Prepared in cooperation with the State of Hawaii Department of Health

Feasibility of Using Benthic Invertebrates as Indicators of Stream Quality in Hawaii

Scientific Investigations Report 2005–5079

U.S. Department of the Interior
U.S. Geological Survey

(A) alien mollusc *Corbicula* sp.;
(B) alien trichopteran *Hydroptila* sp.;
(C) alien trichopteran *Cheumatopsyche pettiti;*
(D) amphipod;
(E) endemic mountain shrimp *Atyoida bisulcata.*
All photographs taken by Reuben H. Wolff

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U.S. Department of the Interior
Gale A. Norton, Secretary

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gram (g)	0.03527	ounce, avoirdupois (oz)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
yard (yd)	0.9144	meter (m)

Datums

Vertical coordinate information is referenced to the local mean sea level.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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Feasibility of Using Benthic Invertebrates as Indicators of Stream Quality in Hawaii

By Reuben H. Wolff

Abstract

Macroinvertebrates were collected from 19 sites on 14 streams on the island of Oahu and from 9 sites on 7 streams on the island of Kauai to evaluate associations between macroinvertebrate assemblages and environmental variables and to determine whether or not it would be feasible, in future studies, to develop macroinvertebrate metrics that would indicate stream quality based on the macroinvertebrate assemblages and/or components of the assemblages. The purpose of applying rapid bioassessment techniques is to identify stream quality problems and to document changes in stream quality. Samples were collected at 10 sites in 1999, 3 sites in 2000, and 5 sites in 2003 on Oahu and at 9 sites on Kauai in 2003. Additionally, multiple year and multiple reach samples were collected at 1 site on Oahu. Macroinvertebrates were collected primarily from boulder/cobble riffles or from the fastest flowing habitat when riffles were absent. Although most streams in Hawaii originate in mountainous, forested areas, the lower reaches often drain urban, agricultural, or mixed land-use areas. The macroinvertebrate community data were used to identify metrics that could best differentiate between sites according to levels of environmental impairment. Environmental assessments were conducted using land-use/land-cover data, bed-sediment and fish-tissue contaminant data, and reach-level environmental data using a calibration set of 15 sites. The final scores of the environmental assessments were used to classify the sites into three categories of impairment: mild, moderate or severe. A number of invertebrate metrics were then tested and calibrated to the environmental assessments scores. The individual metrics that were the best at discerning environmental assessments among the sites were combined into a multimetric benthic index of biotic integrity (BIBI). These metrics were: total invertebrate abundance, taxa richness, insect relative abundance, amphipod abundance, crayfish presence or absence, and native mountain shrimp presence or absence. Because this index is in the preliminary stage of development and additional “pristine” sites need to be sampled and assessed to develop a more robust measure of biotic integrity, the index will be referred to as a Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI). The P-HBIBI scores were then classified into three categories of impairment: mild, moderate, or severe. The P-HBIBI was then used to assess the remaining sites and classify them into impairment categories. The P-HBIBI was correlated ($r^2 = 0.72$; $p < 0.005$) with a reduced environmental assessment determined without contaminants data. The results of this study suggest that the development of a reliable Hawaiian benthic index of biotic integrity (HBIBI), based on macroinvertebrate assemblages, is feasible; however, a much larger sample size, including more samples from ‘pristine’ sites and from the other islands, would be required.

Introduction

Section 303(d) of the 1972 Federal Clean Water Act requires the State of Hawaii Department of Health (HDOH) to generate the Clean Water Act §303(d) List of Water Quality-Limited Segments (WQLS) for surface waters that are exceeding or will likely exceed State Water Quality Standards (WQS) (Henderson and Harrigan-Lum, 2002; Koch and others, 2004). The Clean Water Act’s objective is to restore and maintain the chemical, physical, and biological integrity of the Nation’s surface waters (33 U.S.C. §1251). Surface waters that have been determined to be water-quality limited must then be surveyed to ascertain the Total Maximum Daily Load (TMDL) for each identified constituent that exceeds the State WQS. The TMDL is the maximum daily load of the constituent, established for each WQLS, that can enter the stream without violating the State WQS.

The HDOH has been testing and refining the Hawaii Stream Bioassessment Protocol (HSBP) (Kido, 2002) for the past several years. The purpose of applying rapid bioassessment techniques is to identify stream quality problems associated with both point and nonpoint source pollution and to document long-term regional changes in stream quality (Resh and Jackson, 1993), and to do so in a cost-effective way (Resh and Jackson, 1993; Lenat and Barbour, 1994). The HSBP is currently based on habitat characteristics and the presence of native fish and macrocrustaceans as indicators of biotic integrity (Kido and others, 1999; Burr, 2001; Kido, 2002; Burr, 2003; Henderson, 2003). This approach is consistent with efforts being undertaken by many State agencies across the country. Although organisms used in stream-quality monitoring programs include algae, invertebrates, and fish (Lenat and Barbour, 1994; Barbour and others, 1999), benthic macroinvertebrates are by far the most commonly used group of organisms for this purpose (Rosenberg and Resh, 1993). Therefore, the HDOH is interested in expanding the HSBP to include benthic invertebrates.

Benthic macro-invertebrates offer many advantages in biomonitoring: (1) they are ubiquitous, and consequently can be affected by environmental perturbation in various aquatic systems and habitats; (2) the large number of species offers a wide spectrum of responses to environmental stressors; (3) their basic sedentary nature allows effective spatial analyses of pollutants or disturbance effects; and (4) they have relatively long life cycles, which allows elucidation of temporal changes caused by perturbation (Rosenberg and Resh, 1993). The HDOH intends to use the protocol to screen the biological health of Hawaii's streams for classification purposes and to identify water-quality problems associated with both point and nonpoint source pollution.

The long-term goal of the HDOH is to use assessment protocols that include fish, invertebrates, and algae. The use of diverse groups of organisms in biological monitoring can provide a more robust assessment of stream quality (Lenat and Barbour, 1994). Some studies have indicated that fish communities alone may not always be reliable indicators of habitat and stream quality. For example, in the Upper Merced River in central California, low fish-species richness and the apparent importance of physical barriers in determining fish distributions (both of which are factors in Hawaii streams) led to the conclusion that benthic invertebrates were a more useful and reliable indicator of stream quality (Brown and Short, 1999).

Invertebrate metrics developed for streams in continental settings may not be appropriate in the Hawaiian Islands. For example, the commonly used EPT (Ephemeroptera, Plecoptera, Trichoptera) metric is virtually meaningless in Hawaii, where only a few individuals of one introduced species of Ephemeroptera have ever been reported, and Plecoptera have never been known to exist here (Howarth and Polhemus, 1991). Likewise, in North America, mussels and snails are most often indicators of high-quality environments; in Japan (Karr and Chu, 1997) and Hawaii (Brasher and others, 2004), however, the most common mollusc species are alien or otherwise indicators of degraded conditions. Consequently, metrics specific for Hawaiian streams need to be developed.

As part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program, and in cooperation with the HDOH, invertebrate and habitat information were collected at 10 sites on the island of Oahu in 1999 (1 site was resampled in 2000 and in 2001 and 2 adjacent sites were sampled in 2000) (Brasher and others, 2004). This information represents the most extensive and comprehensive information collected to date on the distribution, abundance, and species composition of benthic freshwater invertebrates in Hawaii. To assess the usefulness of invertebrates as indicators of stream quality, a wider range of streams than those included in the Oahu NAWQA study were sampled, with emphasis on degraded sites. To examine inter-island variability, several reference and degraded sites on the island of Kauai also were sampled to determine if differences exist among the islands.

Objectives

The main objective of this study was to determine if it would be advisable, in future projects, to further develop a multi-metric index of biotic integrity using benthic invertebrates (BIBI) in Hawaiian streams and to identify those components of the invertebrate assemblages that showed the most potential for further investigation. To assess the feasibility of developing a BIBI, this study examined the relations between the benthic invertebrate assemblages and the impairment levels, based on a group of environmental parameters, at a number of sites on Oahu and Kauai. The first phase was to analyze site-specific land-use data, contaminants data, and habitat data to classify the instream impairment levels at each site using the most 'pristine' sites as the reference condition sites. The second phase was to analyze the benthic invertebrate communities collected from these sites and to test whether or not the invertebrate assemblages displayed any discernible and biologically informative patterns as a consequence of the environmental impairment.

