Appendix 2.A: Evaluation of Species Considered for Coverage

2.A Evaluation of Species Considered for Coverage

2.A.1 Longfin Smelt (*Spirinchus thaleichthys*)

2.A.1.1 General

Longfin Smelt is a small, euryhaline, anadromous, and semelparous fish with a life cycle of approximately 2-3 years (Rosenfield 2010). Longfin Smelt reach 90 to 110 millimeters standard length, with a maximum size of 120 to 150 millimeters standard length (Moyle 2002; Rosenfield and Baxter 2007). 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 (Fisch et al. 2013). Young Longfin Smelt occur from tidal freshwater, through the estuary's low-salinity zone (where brackish and fresh waters meet), seaward and into the coastal ocean. Longfin Smelt can be distinguished from other California smelt by their long pectoral fins (which reach or nearly reach the bases of the pelvic fins), their incomplete lateral line, weak or absent striations on the opercular bones, low number of scales in the lateral series (54 to 65), and long maxillary bones (which in adults extend just short of the posterior margin of the eye) (Moyle 2002). Populations of Longfin Smelt occur along the Pacific Coast of North America, from Hinchinbrook Island, Prince William Sound, Alaska to the San Francisco Bay estuary (Lee et al. 1980). Although individual Longfin Smelt have been caught in Monterey Bay (Moyle 2002), there is no evidence of a spawning population south of the Golden Gate. Small and perhaps ephemeral Longfin Smelt spawning populations have been documented or suspected to exist in Humboldt Bay, the Eel River estuary, the Klamath River estuary and the Russian River (Moyle 2002; Pinnix et al. 2004). The San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) population is the southernmost and largest spawning population in California. Longfin Smelt have been historically sampled at numerous locations in the Sacramento–San Joaquin River Delta (Delta) by California Department of Fish and Wildlife trawls. The population has shown extremely low abundance in recent years, as measured by the Fall Midwater Trawl, as part of the pelagic organism decline (POD) (Sommer et al. 2007; Baxter et al. 2010; 77 FR 19756).

2.A.1.2 Legal Status

The Bay-Delta population of Longfin Smelt is the southern-most reproducing population along the Pacific Coast and was petitioned for threatened status under the federal Endangered Species Act (ESA) in 1992, but the petition was denied because the population was surviving well in areas outside the Bay-Delta estuary. Subsequent research indicated that the Bay-Delta population is more geographically isolated from other west coast Longfin Smelt populations than previously thought (summarized in 77 FR 19756). In 2007, the Bay Institute, Center for Biological Diversity, and Natural Resources Defense Council (2007a, 2007b) petitioned to have the Bay-Delta Longfin Smelt population listed as a threatened species under both the California Endangered Species Act (CESA) and the ESA. On May 6, 2008, the U.S. Fish and Wildlife

Service (USFWS) found that a status review for Longfin Smelt was warranted (73 *Federal Register* [FR] 24911). On April 9, 2009, USFWS determined that the Bay-Delta population did not meet the legal criteria for protection as a species subpopulation under the ESA (74 FR 16169). However, this determination was challenged legally and resulted in a settlement agreement to review the criteria for listing the Bay-Delta Longfin Smelt population as a distinct population segment (DPS) under ESA. The review resulted in a finding that listing of the Bay-Delta DPS of Longfin Smelt is warranted (77 FR 19755). Currently, however, listing the Bay-Delta DPS of Longfin Smelt is precluded by higher priority actions to amend the Lists of Endangered and Threatened Wildlife and Plants.

In December 2007, the California Department of Fish and Wildlife (CDFW) completed a preliminary review of the Longfin Smelt petition (California Department of Fish and Game 2007) and concluded that there was sufficient information to warrant further consideration by the California Fish and Game Commission. On February 7, 2008, the California Fish and Game Commission designated the Longfin Smelt as a candidate for potential listing under the CESA. On June 26, 2009, the California Fish and Game Commission ruled to list the status of Longfin Smelt as threatened under the CESA.

