Cyprinella lutrensis* (Cyprinidae)

Legal Status:

Federal None
State None

Distribution

Red shiners are originally from streams in the western and central United States that drain into the Mississippi River and Rio Grande. They are used as a baitfish, and as a result have been planted in other regions including California in 1954. CDFG first planted them in the Sacramento-San Joaquin drainage and in Lake County ponds, but there is no evidence of a successful introduction. They can be anticipated to be present anywhere in the state, and are currently known to be found in the San Joaquin Valley, Coyote Creek, Sacramento Valley streams, the Colorado River drainage, Los Angeles County, San Juan, Big Tijunga, and Aliso Creeks, and various coastal streams. They prefer habitats with turbid, alkaline, shallow, and slow-flowing water such as backwaters and sloughs.

Life History

Red shiners shoal in large groups and feed on the most plentiful organisms present, which may include crustaceans, aquatic insect larvae, surface insects, algae, and larval fish. They can obtain an ultimate size of 80 mm standard length, and a maximum age of 2.5-3.0 years. They typically mature during the summer of their second year. Females are fractional spawners, and therefore fecundity among individuals will vary. Breeding season takes place when water temperatures are 15-30°C, and may be extended from May until October. Spawning takes place in slow-flowing water, and eggs will adhere to a plethora of substrates such as submerged vegetation, gravel and sand, root wads, woody debris, and active sunfish nests. Its early life history has not been described in literature.

Habitat Requirements

Favorable environments of red shiners include both unstable and highly disturbed environments such as intermittent streams, drainage ditches, and reservoirs. They avoid severe environmental conditions, but can tolerate pH values of 4-11, salinities up to 10 ppt, dissolved oxygen levels as low as 1.5 mg/L, and temperatures as high as 39.5°C. They are primarily found in water >30 cm in depth, velocities of 10-50 cm/sec, and near submerged cover over fine substrate.

Ecological Interactions

Red shiners have a great capacity to spread within a region once they become established, and can displace native cyprinids whenever this occurs. They have been linked to declines of native fishes, such as the Virgin River spinedace, through their introduction.

Key Uncertainties

Red shiners are thought to be jeopardizing the future of native cyprinids in southern and central California though there is no direct evidence to support this notion.

Key References

Moyle (2002)

Common Name	**Scientific Name family)**
Black bullhead (Ictaluridae)	*Ameiurus melas*

Legal Status:

Federal	None
State	None

Distribution

Black bullheads have native distributions spanning a great extent of the United States east of the Rocky Mountains and into southern Canada. Introductions have expanded them from their native range to locales within most western states. In California, black bullhead are quite common throughout the Central Valley, the San Francisco estuary, and in coastal drainages from San Luis Obispo County south to the Mexican border. They also have a presence in Monterey Bay tributaries, the lower Colorado River, and the Lost, Owens, and Russian River drainages.

Life History

Adult black bullhead size can range from 17–61cm total length dependant upon such factors as temperature, food availability, and degree of overcrowding. Black bullheads are omnivorous and feed on an array of organisms including aquatic and terrestrial insects, crustaceans, mollusks, earthworms, and both live and dead fish. Adults are nocturnal feeders whereas younger fish tend to have diurnal feeding habits. Spawning occurs in June and July when water temperatures exceed 20°C. Females create small hollows in the substrate as nests, and can lay between 1,000-7,000 eggs that form a cohesive yellow mass when fertilized. Parents care for their young from developing embryos to the time they are approximately 25 mm total length when young disperse to shallow reaches. Black bullhead are quite social, and can often be found shoaling together.

Habitat Requirements

Black bullhead have the ability to adapt to a wide range of environmental conditions, and have therefore been able to easily invade new areas. Their preferred habitats include sloughs and pools of low-gradient streams with muddy bottoms, slow velocities and warm, turbid water, river backwaters, and ponds and small lakes. They can be abundant in habitats such as ditches, brackish waters of estuaries, and temporary habitats such as intermittent streams. They can withstand temperatures up to 35°C, dissolved oxygen concentrations down to 1-2 mg/L, and salinities as high as 13 ppt.

