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Aquatic Insect Taxa as Indicators of Aquatic Species Richness, Habitat Disturbance, and Invasive Species Impacts in Hawaiian Streams[1]

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Abstract

In this study we provide a synthesis of numerous stream assessments in the Hawaiian Islands that began in the early 1990s and have continued to the present. Data from numerous sites within the five major high Hawaiian Islands with flowing streams (excluding Lāna'i, which lacks flowing waters) were used to assess native and introduced aquatic insect communities, the impacts of various invasive freshwater species and the threats from habitat disturbance. The primary objective of this study was to provide the first comprehensive analysis of aquatic insect populations in various urbanized and virtually pristine stream reaches on the five major Hawaiian Islands, and to assess if various suites of introduced aquatic species may be impacting aquatic insect populations.

We were also interested in assessing the suitability of native aquatic insects as key indicator, flagship, or umbrella species regarding the overall health of Hawaiian aquatic ecosystems. If key indicator species can be found, then aquatic habitats with high native biodiversity can be identified and management efforts can be made to ensure this high level of biodiversity persists. These indicator species could also be used for monitoring future rehabilitation programs on disturbed streams.

Introduction

Detailed distribution and abundance data for invertebrates such as aquatic insects are lacking for most tropical regions, and this lack of basic knowledge hinders the development of conservation planning efforts. The Hawaiian Islands are an exception to this rule because of a long history of entomological collections starting in the 1800s, and the infrastructure of a major museum and large university in close proximity to a wide range of aquatic habitats. Because of its extreme isolation, Hawai'i has the greatest percentage of unique fauna in the world with an estimated 98% endemicity rate for the 5,368 described insect species (Eldredge & Evenhuis, 2003). Most research efforts in the Hawaiian Islands have been focused on the amazing adaptive radiations and ecological adaptations found within the terrestrial insect fauna, with far fewer resources devoted to studying insects found within freshwater habitats. In aquatic systems, the insect group historically receiving the greatest attention has been the Odonata (damselflies and dragonflies), with other taxa such as aquatic flies (Diptera) or true bugs (Heteroptera) being assessed at various levels of intensity. While most

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of the early research involved taxonomic descriptions of new species, some early pioneers such as F.X. Williams conducted life history and basic ecological studies on the Hawaiian aquatic insect fauna (Williams, 1936).

Although life history and limited ecological studies have been conducted on a small number of Hawaiian aquatic insect species, this study is the first to examine broad scale patterns of entire communities found within individual watersheds, islands, or different islands. While various authors have demonstrated the impacts of specific introduced aquatic species on native Hawaiian freshwater species (Englund & Polhemus, 2001; Englund, 1999; Font, 1998; Font & Tate, 1994), a quantitative examination of the potential suitability of different aquatic insect taxa as indicator species representing the ecological health of a particular Hawaiian aquatic ecosystem has not previously been attempted. For the purposes of this study we define ecological health as an intact Hawaiian watershed containing greater numbers of native species than an urbanized and highly disturbed watershed.

In this study we provide a synthesis of numerous stream assessments in the Hawaiian Islands that started in the early 1990s and continue to the present. Data from numerous sites within 5 of the major high Hawaiian Islands with flowing streams (excluding Lāna‘i) were used to assess native and introduced aquatic insect communities, the impacts of various invasive freshwater species and the threats from habitat disturbance (see Figs. 1–5 for site maps).

The primary objective of this study was to provide the first comprehensive analysis of aquatic insect populations in various urbanized and virtually pristine stream reaches on the five major Hawaiian Islands, and to assess how various suites of introduced aquatic species may be impacting these aquatic insect populations. Additionally, given that one of the major goals for conservation biologists is maintaining biodiversity in highly endemic areas such as in Hawaii, we were also interested in assessing the suitability of native aquatic insects as key indicator, flagship, or umbrella species regarding the overall health of Hawaiian aquatic ecosystems. If key indicator species can be found, then aquatic habitats with high native biodiversity can be more readily identified and management efforts can be undertaken to ensure this high level of biodiversity persists. These indicator species can also be used for monitoring future rehabilitation programs on disturbed streams.

Many species of native Hawaiian aquatic insects are now threatened with extinction because of reduced ranges resulting from habitat loss and invasive species (Liebherr & Polhemus, 1997; Englund, 1999, 2001, 2002). Preserves for threatened and endangered species are often designed to protect habitats that permit the maximum number of species to be conserved, often by using surrogate species that are believed to represent the needs of other threatened species using the same habitat (Simberloff, 1998; Andelman & Fagan, 2000; Rubinoff, 2001). Three classes of surrogate species have been identified and include: (1) flagship species, or charismatic species attracting public support, (2) umbrella species, or species requiring large areas of habitat needing protection thereby also providing protection for other species, and (3) biodiversity indicators, or species whose presence indicates areas with high species richness (Andelman & Fagan, 2000).

In the present study we make the first attempt to assess the sensitivity of both native fish and aquatic insect species to introduced species and to other major watershed perturbations such as diversions or concrete channelization. This was done by collecting from a wide variety of aquatic insect habitats ranging from heavily urbanized and channelized streams, to pristine sections of watersheds accessible only by helicopter. A holistic evaluation of Hawaiian streams requires not only the assessment of the five native species of freshwater fish and several large species of easily observed invertebrates (i.e., crustaceans), but also the 300–400 estimated species of native Hawaiian aquatic insects. Unlike aquatic vertebrates, many aquatic insects have narrow habitat tolerances meaning they can only live in certain flowing water microhabitats, for example seeps or cascade splash-zones. These narrow habitat preferences also increase the vulnerability of aquatic insects to stream disturbances such as stream channelization, dewatering, sedimentation, and alien species introductions. Because native Hawaiian aquatic insects are much less flexible in their habitat requirements than aquatic vertebrates, it then follows that insects may provide a better monitoring and stream assessment tool than vertebrates. Stream macrofauna such as the native fish, crustaceans, and neritid snails are migratory and are not necessarily co-evolved to a specific stream system, unlike many Hawaiian aquatic insects. This study therefore makes a first attempt at integrating the various factors that appear to be presently limiting the distributions of native aquatic insects in Hawaii, or factors that make habitats suitable for the survival of endemic species.

Materials and Methods

Streams on Kauai, O‘ahu, Moloka‘i, Maui, and Hawai‘i islands (Table 1, Figs. 1–5) were surveyed for both native and introduced species in a wide range of aquatic habitats, ranging from coastal lowlands at sea level to high elevation reaches only accessible by helicopter, thus covering the entire gradient of habitats available in the islands. The highest elevation sampled in a particular stream reach was recorded and determined with a combination of USGS topographic maps and handheld altimeters. Efforts were made to standardize insect collections at each sample site as similar habitats and collecting techniques were used at each station.

Aquatic Insects

Collections of both immature and adult specimens were made with yellow pan traps, aerial sweep nets, aquatic dip nets, kick-netting, and Surber (benthic) samplers around all aquatic habitats at each study site. Visual observations of aquatic insects were also conducted above and around the stream. Sampling of damselflies and dragonflies (Odonata) was also emphasized, because six Hawaiian species are currently considered Candidate Species by the U.S. Fish & Wildlife Service.

Benthic sampling centered on kick-netting and involved vigorously disturbing the substrate upstream of a fine meshed aquatic net to displace any aquatic invertebrates inhabiting the stream substrate. The use of frequent kick-netting allowed for a greater sample size and resulted in increased effort for invertebrate collections. Benthic sampling also included collecting individual variously sized rocks and then using a toothbrush or forceps to remove immature insects. Above and below water visual observations for aquatic insects were also conducted as we hiked between sampling stations. Sampling effort was focused on all suitable aquatic habitats such as splash zones around riffles and cascades, wet rock faces associated with springs and seeps, waterfalls, nearby wetland areas associated with the streams, and variously-sized stream substrates. All aquatic habitats were sampled. All insect specimens were stored in 95% ethanol for curation and identification and voucher specimens are currently housed in the Bishop Museum and Smithsonian Institution collections.

Freshwater Fish, Introduced Crustaceans, and Amphibians

One of the primary objectives of this study was to assess where specific suites of aquatic organisms have been introduced into a particular Hawaiian watershed. Thus, observations and limited collections of freshwater fish, crustaceans, and amphibians were undertaken to verify species identities. Fish and introduced crustaceans and amphibians were either collected with nets and hand seines, or identified underwater while snorkeling. Many of these aquatic insect surveys were jointly conducted with biologists from the Hawaii Division of Aquatic Resources (HDAR) assessing native and introduced fish populations, thus we have integrated the results of their findings with our aquatic insect findings. HDAR fish collection data was accessed from their stream survey website at: [http://www.hawaii.gov/dlnr/dar/streams/stream_data.htm].

Statistical Analysis

Multiple-species data are notoriously difficult to analyze in a clear and meaningful manner. Multivariate statistical analysis of community data offer a means of detecting patterns in similarity of species composition of sample sites, and a means of identifying species associated with specific environmental conditions. Canonical correspondence analysis is an analytical method that can be used to unravel patterns in complex ecological data sets (Leps & Smilauer, 2003).

Presence/absence data for the insect species was subjected to canonical correspondence analysis (CCA), a direct gradient analysis method, which summarizes relationships between response variables (in this case, insect species assemblages in 39 study sites) and environmental variables

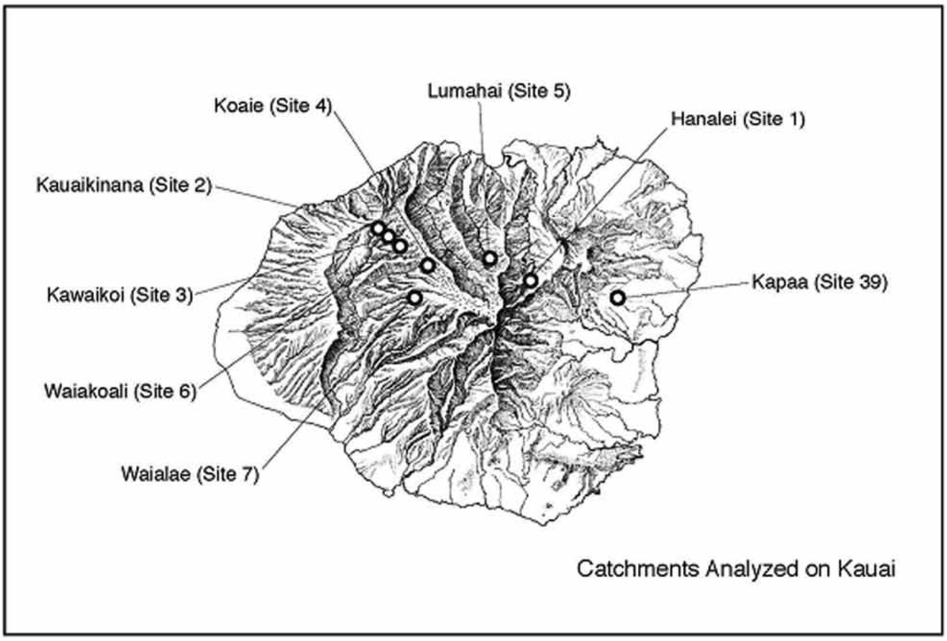

Figure 1. Streams sampled for aquatic biota during this study on the island of Kaua‘i.