2.A.1.3 Distribution and Abundance

The Bay-Delta population of Longfin Smelt occurs throughout the San Francisco Bay and the Delta, and coastal waters west of the Golden Gate Bridge (summarized in 77 FR 19756). Within the San Francisco Estuary, they have been observed north as far as the town of Colusa on the Sacramento River, east as far as Lathrop on the San Joaquin River, and south as far as Alviso and Coyote sloughs in the South San Francisco Bay (Merz et al. 2013; Hobbs et al. 2015a). Longfin smelt spawning occurs in freshwater and low salinity waters (1 to 8 psu) of the estuary (Hobbs et al. 2006; Merz et al. 2013, Grimaldo et al. in review). During nonspawning periods, juvenile and prespawn adults are most often concentrated in Suisun, San Pablo, and north San Francisco Bays (Baxter 1999; Moyle 2002; Rosenfield and Baxter 2007). The species is also common in nearshore coastal marine waters outside the Golden Gate Bridge in late summer and fall (Baxter 1999). Longfin Smelt are periodically caught in the nearshore ocean, suggesting that some individuals migrate out into the Gulf of Farallones to feed and then back into the estuary (Rosenfield and Baxter 2007).

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. Rosenfield and Baxter (2007: pp. 1583–1584) confirmed the positive correlation between Longfin Smelt abundance and freshwater flow as had been previously documented by others (Stevens and Miller 1983, p. 432; Baxter et al. 1999, p. 185; Kimmerer 2002a, 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. The fall midwater trawl index of abundance for 2015 was the lowest on record (Finstad 2015), and came after several years of drought.

2.A.1.3.1 Population Abundance and Relationship to Flow

Freshwater flow influences the physical, chemical, and biological characteristics of estuarine environments (Kimmerer 2002a, 2000b). In the upper San Francisco Estuary, ecosystem services have been found to vary with flow (Kimmerer 2002a, 2000b), including primary production (MAST 2015), secondary consumer production (Kimmerer et al. 2009), and habitat for pelagic fishes (Feyrer et al. 2007). Additionally, flow has been found to affect survival, growth, and population levels of many key estuarine species, including Chinook salmon (Newman and Brandes 2010), Longfin Smelt (Rosenfield and Baxter 2007), and Delta Smelt (IEP MAST 2015).

For Longfin Smelt, focus on estuarine inflow has centered on the positive correlation found between winter-spring outflow and juvenile abundance (Rosenfield and Baxter 2007; Kimmerer et al. 2009). The mechanisms underlying this relationship are poorly understood (discussed below). Further, there are a number of emerging hypotheses about why Longfin Smelt respond to flow, all which may have different implications for potential management actions. The following discussion describes how flow may be important to the growth, survival, and population abundance of different Longfin Smelt life stages.

2.A.1.3.1.1 Mature Adults

As previously mentioned, mature adult Longfin Smelt move upstream to spawning habitats during the late fall and early winter. Spawning movements from the San Francisco Bay to Suisun Bay often occur prior to the initial storms of the winter suggesting that Longfin Smelt are not reliant on a strong freshwater cue to initiate spawning. Nonetheless, Longfin Smelt spawning distribution does seem to vary under wet and dry periods (Rosenfield and Baxter 2007). During wetter periods, adult longfin smelt concentrate in western Suisun Bay and likely other areas of the estuary, including Napa and Petaluma Rivers (Hobbs et al. 2015a). Under drier conditions adult longfin smelt are observed in greater abundance farther upstream (California Department of Fish and Game. 2009), e.g., in the west Delta.

