SACRAMENTO SPLITTAIL
Pogonichthys macrolepidotus (Ayres)

Status: Moderate Concern. The Sacramento splittail was delisted as a threatened species because of the demonstrated resiliency of its populations. Its abundance could be negatively impacted by ongoing changes to the San Francisco Estuary. In particular, the poorly studied but genetically distinct population in the lower estuary is of concern because of its small size.

Description: Splittail are large cyprinids, growing in excess of 40 cm SL, and are distinctive in having the upper lobe of the caudal fin larger than the lower lobe. The body shape is elongate with a blunt head. Small barbels may be present on either side of the subterminal mouth. Splittail possess 14-18 gill rakers, and their pharyngeal teeth are hooked and have narrow grinding surfaces. Dorsal rays number 9-10, pectoral rays 16-19, pelvic rays 8-9, and anal rays 7-9. The lateral line usually has 60-62 scales, but ranges from 57 to 64. Coloration is silver on the sides and dusky grey dorsally. Adults develop a slight hump behind the head (nuchal hump). During the breeding season, the caudal, pectoral, and pelvic fins take on a red-orange hue and males develop small white nuptial tubercles in the head region.

Taxonomic Relationships: The Sacramento splittail was described in 1854 by W. O. Ayres as *Leuciscus macrolepidotus* and by S. F. Baird and C. Girard as *Pogonichthys inaeqilobus.* Ayres' species description came out first so was accepted as the official description, although *Pogonichthys* became the genus name because of its striking difference from other cyprinids (Hopkirk 1973). The genus *Pogonichthys* comprises two species, *P. ciscoides* (Hopkirk 1973) and *P. macrolepidotus.* The former species was endemic to Clear Lake, Lake County, and became extinct in the early 1970s. Baerwald et al. (2008) showed that there are two genetically distinct populations of Sacramento splittail, one centered in San Pablo Bay around the Petaluma and Napa rivers in the lower San Francisco Estuary, and the other centered around the Delta and Suisun Marsh. Analysis of otolith microchemistry validates that the two populations segregate themselves in different habitats (Feyrer et al. 2007). These two populations would qualify as Distinct Population Segments (San Pablo DPS and Delta DPS), if listed under the Federal Endangered Species Act of 1973. The genetic relationships of splittail from San Francisco Bay tributaries (primarily Walnut Creek and Alameda Creek) are unknown.

Life History: The life history of splittail is reviewed in Moyle (2002), Moyle et al. (2004), and Sommer et al. (2007). Splittail depend both on brackish-water rearing habitats in the San Francisco Estuary and on floodplain and river-edge spawning habitats immediately above the estuary. Most migrate between these two habitat types on a near-annual basis. Historically, non-estuarine dependent populations existed, especially in the southern Central Valley (e.g. Lake Tulare), but these populations have been extirpated. The basic life history pattern for the remaining Delta/Suisun Marsh populations is: (1) from November through February adults migrate upstream in pulses in response to flow events; (2) adults spawn on floodplains or flooded edge habitats in March and April and then migrate back downstream; (3) embryos and larvae remain in flooded vegetation for 3-6 weeks during March and April (Crain et al. 2004); (4) in April and May, as flood waters recede, juveniles leave flooded areas and move downstream; and (5) juveniles rear in estuarine marshes for 1-2 years before spawning for the first time. The success of this life cycle depends on extended, large-scale floodplain inundation (e.g., in the Yolo Bypass or lower Cosumnes River), although some spawning is successful even in non-flood years (Moyle et al. 2004). This pattern may be somewhat different for the Petaluma/Napa populations because adults can spawn in brackish water (up to 5 ppt salinity) and juveniles can rear in water up to 14 ppt (Feyrer et al. 2010). Young-of-year splittail typically stay in water of the same salinity in which they were reared, but some individuals move readily between fresh and brackish water (Feyrer et al. 2010).

Splittail are relatively long-lived (7-10 years) and are highly fecund (up to 150,000 eggs per female). Their populations fluctuate on an annual basis, depending on spawning success and strength of the year class (Daniels and Moyle 1983, Sommer et al. 1997). Both male and female splittail mature by the end of their second year although, occasionally, males may mature by the end of their first year and females by the end of their third year. Splittail are about 18-20 cm SL when they attain sexual maturity (Daniels and Moyle 1983). There is some variability in reproductive period: older fish reproduce first, while younger fish tend to reproduce later in the season (Moyle et al. 2004). Generally, gonadal development is initiated by fall with a concomitant decrease in somatic growth (Daniels and Moyle 1983).

Splittail spawn on submerged annual vegetation in flooded areas or along the edges of rising rivers. The most important known spawning areas are the Yolo and Sutter bypasses and the Cosumnes River floodplain; however, ripe splittail have been found in areas as diverse as the Petaluma River, Suisun Marsh, Sacramento River and lower Tuolumne River. Fertilized embryos stick to plants and larvae remain in and among plants for the first few days of life. Sommer et al. (2008) observed that post-larval splittail (ca. 21 mm FL) sought out shallow areas with emergent and submerged vegetation during the day, but moved into deeper water at night among tules and submerged aquatic plants. Larger fish used deeper water more consistently, both day and night. Fish of all sizes exhibited schooling behavior.

