“Basking” behaviour in adults of *Spaniocercoides cowleyi* (Plecoptera: Notonemouridae)

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Abstract

Adult New Zealand stoneflies are rarely seen on the upper surfaces of river stones in full sunlight. However, unusual resting or “basking” behaviour of three notonemourid stoneflies *Spaniocercoides cowleyi*, *Spaniocerca bicornuta* and *Cristaperla waharoa* was observed in the exposed river bed of Carton Creek, South Island, New Zealand. Of 114 individuals identified most were *S. cowleyi*, which appeared to have two distinctive morphotypes; a slightly larger-bodied, golden winged form represented only by females, and a more numerous, smaller, dark-winged form with a male: female ratio of 1: 1.28. Approximately 87% of the stonefly adults observed were by themselves. Individuals occurred on emergent substrata either in the stream or along its immediate margins. Stones of various sizes were used for resting, however boulders and cobbles 10-40 cm wide were preferred. A high proportion of adults basked at the highest points of the stones (78%), and their downstream sides were generally avoided. Most adults faced upstream when resting (51%); the remainder faced downstream or to the side in equal numbers. Adults were rarely observed on wetted stones or near the water edge. Potential explanations for this rarely documented behaviour are discussed, including the possibility that this was basking to increase reproductive development in immature adults.

Keywords: Stoneflies - heliothermy - thermoregulation - adults - behaviour.

Introduction

Adult New Zealand stoneflies are commonly found on the undersides of stones along the margins of streams during the day, frequently aggregating in groups. Few observers have noted stoneflies on the upper surfaces of riverbed substrata (Pendergrast & Cowley 1966; Winterbourn 1966), although anecdotal observations have been made of adults of summer-emerging species basking in North America (DeWalt & Stewart 1995). There is a paucity of literature on the behaviour of New Zealand adult stoneflies however, and no studies provide any indication of the purpose or frequency of this behaviour. A likely explanation is that it is basking behaviour (DeWalt & Stewart 1995). Basking behaviour is well known in insects, and is a relatively common strategy for species that require exothermic energy for flight (Heinrich 1993). Basking has not been widely reported in aquatic insects, except in perching adult dragonflies (May 1976; Rowe & Winterbourn 1981; Rowe 1987), where exothermic behaviours, particularly in higher latitude species, may be important for thermal regulation to assist flight, gonad development, and exoskeleton hardening after emergence (Heinrich 1993). Rowe & Winterbourn (1981) noted heliothermy, primarily by posturing and orienting to the sun by the New Zealand damselfly *Austrolestes colensonis* and metabolic heat production by wing-whirring and circulatory adaptations by the dragonfly *Procordulia smithi*.

This paper reports the chance observation of a large number of adult stoneflies of three species resting on exposed upper surfaces of stones in an open riverbed during hot, sunny conditions.

Study site

Stoneflies were observed along a 460 m reach of Carton Creek near Reefton, South Island, New Zealand. The reach had been deforested in 2002, the creek diverted, and the riverbed dredged for alluvial gold to a depth of about 5 m from September 2002 to May 2004. In May 2004 the channel of the old creek bed was re-established and the stream diverted back to its original course.

Carton Creek is a third order stream, 2.2-4.5 m wide in the study area, with baseflow depths of 0.07-0.2 m and current velocities of 0.28-0.36 m s^{-1}. In the sample reach the stream flows in a north-westerly direction. The substratum was dominated by boulders, cobbles and pebbles. Water temperature in the diverted reach during October 2002 was 7-9 °C. Emergent stones were generally well rounded and devoid of any algae, moss or lichens.

Methods

Systematic observations were made on 20 and 21 October 2004 (early austral spring) after casual observations had revealed the presence of surprisingly high numbers of adult stoneflies sitting on exposed substrata during the middle of the day. The location and orientation of stoneflies were observed and measured over a 2-3 hour period from about 1100-1400 h on each day. Both days were sunny, calm and hot. Air temperatures were not measured but were probably ~25 °C. Distance and substratum size measurements (longest axis) were made with a standard one metre ruler. Representative adult stoneflies were hand collected, preserved in 70% ethanol and returned to the laboratory for identification and measurement of head capsule width and femur length. Identifications were made by Mike Winterbourn and Ian McLellan. No moulting or obviously newly-emerged animals were seen.

