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A Reassessment and New State Records of Trichoptera Occurring in Hawai‘i with Discussion on Origins and Potential Ecological Impacts

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Introduction

The caddisflies (Order Trichoptera) are a group almost invariably aquatic in their immature stages, although a few are wholly terrestrial (see Wiggins, 1996 for a general overview of the order and their biology). The order is not native to the Hawaiian fauna, but several species have appeared in this last century (Zimmermann, 1957). The first specimens were taken in Honolulu in 1940 (Zimmerman, 1943) and subsequently identified by H.H. Ross as *Oxyethira maya* Denning (Ross, 1948). A second species, *Cheumatopsyche analis* Banks was reported by Beardsley (1966). The third species, first reported as *Hydroptila* sp. by Joyce (1969) was subsequently identified as *H. arctia* Ross by Denning & Blickle (1971). Additional material of *Hydroptila* was submitted to the senior author in 1988 by Kumashiro, which turned out to be the recently described *H. potosina* Bueno-Soria (Bueno-Soria, 1984). This species is closely related to *Hydroptila arctia*, and as a consequence a re-examination of the identity of the originally collected material of *Hydroptila* was undertaken, which verified that *H. arctia* was at that time a misidentification for the undescribed species later described as *H. potosina*. In this paper we report on a new record for the state of Hawai‘i, the occurrence of yet another nonindigenous microcaddisfly, *Hydroptila icona* Mosely.

Material in the following collections was examined in the course of this study: Bernice P. Bishop Museum, Honolulu (BPBM); Hawaii Department of Agriculture, Honolulu (HDAH); National Museum of Natural History, Smithsonian Institution, Washington, DC (NMNH).

Family Hydroptilidae

Hydroptila potosina Bueno-Soria **Name change** Figs. 1–8

Hydroptila potosina Bueno-Soria, 1984: 95.

Hydroptila arctia nec Ross: Beardsley, 1971: 15. Denning & Blickle, 1971: 164. Blickle, 1979: 47 (Hawaiian records all misidentifications).

Several examples of the original collection of *Hydroptila* from Hawai‘i that were sent to Denning & Blickle and identified as *H. arctica* were re-examined in this study and the male is unquestionably *potosina*. Thus, the record of *H. arctia* is to be erased from the Hawaiian list and be replaced by *potosina*.

Although *H. arctia* is common and widespread in the western United States and Mexico, *H. potosina* has a much smaller known range. It is confined to the northeastern Mexican states and adjacent Texas. The species is known from the following Hawaiian islands: Kaua‘i (NMNH), O‘ahu (NMNH, BPBM), Maui (BPBM), Moloka‘i (BPBM), Hawai‘i (BPBM, NMNH).

Because the original description of the species is in a journal not widely available, new figures of the male genitalia are given here. In the male, the species is quickly dif-

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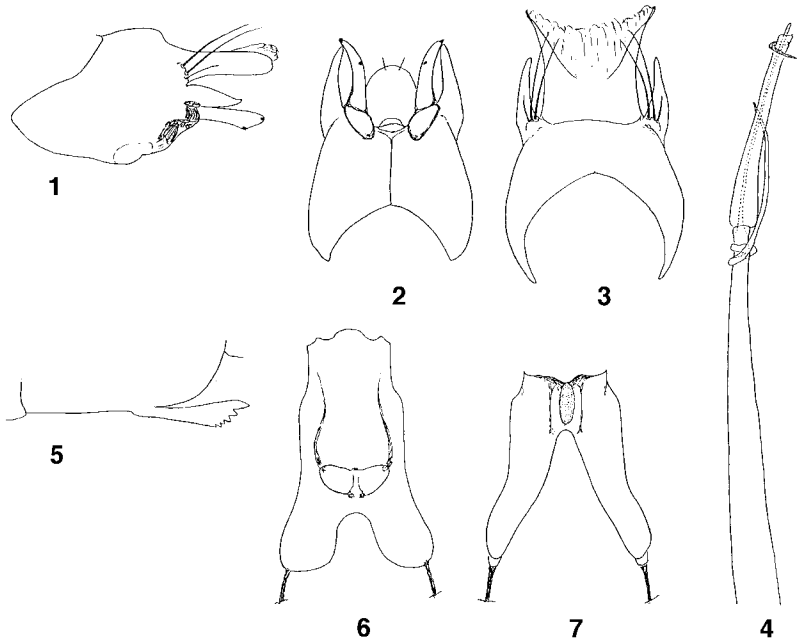