Purpose and Scope

This report presents the macroinvertebrate data collected by the USGS from 1999 to 2003 and assesses the feasibility of developing a multimetric, invertebrate-based, index of biotic integrity for the entire State of Hawaii or for the individual islands. It includes: (1) a description of 28 macroinvertebrate samples and habitat information collected from 26 sites on 21 streams on the islands of Oahu and Kauai; (2) multivariate and multimetric analyses to determine relations among habitat characteristics, stream quality, and the distribution and abundance of benthic invertebrates; and (3) a preliminary assessment of metrics that best differentiate sites according to levels of impairment.

Acknowledgments

Fieldwork for this study was made possible by the assistance of various Federal, State, and local organizations. I especially thank Anne Brasher (USGS) who contributed greatly to the design and fieldwork of this study, and for her insightful review comments. I also thank: Corene Luton, Chad Durkin, Paige Little, Dale Mikami, and Austin Seid (USGS), and Monika Mira, of the Nawiliwili Bay Watershed Council, who all made valuable contributions to the fieldwork. Brady Richards (EcoAnalysts, Inc.) sorted and identified many of the invertebrate samples, and Les Watley (University of Maine) identified the amphipods. We especially thank the National Tropical Botanical Gardens (NTBG) for allowing us access to lower Lawai Stream and Limahuli Stream, Kamehameha Schools for access to Punaluu Stream, and the Honolulu Board of Water Supply for access to Waihee Stream. Lists of invertebrates collected at these sites are available in the appendixes of this report.

Invertebrates in Hawaiian Streams

The Hawaiian Islands are the most isolated island archipelago in the world, located nearly 4,000 kilometers from the nearest continent. The native stream fauna of Hawaii is relatively depauperate compared to that of continental streams. Widespread diverse orders of insects such as Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are absent from the native biota (Howarth and Polhemus, 1991). Historically, the isolation of the Hawaiian archipelago prevented large-scale colonization due to the limited dispersal mechanisms of most aquatic invertebrates. Many native stream species were most likely derived from marine ancestors, although a few arrived by flight, including the ancestors of the native damselflies and dragonflies, or various other mechanisms such as rafting, carried in the jet stream, or attached to migratory birds (Zimmerman, 1947). Native insects of the order Diptera are thought to have all adapted from marine ancestors (Howarth and Mull, 1992). This isolation enabled the few successful colonizers to undergo natural selection and adaptive radiation, resulting in a high degree of endemism and specialization among the islands' biota (Carlquist, 1980).

The native species of Hawaii were well adapted to the unique environment of pre-contact Hawaiian streams and tend to be less aggressive than introduced species (Carlquist, 1980). There is now a proliferation of introduced species that are better competitors and far more tolerant of conditions in altered and degraded streams. These alien macroinvertebrates arrived in Hawaii in assorted ways and for various reasons. Some introductions were state sanctioned, such as the Tahitian prawn *Macrobrachium lar*, while others, such as the Asiatic clam *Corbicula fluminea*, were not, although both were intentionally introduced for food purposes (Devick, 1991). A myriad of insect species were accidentally introduced aboard ships and planes and amongst imported aquatic plants (Eldredge, 1992). Aquatic fish parasites, such as the nematode *Camallanus cotti*, were accidentally introduced together with intentionally released Poeciliid fishes (Font and Tate, 1994; Vincent and Font, 2003a, 2003b).

There is some evidence that species with univoltine life cycles (reproducing once per year) in temperate streams may have the ability to switch to multivoltine life cycles (reproducing throughout the year) in Hawaiian tropical streams, which lack the marked seasonality of temperate streams. This has recently been documented for the introduced caddisfly (Trichoptera) *Cheumatopsyche pettiti* (Kondratieff and others, 1997; Wolff, 2000). Although the seasons in Hawaii are considerably less variable than those in temperate regions, even minor seasonal variations in discharge, water temperature, and sunlight can be important in the development of macroinvertebrate communities in Hawaiian streams (Wolff, 2000).

The larger native stream animals in Hawaii (fish, shrimp, and snails) are primarily amphidromous, having evolved from marine dwelling ancestors, and have retained a marine larval life-stage. Adults lay eggs in the streams, the eggs hatch and the larvae drift to the ocean, where they spend months as plankton before returning to freshwater (Ford and Kinzie, 1982; Kinzie, 1990; Yamamoto and Tagawa, 2000). Unlike the salmon of the Pacific Northwest, there is no current evidence that these animals return to their stream of birth, and it appears that there is enough mixing of the gene pool in the ocean currents to have prevented speciation among islands (Fitzsimmons and others, 1990). The longitudinal distribution of these animals is largely controlled by their ability to migrate upstream unimpeded (Ford and Kinzie, 1982).

In the time since human colonization of the Hawaiian Islands, many native species have been substantially affected by habitat alteration and by the introduction of non-native species (Kirch, 1982). This process has been accelerated during the past 100 years of rapid urbanization. The resident population of Hawaii has increased from about 150,000 in 1900 to more than 1.2 million in 2000 (State of Hawaii, 2000). Anthropogenic influences, both urban and agricultural, can adversely impact stream systems. Effects such as stream channel revetment to allow for flood control or roadways; increases in sedimentation from construction and farming; contaminants from agricultural, urban, and industrial activities transported in storm-water runoff; and diversions to redirect stream water to farms and other off-stream uses can all affect stream quality (Oki and Brasher, 2003).

Environmental impacts such as contamination can directly affect aquatic invertebrate assemblages in a number of ways. The diverse taxa have varied ranges of tolerances for the myriad of pollutants that have been detected in sediments, tissues, and surface waters (Wiederholm, 1984; Rowe and others, 1997). Some invertebrates are sensitive to heavy metals such as arsenic; others are sensitive to pesticides like dieldrin. The levels of contamination, the specific taxa and the life stage of the taxa, and the duration of exposure to the contaminant all play roles in how the community will be affected. In many cases, multiple contaminants have been detected in sediments and fish tissue (Brasher and Wolff, 2004). Most toxicity testing involves only one or two compounds to determine the physiological and biochemical reactions of the test taxa. The effects of exposure to multiple contaminants simultaneously are still unknown.

Challenges to Development of Metrics

The development of invertebrate metrics for the Hawaiian Islands faces challenges that are unique compared to those in most other States. First, entire orders of insects are absent from the native fauna (Howarth and Polhemus, 1991). Zimmerman (1947) noted that 21 orders of the class Insecta were absent from the native biota. There are no aquatic insects in the orders Ephemeroptera, Plecoptera, or Trichoptera represented in the native biota of the Hawaiian Islands. This presents a major challenge because most continental-based benthic metrics use members of these orders as key indicators of stream quality. Ephemeroptera commonly are used as key indicators due to the order's general sensitivity to impairment (Lenat and Penrose, 1996). The often-used EPT metric, the ratio of all three orders, is of no use in Hawaii. Four species of Trichoptera have been introduced in Hawaii (including *Cheumatopsyche pettiti*, *Hydroptila icona*, *H. arctia*, and *Oxyethira maya*); they are widespread and comprise a large percentage of the abundance and biomass of invertebrates in Hawaiian streams (Kinzie and others, 1997; Kondratieff and others, Colorado State University, unpub. data, 1992-93; Wolff, 2000; Brasher and others, 2004). There also have been past intentional introductions of Ephemeroptera species; however, these introductions have failed to become established (Smith, 2000). An accidental introduction of the mayfly *Caenis nigropunctata* became established in the 1940s to 1950s, but has since been infrequently collected. Only four individual larvae of *Caenis nigropunctata* were collected at two sites during this study.

Howarth and Mull (1992) observed that there are more than 1,100 native insect species in Hawaii in the order Diptera, representing 28 families. Few of these native dipterans are collected in quantitative sampling, however, as compared to a few, highly abundant alien dipterans like *Cricotopus* sp. of the family Chironomidae (Kinzie and others, 1997; Wolff, 2000; Brasher and others, 2004). Chironomids commonly are used in benthic metrics as indicators of increasingly poor water quality because of the high tolerances of some species to impaired environmental conditions (Barbour and others, 1999).

