The Effects of Temperature and Desiccation on Surf Smelt (*Hypomesus pretiosus*) Embryo Development and Hatching Success: Preliminary Field and Laboratory Observations

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The Effects of Temperature and Desiccation on Surf Smelt (*Hypomesus pretiosus)* Embryo Development and Hatching Success: Preliminary Field and Laboratory Observations

Abstract

Between May and July 2002, we conducted a field study to investigate possible environmental factors influencing surf smelt (*Hypomesus pretiosu*s) egg mortality at eight beaches on the southern Strait of Georgia, British Columbia (B.C.), Canada. Egg mortality was variable, but was positively correlated to air temperature and increased in June and July when maximum temperature was approximately 30°C. In June 2003, we conducted a preliminary laboratory study to investigate the effects of desiccation on surf smelt egg mortality. Eggs were randomly placed into four relative humidity (RH) groups: dry (62% RH), moist (80% RH), wet (93% RH) and submerged (100% RH). All eggs in the dry and moist group died by the end of the experiment. Mortality of eggs in the wet and submerged groups was not significantly different ($P<0.05$). Eggs in the wet group reached the eyed stage and hatched significantly faster ($P<0.05$) than those in the submerged group. Results suggested a threshold RH requirement of 80 – 93% for successful development and hatching of surf smelt embryos. Moisture and temperature interact to condition RH in the intertidal zone. Shade vegetation, which can cool air temperature in the supralittoral zone, may be important for some populations of surf smelt. Further investigations are required to confirm the findings.

Introduction

The upper intertidal zone is one of the harshest habitats in the marine environment—organisms using these areas have to cope with a variety of stresses relating to frequent emergence and exposure to air. The ability to utilize this habitat is an adaptive strategy for the surf smelt (*Hypomesus pretiosus*), a northeast Pacific osmerid which is harvested by recreational fishers and is also an important forage species for other species. Surf smelt lay their eggs on the fine gravel and sand in the upper intertidal zone of protected waters such as Puget Sound, Washington, and the Strait of Georgia, British Columbia (B.C.). This strategy may provide developing embryos with the advantages of accelerated development via a warmer developmental temperature (Loosanoff 1937), a higher oxygen availability (Martin and Swiderski 2001) and decreased aquatic predation (Tewksbury and Conover 1987). However, because embryos are exposed to an extra-aquatic environment for extended periods on a daily basis, they are faced with the potential problems of terrestrial predation (Griem and Martin 1997), extreme temperatures, and desiccation (Penttila 1978, Martin and Swiderski 2001).

Desiccative and thermal stresses are considered to be the important contributing factors leading to mortality in incubating surf smelt embryos, with higher mortalities occurring under hot, dry conditions as determined by field observations in Puget Sound, Washington (Penttila 2001, Rice 2006). These potential complications may be ameliorated by supralittoral or backshore trees and shrubs which can buffer against the sun's heat and drying winds. The continuous shifting of the surface beach substrate by wave action, which buries newly fertilized eggs to a depth of approximately 1–2 cm after deposition (Loosanoff 1937, Levy 1985) is also likely important. Embryonic development in this specific environment permits sufficient capillary moisture while allowing aeration, and also serves to buffer eggs from direct exposure to the sun and wind, thus maximizing the spawn survival (Middaugh et al. 1983). However, removal of supralittoral vegetation impairs the buffering

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capacity of this microhabitat and is an increasing concern for surf smelt egg viability in the northeast Pacific (Levings and Jamieson 2001, Rice 2006). Unshaded, sun exposed surface beach temperatures of up to 40°C and 31°C at a depth of 4 cm have been documented in grunion (Leuresthes tenuis) intertidal spawning grounds in California, U.S. (Middaugh et al. 1983). Similarly, Rice (2006) reported that unshaded beaches in Puget Sound, which are typically brighter, hotter and drier than shaded beaches, can routinely reach temperatures close to 30°C during the summer months. Surf smelt spawn mortality was higher at the unshaded beaches, presumably from the combined effects of thermal shock and desiccation. A study by Penttila (2001) confirmed that surf smelt egg viability was lower in sun exposed areas (40.3%) relative to shaded or partially shaded areas (64.4%) but did not relate the rate of survival to the degree of desiccation or thermal stress directly. In general, desiccation studies on the spawn of intertidal species have received scant attention (Misitano 1977) despite being frequently suggested as an area of future work (Taylor 1999, Martin and Swiderski 2001).

