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Critical assessment of the delta smelt population in the San Francisco Estuary, California

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Abstract:

The delta smelt (*Hypomesus transpacificus*) is a small and relatively obscure fish that has recently risen to become a major focus of environmental concern in California. It was formally abundant in the low-salinity and freshwater habitats of the northeastern San Francisco Estuary, but is now listed as threatened under the Federal and California State Endangered Species Acts. In the decade following the listings scientific understanding has increased substantially, yet several key aspects of its biology and ecological relationships within the highly urbanized estuary remain uncertain. A key area of controversy centers on impacts to delta smelt associated with exporting large volumes of freshwater from the estuary to supply California's significant agricultural and urban water demands. The lack of appropriate data, however, impedes efforts to resolve these issues and develop sound management and restoration alternatives. Delta smelt has an unusual life history strategy relative to many fishes. Some aspects of its biology are similar to other coastal fishes, particularly salmonids. Smelts in the genus, *Hypomesus*, occur throughout the Pacific Rim, have variable life history strategies, and are able to adapt rapidly to



local environments. By comparison, delta smelt has a tiny geographic range being confined to a thin margin of low salinity habitat in the estuary. It primarily lives only a year, has relatively low fecundity, and pelagic larvae; life history attributes that are unusual when compared with many fishes worldwide. A small proportion of delta smelt lives two years. These individuals are relatively highly fecund but are so few in number that their reproductive contribution only may be of benefit to the population after years of extremely poor spawning success and survival. Provisioning of reproductive effort by these older fish may reflect a bet-hedging tactic to insure population persistence.

Overall, the population persists by maximizing growth, survival, and reproductive success on an annual basis despite an array of limiting factors that can occur at specific times and locations. Variability in spawning success and larval survival is induced by climate and other environmental and anthropogenic factors that operate between winter and mid-summer. However, spawning microhabitats with egg deposition have not been discovered. Spawning success appears to be timed to lunar periods within a water temperature range of about 15 to 20°C. Longer spawning seasons in cooler years can produce more cohorts and on average higher numbers of adult delta smelt. Cohorts spaced in time have different probabilities of encountering various sources of mortality, including entrainment in freshwater export operations, pulses of toxic pesticides, food shortages and predation by exotic species. Density dependence may provide an upper limit on the numbers of juvenile delta smelt surviving to the adult stage. This may occur during late summer in years when juvenile abundance is high relative to habitat carrying capacity. Factors defining the carrying capacity for juvenile delta smelt are unknown, but may include a shrinking volume of physically suitable habitat combined with a high density of competing planktivorous fishes during late summer and fall.

Understanding the relative importance of anthropogenic effects on the population can be improved through better estimates of abundance and measurements of potentially limiting processes. There is little information on losses of larval delta smelt (less than 20 mm fork length, FL) to the export facilities. Use of a population model suggests that water export operations can impact the abundance of post-larval (about 20 mm FL) delta smelt, but these effects may not reflect on adult abundance due to other processes operating in the intervening period. Effects from changes to the estuarine food web by exotic species and toxic chemicals occur but measuring their influence on population abundance is difficult.

Although delta smelt recently performed well enough to meet the current restoration criteria, analyses presented here suggest that there is still a high probability that the population will decline in the near future; the most recent abundance index (2004) is the lowest on record. Overall, the limited distribution, short life span and low reproductive capacity, as well as relatively strict physical and feeding requirements, are indications that delta smelt is at risk to catastrophe in a fluctuating environment. Unfortunately, options for avoiding potential declines through management and restoration are currently limited by large gaps in knowledge. Monitoring of spring water temperatures, however, may provide a useful tool for determining when to reduce entrainment in water export facilities. Actions that target carrying capacity may ultimately provide the most benefit, but it is not clear how that can be achieved given the current state of knowledge, and the limited tools available for restoration. Overall, a better understanding of the life history, habitat requirements, and limiting factors will be essential for developing tools for management and restoration. Therefore, given the implications for managing California water supply and the current state of population abundance, a good investment would be to fill the critical data gaps outlined here through a comprehensive program of research.



Habitat Volume. Delta smelt habitat extends from the tidal freshwater reaches of the Delta seaward to about 19 psu salinity at water temperatures lower than 25°C. The volume and shape of this habitat is determined by climate, anthropogenic regulation of freshwater discharge, tidal forcing, and bathymetry. Inter-annual abundances of various biota are explained by the amount of freshwater outflow as indexed by X2, defined as the average distance (km) of 2 psu bottom salinity from the Golden Gate Bridge (Stevens 1977; Jassby and others 1995; Kimmerer 2002, 2004). Numerous mechanisms may underlie these relationships (Kimmerer 2002). However, unlike many other species, the abundance of delta smelt is not easily explained by this indicator or its analogue, freshwater flow (Figure 11, Stevens and Miller 1983; Kimmerer 2002).

Overall, delta smelt recruitment success is poor during drought and flood years, and highly variable during intermediate flow years when low salinity habitat is located in Suisun Bay (Figure 19A, Moyle and others 1992). This observation was first formalized by Obrebski (1993) who identified a significant relationship between the MWT index and the position of the low salinity zone in Suisun Bay. Herbold (1994) then found a significant relationship between the number of spring days X2 was located in Suisun Bay and adult abundance; a relationship that underlies the logic for the current salinity standards. However, this correlation no longer holds for the MWT index ($r = 0.30$, $P = 0.08$) or adult abundance ($r = 0.31$, $P = 0.06$, Figure 19C). In several recent years (since 1993) adult abundance remained fairly low even though X2 frequently was located in Suisun Bay (Figure 19C). Although recent abundances have been lower than anticipated, adult abundance is always low when X2 is located in the lower Sacramento and San Joaquin rivers (Figure 19A).

One possibility driving the confusion may be that delta smelt are responding differently to X2 since the population declined, or that other

changes to the physical habitat have overridden the influence of freshwater discharge. Recently, Kimmerer (2002) found a positive relationship between juvenile smelt abundance and X2 position before the decline occurred in 1982, and a negative trend (recalculated here including 2003 data; $r = -0.39$, $P = 0.07$) since that time (Figure 19B). Similarly dividing the data into pre- and post-decline years for juvenile abundance and the number of days X2 was located in Suisun Bay, does not improve these relationships (Figure 19D). While these findings are puzzling, the differences in the trends suggest that spawning or rearing habitat in the lower rivers and Delta may have been more favorable for delta smelt before the 1982 than over the last two decades.

The importance of spawning and rearing habitat in Suisun Bay is also suggested by the analyses of Unger (1994). He showed that the overall surface area of habitat bounded by 0.3 to 1.8 psu was maximized with X2 positioned in Suisun Bay. When this habitat measure was weighted by the average monthly occurrence of larval and juvenile smelt he found a significant correlation with adult abundance. This finding is provocative, although it is preliminary and based on a fairly loose definition of delta smelt habitat. Changing habitat volume may be a key mechanism underlying density dependence. MacCall (1990) formalized this process using habitat selection models for pelagic fish. Larger habitat volume reduces crowding and provides opportunities to avoid localized sources of mortality, allowing for the “spreading-of-risk” over space (den Boer 1968). A potential change in habitat volume may underlie the observation that juvenile delta smelt are now rarely caught in the south Delta (DWR–USBR 1993, Sweetnam and Stevens 1993). Thus, it would be worthwhile to revisit this idea using current knowledge of the delta smelt habitat and newer modeling capabilities.