Splittail are benthic foragers that feed mostly on aquatic invertebrates, although detrital material can make up a high percentage of their stomach contents by volume. Juvenile splittail feed on small benthic invertebrates, most consistently chironomid midge larvae; however, diet varies considerably with locality (Feyrer et al. 2007). Adults feed opportunistically on earthworms, clams, insect larvae, and other invertebrates. Historically, splittail fed extensively on opossum shrimp (*Neomysis mercedis*) but their diet shifted with the collapse of shrimp populations, following invasion of the overbite clam, *Potamocorbula amurensis* (Feyrer et al. 2003). Splittail feeding shifted to the clams themselves, as well as other benthic invertebrates.

Splittail are preyed upon by striped bass and other predatory fishes, as well as by aquatic birds. Striped bass preference for splittail as prey has long been recognized by anglers, who often fish for splittail in order to use them as bait.

Habitat Requirements: Splittail are adapted for estuarine life so they are tolerant of a wide range of salinities (0-29 ppt) and temperatures (5-33°C). This tolerance is demonstrated by year-round utilization of Suisun Marsh and the Petaluma River estuary, generally in sloughs < 4 m deep, where summer salinities are typically 6-10 ppt and temperatures range from 15 to 23°C. Feyrer et al. (2010) recorded young-of-year splittail in habitats with salinities as high as 14 ppt; although most young-of-year reared in fresh water, some reared in brackish water. Adults are more tolerant of high temperatures and salinities than juveniles, so optimal conditions are generally where salinities are low (<10 ppt) and temperatures cool (<20°C). They are remarkably tolerant of low dissolved oxygen and can be found, at least for short periods of time, in water where levels are around 1 mg O^2 L^{-1} (Young and Cech 1996, Moyle et al. 2004).

Splittail require a rising hydrograph for upstream migration and flooded vegetation for spawning and rearing areas for their early life history stages. Large flooded areas need to be at least 1 m deep with deeper, more open, areas as refuges from predation for adults and larger juveniles during the day (Sommer et al. 2008). On floodplains, small juveniles prefer to be among vegetation in shallow water during the day but move into deeper water at night.

Both adults and juveniles leave the floodplain as water levels drop and temperatures rise to 15-20°C (Moyle et al. 2007). Young-of-year and yearling splittail are common in beach seine sampling along the Sacramento River between Rio Vista and Chipps Island (R. Baxter, CDFW, pers. comm. 2001). Furthermore, in CDFW Bay Study samples, splittail are most common from stations <20 ft deep. Thus, juvenile splittail appear to concentrate in shallow edge habitats of the Sacramento River as they move downstream to rearing areas. In the lower Napa River watershed, splittail juveniles have been documented using shallow water habitats in recently restored tidal marsh (Stillwater Sciences 2006).

Distribution: The Sacramento splittail is endemic to California's Central Valley and was once distributed in lakes and rivers throughout the Central Valley. Historically, splittail were found as far north as Redding by Rutter (1908), who collected them below Battle Creek Fish Hatchery in Shasta County. Splittail are apparently no longer found in this area, although adults are occasionally observed passing over the fish ladder at Red Bluff Diversion Dam in Tehama County (R. Baxter, CDFW, pers. comm. 2013). They only rarely enter the lower reaches of the Feather River, although Rutter (1908) collected them as far upstream as Oroville. Splittail are observed, on occasion, in the American River and have been collected at the Highway 160 bridge in Sacramento; in the past, Rutter (1908) collected them as far upstream as Folsom. He also collected them from the Merced River at Livingston and from the San Joaquin River at Fort Miller (where Friant Dam exists today). In recent years, they have only been found as high as the confluence of the Tuolumne River and in the lower Tuolumne River. Spawning still occurs on a regular basis in the lower San Joaquin River and juveniles have been found in this region every year from 1995 to 2011 (Contreras et al. 2011, R. Baxter, CDFW, pers. comm. 2013). Occasionally, splittail are caught in San Luis Reservoir, which stores water that has been pumped from the Delta (Moyle et al. 2004).

Splittail were once abundant in Tulare Lake and in other waters of the San Joaquin Valley (Moyle et al. 2004). Snyder (1905) reported catches of splittail from southern San Francisco Bay and the mouth of Coyote Creek in Santa Clara County, but recent surveys are inconclusive as to whether a reproductive population of splittail continues to exist in the South Bay; Leidy (2007) notes records from only 1983 and 2000. Evidence of a persistent population is more convincing in lower Walnut Creek, Contra Costa County, where a 1998 CDFW gill-net survey of tidal reaches of the creek found splittail to be the most abundant fish (Leidy 2007). Sacramento splittail have also been recorded from the estuarine environments of Peyton and Hastings sloughs, near the mouth of Walnut Creek, and in Grayson Creek, just above its confluence with lower Walnut Creek (Leidy 2007).