2.A.1.3.1.2 Larvae

Until recently it was thought that Longfin Smelt egg incubation occurred primarily in freshwater areas (Rosenfield and Baxter 2007; Kimmerer et al. 2009). However, additional review of newly hatched larval distribution from the CDFW Smelt Larval Survey and new results from Grimaldo et al. (in review) are likely hatching in water between 0 and 8 ppt salinity. Using otolith microchemistry, Hobbs et al. (2010) found that Longfin Smelt recruited to the CDFW 20 mm survey mostly hatched and reared in low salinity water (0.33 to 4 ppt). Once larvae develop air bladders (~ 10-12 mm SL), they are able to move within the water column as opposed to being primarily surface-oriented (Bennett et al. 2002). Bennett et al. (2002) found that Longfin Smelt greater than 20 mm SL exhibit reverse diel vertical migrations, hypothesized as a means to remain in areas of favorable food supply or preferred salinity.

Dege and Brown (2004) found that distribution of Longfin Smelt larvae varies with outflow. Larvae smaller than 20 mm SL are 1-5 km seaward of X2 (distance of the 2 ppt isohaline from the Golden Gate Bridge) during high outflow years. In dry years, larvae less than 20 mm SL are found up to 10 km upstream of X2. Larvae greater than 20 mm exhibit a similar pattern, except that by June of wet and dry years, they are found several km (up to 10) seaward of X2. Note that

Dege and Brown (2004) did not analyze Longfin Smelt catches from the Napa River, where they are most abundant overall in the 20 mm Survey.

For discussion of larvae in SWP and CVP salvage, see Section 2.A.2.5.1 *Entrainment by Water Diversions*.

2.A.1.3.1.3 Juveniles

By summer, most juvenile Longfin Smelt are distributed in western Suisun Bay or San Pablo Bay regardless of outflow conditions. Survival of Longfin Smelt juveniles to the fall CDFW Fall Midwater Trawl (FMWT) survey has been found to be positively related to winter-spring outflow conditions (Rosenfield and Baxter 2007; Kimmerer et al. 2009). In recent years, there have been step-declines in the intercept of this relationship, but the slope has remained the same (Mount et al. 2013), suggesting that there has been a decline in the carrying capacity of habitat for Longfin Smelt.

2.A.1.3.2 Mechanisms Underlying Longfin Smelt Flow-Abundance Relationships

Hypothesized mechanisms underlying the flow-abundance relationship are poorly understood (Kimmerer 2002a; Rosenfield and Baxter 2007; Kimmerer 2009). Several hypotheses have advanced possible mechanisms underlying the relationship; not all hypotheses are mutually exclusive. Below is a summary of hypotheses.

2.A.1.3.2.1 Food Availability

Kimmerer (2002) suggested that although Longfin Smelt abundance is affected by a coupling with bottom-up pelagic food webs, the linkage is unlikely to be the result of flow influencing food availability and is more likely to be caused by changes in physical habitat (as indexed by X2). Kimmerer (2002) did find a significant relationship between flow (X2) and abundance of the zooplankter *Eurytemora*, a food source for Longfin Smelt. Various studies have noted the step-decline in the intercept of the flow-abundance relationship following the introduction of Asian clam in 1987 (Kimmerer 2002, Kimmerer et al. 2009, Mount et al. 2013), indicating that food web declines have resulted in less Longfin Smelt abundance for a given flow. Food limitation would be consistent with findings of Rosenfield and Baxter (2007) who found reduced age-class 1 productivity and the disproportionate reduction in age-class 2 recruitment in accordance with low food supply.

2.A.1.3.2.2 Habitat availability

Kimmerer et al. (2009) investigated how the quantity of habitat for Longfin Smelt, as defined primarily by salinity, responded to freshwater flow in the San Francisco estuary, and related this to the extent which Longfin Smelt abundance has a flow response. They found that Longfin Smelt abundance changed by two orders of magnitude over the range of X2 values, with a step decline in the slope after 1987[1]. However, they also found a modest slope in the relation of habitat to X2, which would allow for only about a twofold variation in the abundance index over that X2 range. Ultimately, they concluded increases in habitat, as defined primarily by salinity, may contribute somewhat to Longfin Smelt abundance, but that other factors such as retention may be more important.

