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FISH AND WILDLIFE SERVICE

September 14, 2012

Technical Staff Comments to the State Water Resources Control Board re: the Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan, Public Workshop 2, Bay Delta Fishery Resources (Longfin Smelt)

The US Fish and Wildlife Service (Service) recently evaluated the longfin smelt for listing under the Endangered Species Act. The following excerpts were taken from the twelve-month finding determination published in the Federal Register on April 2, 2012. In this finding, the Service concluded that the San Francisco Bay Delta population of longfin smelt is warranted for protection under the Endangered Species Act, but precluded from immediate listing by other listing actions .

Species Information

Species Description and Taxonomy

Longfin smelt measure 9–11 centimeters (cm) (3.5–4.3 inches (in)) standard length, although third-year females may grow up to 15 cm (5.9 in). The longfin smelt belongs to the true smelt family Osmeridae and is one of three species in the *Spirinchus* genus; the night smelt (*Spirinchus starksi*) also occurs in California, and the shishamo (*Spirinchus lanceolatus*) occurs in northern Japan (McAllister 1963, pp. 10, 15). Because of its distinctive physical characteristics, the Bay-Delta population of longfin smelt was once described as a species separate from more northern populations (Moyle 2002, p. 235). Delta smelt and longfin smelt hybrids have been observed in the Bay-Delta estuary, although these offspring are not thought to be fertile because delta smelt and longfin smelt are not closely related taxonomically or genetically (California Department of Fish and Game (CDFG) 2001, p. 473).

Biology

Longfin smelt are considered pelagic (living in open waters away from the shore) and anadromous (moving from salt water to freshwater to spawn) (Moyle 2002, p. 236), although anadromy in longfin smelt is poorly understood, and certain populations are not anadromous, and complete their entire life cycle in freshwater lakes and streams. Within the Bay-Delta, the term pelagic refers to organisms that occur in open water away from the bottom of the water column and away from the shore. Juvenile and adult longfin smelt have been found throughout the year in salinities ranging from pure freshwater to pure seawater, although once past the juvenile stage, they are typically collected in waters with salinities ranging from 14 to 28 parts per thousand (ppt) (Baxter 1999, pp. 189–192). Longfin smelt are thought to be restricted by high water temperatures, generally greater than 22 degrees Celsius (°C) (71 degrees Fahrenheit (°F)) (Baxter *et. al.* 2010, p. 68), and will move down the estuary (seaward) and into deeper water during the summer months, when water temperatures in the Bay-Delta are higher. Within the Bay-Delta, adult longfin smelt occupy water at temperatures from 16 to 20 °C (61 to 68 °F), with spawning occurring in water with temperatures from 5.6 to 14.5 °C (41 to 58 °F) (Wang 1986, pp. 6–9).

Longfin smelt usually live for 2 years, spawn, and then die, although some individuals may spawn as 1- or 3-year-old fish before dying (Moyle 2002, p. 36). In the Bay-Delta, longfin smelt are believed to spawn primarily in freshwater in the lower reaches of the Sacramento River and San Joaquin River. Longfin smelt congregate in deep waters in the vicinity of the low salinity zone (LSZ) near X2 (see definition below) during the spawning period, and it is thought that they make short runs upstream, possibly at night, to spawn from these locations (CDFG 2009, p. 12; Rosenfield 2010, p. 8). The LSZ is the area where salinities range from 0.5 to 6 practical salinity units (psu) within the Bay-Delta (Kimmerer 1998, p. 1). Salinity in psu is determined by electrical conductivity of a solution, whereas salinity in parts per thousand (ppt) is determined as the weight of salts in a solution. For use in this document, the two measurements are essentially equivalent. X2 is defined as the distance in kilometers up the axis of the estuary (to the east) from the Golden Gate Bridge to the location where the daily average near-bottom salinity is 2 psu (Jassby *et al*. 1995, p. 274; Dege and Brown 2004, p. 51)).

Longfin smelt in the Bay-Delta may spawn as early as November and as late as June, although spawning typically occurs from January to April (CDFG 2009, p. 10; Moyle 2002, p. 36). Longfin smelt have been observed in their winter and spring spawning period as far upstream as Isleton in the Sacramento River, Santa Clara shoal in the San Joaquin system, Hog Slough off the South-Fork Mokelumne River, and in Old River south of Indian Slough (CDFG 2009a, p. 7; Radtke 1966, pp. 115–119).