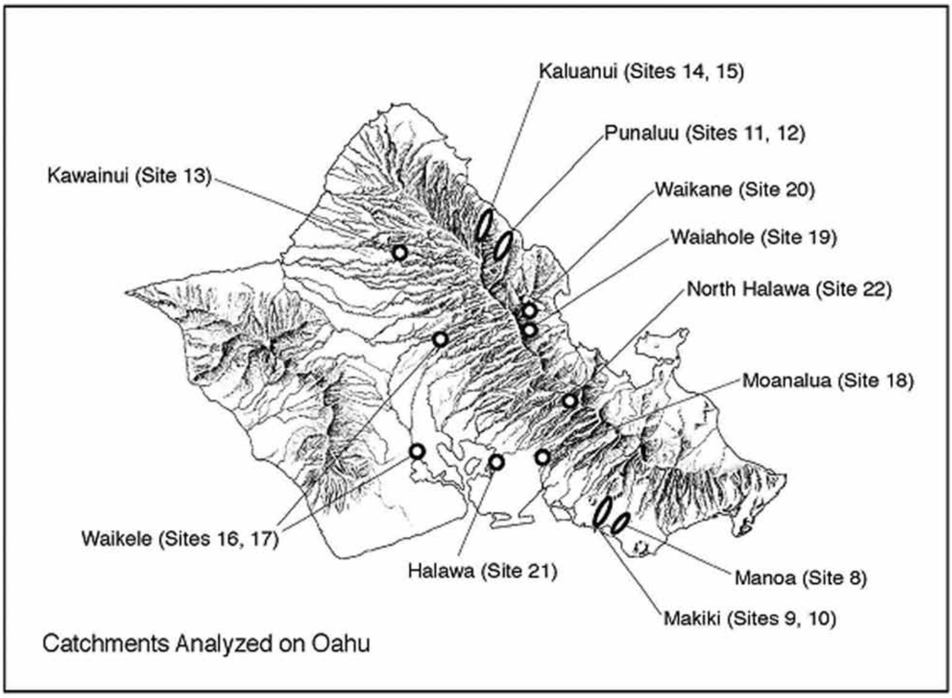

Figure 2. Streams sampled for aquatic biota during this study on the island of O‘ahu.

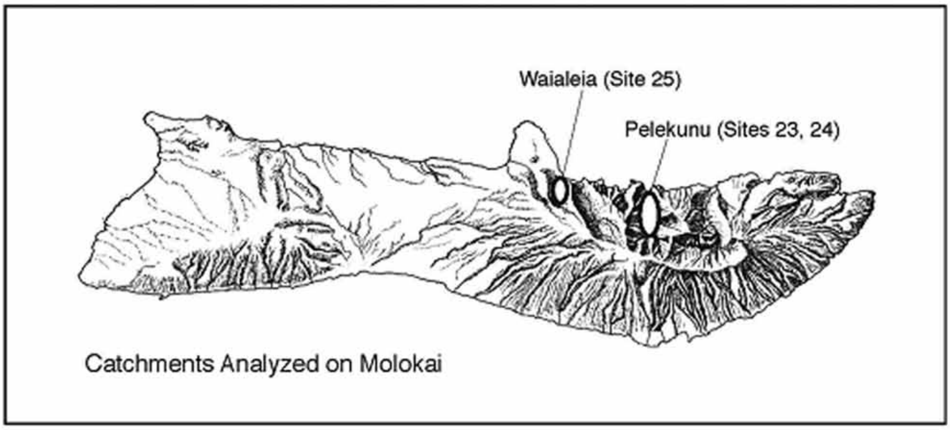

Figure 3. Streams sampled for aquatic biota during this study on the island of Moloka‘i.

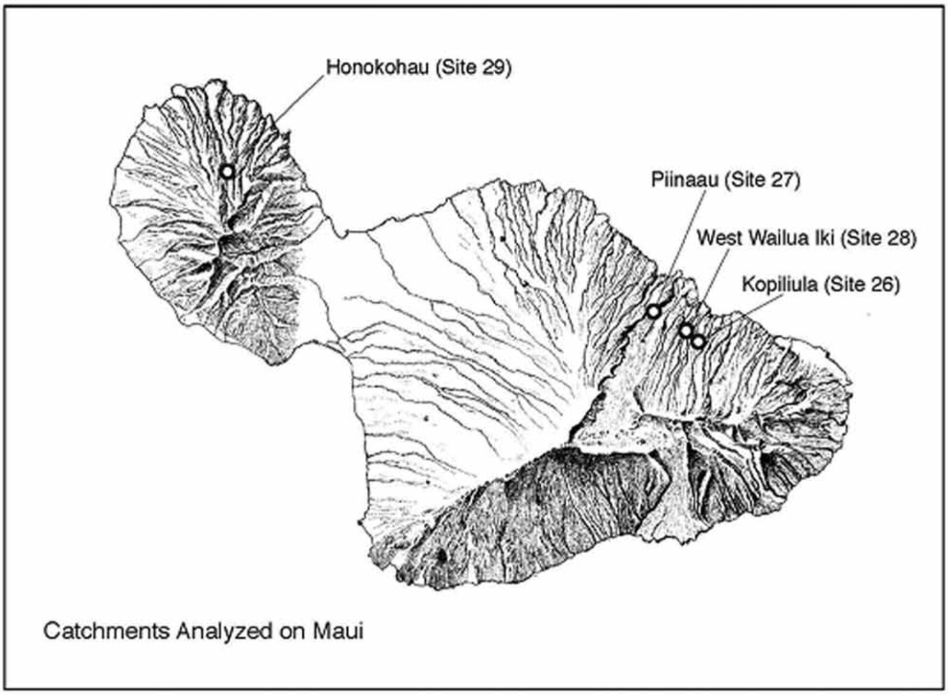

Figure 4. Streams sampled for aquatic biota during this study on the island of Maui.

(Leps & Smilauer, 2003). The analyses were conducted using CANOCO 4.5 and CanoDraw software (Ter Braak & Smilauer, 2002). CANOCO performs multivariate ordination on species data, calculating chi-square distance between samples, and plotting sample and species scores these on canonical (constrained) axes, determined by correlations between specified environmental variables and species scores. Plots of ordinations are generated by CanoDraw (Ter Braak & Smilauer, 2002).

The ordinations were initially done for all species, and then broken down by insect family. Families were analyzed separately as each has different ecological characteristics, and meaningful

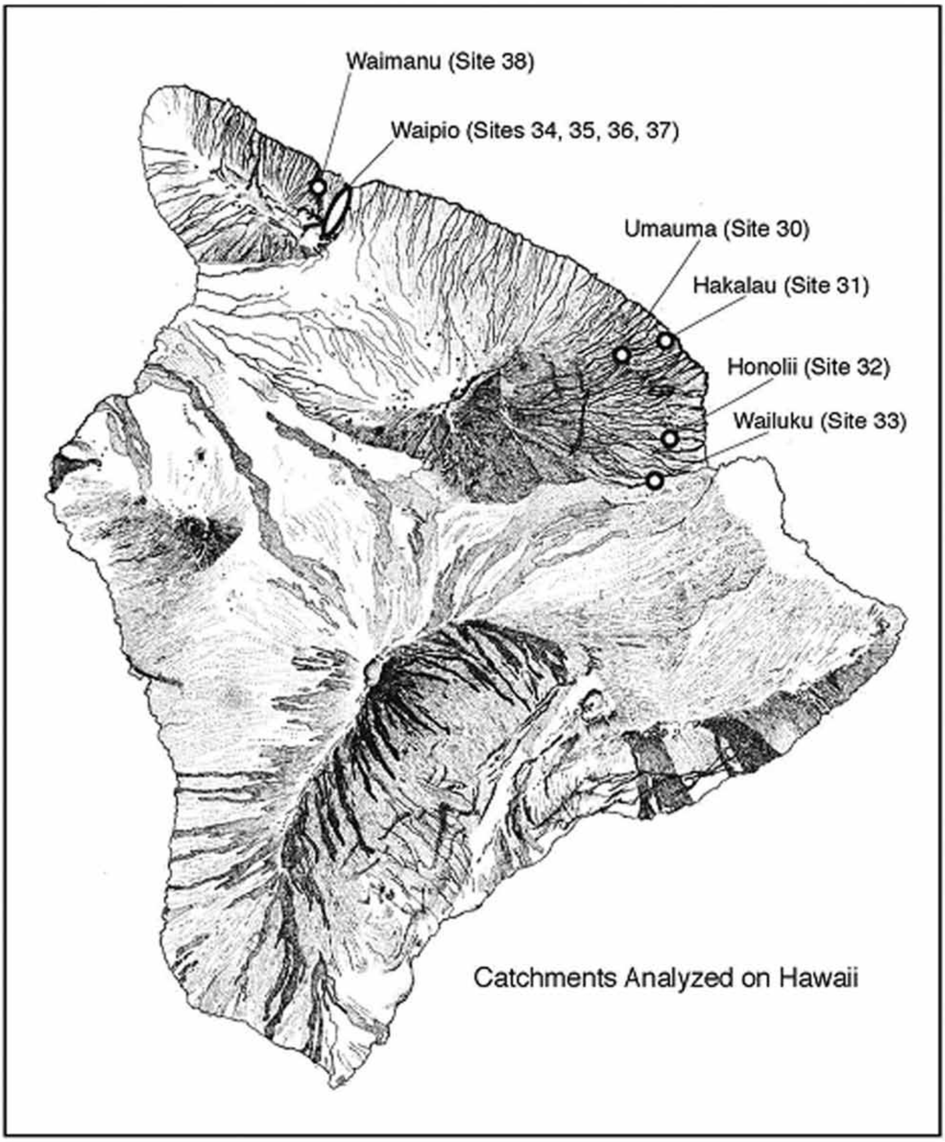

Figure 5. Streams sampled for aquatic biota during this study on the island of Hawai‘i.

graphical analyses could be presented with the reduced data sets. Environmental variables that were selected were: island (coded as 1–5, Kaua‘i =1; Hawai‘i = 5); elevation (m.a.s.l.); type of stream (coded as 1 = undiverted, not channelized; 2 = concrete channel; 3 = channelized no concrete; 4 = diverted, below diversion but not channelized); presence or absence of indigenous and exotic fish species; and presence or absence of exotic frogs. Exotic fish species and frogs were included as environmental variables because they may impact indigenous insects negatively, or in some cases, they may be associated with either positive or negative environmental conditions that are suitable for certain communities of aquatic insects. The former situation is the case for poeciliid fish that are often the only fish species found in concrete channelized Hawaiian streams, while the latter situation is

Table 1. **Island, stream sampling sites, sampling date, and stream type assessed for native and introduced aquatic insects, fishes, crustaceans, and amphibians in the Hawaiian Islands**. The Hawaii Division of Aquatic Resources stream database was also consulted for fish species composition. Stream type at sample reach: 1 = undiverted, not channelized, 2 = concrete channel, 3 = channelized no concrete, 4 = diverted, below diversion.

