Water Research Pergamon Press 1971. Vol. 5, pp. 777–783. Printed in Great Britain

EFFECT OF HIGH WINTER WATER TEMPERATURES ON ADULT EMERGENCE OF AQUATIC INSECTS

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(*Received* 5 *April* 1970)

Abstract—The larvae of 10 species of aquatic insects (Trichoptera, Plecoptera, Ephemeroptera, and Diptera) were subjected to unseasonably high winter water temperatures in the laboratory from November through July. The stonefly *Pteronarcys dorsata* and the burrowing mayfly *Hexagenia limbata* emerged in January, 5 months earlier than their natural June emergence time All other test species exhibited similar premature emergence under test conditions. The time between emergence of males and females was increased by increased water temperatures.

INTRODUCTION

IT IS now recognized that using only lethal temperatures as guidelines for establishing safe temperatures for aquatic life is not a realistic approach, because species are eliminated from lake and stream systems by temperatures that do not approach lethal levels. The increasing addition of artificially heated water into the aquatic environment has made it necessary to know not only the temperatures that kill aquatic life, such as insects, but also those that cause less obvious subtle effects which eliminate species just as readily.

Aquatic insects spend their immature life in water where they are subjected to an aquatic system, and their short adult life as terrestrial flying forms, where they must cope with the problems of a terrestrial existence. Because their existence depends on both environmental situations, a suitable time of emergence is critical when shifting from the aquatic to an aerial existence. One of the factors determining the success of this transition is the temperature of air as well as water.

Water temperature affects the time of emergence of aquatic insects. COUTANT (1967) has shown that a slight temperature increase (1°C) will cause hydropsychid caddisflies to emerge 2 weeks earlier downstream from the Hanford (Washington) reactors than upstream. NEBEKER (1971) has shown that natural stream temperatures in the Rocky Mountains, as influenced by altitude, can delay (or accelerate) emergence of several species of stoneflies by as much as 6 months.

The purpose of this paper is to present data showing that sublethal increases in winter water temperatures will disrupt normal seasonal insect emergence patterns by causing premature emergence of adults during the winter months when air temperatures can be lethal. The larvae of ten species of aquatic insects were subjected to abnormally high winter water temperatures in the laboratory to determine the effect of temperature on the time of emergence of the adults.

MATERIALS AND METHODS

The species of aquatic insects used as test organisms were the stoneflies *Pteronarcys dorsata*, *Isogenus frontalis*, and *Nemoura* sp.; the mayflies *Ephemerella subvaria*, *Baetis* sp., and *Hexagenia limbata*; the caddisflies *Hydropsyche betteni* and *Cheuma-*

topsyche campyla; the midge *Tanytarsus dissimilis*; and the blackfly *Simulium* sp. All organisms were collected from trout streams near Duluth, Minnesota.

Testing was conducted in stainless steel tanks (FIG. 1) immersed in constant temperature water baths where water flow and temperature were carefully controlled. Some of the test species, *P. dorsata*, *I. frontalis*, and *E. subvaria*, were placed in stainless steel wire cages within the test tanks. Clear plastic petri dish covers were placed over the cages (FIG. 1) to prevent escape of adults and permit easy access to the cage interior. The cages were only half submersed so that adequate air space was available for adult emergence. All species were tested at 16° ± 2°C. Three species, *P. dorsata*, *I. frontalis*, and *E. subvaria*, were also tested at 30°, 25°, 20°, 15°, 10°, and 5°C. All species were tested through adult emergence.

The studies were conducted over a 3-yr period for replication and to determine the effects of photoperiod on the emergence at various temperatures. The first year all tests were conducted at a constant photoperiod of 10 h light per day. The second and third year tests were conducted under normal Duluth, Minnesota, photoperiod. The time of day that emergence occurred in the laboratory was also determined for *P. dorsata*, *I. frontalis*, and *E. subvaria*. Continued monitoring of local streams and Lake Superior was maintained for establishing naturally occurring emergence periods under field conditions. The emergence trap designed by LEMKE and MATTSON (1969) was used for much of the field collecting.

Daily counts were made to determine survival of larvae at different temperatures and the number of adults that emerged from each test chamber. Sex ratios were determined for adults of *P. dorsata* and *I. frontalis*. All tests were at least duplicated. Five, 10, or 20 specimens were placed in each cage, depending upon the size and space requirements of the test species, and at least two cages were placed in test tanks at each temperature. Holding temperatures prior to testing were recorded for each species. *Hexagenia limbata* were tested in tanks containing a mud substrate obtained in the stream from which they were collected. They, along with the other plankton and periphyton feeders (*H. betteni*, *C. campyla*, *Simulium* sp., *Nemoura* sp., *Baetis* sp., and *T. dissimilis*), were fed powdered fish-food pellets and cerophyll (powdered cereal grain leaves). *Pteronarcys dorsata* and *E. subvaria* were fed maple leaves in addition. The predator *I. frontalis* was fed daily rations of caddisfly and blackfly larvae.

