Can Delta Smelt Swim in the Dark?

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Delta smelt, *Hypomesus transpacificus*, is a small, estuarine osmerid native to the Sacramento-San Joaquin estuary. During the drought years of the mid-80s to early 90s, the delta smelt population has declined an estimated 90 percent, and the fish was listed by both the federal and state governments as threatened. Entrainment and impingement of young and adult delta smelt in water diversions are considered a possible contributing factor to their population decline. Some water diversions in the delta operate 24 hours a day. No studies had been conducted to find out if delta smelt are more susceptible to entrainment or impingement in the dark than in the light or during the night than during the day. As part of a large study on delta smelt swimming performance, the objective of which is to provide information for developing water diversion approach velocity criteria, we conducted experiments to answer the following questions:

- Do delta smelt swim as well under dark condition as under lighted condition?
- Do delta smelt swim as well during nighttime as during daytime?
- If their swimming is impaired at night, will illumination help delta smelt swimming performance?

Most of the delta smelt used for the study were collected at Grizzly Bay and Suisun Cut on August 14-16, 1995. They were brought to the UC-Davis laboratory and were acclimated to 17°C. The fish measured 4.0-5.9mm standard length. Swimming performance was measured in terms of critical swimming velocity (U_{crit}) using a Brett-type swimming flume enclosed in a black plastic structure to exclude outside light and any distraction that might disturb the fish. A light source with two fluorescent bulbs was directed toward a 3m x 1m white reflecting panel, yielding a light intensity of 50-60 lux in the swimming chamber. A video camera was mounted above the flume, and fish activity was observed through a monitor situated outside the black structure. Under dark conditions, the lights were turned off and observations were made inside the black structure using infrared-sensitive night-vision goggles. Individual fish were placed in the chamber and, after 1 hour habituation, water velocity was increased by 3 cm/s every 10 minutes, starting at 6 cm/s, until fish were fatigued (impinged three times at the downstream end of the chamber). U_{crit} (cm/s) was calculated using: $U_{crit} = U_i + (3 \text{ cm/s} \times T_i/10 \text{ min})$ where: U_i = highest velocity (cm/s) maintained for the prescribed time period, and T_i = time (min) elapsed at fatigue velocity. Fish swimming performance was measured under two photophase conditions: during daytime between 0800 and 1700 hours and during nighttime between 1900 and 2200 hours, and under light intensity of 50-60 lux and in complete darkness (0 lux).

Regardless of illumination and photophase condition 30-33 percent of the delta smelt were unable to swim in the flume. Results of those that did swim show that during daytime under light conditions, mean U_{crit} was 28 cm/s (Figure 1). Under dark conditions, swimming performance was significantly impaired. During nighttime under light conditions, swimming performance was significantly lower compared to that during daytime under light conditions but not significantly different than under daytime dark conditions. During nighttime under dark conditions, swimming performance was even worse and significantly lower than during daytime under dark conditions.

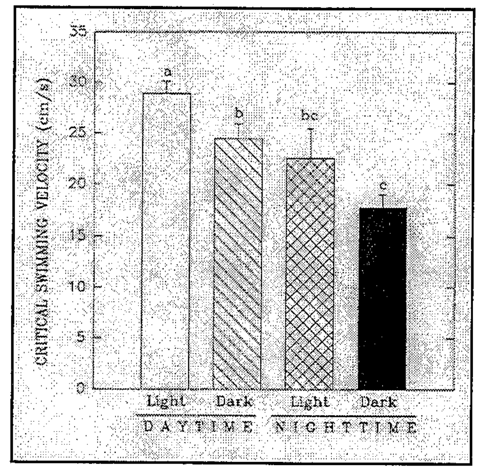

Figure 1
MEAN CRITICAL SWIMMING VELOCITY DURING TWO PHOTOPHASES AND UNDER TWO LIGHT CONDITIONS
Symbols with different letters are significantly different at P<0.05. N=6-14

These experiments show that two factors affect delta smelt swimming performance — illumination and photophase — and both must be present for maximum swimming performance. If a water diversion operates 24 hours a day, it is likely that delta smelt are most susceptible to entrainment and impingement at night. Our results also suggest that presence of 50-60 lux illumination at night does not significantly improve delta smelt swimming performance.