Splittail are now largely confined to the Delta, Suisun Bay, Suisun Marsh, Napa River, Petaluma River, and other parts of the San Francisco Estuary, while spawning on upstream floodplains and channel edges (Moyle et al. 2004). The consistent presence of young-of-year splittail in the Sacramento River over 200 km upstream of the Delta may indicate that a small population persists there, although their presence may also indicate that some adults make long migrations to find suitable spawning areas, especially in dry years (Feyrer et al. 2005, R. Baxter, CDFW, pers. comm. 2013). In the Delta, they are most abundant in the north and west portions, although other areas may be used for spawning. Non-spawning fish are found in Suisun Bay and Suisun Marsh and the Petaluma and Napa marshes. Adults from both populations are found to forage in open waters of Suisun Bay; however, Suisun Marsh is almost exclusively used by juveniles and adults from the Delta population. Fish from the San Pablo population are found mostly in western Suisun Bay. This suggests that San Pablo fish preferentially live in Petaluma and Napa marshes, closer to their natal watersheds (Baerwald et al. 2008) and away from higher salinities in the Bay.

Trends in Abundance: Splittail were once harvested by Native Americans and by commercial fisheries in the 19th and early 20th centuries. Jordan (1884) recorded them as "very common in the Sacramento and … brought in considerable numbers to the San Francisco Market" (p. 617). Their overall abundance and range apparently shrunk with development of California's water system (e.g., the elimination of Lake Tulare) but they remained a common fish in the Delta (Turner and Kelly 1966).

There are currently seven sampling programs that monitor splittail abundance, along with other fishes in the estuary (Moyle et al. 2004). These programs include: (1) CDFW Summer Townet Survey (started in 1959), (2) CDFW Fall Midwater Trawl Survey (1967), (3) USFWS Chipps Island trawl survey (1975), (4) U. C. Davis Suisun Marsh trawling and seining surveys (1980), (5) USFWS Beach Seine Survey (1979), (6) CDFW San Francisco Bay trawling survey (1980), and (7) fish salvage operations at Central Valley Project (CVP) and State Water Project (SWP) pumps in the south Delta (1979). None of these surveys (or indices calculated from them) were designed specifically for splittail so results from each have to be interpreted with caution, although all have been used in analyses of splittail population trends (Moyle et al. 2004). According to Moyle et al. (2004): "Combined, the surveys indicate that (1) splittail populations have high natural variability, a reflection of their life history strategy, (2) some successful reproduction takes place every year, and (3) the largest numbers of young are produced only during years of relatively high outflow. These findings suggest that the majority of adult fish in the population result from spawning in wet years and lowest numbers are produced during drought years" (p. 13). Essentially, no consistent trends were detected from 1962 through 2002.

When numbers are compared from 1980-2008 between the two programs that catch the most splittail, results are similar. The fish salvage operations (Figure 1) capture migrating adults and juveniles during January through July, while the Suisun Marsh program captures resident fish year-round (Figure 2). Both show a peak in abundance in 1980, presumably the result of a series of wet years, followed by a decline through the 1990s, reflecting an eight-year drought. The USFWS (2003) indicated that there was some evidence of decline in splittail numbers but the species was not in danger of declining to extinction. Since then, numbers have fluctuated but have likely been well below the numbers present in the 1980s and earlier. The model of population dynamics presented in Moyle et al. (2004) indicates high resiliency in splittail populations, suggesting they can recover from very low levels quickly. However, the continued decline in abundance shown in the pumping plants suggests that the portion of the population that exists in the southern part of the Delta may be very small (Figure 1), while the northern part of the population, reflected in the Suisun Marsh data, appears to have declined less severely in recent years (Figure 2). Seining surveys at boat ramps around the Delta and lower rivers, which capture mainly young-of-year fish, show high variability in numbers and no real trends; the catches seem to primarily reflect annual spawning success near the seining areas.

Trends for the genetically distinct population in the lower San Francisco Estuary are not known, but it is likely they are much smaller than the Delta populations.