Kido and Smith (1997) suggested that Hawaii-specific metrics could include such species as the native mountain shrimp, *Atyoida bisulcata*, and the native stream snail, *Neritina granosa*, as indicators of higher quality streams. Dipteran insect species from the endemic genera *Telmatogeton*, *Scatella*, and *Procanace* were recommended by Dan A. Polhemus (Smithsonian Institute) as indicators of moderate to excellent quality stream habitat because they display sensitivity to reduced flow (Kido and Smith, 1997). He also suggested that the native damselflies and dragonflies, although difficult to quantify, also could be possible indicators of high stream quality. A second challenge to the development of invertebrate metrics is that the vast majority of invertebrates collected during stream studies in Hawaii are alien species (Kido and Smith, 1997; Kinzie and others, 1997; Kido and others, 1999a; Wolff, 2000; Brasher and others, 2004; D.A. Polhemus, Smithsonian Institute, oral commun., 2004). Although Hawaii has a diverse and unique endemic fauna, many of these native populations have been reduced and restricted to remote areas (Howarth and Mull, 1992; Polhemus, 1997). Although there is no direct empirical evidence that demonstrates the effect of alien aquatic invertebrate introductions on the native biota of Hawaii, it is believed that native species are preyed upon and/or out-competed by less sensitive, more aggressive alien introductions (Simberloff, 1995).

The introduction of alien fishes also may have affected the native benthic macroinvertebrate communities. Alien fish, such as the mosquitofish *Gambusia affinis*, were introduced intentionally for mosquito control (Van Dine, 1907; Maciolek, 1984; Devick, 1991), but have affected non-target species as well. Polhemus (1997) speculated that the decreased abundances and the narrowing of the native ranges of many species of the endemic damselfly genus *Megalagrion* was due to predation by alien species such as the mosquitofish *G. affinis*, as observed by Zimmerman (1948) and competition from alien species such as the introduced damselflies (*Ischnura ramburii*, *I. posita*, and *Enallagma civile*) and dragonflies. More than 50 species of stream fish, crustaceans, molluscs, amphibians, and reptiles have been introduced into Hawaiian streams (Devick, 1991). Many of these alien species prey on invertebrates. Native invertebrates evolved apart from these predaceous species and sometimes lack the necessary survival responses and life history traits that the alien insects developed, thus giving a survival advantage to the alien species. Additionally, the rates at which the alien species spread to adjacent basins or to other islands are dependent on the dispersal capabilities of the particular species and therefore not necessarily consistent among species and islands. People have accelerated the spread of many alien species as well, either by accident or sometimes purposefully. All these factors, compounded with new records of alien species being brought into Hawaii each year (Evenhuis, 2000; Wolff and others, 2002), makes it difficult to decipher all of the influences that act to create the invertebrate assemblages that we sample.

Methods of Study

Several field procedures and analytical methods were used in this study. These were used to (1) select the sampling sites, (2) collect and process the invertebrate samples, (3) characterize the stream habitat, (4) assess and classify the sites, and (5) develop the preliminary Hawaii benthic index of biotic integrity.

Selection of Sampling Sites

Sampling sites were selected to represent a range of land-use and habitat characteristics on the islands of Oahu and Kauai, including urban (developed, residential and commercial), agricultural, mixed (agriculture and urban), and forested watersheds (figs. 1 and 2). The sites also were selected to represent the different climatic conditions around the islands caused by the prevailing trade winds and mountain ranges. Windward areas tend to have greater mean annual rainfall and cloud cover, leeward areas tend to be sunnier and drier, and central areas have variable weather depending on the elevations of the terrain (Armstrong, 1983). Twenty-one streams were selected to be the focus of the sampling efforts, with one reach on each stream, except for an upper and lower reach on both Kapaa Stream (Makaleha tributary) and Lawai Stream on Kauai (table 1). In addition, at Punaluu Stream, two reaches were selected, one directly upstream of a water diversion and one directly downstream of the diversion. Study reaches were located near USGS streamflow gaging stations whenever possible.

Four additional samples were collected as part of the overall study. Waihee Stream (reach B), first sampled in 1999, was re-sampled in 2000 and 2001 to evaluate consistency over time. Additionally, two adjacent reaches (A, downstream of reach B, and C, upstream of reach B) on Waihee Stream were sampled in 2000 to evaluate consistency among reaches.

Oahu

Samples were collected at 19 sites on 14 streams on Oahu (fig. 1 and table 1). Sites on leeward Oahu included Manoa Stream (MANO), Waiakeakua Stream (WKEA), Nuuanu Stream (NUUA), Waiawa Stream (WAIW), and Kalauao Stream (KALA). Manoa Stream drains the largely residential community of Manoa Valley, which includes the University of Hawaii, and discharges into the Ala Wai Canal near Waikiki. Waiakeakua Stream, a tributary to Manoa Stream, has a mostly forested basin with some small-scale horticulture. Sites on windward Oahu included the urban and agricultural drainages of Waimanalo Stream (WAIM), Luluku Stream (LULU), and Kaneohe Stream (KANE), and forested drainages including Punaluu Stream [above the diversion (PUNA) and below (PUNB)], Waiahole Stream (WHOL), Waihee Stream (WHEE), and Kaluanui Stream (KALU). Central Oahu sites included the urban and agricultural drainages of Waikakalaua Stream (WKAK) and Waikele Stream (WKEL).

Kauai

Samples were collected at 9 sites on 7 streams on the island of Kauai (fig. 2 and table 1). Sites on windward Kauai included forested reference sites at Limahuli Stream (LMAH), within the Limahuli Garden of the National Tropical Botanical Garden, and Hanakapiai Stream (HNKP) within the Na Pali Coast State Park. Central Kauai sites included Makaleha Stream, a tributary to Kapaa Stream (UKPA), and Kapaa Stream (MKPA). Leeward Kauai sites included Huleia Stream (HULA), Puali Stream (PUAL), and Nawiliwili Stream (NWIL) all of which flow into Kalapaki Bay. Lawai Stream, also on the South shore of Kauai, was sampled at an upstream site (ULWI) and at a downstream site (LLWI), the latter within the McBryde Garden of the National Tropical Botanical Garden.

Collection of Invertebrate Samples

Two types of invertebrate samples, quantitative and qualitative, were collected at each site following standard NAWQA protocols (Cuffney and others, 1993). All sampling was conducted during base-flow conditions. Quantitative richest targeted habitat (RTH) samples were collected from the faunistically richest community of benthic invertebrates, which for Hawaiian streams is located in fast-flowing riffles (Michael Kido, Hawaii Stream Research Center; Robert Kinzie, University of Hawaii; and Gordon Smith, U.S. Fish and Wildlife Service, oral commun., 1998; Brasher and others, 2004). Quantitative (RTH) samples provide relative abundances to allow comparisons among sites. Qualitative multi-habitat (QMH) samples were collected from all available habitats within the reach at each site, to provide a comprehensive species list.

