# Is Flow the Cure for the Summertime Blues? A 12-Year Record of Summer Growth for Delta Smelt

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**Problem statement:** The delta smelt, as well as several other pelagic species that occupy the Low-Salinity Zone in summer have declined. Growth in the early life has been linked to recruitment success and year-class strength in many estuarine species from around the world. Freshwater flow has been hypothesized to be the key driver. In this study we investigate inter-annual variability of delta smelt growth for fish collected in summer months.

**Approach:** We use the otolith increment widths as a proxy of growth during in the early life stages of delta smelt collected in the Summer Tow-net Surveys from 1999 to 2013. This study covers the period prior to the pelagic organism decline and includes several periods of dry conditions as well as an extreme wet year.

**Results:** Summer growth rate varied between dry years and wetter periods and exhibited a greater than 30% decline in growth rate during the pelagic organism decline. Growth during 2011, when freshwater outflow was the second highest in the past 30 years was significantly faster than prior years and dry years following 2011.

**Conclusions/Relevance:** This study documents a significant change in vital rates of juvenile delta smelt associated with freshwater outflow and suggests dry conditions are correlated with slow growth. Slow growth is likely to lead to reduced recruitment success and year-class strength.

**Keywords:** Delta Smelt, otoliths, growth, recruitment, POD, freshwater flow
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## Winter Food-Limitation: Impacts on Adult Delta Smelt Reproduction and Health

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The delta smelt (*Hypomesus transpacificus*) is endemic to the San Francisco Bay Estuary (Bay-Delta), and is listed federally as an endangered species. The Bay-Delta is a highly dynamic system, with natural and anthropogenic factors acting to change and impact the habitat of pelagic fish species, such as the delta smelt. One hypothesis of the cause of the decline observed in the delta smelt population is that limited food-availability, caused by changes in the species composition and abundances in phytoplankton and zooplankton communities, has affected resources available to sustain healthy numbers of fish in the population. To test the effects of food-limitation on the reproduction and general health of the delta smelt, an experiment was conducted in which fish were fed a ration reduced by 40% compared to controls for eight weeks. The experiment was conducted in the winter months just prior to the spawning season. Preliminary results show that test females experienced delays in spawning and had higher ratios of Omega-6/Omega-3 fatty-acid in eggs than control fish. Omega-3's are essential fatty-acids for growth and neural development and a higher ratio of Omega-6/Omega-3 fatty acids has shown to negatively affect embryo development. Although preliminary, the results indicate that food-limitation can play a significant role in partitioning energy resources for gonadal maturation, which can negatively impact adult reproduction and progeny produced. Additional analysis of health and reproductive biomarkers (i.e. triglycerides, histology, hormonal assays) and fecundity indices (i.e. egg size, number of clutches) are a work in progress and will be presented.

Understanding the factors affecting delta smelt population abundances and the viability of successive generations, would help Bay-Delta managers understand the ecological relevance, and impact, of changes to the community food-web and food-availability in the Bay-Delta.

**Keywords:** Delta Smelt, Food-limitation, Reproduction, Fecundity, Health
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# Organismal and Mechanistic Sensitivity to Elevated Temperature and Salinity in Delta Smelt