[1] Mount et al. (2013) updated the X2-abundance regression and found step changes for 1987/1988 and 2002/2003.

California Department of Fish and Wildlife (CDFW) recently hypothesized increases in turbidity levels during higher outflow events results in lower predation rates. Ultimately, this could be an important mechanism influencing Longfin Smelt survival but there is little information to suggest that predators are having large effects on small pelagic fishes in the estuary because pelagic fish such as Longfin Smelt and Delta Smelt are rarely found in the stomachs of predators. This does not suggest that predation is not important periodically or over the long-term, it has just been difficult to observe. See additional discussion in Section 2.A.2.5.3 *Reduction in Turbidity* and Section 2.A.2.5.6 *Predation and Competition*.

Recent investigations by Grimaldo et al. (in review) of stationary habitat found that larval Longfin Smelt were abundant in tidal marsh and shallow open waters of the low salinity zone. This work suggests that shallow habitat provides key rearing habitat for larval Longfin Smelt. More work is needed to understand how suitable rearing habitat varies throughout the spawning range of Longfin Smelt. Presumably, spawning habitat in the interior Delta is poor given that much of the area is colonized by invasive SAV and the channels are typically lined with rip rap.

2.A.1.3.2.3 Transport and Advection

Early Longfin Smelt larvae (before swim bladder development) appear to be surface-oriented and therefore subject to net transport flows (Bennett et al. 2002). In tidal environments, early larval fish in channel habitats are likely to move several kilometers upstream and downstream with the tides. For early Longfin Smelt rearing in the Sacramento or San Joaquin Rivers, net transport downstream would occur faster under higher outflows than lower outflows. It is unclear if early larvae (i.e., without swim bladders) are able to exhibit behavior to retain their position once they reach the broader reaches Suisun Bay, which is physically and hydrodynamically complex. For early Longfin Smelt larvae hatched in shallow and tidal waters of Suisun Bay, net transport may have less of an effect on their position in the estuary, especially if larvae can remain close to shore in eddies or habitats that are less subject to transport flows (Grimaldo et al. in review). Larger larvae with developed air bladders have been shown to undergo reverse vertical diel migrations (Bennett et al. 2002), which is believed to help them retain position in habitat favorable for physio-chemical conditions and food.

2.A.1.3.2.4 Stratification and Retention

Kimmerer et al. (2009) recently hypothesized that one potential mechanism underlying the flow-abundance relationship is related to the physics of the estuary under high flow and low flow conditions. Under high flow conditions, residual circulation increases (Monismith et al. 2002), thus resulting in a stronger and more rapid transport of bottom-oriented species to upstream suitable habitats. For juvenile Longfin Smelt, which are bottom-oriented once vertical movement capabilities are established, the underlying mechanism may be related to retention in suitable rearing habitat (low-salinity areas, as reflected in the relatively greater nursery contribution of such habitats compared to freshwater and brackish habitats; Hobbs et al. 2010); retention would be higher under high-flow conditions.

2.A.1.4 Life History

Longfin Smelt are anadromous and semelparous, moving from saline to brackish or freshwater for spawning from November to May (Moyle 2002; Rosenfield and Baxter 2007). 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 (Rosenfield 2010). Age-2 adults generally migrate upstream to spawning areas during the late fall and early winter (Rosenfield and Baxter 2007). Spawning occurs at temperatures that range from 7.0 to 15.0°C, with larvae hatching in 40 days at 7°C (Moyle 2002). Peak spawning takes place in January and February of most years, when water temperatures are between 8 and 11ºC. Based on CDFW SLS data (distribution and length), spawning appears to be centered in brackish water (1-8 ppt), which typically extends from Suisun Bay to the confluence of the Sacramento River and San Joaquin River. Hobbs et al. (2010) provides considerable evidence that the larvae to recruit to later life stages are those that reared around 2 ppt. There was less evidence of successful recruits having reared as early larvae in waters less than 1 ppt or greater than 6 ppt. Evidence for individuals spawning multiple times in a season has not been investigated, but given that Longfin Smelt have such a broad spawning window (5-6 months) it may be that some females undergo repeated spawning events.

