

Scientific Note

Larvae of the caddisfly, *Nerophilus californicus* Banks, 1899 (Trichoptera: Odontoceridae), as scavengers of an American bullfrog, *Lithobates catesbeianus* Shaw, 1802 (Anura: Ranidae), carcass

In headwater lotic ecosystems, energy flow models focus on allochthonous and autochthonous inputs fueling food webs that support insect and vertebrate consumers (Vannote et al. 1980, Allan 1995). Energy and nutrient transfers across trophic levels are considered to flow primarily from terrestrial organisms to aquatic ones (Horne & Goldman 1994, Torres-Ruiz et al. 2007). Energy flow in the opposite direction, through linkages from aquatic to terrestrial habitats in headwater systems, is seldom considered. Larval aquatic insects, through their biphasic lifestyles, provide such linkages by shredding or scavenging allochthonous materials or predated other insects. Once transformed into winged adults, they transport stored energy into terrestrial uplands as prey to a variety of predators, or when they expire and become food for microbes (Bartrons et al. 2018). Caddisflies (Trichoptera) are a diverse group of aquatic insects whose larvae play important roles in aquatic habitats by consuming allochthonous materials such as leaves, dead plants, and benthic algae and predated invertebrate animals (Jannot et al. 2008). Here, we report an observation of an unusual scavenging event that may provide evidence of an additional linkage bringing energy flow to terrestrial habitats from aquatic ones.

On 2 November 2017, while conducting a radiotelemetry study in the upper headwaters of Copeland Creek in Sonoma County, California, we located one of our radioed American bullfrogs (*Lithobates catesbeianus* Shaw, 1802) lying on its back on the bottom of a shallow channel. The non-native frog was deceased and lying belly-up in a steeply incised, low-flow section with a cobbled substrate. At first glance, it looked as though the bullfrog had been impaled by three projectiles, but when we removed it from the water with a net we could see that it had three caddisfly cases protruding from its ventral side near the throat and right arm (Fig. 1). It was apparent that the caddisflies had penetrated the bullfrog's skin post-mortem because there was no blood supplying the wounds and a faint aroma of decomposition was present (Fig. 2). Though the cause of death was not determined, a cursory post-mortem inspection revealed several larval *Nerophilus californicus* Banks, 1899 either attached to or feeding on the dorsal surface of the bullfrog, many tumbling into the net when we turned the bullfrog over. Three *N. californicus* larvae were found inside the bullfrog: two had entered through the mouth and one had bored its way through the dorsal surface. Most of the pectoral and mouth and throat muscles had been consumed. Two of the larvae that had penetrated the thorax were actively feeding on the heart. Eight of the 11 *N. californicus* larvae that we encountered were feeding on the side of the frog facing the substrate. The eye and the tympanum of the bullfrog were eaten (Fig. 3), and many "tracks" were left on the skin surface of the bullfrog by *N. californicus* larvae feeding on the pigmented layer of the dermis (Fig. 4).

Nerophilus californicus, native to Oregon and California, larvae are found in springs and small to medium-sized streams and rivers where they inhabit slow-flowing areas or depositional zones. They forage in low light or after dark, emerging from diurnal hiding places in sandy or gravelly substrates (Holzenthal et al 2007, L. Serpa, in litt.). Their cases



Figure 1. Three *Nerophilus californicus* larval cases protruding from a deceased, male American bullfrog.

are often constructed of sand and larger fragments, and larvae are omnivorous with a dietary range that includes detritus, vascular plants, algae, and aquatic arthropods.

The discovery of this invertebrate feeding on a bullfrog is novel, but *N. californicus* exploiting a high protein food source is not unexpected. Caddisflies with high protein diets have been found to have a larger mass at the time of metamorphosis (Ito 2005,



Figure 2. The lack of blood supply to penetration wounds made by scavenging larval *Nerophilus californicus* indicates the wounds were made post-mortem.

Jannot et al. 2008, Pritchard & Berte 1987, Wartenberg et al. 2017). Increased mass at metamorphosis is correlated with fecundity in females and mating success in males (Honek 1993, Pritchard & Berte 1987, Wissinger et al. 2004). The scavenging opportunity we observed shows that feeding strategy of *N. californicus*, and possibly other caddisflies as well, extends beyond the plants and invertebrates previously



Figure 3. The missing eye and tympanum of an American bullfrog consumed by scavenging larval *Nerophilus californicus*.

reported and into vertebrate remains. It is also an example of energy flow in a unique direction, from aquatic to terrestrial.

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Figure 4. Feeding tracks in the dermis of an American bullfrog created by scavenging larval *Nerophilus californicus*.

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