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The delta smelt (*Hypomesus transpacificus*) is an endemic fish in the San Francisco Bay–Delta and is an important indicator of ecosystem health. Delta smelt have been rapidly declining in the past 30 years due to a variety of physiological and ecological stressors, and climate change is expected to further impact this species by altering regional temperatures and salinities. The delta smelt is also an annual migratory species that encounters differential thermal and salinity regimes across ontogenetic stages. Some studies have investigated whole organism tolerance to these stressors in adults, but little is known about how tolerance thresholds or their mechanistic drivers vary through development. We sought to understand thermal and salinity impacts on delta smelt by conducting a series of exposures on both chronic and acute timescales. We assessed temperature and salinity tolerance limits, and proportional survival, as well as changes in gene expression to evaluate sublethal stress responses. Larval stages (30 and 60 days post-hatch, dph) of delta smelt exhibited higher thermal tolerance relative to juvenile (150 dph) and adult stages (200 dph), but were more sensitive to salinity than these older stages. We associated tolerance data with gene response profiles, and detected induction of osmotic, oxidative, and other sublethal stress responses with increasing temperatures and salinities; which varied among lifestages. Genomic responses were induced at Critical Thermal Maxima (CTMax)-4◦C, and higher, but not CTMax-6◦C, suggesting a sublethal threshold for heat stress. Our results demonstrate the importance of understanding mechanistic thresholds, as well as considering ontogeny, when evaluating sensitivity to environmental stressors. Results highlight mechanistic and whole organism thresholds for Delta Smelt thermal and salinity sensitivity, data that is highly relevant to ecosystem management in the face of climate change, as it relates to this and other species.

**Keywords:** Delta Smelt, Temperature, Salinity, Sensitivity, Mechanisms, Gene Expression, CTMax, Sublethal
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## Environment Parameters: The Choices of Delta Smelt

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Natural and anthropogenic variability in the Delta change the habitat of Delta Smelt with time making it difficult to predict their behavior. Developing a better understanding of the Delta Smelt's response to water temperature, salinity, and turbidity under controlled conditions may help predict fish location in the field. Therefore, in the present study we investigated the behavioral response of Delta Smelt to a wide range of thermal and salinity conditions using a shuttle box system (two tanks connected by a narrow passage) in which the temperature differed by two degrees and salinity by three ppt. By monitoring the fish's movement and residence time in each tank, we can learn about sensitive temperature and salinity ranges, e.g. ranges unfavorable for them.

The Delta Smelt appear to show a consistent behavior in avoiding warm temperatures starting at a specific temperature level, which was 23°C for fish acclimated to 14°C and 25°C for fish acclimated to 17°C. Increased mortality was found at 28°C in both cases, which indicates the lethal temperature for Delta Smelt is the same no matter what temperature they were acclimated to. In the salinity trials, in which the salinity was slowly increased at a rate of 5 ppt per three hours, the proportion of fish that stayed in the tank with higher salinity declined as salinity increased, indicating they are tolerant of high salinity but will consistently move to a lesser salinity given the choice. The enzymatic biomarker (AChE) activities in the brain of tested fish increased slightly with increasing temperature and remained high when the fish were held in high temperature (27- 28°C) for six hours, but the activities started to decrease after that. Fish experiencing the increase in salinity from 0 to 23 ppt in fifteen hours, the AChE decreased slightly but not significantly ($P>0.05$).

**Keywords:** Shuttle box, Delta Smelt, stimulus, behavioral response, enzymatic biomarker
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## Spawning Behavior of Cultured Delta Smelt in a Conservation Hatchery

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Understanding reproductive behavior of cryptic species is crucial for their conservation. The Delta Smelt, *Hypomesus transpacificus*, is a federally threatened, state endangered fish, whose reproductive behavior is poorly understood. We used genetic techniques to investigate the spawning behavior of cultured delta Smelt at a conservation hatchery for Delta Smelt. We conducted a "natural tank-spawning" experiment in a total of four separate tanks during two spawning seasons. Tanks holding adult Delta Smelt were allowed to spawn on their own in order to investigate spawning patterns using genetic parentage analysis of fry produced. In total, 2,474 fry were assigned parents with >80% likelihood. We found that many adults were not assigned any offspring. Males spawned proportionally more than females, and were generally assigned offspring on more dates than females. We also found high variance in family size, leading to reduced $N_e$ and increased inbreeding. Finally, we found no evidence that Delta Smelt preferred to mate with unrelated individuals. This study improves our understanding of how reproductive information informs conservation of cryptic species such as Delta Smelt.