Longfin Smelt eggs are adhesive (demersal) (Moyle 2002). In Lake Washington, Longfin Smelt spawn over sandy substrate, but spawning substrates are unknown in the San Francisco Estuary. Evidence from Grimaldo et al. (2014) suggests spawning habitats include open shallow water and tidal marshes. Longfin Smelt produce between 1,900 and 18,000 eggs, with fecundity greater in fish with greater lengths (CDFG 2009). Incubation times for egg development range between 25 to 42 days (Rosenfield 2010).

Newly hatched Longfin Smelt larvae are surface-oriented and probably have little ability to control their position in the water column before they develop their air bladder. Once their air bladder is developed (~12 mm SL) they are capable of controlling their position in the water column by undergoing reverse diel vertical migrations (Bennett et al. 2002). Bennett et al. (2002) believed that the ability of Longfin Smelt to undergo reverse diel vertical migrations allows them to maintain their position on the axis of the estuary. During the first few months of their lives (approximately January through May), Longfin Smelt primarily prey on calanoid copepods such as *Pseudodiatomus forbesi* and *Eurytemora affinis*, before switching to mysids as soon as they are capable (Slater 2008; Baxter et al. 2010).

The geographic distribution of larval and early juvenile life stages of Longfin Smelt may be influenced by freshwater inflows to the Delta during the late winter and spring, although the mechanisms are complicated and not fully understood. (Hieb and Baxter 1993; Baxter 1999; Dege and Brown 2004). Larval Longfin Smelt are typically collected in the region of the estuary extending from the west Delta into San Pablo Bay. Their central tendency distribution moves toward the low-salinity zone in response to Delta outflow, with local tributary flow (Napa River flow) contributing to the downstream distribution (Baxter 1999; Dege and Brown 2004). In years when winter-spring Delta outflow is low, few larvae are detected in San Pablo Bay. In years when winter-spring Delta outflow is high, few larvae remain in the west Delta, but they are abundant in San Pablo Bay and may reach northern San Francisco Bay (Baxter 1999). The center of larval distribution is closely tied to the location of the low-salinity zone, as indicated by the position of X2 at all Delta outflows (Dege and Brown 2004).

Prior to 2009, much of the information on larval Longfin Smelt was focused on the CDFW 20 mm survey, which was not designed to sample smaller (yolk-sac to 20 mm SL) larvae (although does catch smaller individuals), nor conducted during the time period coinciding with peak spawning (January and February). In 2009, CDFW initiated the Smelt Larval Survey (SLS), which was designed to target small Longfin Smelt larvae (from newly hatched size to 20-mm SL) during peak spawning months. Despite the large historical information gap, the SLS has been informative over the last 6 years. The survey data show that small larvae exhibit distribution trends similar to what Dege and Brown (2004) described for large larvae and early juveniles. During wet years, small larvae are distributed towards the western Suisun Bay and in dry years, larvae are distributed towards the river confluence. Inspection of the length data from SLS suggests that spawning and hatching is not primarily located in freshwater as previously hypothesized (Rosenfield and Baxter 2007; Kimmerer et al. 2014). Many yolk-sac sized larvae are collected in brackish water, which is consistent with new findings of Grimaldo et al. (2014) who found high numbers of yolk-sac larvae (less than 7 mm SL) in shallow habitats and tidal marshes around Suisun Bay in water up to 8 ppt.