Using both field and laboratory approaches, our preliminary study addressed the following questions: (1) how will temperature and desiccation affect surf smelt embryo development and survival and (2) is there a mean threshold relative humidity (RH) necessary to facilitate successful hatching? We present a small data set on these topics which may to useful to guide further work.

Methods

Field Observations of Egg Mortality

We sampled surf smelt eggs on seven beaches in outer Vancouver Harbor, B.C., on 10 occasions between 8 May and 5 July 2002. One site outside the harbor, Furry Creek, on Howe Sound, a fjord adjacent to the harbor, was also sampled. All beaches had a south or west aspect and thus were subjected to full exposure to sunlight for the majority of the day. The supralittoral vegetation at all the sites had been disrupted by anthropogenic activities such as seawalls, parks, and a golf course. We selected horizontal transects across the beach at approximately 3-m linear distance below the higher high water, mean tide mark, which was located using drift materials (e.g. wrack, driftwood) at about 4 m above Canadian chart datum (Levings and Jamieson 2001). At random locations on each transect, we used a putty knife to remove the upper 1 cm of sediment from the beach. Approximately 1 kg of sediment from a depth of 2–4 cm was collected. The bags containing the sediment samples were returned to the laboratory and placed in a cool, dark location. About 500 g of sediment from each bag was then emptied into a 2.360-mm mesh sieve (20-cm diameter) placed directly above a 0.355-mm sieve. Seawater was poured over the sediment and the fraction retained in the 0.355-mm sieve was used for analysis. The retained sediment fraction was placed into a 4-L bucket and seawater was added to a depth of about 2 cm. The sediment was agitated gently and manually swirled. This winnowing procedure (Penttila 1995) brought lighter materials (including eggs) to the surface of the sediment fraction. A square Petri dish was used to skim off the top layer of sediment, which was then examined under a dissecting microscope (6–12X magnification) using a cold light source. Both live and dead eggs were tallied. If cloudiness was observed in an egg, it was considered dead and scored as such.

Maximum air temperature data for the particular collection days were obtained from Environment Canada's meteorological station at the Vancouver International Airport (YVR), about 10 km from Vancouver Harbor.

Experimental Methodology to Investigate Effects of Humidity

On 10 June 2003, sediment containing surf smelt eggs was collected at Sandy Cove beach on outer Vancouver Harbor, adjacent to our laboratory in West Vancouver. To obtain eggs for the experiment, the winnowing procedure described above was repeated three times for each sediment fraction. Surf smelt eggs adhere firmly to the sediment. Using forceps, we removed each egg as well as the piece(s) of sediment to which it was attached, leaving the eggs untouched. Fertilized eggs were selected and egg viability was determined by the presence of a perivitelline space. Only eggs in which developing organs were not visible were selected for this study (i.e. < three days post-fertilization; Levy 1985). After winnowing approximately 5 kg of sediment, 180 viable eggs were collected.

As this was a preliminary study we chose a relatively simple experimental methodology, modeled after the procedures used by Marliave (1981) and Yamahira (1996). Fifteen eggs were randomly placed into each of 12 sample plastic baskets (8-cm diameter x 5-cm high, 0.5-mm plastic mesh on one end) (Figure 1). Three baskets were assigned to each dry, moist, wet or submerged group. The baskets were placed within darkened water baths, which were inundated with seawater (12.1 ± 0.5°C, 30.9 ± 0.5‰) flowing at a rate of 0.5 L min^{-1}. The submerged group remained in the water baths over the entire duration of the experiment. The other groups were placed in seawater water baths daily for 4 hr. For the remaining 20 hr, each basket was placed in an individual large zippered plastic bag (Figure 1). In the bag, a dry, moist or saturated cloth (8 x 8 cm) was positioned directly beneath each basket and the bag was subsequently sealed and placed in a dark drawer. Relative humidity (RH) was recorded by placing a hygrometer in each bag. Mean RH for the dry, moist, wet, and submerged groups was 62.1 ± 0.8%, 79.8 ± 0.5%, 92.8 ± 0.6%, and 100%, respectively, over the course of the experiment. Mortality was assessed by relative cloudiness of the eggs and was monitored daily until all surviving eggs hatched.