Ecological Interactions

Black bullhead are becoming increasingly more prominent in highly disturbed lowland aquatic environments and can support small recreational fisheries. In California they can oftentimes be found among other introduced species with similar habitat preferences including bluegill, green sunfish, inland silverside, carp, red shiner, fathead minnow, goldfish, channel catfish, and threadfin shad.

Key Uncertainties

The distribution of black bullhead appears to be expanding, and it is not known what effect this will have on other native and nonnative species.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Brown bullhead	*Ameiurus nebulosus*
(Ictaluridae)	

Legal Status:

Federal None
State None

Distribution

Brown bullhead have a native range encompassing the majority of the United States east of the Great Plains and southeastern Canada, and have been introduced throughout most of southwestern Canada and the western United States where they exist in every major river system. In California they are currently in the majority of larger coastal drainages from the Klamath River to Southern California, the upper Klamath basin, all of the Sacramento-San Joaquin system, the Owens River, and potentially in California sections of the Truckee, Walker, and Carson rivers. Their greatest abundance is in large water bodies such as the sloughs of the Sacramento-San Joaquin Delta, Clear Lake, and foothill reservoirs though they have adapted to a variety of habitats ranging from warm, turbid sloughs to clear mountain lakes.

Life History

Brown bullhead can reach ultimate lengths of 53 cm total length and maximum weights of 2.2 kg, although commonly do not grow more than 30 cm total length and 0.45 kg. Spawning usually begins in their third year, and in California takes place from May through July when water temperatures surpass 21°C. Females lay 2,000-14,000 eggs in batches within nests formed from hollows dug in sand or gravel that are closely associated with in-stream cover. Hatching occurs in 6-9 days, and yolk-sac fry will remain in the nest for roughly one week while being guarded by both parents. Smaller fish primarily consume chironomid midge larvae and small crustaceans, and graduate to larger insect larvae and fish as they grow. They are both omnivorous and opportunistic and will consume most organisms of adequate size.

Habitat Requirements

Habitat preference of brown bullheads includes the deep portion of the littoral zone in association with aquatic vegetation and soft substrate, and in sluggish, turbid, low-gradient reaches of rivers. They prefer temperatures between 20-33°C, but can tolerate temperatures of 0-37°C. They can withstand a wide span of salinities (>13ppt) and pH (>9), and oxygen levels as low as 1 mg/L.

Ecological Interactions

Brown bullheads are most abundant in anthropogenically altered habitats and have become an important recreational fishery.

Key Uncertainties

The effect of this introduced species on native fishes and introduced species is not known.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Channel catfish	*Ictalurus punctatus* (Ictaluridae)

Legal Status:

Federal None
State None

Distribution

Channel catfish originated in the Mississippi-Missouri River system and have been introduced throughout North America. It is assumed that the channel catfish population in the Central Valley originated from fish planted in the American River in the late 1920s. Catfish have been reared in hatcheries since the 1960s, which widened their distribution to all public waters and private ponds and can be expected wherever suitable conditions are available.

Life History

Channel catfish are fast growing, reaching up to 53 cm TL at 10 years of age in California. They reach sexual maturity between 2–8 years at 18–56 cm. Spawning requires temperatures between 21–29°C (optimum 26–28°C). In California, they spawn between April and August using cave-like sites for nesting, including undercut banks, log jams, or old barrels. The male guards the nest and cares for the young, including aerating the embryos with movements of his body. The embryos hatch within 5–10 days and the young leave the nest after about a week. The young may stay together for another week or two, then they disperse into shallow, flowing water. Channel catfish forage mainly on a wide variety of invertebrates and fish, but also maybe incidentally feed on detritus and plant material. Young catfish feed primarily on crustaceans and the larval aquatic insects.

Habitat Requirements

Catfish live in the mainstem of larger streams, spending days in deeper pools and foraging during the night in the water column. Young-of-year prefer living in riffles. Optimal stream habitat is characterized by clean, warm water with sand or gravel bottoms. They can survive temperatures of 36–38°C and oxygen minima of 1–2mg/liter. They can tolerate moderate salinities, but are not common in brackish water.

Ecological Interactions

They prey upon many native fish and fish larvae, as well as invertebrates and smaller mammals.