Results

The location and orientation of 114 stonefly adults were observed and recorded and 71 individuals were collected for identification. They belonged to three notonemourid species *Spaniocercoides cowleyi*, *Spaniocerca bicornuta* and *Cristaperla waharoa*, of which *S. cowleyi* was the most abundant (94%). It was represented by two distinct morphotypes:

a smaller bodied, black-winged form (headwidth 0.9-1.0 mm, hind femur length 1.6-1.9 mm), which dominated the population (80%), and included males and females in a ratio of 1: 1.28; and a slightly larger bodied, golden-winged form (headwidth 1.0-1.1 mm, hind femur length 1.9-2.1 mm), which accounted for 14% of the population and consisted entirely of females. Subsequent dissection of the smaller bodied, black-winged females showed that their guts contained southern beech (*Nothofagus*) spores, but no well-developed ovarioles or eggs were present. In contrast, the abdomens of females of the larger bodied form were full of eggs. The co-occurrence of several cohorts of adults of differing sizes has been observed in other stoneflies (Harper 1973).

Both *Spaniocerca bicornuta* and *Cristaperla waharoa* were collected in low numbers. They were easily distinguished from *S. cowleyi* in the field and exhibited similar resting behaviour to that species.

Most adult stoneflies (87%) were alone on stones; only one pair was observed mating, and on two large boulders groups of three and five stoneflies, respectively, were seen (Figure 1).

On both of these boulders the stoneflies were 5-7 cm apart and did not seem to be interacting. There was a strong preference for the stoneflies to occupy either emergent substrata within the stream, or stones and boulders along the banks (Figure 2a), and the furthest any stonefly was recorded from the water margin was 97 cm. Adults were found on substrata ranging from cobbles (<10 cm) to large boulders (> 61 cm), with the majority using 21-40 cm substrata (Figure 2b). Almost 80% of stoneflies were observed at the highest point of a stone (Figure 3). Those that occurred lower on the substratum tended to be on the upstream rather than downstream side. Preference for locations high on stones meant that few adults were on damp substrata. Adult stoneflies also showed a

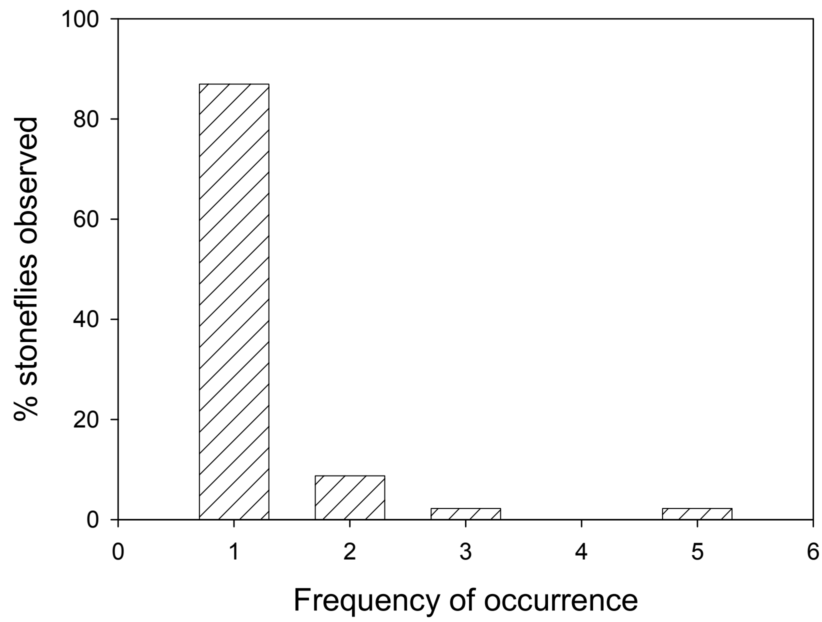

Figure 1. Numbers of stoneflies (%) occurring alone on stones or present with conspecifics (n = 46 observations).