Exact spawning locations in the Delta are unknown and may vary from year to year in location, depending on environmental conditions. However, it seems likely that spawning locations consist of the overlap of appropriate conditions of flow, temperature, and salinity with appropriate substrate (Rosenfield 2010, p. 8). Longfin smelt are known to spawn over sandy substrates in Lake Washington and likely prefer similar substrates for spawning in the Delta (Baxter *et. al.* 2010, p. 62; Sibley and Brocksmith 1995, pp. 32–74). Baxter found that female longfin smelt produced between 1,900 and 18,000 eggs, with fecundity greater in fish with greater lengths (CDFG 2009, p. 11). At 7°C (44.6°F), embryos hatch in 40 days (Dryfoos 1965, p. 42); however, incubation time decreases with increased water temperature. At 8–9.5°C (46.4–49.1 °F), embryos hatch at 29 days (Sibley and Brocksmith 1995, pp. 32–74).

Larval longfin smelt less than 12 millimeters (mm) (0.5 in) in length are buoyant because they have not yet developed an air bladder; as a result, they occupy the upper one-third of the water column. After hatching, they quickly make their way to the LSZ via river currents (CDFG 2009, p. 8; Baxter 2011a, pers comm.). Longfin smelt develop an air bladder at approximately 12–15 mm (0.5–0.6 in.) in length and are able to migrate vertically in the water column. At this time, they shift habitat and begin living in the bottom two-thirds of the water column (CDFG

2009, p. 8; Baxter 2008, p. 1).

Longfin smelt larvae can tolerate salinities of 2–6 psu within days of hatching, and can tolerate salinities up to 8 psu within weeks of hatching (Baxter 2011a, pers. comm.). However, very few larvae (individuals less than 20 mm in length) are found in salinities greater than 8 psu, and it takes almost 3 months for longfin smelt to reach juvenile stage. A fraction of juvenile longfin smelt individuals are believed to tolerate full marine salinities (greater than 8 psu) (Baxter 2011a, pers. comm.).

Longfin smelt are dispersed broadly in the Bay-Delta by high flows and currents, which facilitate transport of larvae and juveniles long distances. Longfin smelt larvae are dispersed farther downstream during high freshwater flows (Dege and Brown 2004, p. 59). They spend approximately 21 months of their 24-month life cycle in brackish or marine waters (Baxter 1999, pp. 2–14; Dege and Brown 2004, pp. 58–60).

In the Bay-Delta, most longfin smelt spend their first year in Suisun Bay and Marsh, although surveys conducted by the City of San Francisco collected some first-year longfin in coastal waters (Baxter 2011c, pers. comm.; City of San Francisco 1995, no pagination). The remainder of their life is spent in the San Francisco Bay or the Gulf of Farallones (Moyle 2008, p. 366; City of San Francisco 1995, no pagination). Rosenfield and Baxter (2007, pp. 1587, 1590) inferred based on monthly survey results that the majority of longfin smelt from the Bay-Delta were migrating out of the estuary after the first winter of their life cycle and returning during late fall to winter of their second year. They noted that migration out of the estuary into nearby coastal waters is consistent with captures of longfin smelt in the coastal waters of the Gulf of Farallones. It is possible that some longfin smelt may stay in the ocean and not re-enter freshwater to spawn until the end of their third year of life (Baxter 2011d, pers. comm.). Moyle (2010, p. 8) states that longfin smelt that migrate out of and back into the Bay-Delta estuary may primarily be feeding on the rich planktonic food supply in the Gulf of Farallones. Rosenfield and Baxter (2007, p. 1290) hypothesize that the movement of longfin smelt into the ocean or deeper water habitat in summer months is at least partly a behavioral response to warm water temperatures found during summer and early fall in the shallows of south San Francisco Bay and San Pablo Bay (Rosenfield and Baxter 2007, p. 1590).

