CENTRAL CALIFORNIA ROACH
Lavinia symmetricus symmetricus (Baird and Girard)

Status: Moderate Concern. Although Central California roach do not face extinction risk as a species, there remains a high degree of uncertainty regarding the status, abundance and taxonomy of many populations. Because roach systematics are poorly understood, it is possible that small, distinctive, populations may be lost before they can be provided the protection they deserve as distinct taxa.

Description: Central California roach are small, stout-bodied minnows (cyprinids) with a narrow caudal peduncle and a deeply forked tail. Fish rarely achieve lengths greater than 100 mm total length. The head is large and conical, eyes are large, and the mouth is subterminal and slants at a downward angle. Some populations, especially those in the streams of the Sierra Nevada, develop a cartilaginous plate on the lower jaw, often referred to as a "chisel lip". The dorsal fin is short (7-9 rays) and is positioned behind the insertion point of the pelvic fin. The anal fin has between 6-9 rays. Fish with more dorsal and anal fins rays are likely hybrids with hitch (*Lavinia exilcauda*) (Miller 1945b). The pharyngeal teeth (0,5-4,0) have curved tips which overhang grinding surfaces of moderate size. Roach are usually dark on the upper half of their bodies, ranging from a shadowy gray to a steel blue, while the lower half of the body is much lighter, usually a dull white/silver color. The scales are small, numbering 47-63 along the lateral line and 32-38 before the dorsal fin. Subspecies are distinguished by various distinctive subsets of characters, especially fin ray and scale counts.

Roach exhibit general (non-nuptial) sexual dimorphism (Snyder 1908a, Murphy 1943). In tributaries to San Francisco Bay, Snyder (1905, 1908a) demonstrated that the sexes could be differentiated by the ratio of pectoral fin length to body length. Males exhibited a ratio of $\geq$.21 while females bore pectoral fins between .16 and .20 the length of their body. Both sexes exhibit bright orange and red breeding coloration on the operculum, chin and the base of the paired fins. Males may also develop numerous small breeding tubercles (pearl organs) on the head (Murphy 1943).

Taxonomic Relationships: The Central California roach was first described as *Pogonichthys symmetricus* (Baird et al. 1854a) from specimens collected from the San Joaquin River at Fort Miller near the present-day location of Friant Dam. It was subsequently reassigned to the old world genus *Rutilus* until 1913, when John O. Snyder erected the genus *Hesperoluecus* and described the following six species based on locality, isolation and morphological differences:

1. *Hesperoleucus mitrulus* from the tributaries to Goose Lake, Lake County, Oregon. Dempster et al. (1979) referred roach from the Upper Pit River, Modoc County to this taxon.
2. *Hesperoleucus navarroensis* from the Navarro River, Mendocino County.
3. *Hesperoleucus parvipinnis* from the Gualala River, Sonoma County.
4. *Hesperoleucus symmetricus* from the Sacramento and San Joaquin rivers and their tributaries.

5. *Hesperoleucus venustus* from the Russian River and streams tributary to San Francisco Bay. Snyder (1913) included roach from Tomales Bay tributaries in this taxon.
6. *Hesperoleucus subditus* from the major streams flowing into Monterey Bay.

The generic name *Lavinia* (Baird et al. 1854a) has precedence over *Hesperoleucus* (Snyder 1913) and is preferred because roach and hitch (the only other species in the genus) are interfertile and closely related genetically (Avise et al. 1975, Avise and Ayala 1976, Massingill and Moyle 1981, Bernardi et al. 2002, Aguilar et al. 2009). Roach are known to hybridize with hitch in the Pajaro and Salinas rivers (Miller 1945b), in Coyote, Alameda, and Walnut creeks (Miller 1963, Leidy 1984, Leidy 2004, pers. comm.), in the Sacramento-San Joaquin drainages (Avise et al. 1975, Jones 2001), and with arroyo chub (*Gila orcutti*) in the Cuyama River (Greenfield and Greenfield 1972). Hybridization may occur as a result of low water conditions whereby hitch and roach, which normally occupy different habitats (roach use higher gradient stream sections than do hitch), become restricted to the same isolated pools as streams dry (Miller 1945b, Jones 2001). Hybrids are fertile in the Pajaro River; Avise et al. (1975) found 8% of the *Lavinia* examined to be F_1 hybrids and 5% to be backcrossed individuals.