**Keywords:** delta smelt, genetics, parentage, conservation, hatchery
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## Sampling Uncharted Waters: Examining Longfin Smelt and Delta Smelt Rearing Habitat in Fringe Marshes of the Low Salinity Zone

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Despite a rich monitoring history (> 40 years) for invertebrates and fish in the San Francisco Estuary, very little is known about how invertebrates and fish use tidal marshes along the axis of the low salinity zone. Our study investigated the abundance and distribution of larval fish communities in fringe marshes and shallow waters of Suisun Bay (between Antioch and Benicia) that have been overlooked by the long-term monitoring programs. Ichthyoplankton were sampled every two weeks between February and June in 2013 and 2014 using a 505 µm mesh net towed from the stern of a small boat. Zooplankton and water quality (salinity, turbidity, DO, PH, Chl *a*) were sampled concurrently to determine what factors affected abundance and distribution of key species of interest. Our results show longfin smelt larvae are widely distributed in shallow waters and tidal marshes of the low salinity zone. During some sampling periods, longfin smelt densities in tidal marshes were similar or higher than densities observed in the channel stations of the California Department of Fish and Wildlife Smelt Larval Survey. Delta smelt were also observed in shallow habitats, but their densities were far lower than longfin smelt densities. Striking differences in water quality was observed between open water and tidal marsh habitats, which appear to be driven by wind and hydrodynamic residence times and exchange. Our study indicates that tidal marshes from the Suisun Bay area provides key rearing habitat for longfin smelt. Information from our study could be used to guide future restoration in the area, design additional monitoring stations for the larval fish surveys, and understand the role of food generated within marshes to support secondary production in adjacent open waters.

**Keywords:** Tidal Marsh, Longfin smelt, Suisun Bay, Delta Smelt, Larval Fish
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# Ancient Fish and Recent Invaders: White Sturgeon (*Acipenser transmontanus*) Diet Response to Invasive Species-Mediated Changes in a Benthic Prey Assemblage

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Invasive organisms can have significant impacts on native species and the San Francisco Estuary, California (SFE) is one of the world's most invaded estuaries. Decline of native white sturgeon (*Acipenser transmontanus)* in the SFE has been acknowledged, but is poorly understood. Invasion by the overbite clam (*Potamocorbula amurensis*) drastically altered the SFE benthic prey community yet little is known about how this change has affected sturgeon. Elucidating feeding ecology response to this invasion is essential to future white sturgeon management. This study investigated the effect of the overbite clam invasion and subsequent shift in the SFE benthic prey assemblage on the feeding ecology of white sturgeon. Gut content analysis was used to compare prey composition and dietary importance between the pre- and post-invasion periods. Additionally, stable isotope analysis was employed to estimate the assimilation of prey items to sturgeon biomass. Overbite clams dominated diets in the post-invasion period accounting for > 80% of total volume. Stable isotope analysis confirmed the importance of this prey item, although their contribution to sturgeon biomass was estimated to be less (~73%) than gut contents indicated. The frequency of fish increased in the post-invasion period and isotopic analysis indicated relatively large contributions of fish to sturgeon biomass (8 to 25%). The trophic adaptability of white sturgeon has allowed them to exploit this new prey source. Future conservation and restoration efforts must consider a potentially destabilized food web given the large importance of a single prey item, coupled with the potential transfer of toxins to sturgeon.

**Keywords:** stable isotopes, white sturgeon, food web, diet, invasion
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# Connectivity and Effective Size of the Two Splittail (*Pogonichthys macrolepidotus)* Populations in the San Francisco Estuary