In the Bay-Delta, calanoid copepods such as *Pseudodiatomus forbesi* and *Eurytemora sp.*, as well as the cyclopoid copepod *Acanthocyclops vernali* (no common names), are the primary prey of longfin smelt during the first few months of their lives (approximately January through May) (Slater 2009b, slide 45). Copepods are a type of zooplankton (organisms drifting in the water column of oceans, seas, and bodies of fresh water). The longfin smelt's diet shifts to include mysids such as opossum shrimp (*Neomysis mercedis*) and other small crustaceans (*Acanthomysis* sp.) as soon as they are large enough (20–30 mm (0.78–1.18 in)) to consume these larger prey items, sometime during the summer months of the first year of their lives (CDFG 2009, p. 12). Upstream of San Pablo Bay, mysids and amphipods form 80–95 percent or more of the juvenile longfin smelt diet by weight from July through September (Slater 2009, unpublished data). Longfin smelt occurrence is likely associated with the occurrence of their prey, and both of these invertebrate groups occur near the bottom of the water column during the day under clear water marine conditions.

Habitat

The Bay-Delta is the largest estuary on the West Coast of the United States (Sommer *et al*. 2007, p. 271). The modern Bay-Delta bears only a superficial resemblance to the historical Bay-Delta. The Bay-Delta supports an estuary covering approximately 1,235 square kilometers (km^2) (477 square miles (mi^2)) (Rosenfield and Baxter 2007, p. 1577), which receives almost half of California's runoff (Lehman 2004, p. 313). The historical island marshes surrounded by low natural levees are now intensively farmed and protected by large, manmade structures (Moyle 2002, p. 32). The watershed, which drains approximately 40 percent of the land area of California, has been heavily altered by dams and diversions, and nonnative species now dominate, both in terms of numbers of species and numbers of individuals (Kimmerer 2004, pp. 7–9). The Bay Institute has estimated that intertidal wetlands in the Delta have been diked and leveed so extensively that approximately 95 percent of the 141,640 hectares (ha) (350,000 acres (ac)) of tidal wetlands that existed in 1850 are gone (The Bay Institute 1998, p. 17).

The physical and biological characteristics of the estuary define longfin smelt habitat. The Bay-Delta is unique in that it contains significant amounts of tidal freshwater (34 km^2 (13 mi^2)) and mixing zone (194 km^2 (75 mi^2)) habitat (Monaco *et al*. 1992, pp. 254–255, 258). San Francisco Bay is relatively shallow and consists of a northern bay that receives freshwater inflow from the Sacramento-San Joaquin system and a southern bay that receives little freshwater input (Largier 1996, p. 69). Dominant fish species are highly salt-tolerant and include the commercially important Pacific sardine (*Sardinops sagax*) and rockfish (*Sebastes* spp.). Major habitat types include riverine and tidal wetlands, mud flat, and salt marsh, with substantial areas of diked wetland managed for hunting. The sandy substrates that longfin smelt are presumed to use for spawning are abundant in the Delta.