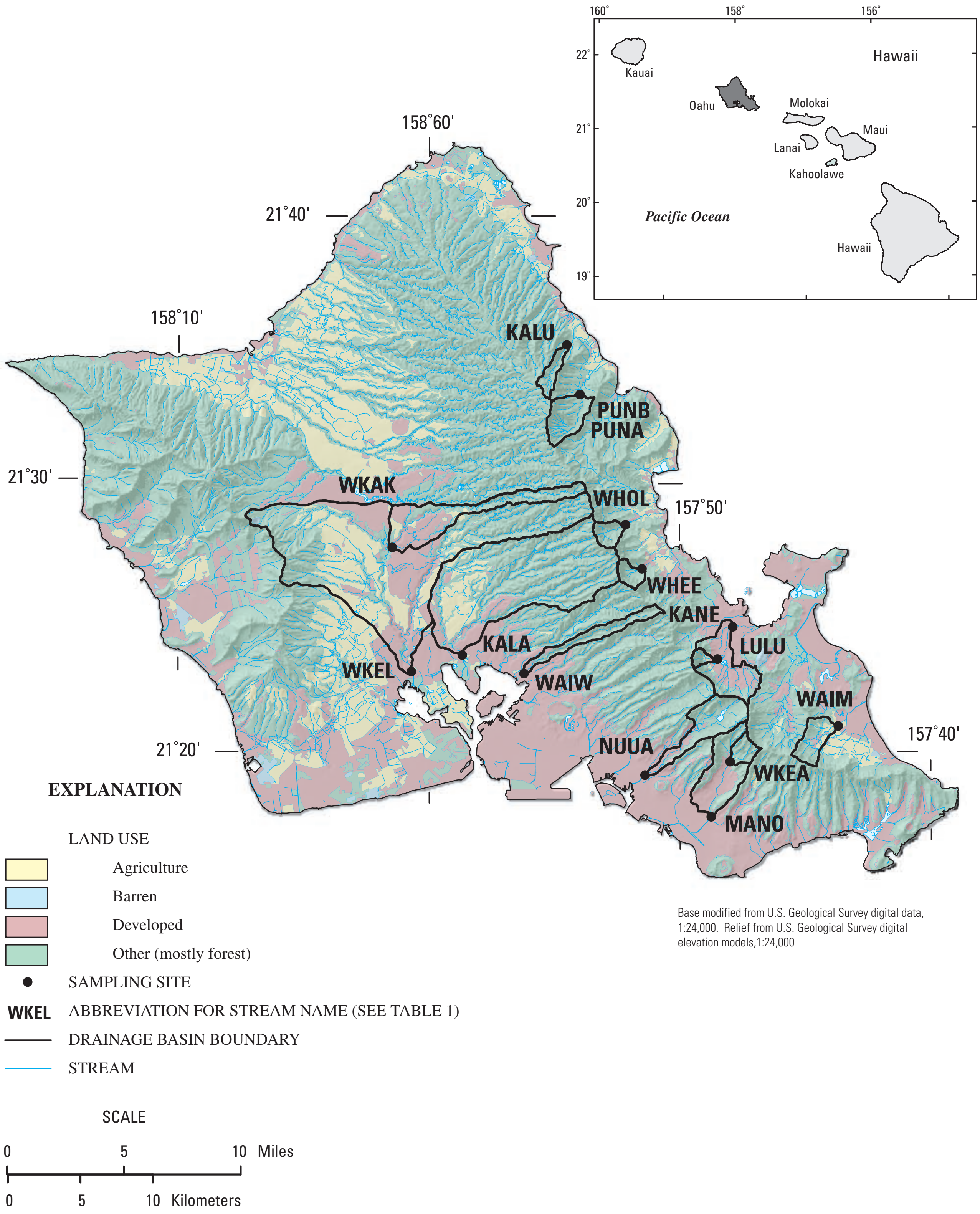


Figure 1. Land use and sampling sites on the island of Oahu, Hawaii. (Modified from Klasner and Mikami, 2003).

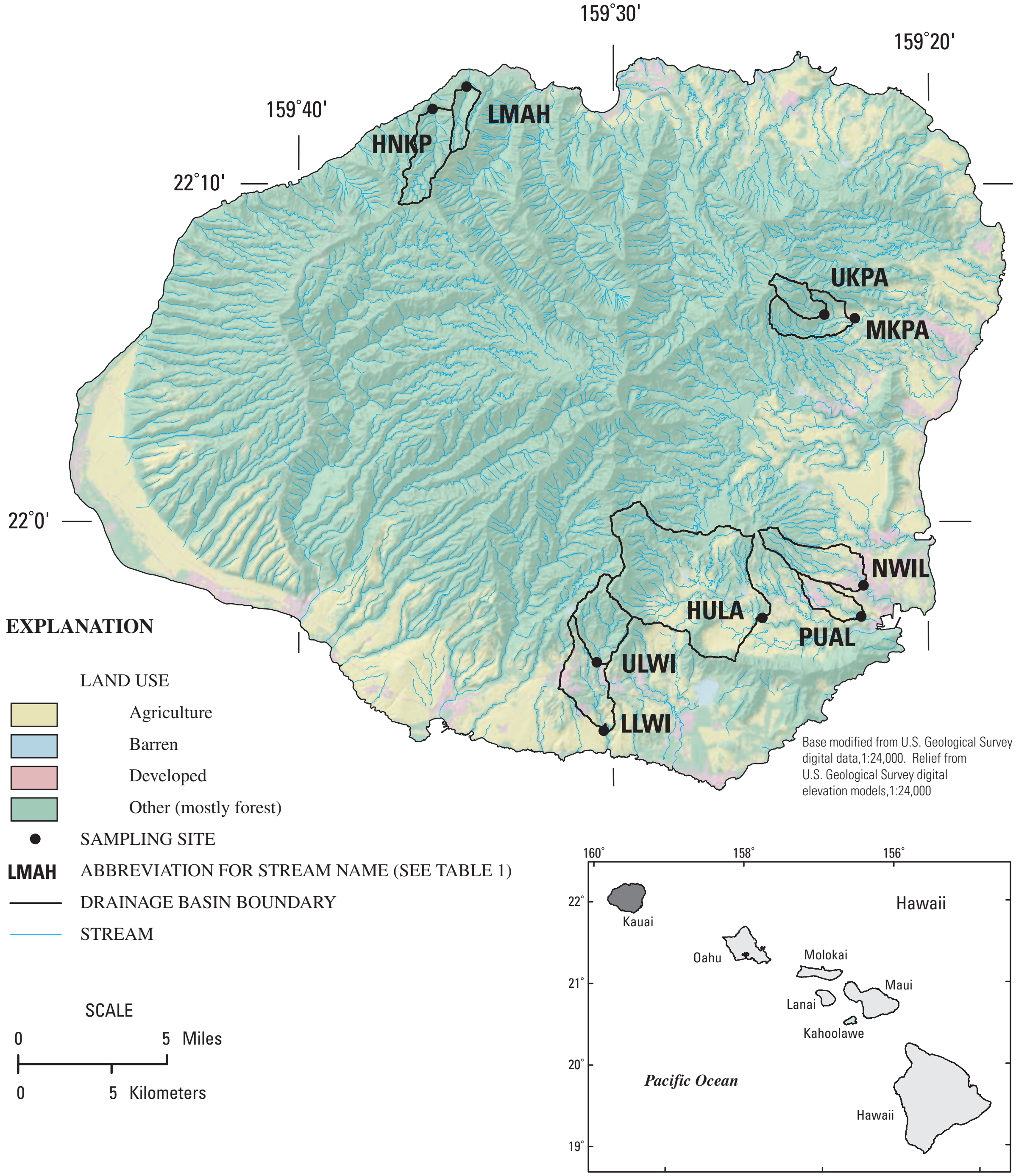


Figure 2. Land use and sampling sites on the island of Kauai, Hawaii.
The Kauai map has been modified to reflect changes in land cover to land use as described in table 3. (Modified from National Oceanic and Atmospheric Administration, 2000).

Table 1. Invertebrate sampling sites and associated land-use percentages.

[Location of sampling sites shown in figures 1 and 2. **Sediment:** M, metals; O, organochlorine compounds. **Used in calibration data set:** ×, site used to calibrate the metrics]

Island	Stream	Reach	Acronym	Invertebrate sampling date	Contaminant sampling		Percentage of land use			Used in calibration data set
					Sediment	Tissue	Agriculture	Developed	Forest	
Oahu	Kalauao		KALA	04-19-02	O[1]	O[1]		13.2	86.8	
	Kaluanui		KALU	08-31-99	M[1]	O[1]			100	
	Kaneohe		KANE	08-17-99	O,M	O	2.7	61.8	35.6	×
	Luluku		LULU	04-24-02	O,M	O	16.9	12.6	70.5	×
	Manoa		MANO	05-10-99	O,M	O	1	38.4	60.7	×
	Nuuanu		NUUA	04-17-02	O,M	O		20.2	79.8	×
	Punaluu	A	PUNA	06-15-99					100	×
	Punaluu	B	PUNB	06-14-99					100	
	Waiahole		WHOL	06-29-99					100	×
	Waiakeakua		WKEA	08-03-99	O,M	O	4.2	0.2	95.6	×
	Waiawa		WAIW	04-23-02	O,M	O	15.3	10.9	73.8	×
	Waihee	B	WHEE B-99	06-08-99	O,M	O		1.2	98.8	×
	Waihee	A	WHEE A-00	05-03-00				1.2	98.8	
	Waihee	B	WHEE B-00	05-02-00				1.2	98.8	
	Waihee	C	WHEE C-00	05-02-00				1.2	98.8	
	Waihee	B	WHEE B-01	05-21-01				1.2	98.8	
	Waikakalaua		WKAK	07-13-99	O,M	O	7.3	40.5	52.2	×
	Waikele		WKEL	05-19-99	O,M	O	25.6	28.5	46	×
	Waimanalo		WAIM	04-15-02	O,M	O	18.5	9.8	71.7	×
Kauai	Hanakapiai		HNKP	05-13-03					100	×
	Huleia	Middle	HULA	06-25-03			6.3	.8	92.9	
	Kapaa	Middle	MKPA	05-05-03			.3	.4	99.4	
	Makaleha	Upper	UKPA	05-14-03			.3	0	99.6	
	Lawai	Upper	ULWI	05-06-03			0	.5	99.5	
	Lawai	Lower	LLWI	05-07-03			1.1	8.8	90.1	
	Limahuli	Upper	LMAH	05-08-03					100	×
	Nawiliwili		NWIL	05-12-03	O,M	O	9	15.6	75.4	×
	Puali		PUAL	05-15-03		O[1]	5.9	22.7	71.4	

[1] Ancillary contaminants data.