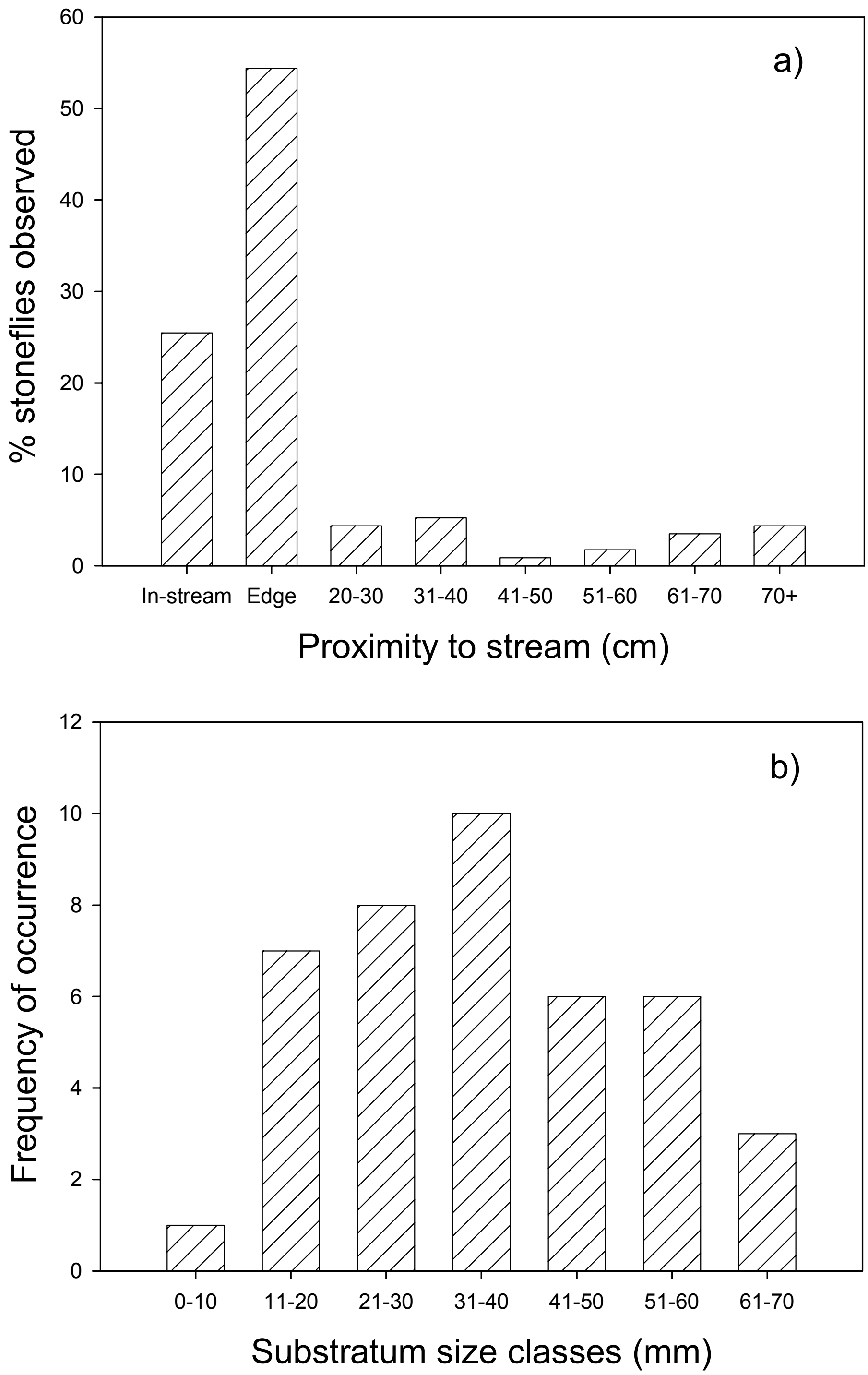

Figure 2. a) Location and proximity of adult stoneflies to the stream ($n = 114$) and b) frequency of substratum sizes used by stoneflies for basking ($n = 41$).