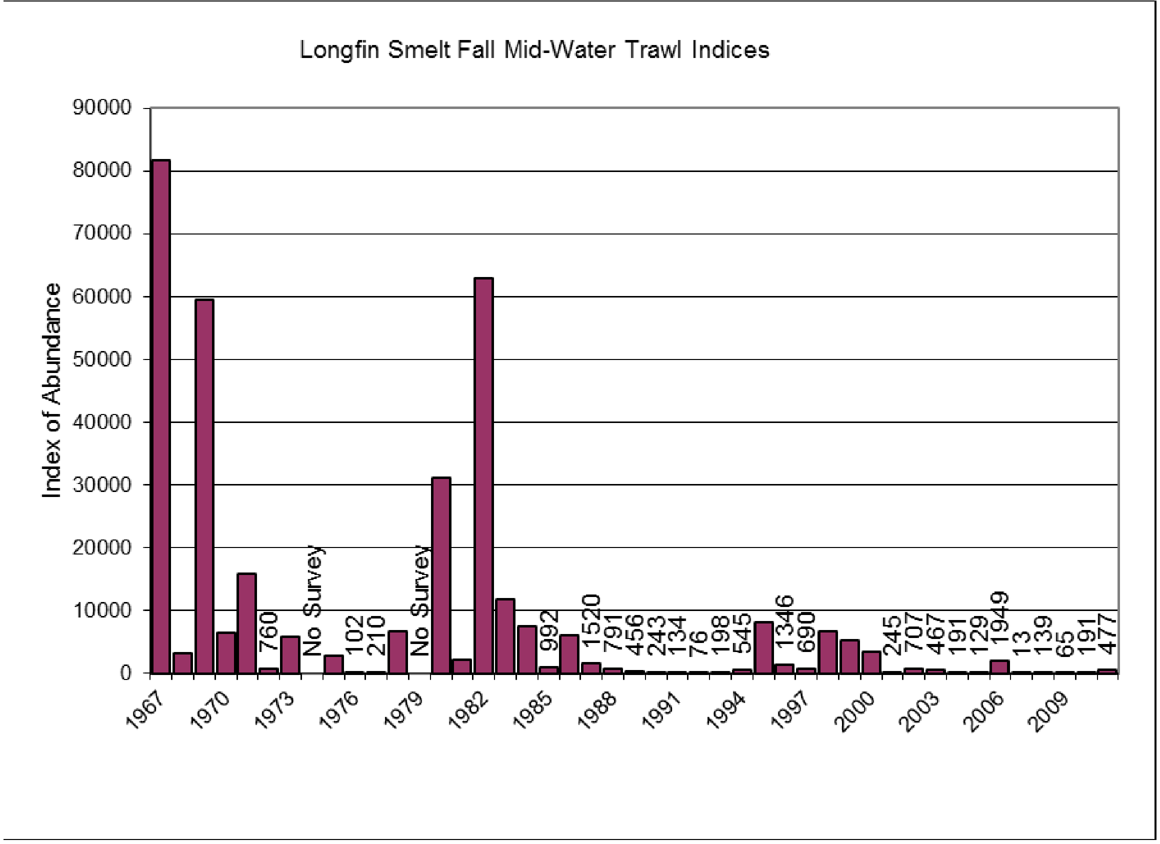
Abundance

Longfin smelt numbers in the Bay-Delta have declined significantly since the 1980s (Moyle 2002, p. 237; Rosenfield and Baxter 2007, p. 1590; Baxter *et. al.* 2010, pp. 61–64). Rosenfield and Baxter (2007, pp. 1577–1592) examined abundance trends in longfin smelt using three long-term data sets (1980–2004) and detected a significant decline in the Bay-Delta longfin smelt population. They confirmed the positive correlation between longfin smelt abundance and freshwater flow that had been previously documented by others (Stevens and Miller 1983, p. 432; Baxter *et al*. 1999, p. 185; Kimmerer 2002b, p. 47), noting that abundances of both adults and juveniles were significantly lower during the 1987–1994 drought than during either the pre- or post-drought periods (Rosenfield and Baxter 2007, pp. 1583–1584).

Despite the correlation between drought and low population in the 1980s and 90s, the declines in the first decade of this century cannot be fully explained by hydrology. Abundance of longfin smelt has remained very low since 2000, even though freshwater flows increased during several of these years (Baxter *et al*. 2010, p. 62). Abundance indices derived from the Fall Midwater Trawl (FMWT), Bay Study Midwater Trawl (BSMT), and Bay Study Otter Trawl (BSOT) all show marked declines in Bay-Delta longfin smelt populations from 2002 to 2009 (Messineo *et al.* 2010, p. 57). Longfin smelt abundance over the last decade is the lowest recorded in the 40-year history of CDFG's FMWT monitoring surveys. Scientists became concerned over the simultaneous population declines since the early 2000s of longfin smelt and three other Bay-Delta pelagic fish species—delta smelt (*Hypomesus transpacificus*), striped bass (*Morone saxatilis*), and threadfin shad (*Dorosoma petenense*) (Sommer *et al*. 2007, p. 273). The declines of longfin smelt and these other pelagic fish species in the Bay-Delta since the early 2000s has come to be known as the Pelagic Organism Decline, and considerable research efforts have been initiated since 2005, to better understand causal mechanisms underlying the declines (Sommer *et al*. 2007, pp. 270–277; MacNally *et al*. 2010, pp. 1417–1430; Thomson *et al*. 2010, pp. 1431–1448). The population did increase in the 2011 FMWT index to 477 (Contreras 2011, p. 2), presumably in a response to an exceptionally wet year.

The FMWT index of longfin smelt abundance in the Bay-Delta shows great annual variation in abundance but a severe decline over the past 40 years (Figure 2). The establishment of the overbite clam (*Corbula amurensis*) in the Bay-Delta in 1987 is believed to have contributed to the population decline of longfin smelt, as well as to the declining abundance of other pelagic fish species in the Bay-Delta (Sommer *et al*. 2007, p. 274). Figure 2 shows low values of the abundance index for longfin smelt during drought years (1976–1977 and 1986–1992) and low values overall since the time that the overbite clam became established in the estuary.