Juvenile Longfin Smelt move seaward, mostly west of Carquinez Bridge, by late summer and fall. Rosenfield and Baxter (2007) suggest that juvenile Longfin Smelt seek cooler and deeper water in the summer months. Their diets shift to large prey, such as mysids and amphipods, as they transform from early juveniles to sub-adults (Moyle 2002). Little is known about the biology of sub-adult Longfin Smelt upon entry into their Age-1 life stage. Rosenfield and Baxter (2007) noted there is a sharp decline in their abundance during this life stage but also acknowledge that some may be moving outside the sampling range of the CDFW sampling programs (i.e., to the ocean). It appears that some individuals move upstream with Age-2 spawners. Overall, ocean rearing of Age-1 and some Age-2 fish is not well understood, in part, for a lack of ocean monitoring information. Longfin Smelt have been captured periodically in sampling programs outside the Golden Gate bridge and in some tributaries to the north, including the Russian River, Eel River, and Klamath River (CDFG 2009); it is not known what portion of ocean-bound fish return to San Francisco Bay each year or if they return to other coastal streams north and south of San Francisco Bay. New information suggests that, at least seasonally, adult Longfin Smelt use tidal marshes in the South Bay to some degree, perhaps to take advantage of large densities of mysid shrimp (Hobbs et al. 2015b).

2.A.1.5 Threats

A number of threats may affect Longfin Smelt, and were reviewed by California Department of Fish and Game (2009) and in the USFWS 12-month finding on the petition to list Longfin Smelt under the ESA (77 FR 19756). The discussion below outlines some of the main threats to Longfin Smelt that were discussed in those reviews, in addition to others that may be of importance.

2.A.1.5.1 Entrainment by Water Diversions

Water diversions result in entrainment of all life stages. Salvage of juvenile and adult Longfin Smelt at the State Water Project (SWP) and Central Valley Project (CVP) is typically low during most water year types, but historically was occasionally higher in some years and negatively related to Old and Middle River flows, a hydrodynamic indicator of SWP/CVP entrainment risk. Larval Longfin Smelt could be entrained in relatively high numbers; however, because the SWP and CVP salvage facilities do not sample fish smaller than 20 mm SL, it is difficult to ascertain how many larvae are actually entrained (California Department of Fish and Game 2009). Real-time management of hydrodynamic conditions (e.g., Old and Middle River flows) in relation to

Longfin Smelt distribution aims to limit the potential for entrainment loss, as required by the DFW 2009 ITP for operation of the SWP. Other sources of entrainment include the North Bay Aqueduct Barker Slough Pumping Plant, the direct-cooled power plant at Pittsburg on Suisun Bay, and smaller diversions.

2.A.1.5.2 Reduced Freshwater Flow

As previously described in Section 2.A.2.3. *Distribution and Abundance*, Longfin Smelt abundance is positively related to freshwater flow, as represented by Delta outflow/ X2 (Jassby et al. 1995; Kimmerer 2002; Kimmerer et al. 2009; Baxter et al. 2010; Mac Nally et al. 2010; Thomson et al. 2010; Mount et al. 2013; Nobriga and Rosenfield 2016) or by general indicators of hydrological conditions (watershed runoff; Maunder et al. 2015). Kimmerer et al. (2009) concluded that habitat volume, as defined by salinity and water clarity, may be partly responsible for the Longfin Smelt abundance relationship with Delta outflow (X2) but that other mechanisms such as outflow-driven retention are more important (see previous discussion in Section 2.A.2.3.2 *Mechanisms Underlying Longfin Smelt Flow-Abundance Relationships*). With respect to habitat availability, although freshwater flow affects dynamic habitat availability, recent investigations by Grimaldo et al. (in review) of stationary habitat found that larval Longfin Smelt were relatively abundant in tidal marsh and shallow open waters of the low salinity zone. This work suggests that stationary shallow habitat also provides key rearing habitat for larval Longfin Smelt.

2.A.1.5.3 Reduction in Turbidity

As described in Section 2.1.3 *Species Threats*, there are positive associations between turbidity and Delta Smelt early life feeding success, predation avoidance, spatial distribution and spawning migrations. Turbidity levels have declined in the Delta (Cloern et al. 2011) and although Delta Smelt has often been the focus for potential effects of turbidity reduction, some of the same mechanisms could be important for Longfin Smelt. For example, young juvenile Longfin Smelt distribution in spring is negatively associated with water clarity (Kimmerer et al. 2009) and trends in abundance are also negatively associated with water clarity in fall (Thomson et al. 2010), which to some extent could reflect changes in catchability of surveys (fish are better able to avoid the trawls with clearer water; Latour 2016).