Water from Lake Superior, obtained through the Duluth city water system, and carbon filtered just prior to use, was used for all testing. The water was analyzed daily for residual chloramines from the carbon filters; this remained near 0.003 mg l^{-1} (range 0.0–0.019 mg l^{-1}) throughout the testing period (non-toxic to insects at this level). The water was also analyzed daily for dissolved oxygen concentration and percentage saturation until it was apparent that levels remained at saturation (±5 per cent) at all times. Several other chemical characteristics were measured weekly (AMERICAN PUBLIC HEALTH ASSOCIATION, 1965), or at greater intervals if they remained constant: pH, 7.5–7.8; total hardness, 43–46 mg l^{-1} (as $CaCO_3$); total alkalinity, 39–41 mg l^{-1} (as $CaCO_3$); calcium hardness, 34–37 mg l^{-1}; copper, 0.0018 mg l^{-1}; chlorides, 2.0–3.0 mg l^{-1}; total nitrogen, 0.25–0.5 mg l^{-1}; total phosphates, 0.005–0.006 mg l^{-1}; and total acidity, 0.5–1.5 mg l^{-1}.

RESULTS

The emergence tests showed that at temperatures lower than those that proved

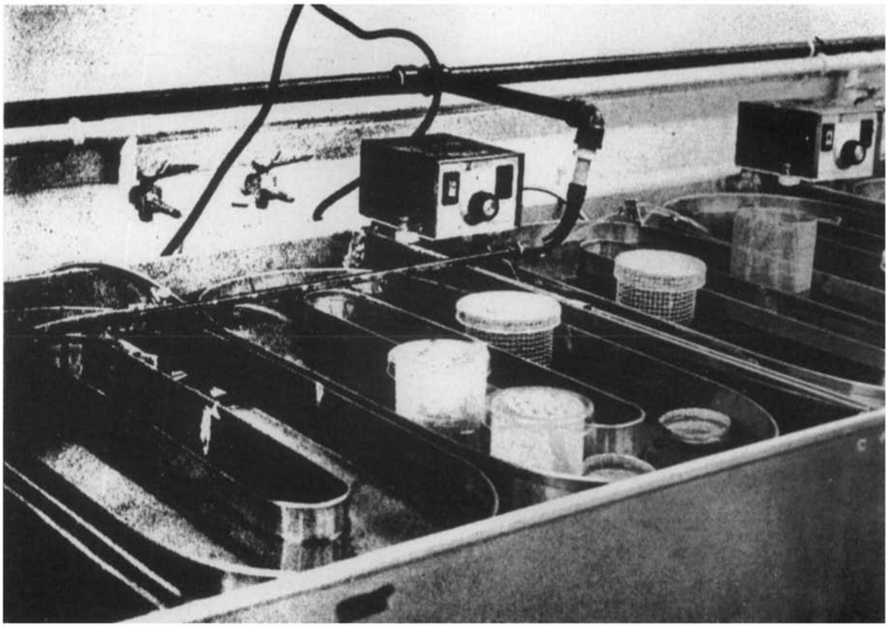

FIG. 1 Artificial test streams with holding-cages containing test animals.