FIGURE 2. Longfin smelt abundance (total across year-classes) as indexed by the Fall Mid-Water Trawl of the Bay-Delta, 1967–2011.



* The survey was not conducted in 1974 or 1979.

** Index values for years of very low abundance were added.

Using data from 1975–2004 from the FMWT survey, Rosenfield and Baxter 2007 (p. 1589) found that longfin smelt exhibit a significant stock-recruitment relationship—abundance of juvenile (age-0) fish is directly related to the abundance of adult (age-1) fish from the previous year. They found that the abundance of juvenile fish declined by 90 percent during the time period analyzed. Rosenfield and Baxter (2007, p. 1589) also found a decline in age-1 individuals that was significant even after accounting for the decline in the age-0 population. If unfavorable environmental conditions persist for one or more years, recruitment into the population could be suppressed, affecting the species' ability to recover to their previous abundance. The current low abundance of adult longfin smelt within the Bay-Delta could reduce the ability of the species to persist in the presence of various threats.

Threats

When evaluating a species for federal ESA listing, we are required to access the species for threats. The following threats have been identified as significant because we believe that they are at least in part responsible for driving the population trend of the species.

Reduced Freshwater Flow

Many environmental attributes respond to variance in freshwater flow into the estuary, including patterns of flooding and drought, nutrient loading, sediment loading (turbidity), concentration of organic matter and planktonic biota, physical changes in the movement and compression of the salt field, and changes in the hydrodynamic environment (Kimmerer 2002a, p. 40). The San Francisco Estuary exhibits one of the strongest and most consistent responses of biota to flow among large estuaries (Kimmerer 2004, p. 14).

Reduced freshwater flows into estuaries may affect fish and other estuarine biota in multiple ways. Effects may include: (1) Decreased nutrient loading, resulting in decreased primary productivity; (2) decreased stratification of the salinity field, resulting in decreased primary productivity; (3) decreased organic matter loading and deposition into the estuary; (4) reduced migration cues; (5) decreased sediment loading and turbidity, which may affect both feeding efficiency and predation rates; (6) reduced dilution of contaminants; (7) impaired transport to rearing areas (e.g., low-salinity zones); and (8) reduction in physical area of, or access to, suitable spawning or rearing habitat Kimmerer (2002b, p. 1280).

Freshwater flow is strongly related to the natural hydrologic cycles of drought and flood. In the Bay-Delta estuary, increased Delta outflow during the winter and spring is the largest factor positively affecting longfin smelt abundance (Stevens and Miller 1983, pp. 431–432; Jassby *et al*. 1995; Sommer *et al*. 2007, p. 274; Thomson *et al*. 2010, pp. 1439–1440). During high outflow periods, larvae presumably benefit from increased transport and dispersal downstream, increased food production, reduced predation through increased turbidity, and reduced loss to entrainment due to a westward shift in the boundary of spawning habitat and strong downstream transport of larvae (CFDG 1992; Hieb and Baxter 1993; CDFG 2009a). Conversely, during low outflow periods, negative effects of reduced transport and dispersal, reduced turbidity, and potentially increased loss of larvae to predation and increased loss at the export facilities result in lower young-of-the-year recruitment. Despite numerous studies of longfin smelt abundance and flow in the Bay-Delta, the underlying causal mechanisms are still not fully understood (Baxter *et al*. 2010, p. 69; Rosenfield 2010, p. 9).