Miller (1945b p. 197) in the same paper that described hitch/roach hybrids from the Pajaro River suggested that "preliminary analysis of the forms of *Hesperoleucus* shows that many if not all, of those described as species are geographic subspecies of *H. symmetricus*." In his unpublished M.S. thesis, Murphy (1948c) reanalyzed data from Snyder (1913), along with his own data from coastal California streams, and concluded that coastal forms should be relegated to subspecies of *H. symmetricus.* Murphy did not include *H. mitrulus* in his study. In his arguments for merging coastal forms into *Hesperoleucus symmetricus,* Murphy (1948c p. 49) did not dispute that Snyder's species were morphologically and genetically distinct, instead, he followed what appears to be a strict interpretation of the biological species concept as outlined by Mayr (1942, 1954). Murphy argued that the distinctiveness of isolated populations, such as those in the Gualala River, was due to "merely a chance genetic divergence" resulting from small numbers of colonizing individuals and, if physical barriers were removed from between forms isolated in separate basins, "a population would soon lose its identity". Although it was never published, Murphy's (1948c) diagnosis was adopted by subsequent workers (Hopkirk 1973, Moyle 1976) and by the California Academy of Sciences (Dempster et al. 1979).

Hopkirk (1973) pointed out that Murphy's principal argument in denying specific status to coastal roach populations, the concept of a "chance genetic divergence" during colonization, was actually an important mechanism in speciation; e.g., the "founder effect" (Mayr 1942, 1954, among others). Hopkirk also asserted that natural selection contributed to differences among roach populations and, therefore, the distinctiveness of populations was "not due solely to the chance combination of genetic factors," as Murphy had maintained. Regardless of his critique of Murphy's species concept, Hopkirk agreed that Murphy was correct in placing all roach in one species, but he differed in his conclusions as to which populations should be accepted as subspecies. Hopkirk (1973) recognized *H. s. symmetricus, H. s. parvipinnis, and H. s. subditus* as subspecies and suggested that roach from the Russian River should be grouped with *H. s. navarroensis* and those from the Tomales Bay region be given subspecific status. Hopkirk (1973) also concluded that *H. venustus* from San Francisco Bay tributaries and roach from the Clear Lake drainage were synonymous with *H. symmetricus* from the Central Valley. Hopkirk (1973) further cautioned that *H. s. symmetricus* likely consisted of several subspecies, citing as an example a population from the Cosumnes River that exhibited morphologically distinctive characters (Hopkirk 1973).

Some support for Hopkirk's assertion of variability in Sacramento Valley roach populations was provided by Loggins (1997) who, using DNA fingerprinting techniques, found evidence for fairly long isolation of four adjacent Sacramento populations. Similarly, in the San Joaquin drainage, Brown et al. (1992) found that populations from different drainages could be distinguished by multivariate analysis of 15 morphometric characters. Populations from the Kaweah River and from the Red Hills (i.e., Horton Creek and other small creeks near Sonora, Tuolumne County) were particularly distinctive because of the high frequency of a "chisel lip" feature. Bernardi et al. (2002, p. 261) found that the Red Hills roach population appeared "reciprocally monophyletic for assayed mitochondrial DNA markers" and this combination of morphological and genetic distinctiveness in the Red Hills roach led Moyle (2002) to assign it subspecific status. While acknowledging the need for a taxonomic reevaluation of *Lavinia,* Moyle (2002 p. 140) simultaneously recognized eight subspecies of roach and called for a thorough biochemical and morphological investigation into the roach "species complex."

In the most comprehensive genetic study of *Lavinia* to date, Aguilar and Jones (2009) used both nuclear microsatellite (nDNA) and mitochondrial DNA (mtDNA) markers. Employed in tandem, these two genetic markers supply insight into both the relationships between populations (phylogenetics) and the distinctiveness of individual populations (taxonomy). The microsatellite analysis of Aguilar and Jones (2009) clearly defined Gualala, Pit, Navarro and Red Hills populations as distinct genetic units and largely supports the subspecies proposed by Moyle (2002), with the notable exception that separate groupings were found for Russian River and Clear lake populations. Analysis of mtDNA identified roach from the Pit and Gualala rivers to be highly divergent from all other populations and reciprocally monophyletic for the haplotypes assayed, suggesting that these populations have been isolated for considerable time. In addition, mitochondrial results show Tomales, Red Hills and Russian River/Clear Lake roach populations to be highly supported clades.

In light of: (1) the recent genetic analysis (nuclear and mtDNA) that corroborates the distinctiveness of the species that Snyder (1913) originally described, and (2) the fact that Snyder's original species names were never properly submerged (i.e. through formal publication of an analysis in the peer-reviewed literature), the following taxonomic designations should be regarded as valid; however, a thorough analysis needs to be published in the peer-reviewed literature in order to solidify this taxonomy:

1. The Northern roach (Pit roach) is a valid full species. The subspecies name, *Lavinia s. mitrulus* (Murphy 1948c) is pre-occupied by *Lavinia mitrulus* (Snyder 1913).

2. The Gualala roach is a valid full species. *L. s. parvipinnis* (Murphy 1948c) is pre-occupied by *Lavinia parvipinnis* (Snyder 1913).

3. The subspecific designations for the Navarro, Tomales, and Red Hills roach subspecies should be retained. These taxa are probably sufficiently distinct to warrant full species status but genetic evidence from a sufficient sample size is necessary to allow

increased statistical support for such a conclusion. Based on all evidence gathered to date, the following is a list of the taxonomic units for roach in California. Full species are denoted in bold.