Site No.	Stream (elevation surveyed- m)	Stream Type	Date(s) Sampled	Reference
Kaua‘i				
1	Hanalei (380 m)	1 (Undiverted)	Nov 1994	Polhemus (1995)
2	Kauaikinana (1035 m)	1 (Undiverted)	Aug 1997, Aug 1998, Jan 1999	Englund and Polhemus (2001)
3	Kawaikoi (1035 m)	1 (Undiverted)	Aug 1997, Aug 1998, Jan 1999	Englund and Polhemus (2001)
4	Koaie (1175 m)	1 (Undiverted)	Aug 1997, Jan 1999, July 2000	Englund and Polhemus (2001)
5	Lumahai (430 m)	1 (Undiverted)	Nov 1994	Polhemus (1995)
6	Waiakoali (1035 m)	1 (Undiverted)	Aug 1997, Aug 1998, Jan 1999	Englund and Polhemus (2001)
7	Waialae (1095 m)	1 (Undiverted)	Jan 1999	Englund and Polhemus (2001)
O‘ahu				
8	Manoa (5-75 m)	2 (Concrete Channel)	April 2004	Englund and Arakaki (2004)
9	Makiki (2 m)	2 (Concrete Channel)	April 2004	Englund and Arakaki (2004)
10	Makiki (45 m)	2 (Concrete Channel)	April 2004	Englund and Arakaki (2004)
11	Punaluu (31 m)	1 (Undiverted)	Nov 2002	Englund *et al.* (2003a)
12	Punaluu (275 m)	1 (Undiverted)	Nov 2002	Englund *et al.* (2003a)
13	Kawainui (Anahulu trib) (305 m)	1 (Undiverted)	Apr 2003	Englund *et al.* (2003a)
14	Kaluanui (100 m)	1 (Undiverted)	Nov 2002	Englund *et al.* (2003a)
15	Kaluanui (762 m)	1 (Undiverted)	Jan 1994	Englund *et al.* (2003a)
16	Waikele (0-1 m)	3 (Channelized, no concrete)	Mar 1993, Dec 1997, Aug 1998	Englund and Filbert (1999), Englund *et al.* (2000)
17	Waikele (381 m)	1 (Undiverted)	Mar 1993	Englund (1993)
18	Tripler Stream (79 m)	1 (Undiverted)	Mar 1995-Jan 2005	Evenhuis *et al.* (1995), Englund 2001
19	Waiahole (Waianu trib) (60 m)	1 (Undiverted)	Feb-Aug 1995, Feb, May, Nov 2002, Apr 2003	Filbert and Englund (1995), Englund *et al.* (2003b)
20	Waikane (210 m)	1 (Undiverted)	Feb-Aug 1995, Feb, Nov 2002, Mar 2003	Filbert and Englund (1995), Englund *et al.* (2003b)
21	Halawa (0-1 m)	2 (Concrete Channel)	Nov, Dec 1997, Mar-Aug 1998	Englund *et al.* (2000)
22	N. Halawa (300 m)	1 (Undiverted)	Jan 1991-Feb 1994	Polhemus (1994)

Table 1. (continued)

Site No.	Stream (elevation surveyed- m)	Stream Type	Date(s) Sampled	Reference
Moloka'i				
23	Pelekunu (0-1 m)	1 (Undiverted)	Jan 1991, Apr 2000, May 2001, May 2002	Englund & Arakakii (2003)
24	Pelekunu (182-237 m)	1 (Undiverted)	Apr 2000, May 2001, May 2002	Englund & Arakaki (2003)
25	Waialeia (0-60 m)	1 (Undiverted)	Nov 1998	Englund, unpublished data
Maui				
26	Kopiliula (610 m)	1 (Undiverted)	Jan 2003	Englund *et al.* (2003a)
27	Piinaau (731 m)	1 (Undiverted)	Jan 2003	Englund *et al.* (2003a)
28	W. Wailua Iki (493)	1 (Undiverted)	Jan 2003	Englund *et al.* (2003a)
29	Honokohau (450 m)	1 (Undiverted)	Jan 2003	Englund *et al.* (2003a)
Hawai'i				
30	Umauma (713 m)	1 (Undiverted)	Mar 2003	Englund *et al.* (2003a)
31	Hakalau (0-10 m)	1 (Undiverted)	Dec 1993	Polhemus (1995)
32	Honolii (536-640 m)	1 (Undiverted)	Feb 2002, Mar 2003	Englund *et al*. (2002), Englund *et al.* (2003a)
33	Wailuku (670 m)	1 (Undiverted)	Mar 2003	Englund *et al.* (2003a)
34	Wailoa (Waipio) (0-1 m)	4 (Diverted)	Mar 2001, 2003-2005 (quarterly)	Englund *et al.* (2001)
35	Hiilawe (Waipio) (15 m)	1 (Undiverted)	Mar 2003-2005 (quarterly)	Englund *et al.* (2001)
36	Wailoa (Waipio) (190 m)	4 (Diverted)	Oct 1996, Nov 1998	Englund & Filbert (1997), Englund & Preston (1999)
37	Kawainui (Waipio) (425 m)	1 (Undiverted)	Oct 1996	Englund & Filbert (1997)
38	Waimanu (90 m)	1 (Undiverted)	Dec 1998	Englund & Preston (1999)
Kaua'i				
39	Kapa'a (80-120 m)	1 (Undiverted)	Nov 1994	Polhemus (1995)

also true for the indigenous fish species included. Their association with certain insect species, demonstrated by their correlation as “environmental variables” may serve as a surrogate for true environmental variables that were not directly measured. For each analysis, environmental variables that significantly affected variation in community structure were selected by Monte Carlo simulation (499 permutations), with the six best predictors selected automatically by CANOCO.

The results of these analyses provide extensive information about the communities analyzed (Leps & Smilauer, 2003). Sample sites are arranged in space (the ordination) based on similarity of insect communities; species are similarly arranged, and their proximity to sample sites and other species in the ordination are indicative of their association with sites, and other species. Environmental variables are plotted as vectors on the ordinations, each indicating the relative contribution it makes toward defining each axis plotted. The longer the vector, the greater the effect is has in explaining an environmental gradient; the smaller the angle between a vector and an axis, the more closely correlated that variable is with the gradient of points plotted. Finally, canonical correspondence axes (CCA) can be viewed as linear combinations of environmental variables along which insect community data are plotted according to similarity of species composition.

A primary objective of this study was to determine what insect species are typically associated with pristine or disturbed habitats. The availability of presence / absence data for fish and frogs in these habitats allowed us furthermore to assess the contribution that they might have on shaping insect communities, and also to determine whether any are specifically associated with pristine habitats.

Results

A list of species collected during this study can be found in the Appendix, along with a code number for each species as shown in Figs. 6–13. The ordination of all species in the data set, from all sites, showed that there were patterns along gradients, but these could not be clearly explained from the full data set (which produced a complex graph with many overlaid points, and no distinct patterns). To better understand the patterns within the data, each family of native insects was analyzed separately. The cumulative percentage of variation on species composition and species environment relationship for families and selected genera is shown in Table 2. Higher variance and species environment relationship accounted for with large, diverse taxonomic assemblages (e.g., Dolichopodidae) provide more robust and meaningful results when compared to smaller taxonomic assemblages such as Telmatogeton.

Coenagrionidae

Figure 6 shows the ordination for the native Coenagrionidae (*Megalagrion*) and the three introduced damselfly species (numbered 16, 17, and 18 on Fig. 6), where 84.5% of the species-environment relation was explained (Table 2) by the first three correspondence axes. This ordination clearly defines the sample sites along a gradient defined by “island” and “elevation”. Elevation was autocorrelated with stream type, and they are thus largely functionally equivalent in these analyses. The Kauai samples were grouped in a clearly defined cluster along CCA1, with the Hawai‘i samples at the other end of that spectrum, for a loosely defined cluster. O‘ahu, Moloka‘i and Maui are distributed along the gradient (Fig. 6). The second axis (CCA 2) was defined by introduced Mexican molly *Poecilia mexicana*, and the introduced bullfrog *Rana catesbeiana* and elevation. This may be interpreted as the Kauai sites being associated with highest elevation and absence of *P. mexicana* and *R. catesbeiana*; clearly there is a negative correlation of the presence of these two species and the absence of native *Megalagrion* damselflies. Of particular interest was the fact that the three introduced damselfly species *Ischnura posita*, *Ischnura ramburii*, and *Enallagma civile*, (numbers 16-18 on Fig. 6) were also closely clustered around axis of the introduced *P. mexicana* and the disturbed streams and sites associated with this fish species. These results were also encouraging as it indicates that our CCA results were sensitive at delineating communities of introduced taxa, even though all of these introduced damselflies are commonly caught with native *Megalagrion* damselflies.

It is interesting to note that O‘ahu streams at elevations lower than 200 m.a.s.l. were clustered

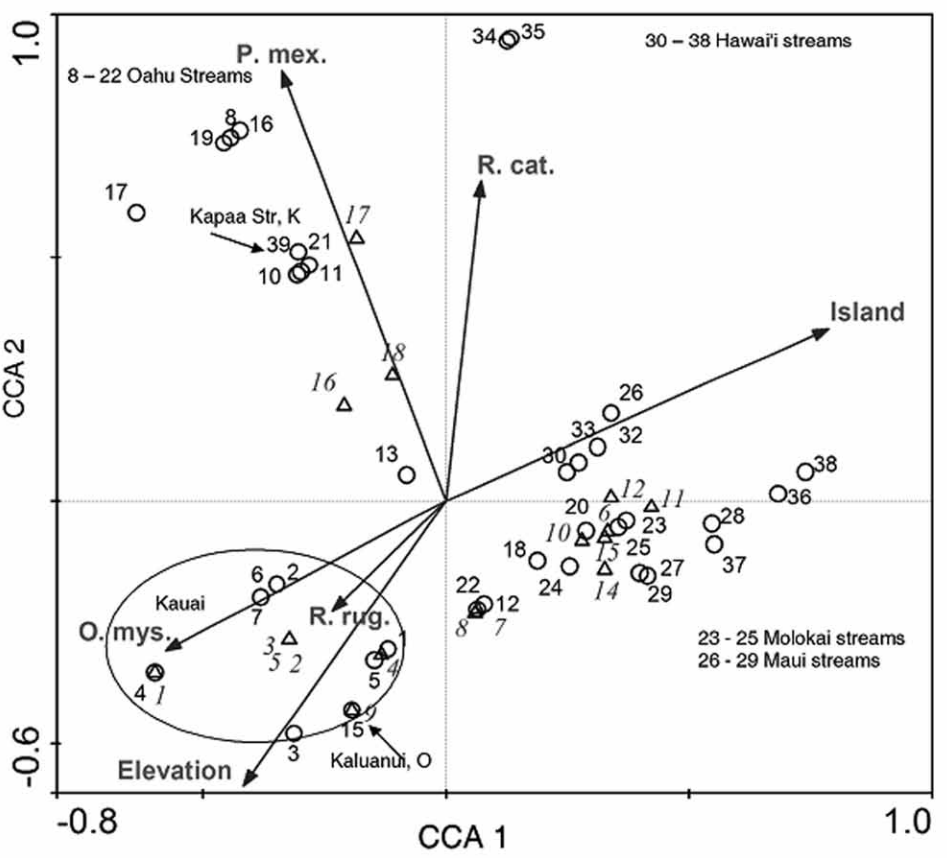

Figure 6. Canonical correspondence (CCA) ordination of sites and species-environment relationship for native Coenagrionidae (*Megalagrion*).

in a distinct group, and that Kapa‘a Stream, Kaua‘i (site 39) was grouped with them, rather than with the other Kaua‘i streams. In contrast, Kaluanui Stream (O‘ahu, 762 m.a.s.l.) was grouped with the Kaua‘i sample sites (Fig. 6). Indeed, most higher elevation sites from O‘ahu, such as Kawainui (upper Anahulu) (site 13), Waikane (site 20), and North Halawa (site 22), had greater similarity with less disturbed islands than low elevation sites on O‘ahu. A number of species such as *Megalagrion eudytum*, *M. heterogamias*, *M. oresitrophum*, *M. orobates*, and *M. vagabundum* (all Kauai endemics) were closely associated with the pristine sites on Kaua‘i.