It is important to note that in the case of the Bay-Delta, freshwater flow is expressed as both Delta inflow (from the rivers into the Delta) and as Delta outflow (from the Delta into the lower estuary), which are closely correlated, but not equivalent. Freshwater flow into the Delta affects the location of the low salinity zone and X2 within the estuary. Because longfin smelt spawn in freshwater, they must migrate farther upstream to spawn as flow reductions alter the position of X2 and the low-salinity zone moves upstream (CDFG 2009, p. 17). Longer migration distances into the Bay-Delta make longfin smelt more susceptible to entrainment in the State and Federal water pumps (see Factor E: Entrainment Losses). In periods with greater freshwater flow into the Delta, X2 is pushed farther downstream (seaward); in periods with low flows, X2 is positioned farther landward (upstream) in the estuary and into the Delta. Not only is longfin smelt abundance in the Bay-Delta strongly correlated with Delta inflow and X2, but the spatial distribution of longfin smelt larvae is also strongly associated with X2 (Dege and Brown 2004, pp. 58–60; Baxter *et al*. 2010, p. 61). As longfin hatch into larvae, they move from the areas where they are spawned and orient themselves just downstream of X2 (Dege and Brown 2004, pp. 58-60). Larval (winter-spring) habitat varies with outflow and with the location of X2 (CDFG 2009, p. 12), and has been reduced since the 1990s due to a general upstream shift in the location of X2 (Hilts 2012, unpublished data). The amount of rearing habitat (salinity between 0.1 and 18 ppt) is also presumed to vary with the location of X2 (Baxter *et al.* 2010, p. 64). However, as previously stated, the location of X2 is of particular importance to the distribution of newly-hatched larvae and spawning adults. The influence of water project operations from November through April, when spawning adults and newly-hatched larvae are oriented to X2, is greater in drier years than in wetter years (Knowles 2002, p. 7).

Climate change may exacerbate the effects of reduced freshwater flow. Global sea level rose at an average rate of 1.8 mm (0.07 in) per year from 1961 to 2003, and at an average rate of 3.1 mm (0.12 in) per year from 1993 to 2003 (IPCC 2007a, p. 49). The IPCC (2007b, p. 13) report estimates that sea levels could rise by 0.18 to 0.58 m (0.6 to 1.9 ft) by 2100; however, Rahmstorf (2007, p. 369) indicated that global sea level rise could increase by over 1.2 m (4 ft) in that time period (CEC 2009, p. 49). Even if emissions could be halted today, the oceans would continue to rise and expand for centuries due to their capacity to store heat (CEC 2009, pp. 49–50). In the Bay-Delta, higher tides combined with more severe drought and flooding events are likely to increase the likelihood of levee failure, possibly resulting in major alterations of the environmental conditions (Moyle 2008, pp. 362–363). It is reasonable to conclude that more severe drought and flooding events will also occur in other estuaries where the longfin smelt occurs. Sea level rise is likely to increase the frequency and range of saltwater intrusion. Salinity within the northern San Francisco Bay is projected to rise 4.5 psu by the end of the century (Cloern *et al*. 2011, p. 7). Elevated salinity levels could push the position of X2 farther up the estuary and could result in increased distances that longfin smelt must migrate to reach spawning habitats. Elevated sea levels could result in greater sedimentation, erosion, coastal flooding, and permanent inundation of low-lying natural ecosystems (CDFG 2009, p. 30).

Introduced Species

The Bay-Delta is considered one of the most highly invaded estuaries in the world (Sommer *et al*. 2007, p. 272). Longfin smelt abundance in the Bay-Delta has remained low since the mid-1980s. This long-term decline has been at least partially attributed to effects of the introduced overbite clam (Kimmerer 2002a, p. 47; Sommer *et al*. 2007, p. 274; Rosenfield and Baxter 2007, p. 1589; Baxter *et al*. 2010, pp. 61–62). The overbite clam has impacted zooplankton abundance and species composition by grazing on the phytoplankton that comprise part of the zooplankton's food base (Orsi and Mecum 1996, pp. 384–386) and by grazing on larval stages of certain zooplankton like *Eurytemora affinis* (no common name) (Kimmerer 2002, p. 51; Sommer *et al*. 2007, pp. 274–276). These data suggest that changes in the estuary's food web following introduction of the overbite clam have had substantial and long-term impacts on longfin smelt population dynamics in the Bay-Delta.

In Suisun Bay, a key longfin smelt rearing area, phytoplankton biomass is influenced by the overbite or Amur River clam. A sharp decline in phytoplankton biomass occurred following the invasion of the estuary by this species, even though nutrients were not found to be limiting (Alpine and Cloern 1992, pp. 950-951). Abundance of zooplankton decreased across several taxa, and peaks that formerly occurred in time and space were absent, reduced or relocated after 1987 (Kimmerer and Orsi 1996, p. 412). The general decline in phytoplankton and zooplankton is likely affecting longfin smelt by decreasing food supply for their prey species, such as *N. mercedis* (Kimmerer and Orsi 1996, pp. 418 –419). Models indicate that the longfin smelt abundance index has been on a steady linear decline since about the time of the invasion of the non-native overbite (or Amur) clam in 1987 (Rosenfield and Swanson 2010, p. 14) even after adjusting for Delta freshwater flows (Nobriga 2010, slide 5).