1. **Northern roach,** *L. mitrulus*
2. **Gualala roach***, L. parvipinnis*
3. **California roach,** *Lavinia symmetricus*
   3a. Central California roach, *L. s. symmetricus*
   3b. Navarro roach, *L. s. navarroensis*
   3c. Monterey roach, *L. s. subditus*
   3d. Clear Lake roach, *L. s. ssp.*
   3e. Russian River roach, *L. s. spp*.
   3f. Tomales roach, *L. s. ssp.*
   3g. Red Hills roach, *L. s. ssp.*

The central California roach consists of many populations that are isolated to varying degrees. This isolation was partially natural because roach populations seem to become easily isolated from one another and adapted to local conditions (Bennett et al. 1992). Many of these isolated populations are distinguishable, both morphologically (Brown and Moyle 1993) and genetically (Aguilar and Jones 2009), but the interrelationships are complex and poorly understood. Gaps in their distribution (e.g., Fresno River) suggest recent extirpations (Bennett et al. 1992). One population, found in small streams in the Red Hills near Sonora, Tuolumne County, is distinct both morphologically and genetically (see the Red Hills roach account in this report) and it is possible that a thorough analysis of central California roach systematics will identify other taxonomically distinct populations (e.g., Cosumnes River, Peoria Creek, Kaweah River, Los Gatos Creek) that would merit further recognition.

Life History: Roach are opportunistic omnivores whose diet varies greatly across watershed, habitat type and season. In small, warm, streams they primarily graze on filamentous algae, which is seasonally abundant, although they also ingest crustaceans and aquatic insects, which can account for nearly a third of stomach contents by volume (Fry 1936, Fite 1973, Greenfield and Deckert 1973). In larger streams, such as the North Fork Stanislaus River, roach have been observed to feed on drift and aquatic insects may dominate their diet year-round (Roscoe 1993). Juvenile roach consume large quantities of crustaceans and small chironomid midge larvae, while adult roach are more opportunistic feeders, feeding both off the substrate and from drifting insects in the water column. Although roach are primarily benthic feeders, Moyle (2002) observed roach feeding in the Tuolumne River in swift current on drift organisms, including terrestrial insects. Adult roach show little preference for food type and small midge, mayfly, caddisfly and stonefly larvae, along with elmid beetles, aquatic bugs and amphipods, are taken roughly in proportion to their availability in the benthos and drift (Fite 1973, Roscoe 1993, Feliciano 2004). Adult roach have also been observed to consume larger prey and one individual in the Navarro River contained three larval lampreys (Moyle 2002). As a result of their benthic feeding habits, stomach contents of adult roach are often found to contain considerable amounts of detritus and fine debris. It is thought that roach extract some nutritional value from this material because its retention is facilitated by the gill rakers and mucus secretions from epithelial cells (Cech et al. 1991).

Growth is highly seasonal, with most rapid growth typically occurring in early summer (Fry 1936, Barnes 1957). In perennial streams, roach frequently exceed 40 mm SL in their first summer, reach 50-75 mm by their second year and 80-95 mm SL by their third summer (Fry 1936, Roscoe 1993). Few individuals exceed 120 mm SL or live beyond 3 years, although a 6 year-old specimen was recorded in San Anselmo Creek, Marin County (Fry 1936).

Roach typically mature at 45-60 mm SL in their second or sometimes third year (Fry 1936). Fecundity is dependent on size and ranges from 250 – 2,000 eggs per female (Fry 1936, Roscoe 1993). Spawning activity is largely dependent on temperature and typically occurs in March through early July, when water temperatures exceed 16˚C. Spawning occurs in riffles over small rock substrates, 3-5 cm in diameter. Roach spawn in large groups over coarse substrates where each female repeatedly deposits eggs, a few at a time, into the interstices between rocks which are immediately fertilized by one or more attendant males. Spawning aggregations can be quite conspicuous and spawning fish can splash so vigorously that, at times, the splashing can be heard at some distance (Moyle 2002). This activity clears silt and sand from interstices of the gravel which improves adhesion for sticky fertilized eggs. Eggs hatch after 2-3 days, and larvae remain in the gravel until large enough to actively swim. Larval development is described by Fry (1936). The population studied in Bear Creek, Colusa County, apparently spawned in emergent vegetation and newly hatched larvae remained among the plants for some time (Barnes 1957). Once the yolk is absorbed, larval roach feed primarily on diatoms and small crustaceans (Fry 1936).

Larval drift may be a significant form of dispersal for roach during some years. Roach embryos and larvae in Eel River tributaries (introduced population) made up a significant portion of the nighttime planktonic drift from May through July (Harvey et al. 2002, White and Harvey 2003). White and Harvey (2003) suggest that the timing of roach spawn (in late spring as flows recede) and apparent short period of drift for individual larvae are adaptations that may reduce the risk of roach drifting downstream into unsuitable habitats types. In Central Valley streams, these attributes would largely prevent young roach from being passively transported to unsuitable valley-floor habitats.