Statistical Analysis

We present mean values with the standard error of the mean and used $P < 0.05$ as the level of statistical significance. We conducted a Pearson correlation analysis for percentage of dead eggs and air temperature on untransformed (skewness 0.09, kurtosis -1.42) and arc sine transformed (skewness 0.93, kurtosis -0.96) percent data . We used a Students t-test to compare mortality and hatching rates. Graphical analysis of the latter data indicated they were normally distributed.

Results

Observations of Mortality in the Field and Relation to Air Temperature

We collected between 0 and 211 eggs at each beach sampled. Egg mortality ranged from 0% on 8 May 2002 to 95% on 26 and 27 June 2002. Maximum air temperature at YVR ranged from 10.8°C on 8 May 2002 to 30.2°C on 26 June 2002 (Figure 2). The percentage of dead eggs was positively and significantly correlated (r = 0.78) with maximum air temperature using both transformed and untransformed percentage data.

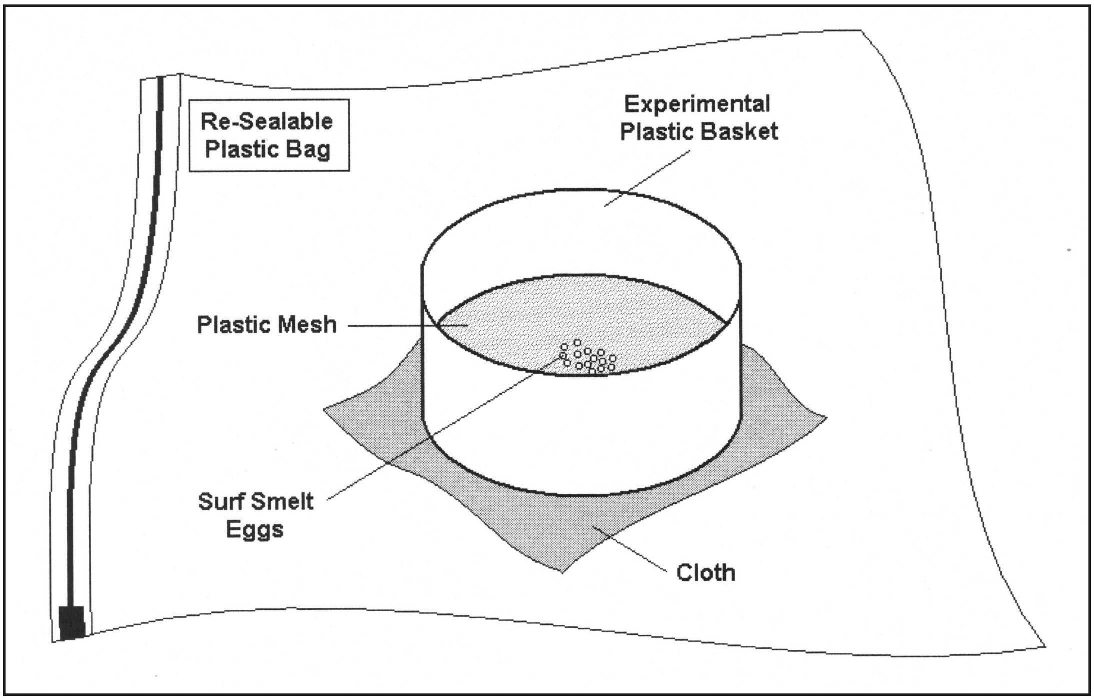

Figure 1. Experimental apparatus used to investigate relative humidity effects on surf smelt eggs.