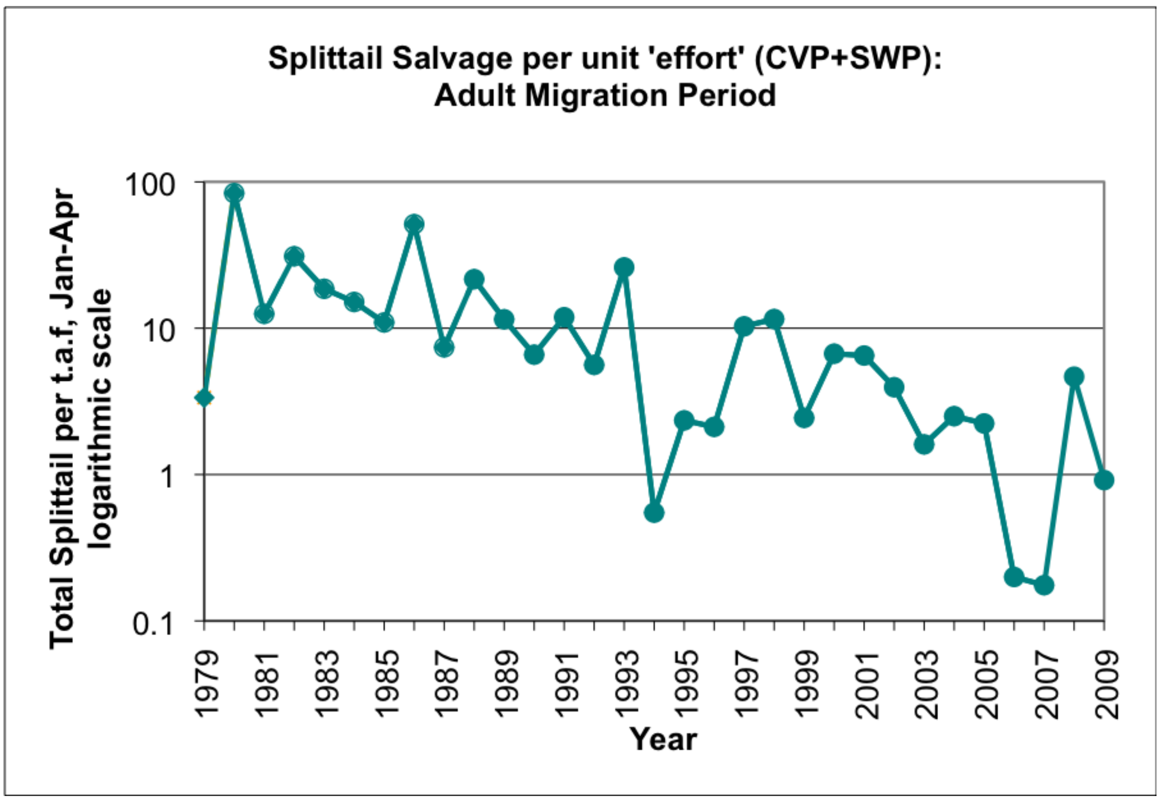

Figure 1. Number of splittail captured per thousand acre feet of water in the pumps of the South Delta, January-April, 1979-2009. Note the logarithmic scale on the Y vertical axis. Graph courtesy of David Wright, California Department of Fish and Wildlife.

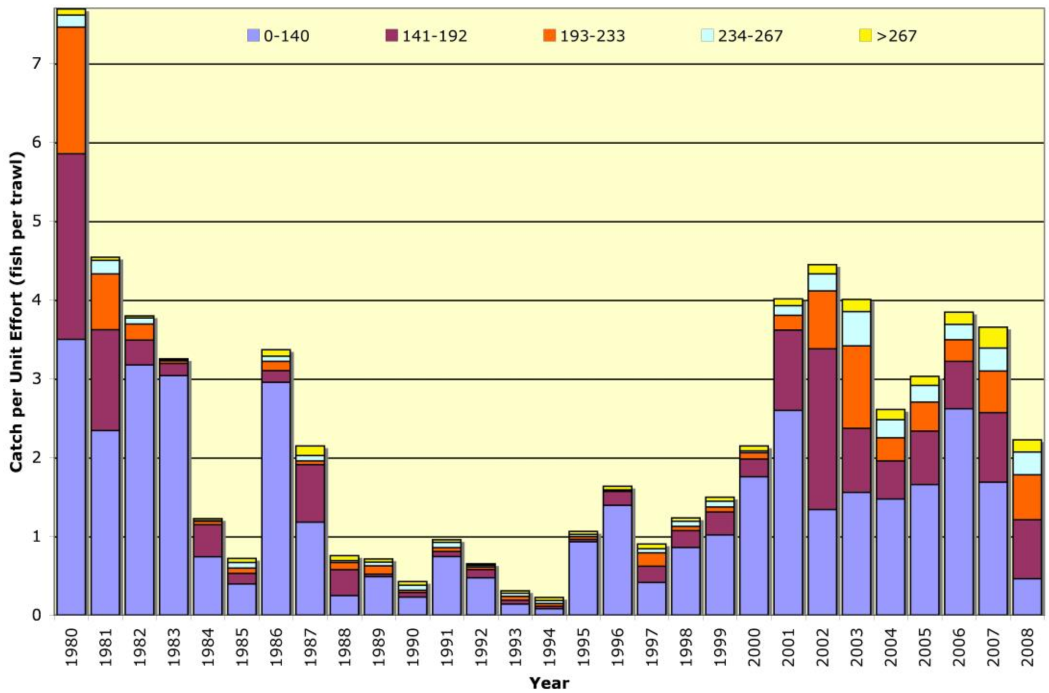

Figure 2. Annual catch per effort of splittail of different size classes (mm SL) in Suisun Marsh, 1980-2008. Each bar represents 150-200 trawls. The bottom-most section of each bar represents catches of young-of-year. Graph by Teejay Orear, UC Davis.