Habitat Requirements: Central California roach are generally found in small streams and are particularly well adapted to life in intermittent watercourses; dense populations are frequently observed in isolated pools (Fry 1936, Moyle et al. 1982, Leidy 2007). Roach are most abundant in mid-elevation streams in the Sierra Nevada foothills and in lower reaches of some San Francisco Bay streams but they may also be found in the main channels of some rivers, such as the Stanislaus (Roehrig 1988) and Tuolumne (Moyle 2002). Roach tolerate a relatively wide range of temperatures and dissolved oxygen levels, as evidenced by the fact that they occupy habitats as varied as cold, clear well-aerated “trout” streams (Moyle et al. 1982, Roscoe 1993) and intermittent streams where they can survive extremely high temperatures (30 to 35˚ C) and low dissolved oxygen levels (1-2 ppm) (Moyle et al. 1982, Knight 1985, Castleberry et al. 1990).

In the tributary streams to the San Francisco Bay, roach occupy suitable habitats from headwaters to the mouth but are intolerant of saline waters (Moyle 2002). They have been recorded in salinities up to 3 ppt, but perish before salinities reach 9-10 ppt

(Moyle unpublished data). In headwater reaches of San Francisco Bay tributaries, roach typically co-occur with rainbow trout (*Oncorhynchus mykiss*), juvenile Sacramento sucker (*Catostomus occidentalis)* and prickly or riffle sculpin (*Cottus asper* and *gulosis*, respectively*)* (Leidy 2007). In small, warm, intermittent estuary streams, roach are most often found with juvenile Sacramento suckers and, occasionally, with green sunfish (*Lepomis cyanellus*) (Leidy 2007). In lower mainstem stream channels, roach occur as part of a predominately native fish assemblage which, depending on location, is characterized by combinations of Pacific lamprey (*Entosphenus tridentatus*), Sacramento pikeminnow (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), Sacramento sucker, riffle sculpin, prickly sculpin and tule perch (*Hysterocarpus traskii*) (Leidy 2007).

Although common in streams that support native fishes, roach are most abundant when found by themselves or with just one or two other species (Moyle and Nichols 1973, Leidy 1984, 2007, Brown and Moyle 1993). When found alone, roach will occupy open water in large pools; when found as part of complex fish assemblages, roach tend to congregate in low velocity (<40 cm/sec), shallow (<50cm) habitats (Baltz and Moyle 1985). Similarly, when collected with non-native fishes in the lower portions of Alameda, Coyote and Walnut creeks, roach were typically found in the shallow margins of pools (Leidy 2007). In the presence of native predators (e.g., pikeminnow) roach are also restricted to the edges of pools, riffles, and other shallow-water habitats or in dense cover, such as that provided by fallen trees (Brown and Moyle 1991, Brasher and Brown 1995). In Alameda Creek, juvenile roach and Sacramento sucker (<20 mm TL) are often found in great abundance in very shallow (< 10 cm) edgewater habitats of pools with sandy substrates (R. Leidy, pers. obs. 2009).

While roach rarely display aggressive behavior towards other fishes, they are important predators of lower trophic levels and may play a key role in regulating aquatic food webs, especially in watersheds where they are introduced. For instance, using net-pen mesocosm experiments, Marks et al. (1992) demonstrated that introduced roach suppressed benthic insects and affected persistence of algae in the South Fork Eel River.

Water temperatures in many Eel River tributaries have substantially warmed over the last 50 years (Harvey et al 2002). This change in thermal regime is attributed to a combination of human activities, primarily heavy logging, and to the large floods of the 1950s and 1960s which dramatically altered channel configurations (Moyle and Nichols 1973, Harvey and White 2003). Harvey et al. (2002) suggest that these changes in temperature regime enhanced the invasion of the drainage by California roach and Sacramento pikeminnow. Evidence from the Gualala and Navarro watersheds also suggests that human alteration of coastal watersheds creates thermal regimes favorable to roach.

Distribution: Central California roach are found in tributaries to the Sacramento and San Joaquin rivers and tributaries to San Francisco Bay. Their historic distribution in the upper Sacramento River basin is poorly understood but their upstream range limit is thought to have been Pit River Falls. Roach found above the falls are northern roach (*L. mitrulus*). They are absent today from the Fresno River and other tributaries to the San Joaquin River, where they might be expected, as the result of habitat change and invasions of alien predators (Moyle and Nichols 1973, Moyle 2002). They are also absent from most of their historic range in the Cosumnes River (Moyle et al. 2012).