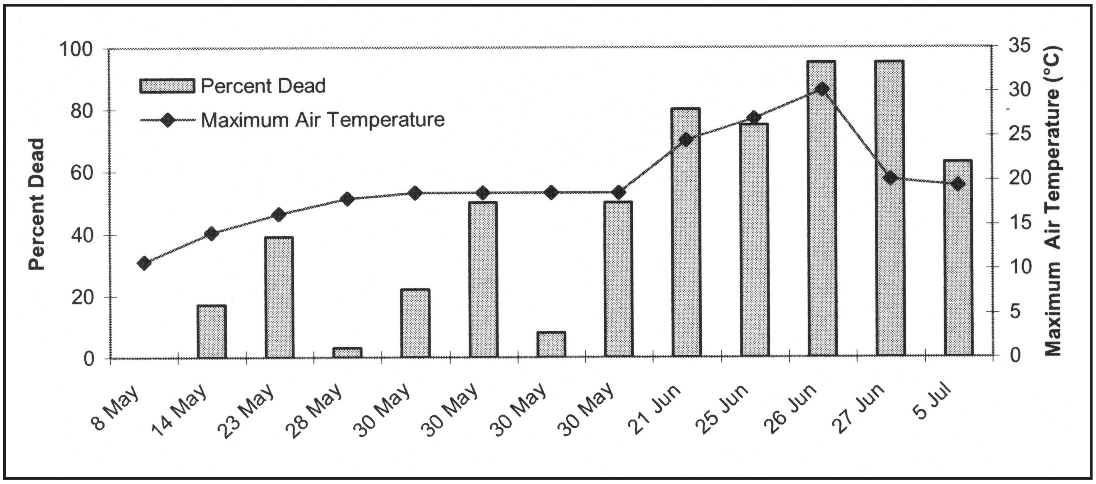

Figure 2. Percentage of dead surf smelt eggs in sediment at beaches in Vancouver Harbor, May to July 2002. Maximum air temperatures at Vancouver International Airport (YVR) on the collection dates are also shown.

The Effect of Desiccation on Embryo Survival

All of the eggs in the dry and moist groups died by the end of the experiment. Mean mortality of the wet and submerged groups was not significantly different (mean 11.7; SE 0.3 dead eggs per basket and 12.0; SE 0.6 dead eggs per basket) (Table 1). Mean percent hatching rates were 22.2%; SE 2.2 and 20.2%; SE 3.8 for wet and submerged. Desiccation stress was evident in the dry group with many of the eggs displaying a dimpled chorion. Although organ rudiments were observed in the eggs of the dry group, all eggs had died by day four. In the moist group, eggs began to develop, reaching the eyed stage (defined as the initial gray-black color differentiation of the eye tissue in the embryo) by day four – five. However, development arrested and eggs began to decay soon thereafter. Mean times to eyed stage were not significantly different between the moist and wet group (4.4 days; SE 0.2 and 4.6 days; SE 0.2). Mean time to eyed stage was significantly higher for the moist and wet group compared to the submerged group (6.3 days; SE 0.2). Mean time to hatch for the wet group (8.9 days; SE 0.1) was significantly lower compared to the submerged group (13.7 days; SE 0.4) (Table 1).

Discussion

This study is one of the first field and laboratory projects to examine the effects of temperature and desiccation on surf smelt embryo development and survival. Studies examining the effect of desiccation on intertidal spawners have been

TABLE 1. Mortality, development, and hatch parameters for surf smelt relative humidity (RH) experiment. There were three replicate baskets for each RH group. Groups not having a superscript letter in common were significantly different ($P<0.05$) using a Students t-test. Mean values ± SE are shown.

Group	Percent Humidity	Total Eggs	Total Mortality	Mortality Per Basket	Total Hatched	Hatched Per Basket	Percent Hatch	Days to Eyed Stage	Days to[1] Hatch
Dry	62.1 ± 0.8	45	45	15	-	-	-	-	-
Moist	79.8 ± 0.5	45	45	15	-	-	-	4.4 ± 0.2[a]	-
Wet	92.8 ± 0.6	45	35	11.7 ± 0.3[a]	10	3.3 ± 0.3	22.2 ± 2.2	4.6 ± 0.2[a]	8.9 ± 0.1[a]
Submerged	100.0	45	36	12.0 ± 0.6[a]	9	3.0 ± 0.6	20.0 ± 3.8	6.3 ± 0.2[b]	13.7 ± 0.4[b]