Dolichopodidae

“Island” and elevation were the major determinates of CCA 1 for these aquatic flies (Fig. 7) with the high elevation Kaua‘i sites forming a distinct group, O‘ahu also distinct, and the other islands showing a spread along the axis. CCA 2 was largely a function of the presence of indigenous fish, depending on their presence or absence. While not as high damselflies, 65% of the cumulative variance in species composition (Table 2) was explained by the first three correspondence axes. This ordination clearly identifies Dolichopodidae as being effective indicators of stream quality, for example, there are certain species associated with the Kaua‘i sites that could perform such a function. What was especially striking, was the occurrence of indigenous fish species being correlated with certain Dolichopodidae species, particularly for the Moloka‘i, Maui, and Hawai‘i sample sites. Of great

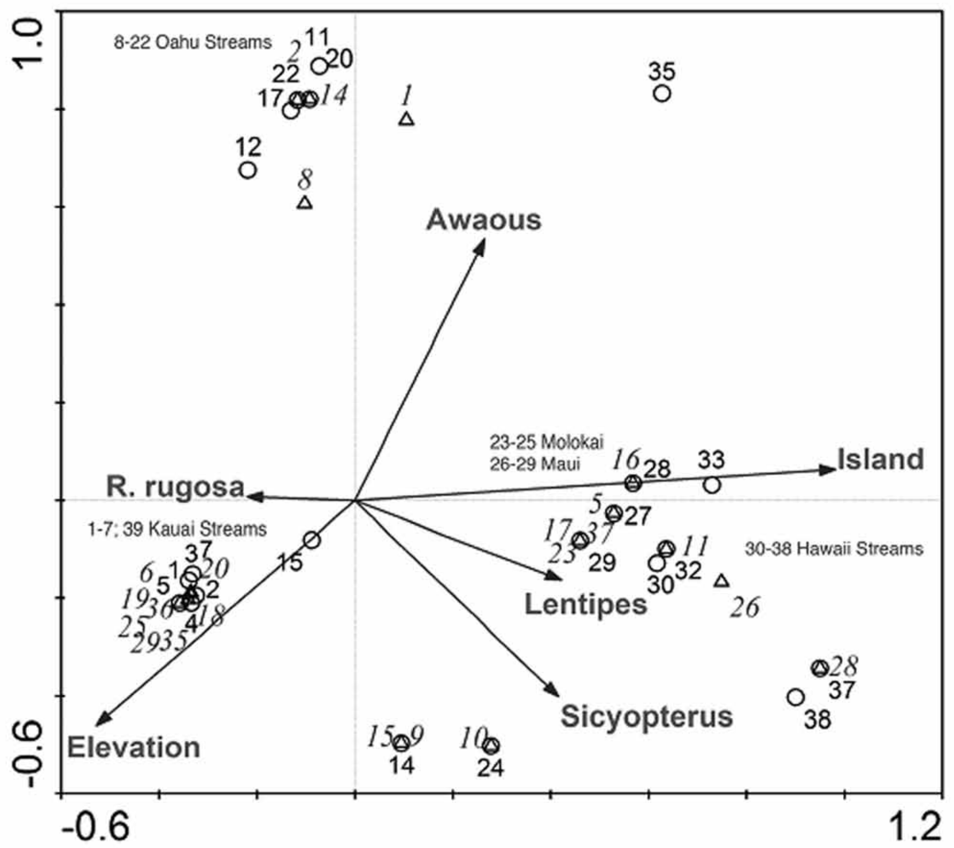

Figure 7. Native Dolichopodidae (all taxa) sites and species-environment relationship using CCA (CCA1 vs. CCA2).

interest was that the top three fish species associated with the Dolichopodidae were the 3 native stream species; *Lentipes concolor*, *Awaous guamensis*, and *Sicyopterus stimpsoni* (Figure 7).

Chironomidae

The ordination for this family of aquatic flies provided 70.4% explanation of variability by the first two axes, with all environmental variables retained (Fig. 8, Table 2). The resolution of this ordination is relatively high; however, it shows strong associations of these flies with alien taxa (Fig. 8). If the analysis was reduced to only the genus *Telmatogeton*, and excluding crustaceans as environmental variables, yet adding indigenous fish, the ordination (Fig. 9) shows clear separation of samples by "island", and strong associations of *Telmatogeton abnormis*, *T. fluviatilis*, *T. hirtus,* and *T. williamsi* with indigenous fish species (e.g. *Lentipes concolor*).

Ephydridae

The ordination (CCA1 vs. CCA2) (Fig. 10) was severely skewed by sample site 21 (Halawa Stream at Pearl Harbor) and the native *Atissa oahuensis* (species 99) (Fig. 11); CCA 2 and 3 accounted for 83.1% of the variation (Table 2), with the samples forming groups defined primarily by "island". However, it would appear that the Ephydridae may be less responsive to the environmental variables we examined. Site 39 (Kapa‘a Stream, an impacted, low elevation stream), for example, is included with other Kaua‘i sites, which from an overall indicator species perspective offers little in terms of

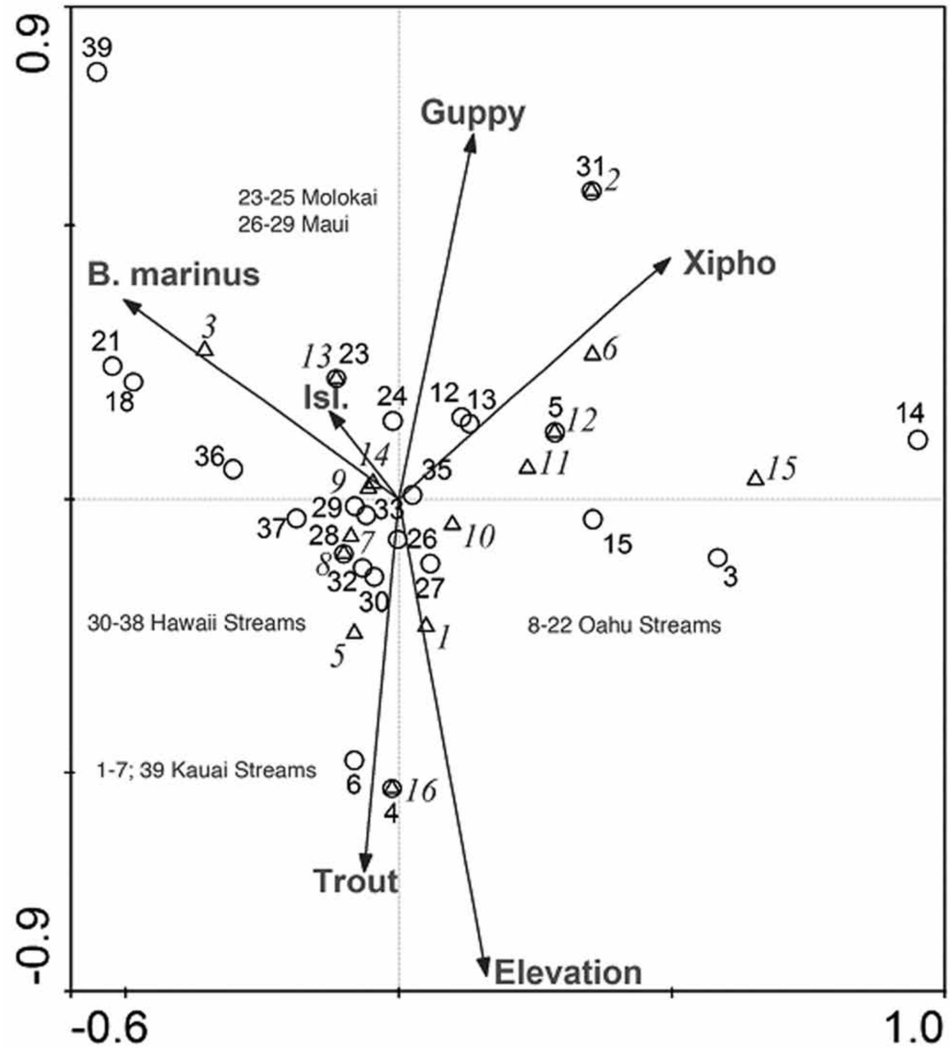

Figure 8. Native Chironomidae (all taxa) sites and species-environment relationship using CCA (CCA1 vs. CCA2).

identifying impacted habitats. It was also of interest to examine the genus *Scatella* because it is one of most dominant native aquatic insect groups in Hawaiian streams. CCA 2 and 3 accounted for 82.8% of the variation (Fig. 11, Table 2), thus *Scatella* by itself is responsive to environmental variables. They were, however, most strongly associated with alien fish and amphibian species, and low elevation native fish species. In contrast to the native species where environmental associations were not always clear, certain introduced ephydrids were clearly associated with disturbed environments, such as *Placopsidella marquesana*, *Scatella stagnalis*, and *Donaceus nigronotatus*.