RTH samples were collected from five undisturbed riffles using a modified Surber sampler (Slack sampler) with a 425-mm mesh net (Cuffney and others, 1993). All substrate within a 0.25-m^2 area in front of the net was gently dislodged and thoroughly scrubbed to remove all organisms. The five samples were composited and then elutriated and collected on a 425-mm mesh sieve in the field to produce a single sample of approximately 0.75 L.

QMH samples were collected from all available habitats within the reach using a D-frame kick net with a 210-mm mesh. Samples were collected using techniques appropriate for the various habitats being sampled (Cuffney and others, 1993; Brasher and others, 2004). The D-frame kick net collections were supplemented by visual collection, which included manually turning over large rocks, woody debris, and other substrates, and removing all invertebrates present. QMH samples were composited and then elutriated and collected on a 212-mm mesh sieve in the field to produce a single sample of approximately 0.75 L.

Samples collected in 1999 to 2001 were preserved in 10 percent formalin and sent to the USGS National Water-Quality Laboratory Biological Unit in Lakewood, Colorado, for identification and enumeration. Samples collected after 2001 were preserved in 90 percent ethanol and sent to a contract laboratory, EcoAnalysts, Inc. in Moscow, Idaho. Experienced taxonomists did verification of problematic taxa and routine quality-assurance checks on taxonomic identifications.

Data reported for the RTH samples included both species occurrence and density using numeric (300-fixed-count) and time (total sorting time) criteria (Moulton and others, 2000). Data for the QMH samples were analyzed only for species occurrence, using a timed visual sort method. The QMH sampling data were appended with data regarding the presence of macro-crustaceans: *Atyoida bisulcata*, *Macrobrachium grandimanus*, *M. lar*, *Neocaridina denticulata sinensis*, and *Procambarus clarkii*, collected using electrofishing during the Oahu NAWQA study. A voucher collection of the invertebrates is maintained at the USGS, Water Resources office in Honolulu, Hawaii.

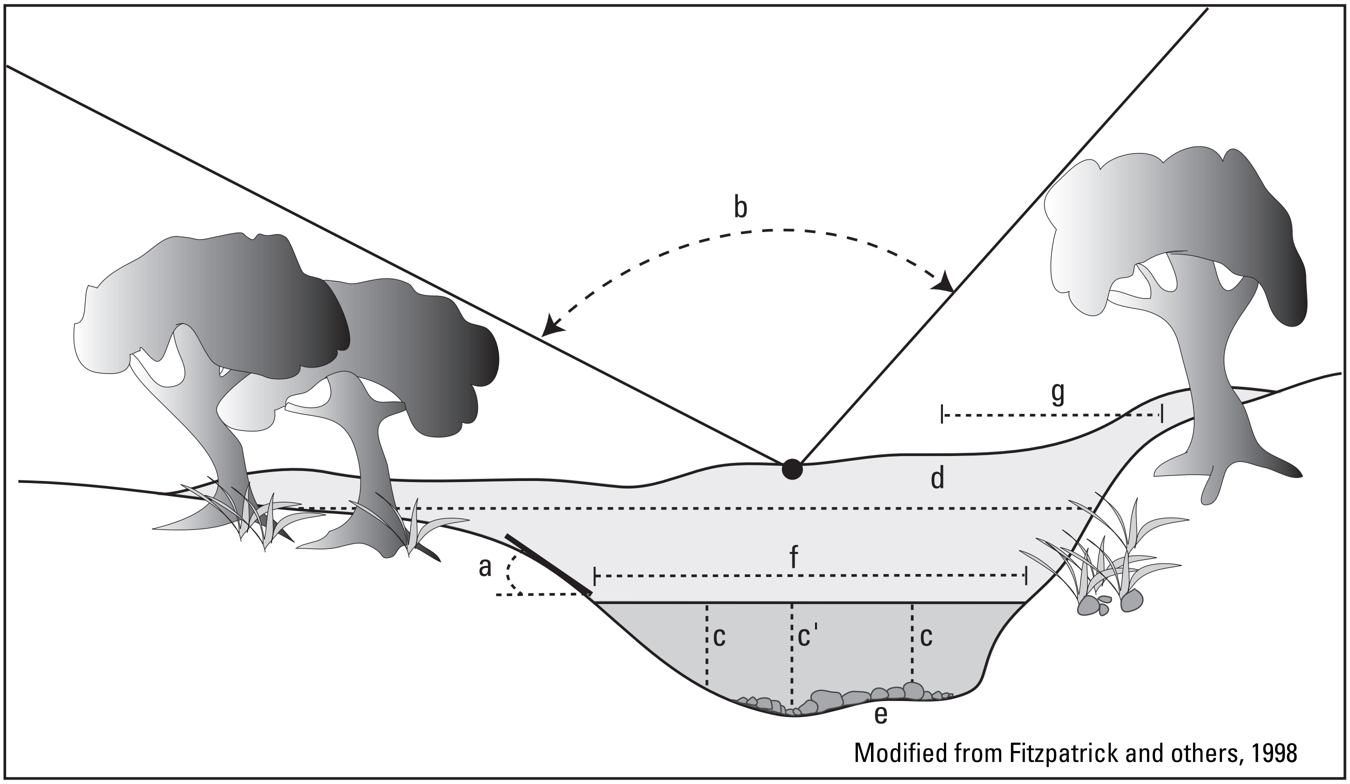
Determination of Habitat Characteristics

Habitat characteristics were determined at multiple spatial scales (basin, reach, transect, and point) following standard NAWQA protocols (Fitzpatrick and others, 1998). Basin characteristics (watershed scale features) such as land use, drainage area, and gradient, were determined using geographic information system (GIS) data and topographic maps. Reach, transect, and point measurements were made at each site on the same day (though in some cases the following day) that the invertebrate samples were collected.

Reach length at each sampling site was determined as the distance equal to 20 times the average stream width, with a minimum length of 100 m. Within each reach, 11 equally spaced transects were established across the stream perpendicular to the direction of flow. Physical measurements of bank and riparian features and instream characteristics were made at each transect (fig. 3). Bank and riparian features included bank angle, erosion, and solar irradiance. Instream habitat measurements included those of features such as the presence or absence of silt, wetted perimeter, depth, velocity, and substrate size. Point measurements of depth and velocity also were made at each location where a quantitative invertebrate sample was collected. At transects 3, 6, and 9 within each reach, a Solar Pathfinder™ was used to estimate the monthly amount of solar irradiance based on the amount of riparian shading and the annual path of the sun.

Environmental Assessments

The following section describes the methods used to assess the environmental quality of the sampling sites. The factors used to assess the sites include land-use and land-cover information, contaminant concentrations in the streambed sediment and in fish tissue, and in-stream habitat conditions.



Modified from Fitzpatrick and others, 1998

Figure 3. Selected habitat measurements made at each transect: (a) bank angle, (b) open canopy angle, (c) stream depth, (c′) thalweg (deepest depth), (d) bank full width, (e) substrate size, (f) wetted channel width, (g) riparian canopy closure.

Basin Characteristics

Point files were created for each island, marking the locations of the sampling sites. Point files were created by the use of a handheld Global Positioning System (GPS) device and interpretation from USGS 1:24000 scale topographic maps in a geographic information system (GIS). Drainage basins for each sampling site were then created using the GIS Weasel, an interface for geospatial information. The GIS Weasel used the point files and the 10 m Digital Elevation Model (DEM) files for each island for the interpretation (Leavesley and others, 1997). Twenty-seven morphometric basin characteristics were then computed using the Basinsoft computer program developed by the USGS (Majure and Soenksen, 1991; and Eash, 1994) with the drainage basin created by the GIS Weasel along with National Hydrography Dataset (NHD) stream data for each island, and the 10 m DEM file (table 2).

