of San Leandro II-10-88 (Powell, UCB). Contra Costa Co.: Orinda VII-3/11-85 (C. D. MacNeill, OM); Russell Reserve N of Lafayette X-22-85 (Brown & Powell, UCB). Marin Co.: Audubon Cyn. nr. Bolinas V-17-87, larvae on *C. maculatum* (R. Peterson, photo UCB.) Monterey Co.: Big Creek Reserve X-7 to XI-10-89 (F. Arias, BCR, UCB). San Mateo Co.: San Bruno Mt. XI-28-83 and later dates (R. Langston, CAS, RLC) and reared from larvae on *C. maculatum* IV-86 (JAP 86D1), V-86 (JAP 86E12), III-87 (JAP 87C56) (J. De Benedictis, UCB). Santa Clara Co.: nr. Milpitas IV-25-90, larvae on *C. maculatum* (L. Spahr, UCB). Siskiyou Co.: Mt. Shasta City VI-9-89, larvae on *C. maculatum* (B. Villegas, CDFA). COLORADO: No. Platte, 6600' [1980 m] Jefferson Co. VIII-20-87, at light (P. A. Opler, UCB). IDAHO: 5 mi. [8 km] SW Cul de Sac, Nez Perce Co. VII-10-84, reared from *C. maculatum* (F. Merickel, USNM). OREGON: Morrow Co. VI-14-83 (no collr. given, USNM). Multnomah Co.: Hayden Isl., Portland IX-19-86 (Powell, UCB), UTAH: Cache Co.: Hyrum St. Park VIII-5-86 (Passoa, SPC); Logan X-1-83 (D. Veirs, UCB). WASHINGTON: Walla Walla Co.: Walla Walla VI-6-85, reared from *C. maculatum* (no collr. given, USNM). Whatcom Co.: Blaine V-30-85, larvae on *C. maculatum* (Passoa, SPC). Whitman Co.: Hooper V-30-85, larvae on *C. maculatum* (S. Passoa, UCB). (CAS = California Academy of Sciences, San Francisco; CDFA = Calif. Dept. Food & Agric., Sacramento; OM = Oakland Museum, Oakland, California; RLC = R. Langston collection, Kensington, California; SPC = S. Passoa Collection, Reynoldsburg, Ohio; UCB = Essig Museum of Entomology, U. Calif. Berkeley; USNM = U.S. National Museum of Nat. Hist., Washington, D.C.).

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## COLD HARDINESS OF *HYALOPHORA EURYALUS KASLOENSIS* (SATURNIIDAE) FROM THE OKANAGAN VALLEY, BRITISH COLUMBIA

**Additional key words:** supercooling, freezing tolerance, overwintering, cocoons.

Overwintering temperate zone insects that are not freezing tolerant (able to survive formation of ice in extracellular body fluids) must avoid freezing to survive. They do so by lowering the freezing point of their body fluids (supercooling), as low as −53°C in some species (Somme, L. 1982, Comp. Biochem. Physiol. 73A:519–543), with the aid of biochemical antifreezes such as sugar alcohols and thermal hysteresis proteins. Also, to avoid freezing, some insects seek sheltered microhabitats or construct elaborate cocoons, or both, in preparation for overwintering; such activities may also provide protection from predators while the overwintering insect is immobile (Danks, H. V. 1978, Can. Entomol. 110:1167–1205). The three species (*sensu* Lemaire, C. 1978, The Attacidae of America. Attacinae, Edition C. Lemaire, 42 Boulevard Victor Hugo, Neuilly-sur-Seine, France, pp. 114–125) of the North American genus *Hyalophora* Duncan (Saturniidae) are large univoltine moths that overwinter as diapausing pupae within well-constructed double cocoons. The well-known species *H. cecropia* (L.) has been the subject of a variety of ecological, behavioral, and physiological studies and is known to be freezing tolerant

(e.g., Asahina, E. & K. Tanno 1966, Low Temp. Sci. Ser. B. 24:25–34). In contrast, *H. euryalus* (Boisduval), native to the Pacific coast and western mountains from Baja California to British Columbia, has not been well studied. The form known as *H. euryalus kasloensis* (Cockerell) is found in the interior of British Columbia and in northern Washington and Idaho (Ferguson, D. C., *in* Dominick, R. B. et al. 1972, The moths of America north of Mexico, fasc. 20.2B, Bombycoidea (in part)) but its geographic range has not been clearly defined. Although the taxonomic status of *H. e. kasloensis* has yet to be firmly established, the form is herein considered distinct (*cf.* Morewood, W. D. 1991, J. Entomol. Soc. Brit. Columbia 88, *in press*).

In May 1988 a small captive colony of *H. e. kasloensis* was established from an adult female collected at Kelowna, in B.C.'s Okanagan Valley, and larvae were reared indoors on cuttings of *Ceanothus sanguineus* Pursh (Rhamnaceae) under ambient conditions in the Okanagan Valley. The colony was maintained and enlarged by mating several reared females with wild males in the Okanagan in 1989 and 1990 using mating cages constructed from coffee cans, as described by T. A. Miller and W. J. Cooper (1976, J. Lepid. Soc. 30: 95–104). Larvae were reared on *C. sanguineus* in the Okanagan during the summer of 1989 and on *Rhamnus purshiana* DC. (Rhamnaceae) in Victoria, B.C., during the summer of 1990. Pupae were overwintered outdoors in Victoria each year.