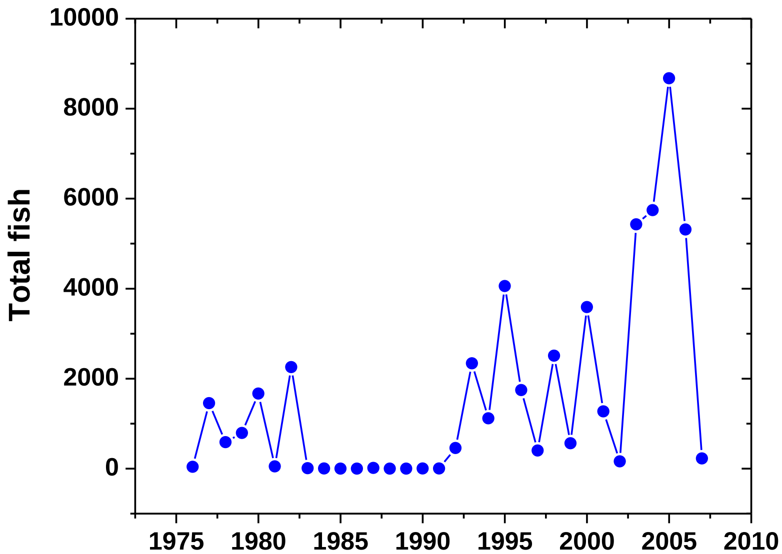

Figure 3. Splittail catch from USFWS Beach Seine Survey. Points are total annual catch over 20 stations consistently sampled each year from 1976-2007. Total catch is weighted by the number of months sampled each year, especially in the mid-80s to mid-90s. Values over the past decade are not influenced by the weighting (i.e., 11-12 months were sampled in each year). Graph by W. A Bennett.

Nature and Degree of Threats: The splittail is a resilient species (Sommer et al. 1997, Moyle et al. 2004) but it lives in a rapidly changing environment that is increasingly modified for human use (Table 1). Its present status may reflect short-term stability in an otherwise long-term decline. Between the period of massive influx of non-native peoples into California in the 1850s and the completion of Oroville Dam in 1962 (the final large dam constructed in the Central Valley of California), the range and total abundance of splittail declined. The splittail is now largely restricted to the Sacramento-San Joaquin Estuary, limited floodplain and riverine habitats upstream, and channels between Delta islands. Its populations are highly dependent on artificially maintained flows and floodplains, as well as on unusually wet years that create widespread flooding, such as occurred in 2011. Long-term persistence of splittail populations depends upon favorable estuary conditions, adequate spawning habitats, and access to those habitats.

Major dams. Splittail depend on outflows from the Sacramento and San Joaquin rivers and their major tributaries for successful life cycle completion. These rivers are all highly regulated by dams. Major dams have largely eliminated splittail habitat in the San Joaquin River above the mouth of the Merced River by shutting off flows completely and reducing suitable habitat downstream. Likewise, the Tulare Basin no longer supports splittail because dams and downstream diversions have dried large areas of former aquatic habitats. One of the few places where spawning can take place in most years is the re-created floodplain on the lower Cosumnes River; the river is unregulated so frequent flooding occurs (Moyle et al. 2007).

Spawning in the Sacramento River depends on releases from large rim dams (usually for flood control), high flow events from small tributaries (e.g., Cache and Putah creeks), and occasional passive spills from large dams. Strong year classes of splittail are created when the Yolo and Sutter bypasses and other floodplain areas are inundated for at least six weeks in late February through April, provided depths are adequate and temperatures are <20°C. These conditions need to occur, at a minimum, every 3-4 years to maintain large adult populations. Separation of floodplains from Central Valley rivers in the 19th and early 20th centuries must have been devastating to splittail populations, especially in the San Joaquin River. Fortunately, the creation of huge artificial floodways (Yolo and Sutter bypasses) in the 1920s and 1930s coincidentally created near-ideal conditions for splittail spawning and rearing and maintained their populations (Sommer et al. 2007). However, splittail numbers reached record lows in the estuary in 1994, following six years of drought, which greatly reduced the amount and frequency of flooding. Given the increasing human demand for water, and trends towards managing the Yolo and Sutter bypasses in ways that reduce or control flooding, it is uncertain whether these areas will continue to provide favorable splittail spawning habitat. The creation of a new floodplain area along the Cosumnes River (Moyle et al. 2007) and proposals to do so elsewhere are positive signs that additional spawning habitats may be created.