Canacidae

Because of their association with torrenticolous habitats it was hypothesized that the endemic genus *Procanace* would be sensitive to disturbed habitats or introduced aquatic taxa. The ordination for this family provided 86.5% explanation (Table 2) of variability by the first two axes, with all environ-

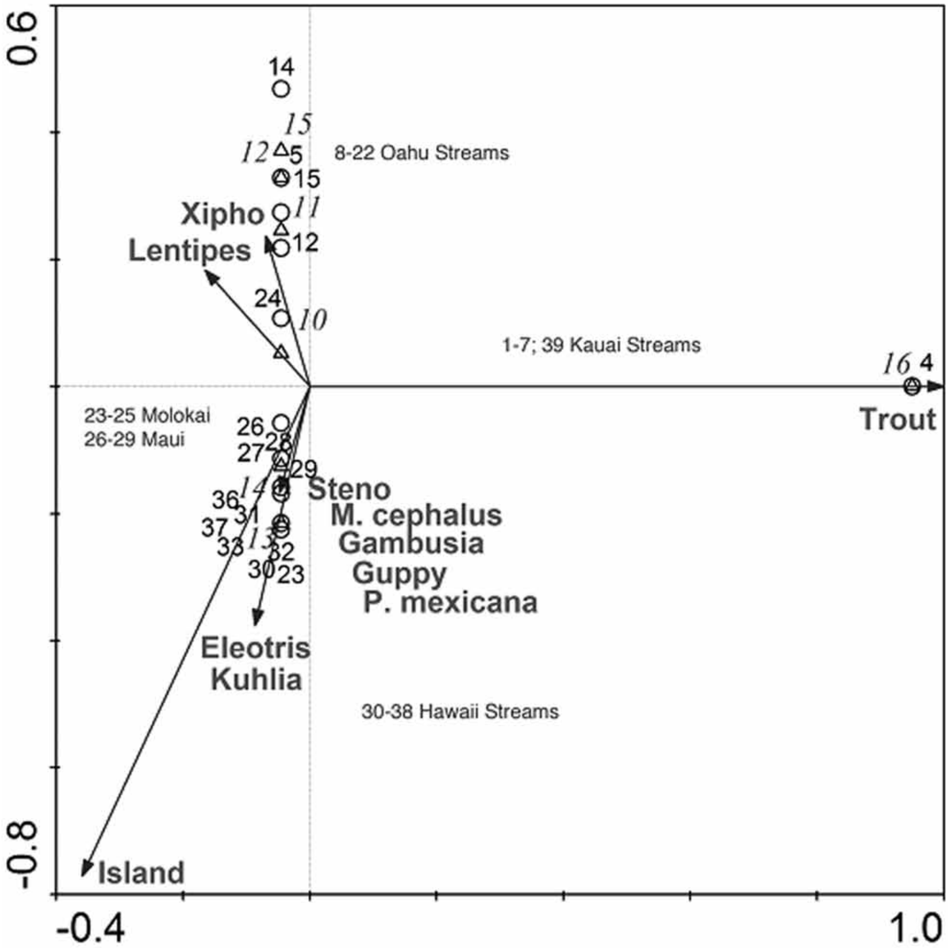

Figure 9. Native Chironomidae (*Telmatogeton* spp. only) sites and species-environment relationship using CCA (CCA1 vs. CCA2).

mental variables retained (Fig. 12). Running CCA for only the genus *Procanace* increased the level of variability to 92.3% (Fig. 13, Table 2), with good resolution by island, and accounted for relatively strong associations with indigenous fish species.

Amphibian Impacts

Hawai‘i currently has three species of introduced aquatic amphibians, *Bufo marinus*, *Rana catesbeiana*, and *R. rugosa*. Of greatest concern according to CCA analysis was *R. catesbeiana*, with the other two species showing little impact in regard to native insect taxa. This is because *B. marinus* is found in mainly highly disturbed low elevation areas, while *R. rugosa* is found in high elevation areas and is often co-associated with endemic aquatic insects. As shown on Fig. 6, *R. catesbeiana* was associated with *Poecilia mexicana* in degraded habitats, while *R. rugosa* was by contrast usually found in high quality habitats on Kaua‘i and O‘ahu (see Figs. 6 or 12), and likely because of its small size is having little impact on dolichopodid Diptera or native damselflies, except perhaps to exclude certain species of the latter from preferred fast water breeding sites with its gelatinous egg masses.

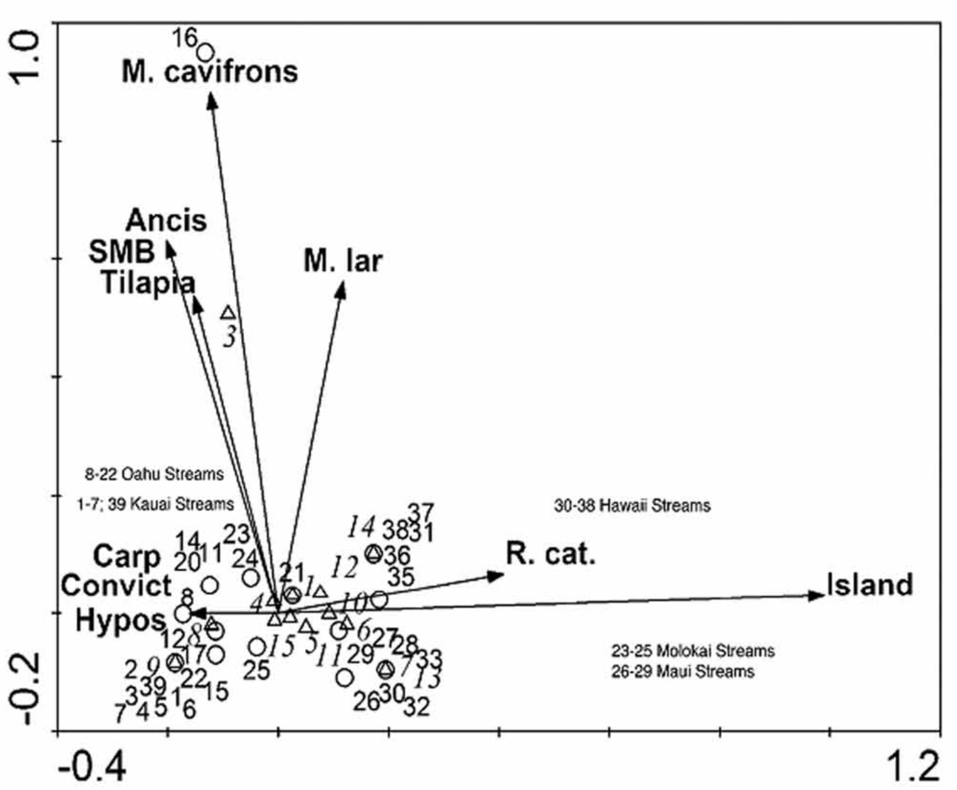

Figure 10. Native Ephydridae site and species-environment relationship using CCA (CCA2 vs. CCA3).

Discussion

These findings represent the first attempt at elucidating statistical associations of native aquatic insect faunas with environmental variables such as alien fish species, elevation, and stream disturbance. Our results have also allowed us to explore relationships between native aquatic insects and indigenous stream fish. The primary objective of this study was determine what, if any, species of aquatic insects are associated with pristine or disturbed habitats. A significant finding was that at least two groups, the native *Megalagrion* damselflies and dolichopodid flies, exhibited statistical relationships that appear to reflect correlations with disturbed and undisturbed environments (Figs. 6 and 7). Several aquatic insect families also exhibited obvious groupings, with sites from Kaua‘i and O‘ahu often clustered together, while Maui and Moloka‘i sites often grouped together with the Hawai‘i sites, as shown in Figs. 6 and 7. That these patterns may reflect the evolutionary history of the *Megalagrion* and dolichopodid species is of great future research interest; as is the fact that these patterns also show consistency in identifying sites with similar levels of impact among the different islands. *Telmatogeton* spp. was another assemblage of taxa showing clear separation by islands and strong associations with native fish taxa such as *Lentipes concolor*.

These findings then lend credence that *Megalagrion* damselflies, dolichopodid flies, *Procanace* spp., and *Telmatogeton* spp. (giant Hawaiian midges) are all suitable as indicator species for diverse aquatic habitats worthy of preservation and conservation attention. Ephydridae also had high resolution, but this associated with disturbance rather than with pristine conditions. At the family level, dam-

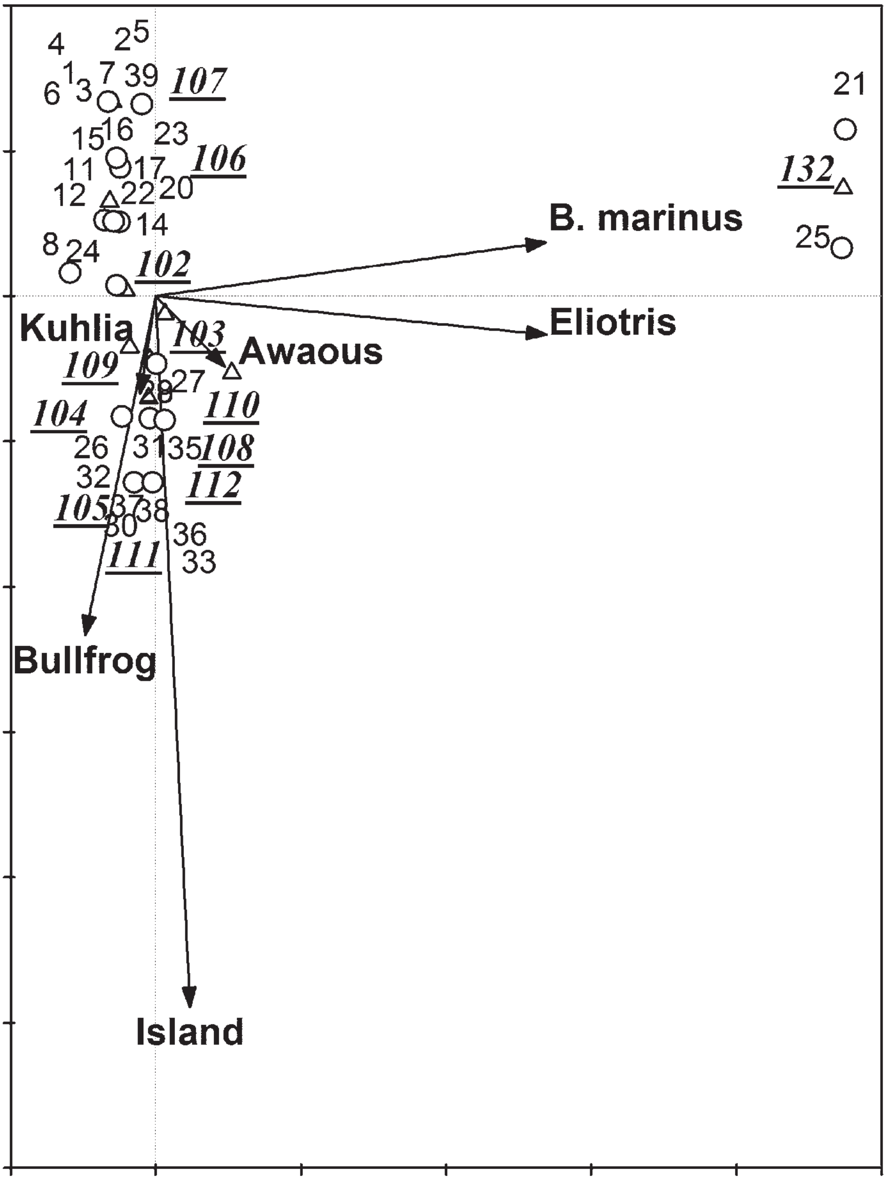

Figure 11. Native Ephydridae (*Scatella* spp. only) species-environment relationship using CCA.