[1] Eggs ≤ 3 days old at start of experiment

somewhat contradictory, reporting either a strong (Marliave 1981, Penttila 2001, Rice 2006) or negligible influence (Tewksbury and Conover 1987, Yamahira 1996) on survival. One of the reported problems of conducting studies on surf smelt is that the eggs are highly sensitive and are particularly susceptible to fungus. Morgan and Levings (1989) also conducted a laboratory study and reported that naturally fertilized surf smelt eggs had the lowest percent hatch (31%) relative to lingcod (*Ophiodon elongatus*) (88%) and Pacific herring (*Clupea harengus*) (92%). Similarly, Misitano (1977) reported a very low percentage of artificially fertilized eggs and a very high mortality rate thereafter due to fungus. Penttila (1978) reported that under optimal conditions, mortality through the incubation period may be only 20 – 30%, but under more natural conditions, may be in the vicinity of 90%. The results of such studies may indicate that successful development of surf smelt embryos are dictated by a narrow range of environmental conditions. Our survivorship data for smelt eggs falls within the ranges reported in the latter studies. We did not observe the appearance of fungus in any of our samples over the course of the experiment, which may have been the result of the constant flow of seawater over the eggs when submerged as well as the relative low density of eggs in each basket.

Our estimates suggest a minimum RH of about 80 – 93% throughout development is required for successful hatching of surf smelt embryos. Whereas the embryos held in the dry regime did not develop to an appreciable degree, the six embryos in the moist group reached the eyed stage before developmental arrest. Rice (2006) found the minimum RH over the sediment on Puget Sound beaches in summer was 68% on a natural beach but only 56% on a beach modified by vegetation removal and armoring with a vertical concrete bulkhead in the high tide zone. This RH value is clearly below our driest test group (about 62%), where we found 100% mortality within four days.

Indirect support for the effect of RH on surf smelt egg survival was provided by the positive correlation between the percent of dead eggs observed on the beaches and maximum temperature on the days they were collected. The relationship between RH and temperature is complex, and some warming at appropriate RH may be beneficial. However it is reasonable to assume that owing to evaporation, surficial sediments in the high intertidal area would be drier and RH lower on very warm days. The upper intertidal zone in southwestern B.C. is exposed to the air almost all day in May and June, enabling at least eight hours of drying time. Daytime low tides of at least 2.3 m below high tide level where surf smelt eggs tend to concentrate occurred in the week before each of our field collections were made. Differences in submergence/emergence times were therefore probably not a confounding factor in the relationship between egg mortality and air temperature.

Although the scope of our experiment did not permit extensive examination on the effect of temperature on development rate, it was clear that time to the eyed stage and hatching were significantly faster in the wet group, relative to the submerged group, in which the eggs remained submerged for the duration of the experiment. Specifically, the daily 8°C increase in air temperature in the wet group resulted in least a 37% decrease in time to eyed stage and a 54% decrease in hatching time relative to the submerged group. Elevated daily temperature periods associated with terrestrial exposure may be an adaptive survival strategy to accelerate the rate of development and to decrease the likelihood of predation.

Our findings have management implications and may be useful for development of guidelines to assist fish habitat managers concerned with the nearshore ecosystem and provide additional support for the concept of vegetation reserves along shorelines where surf smelt are spawning in spring and summer (Levings and Jamieson 2001, Rice 2006). Shading or attenuation of RH, together with maintenance of soil stability and hence reduction in suspended solids which can also affect egg survival (see Morgan and Levings 1989) and spawning habitat quality are likely supralittoral vegetation functions that are of specific value to this species. For example, we measured the seaward erosion rate for mud at a supralittoral area above a surf smelt spawning ground in Burrard Inlet during a period of heavy rainfall (January 2003). Erosion rate was 3 g d^{-1} m^{-1} at an intact area compared to 50 g d^{-1} m^{-1} at a disrupted site and this difference was significantly different (*t*-test, $P<0.05$). Other functions such as water quality and provision of invertebrate fish prey are other ecosystem functions of supralittoral vegetation that are important to additional species (Brennan 2004, Romanuk and Levings 2003).