Land Use / Land Cover

Land-cover data for the island of Kauai was downloaded from the National Oceanic and Atmospheric Administration (NOAA) website (2000) (http://www.csc.noaa.gov/crs/lca/hawaii.html). Land-use data for the island of Oahu was taken from Klasner and Mikami (2003). The land-use/land-cover data were then converted into a grid file using ArcToolbox™ (version 8.1). Using ArcInfo (version 8.0.2), the grid file was clipped using the drainage basin for each site. The clipped grid attribute table contains a column with the number of grid cells (900 m^3 per cell) for each land-use/land-cover classification. The NOAA land-cover classifications for Kauai were reclassified to fit with the land-use classification scheme used by Klasner and Mikami (2003) (table 3). The percentage each of NOAA land-cover classification within the drainage basin was then calculated by dividing the total number of grid cells for each new land-use classification within the basin by the total number of grid cells within the entire drainage basin.

Contaminants

Fish tissue and/or streambed sediment samples were collected from 14 of the study streams (table 1), primarily as part of the NAWQA program to assess the occurrence and distribution of hydrophobic organic compounds (including organochlorine pesticides, polychlorinated biphenyls, and semi-volatile organic compounds) and trace elements (Brasher and Anthony, 2000; Brasher and Wolff, 2004). Methods for collecting and processing sediment and biota followed NAWQA protocols (Crawford and Luoma, 1993; Shelton and Capel, 1994), and all samples were analyzed at the USGS National Water Quality Laboratory in Arvada, Colorado.

Table 2. Basin characteristics calculated using the Basinsoft program.

[**Source:** Majure and Soenksen, 1991. **Abbreviations:** mi^2, square mile; mi, mile; ft/mi, foot per mile; ft, foot; °,degree; mi/mi^2, square mile per mile]

Basin-area quantifications (mi^2)
NCDA–Noncontributing drainage area
TDA–Total drainage area
Basin-length quantifications (mi)
BL–Basin length
BP–Basin perimeter
Basin-relief quantifications
BS–Average basin slope (ft/mi)
BR–Basin relief (ft)
Basin-aspect quantification (°)
BA–Basin azimuth
Basin computations
RR–Relative relief (ft/mi)
SF–Shape factor (dimensionless)
ER–Elongation ratio (dimensionless)
BW–Effective basin width (mi)
CDA–Contributing drainage area (mi^2)
CR–Compactness ratio (dimensionless)
RB–Rotundity of basin (dimensionless)
Channel- or stream-length quantifications (mi)
MCL–Main channel length
TSL–Total stream length
Channel-relief quantification (ft/mi)
MCS–Main-channel slope
Channel or stream computations
MCSP–Main channel slope proportion (dimensionless)
CCM–Constant of channel maintenance (mi^2/mi)
MCSR–Main-channel sinuosity ratio (dimensionless)
RN–Ruggedness number (ft/mi)
SD–Stream density (mi/mi^2)
SR–Slope ratio of main-channel slope to basin slope (dimensionless)
Stream-order quantifications
BSO–Basin Stream Order (dimensionless)
FOS–Number of first-order streams within the CDA (dimensionless)
Stream-order computations
DF–Drainage frequency (number of first-order streams per mi^2)
RSD–Relative stream density (dimensionless)

Table 3. Reclassification scheme for National Oceanic and Atmospheric Administration (NOAA) land-cover classes.

[**Source**: Klasner and Mikami, 2003]

NOAA land-cover class	Land-use classes
	Level 1 reclassification
Background	Forest
Unclassified	Forest
High intensity developed	Developed
Low intensity developed	Developed
Cultivated land	Agriculture
Grassland	Agriculture
Deciduous forest	Forest
Evergreen forest	Forest
Mixed forest	Forest
Scrub/shrub	Agriculture
Palustrine forested wetland	Forest
Palustrine scrub/shrub wetland	Forest
Palustrine emergent wetland	Forest
Estuarine forested wetland	Forest
Estuarine scrub/shrub wetland	Forest
Estuarine emergent wetland	Forest
Unconsolidated shore	Forest
Bare land	Forest
Water	Forest

Guidelines have been established for certain contaminants to help determine concentrations of chemicals likely to be associated with adverse biological effects. Concentrations of chemicals in streambed sediments were evaluated using the Canadian Sediment Quality Guidelines (CSQG) for aquatic life (Canadian Council of Ministers of the Environment, 1999). Concentrations of chemicals in fish tissue were compared with the NYSDEC (New York State Department of Environmental Conservation) guidelines for the protection of mammals and birds that consume fish (Newell and others, 1987). Two assessment values have been calculated for the CSQG. The lower value, or Interim Sediment Quality Guidelines (ISQG), represents the concentration below which adverse effects to aquatic biota are rarely expected to occur. The upper value, the Probable Effect Level (PEL), defines the level above which adverse effects to aquatic biota are expected to occur frequently. These guidelines are based on chronic (long-term) effects of contaminants on aquatic organisms (Canadian Council of Ministers of the Environment, 1999).

Streambed Sediment

A total of 32 organochlorine compounds and 48 trace element concentrations were analyzed in streambed sediment from 11 of the study streams (table 1). Bed sediment at two additional sites was analyzed for either organochlorine compounds only (KALA) or trace elements only (KALU). Sediment samples were collected from undisturbed depositional zones along a 100-m reach at each stream. Sampling was confined to the upper 2 cm of bed sediment, which reflects contaminants most recently deposited in the stream. Subsamples from along the reach were composited and wet-sieved in the field (Shelton and Capel, 1994).

Fish Tissue

Twenty-eight organochlorine compounds were analyzed in fish tissue samples from 14 of the study streams (table 1). Non-native (aquarium) fish were collected using an electrofisher, supplemented by seining as needed. Whole fish were used for analysis, and all fish collected at a site were composited to form a single sample of at least 100 g.

Calibration of Environmental Assessment Classification

A subset of 15 sites was selected to develop and calibrate an impairment classification approach (table 1). These sites were selected because they had the most complete sets of data on land use, contaminants, and habitat. A principal components analysis (PCA) (Kovach, 1998) of the data was used to look for trends that would group sites that were similar in their composition of the environmental variables. Spearman's rank-order correlation analysis, a nonparametric measure, was used to examine the relations among environmental variables and sites to remove redundant variables (SAS Institute, 1993). Percentage variables were arcsine-square root transformed prior to statistical analysis. An outline of the calibration procedures is shown in figure 4.

A combination of parameters from the three datasets was used to determine the level of impairment at each site. The selected parameters within each of the three datasets were individually scored. The final score was determined by summing the individual scores for each site. In some cases, the cumulative distribution function (CDF) method described in Black and MacCoy (1999) was used to score the individual parameters. The cumulative distribution function allows one to observe natural breaks in the data, or, if there are no recognizable breaks, to assign cut-offs at the 33rd and 67th percentiles. An example of the CDF method is shown in figure 5. The *x*-axis represents the values of the hypothetical parameter. The *y*-axis represents the cumulative percentage of the sites. Sizeable vertical stretches between points along the *y*-axis reveal where more than one site had the same value. Sizeable horizontal stretches between points along the *x*-axis reveal gaps in-between the recorded values. If there are no recognizable gaps along the axis, then the values at the intersections of the 33rd and 67th percentiles (the two horizontal dashed lines) and the distribution can be used.

Two land-use categories were used in the analysis (table 4). These included the Level 1 categories: percentage of agricultural land and percentage of developed land. The scores were determined by plotting the CDF for each parameter and identifying breaks in the data (SAS Institute, 1999). If there were no natural breaks in the data, values at the 33rd and 67th percentiles were used.