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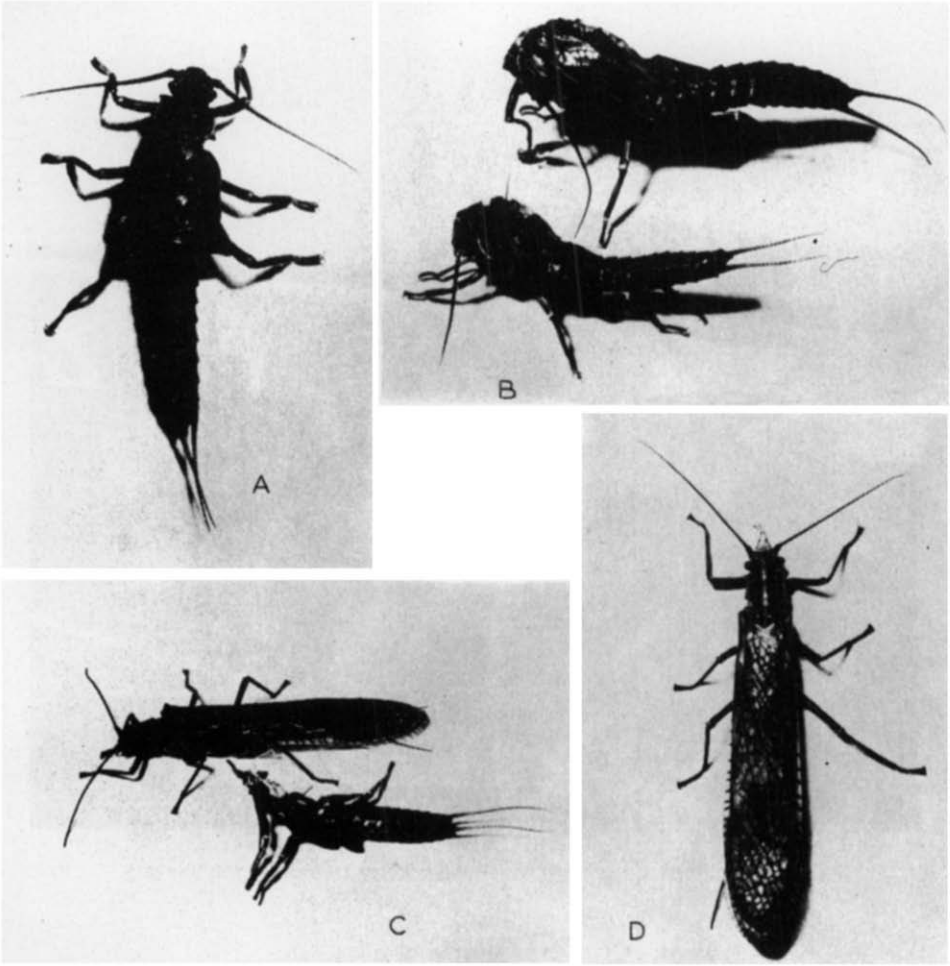

Fig 2 The stonefly *Pteronarcys dorsata* (actual size). emergence of the adult from the larvae A Mature larvae (with adult fully formed within) B Adult female (above) and male (below) partially emerged from larval skin. C Adult male (above) just after successful emergence from larval skin (below). D Fully emerged adult female

lethal increased water temperature during the winter months causes premature emergence of fully developed adults. No obvious differences in emergence were observed between the constant photoperiod and normally changing light period, and no insect, except *T. dissimilis*, emerged before mid-December.

The emergence of the large stonefly *P. dorsata* (FIG. 2) under constant light and constant temperature conditions indicates that normally increasing photoperiod and rising temperatures are not required. However, temperature increases of a few hours' duration will consistently cause insects to emerge if they are ready. The stoneflies were collected in November and no further larval molting occurred during the winter months prior to adult emergence, indicating that the last larval molt had occurred before winter testing began. Emergence of *P. dorsata* during the second and third year was essentially the same as the first year; the stoneflies died at the same temperatures and emerged in the same premature way at the higher temperatures (FIG. 3).

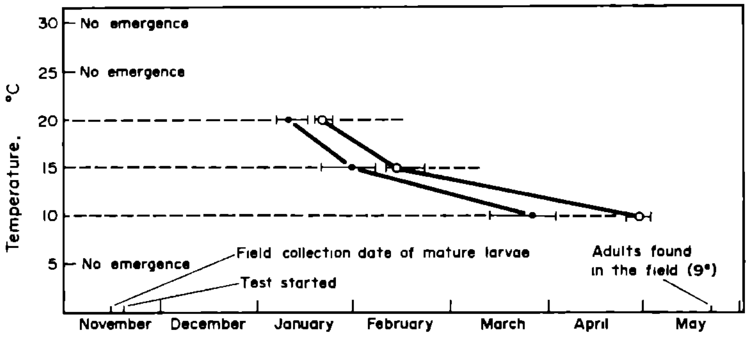

FIG. 3. Effect of temperature on the adult emergence of the stonefly *Pteronarcys dorsata* in the laboratory. (● = mean emergence date of males; ○ = females.) (——— = time from date of first adult emergence to date of last adult death.)