2.A.1.5.4 Reduction in Food Resources

Longfin Smelt, along with other POD species, have experienced a significant decline in food resources in recent decades. The changes in the zooplankton species composition have affected the quality of food resources available to Longfin Smelt (Resources Agency 2007; Sommer 2007). A decrease in foraging efficiency and/or the availability of suitable prey for various life stages of Longfin Smelt may result in reduced growth, survival, and reproductive success, contributing to an observed lower population abundance and a downward shift in the flow-abundance relationship, particularly after the introduction of the invasive clam *P. amurensis* (see also discussion for Delta Smelt in Section 2.1.3 *Species Threats*). Other factors affecting food resources are discussed in Section 2.1.3 *Species Threats* for Delta Smelt; among these is ammonium, which was found to be negatively associated with Longfin Smelt abundance in the population dynamics model of Maunder et al. (2015).

2.A.1.5.5 Exposure to Toxins

Toxic substances can result from point and nonpoint sources associated with agricultural, urban, and industrial land uses, and conceptually could affect Longfin Smelt directly in winter/spring through migratory release of toxins from fat reserves, acute toxicity to larvae and juveniles, impaired behavior, and increased disease susceptibility; in addition to directly or indirectly limiting food in spring (Brooks et al. 2012). Longfin Smelt can potentially be exposed to these toxic materials, including pesticides, herbicides, endocrine disrupting compounds, and metals, during their period of residence within the Delta. However, no studies directly link mortality of Longfin Smelt with exposure to toxic chemicals in the Delta (Resources Agency 2007), although life stages present during first-flush runoff events would presumably be particularly susceptible to contaminant exposure (Baxter et al. 2010). Exposure to toxins from harmful algal blooms such as *Microcystis* does not coincide with the seasonal occurrence of Longfin Smelt and therefore is not likely to be a threat to the species (77 FR 19756).

2.A.1.5.6 Predation and Competition

The effect of nonnative predators, such as inland silversides and striped bass, has been identified as a potential threat to Longfin Smelt populations (Sommer 2007; Rosenfield 2010), with potentially large predation losses even if the predation rate is low (California Department of Fish and Game 2009). A composite index of predatory fish density in Central Bay and San Pablo Bay was found to be negatively associated with trends in Longfin Smelt abundance in population dynamics modeling by Maunder et al. (2015). Competition could occur with species such as age-0 striped bass, although the extent of this is not known.

2.A.1.5.7 Water Temperature and Climate Change

Water temperature tends to limit the upstream distribution of Longfin Smelt in the warmer months (Baxter et al. 2010) and spring (April–June) water temperature is negatively associated with survival (Maunder et al. 2015). As described further in Section 4.2.7.1 *Cumulative Effects* of Chapter 4 *Take Analysis*, greater sensitivity to higher water temperatures in Longfin Smelt compared to Delta Smelt suggests that Longfin Smelt may have little tolerance for future warming in California under climate change (Jeffries et al. 2016). By analogy to Delta Smelt (Brown et al. 2013, 2016), climate change could result in detrimental effects on Longfin Smelt ecology related to factors such as maturation and spawning season length and timing, as well as reduction in habitat extent.

2.A.1.5.8 Bycatch in Bay Shrimp Fishery

Longfin Smelt are large enough to be taken as bycatch in the commercial bay shrimp fishery in San Francisco Bay (California Department of Fish and Game 2009; 77 FR 19756). As discussed further in Section 4.2.7.1 *Cumulative Effects* of Chapter 4 *Take Analysis*, the extent of this threat has likely decreased in recent years with a reduction in fishing effort.

2.A.1.6 References Cited

2.A.1.6.1 Literature Cited

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