The ability of roach to persist in small, high gradient, often intermittent tributaries has led, through erosional capture of interior headwater streams, to their colonization of adjacent drainages in a number of areas (Snyder 1908, 1913, Murphy 1948c, Moyle 2002). Because they are relatively intolerant of saline waters, dispersal to these coastal streams could not have occurred through ocean waters, although connections at low elevations may have been possible in some cases when sea levels were lower and freshwater estuaries existed that joined the mouths of rivers (Moyle 2002). Similarly, populations in the San Francisco Estuary are isolated from each other, to some extent, by the inability of roach to disperse through saline waters of the estuary. Exchange between populations may, nevertheless, occur during flood years when freshwater outflow is high enough to create freshwater lenses in the surface waters of the estuary. This process may, at times, allow fish intolerant of saline waters to exchange between watersheds around the estuary and provide inland fish swept downstream from the Central Valley access to Bay tributaries (Ayers 1862, Snyder 1905, Murphy 1948c, Leidy 2007). Historically, during high water periods, fish may also have been able to disperse through flooded marshes on the fringes of the estuary. Today, it thought that such dispersal happens only very rarely, if at all, because the marshes and floodplains that once fringed the estuary have been highly altered or narrowed to such a degree that movement between watersheds is very difficult for fish as small as roach (Moyle et al. 2012).

In a few instances, the range of central California roach has been expanded through introductions. Their small size makes roach an attractive bait fish and increases risk of illegal "bait bucket" transfer between watersheds by anglers. For example, Hetch-Hetchy Reservoir, on the upper Tuolumne River, supports a large pelagic population, high above a series of natural barriers (P. Moyle, unpublished observations). Soquel Creek and the Cuyama River, in southern California, support presumed introduced populations, although genetic investigations may reveal that both Southern California populations are actually native (Moyle 2002). Roach are widespread in the Eel River, apparently from an introduction in the 1970s; the origin of these roach is unknown but it is most likely from a Sacramento River tributary (Moyle 2002).

Trends in Abundance: In absolute terms, Central California roach are still abundant but growing evidence suggests that Central Valley populations are declining (Moyle and Nichols 1973, Daniels and Moyle 1982, Bennett et al. 1992, Brasher and Brown 1995). For example, surveys indicate that roach have been completely extirpated from the entire Fresno River watershed (Moyle 2002) and the South Fork Yuba River, except for one small population (Gard 2004). Between 1970 and 1990, roach were eliminated from numerous locations, such as the Cosumnes River (Moyle and Nichols 1973, Brown and Moyle 1991 & 1993, Moyle et al. 2003), in the San Joaquin Valley. In contrast, two comprehensive studies of San Francisco Bay tributaries (Leidy 1984, 2007) found roach to be abundant in both surveys. They were the most commonly collected native fish and populations appeared to be relatively stable.

Nature and Degree of Threats: The small streams that comprise the majority of roach habitat in their native range are acutely vulnerable to human alteration. Low elevation streams in the Sierra Nevada foothills are heavily altered by rural development, ranching and agriculture (Moyle and Nichols 1973), while all populations face some degree of threat from water diversion, urban and suburban development, and introduced fishes (Moyle 2002). These factors work in conjunction with the isolation of most roach populations, especially small populations in intermittent streams, because they collectively prevent recolonization following local extirpation. The factors which threaten roach persistence in their native range are multiple (Table 1) and differ at each locality.

Dams. Dams of all sizes have multiple effects on roach distribution and abundance: dams create impassible barriers for small fish moving upstream; impoundments generally support populations of predators that eliminate roach and other native fishes in upstream areas; dams alter downstream flows, which may or may not be beneficial to roach (although roach are rarely found below dams); and small dams divert water from streams, limiting and sometimes completely drying preferred roach habitats. Generally, where dams exist on Central Valley streams, Central California roach persist only in small tributaries above them. Since dams effectively isolate roach populations, when localized extinctions occur, otherwise suitable habitats cannot be recolonized naturally.

Agriculture. Roach are generally absent from streams flowing through intensively farmed lands. Such streams are usually: (1) diverted and may be dried by excessive pumping on occasion, (2) heavily polluted with irrigation return water containing fertilizers, pesticides and sediment, (3) channelized and rip-rapped with little complex habitat roach require, and (4) habitats favored by non-native fishes that prey on or compete with roach. Given the extensive conversion of lands to agricultural use across much of the roach's historic range, especially at lower elevations, their populations have likely been heavily impacted by agriculture and further isolated from one another due to the unsuitability of such streams.

Grazing. Central California roach are often found in streams flowing through pastures that have generally altered or degraded aquatic habitats; however, they may persist as long as stream banks are relatively intact and riparian trees and deep pools provide shading and cover. Heavy grazing may lead to stream bank collapse, increased sedimentation of pools, pollution input from animal wastes and reduced shading and cover. Despite their high tolerance of adverse conditions, roach populations can be extirpated from waters heavily impacted by grazing, especially in areas where cattle are allowed direct access to streams. Ponds used to provide water for cattle and other livestock divert water from streams and often support populations of alien predatory fishes. These fishes (e.g., green sunfish, largemouth bass) may escape stock ponds during wet periods if ponds spill and become connected to adjacent streams. Roach have disappeared from the south fork of Dye Creek, Tehama County, because of the invasion of green sunfish from stock ponds (Moyle, unpublished data).