Key Uncertainties

The impacts of channel catfish on native fish, amphibians, and invertebrate assemblages are not known. However, due to their predatory behavior, it is assumed that it is negative.

Key References

Moyle 2002; Scott and Crossman 1985

Common Name	**Scientific Name (family)**
White catfish	*Ameiurus catus* (Ictaluridae)

Legal Status:

Federal None
State None

Distribution

White catfish evolved in the lower reached of streams of the Atlantic coast. In 1874, white catfish were planted in the San Joaquin River. They spread naturally throughout the Central Valley and were also planted in several lakes and reservoirs.

Life History

White catfish growth is variable, with the slowest populations found in the south and central Delta. Males grow faster and become larger than females and can reach up to 60 cm TL and 3 kg in their native streams and tend to be smaller in California. White catfish reach maturity when they are between 3 and 5 years old. Spawning occurs in June and July when water temperatures exceed 21°C. Eggs are spawned in a nest made by the male, who also cares for the young. Eggs hatch within a week at 24–29°C.

White catfish are mainly piscivorous, but also feed on smaller organisms, such as amphipods, shrimp, and chironomid larvae. They forage mainly along the bottom.

Habitat Requirements

White catfish prefer areas of slow velocity and avoid deep, faster velocity channel waters. During the day they avoid shallow vegetated areas, however, at night they move into shallow waters. They prefer temperatures exceeding 20°C and can survive temperature of 29–31°C and salinities as high as 11–14.5 ppt.

Ecological Interactions

White catfish can change species compositions in ecosystems where they are introduced to due to their piscivorous feeding behavior. In Clear Lake, for example, they are responsible for the decline of native cyprinids.

Key Uncertainties

The extent that white catfish are predators on outmigrating salmonids is not known.

Key References

Moyle 2002

Common Name	**Scientific Name (family)**
Striped bass	*Morone saxatilis* (Moronidae)

Legal Status:

Federal None
State None

Distribution

Striped bass originated from streams of the Atlantic coast. They were introduced into California into San Francisco Bay in 1879. There found now in salt waters between Mexico and southern British Columbia, with the main breeding population still located in San Francisco Bay. They have also been raised in hatcheries and released into reservoirs and rivers flowing into the Central Valley.

Life History

Female striped bass can reach over 30 years in age. Growth is variable but rapid during the first four years, with the largest fish caught in California measuring 30.6 kg. Females mature between 4 and 6 years and can spawn every year. Spawning begins in April and requires temperatures above 14°C and below 21°C. Eggs slowly sink but even a slight current can keep them suspended. They hatch in about 2 days and feed off their yolk sac for up to 8 days. With increasing swimming abilities they start feeding on zooplankton. In the San Joaquin River embryos stay in the same general area in which spawning took place, as outflow is balanced by tidal currents. Larvae undergo vertical migrations to actively use riverine and tidal currents. Striped bass are pelagic, opportunistic predators, feeding on invertebrates and fishes.

Habitat Requirements

Striped bass are tolerant of wide range of environmental conditions, surviving temperatures up to 34°C, low oxygen levels between 3–5ml/L, and high turbidity. They require a large cool river for spawning, a large body of water with large population of small fishes for foraging, and an estuary as a nursery ground for larvae and juveniles.

Ecological Interactions

It is possible that striped bass contributed to the decline of native fishes, including salmon, thicktail chub, and Sacramento perch, due to predation and competition. For example, striped bass consume up to 99% of juvenile salmon drawn to Clifton Court Forebay. However, other native fish, such as delta smelt and splittail, seem to be able to coexist with striped bass.

Key Uncertainties

It is unknown whether or not native fish species can recover in the presence of large striped bass populations.

Key References

Moyle 2002.

Common Name	**Scientific Name (family)**
Bigscale logperch	*Percina macrolepia* (Percidae)

Legal Status:

Federal None
State None

Distribution

Bigscale logperch are found in numerous Gulf Coast river systems, and in 1954 were accidentally imported into lakes within Yuba County, CA. They have since spread throughout the Sacramento-San Joaquin watershed, the San Joaquin Valley, reservoirs receiving water from the California Aqueduct, and other reservoirs within central and southern California where they were potentially introduced by bait fishermen. They inhabit an array of lake and stream habitats, especially in "slower-moving stretches of warm, clear streams or in shallow waters of reservoirs on bottoms of mud, gravel, rocks, sticks, or large pieces of debris" (Moyle 2002).