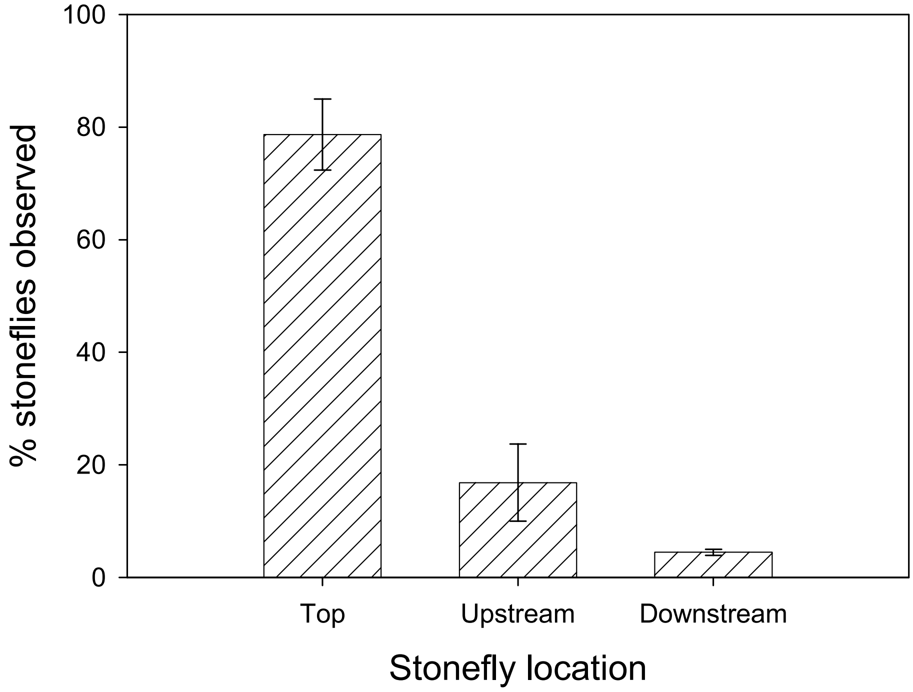

Figure 3. Mean (± 1SE, *n* = 76) numbers of adult stoneflies (%) at the top, on the upstream side and on the downstream side of stones.

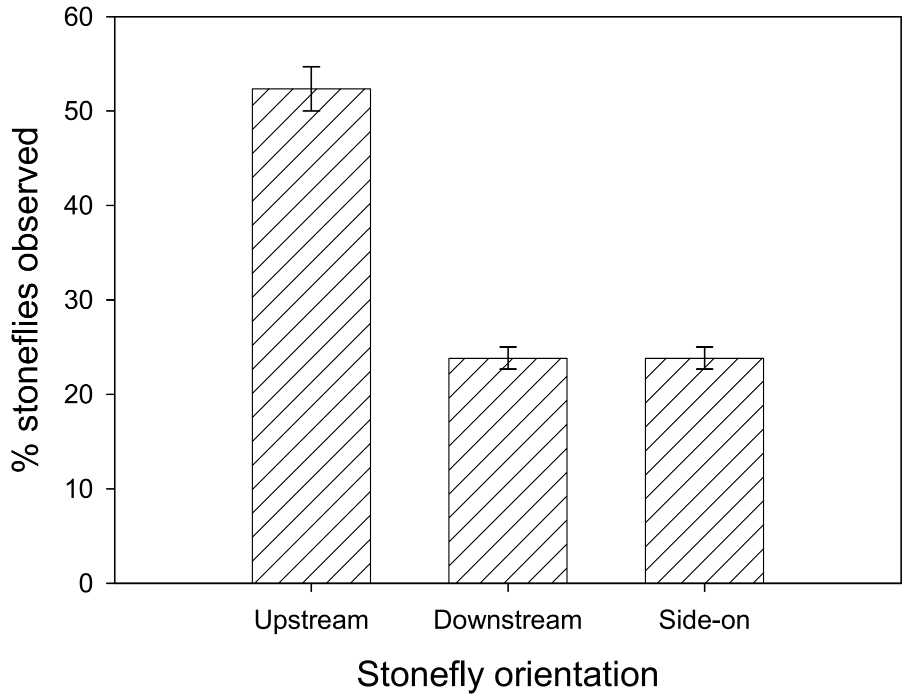

Figure 4. Mean (± 1SE, *n* = 76) directions faced by basking adult stoneflies on stones.

strong orientation preference, with most facing upstream (51%) and the remainder facing downstream or to the side in equal proportions (Figure 4).

Discussion

Why has this phenomenon rarely been recorded?

The nymphs of *S. cowleyi* are thought to be phreatic and are rarely collected in significant numbers for this reason (McLellan 1991). The unusual abundance of adults at Carton Creek may have been an artefact of the severe upheaval of the riverbed caused by recent alluvial gold mining, which loosened and exposed substrata and deep riverbed gravels. The extreme disturbance of this river may have created an unusual situation, although adults of *Zelandoperla decorata* have also been observed on the tops of stones in other gravel-bed rivers in direct sunlight (Winterbourn 1966).

What is this behaviour?

There are several possible reasons why large numbers of adult stoneflies should be present at the same time on the upper surfaces of stones.