Rural residential development. The Sierra Nevada foothills are undergoing dramatic change due to dispersed rural development. While roach populations can persist in the face of moderate development (and even increase when summer dams for swimming are built), they may be extirpated in areas of heavy development due to excessive water diversion or ground water pumping (e.g., wells) during low-flow periods, polluted inflow from septic tanks, siltation and instream passage impediments from roads, and loss of complex habitat through bank stabilization or flood control projects.

Urbanization. Roach tend to disappear from streams flowing through urban areas, presumably because of often dramatic habitat alteration and simplification, reduced and/or highly regulated flows, pollution inputs from surface runoff and wastewater effluents, and the presence of alien fishes that favor such altered habitats. However, Leidy (2007) found that roach were common in streams flowing into San Francisco Bay, many through urban areas. Nevertheless, roach distribution in San Francisco Bay tributaries, especially those in the south bay, which flow through a dense urban matrix, are limited by channelization and water pollution.

Mining. Roach are typically absent from streams heavily influenced by mining, especially instream mining. For example, they were apparently eliminated from the South Fork Yuba River because of hydraulic mining in the 19th century and have apparently been unable to recolonize (Gard 2004), in spite of 150+ years of generally favorable habitat recovery.

Estuarine alteration. Historically, exchange between San Francisco Estuary watersheds was facilitated by a band of seasonal freshwater wetlands at the fringe of the estuary that periodically connected the surface waters of tributaries, especially in South San Francisco Bay (Snyder 1905, Leidy 2007). These wetlands and dispersal pathways have been almost entirely eliminated; drained and paved over by urban development, leading to the isolation of roach populations.

Transportation. Many streams and rivers within the historic range of roach have one or more adjacent roads, often leading to the channelization of streambeds, simplification of aquatic habitats, and increased input of sediments and pollutants. Culverts and other road crossing may also form barriers to upstream fish movement, which can lead to the isolation of stream reaches and roach populations. If local populations are extirpated, such passage impediments may prevent natural recolonization of suitable habitats.

Fire. Central California roach are distributed in streams frequently affected by fires. Their continued presence in such areas indicates adaptation to stochastic events, including fire. However, fire intensity and frequency have increased because of human changes to the landscape, coupled with long-standing policies to suppress wildfires which have led to increased fuels in many areas. In conjunction with the predicted outcomes of climate change, if roach are eliminated due to the direct or indirect impacts from fire, recolonization may be inhibited by other changes to streams (reduced base flows, dams, diversions, passage barriers, etc.).

Alien species. Central California roach cannot coexist with large populations of alien fishes, especially centrarchids such as green sunfish (*Lepomis cyanellus*) and black basses (*Micropterus* spp.). As noted, green sunfish have almost entirely replaced roach in Dye Creek, Tehama County, in the intermittent pools of the south fork, while in the cooler, more permanent north fork, sunfish have not invaded and roach still dominate (Moyle 2002). In the mainstem below the union of the forks, the two species coexist but roach are largely absent from pools. In lower Deer Creek, tributary to the Cosumnes River, El Dorado County, Moyle et al. (2003) documented roach being displaced by invading green sunfish over the course of a summer. In the rest of the Cosumnes River watershed, roach were only found in clear, cool tributaries upstream of barriers that prevented invasion of redeye bass (*Micropterus coosae*) (Moyle et al. 2003). Gard (2004) indicated that predation pressure from smallmouth bass in the lower South Fork

Yuba River limited roach distribution to a single high gradient tributary. These examples highlight the importance of barriers in preventing upstream invasions of alien species into headwater areas that maintain enclaves of native fishes. However, the potential for transportation of fishes over barriers by humans and the escape of alien fishes (usually centrarchids) from numerous stock ponds in watershed above barriers suggests that even native fish refuges protected by barriers may succumb to invasion.

Roach display few aggressive behaviors towards other fishes and are typically displaced from prime feeding habitats by more aggressive fishes (e.g., green sunfish, Moyle et al. 2003; rainbow trout, Feliciano 2004 and smallmouth bass (*Micropterus dolomieu*), Gard 2004). Even where roach are not eliminated by other fishes, they may exhibit reduced growth and survival in their presence (Brown and Moyle 1991).