If freshwater outflows are further reduced in the future, the amount of brackish water habitat in the Estuary may decrease. Such habitat supports the principal rearing areas for splittail. The effect is likely to be especially strong in conjunction with predicted sea level rise.

	Rating	Explanation
Major dams	High	Splittail are dependent upon dam-regulated flows throughout their range
Agriculture	High	Agricultural return waters reduce habitat quality; channel modifications (e.g., levees) reduce habitat quantity and limit access to floodplains; entrainment occurs in major diversions
Grazing	n/a	Included as part of agriculture
Rural residential	Low	Residential areas on the edges of Petaluma, Napa, and Suisun marshes may create localized impacts (e.g., reclamation of tidal marshes, pollution input)
Urbanization	Medium	Numerous large metropolitan areas throughout range
Instream mining	n/a	
Mining	Low	Legacy effects of gold mining (e.g., mercury) may impact splittail; effects unknown
Transportation	Low	Roads and railroad may affect Suisun Marsh
Logging	n/a	
Fire	n/a	
Estuary alteration	High	San Francisco Estuary is highly modified and continues to change rapidly
Recreation	Low	Recreational boating, etc. may affect behavior and habitat utilization
Harvest	Low	Some harvest for bait; limited harvest of migrating adults for food
Hatcheries	n/a	
Alien species	High	Invasive species numerous and widespread across splittail range; alteration of food webs; new invasions are an ongoing potential threat

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Sacramento splittail. 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 high. See Methods section for descriptions of the factors and explanation of the rating protocol.

Agriculture. All habitats used by splittail are heavily influenced by agriculture. Suisun Marsh has been diked and drained to create a combination of cattle pasture and marsh for waterfowl habitat, as have the Napa and Petaluma marshes. River flows are regulated to provide water for agriculture. The bypasses and floodplains used by splittail for spawning are largely devoted to agriculture. Migrating fish are subject to entrainment in agricultural diversions, including the large pumps in the South Delta. Agricultural return waters generally increase temperatures and deliver pollutants; some rivers (e.g., the lower San Joaquin River) are consequently unsuitable for splittail and other native fishes. Some contaminants, such as selenium from San Joaquin Valley agricultural drainage, can accumulate in splittail and potentially interfere with reproduction and change behavior.

While Feyrer et al. (2007) showed that juvenile splittail are very flexible in their diet and habitat utilization characteristics, they also note that habitat quality varies widely across their range, as reflected in reduced growth rates in some areas. Currently, splittail are thriving in the highly altered Suisun and Petaluma marshes, although growth rates are somewhat reduced following food web alterations from the overbite clam invasion. In Suisun Marsh, periodic dissolved oxygen 'sags' occur from return water from duck clubs and other agricultural operations, which are laden with organic matter (R. E. Schroeter, unpublished data). While efforts are being made to reduce these impacts, poor water quality remains a stressor in Suisun Marsh and other portions of the Delta.

Urbanization. The San Francisco Estuary receives large amounts of urban runoff and both point and non-point sources of pollution inputs. The effects of pesticides and other toxic substances from urban runoff on splittail are not known, but there may be considerable potential for negative impacts (Sommer et al. 2007). Because splittail forage on the bottom, consuming large amounts of detritus, they may be particularly susceptible to contaminants that accumulate in substrates or in benthic organisms. Selenium, from urban and agricultural sources, is of particular concern because it accumulates in overbite clams, which splittail consume, and has been demonstrated to inhibit growth and reproduction in splittail and other fishes (Sommer et al. 2007). In addition, sewage outflows release micropollutants (hormones, etc.) that can affect splittail and other fishes. Thus, the proposed increase in tertiary treated sewage water flowing into the Suisun Marsh from Fairfield could affect splittail in a number of ways, both positive and negative. In addition, a largely undocumented effect of urbanization on splittail is the creation of large levees to protect urban areas from flooding, which have greatly diminished spawning and rearing habitat for splittail.

Mining. The mercury legacy from mining during the Gold Rush era has some potential to affect splittail reproduction and survival (e.g., Deng et al. 2008), but population-level effects are not known.

Transportation. Transportation corridors have contributed to alteration of splittail habitats, but the effects are minor compared to other habitat impacts. Transportation-related impacts may be particularly acute in Suisun Marsh, which is crossed by a railroad and restricted by highways. Ship channels may disrupt migration patterns or otherwise negatively affect splittail habitat utilization.