First, it could be part of the mate finding and courtship behaviour of at least some of these stoneflies. The mating strategies of New Zealand notonemourids have not been documented, and nothing is known about their courting behaviour. Sitting on the upper surfaces of prominent stones is a plausible behaviour for mate finding, but of the 114 stoneflies I observed, only a single pair were mating. As adult New Zealand stoneflies are usually observed on the under surfaces of stones during the day it seems likely that mating occurs at night. Furthermore, dissected small-bodied *S. cowleyi* females did not contain eggs, whereas females of larger-bodied golden-winged forms did contain eggs and exhibited the same behaviour. During my observations most adults remained stationary, they rarely moved except when I touched their antennae or cerci, and it seems likely that they may not rely on visual acuity but on tactile detection of mates. It is not known whether they produce pheromones, and the drumming behaviour widely recorded in northern hemisphere stoneflies has not been observed in New Zealand.

It is also unlikely that the presence of stoneflies on tops of stones was associated with an activity such as foraging for food. No organic material or potential food was visible on the substrata occupied by these adults and the individuals were generally stationary, rarely moving during my observations. Dissection of several females showed that beech spores were present in the smaller-bodied forms of *S. cowleyi* but food items were not detected in the larger-bodied adults of this species. Winterbourn (2005) found that adults of *Spaniocera zelandica* and *Cristoperla fimbria* fed on sooty mould fungi, fungal spores, pollen and other fine organic matter, and Hynes (1976) suggested that many adults need to feed in order to complete development.

Another explanation is that the smaller-bodied *S. cowleyi* were recently emerged, immature adults that were still undergoing gonadal development, and that they were exhibiting basking behaviour. Dissections of several smaller-bodied females showed they had tissue in their abdomens consistent with this hypothesis and no developed ovarioles or eggs were seen. Petersen & Hildrew (2003) noted that adults of *Leuctra nigra* mate soon after emergence, whereas maturation of the eggs can take several further weeks, while Hynes (1976) noted that females of many stonefly species may take days or weeks for their eggs to develop subsequent to mating. Winterbourn (2005) noted that adult females of *S. zelandica* and *C. fimbria* collected from a small beech forested stream included immature, gravid and spent individuals, however, no information exists on New Zealand adult stonefly development, and there is limited information on adult longevity. Collier & Smith (2000) examined the longevity of adult stoneflies of three species *Zelandobius furcillatus*, *Zelandoperla decorata* and *Acroperla trivacuata* in the laboratory and found it varied considerably among species, males and females and temperatures. Females of *Z. furcillatus* had a mean longevity of 10 days, females of *Z. decorata* lived on average 13.5 days and those of *A. trivacuata* 9.9 days at 10 °C. However, some adults of *Z. decorata* lived up to 53 days.

Basking has not been documented in New Zealand stoneflies, although it is well known in dragonflies (May 1976; Rowe & Winterbourn 1981), and has been observed in arctic mosquitoes (Downes 1965). The North American nemourid stonefly *Zapada cinctipes* was found to thermoregulate behaviourally by entering warmer lake water at subzero night temperatures (Tozer 1979). The behaviour I observed exposed the adults to possible predation from spiders, lizards and insectivorous birds all of which were present in the catchment, so its advantages must be greater than its risks.

Why might a small stonefly need to bask?

Critical temperature thresholds may influence feeding, swarming, mating and oviposition. By basking and thereby gaining heat, either directly from the sun, or from substrata with high heat absorbance, animals may attain critical thermal values more rapidly. Although most stoneflies are poor fliers, reaching critical temperatures may enable them to fly short distances. Perhaps more importantly, raising the body temperature may speed up development and reduce the time prior to oviposition.

Most stoneflies in Carton Creek faced upstream, roughly in a south-easterly direction and at an oblique angle to the sun. However, their small body size and "wrap-around" wings that conceal potential heat-uptake surfaces, may make absorption of heat directly from the sun relatively ineffective. In contrast, absorbing heat from the substratum may enable these small insects to increase and maintain a high body temperature. Little is known about the thermal tolerances of New Zealand stoneflies, although Collier & Smith (2000) and Smith & Collier (2005) showed that prolonged exposure to high temperature (25 °C) in the laboratory reduced adult longevity. However, small stoneflies such as those seen at Carton Creek probably spent only a portion of the day basking.

In conclusion, no definitive explanation can be offered for the observed behaviour and a more intensive and focused study will be required to resolve its purpose. The paucity of studies on the ecology and behaviour of adult New Zealand stoneflies, and our inability to adequately explain this unusual phenomenon, highlight the need for more fundamental research on the biology of New Zealand stream insects, especially their non-aquatic stages.

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