## Critical Dissolved Oxygen Minima in Splittail

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Because the splittail population had declined dramatically and its original range has decreased by two-thirds (Herbold *et al* 1992; Moyle and Yoshiyama 1992; Meng and Moyle 1995) we conducted the study on "Environmental Tolerances and Requirements of the Sacramento Splittail, *Pogonichthys macrolepidotus* (Ayres)" to assist in effective water and habitat management and restoration of this species. This report on the critical dissolved oxygen minima (CDOMin) of splittail is part the study.

CDOMin were measured in young-of-the-year (1-4 g), juveniles (19-48 g), and subadults (72-187 g) using a modified method of Cox (1974) and Becker and Genoway (1979) defined by a loss of equilibrium (endpoint). As dissolved oxygen level decreased to the endpoint, splittail increased activity (turning, swimming, or darting around) then decreased activity but increased ventilatory frequency and gasping. Post-CDOMin recovery (restoration of equilibrium) generally took ≤3 minutes. Mean CDOMin values were low (9-18 torr oxygen partial pressure ($PO_2$) or 0.6-1.2 $mgO_2/L$) for all size groups of splittail (Figure 1).

The splittail's preferred habitat (slow-moving sections of rivers and sloughs) can have very low dissolved oxygen levels. For example, in Buckley Cove (in the Stockton Ship Channel part of the San Joaquin River), at midday at 92 cm below the surface, the dissolved oxygen level can drop to 0.4 $mgO_2/L$ (DWR 1992). Fish generally avoid hypoxic conditions by moving away from them. However, when food abundance is low, fish (especially benthic foragers) readily forage in hypoxic waters (Rahel and Nutzman 1994). Splittail are benthic foragers (Caywood 1974; Daniels and Moyle 1983), and their short-term low dissolved oxygen tolerance may increase survival by permitting foraging in hypoxic benthic areas at times of low food availability.

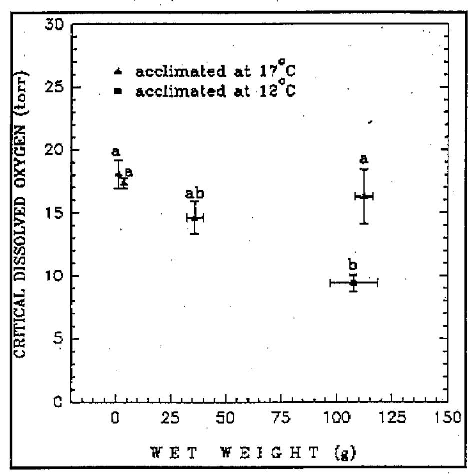


Figure 1
MEAN (± SEM) CRITICAL DISSOLVED OXYGEN MINIMA (TORR $PO_2$) OF DIFFERENT SIZE GROUPS OF SPLITTAIL
Subadults acclimated at 17 and 12 degrees Centigrade; Symbols with different letters are significantly different from each other; n = 4-10

Difference in size (1-187 g) had no significant effect on the CDOMin of splittail acclimated at 17°C. However, an increase in temperature increased the CDOMin. Subadult splittail acclimated at 17°C had a significantly higher ($P < 0.05$) mean CDOMin (16 torr $PO_2$ or 1.1 $mgO_2/L$) than those acclimated at 12°C (9 torr $PO_2$ or 0.6 $mgO_2/L$). This is probably because at higher temperature, fish have higher oxygen consumption rates than those at lower temperature (reviewed by Fry 1970) and, thus, require higher dissolved oxygen levels in the water. Davis (1975) explained that at higher temperatures, fish blood oxygen dissociation curves relating blood percentage saturation to the $PO_2$ typically shift to the right (indicating a higher oxygen requirement to fully saturate the blood), increasing the $PO_2$ threshold for hypoxia responses.