Figs. 1–7. *Hydroptila potosina* Bueno-Soria. **1**, male genitalia, lateral; **2**, same, ventral; **3**, same, dorsal; **4**, phallus, dorsal; **5**, seventh sternum and process, lateral; **6**, female eighth sternum; **7**, same, eighth tergum.

ferentiated from *Hydroptila arctia* by the process on the seventh sternum which is large, arcuate and serrate on its outer margin. This process in *arctia* is much smaller, sharply pointed and lacks all serrations. We also here figure the female genitalia for the first time to facilitate the separation of the two Hawaiian *Hydroptila* species in this sex.

The cases of the immature stages of the two *Hydroptila* species are easily distinguished. The case of *H. potosina* is silken with many, very small, sand grains embedded in its surface. It also appears rather smooth and regular (Fig. 10). In contrast the case of *H. icona*, also basically of silk and purse-shaped, contains embedded fragments of algal filaments arranged in oval bands and the entire case has a "fuzzier" appearance. *Hydroptila potosina* appears to be the most abundant hydroptilid in Hawai'i, with medium to high densities of larvae observed in most streams.

Material examined. **O'AHU:** Honolulu Apt., 20 May 1968, C.R. Joyce, light trap, 1 male; same, but 28 May 1968, 1 male; same, but 24 Jun 1968, 1 female (NMNH). Mililani, 17 Apr 1988, J. Michishima, at light in garage, 2 males, 1 female (NMNH), 1 male (HDAH). Honolulu, University of Hawaii, 25 Apr 1969, J.W. Beardsley, 1 male, 1 female (HDAH). **KAUA'I:** Keālia Str., 15 Mar 1979, J. Maciolek, 2 male, 2 females (NMNH). **HAWAI'I:** Waipi'o Valley, BPBM Survey Site #4a/5, 4 m, 14 Mar 2001, R.A. Englund, N.L. Evenhuis & D.J. Preston, MV bulb, 2 females (BPBM); same, but Site # 5 (5 m), light trap off sheet, 3 female (BPBM); same but Site #6 (30 m), brushed off boulders, 25 larvae, 1 male metamorphotype, 8 pupae (BPBM, NMNH); same but 15 Mar, Site #6, 40 m,

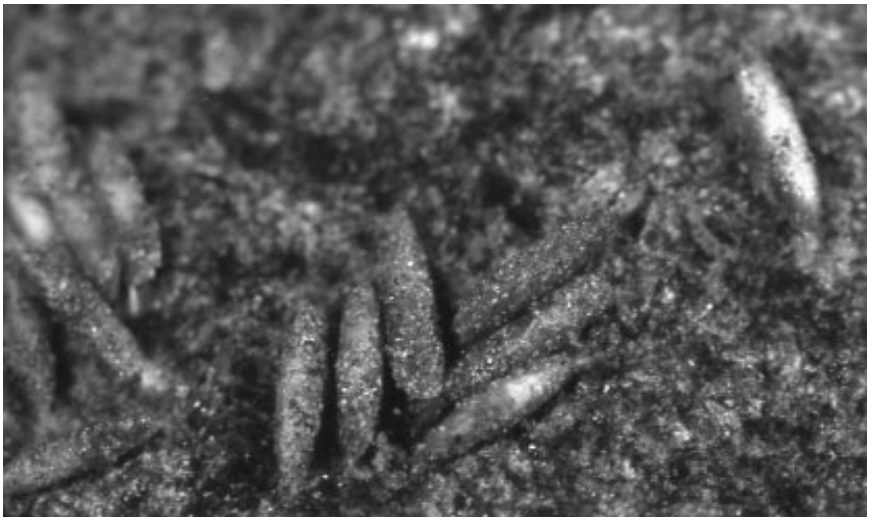


Fig. 8. *Hydroptila potosina* Bueno-Soria, larval and pupal cases from in Wailoa River, Waipi‘o Valley, Hawai‘i Island, 42 m elevation. Photo: R.A. Englund & D.J. Preston.

1 larva, 2 male metamorphotypes, 14 pupae (BPBM, NMNH). **MAUI:** Olowalu Stream, 21 Jul 1994, 365 m, l larva, 1 male, D.A. Polhemus (BPBM); ‘Īao Stream, 19 Dec 2001, 280 m, 3 larvae, R.A. Englund & D.J. Preston (BPBM).