To find out if the use of light intensities other than 50-60 lux during night operation of delta water export pumps will help delta smelt perceive and better react to their environment, we have to find out first how delta smelt behave (*eg*, attracted to light or not) near fish screens under these different light intensities. These studies should simulate reality (*eg*, with complex flow fields, multi-individual groups of delta smelt, presence of predators, and other relevant factors included) as closely as possible using methods and equipment (*eg*, fish treadmill) that simulate environmental conditions like those near water diversions in the delta.

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Swimming Performance of Delta Smelt

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Entrainment of delta smelt (*Hypomesus transpacificus*) in water diversions may have been a factor in the population decline of this fish observed in the drought years of the mid-1980s through early 1990s (Moyle *et al* 1992; USFWS 1994). Currently, water diversion flow regulations in the delta are based on data from other species (American shad and chinook salmon). In 1993, we began research on swimming performance and behavior of delta smelt to provide information use in developing approach velocity criteria appropriate for this species.

Delta smelt swimming performance was measured in terms of critical swimming velocity (U_{crit}, cm/s), the maximum velocity a fish can maintain for a specified amount of time; and endurance (min), the length of time a fish can sustain swimming at a constant velocity (Brett 1964). These two indices of swimming performance have been used to develop approach velocities for a number of species, including salmonids and striped bass (Clay 1995). For both experiment types, the endpoint was fatigue, indicated by the fish failing to hold position against the current and becoming impinged repeatedly on the downstream screen of the swimming flume. Experiments were conducted using juvenile (<4.5 cm standard length), subadult (4.5-5.9 cm standard length), and adult delta smelt ($\geq$6.0 cm standard length) acclimated to temperatures of 12-21°C in fresh water (0 ppt), in a laminar flow, Brett-type swimming flume.

Delta smelt are extremely sensitive to stress and confinement (Swanson and Cech 1995). Many fish had difficulty swimming in the flume; 29-39% of the fish failed to swim adequately, became impinged repeatedly on the flume screen at submaximal velocities, and did not yield a U_{crit} or endurance measurement. In the U_{crit} experiments, 55% of the fish that swam to the experimental endpoint became impinged temporarily at submaximal velocities; the velocity at which these fish first became impinged was designated U_{imp1} (cm/s). In the endurance experiments, delta smelt frequently became impinged temporarily but then continued swimming for an extended period; the time (minutes) of the first incidence of impingement was designated Imp1.

Critical swimming velocity (Table 1) was not affected by acclimation temperature or fish size (both tests, $p > 0.1$); mean maximum swimming velocity of delta smelt was 27 ± 6 cm/s. Uimp1 was not affected by temperature ($p > 0.1$) but increased slightly with increases in size ($p < 0.05$). However, the proportion of fish that became temporarily impinged at submaximal velocities decreased with increases in fish size ($p < 0.05$); juvenile delta smelt impinged at low velocities more frequently than large adult delta smelt.

Table 1
CRITICAL SWIMMING VELOCITY (Ucrit, cm/s, mean±SD), VELOCITY AT TIME OF FIRST IMPINGEMENT (Uimp1), AND PERCENTAGE OF FISH IMPINGED AT SUBMAXIMAL VELOCITY OF DELTA SMELT

Stage (SL)	U_{crit} (n)	U_{imp1} (n)	%
Juvenile (<4.5)	26.7±4.7 (18)	10.2±3.2 (14)	78
Subadult (4.5-5.9)	29.3±5.4 (23)	14.4±2.0 (13)	57
Adult (6.0)	27.5±7.7 (37)	14.5±4.6 (16)	43

Endurance and Imp1 (Table 2) were highly variable; significant effects of temperature, life history stage, and size were not detected (all tests, $p > 0.05$). Both endurance and Imp1