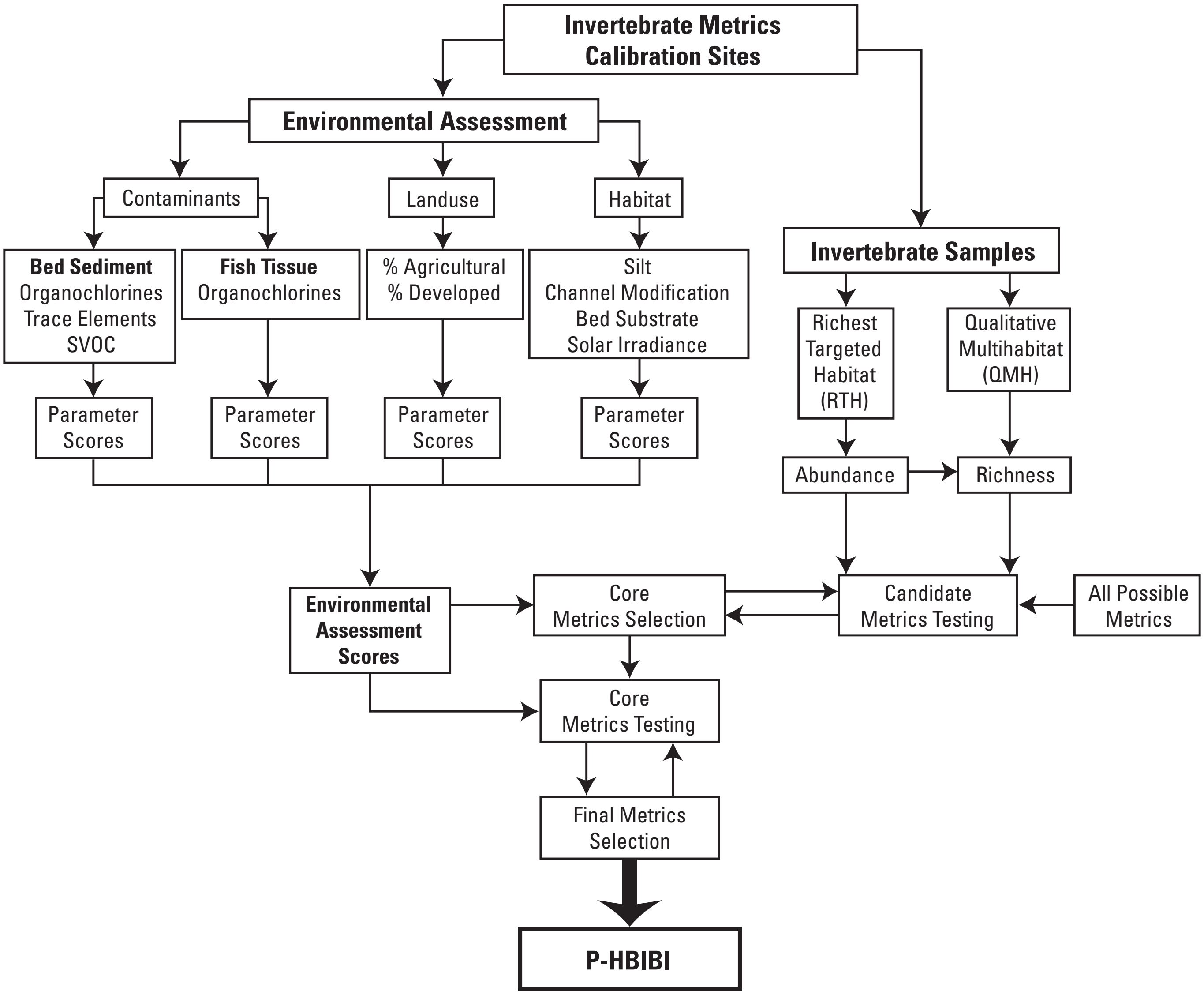


Figure 4. Analytical procedures used to create the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI).

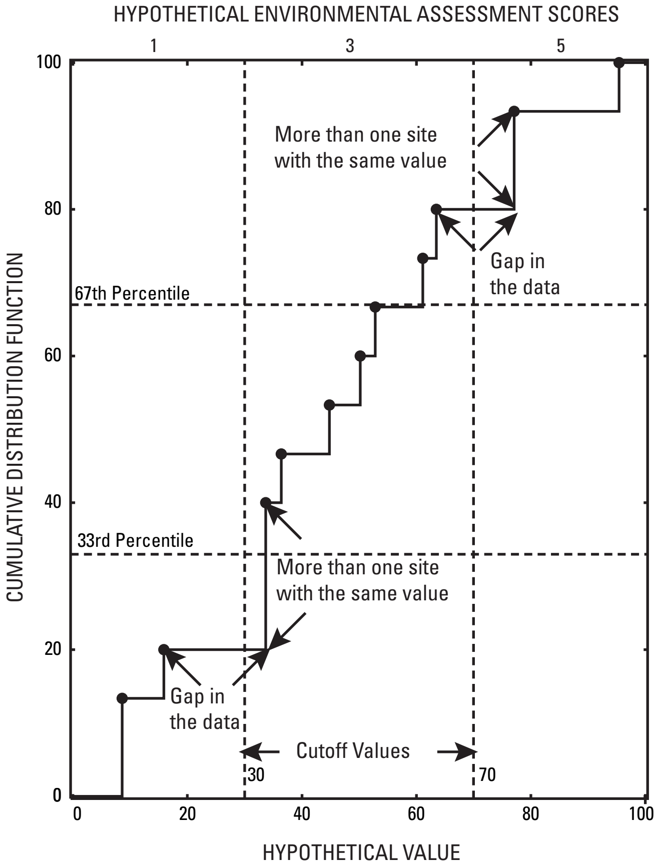


Figure 5. An example of a Cumulative Distribution Function (CDF) used for scoring environmental variables and metrics. Scoring was based on gaps in the data or at the 33rd and 67th percentiles.

Table 4. Criteria and scoring of level 1 land-use categories.

[≤, less than or equal to; >, greater than]

Category	Criteria	Score
Percentage of agricultural land	≤ 0.5	1
	> 0.5 and ≤10.0	3
	> 10.0	5
Percentage of developed land	≤ 0.5	1
	> 0.5 and ≤ 10.0	3
	> 10.0	5

Trace Elements in Bed Sediment: Concentrations of the trace elements arsenic (As), lead (Pb), mercury (Hg) and zinc (Zn) were used to distinguish levels of impairment (table 5). For each constituent, if the ISQG was exceeded, the parameter was scored 1. If the PEL was exceeded, the parameter was scored 2. If neither criterion was exceeded, the parameter was scored 0. The parameter scores for each site were then summed and the sites were scored 1 if the summed score was less than 2, 3 if the sum was greater or equal to 2 and less than 5, and 5 if the sum was greater than or equal to 5.

Organochlorine Compounds in Bed Sediment: Only those compounds with established guidelines were used in the analysis. These included: total DDD, total DDE, total DDT, total chlordane, total heptachlor, total polychlorinated biphenyls (PCBs), and dieldrin. If the ISQG was exceeded, the parameter was scored 1. If the PEL was exceeded, the parameter was scored 2. If neither criterion was exceeded, the parameter was scored 0. The parameter scores for each site were then summed and the sites were scored 1 if the summed score was 0, 3 if the sum was between 1 and 5, and 5 if the sum was greater than 5 (table 6).

Table 5. Criteria and scoring of trace elements in bed sediment.

[<, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to; ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999)]

Criteria	Parameter score	Score
< ISQG	0	
≥ ISQG but < PEL	1	
PEL	2	
Sum of parameter scores	<2	1
	≥ 2 and <5	3
	≥ 5	5

Table 6. Criteria and scoring of organochlorine compounds in bed sediment.

[<, less than; ≤, less than or equal to; >, greater than; ≥ , greater than or equal to; ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999)]

Criteria	Parameter score	Score
< ISQG	0	
≥ ISQG but < PEL	1	
≥ PEL	2	
Sum of parameter scores	0	1
	>1 and ≤5	3
	>5	5

Semivolatile Organic Compounds in Bed Sediment: Only those compounds with established guidelines were used in the analysis. If the ISQG was exceeded, the parameter was scored 1. If the PEL was exceeded, the parameter was scored 2. If neither criterion was exceeded, the parameter was scored 0. The parameter scores for each site then were summed and the sites were scored 1 if the summed score was 0, 3 if the summed score was between 1 and 10, and 5 if the summed score was greater than 10 (table 7).

Organochlorine Compounds in Fish Tissue: The final scores for these compounds were calculated in a three-step procedure (table 8). First, the concentrations of the organochlorine compounds were summed and assigned a score of 0, 1, or 2, according to breaks in the data identified using the CDF technique. Second, if a constituent exceeded the NYSDEC, the constituent was scored 1. If the constituent did not exceed the NYSDEC guideline it was scored 0. Third, both scores were summed and a site score was determined using the CDF technique assigning a site score of 1 if the sum was less than 1, 3 if the sum was less than or equal to 3, and 5 if the sum was greater than 3.

Table 7. Criteria and scoring of semivolatile organic compounds in bed sediment.

[<, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to; ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999)]

Criteria	Parameter score	Score
< ISQG	0	
≥ ISQG but < PEL	1	
≥ PEL	2	
Sum of parameter scores	0	1
	>1 and ≤10	3
	>10	5

Table 8. Criteria and scoring of organochlorine compounds in fish tissue.