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Literature Cited

Brennan, J. 2004. Riparian functions and the development of management actions in marine nearshore ecosystems. *In* J. P. Lemieux, J. Brennan, M. Farrell, C. D. Levings, and D. Myers (editors), Proceedings of the DFO/PSAT Sponsored Marine Riparian Experts Workshop, Tsawwassen, British Columbia, February 17-18, 2004. Canadian Manuscript Report of Fisheries and Aquatic Science 2680:10-22.

Griem, J. N., and K. L. M. Martin. 1997. Predatory birds are present on the beach before and during California grunion runs. American Zoologist 37:82A.

Levings, C. D., and G. Jamieson. 2001. Marine and estuarine riparian habitats and their role in coastal ecosystems, Pacific Region. Canadian Science Advisory Secretariat Research Document 2001/109. Available online at http://www.dfo-mpo.gc.ca/csas/English/Research_Years/ 2001/2001_109e.htm.

Levy, D. A. 1985. Biology and management of surf smelt in Burrard Inlet, Vancouver, British Columbia, Technical Report (Westwater Research Centre) 28:1-48.

Looseanoff, V. L. 1937. The spawning run of the Pacific surf smelt, *Hypomesus pretiosus* (Girard). Internationale Revue der Gesamten Hydrobiologie und Hydrographie 36:170-187.

Marliave, J. B. 1981. High intertidal spawning under rockweed, *Fucus distichus*, by the sharpnose sculpin, *Clinocottus acuticeps*. Canadian Journal of Zoology 59:1122-1125.

Martin, K. L., and D. L. Swiderski. 2001. Beach spawning in fishes: phylogenetic tests of hypotheses. American Zoologist 41:526-537.

Middaugh, D. P., H. W. Kohl, and L. E. Burnett. 1983. Concurrent measurement of intertidal environmental variables and embryo survival for the California grunion, *Leuresthes tenuis*, and Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). California Fish and Game 69:89-96.

Misitano, D. A. 1977. Technique for incubating and hatching eggs of surf smelt for bioassay. The Progressive Fish-Culturist 39:187.

Morgan, J. D. and C. D. Levings. 1989. Effects of suspended sediment on eggs and larvae of lingcod (*Ophiodon elongatus*), Pacific herring (*Clupea harengus pallasi*), and surf smelt (*Hypomesus pretiosus*). Canadian Technical Report of Fisheries and Aquatic Sciences 1729:1-31.

Penttila, D. E. 1978. Studies of the surf smelt (*Hypomesus pretiosus*) in Puget Sound Washington. Department of Fish and Wildlife Technical Report 42:1-47.

Penttila, D. E. 1995, The Fish and Wildlife's Puget Sound intertidal baitfish spawning beach survey project. *In*: Puget Sound Research-95 Conference Proceeding, Vol. 1, Puget Sound Water Quality Authority, Olympia, WA, pp. 235-241.

Penttila, D. E. 2001. Effects of shading upland vegetation on egg survival for summer spawning surf smelt on upper intertidal beaches in Puget Sound. In Proceedings of Puget Sound Research 2001. Available online at http://www.psat.wa.gov/Publications/01_proceedings/sessions/oral/2a_pentt.pdf.

Rice, C. A. 2006. Effects of shoreline modification of a Northern Puget Sound beach: microclimate and embryo mortality in surf smelt (*Hypomesus pretiosus*). Estuaries and Coasts 29:63-71.

Romanuk, T. N. and C. D. Levings. 2003. Associations between arthropods and supralittoral ecotone: dependence of aquatic and terrestrial taxa on riparian vegetation. Environmental Entomology 32:1343-1353.

Taylor, M. H. 1999. A suite of adaptations for intertidal spawning. American Zoologist 39:313-320.

Tewksbury, H. T. II and D.O. Conover. 1987. Adaptive significance of intertidal egg deposition in the Atlantic silverside *Menidia menidia*. Copeia 1987:76-83.

Yamahira, K. 1996. The role of intertidal egg deposition on survival of the puffer, *Takifugu niphobles* (Jordan and Snyder, 1901) embryos. Journal of Experimental Marine Biology and Ecology 198:291-306.

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