selflies and canacid flies received the highest species-environment relationship score (84.5%) for the CCA. Because Hawaiian damselflies have a larger species assemblage than canacids (18 vs. 12 species analyzed here) their results are more meaningful than canacids, suggesting that damselflies have the most easily detected sensitivity of the aquatic insect taxa we assessed, and show the clearest patterns in community composition and responses to environmental factors. Odonata are well known to the public because of their large size and stunning appearance, and because of this would certainly qualify as the most charismatic of the aquatic insects in Hawaii, and thus could also be considered a flag-

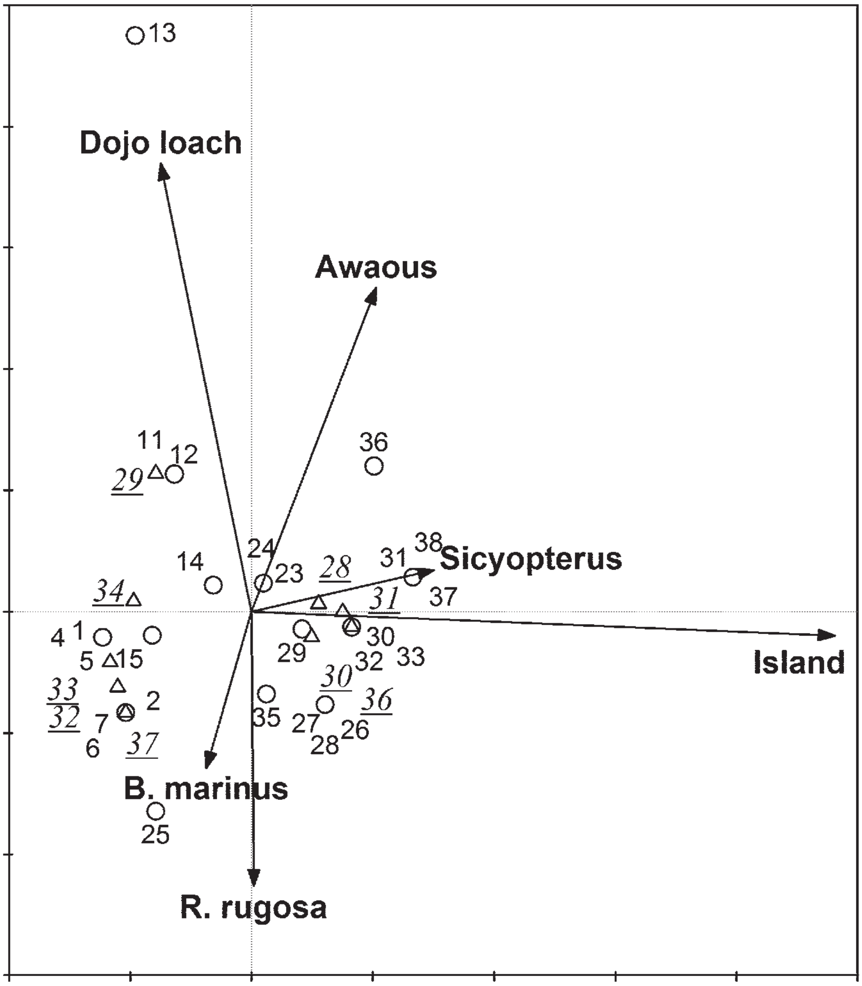

Figure 12. Native Canacidae (all taxa) site and species-environment relationship using CCA (CCA1 vs. CCA2).

ship species (Andelman & Fagan, 2000). On a more controversial note, our data suggest that Hawaiian damselflies would fall under the dual role of an umbrella species (Andelman & Fagan, 2000), or species defined as requiring such large areas of habitat that their protection might simultaneously protect other aquatic species. Because native damselflies will only be found in areas with little disturbance, this would in turn lead to healthy populations of native stream fish species being found in the same area. In contrast, ephydrids and all chironomids had well defined axes and groupings associated with disturbed habitats in our analyses (Figs. 10–13), suggesting these species are more resistant to both a disturbed environment and alien aquatic species, and are thus not good indicator candidates for pristine conditions. One of the weaknesses of the current study, which used presence / absence data rather than abundance data. The availability of abundance data would make the CCA considerably more robust. Nonetheless, the analyses provide credible characterizations of the streams surveyed.

Field observations indicate that *Telmatogeton* spp. are now found only in exceedingly pristine, high volume, and high water quality environments. Because of these requirements and the prevalence of water diversions on Hawaiian streams *Telmatogeton* are now difficult to find in the

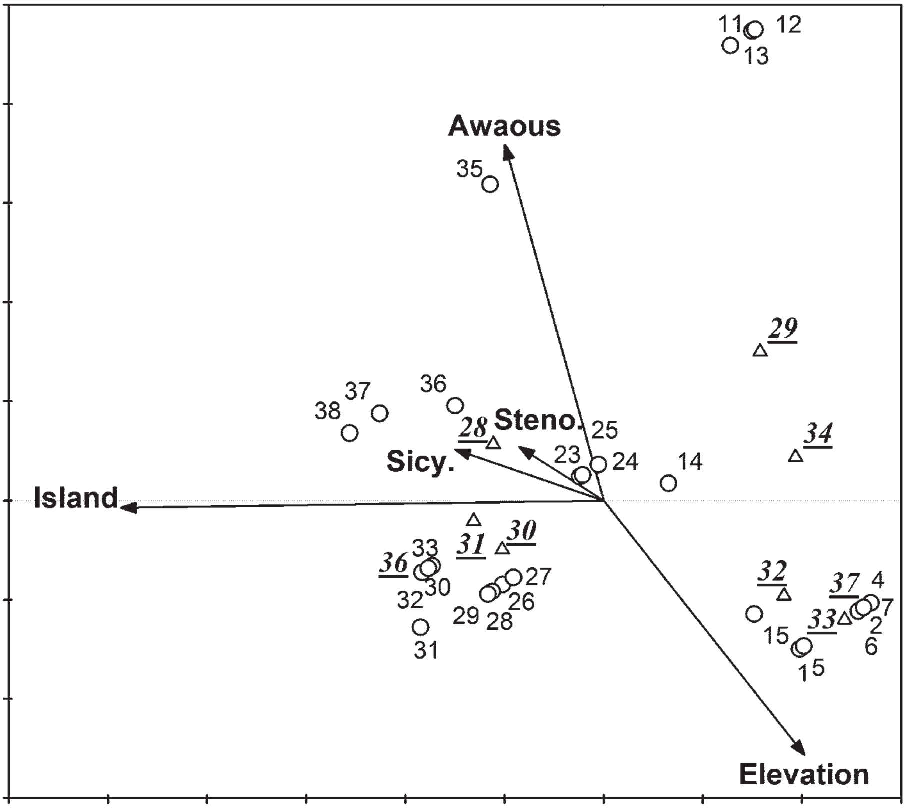

Figure 13. Native Canacidae (*Procanace* spp. only) species-environment relationship using CCA.

Hawaiian islands and are becoming increasingly rare, and for example, this genus is now found in only 4 of 57 streams on O‘ahu (Englund & Polhemus, unpubl. data). The current rarity and naturally low species richness (7 spp.) in the genus *Telmatogeton* resulted in an inflated degree of variance accounted for; rarity of species in this genus precludes them from being an effective indicator species. These giant Hawaiian chironomids may not be as charismatic as the Hawaiian damselflies, they are easy for untrained observers to identify in the field because of their large and distinctive white larval cases on stream boulders, and hence could make an ideal suite of indicator species if they were more common.

The conservation community has recently had heated debates on the various conceptual and practical values of indicator, umbrella, flagship, and keystone species (Simberloff, 1998; Andelman & Fagan, 2000; Rubinoff, 2001) when it comes to the assessment and preservation of biodiversity. In the Hawaiian Islands there has also been some degree of controversy, with inappropriate attempts to use Index of Biotic Integrity (IBI), developed for continental salmonid streams, to rank and assess Hawaiian streams (Parham, 2005). The shortcomings of the use of IBI in tropical insular streams with low natural fish diversity were well recently documented (Parham, 2005), but further problems exist with IBI as used in Hawai‘i in that native aquatic insects are excluded from the metrics. Thus, in Hawai‘i the dominant component of native aquatic biodiversity, the 400+ species of native aquatic insects, have been overlooked. Our findings that certain native insect taxa such as the *Megalagrion* damselflies, canacid, and dolichopodid flies are correlated with the presence of native

Table 2. Cumulative percentage of variation in species-environment and species composition explained by correspondence axes 1–3 by family or genus.

Insect family / taxon (# spp. included in analysis)	% Variance account for by first three axes Spp.-environment	 Species only
Coenagrionidae (18)	84.5	30.4
Dolichopodidae (38)	65.0	22.9
Chironomidae (16)	70.4	26.3
Canacidae (12)	84.5	32.7
Ephydridae (15)	83.1	40.9
Telmatogeton (genus level) (7)	78.9	54.3
Procanace (genus level) (10)	92.3	29.5
Scatella (genus level, native only) (14)	82.8	40.1

indigenous stream fish indicates that any assessment of native streams should necessarily be conducted in a more holistic fashion than has been practiced with IBI in Hawai‘i (e.g., Parham, 2005).

While the indicator species concept has received considerable criticism because it is both difficult to determine which species are the best indicators, or even what a species should indicate (Simberloff, 1998), we feel the indicator concept still has value for Hawaiian streams, especially in light of our findings from the present study indicating certain native aquatic insect taxa are sensitive to physical disturbance and alien species. For example, with funding for habitat conservation measures likely to remain at a low level, these findings can be used to identify taxa and stream areas that have high conservation value, thus prioritizing allocation of resources. In this case, we define areas of high conservation value as Hawaiian streams and adjacent wetlands with high biodiversity of native aquatic taxa. The presence of native species from the highly diverse groups such as dolichopodid and *Megalagrion* damselflies in a Hawaiian stream indicates that the stream has not been greatly disturbed by alien species or physically altered. In addition, if these two groups of taxa are present it usually means that many endemic and indigenous species will be co-associated with them, and that there will often be healthy populations of native stream fish as well.

We therefore conclude that for the highly endemic and diverse aquatic insect fauna in Hawaiian streams the indicator species concept still has value. Until now, most attention and resources have been focused on freshwater fish as indicators (Parham, 2005), but our results indicate the nearly exclusive use of native Hawaiian stream fish as indicator species in models such as is the current practice with IBI in Hawai‘i should be re-examined.

Our results indicate that there are certain advantages to using certain aquatic insect taxa as indicators for highly diverse Hawaiian aquatic habitats, and streams that maintain these indicator species should have a high conservation priority. Although the use of aquatic insects as indicator species in Hawaiian streams has both advantages and drawbacks (Table 3) as compared to native fish, advantages include greater specificity and increased sensitivity to external disturbances.

While data for this research of necessity was collected in a species presence or absence format, future directions in Hawaiian aquatic insect research could focus on developing techniques to further quantify specific aquatic insect populations. This study is the first to shed light on the fact that Hawaiian aquatic insects and native stream fish populations are closely linked, yet we are only just beginning to understand the relationships between different groups of native aquatic insects, let alone the interactions between stream fish and insects. Two major obstacles remain in obtaining quantitative data on native Hawaiian aquatic insect populations, taxonomic and ecological. Most of the taxonomic descriptions and illustrations of native aquatic insect taxa have been from the adult aerial stage, and few systematic larval descriptions exist for most taxa. Even some of the well-studied groups such as the genus *Megalagrion* have numerous undescribed larval stages. Very few descriptions exist for the other aquatic insect groups, and some taxa such as the diverse Chiro-

Table 3. Summary of advantages and disadvantages of using native aquatic insects versus native freshwater fish as species for monitoring the health of an aquatic ecosystem.