Estuary alteration. The upper San Francisco Estuary, a key portion of the splittail's range, is completely altered in structure and function; the Delta has become a collection of heavily farmed, subsided islands, protected by inadequate levees, which force water to flow through deep channels with little edge habitat (Lund et al. 2007, 2010). Freshwater is delivered into this changed system from altered rivers with controlled flow regimes. The San Joaquin River contributes minimal inflow that is highly polluted with agricultural drainage and urban wastewater. The Sacramento River contributes more water in the summer (and less in winter) than it did historically; this water is moved across the Delta to the giant pumps of the State Water Project and the federal Central Valley Project, dramatically changing the normal seaward gradients of flow, salinity, and other factors that fish evolved with and respond to. As Moyle and Bennett (2008) documented, the Delta has increasingly become, from a fish perspective, more like a freshwater lake than the upper part of an estuary. This lake-like habitat does not provide optimal conditions for splittail (Nobriga et al. 2005); however, splittail can still migrate through the Delta during times when flows are high and the Sacramento River outflow passes through floodplains. Likewise, net flow is usually downstream in spring when most juvenile splittail are out-migrating to rearing areas, although this does not prevent millions from being entrained in the CVP and SWP pumps in some years. In most years, splittail have only limited places to rear, mainly Suisun Marsh, Petaluma and Napa rivers, Suisun Bay, and, perhaps, the western Delta, with a limited number of suitable rearing areas elsewhere, such as the Sutter Bypass. In spite of these habitat limitations, splittail have sustained what appear to be large populations (Moyle et al. 2004), although there are no real estimates of numbers.

Continued changes to the Estuary may pose additional threats to splittail and other native fishes. Of note is the continuous increase in water diversion, both upstream of the Delta and from the Delta itself, although diversions from the south Delta have been reduced since 2007 to protect delta smelt and Chinook salmon. There are now immense pressures on the system to find ways to continue to remove more fresh water, including increasing upstream diversions, such as the recent push to develop bypass tunnels to divert water from the lower Sacramento River, transport it around the Delta, and deliver it directly into the SWP and CVP aqueducts. Substantial changes may occur in the Delta and Suisun Marsh as a consequence of predicted sea level rises and corresponding levee failures. In the Delta, subsided islands may fill with saline or fresh water, depending on location, creating large areas of open water (Lund et al. 2007, Moyle 2008). Breached islands will also increase the tidal prism, leading to more salt being drawn into the Delta. In Suisun Marsh, the patchwork of freshwater marsh maintained by duck hunting clubs and wildlife areas will likely be converted into tidal and subtidal habitat (Moyle et al. 2014). The outcomes and potential impacts of these systemic changes to splittail and other fishes in the Estuary remain uncertain; therefore, continued monitoring of populations and their habitats is imperative.

Harvest. Although splittail have been harvested as food and bait by recreational anglers, there is no evidence that this exploitation has contributed to their decline. However, an annual fishery concentrates on migrating spawners which could pose a threat if harvest of large females becomes excessive (Sommer et al. 2007). This potential impact was greatly alleviated by angling regulations implemented in 2010, which went from no daily bag limit for splittail to a daily limit of 2 splittail for inland waters.

Alien species. Introduced species are an ongoing threat to the San Francisco Estuary, especially those introduced from the ballast water of ships. The most recent introductions have been of several species of planktonic copepods, Brazilian waterweed (*Egeria densa*), and the overbite clam. The copepods are important food for larval and juvenile splittail and a shift in species, especially towards the tiny and apparently inedible *Limnoithona tetraspina*, is a cause for concern, although no effects have been detected. Changes in copepod abundance and composition are, at least in part, the result of the invasion by the overbite clam. This clam has become extremely abundant in Suisun Bay, from which it filters out much of the planktonic algae, the base of the food web that supports splittail (Feyrer et al. 2003). Increase in abundance of the clam led to collapse of the mysid shrimp population, a major food of splittail. The overbite clam has had much less of an impact on planktonic invertebrates in Suisun Marsh than it has elsewhere, perhaps accounting for high splittail abundance in this area. Adult splittail feed directly on the clams so, in this case, their presence may be beneficial to splittail, although selenium that accumulates in the clams may ultimately have a negative effect on splittail reproduction. However, any benefits from providing adult forage base may be offset by alterations to other components of the food web that support larvae and juveniles. Ultimately, alien species represent a threat to the entire estuary ecosystem because of their abundance and unpredictable effects.

Effects of Climate Change: Climate change will result in two major factors that will likely affect splittail and other native fishes: increased variability in flooding, and rise in sea level. An example of potential effects of increased variability in flooding, along with drought, can be seen in the period from 1980-1995, a period with some of the most extreme conditions the estuary has experienced since the arrival of Europeans. Within this 15-year period, an extended drought persisted from 1986-1992. Ironically, there were exceptionally high outflows at the beginning of the drought because of severe rain in February, 1986. The prolonged drought had two major interacting effects: a natural decrease in freshwater outflow to the Estuary, and an increase in the proportion of inflowing water being diverted from the Estuary. A natural decline in splittail numbers would be expected from greatly reduced outflow over an extended time because of the reduced availability of spawning and larval rearing habitat. The strong year class produced from the 1986 flooding was presumably an important factor in allowing splittail to persist through six years of drought, although some young-of-year were produced every year (Figure 2). It is important to recognize that extreme floods and droughts have occurred in the past, yet splittail populations have endured. However, climate change is predicted to greatly increase flow variability, with bigger floods (probably good for splittail if the timing is right) but longer droughts, with more extended periods of low flows. These extreme conditions will be made more severe by increased diversion of water both upstream and in the Delta. The net effects are likely to be more extreme fluctuations in splittail populations, with the potential to reach critically low numbers during extended drought.