Hydroptila icona Mosely **New state record** Figs. 9–10

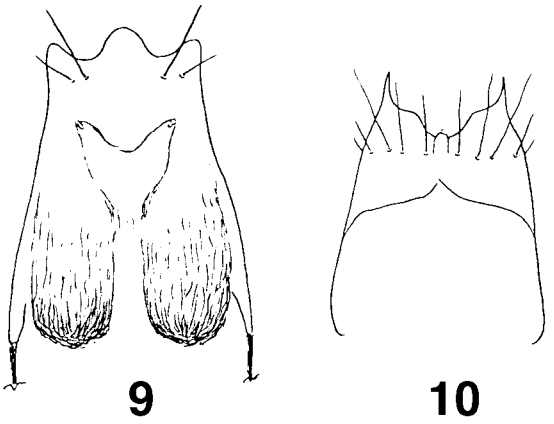
Hydroptila icona Mosely, 1937: 161. Ross, 1944: 154. Harris & Holzenthal, 1999: 38.

This species is newly discovered in the Hawaiian Islands, but already seems widely distributed, having been collected on Moloka‘i (BPBM, NMNH), O‘ahu (NMNH), and Maui (NMNH). It was originally described from Chiapas and Sinaloa in Mexico and subsequently recorded from Honduras, Nicaragua, Costa Rica, and USA (Texas, Oklahoma, New Mexico, Arizona, and California).

The male genitalia have been well figured by Mosely (1937), Ross (1944), and Harris & Holzenthal (1999). The female terminalia have not been previously figured. We provide figures of the female terminalia here for comparison with those of *H. potosina*.

As mentioned above, the larval cases of this species are easily distinguished from those of *H. potosina*. In *H. icona* they are silken with embedded bits of algal filaments arranged in concentric, oval rings with the entire case appearing a bit shaggy.

Hydroptila icona was first collected in Pelekunu Stream, Moloka‘i during annual surveys conducted in 2001. This species had not been observed during earlier monitoring of this stream in either 1991 or 2000 (Englund, 2001), and was collected in stream habitats just above the ocean to approximately the 30 m elevation level, but no higher. By 2002 *H. icona* was found in Pelekunu Stream to the highest elevation surveyed of over



Figs. 9–10. *Hydroptila icona* Mosely. **9**, female eighth sternum; **10**, same, eighth tergum.

260 m above sea level, and thus appears to have successfully invaded the entire Pelekunu watershed. *Hydroptila icona* was found in high densities during both 2001 and 2002 in Pelekunu Stream riffles. The center-channel areas were the primary habitat preferred by this species, in the mid-channel areas of the most heavily flowing water. Of particular concern is the ability of *H. icona* to tolerate the high water velocities found in the v-shaped area at the beginning, or upstream end of cascades in riffles; these are areas of the stream containing the greatest water volume. The highest water velocities of Hawaiian streams are also the most favored by native aquatic insect species (Howarth & Polhemus, 1991).

This species has likely been present on O‘ahu for several years, but published or unpublished reports regarding the occurrence of *H. icona* on this island have not been found. It is undoubtedly widely distributed throughout O‘ahu.

Material examined. **MOLOKA‘I**: Pelekunu Stream, 23 May 2001, R. Englund, sea level, fast riffle, 1 male, 2 female metamorphotypes, 14 pupae (BPBM, NMNH); same, but 20–30 m, 3 larvae, 1 male metamorphotype, 5 pupae, many empty cases (BPBM). Pelekunu Stream, R.A. Englund, 28 May 2002, upstream of Papaiki camp, 150 m, 29 May 2002, 6 larvae; Pelekunu Stream, 260 m (Pilipililau Tributary), 3 larvae (BPBM). **O‘AHU:** S. Fork Kaukonahua Stream, 10 Sep 2002, 304 m, riffles, above Canon Dam, 2 larvae; Punalu‘u Stream (BPBM), 5-100 m, riffles, 30 larvae, R.A. Englund & D.J. Preston, 4–7 Nov 2002 (BPBM). **MAUI:** West Wailua Iki Stream, 22 Jan 2003, 490 m, riffles, 20 larvae, many empty cases (BPBM, NMNH).