Taxa	Advantages	Disadvantages
Fish	1. Easily identifiable 2. Charismatic species 3. Culturally important	1. Open system: impacts outside watershed have great influence 2. Broad habitat preferences (less sensitive to disturbance) 3. Found only at lower elevations (900 m max) 4. Usually not above diversions/dams 5. Migratory: impacts outside watershed influence Population 6. Only 5 species
Insects	1. Closed system: impacts outside of watershed have no influence 2. Certain groups easily identifiable 3. Charismatic species (a few) 4. Narrow habitat Preferences 5. More sensitive to disturbance 6. Found above diversions 7. Occurrence correlated with indigenous fish 8. 400+ species	1. Many groups difficult to identify (taxonomic knowledge required) 2. 400+ species

nomidae are taxonomically quite difficult in the larval stage. With the exception of the *Megalagrion* damselflies, most native aquatic insects evolved in wave-swept marine habitats and have secondarily invaded and radiated into freshwater habitats (Howarth & Polhemus, 1991). These native insects are almost exclusively then found in torrenticolous riffle and cascade habitats, which are difficult to quantify with benthic enumeration devices such as a Surber or Hess sampler. Future research should be directed at further refining quantitative sampling methods for such taxa. For instance, new technologies such as DNA extraction from larval aquatic insects, statistically sound methods of collecting adults, and new methods to sample torrenticolous habitats would increase our knowledge of this highly endemic fauna, thus helping to ensure its ultimate preservation.

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Literature Cited

Andelman, S.J. & W.F. Fagan. 2000. Umbrellas and flagships: efficient conservation surrogates or expensive mistakes? *Proceedings of the National Academy of Sciences* **97**: 5954–5959.

Eldredge, L.G. & N.L. Evenhuis. 2003. Hawaii’s biodiversity: a detailed assessment of the number of species in the Hawaiian Islands. *Bishop Museum Occasional Papers* **76**: 1–28.

Englund, **R**.**A**. 1993. A survey of the fish and aquatic insect fauna of the Waikele/Kipapa Streams, Oahu, Hawaii. BHP Environmental Technologies report prepared for Halekua Development Corp., Honolulu. 20 pp.

———. 1999. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on Oʻahu Island, Hawaii. *Journal of Insect Conservation* **3**: 225–243.

———. 2001. Long-term monitoring of one of the most restricted insect populations in the United States, *Megalagrion xanthomelas* (Selys-Longchamps), at Tripler Army Medical Center, Oʻahu, Hawaii (Zygoptera: Coenagrionidae). *Odonatologica* **30**: 255–263.

———. 2002. The loss of native biodiversity and continuing nonindigenous species introductions in freshwater, estuarine, and wetland communities of Pearl Harbor, Oʻahu, Hawaiian Islands. *Estuaries* **25**: 418–430.

———. **& Arakaki**, **K**.**T**. 2003. Report on long-term aquatic insect monitoring by Hawaii Biological Survey, Bishop Museum in Pelekunu Valley, Molokaʻi, Hawaii. Report prepared for TNCH Molokaʻi Office. 10 pp.

———. **& Arakaki**, **K**.**T**. 2004. Rapid biological inventories of streams in the Ala Wai watershed, Oʻahu Island, Hawaiʻi. Hawaii Biological Survey Report prepared for Oceanit Laboratories, Inc., Honolulu, Hawaiʻi. 16 p.

———., **Arakaki**, **K**.**T**., **D**.**J**. **Preston**, **N**.**L**. **Evenhuis and M**.**K**.**K**. **McShane**. 2003a. Systematic Inventory of Rare and Alien Aquatic Species in Selected Oʻahu, Maui, and Hawaiʻi Island Streams. Final report prepared for Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu. 14 pp.

———. **& R**.**B**. **Filbert**. 1997. Native and exotic stream organisms study in the Kawainui, Alakahi, Koiawe, and Lalakea Streams, Lower Hamakua Ditch watershed project, County of Hawaii. USDA-NRCS Contract No. 53-9251-6-275. 71 pp.

———. **& R**.**B**. **Filbert**. 1999. Flow restoration and persistence of introduced species in Waikele Stream, Oahu. *Micronesica* **32**: 143–154.

———. **& Polhemus**, **D**.**A**. 2001. Evaluating the effects of introduced rainbow trout (*Oncorhynchus mykiss*) on native stream insects on Kauai Island, Hawaii. *Journal of Insect Conservation* **5**: 265–281.

———. **& Preston**, **D**.**J**. 1999. Biological Assessment of the Lower Hamakua Ditch on the Hawaiian Stream Fly (*Sigmatineurum meaohi*) and other aquatic insects. Report. Bishop Museum. 31 pp.

———., **Preston**, **D**.**J**., **K**. **Arakaki & M**.**K**.**K**. **McShane**. 2003b. Aquatic insect surveys of four windward Oʻahu stream systems impacted by the Waiāhole Ditch. Hawaii Biological Survey Report prepared for Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu. 8 pp.

———., **Preston**, **D**.**J**., **N**.**L**. **Evenhuis**, **R**.**H**. **Cowie**, **C**. **Imada**, **C**. **Puttock**, **& K**. **Arakaki**. 2001. Native and exotic organism study. Lower Wailoa River, Waipiʻo, County of Hawaii. Report prepared for USDA Natural Resources Conservation Service, Honolulu, Hawaii. 57 p.

———., **Preston**, **D**.**J**., **R**. **Wolff**, **S**. **L**. **Coles**, **L**. **G**. **Eldredge & K**. **Arakaki**. 2000. Biodiversity of freshwater and estuarine communities in lower Pearl Harbor, Oʻahu, Hawaiʻi with observations on introduced species. *Bishop Museum Technical Report* **16**: 1–166.

Evenhuis, **N**.**L**, **D**. **Polhemus**, **S**. **Swift**, **K**. **Arakaki**, **& D**. **Preston**. 1995. A study of the biology of the orangeblack Hawaiian damselfly (*Megalagrion xanthomelas*), with special reference to conservation of the population at Tripler Army Medical Center, Oahu. *Bishop Museum Technical Report* **8**, 81 pp.

Filbert, **R**. **& R**.**A**. **Englund**. 1995. Waiāhole ditch water contested case: biological assessments of windward and leeward streams. Pacific Aquatic Environmental consultants report prepared for Kamehameha Schools/Bishop Estate. 140 pp.

Font, **W**.**F**. 1998. Parasites in paradise: patterns of helminth distribution in Hawaiian stream fishes. *Journal of Helminthology* **72**: 307–311.

———. **& D**.**C**. **Tate**. 1994. Helminth parasites of native Hawaiian freshwater fishes: an example of extreme ecological isolation. *Journal of Parasitology* **80**: 682–688.

Howarth, **F**. **G**. **& Polhemus**, **D**.**A**. 1991. A review of the Hawaiian stream insect fauna. In: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems, Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii*, p. 40–51. Hawaii Division of Aquatic Resources, Honolulu.

Leps, **J**. **& Smilauer**, **P**. 2003. *Multivariate analysis of ecological data using CANOCO*. Cambridge University Press. pp. 269.

Liebherr, **J**. **& D**.**A**. **Polhemus**. 1997. Comparisons to the century before: the legacy of the R.C.L. Perkins and Fauna Hawaiiensis as the basis for a long-term ecological monitoring program. *Pacific Science* **51**: 490–504.

Nishida, **G**.**M**. 2002. Hawaiian terrestrial arthropod checklist. Fourth edition. *Bishop Museum Technical Report* **22**, 313 pp.

Parham, **J**.**E**. 2005. Survey techniques for freshwater streams on oceanic islands: important design considerations for the PABITRA Project. *Pacific Science* **59**: 283–291.

Polhemus, **D**.**A**. 1994. The aquatic insect fauna of North Halawa, Oahu, Hawaii. *In* F.G. Howarth *et al.*, A natural history survey of North Halawa Valley, Oahu, Hawaii. Bishop Museum report to Hawaii State Department of Transportation, H-3 Project. pp. 75–85. Bishop Museum, Honolulu, Hawaii. 112 pp.

———. 1995. A survey of the aquatic insect faunas of selected Hawaiian streams. Hawaii Biological Survey Report for the Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawaii. Department of Natural Sciences, Bishop Museum. 128 pp.

Rubinoff, **D**. 2001. Gnatcatcher as umbrella species for insects. *Conservation Biology* **15**: 1374–1383.

Simberloff, **D**. 1998. Flagships, umbrellas, and keystones: is single-species management passé in the landscape era? *Biological Conservation* **93**: 247–257.

Ter Braak, **C**.**J**.**F**. **& Smilauer**, **P**. 2002. CANOCO reference manual and ConoDraw for Windows users guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, New York. 500 pp.

Williams, **F**.**X**. 1936. Biological Studies in Hawaiian water-loving insects. Part 1. Coleoptera or beetles. Part 2. Odonata or dragonflies. *Proceedings of the Hawaiian Entomological Society* **9**: 235–345.

Yamamoto, **M**.**N**. **& A**.**W**. **Tagawa**. 2000. *Hawai'i's native and exotic freshwater animals*. Mutual Publishing, Honolulu. 200 pp.

APPENDIX

Biota found during this study and their native or introduced status. [Status taken from Yamamoto (2000) and Nishida (2002).]