Life History

Bigscale logperch can reach a maximum size of 125 mm standard length at age 3+ years. They generally reach maturity in their second year, and during spawning females can produce 150-400 eggs. Spawning occurs between February and July in small gravel pits or within vegetation where the eggs are attached. Larvae are pelagic, and are consequently washed into side channels where they settle. Bigscale logperch are opportunistic, and their diet consists of whatever dominant insect larvae, amphipod, and planktonic crustaceans are present. They are benthic feeders, but will also rise from the bottom to collect free-swimming organisms.

Habitat Requirements

Bigscale logperch are generally inactive and reside along the edges of emergent vegetation or on the bottom, oftentimes in pits they have dug or buried within gravel substrate. They tend to prefer habitats with fine substrate and warm, turbid water. They have been found in waters with salinities of up to 4.2 ppt.

Ecological Interactions

Exotic species such as the common carp, fathead minnow, various catfish species, inland silverside, bluegill, largemouth bass, and black crappie are primarily associated with bigscale logperch in addition to the native Sacramento blackfish.

Key Uncertainties

Native and desirable game fishes may be affected by bigscale logperch but the effects may be minimal due to their exclusive use of highly disturbed habitats.

Key References

Moyle (2002)

Common Name	**Scientific Name (family)**
Mosquitofish	*Gambusia affinis* (Poecillidae)

Legal Status:

Federal	None
State	None

Distribution

Mosquitofish are native to central North America, and have been introduced for mosquito control throughout the world. In 1922, they were introduced to California where they have rapidly spread throughout the state both through plantings and on their own. They are ubiquitous throughout portions of the state that do not have extended periods of cool water temperatures, and are still extensively planted.

Life History

Mosquitofish are omnivorous and opportunistic feeders on whatever organisms are most abundant. Growth is dependant upon factors such as sex, and various other environmental factors including productivity and temperature. Maximum size is 35 mm total length for males and 65 mm total length for females, and is typically achieved in one growing season. Fifteen months is generally the upper limit of survival for these fish because the majority die the same summer they reach maturity. Depending on genetics and environmental conditions factors such as time to maturity, gestation period, number of embryos per brood, and broods per season will vary. Under optimal conditions, females can contain up to 315 embryos, and 3-4 generations per year are feasible, though 50 embryos per brood and two generations per season are most common in the Central Valley. Mosquitofish are livebearers, and young are usually expelled in shallow water or among aquatic vegetation. Mosquitofish are omnivorous and besides consuming mosquito larvae and pupae, they will opportunistically feed upon such organisms as algae, zooplankton, terrestrial insects, diatoms, and various aquatic insects.

Habitat Requirements

In California streams, mosquitofish occur in disturbed portions of low-elevation streams, especially warm, turbid pools with beds of emergent aquatic plants. Within watersheds, mosquitofish can inhabit a wide array of habitats including brackish sloughs, salt marshes, warm ponds, lakes, and streams. They have a remarkable capability to withstand and even thrive under extreme environmental fluctuations. Though preferred conditions fall more centrally within the ranges, they can occur in temperatures of 0.5-42°C, pH of 4.7-10.2, salinities of 0-58ppt, and dissolved oxygen levels of as low as 0.2 mg/L. They tend to be associated with aquatic vegetation, but will only be found along the periphery of plant growth if it is too thick.

Ecological Interactions

Although mosquitofish introduction can be used effectively as a biological control method for mosquito populations, plantings can have a negative affect on native populations of small fish, amphibians, and endemic invertebrates through predation on various life stages and harassment of adults that can keep breeding from occurring. They are thought to be responsible for eliminating or significantly reducing certain small fish species, such as the Amagrosa pupfish, worldwide. Mosquitofish can also develop resistance to local pesticides, although low reproductive rates have directly correlated with high selenium levels from agricultural runoff in the San Joaquin Valley.

Key Uncertainties

Methods to control populations of mosquitofish where they currently coexist with native species are not well understood.

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