	Rating	Explanation
Major dams	High	Most central California populations are isolated by major dams and reservoirs which alter flows, reduce habitat suitability and prevent movement among and between populations
Agriculture	High	Roach are generally absent from streams in intensively farmed areas; agriculture is pervasive throughout their range
Grazing	Medium	Streams in heavily grazed pastures tend not to support roach
Rural residential	Medium	Development degrades roach habitats through diversion and pollution
Urbanization	High	Roach are absent from many streams flowing through dense urban areas; many urban areas exist across their range
Instream mining	Low	Gravel quarries create lentic habitats preferred by exotic predatory fishes
Mining	Low	Little direct effect known but contamination from mine effluent likely to have negative effects on roach
Transportation	Medium	Roads often border rivers and streams throughout the range of roach, leading to habitat degradation and simplification, sediment and pollutant input, and creating potential barriers (e.g., culverts)
Logging	Low	Roach are well adapted to the shallow, warm, exposed stream conditions often found in logged areas; intensively logged habitats may lead to increased sediment input and loss of riparian shading
Fire	Low	Increased isolation of roach populations, coupled with more frequent and intense fires, may lead to localized extirpation by fire
Estuary alteration	Medium	Key freshwater habitats that historically allowed interconnection of populations have been almost entirely eliminated; especially acute in San Francisco Estuary
Recreation	Low	Stream alterations for recreation can have both positive and negative effects
Harvest	n/a	
Hatcheries	n/a	
Alien species	High	Intolerant of predatory fishes, especially centrarchids

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Central California roach. Factors were rated on a five-level ordinal scale where a factor rated “critical” could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated “high” could push the species to extinction in 10 generations or 50 years whichever is less; a factor rated “medium” is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated “low” may reduce populations but extinction is unlikely as a result. A factor rated “n/a” has no known negative impact. Certainty of these judgments is moderate. See methods section for descriptions of the factors and explanation of the rating protocols.

Effects of Climate Change: Climate models for Central California provide scenarios that strongly indicate that the streams in which central California roach occur will become increasingly unsuitable for sustaining populations (Knowles and Cayan 2002, Miller et al. 2003, Carlisle et al. 2010, Null et al. 2012). In general, these scenarios suggest that streams, especially small streams, will become warmer by 2100 (2-6 degrees C), while base flows will be reduced, presumably drying larger portions of many streams in which roach now occur on a seasonal basis. Multi-year droughts are likely to become more frequent, while major high flow events are predicted to occur earlier and become flashier, especially during 'rain on snow events.' In short, these widely accepted scenarios indicate that streams will become more variable in flows and temperatures, with extreme conditions reached more often.

The dependence of Central California roach on small, frequently intermittent streams suggests that they are particularly susceptible to increasingly harsh environmental conditions. This is despite the fact that roach are one of the few native fishes that are able to endure life in isolated summer pools where temperatures are high, dissolved oxygen levels are low, and most other fishes die. John O. Snyder (1905 p. 332) observed roach were able to persist when "nothing remains of the stream but a few small disconnected pools." While such tenacity bodes well for roach in a future of dwindling in-stream water supplies, it also suggests that they are likely to be extirpated from streams which may dry completely under the dual strains of altered precipitation patterns and increased human water use, especially where water is diverted for residential and agricultural use.

Despite its wide distribution and tolerance to adverse conditions, Moyle et al. (2013) rated the central California roach as "highly vulnerable" to extinction in the next 100 years if present trends continue.

Status Determination Score = 3.3 – Moderate Concern (see Methods section Table 2). If central California roach are assumed to be a single taxon, there appears to be little danger of extinction in the near future (Table 2). However, it is very likely that this form actually comprises multiple taxa, some of which may be under more immediate threat. It is of particular concern that the small, isolated populations which are the most likely to be extirpated also tend to be the most distinctive (Bennett et al. 1992). Emerging appreciation of the variation with the taxon (Moyle et al. 1989, Bennett et al. 1992, Jones 2001, Jones et al. 2002, Aguilar and Jones 2009) has highlighted the need to preserve distinctive populations endemic to specific areas.

Metric	Score	Justification
Area occupied	5	Sacramento, San Joaquin and San Francisco Bay drainages support many apparently independent populations
Estimated adult abundance	5	Many large populations
Intervention dependence	3	Increased isolation may limit recolonization after localized extirpation and necessitate deliberate reintroductions from adjacent watersheds
Tolerance	4	Broad environmental tolerances but vulnerable to exclusion by introduced fishes
Genetic risk	3	Distinct subpopulations are increasingly at genetic risk from small size and isolation
Climate change	2	Drying and warming of streams may eliminate many populations, particularly those isolated in small headwater tributaries
Anthropogenic threats	1	See Table 1
Average	3.3	23/7
Certainty (1-4)	3	Little information on abundance; taxonomy uncertain

Table 2. Metrics for determining the status of central California roach in California, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

Management Recommendations: The California roach species complex, in general, and the Central California roach, in particular, are in need of comprehensive study of their abundance, status, distribution and systematics. A thorough review of systematics is highlighted by the discovery of the Red Hills roach and indications that a number of undescribed forms likely exist around the state (Hopkirk 1973, Bennett et al. 1992, Jones et al. 2002, Aguilar and Jones 2009). One of the greatest threats facing Central California roach is our limited understanding of roach systematics, which may lead to the prospect of losing distinct taxa before they are described. A clear parallel exists in the lack of protection provided to distinct but undescribed populations of other widespread California fish species. For example, in Clear Lake, Lake County, formal description came too late to contribute to the conservation of the endemic Clear Lake splittail (*Pogonichthys ciscoides,* Hopkirk 1973); it became extinct almost a decade before being described.