Taxa	**Species** (Ind = Indigenous; End = Endemic; Int = Introduced)	**Species Number on Figures 6–13**
Native (Endemic)		
Aquatic Insects		
Odonata		
Aeshnidae	*Anax strenuus* (End)	1
Libellulidae	*Nesogonia blackburni* (End)	2
Coenagrionidae	*Megalagrion eudytum* (End)	3
	Megalagrion heterogamias (End)	4
	Megalagrion oresitrophum (End)	5
	Megalagrion orobates (End)	6
	Megalagrion vagabundum (End)	7
	Megalagrion hawaiiense (End)	8
	Megalagrion leptodemas (End)	9
	Megalagrion nigrohamatum nigrolineatum (End)	10
	Megalagrion oceanicum (End)	11
	Megalagrion xanthomelas (End)	12
	Megalagrion blackburni (End)	13
	Megalagrion calliphya (End)	14
	Megalagrion nesiotes (End)	15
	Megalagrion nigrohamatum nigrohamatum (End)	16
	Megalagrion oceanicum (End)	17
Heteroptera		
Nabidae	*Nabis gagneorum* (End)	18
	Saldula exulans (End)	19
Saldidae	*Saldula oahuensis* (End)	20
	Saldula procellaris (End)	21
Veliidae	*Microvelia vagans* (End)	22
Coleoptera		
Dytiscidae	*Rhantus pacificus* (End)	23
Hydrophilidae	*Limnoxenus semicylindricus* (End)	24
Lepidoptera		
Cosmopterigidae	*Hyposmocoma* sp. (End)	25
	Hyposmocoma sp. nr *montivolans* (End)	26
	Hyposmocoma sp. nr *saccophora* (End)	27
Diptera		
Canacidae	*Procanace acuminata* (End)	28
	Procanace bifurcata (End)	29
	Procanace confusa (End)	30
	Procanace constricta (End)	31
	Procanace nigroviridis (End)	32
	Procanace quadrisetosa (End)	33
	Procanace wirthi (End)	34
	Procanace new sp. 1 (End) (Oahu - Rare Alien Survey)	35
	Procanace new sp. 1 (End) (Hawaii koa timber survey)	36
	Procanace sp. (End)	37

Taxa	**Species** (Ind = Indigenous; End = Endemic; Int = Introduced)	**Species Number on Figures 6–13**
Native (Endemic) Aquatic Insects		
Ceratopogonidae	*Dasyhelea digna* (End)	38
	Dasyhelea hawaiiensis (End)	39
	Dasyhelea sp. (not *hawaiiensis*) (End)	40
	Dasyhelea platychaeta (End)	41
	Dasyhelea sp. (End)	42
	Forcipomyia hardyi (End)	43
	Forcipomyia kaneohe (End)	44
	Forcipomyia sp. (End)	45
Chironomidae	*Chironomus* sp. (End)	46
	Chironomus hawaiiensis (End)	47
	Clunio sp. nr. *vagrans* (End)	48
	Micropsectra sp. (End)	49
	Micropsectra hawaiiensis (End)	50
	Orthocladius sp. (End)	51
	Orthocladius grimshawi (End)	52
	Pseudosmittia paraconjuncta (End)	53
	Telmatogeton abnormis (End)	54
	Telmatogeton fluviatilis (End)	55
	Telmatogeton hirtus (End)	56
	Telmatogeton japonicus (End)	57
	Telmatogeton torrenticola (End)	58
	Telmatogeton williamsi (End)	59
	Telmatogeton sp. (End)	60
Dolichopodidae	*Campsicnemus brevipes* (End)	61
	Campsicnemus gloriosus (End)	62
	Campsicnemus labilis (End)	63
	Campsicnemus lepidochaites (End)	64
	Campsicnemus longitibia (End)	65
	Campsicnemus nigricollis (End)	66
	Campsicnemus modicus (End)	67
	Campsicnemus miritibialis (End)	68
	Campsicnemus patellifer (End)	69
	Campsicnemus ridiculus (End)	70
	Campsicnemus tibialis (End)	71
	Campsicnemus nr. *truncatus* (End)	72
	Campsicnemus williamsi (End)	73
	Campsicnemus sp. (End)	74
	Campsicnemus new sp. 1 (End) (Oahu- Rare Alien Surveys)	75
	Campsicnemus new sp. 2 (End) (Maui - Rare Alien Surveys)	76
	Campsicnemus new sp. 3 (End) (Maui- Rare Alien Surveys)	77
	Campsicnemus lawakua (End) Kokee	78
	Eurynogaster mediocris (End)	79
	Major minor (End)	80
	Elmoia multispinosa (End)	81
	"*Eurynogaster*" sp. (End)	82
	"*Eurynogaster*" new sp. (End) (Maui - Rare Alien Surveys)	83
	"*Eurynogaster*" new sp. (End) (Koa Timber survey -Hawaii)	84
	Paraliancalus metallicus (End)	85
	Sigmatineurum englundi (End)	86
	Sigmatineurum iao (End)	87
	Sigmatineurum meaohi (End)	88
	Sigmatineurum napali (End)	89
	Sigmatineurum nigrum (End)	90

Taxa	**Species** (Ind = Indigenous; End = Endemic; Int = Introduced)	**Species Number on Figures 6–13**
Native (Endemic)		
Aquatic Insects		
Dolichopodidae (cont.)		
	Sigmatineurum parenti (End)	91
	Sigmatineurum mnemogagne (End) (Hanawi)	92
	Sigmatineurum omega (End)	93
	Sigmatineurum puleloai (End) (Moloka‘i)	94
	Sigmatineurum n. sp. 1 (End) Koke‘e	95
	Sigmatineurum n. sp. 2 (End) Koke‘e	96
	Sigmatineurum n. sp. (End) (Maui - Rare Alien Surveys)	97
	Thambemyia acrostichalis (End) (formerly *Paraphrosylus* sp.)	98
Ephydridae	*Atissa oahuensis* (End)	99
	Hydrellia tritici (End)	100
	Notiphilia insularis (End)	101
	Scatella cilipes (End)	102
	Scatella clavipes (End)	103
	Scatella (*Apulvillus*) *femoralis* (End)	104
	Scatella fluvialis (End)	105
	Scatella hawaiiensis (End)	106
	Scatella kauaiensis (End)	107
	Scatella (*Apulvillus*) *mauiensis* (End)	108
	Scatella oahuense (End)	109
	Scatella warreni (End)	110
	Scatella williamsi (End)	111
	Scatella new sp. (End) (Waimanu)	112
Muscidae	*Lispe* sp. (End)	113
	Lispocephala new sp. 1 (End) (Maui - Rare Alien Surveys)	114
	Lispocephala new sp. 2 (End) (Maui - Rare Alien Surveys)	115
Psychodidae	*Psychoda* sp. (End)	116
	Trichomyia hawaiiensis (End)	117
	Trichomyia sp. (End)	118
Limoniidae	*Dicranomyia hawaiiensis* (End)	119
	Dicranomyia grimshawi (End)	120
	Dicranomyia jacoba (End)	121
	Dicranomyia kauaiensis (End)	122
	Dicranomyia nigropolita (End)	123
	Dicranomyia perkinsi (End)	124
	Dicranomyia swezeyi (End)	125
	Dicranomyia stygipennis (End)	126
	Dicranomyia sp. (End)	127
	Gonomyia sp. (End)	128
Native (Indigenous)		
Insects		
Odonata		
Aeshnidae	*Anax junius* (Ind)	129
Libellulidae	*Pantala flavescens* (Ind)	130
Diptera		
Chironomidae	*Chironomus esakii* (Ind)	131
Ephydridae	*Scatella sexnotata* (Ind)	132
Tethinidae	*Dasyrhicnoessa insularis* (Ind)	133
	Dasyrhicnoessa (Ind)	134
	Dasyrhicnoessa vockerothi (Ind)	135

Taxa	**Species** (Ind = Indigenous; End = Endemic; Int = Introduced)	**Species Number on Figures 6–13**
Introduced Aquatic Insects		
Odonata		
Libellulidae	*Tramea abdominalis* (Int)	136
	Tramea lacerata (Int)	137
	Crocothemis servilia (Int)	138
	Orthemis ferrugenia (Int)	139
Coenagrionidae	*Ischnura posita* (Int)	140
	Ischnura ramburii (Int)	141
	Enallgma civile (Int)	142
Heteroptera		
Mesoveliidae	*Mesovelia amoena* (Int)	143
	Mesovelia mulsanti (Int)	144
Notonectidae	*Notonecta indica* (Int)	145
	Buenoa pallipes (Int)	146
Coleoptera		
Dytiscidae	*Rhantus guttulosus* (Int)	147
	Copelatus parvulus (Int)	148
Hydrophilidae	*Tropisternus lateralis* (Int)	149
Diptera		
Canacidae	*Procanace williamsi* (Int)	150
	Canaceioides angulatus (Int)	151
Ceratopogonidae	*Forcipomyia* sp. (Int)	152
	Atrichopogon jacobsoni (Int)	153
Chironomidae	*Cricotopus bicinctus* (Int)	154
	Polypedilum nubiferum (Int)	155
Dixidae	Dixa longistyla (Int)	156
Dolichopodidae	*Condylostylus longicornis* (Int)	157
	Chrysosoma globiferum (Int)	158
	Chrysotus longipalpus (changed from *pallidipalpus*) (Int)	159
	Chrysotus sp. 1 (Int)(Waipio)	160
	Dolichopus exsul (Int)	161
	Pelastoneurus lugubris (Int)	162
	Syntormon flexibile (Int)	163
	Tachytrechus angustipennis (Int)	164
	Thinophilus hardyi (Int)	165
Empididae	*Hemerodromia stellaris* (Int)	166
Ephydridae	*Brachydeutera ibari* (Int)	167
	Ceropsilopa coquilletti (Int)	168
	Discocerina mera (Int)	169
	Hecamede granifera (Int)	170
	Hydrellia williamsi (Int)	171
	Donaceus nigronotatus (Int)	172
	Lytogaster gravida (Int)	173
	Ochthera circularis (Int)	174
	Paratissa pollinosa (Int)	175
	Placopsidella marquesana (Int)	176
	Typopsilopa sp. (Int)	177
	Scatella stagnalis (Int)	178
Muscidae	*Lispe assimilis* (Int)	179

Taxa	**Species** (Ind = Indigenous; End = Endemic; Int = Introduced)	**Species Number on Figures 6–13**
Introduced Aquatic Insects		
Diptera (cont.)		
Psychodidae	*Clogmia albipunctata* (Int)	180
Sciomyzidae	*Sepedon aenescens* (Int)	181
Tethinidae	*Tethina variseta* (Int)	182
Limoniidae	*Dicranomyia advena* (Int)	183
	Erioptera bicornifer (Int)	184
Trichoptera		
Hydropsychidae	*Cheumatopsyche analis* (Int)	185
Hydroptilidae	*Hydroptila icona* (Int)	186
	Hydroptila potosina (Int)	187
	Oxyethira maya (Int)	188
Fish	*Lentipes concolor* (End)	189
	Sicyopterus stimpsoni (End)	190
	Awaous guamensis (Ind)	191
	Stenogobius hawaiiensis (End)	192
	Eleotris sandwicensis (End)	193
	Mugil cephalus (Ind)	194
	Kuhlia xenura (End)	195
	Gambusia affinis (Int)	196
	Poecilia reticulata (Int)	197
	Poecilia mexicana (Int)	198
	Poecilia latipinna (Int)	199
	Limia vittata (Int)	200
	Poecilia (misc) spp. (Int)	201
	Xiphophorous helleri (Int)	202
	Micropterus dolomieui (Int)	203
	Oncorhynchus mykiss (Int)	204
	Misgurnus anguillicaudatus (Int)	205
	Mugilogobius cavifrons (Int)	206
	Tilapia/Oreochromis spp. (Int)	207
	Cichlasoma managuense (Int)	208
	Archocentrus (*Cichlasoma*) *nigrofasciatus* (Int)	209
	Hemichromis elongatus (Int)	210
	Melanochromis johanni (Int)	211
	Hypsophrys nicaraguensis (Int)	212
	Amphilophus citrinellum (Int)	213
	Ancistris temminicki (Int)	214
	Hypostomous watwata (Int)	215
	Cyprinus carpio (Int)	216
Amphibians	*Bufo marinus* (Int)	217
	Rana catesbeiana (Int)	218
	Rana rugosa (Int)	219
Crustaceans	*Procambarus clarkii* (Int)	220
	Macrobrachium lar (Int)	221