All specimens died after 2 weeks at 30°C and began dying after 2–5 weeks at 25°C. Forty-five per cent lived and emerged from the 20°C chamber (in January). Ninety per cent emerged from the 15°C chamber (January and February). Emergence began in March at 10°C, with 75 per cent completing adult development. Thus the larvae began to emerge at 20°C after 2 months, 15°C after 2.5–3 months, and at 10°C after 4.5 (males) and 5.5 (females) months; survival and emergence were best at 15°C, the temperature at which emergence occurred in streams near Duluth. Males began to emerge at an earlier date than did females. The separation in time of emergence of the sexes increased with time held at elevated temperatures. Earlier emergence of males is typical and well documented in the literature (BRINCK, 1949; NEBEKER, 1970; and others), but the difference in time of emergence between sexes under natural conditions is from a few hours to a few days at most.

The emergence of the small mayfly *E. subvaria* was also influenced by increase in temperature (FIG. 4). No emergence occurred at 19°C or above, even though the larvae can live for a few days at temperatures up to 22°C (NEBEKER and LEMKE, 1968). Emergence began first at 18°C and was delayed at the lower temperatures. Sexual differences were not established as only the subimago was observed.

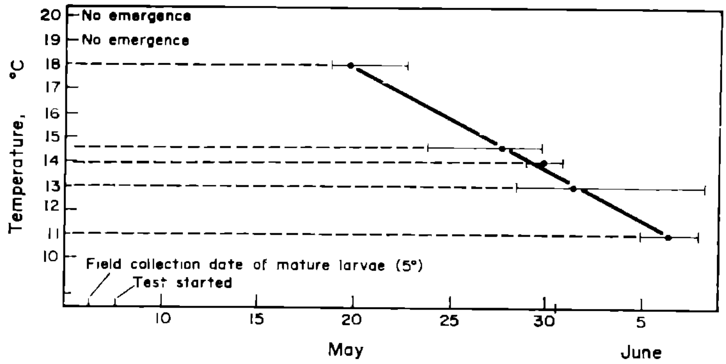

FIG. 4. Effect of temperature on the adult emergence of the mayfly *Ephemerella subvaria* in the laboratory (● = mean emergence of subimago) (——— = range of emergence)

Isogenus frontalis, a medium-sized carnivorous stonefly, when exposed to relatively short periods (30 days) of high temperature, showed the same trend as *P. dorsata*; they emerged earlier at the higher temperatures. However, no emergence occurred above 18°C, which is only 4.5°C below the 96-h TL_{50} value of 22.5°C (NEBEKER and LEMKE, 1968). Male and female emergence times were separated in this species as in *P. dorsata*.

The remaining seven test species were held at 16°C only (FIG 5). Several hundred individuals emerged, with many emerging in January, although their normal emergence

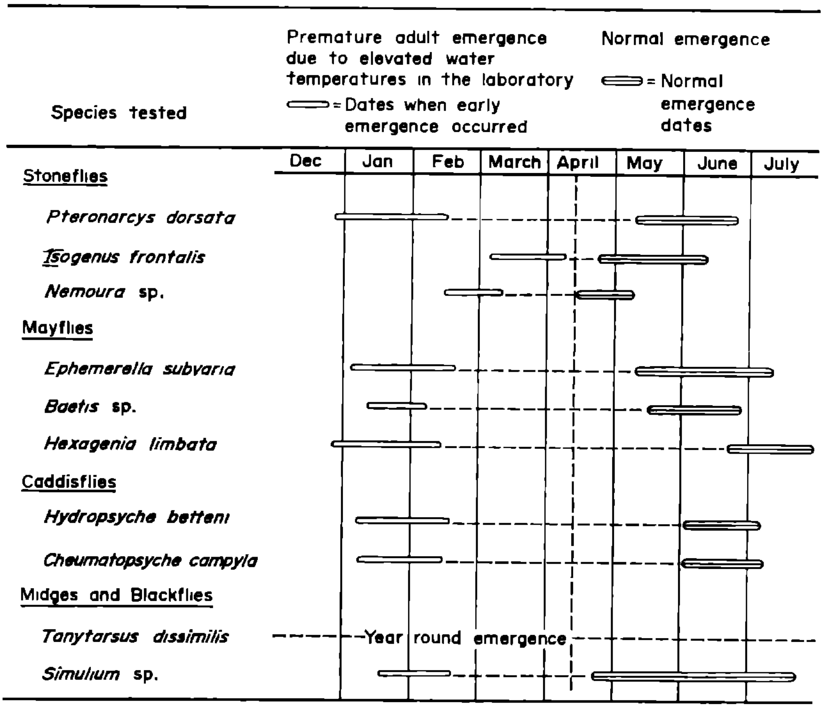

FIG. 5. Effect of increased temperature on time of emergence of 10 species of aquatic insects in the laboratory.