Ammonium

Ammonia is un-ionized and has the chemical formula NH_3. Ammonium is ionized and has the formula NH_4^+. The major factors determining the proportion of ammonia or ammonium in water are water pH and temperature. This is important, as NH_3 ammonia is the form that can be directly toxic to aquatic organisms, and NH_4+ ammonium is the form documented to interfere with uptake of nitrates by phytoplankton (Dugdale *et al.* 2007, p. 17; Jassby 2008, p. 3).

Effects of elevated ammonia levels on fish range from irritation of skin, gills, and eyes to reduced swimming ability and mortality (Wicks *et al*. 2002, p. 67). Delta smelt have been shown to be directly sensitive to ammonia at the larval and juvenile stages (Werner *et al*. 2008, pp. 85–88). Longfin smelt could similarly be affected by ammonia as they utilize similar habitat and prey resources and have a physiology similar to delta smelt. Ammonia also can be toxic to several species of copepods important to larval and juvenile fishes (Werner *et al*. 2010, pp. 78–79; Teh *et al*. 2011, pp. 25–27).

In addition to direct effects on fish, ammonia in the form of ammonium has been shown to alter the food web by adversely impacting phytoplankton and zooplankton dynamics in the estuary ecosystem. Historical data show that decreases in Suisun Bay phytoplankton biomass coincide with increased ammonia discharge by the SRWTP (Parker *et al*. 2004, p. 7; Dugdale *et al*. 2011, p. 1). Phytoplankton preferentially take up ammonium over nitrate when it is present in the water. Ammonium is insufficient to provide for growth in phytoplankton, and uptake of ammonium to the exclusion of nitrate results in decreases in phytoplankton biomass (Dugdale *et al*. 2007, p. 23). Therefore, ammonium impairs primary productivity by reducing nitrate uptake in phytoplankton. Ammonium's negative effect on the food web has been documented in the longfin smelt rearing areas of San Francisco Bay and Suisun Bay (Dugdale *et al.* 2007, pp. 26–28). Decreased primary productivity results in less food available to longfin smelt and other fish in these bays.

Threats are acting synergistically

The primary threat to the DPS is from reduced freshwater flows. Upstream dams and water storage exacerbated by water diversions, especially from the SWP and CVP water export facilities, result in reduced freshwater flows within the estuary, and these reductions in freshwater flows result in reduced habitat suitability for longfin smelt. Freshwater flows, especially winter-spring flows, are significantly correlated with longfin smelt abundance—longfin smelt abundance is lower when winter-spring flows are lower. While freshwater flows have been shown to be significantly correlated with longfin smelt abundance, causal mechanisms underlying this correlation are still not fully understood and are the subject of ongoing research on the Pelagic Organism Decline.

In addition to the threat caused by reduced freshwater flow into the Bay-Delta, and alteration of natural flow regimes resulting from water storage and diversion, there appear to be other factors contributing to the Pelagic Organism Decline (Baxter 2010 *et al*., p. 69). Models indicate a steady linear decline in abundance of longfin smelt since about the time of the invasion of the nonnative overbite clam in 1987 (Rosenfield and Swanson 2010, pp. 13–14). However, not all aspects of the longfin smelt decline can be attributed to the overbite clam invasion, as a decline in abundance of pre-spawning adults in Suisun Marsh occurred before the invasion of the clam, and a partial rebound in longfin smelt abundance occurred in the early 2000s (Rosenfield and Baxter 2007, p. 1589).

The threats identified are likely acting together to contribute to the decline of the population (Baxter *et al*. 2010, p. 69). Reduced freshwater flows result in effects to longfin smelt habitat suitability, at the same time that the food web has been altered by introduced species and ammonium concentrations. It is possible that climate change could exacerbate these threats.   The combined effects of reduced freshwater flows, the invasive overbite clam (reduced levels of phytoplankton and zooplankton that are important to the Bay-Delta food web), and high ammonium concentrations act to reduce habitat suitability for longfin smelt.