Oxyethira maya Denning

Oxyethira maya Denning, 1947:16. Zimmerman, 1943: 350; 1957: 173. Ross, 1948:257. Kelley & Morse, 1982: 262.

This was the first caddisfly reported from the islands and is now quite widespread throughout Hawai‘i. Because of its small size *Oxyethira maya* is frequently overlooked in Hawaiian streams, and is more often collected light trapping around streams at night than observed in the stream benthos. There seems to be no doubt as to the identity of this species. It has not

been encountered frequently on the continent, being known from the southeastern states as far west as Texas. The senior author has also seen it in abundance from Barro Colorado Island, Panama (unpubl. observ.).

There are good published figures of the male genitalia of this species in Zimmerman (1957), and of the female genitalia in Kelley & Morse (1982). Larvae are found in transparent whitish cases about 3 mm long that are made of extremely fine silk, with no rocks attached; these cases are elongate, flattened, and narrowed at the posterior end (Beardsley, 1971).

The species was first reported from O‘ahu (BPBM), and is also known from Kaua‘i (NMNH, BPBM), Maui (BPBM), and Hawai‘i (BPBM).

Material examined. **KAUA‘I**: Keālia Str., 15 Mar 1979, J. Maciolek, 1 male, 3 females (NMNH). **HAWAI‘I**: Waipi‘o Valley, BPBM Survey Site #4a/5 (4 m), 14 Mar 2001, N. Evenhuis, R.A. Englund & D.J. Preston, MV bulb, 1 female (BPBM). **MAUI:** Hanawī Stream, Malaise trap, 915 m, 12 Nov 1992, D.A. Polhemus & R.A. Englund, 1 male, 1 female (BPBM).

Family Hydropsychidae

Cheumatopsyche analis (Banks) **Name change**

Hydropsyche analis Banks, 1903: 243.
Hydropsyche pettiti Banks, 1908: 265.
Cheumatopsyche analis (Banks). Ross, 1944: 112 [*pettiti* as junior synonym]. Beardsley, 1966: 145.- Denning & Beardsley, 1967: 56

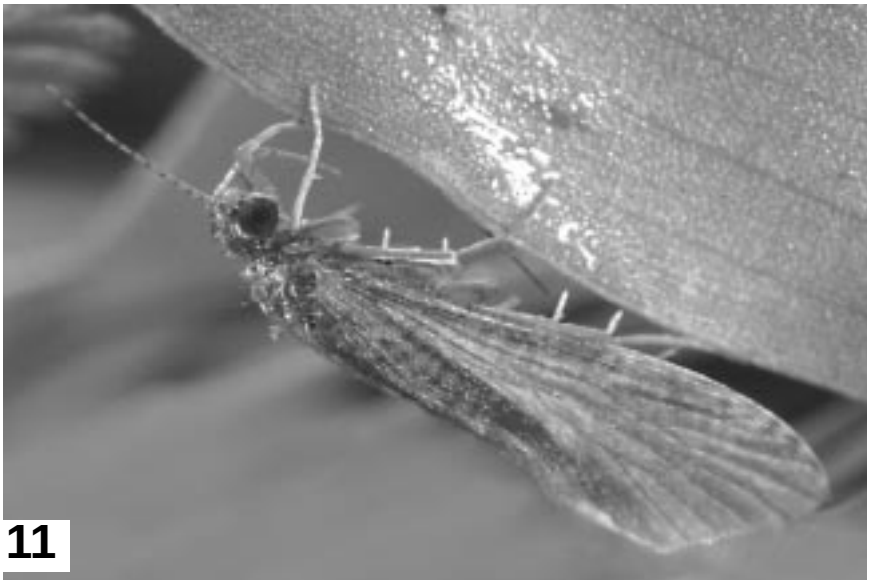
The name *analis* has had a controversial history in the last decades. Ross (1944), although stating that the type was damaged, felt sure that he was able to recognize the species on the remaining characteristics of the male genitalia. However, Gordon (1974), because the genitalia was incomplete, relegated *analis* to a *nomina dubia* status and resurrected *pettiti* for the same taxon. We consider Ross (1944) in his treatment of the group, which was the first large revision of the North American species in the genus, established the identity of *analis* on the basis of First Revisor, and will continue to use the name with *pettiti* placed as a junior synonym.