period is June. All except the midge were collected in the field in early winter (November and December) after they had been exposed to at least 1 month of cold water (winter chill period). Water temperatures in the artificial laboratory streams were raised to 16° ± 2°C from the normal winter stream temperatures of 2° ± 2°C. The small midge *Tanytarsus dissimilis* emerged year-round in the laboratory, completing a full life cycle in 30–40 days (16°C). The burrowing mayfly *Hexagenia limbata* began emergence in late December, with several "hatches" occurring later as younger groups of larvae matured. The year-round emergence of this species, and a closely related species, *Hexagenia bilineata*, in the laboratory has been demonstrated by FREMLING (1967). However, by contrast, BRITT (1962) showed that a related species, *Ephoron album*, requires a chill period below 10°C before the life cycle can be completed.

Several additional species were also brought into the laboratory from ice-bound streams in January, February, and March, and many, such as blackflies, several species of midges, caddisflies, and small stoneflies, began to emerge within a few days, indicating that many species complete most of their development prior to the onset of cold weather and are ready to emerge when warming of the water occurs. Thus, part of the effect of elevated temperature appears to be a triggering effect, in addition to increasing rate of development.

Light had a definite effect on the time of day that the insects emerged. The stoneflies emerged only at night (laboratory darkness). As soon as the lights in the laboratory went out they began to crawl out of the water and emerge. At times they were found just completing their emergence when the lights came on in the morning. The stonefly larvae were also more active at night, with many of them drifting with the current. The mayfly, *E. subvaria*, which is day-active as an adult, began emerging in midmorning.

DISCUSSION

All the test species exhibited the same premature emergence pattern when subjected to elevated winter water temperatures. This result is in general agreement with previous studies of temperature and emergence. PLESKOT (1953) showed that the mayfly *Habroleptoides modesta* emerges early in the summer, coming out earlier in warmer water and in warmer seasons. SMITH (1968) found that nearly uniform temperature conditions prevalent in an Idaho spring altered the normal fall emergence of the caddisfly *Rhyacophila verrula* so that it emerged in June and July. Constant temperature springs in Utah caused the small winter stonefly *Capnia nana* to emerge 2 months earlier than the same species living in a nearby river which had normal seasonal temperature fluctuations (NEBEKER and GAUFIN, 1967). THUT (1968) also showed that insects which had limited seasonal emergence in streams emerged during different times of the year when temperatures were altered by springs.

Where adult insects can survive winter air temperatures, increases in productivity can be achieved and increased numbers of fish-food organisms can be produced. Aquatic insects, primarily hydropsychid caddisflies, which do not normally emerge during winter, have been observed emerging year-round below outfalls of thermoelectric utility plants in the southern states (JACKSON, personal communication). The year-round emergence of the midge *T. dissimilis* in the laboratory is another example of the changing of insect emergence patterns by altered temperatures.

This study shows that many insect species complete most of their development prior to the onset of winter and await spring temperature increases to initiate emergence. This was also shown by Lutz (1968) who reported that the emergence of the damselfly *Lestes eurinus* is temperature-dependent in both the field and laboratory. Development was rapid in the warmer months and retarded between October and March. Rising vernal temperatures were the most important factor in seasonal regulation.

The rate of growth of aquatic insects is related to their ambient temperature, the warmer the temperature, up to a point, the faster they will grow and emerge as adults. If stream or lake temperatures are raised by just a few degrees by natural or man-made causes, the growth of the immature insects will be stimulated. This will present few problems in areas where air temperatures remain fairly high throughout the year, but in the northern United States and Canada where air temperatures remain near or below freezing for 5 or 6 months, problems may occur when water temperatures are unseasonably elevated. When the insect larvae grow more rapidly than usual they become ready to emerge as adults out of phase with the ambient air temperature, and the smooth shift from the aquatic to an aerial existence is disrupted. Many species which normally emerge in May or June, when air temperatures are mild, may emerge in February or March and face almost certain death by freezing, or will be prevented from mating because of being inactivated by the low air temperatures Also, if a small increase in stream temperature caused an exaggeration in the separation of the emergence of males and females, the males might emerge and die before the females emerge; mating would be prevented and the species eliminated.

The small increases in temperature that can eliminate a species by disrupting emergence patterns are far less than those found to kill larvae in 96-h tests. These factors must be taken into consideration when establishing safe temperatures for aquatic life.

Acknowledgement—I wish to thank Henry Bell and David DeFoe for aid in collecting specimens, Armond Lemke and Vincent Mattson for conducting many of the field collections of adults, and James Tucker for photographic assistance.

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