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The discovery of two genetically distinct splittail populations within the San Francisco Estuary, one that spawns in the rivers of the Central Valley and another in the Petaluma and Napa Rivers, prompted the need to assess their degree of connectivity and relative sizes. We genotyped multiple age-0 splittail cohorts using 19 microsatellite loci to monitor spatiotemporal changes in the distribution of the two populations and estimate their respective effective population size (Ne). Genetic population assignments demonstrated that while age-0 splittail of the two populations generally remain spatially segregated from one another, substantial geographical overlap may occur during years of high precipitation. However, nearly a decade with similarly wet years has passed since the original discovery of the two populations and yet their level of genetic differentiation remains stable. This indicates that the observed population structure will likely persist in the near future due to a certain isolating mechanism (e.g. strong philopatry and/or adaptive differences). We also found that Ne estimates were generally lower for the Petaluma-Napa population than the Central Valley population, which is consistent with the relative amount of habitat availability in the two locations and previous genetic diversity indices. The relative isolation and apparent lower Ne of the Petaluma-Napa splittail population indicate the need of a closer monitoring for this less studied population.

**Keywords:** effective population size, population genetics, splittail, population structure
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# Metapopulation Structure of a Semi-Anadromous Migratory Fish (Sacramento Splittail, *Pogonichthys macrolepidotus*) Shaped by Climate-Induced Dynamic Habitat Fragmentation

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The Sacramento splittail, *Pogonichthys macrolepidotus,* is a relatively large (400mm) and long-lived (8 years) demersal cyprinid of conservation importance that is endemic to the San Francisco Estuary (SFE). The species exhibits a semi-anadromous life cycle in that it spends the majority of its adult life in low to moderate salinity (0-12) habitat and migrates into upstream freshwater rivers and inundated floodplains for spawning during late winter and spring. The species persists as two genetically distinguishable populations—one dominant and one subordinate—separated by discrete spawning habitats resembling an island-mainland metapopulation structure. The two populations overlap in distribution in the SFE yet segregation is maintained at multiple scales, with individuals tending to aggregate/school with others of similar population heritage and natal origin. The two populations are connected via dispersal of the dominant population into the subordinate population's spawning habitat when climate patterns produce enough rainfall and associated freshwater outflow to form a bridge of suitable low-salinity habitat across the upper SFE in Suisun and San Pablo Bays. Habitat affinities of the two populations, hydrodynamic modeling studies, and historical outflow records together suggest such climatic conditions occur with a frequency of 1 out of 3 years and with an irregular frequency. This dynamic pattern of connectivity controlled by climate variability may drive demographically-meaningful gene flow. The future trajectory of splittail evolution and population structure likely will be shaped by future climate conditions, providing a unique example in an estuary of how metapopulation models must consider climate variability as a driver of habitat fragmentation and population structure.

**Keywords:** population ecology, metapopulation, otolith, genetics
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## Fall Run Chinook Pre-Smolt Outmigration to Alternate Rearing Areas in the Sacramento-San Joaquin Valley

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Numerous pre-smolt fall run Chinook leave their natal rivers to rear in floodplains, the delta, and bays of the Sacramento-San Joaquin River system. Both the number migrating and the timing of migration vary interannually, though the underlying cause of this migration has not been established. The objective of this study was to relate river outmigration to environmental variables. A generalized linear mixed model framework was used to develop a predictive model of river outmigration. Many environmental covariates were found to be significantly related to Sacramento River pre-smolt river outmigration. Of these covariates, the probability of migration increased with photoperiod and flow, and decreased with water temperature. Pre-smolt outmigration from the Stanislaus River responded to different covariates; change in temperature was more relevant than temperature and positively related to outmigration probability, whereas flow was no longer significant. Photoperiod was the most substantial term followed by change in temperature, with larger, parr-sized individuals more influenced by photoperiod and smaller, fry-sized fish by change in temperature. Outmigration to floodplain, delta, and bay rearing habitats results in dissimilar survival rates of pre-smolts, which may affect the number of returning adults. Photoperiod is rather constant with time, while temperatures and flows in these rivers are regulated, allowing for estimates of river outmigration and the survival consequences. These processes will ultimately be simulated in a full life cycle model of Central Valley fall run Chinook, with the goal of aiding management.

**Keywords:** Central Valley, Chinook, fall run, fry, GLMM, migration, parr, pre-smolt
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