Although several species closely related to *analis* have been described (i.e., *smithi* Gordon, *rossi* Gordon), the examples from Hawaii do not seem to be either of these forms. It is rather doubtful, in fact, if either of these falls outside the normal level of variation found in *analis*. This is, in North America, a confusing genus of many very similar species whose validity will need some type of molecular testing to substantiate.

The larval case of *C. analis* is a loosely woven aggregation of relatively large pebbles, with the cases sometimes forming silken tunnel retreats for the larvae. When compared to the other Hawaiian caddisfly species the larvae are much larger (15–18 mm) and more common, forming the predominant aquatic insect biomass within the substrate of Hawaiian streams, while the hydroptilid species are generally less important because of their much smaller size.

This is one of the most widespread and ubiquitous caddisflies in North America, and the most widely distributed species in the Hawaiian Islands. It is found from the Atlantic to the Pacific in both the United States and Canada. The species has also become widespread across the islands, with records from Kaua‘i (BPBM), O‘ahu (NMNH, BPBM), Moloka‘i (BPBM), Maui (NMNH), Hawai‘i (NMNH, BPBM).

Material examined. **O‘AHU**: U[niversity] H[awaii] Campus, Hon[olulu], Aug 1966, J.W. Beardsley, 2 female (NMNH). Public Health Dep. light trap, Jun 1966, J.W. Beardsley, 2 male (NMNH). **MAUI:** ‘Īao Valley St. Pk., 160 m, 6 Dec 1976, D. & M. Davis, 1 male (NMNH). **HAWAI‘I:**



Figs. 11–12. *Cheumatopsyche analis* Banks **11**, Adult *Cheumatopsyche analis*, Wailoa River, Waipiʻo Valley, Hawaiʻi Island, 4 m; **12**, Larval *Cheumatopsyche analis*, Waiāhole Stream, Oʻahu Island, near sea level. Photos: R.A. Englund & D.J. Preston.

14 mi. W. Hilo, Stainback Hwy, 400 m, 10 Dec 1976, D. & M. Davis, 1 female (NMNH). 10.4 mi. NW. Hilo, 19 Sep 1972, O.S. & C.M. Flint, 8 male, 2 female (NMNH). Waipiʻo Valley, BPBM Survey Site #5 (4 m elev), 14 Mar 2001, N. Evenhuis, R.A. Englund & D.J. Preston, MV light trap, 3 male, 5 female (BPBM); same but Site #6, 40 m, brushed off boulders, 3 larvae (BPBM). Honoliʻi Stream, 8 Feb 2002, R.A. Englund, D.J. Preston, G.A. Samuelson, 975 m, 1 adult male. **MOLOKAʻI:** Pelekunu Stream, 23 May 2001, R.A. Englund, sea level, fast riffle, 1 larva (BPBM). **KAUAʻI**: Koaiʻe Stream, 8 Jan 1999, R.A. Englund & D.J. Preston, 1160 m, Surber sample #3 by USGS stream gage, 6 larvae (BPBM).

Discussion

With the discovery of a fourth species of caddisfly on the Hawaiian Islands, which originally harbored no species of this order, it becomes possible to speculate on the source of these immigrants. *Hydroptila potosina* is the species with the most limited native home range and is presently known only from the northeastern states of Mexico and Texas. *Hydroptila icona* and *Oxyethira maya* both occur in this same area with *H. icona* extending a bit further into the USA and throughout Central America, while *O. maya* extends along the Gulf Coast of the USA and south to Panama. *Cheumatopsyche analis* is found throughout the U.S. and Canada and does enter Texas but not Mexico. Assuming that all four species have a similar origin, a site in Texas seems to be a probable source location. Even if these four caddisfly species had different origins, sites along the western Gulf coast in the U.S. or Mexico would still be likely source areas.

How the caddisflies might have been transported to Hawaiʻi is less certain than determining possible origins. The caddisfly *Cheumatopsyche analis* was first collected at light traps in 1965 in various locations throughout Oʻahu (Denning & Beardsley, 1967). Species in this genus are found in lotic habitats or fast-flowing areas of streams (Merritt & Cummins, 1996). Although it seems possible that this species could have inadvertently been introduced into Hawaiʻi during unsuccessful attempts in the early 1960s to establish several species of mayfly [Ephemeroptera] to serve as forage for sport fish in Kauaʻi streams (see Usinger, 1972), this appears unlikely. Several lines of evidence appear to corroborate *C. analis* coming in with aquarium plants, mainly because adult caddisflies are short-lived and would likely not survive transport as would the eggs or perhaps larvae. Also, the first record of *C. analis* was from light-traps on Oʻahu; J.W. Beardsley had been regularly checking light traps from all the Hawaiian Islands since the late 1950s (J.W. Beardsley, pers. comm.), and believed it was much more likely that *C. analis* eggs or larvae were transported into Hawaiʻi with aquatic vegetation or some other aquatic substrate. The first record of *C. analis* from Kauaʻi, the island with the attempted mayfly introductions in 1961, was 1971 (Kawamura ,1974).