As sea level rises, large parts of Suisun and Petaluma marshes will become inundated and saltier, unless action is taken to reduce the effects (Moyle et al. in press). As these key rearing areas change, food organism and predator populations will change in response. It is possible that flooded islands in the Delta or new tidal marsh habitat (e.g., Cache Slough region) will replace habitat lost elsewhere. Overall, rise in sea level has the potential to dramatically change splittail habitat; however, the effects of these changes cannot be predicted and may be negative, neutral, positive, or some combination thereof. Moyle et al. (2013) rated the splittail “highly vulnerable” to extinction in the next 100 years as the result of the added impacts of climate change to the estuary and its spawning habitats.

Status Determination Score = 3.1 - Moderate Concern (see Methods section; Table 2). Splittail have highly variable populations but do not appear to be threatened with extinction in the immediate future. Because the San Francisco Estuary and Central Valley rivers may become dramatically altered as a result of climate change and associated sea level rise, increases in flow variability, and more frequent and extended drought, splittail habitats cannot be regarded as secure (Sommer et al. 2007). The splittail was listed as a federally threatened species in 1999 by the USFWS, but was delisted in 2003 as the result of new information on its biology and status (Moyle et al. 2004, Sommer et al. 2007). The American Fisheries Society lists splittail as "Vulnerable," while NatureServe lists it as "Imperiled" (G2) (Jelks et al. 2008). Not recognized in these status evaluations is recent information indicating that the splittail consists of two Distinct Population Segments, one in the lower estuary (San Pablo DPS) and one centered in the Delta (Delta DPS). The San Pablo DPS is apparently much smaller than the Delta DPS and may, consequently, be in greater likelihood of severe decline or extinction.

Metric	Score	Justification
Area occupied	2	Delta, portions of Sacramento/San Joaquin rivers, Suisun Bay and Marsh, and Petaluma/Napa marshes and lower river watersheds
Estimated adult abundance	5	Large in Delta DPS, unknown in San Pablo DPS
Intervention dependence	4	All habitats heavily managed for things other than splittail production
Tolerance	5	One of the physiologically most tolerant native fish species
Genetic risk	3	Two distinct populations; San Pablo DPS may be at more risk of extinction, lowering diversity
Climate change	2	Highly vulnerable to droughts and sea level rise
Anthropogenic threats	1	See Table 1
Average	3.1	22/7
Certainty (1-4)	4	Well studied in many areas

Table 2. Metrics for determining the status of Sacramento splittail, 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: Sacramento splittail are a relatively easy species to manage due to their high physiological tolerances, high fecundity, relatively long life span, and because of our good understanding of splittail life history requirements. Conversely, their restricted distribution and migration between two very different habitat types, both of which are already highly modified and likely to further change in response to climate change and sea level rise, may create significant management challenges. Management recommendations include:

1. Continue to monitor splittail abundance and age class structure on an annual basis in Suisun Marsh, in order to document changes in year class success.

2. Institute a monitoring program for the Petaluma and Napa river populations to determine population dynamics, habitat requirements, and migratory patterns, especially under various climate change models (see #5 below). The ecology and phylogenetic relationships of splittail in San Francisco Bay also need to be determined.

3. Create more suitable floodplain habitats that will support splittail spawning and rearing on a regular basis (at least every 2-3 years). Recent studies suggest that even small amounts of regularly flooded habitat can be used successfully by splittail to supplement populations in dry years (Feyrer et al. 2006, Moyle et al. 2007, Sommer et al. 2002, 2008).

4. Actively manage floodplain areas of known importance for splittail spawning (e.g., Yolo and Sutter bypasses, Cosumnes River floodplain) to maximize splittail spawning success. This could be done by annual flooding of relatively small areas.

5. Perform modeling and other studies to determine predicted changes to, and corresponding suitability of, existing estuarine splittail habitats under various sea level rise and climate change scenarios. Among questions to address is how varying levels of inundation will affect portions of Suisun Marsh and the Delta. Modeling could also focus on splittail 'salvage' in the South Delta pumps and how existing and/or modified operations may affect populations.

6. Restore habitats for splittail in the San Joaquin River and associated parts of the Delta so a large population, independent of the Sacramento River-Suisun Marsh population, can be reestablished.

7. Continue to assess the sport fishery for splittail during their spawning migration on the Sacramento River to determine impacts (if any) on populations. Similar monitoring should also occur on the Petaluma and Napa river populations.

Figure 4. Distribution of Sacramento splittail, *Pogonichthys macrolepidotus* (Ayres), in California. Historic distribution included most of the Central Valley, including the San Joaquin River, lower portions of its tributaries, and Tulare Lake (now dry).