In mid-January 1990, 16 pupae (6 male, 10 female) were removed from their cocoons and cooled at a continuous rate of 0.3°C per minute from 0 to −30°C using the materials and methods described by L. M. Humble and R. A. Ring (1985, Cryo-Letters 6:59–66). Freezing of the pupae was indicated by the release of the heat of fusion, detected via thermocouples in contact with the pupal case. The temperature at which the pupae froze, their supercooling point, was −21.0 ± 0.40°C (mean ± SE); males and females did not differ significantly (−20.2 ± 0.49°C for males versus −21.5 ± 0.52°C for females; $t_{(2)13} = 1.8482$, $0.05 < P < 0.10$). These pupae were cooled further to −30°C to ensure that they had frozen, and they were immediately returned to outdoor temperatures (between 0 and 10°C at that time). Only one of the pupae that had been frozen failed to produce an adult in the spring of 1990 (this adult emerged on 4 July 1991). The others emerged successfully (even one that had been accidentally dropped 5 May, splitting the pupal case!) between 25 May and 11 June, with a distinct peak of emergence on 29 May. This pattern corresponded very closely with that of 33 pupae that had not been frozen, including 15 that had been removed from their cocoons shortly after pupation in August and 4 that failed to produce adults in the spring of 1990 (two of these adults emerged on 27 June 1991, the other two on 3 and 7 July 1991). It is not uncommon for a small proportion of an insect population to remain in diapause for more than one year (Danks, H. V. 1987, Insect dormancy: An ecological perspective, Biological Survey of Canada (Terrestrial Arthropods), pp. 179–184). Although overall fecundity was not assessed, one female that had been frozen mated with a sibling male and laid at least 134 eggs, of which 121 (90%) hatched.

In September 1990 all pupae were removed from their cocoons for weighing, as part of a separate study, and were placed in small plastic boxes lined with paper towels for overwintering. In early January 1991 three groups of seven male and eight female pupae each were placed directly into a freezer and held at −30 ± 2°C. One group was removed after 24 h, another after seven days, and the last after four weeks. In each case the pupae were returned directly to outdoor temperatures, which varied between 0 and 10°C. Two pupae in each group died and had desiccated by spring whereas two pupae that had been frozen for seven days failed to produce adults (but may do so after another year of diapause, see above); all of the remaining pupae produced adults between 15 June and 13 July 1991. In the control group of 17 pupae that were not frozen, one died, one failed to produce an adult, and the remainder all produced adults between 18 June and 1 July 1991. Three matings were obtained between males and females that had both been frozen for four weeks as pupae. These females laid 156, 113, and 118 eggs after mating, of which 111 (71%), 92 (81%), and 113 (96%) hatched, respectively. These data compare favorably with the results of two matings between adults from the control group wherein the females laid 105 and 91 eggs after mating, of which 98 (93%) and 63 (69%) hatched, respectively.

Thus, *H. e. kasloensis* is capable of moderate supercooling during pupal diapause and

is also tolerant of freezing below the supercooling point and may remain frozen for up to four weeks without adverse effects on subsequent survival and fecundity. Such a level of cold hardiness would be ample for winter survival in the Okanagan Valley where, at Penticton for example, the average daily minimum temperature for the coldest month of the year was −5.9°C and the absolute minimum temperature was −26.7°C during a 19 year period (Meteorological Office 1980, Tables of temperature, relative humidity, precipitation and sunshine for the world, Part 1 North America and Greenland, HMSO, London, p. 14). In contrast with *H. cecropia*, whose larvae enter a wandering phase prior to selecting a cocoon spinning site (Scarbrough, A. G., J. G. Sternburg & G. P. Waldbauer 1977, J. Lepid. Soc. 31:153–166), over 80% (n = 76) of the *H. e. kasloensis* larvae reared during the summer of 1989 simply spun their cocoons attached to twigs amongst the foliage on which they had been feeding (those that did wander may have been responding to overcrowded conditions). If this represents normal behavior for these larvae then most overwintering pupae would be exposed to extremes in ambient air temperature. However, the level of cold hardiness demonstrated in this study indicates that the pupae are well able to survive such extremes even without the thermal buffer provided by the double-walled cocoon and its trapped air spaces. *H. e. kasloensis* pupae may overwinter primarily in the supercooled state but also must freeze commonly enough that their ability to survive freezing has been maintained and this ability would obviate any protection from freezing provided by the cocoon. On the other hand, the cocoon represents a considerable investment of energy and material reserves and must therefore be of great importance for overwintering survival.

A variety of factors, including mechanical damage, mold, predators, and parasitoids, probably all contribute to the importance of the protective barrier provided by the cocoon. For example, F. L. Marsh (1937, Ecology 18:106–112) reported that the primary parasitoid of *H. cecropia*, *Gambrus* (= *Spilocryptus*) *extrematis* (Cresson) (Hymenoptera: Ichneumonidae), laid eggs only during the period of cocoon spinning even though adult parasitoids were present both before and after this period. This would suggest that active larvae are either unsuitable as hosts or are mobile enough to avoid attack and that the completed cocoon provides an effective barrier against entomophagous arthropods. Overwintering *H. cecropia* pupae suffer heavy predation by woodpeckers (Picidae) when their cocoons are spun high in trees (Waldbauer, G. P. & J. G. Sternburg 1967, Ecology 48: 312–315). Also, deermice (*Peromyscus* spp.) (Muridae: Cricetinae) may open cocoons spun close to the ground; however, house mice (*Mus musculus*) (Muridae: Murinae) will eat bare pupae but will not open cocoons (Scarbrough, A. G., G. P. Waldbauer & J. G. Sternburg 1972, Oecologia 10:137–144). Many other potential predators are probably prevented from feeding on saturniid pupae by the presence of sturdy cocoons. Surveys of cocoon sites and winter mortality would help to clarify the role of the cocoon and spinning site in winter survival of *H. e. kasloensis*.

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Voucher specimens (one male, one female) have been deposited at the Royal British Columbia Museum, Victoria (catalogue numbers ENT990-1800 and ENT990-1801).

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