Prior to 1985, most aquatic plant shipments originated from the mainland U.S., with California, Texas, and Florida having the greatest shipments to Hawaiʻi (Domingo Cravalho, Hawaii State Department of Agriculture, pers. comm.). Since that time, most aquatic plants entering Hawaiʻi originate from Singapore, with the state a major trans-shipment point for plants destined for the mainland U.S.; however, some aquatic plants such as *Elodea* spp. and *Cabomba* spp. still enter Hawaiʻi from California, with lesser amounts from Texas and Florida (Domingo Cravalho, Hawaii State Department of Agriculture, pers. comm.).

The pattern of caddisfly introductions into the Hawaiian Islands is exemplified by *C. analis*, which after its initial Oʻahu introduction in 1965 spread rapidly to the other islands, and was found on all the major islands by 1971 (Table 1). It is likely that the small *Hydroptila potosina* was present earlier on Kauaʻi, Maui, and Hawaiʻi islands but was overlooked and not reported to occur on these islands until the 1990s.

Table 1. First collection record by Hawaiian island of four currently known introduced caddisfly species.

Caddisfly Species	Island	First Collected	First Reference
Cheumatopsyche analis	O‘ahu	1965	Denning and Beardsley (1967)
	Moloka‘i	1969	Joyce (1970)
	Kaua‘i	1971	Kawamura (1974)
	Hawai‘i	1971	Shiroma (1972)
	Maui	1971	Denning and Blickle (1971)
Oxyethira maya	O‘ahu	1940	Zimmerman (1957)
	Hawai‘i	1957	Adachi (1958)
	Kaua‘i	1959	Beardsley (1960)
	Maui	1970	Beardsley (1971)
Hydroptila potosina	O‘ahu	1968	Joyce (1969)
	Kaua‘i	1979	J. Maciolek specimen (NMNH)
	Hawai‘i	1990	Polhemus (1995)
	Maui	1994	Polhemus (1995)
Hydroptila icona	Moloka‘i	2001	This study
	O‘ahu	2002	This study
	Maui	2003	This study

Because most native Hawaiian aquatic insects have evolved from marine shoreline areas and dwell in highly turbulent riffle, cascade, and waterfall areas (Howarth and Polhemus 1991), the establishment of caddisflies in Hawaiian streams may also have in some cases either led to the successful establishment of several species of non-indigenous fish, or at the very least provided a more favorable food base for introduced fish species than was previously available in Hawaiian streams. For example, Englund & Polhemus (2001) found that *C. analis* comprised nearly 20% of the diet for naturally reproducing introduced rainbow trout (*Onchorhynchus mykiss*) in Kaua‘i streams. Similarly high percentages in the diet of the highly predatory introduced smallmouth bass (*Micropterus dolomieui*) on Kaua‘i have also been found for *C. analis* (R.A. Englund & D.J. Preston, unpubl. data).

Although cause and effect data are difficult to obtain, *C. analis* (and other introduced caddisflies) has likely adversely influenced native aquatic invertebrate populations, perhaps through competition for space and resources, or simply because of its large size and great abundance in Hawaiian streams. By their sheer numbers introduced caddisflies are likely having some impacts on the native aquatic insect fauna, for example, in upper elevation Kaua‘i streams *C. analis* accounted for 57% (by number) of the stream benthos during Surber sampling (Englund *et al*., 2000). Although no hard evidence is currently available, the late J.W. Beardsley (pers. comm.) speculated that the decline of the giant endemic freshwater chironomids in the genus *Telmatogeton* spp. appeared to be correlated with the introduction of caddisflies in the late 1960s. Of the 57 perennial streams on O‘ahu, only four streams (Englund & Polhemus, unpubl.) are currently known to have populations of the formerly common *Telmatogeton* while caddisflies now inhabit every O‘ahu stream.

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