Although roach populations remain geographically widespread, their status should be closely monitored in order to ensure that current population levels are maintained. Consideration should also be given to the possible reintroduction of roach into watersheds with suitable habitats in which they were historically present but have since been extirpated. Where possible, roach reintroductions should come from immediately adjacent watersheds, as proximate populations are more likely to have adaptations for local conditions. For example, roach could be reintroduced into the South Fork Yuba

River by using fish from Kentucky Ravine, which is an isolated tributary that supports the sole remaining population in the watershed.

Aquatic Diversity Management Areas, or protectively managed streams, should be established throughout the range of the Central California roach in order to protect roach genetic diversity and provide sanctuary for other California fishes, amphibians and aquatic invertebrates (Moyle et al. 1995).

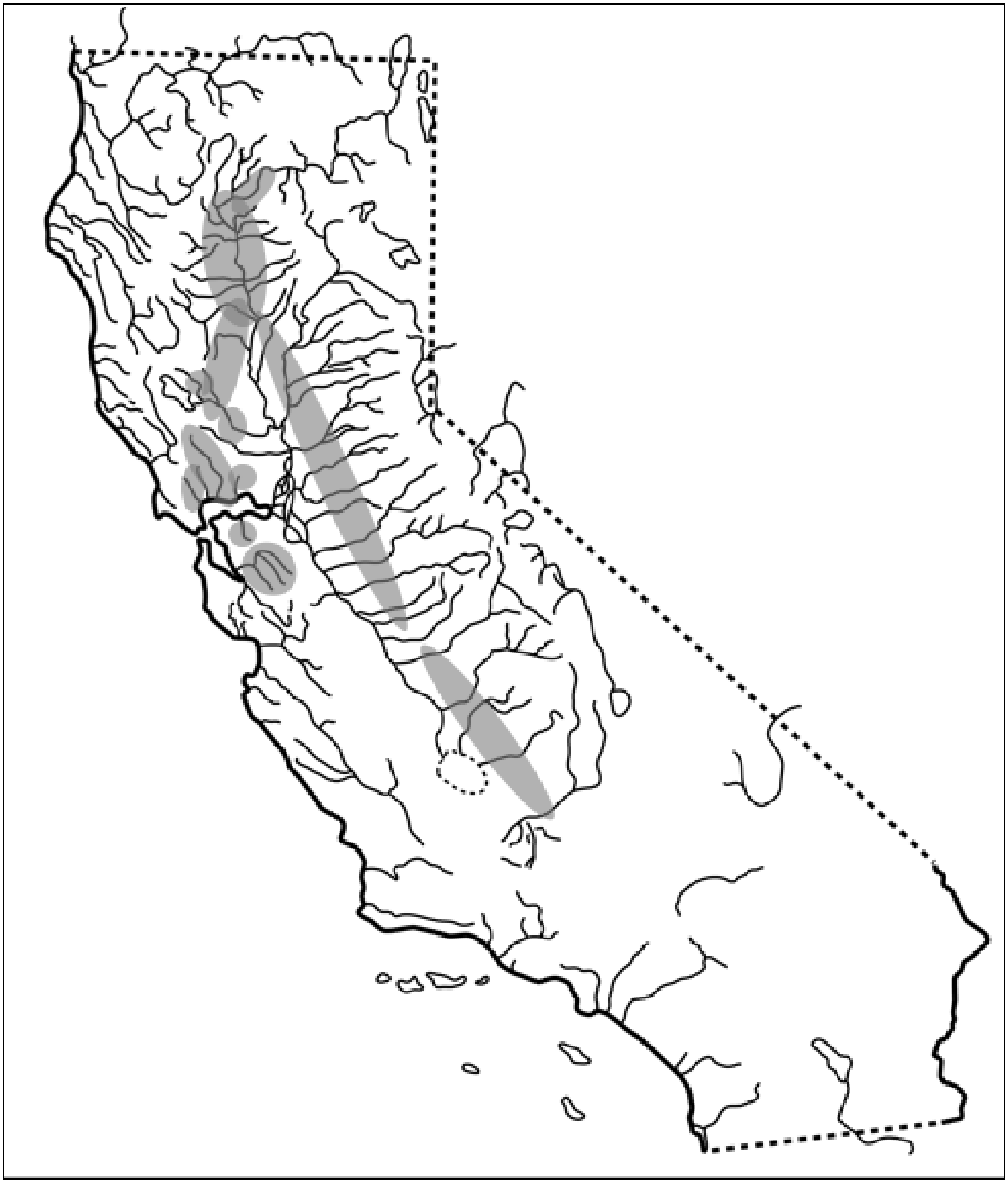

Figure 1. Historic distribution of Central California roach, *Lavinia symmetricus symmetricus* (Baird and Girard), in California. Current distribution is highly fragmented.