One must be cautioned in using the CDOMin for establishing criteria for dissolved oxygen levels. These values should be considered as extreme endpoints, approximating lethal limits. Complete loss of equilibrium in fish (endpoint) indicates the detrimental effects of the experimental variable so the fish becomes physically disorganized and loses its ability to escape from the harmful conditions, leading to its death (Becker and Genoway 1979). The International Joint Commission (1979) and the U.S. Environmental Protection Agency (1986) recommended that the effects of low dissolved oxygen level on growth be studied to determine minimum dissolved oxygen criteria. EPA (1986) reported that mortality or loss of equilibrium in salmonid and salmonid-like species occurred at the 1-3 $mgO_2/L$ level. However, based on growth studies, the EPA established dissolved oxygen minimum levels of 9.5 $mgO_2/L$ for early life stages, and 6.5 $mgO_2/L$ in other life stages in salmonid and salmonid-like species, higher than the 1976 criterion of 5.0 $mgO_2/L$.

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## Temperature and Salinity Tolerances of Delta Smelt

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In 1992, we began a study of the environmental tolerances and habitat requirements of the delta smelt, *Hypomesus transpacificus*, at that time a candidate species for listing under the State and Federal Endangered Species Acts. The objective of our research was to provide information useful for defining delta smelt critical habitat and developing management guidelines for the species. In this report we describe results of our studies on temperature and salinity tolerances of the delta smelt and implications of these results for management and protection of this fish.

Delta smelt spawn seasonally and complete their life cycle in a single year; life history stages tend to be strongly correlated with seasonal temperature regimes. Therefore, we conducted our experiments using juvenile (<4.5 cm standard length), subadult (4.5-6.0 cm SL), and adult fish (>6.0 cm SL) acclimated to seasonally appropriate ranges of temperatures that represented, for each life history stage, a low and high temperature level (juveniles and subadults in summer and fall, 17 and 21°C; subadults and adults in winter and spring, 12 and 17°C). Delta smelt may also exhibit seasonal preferences in salinity. Juveniles and subadults are most abundant in the brackish entrapment zone; adults move upstream to fresh water prior to spawning. Therefore, we measured temperature tolerances in fish acclimated to both fresh (0 ppt) and brackish (4 ppt) water.

### Temperature Tolerance

Temperature tolerance limits were measured in terms of critical thermal maxima ($CT_{max}$) and minima ($CT_{min}$), a protocol in which the fish were subjected to relatively rapid change in temperature (6°C/h increase or 5°C/h decrease). The tolerance limit was defined by a sublethal response, loss of equilibrium, although in the wild such a response would probably be lethal.

Delta smelt tolerated moderate acute changes in temperature (Figure 1). $CT_{max}$ was significantly affected by acclimation temperature; fish acclimated to warmer temperatures tolerated higher temperatures. However, the magnitude of the tolerated temperature increase was similar (5-7°C) for all three acclimation groups. An increase in salinity to 4 ppt significantly increased the delta smelt's tolerance to temperature increases. $CT_{min}$ was less dependent on acclimation temperature and independent of salinity. Fish size (or life history stage) did not affect either $CT_{max}$ or $CT_{min}$. These results show that delta smelt are

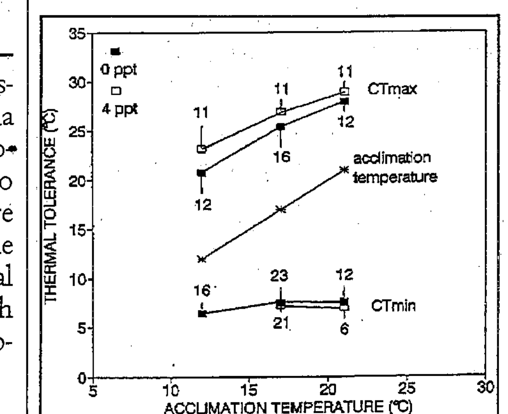


Figure 1
MEAN (±SD) CRITICAL THERMAL MAXIMA ($CT_{max}$) AND MINIMA ($CT_{min}$) OF DELTA SMELT ACCLIMATED TO 12, 17, and 21°C IN 0 AND 4 PPT
Sample sizes for each temperature/salinity combination are above or below the points.
$CT_{min}$ in 12°C was only measured in 0 ppt.