[<, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to; NYSDEC, New York State Department of Environmental Conservation guidelines (Newell and others, 1987); Criteria based on the total sum of organochlorine compound concentrations in micrograms per gram dry weight [µg/g]

Criteria	Score 1	Guideline	Score 2
0	0	< NYSDEC	0
>0 but <1,000	1	≥ NYSDEC	1
≥1,000	2		
Final score criteria		**Final score**	
Sum score 1 + Score 2	≤1	1	
	≤3	3	
	>3	5	

Habitat: A principal component analysis and Spearman's rank-order correlation analysis were used to identify and remove redundant correlated habitat variables (SAS Institute, 1993). Variables that failed to differentiate among the sites due to limited ranges of values also were removed. A final set of four habitat parameters, determined at the reach scale, was selected to assess the site condition (table 9). These included channel modification, solar irradiance, dominant bed substrate, and silt. Channel modification, a categorical variable, was assigned scores based on the degree that the stream channel had been altered from its original configuration. The mean annual solar irradiance, determined using a solar pathfinder, was scored using the CDF technique. Solar irradiance values between 30 and 70 percent were scored 1, values less than 30 percent (closed canopy sites) were scored 2, values greater than 70 percent (open canopy sites) were scored 3. Dominant bed substrate scores were determined by, first,

Table 9. Criteria and scoring of habitat parameters.

[<, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to]

Habitat parameter	Criteria	Score
Channel modification	Not modified or lightly modified	1
	Channelized, not stabilized	3
	Stabilized and dredged	5
Solar irradiance	> 30 percent and <70 percent	1
	≤ 30 percent	2
	≥ 70 percent	3
Dominant bed substrate	> 7	1
	>5 and ≤ 7	3
	≤ 5	5
Silt	< 0.52	1
	≥ 0.52	3
	≥ 0.85	5

assigning values to the recorded substrate data (table 10). The values then were summed and divided by the total number of recorded measurements to determine the mean substrate value. The mean values then were scored using the CDF technique Silt scores were calculated from the presence or absence data for silt determined at three locations along each transect. If silt was present at the location, it was assigned a value of 1, if absent it was assigned a value of 0. These values were summed and divided by the number of measurements taken to determine the mean. The mean values then were scored using the CDF technique.

The final environmental assessment scores were calculated by summing the results of all the individual parameters. The CDF method was used to identify breaks in the data and classify the sites as mildly impaired, moderately impaired, or severely impaired (table 11). After the calibration set of sites was classified, the remaining test sites were classified on the basis of a reduced environmental assessment (without the contaminants data), comparisons with the original environmental assessment, and a principal components analysis of the environmental data to identify sites that were similar.

Table 10. Categories and values of substrate.

[**Abbreviations:** mm, millimeter; >, greater than]

Value	Category
1	Smooth bedrock/concrete/hardpan
2	Silt/clay/marl/muck/organic detritus
3	Sand (>0.063–2 mm)
4	Fine/medium gravel (>2–16 mm)
5	Coarse gravel (>16–32 mm)
6	Very coarse gravel (>32–64 mm)
7	Small cobble (>64–128 mm)
8	Large cobble (>128–256 mm)
9	Small boulder (>256–512 mm)
10	Large boulder, irregular bedrock, irregular hardpan, irregular artificial surface (>512 mm)

Table 11. Final ranges classifying the environmental assessment site scores.

[**Abbreviations:** ≤, less than or equal to; >, greater than]

Total score	Impairment category
≤20	Mild
>20 but ≤35	Moderate
>35	Severe

Development of Metrics

The following section describes the diagnostic methods used to resolve taxonomic ambiguities and any differences in laboratory taxonomic-level designations in the data set prior to data analyses. The statistical methodology used to develop the benthic invertebrate multimetric index of biotic integrity also is described.

Taxonomic Ambiguity and Resolution

Before statistical analyses were conducted, the macroinvertebrate RTH data set was reviewed and edited to resolve the occurrences of ambiguous taxa (Maret and others, 2001; Cuffney, 2003). Ambiguous taxa are those taxa whose identifications cannot accurately be determined to the lowest common taxonomical level. For example, some individuals might be identified only to the family level while others may be identified to a genus level within that family, and still others to a species level within that genus. These unresolved taxa frequently are the result of either damaged or immature individuals. The decision-making guidelines that were followed to resolve these ambiguous taxa were: (1) if only one child taxon was present and (a) the abundance of the parent taxon was less than the abundance of the child, the abundance of the parent was added to the child; (b) the abundance of the parent taxon was greater than the abundance of the child, the abundance of the child was added to the parent; (2) if more than one child taxon was present and the abundance of the parent taxon was less than the sum of the child taxa abundance, the abundance of the parent taxon was distributed proportionally among the child taxa according to their abundance.

The RTH and QMH data sets also were edited and standardized for laboratory taxonomic resolution prior to data analyses (appendixes A, B, and C). Several taxonomists at two laboratories processed the invertebrate samples collected over a 5-year period. Differences within and between laboratories can create variability in the numbers and types of taxa in the samples (Maret and others, 2001). The areas of expertise of the laboratory personnel as well as the goals of the NAWQA study resulted in data sets that were unevenly identified to lower taxonomic levels. For example, the NAWQA protocol set the resolution level for aquatic worms at the family taxonomic level. However, the EcoAnalysts, Inc., laboratory identified the aquatic worms to the species level. To standardize these differences, the lower taxa were combined into the higher taxonomic designation that was common to all the sample results. These resolutions were especially important in the insect family Chironomidae. The final richness data set was a combination of the RTH, QMH, and crustacean data collected during electrofishing surveys (appendix D).

Many of the taxonomical designations were not resolved to the species level, but designations to the genus, family, or order levels were common. Because many species were commonly within these higher designations, and some of these species were native to Hawaii while others were not, the residency status of these taxa was described as “undetermined.” The residency status for endemic species (known only from Hawaii) and indigenous species (naturally occurring in Hawaii as well as other places) was described as “native,” while all introduced species were described as “alien.” Only in cases in which the entire genus or family was endemic to Hawaii were they described as “native” (Merritt and Cummins, 1984; Nishida, 2002).

Metrics

A large number of metrics for aquatic invertebrate communities have been developed and used by previous investigations to evaluate environmental conditions (For a detailed list, see Barbour and others, 1999; Black and MacCoy, 1999). The Invertebrate Data Analysis System (IDAS), developed for the NAWQA program, lists more than 140 community metrics (Cuffney, 2003). These potential metrics require testing and calibrating to validate their ability to distinguish impaired sites from unimpaired sites on a regional basis (Barbour and others, 1999). Four basic categories of metrics were investigated for this study:

- *Taxa Richness:* the number of distinct taxa regardless of abundance of the taxa. This can be the overall number of distinct taxa, or the number of taxa within a group such as a family. Richness metrics also include the percentage of the total richness represented by a group.

- *Taxa Abundance:* the number of individuals. Abundance metrics can include the total number of individual invertebrates in a sample or the number of invertebrates within a group such as a species. Abundance metrics include relative abundance attributes such as the percentage of the total represented by a group.

- *Tolerance/intolerance*: abundance and richness metrics based on regional tolerance values compiled from Barbour and others (1999) and Mandaville (2002) and modified for sensitive Hawaiian endemic species. The Hilsenhoff Biotic Index uses the tolerance values to calculate the impairment level of sites (Hilsenhoff, 1988).

- *Trophic functional feeding groups*: abundance and richness metrics based on behavioral attributes such as “scrapers” or “predators.” Aquatic insect functional groups were based on Merritt and Cummins (1984).

Most metrics developed for continental streams have known predicted responses to environmental impacts (Barbour and others, 1999; Black and MacCoy, 1999). In Hawaii, however, these predicted responses might not be the same. The known predicted responses of the possible metrics were compared to the responses determined in Hawaiian streams.

The limited number of taxa identified in the samples narrowed down the list of possible candidate metrics. Individual candidate metrics were tested with data from the subset of sites that previously had been assigned an impairment classification using the environmental assessment methods mentioned earlier. Candidate metrics that demonstrated an ability to differentiate among sites were added to the model for further testing. Each metric value was plotted against the site impairment classification in an XY (scatter) chart. The plots were examined to observe the degree of separation of the mildly impaired sites from the severely impaired sites. Metrics that were capable of differentiating mildly impaired sites from severely impaired sites were included in the analysis as core metrics.

Each core metric that was incorporated into the analysis was scored using the CDF method of Black and MacCoy (1999) as described in the site classification methods mentioned earlier. Ranges of values were scored as 1, 3, or 5, (a score of 7 was possible in one metric) as derived by either natural breaks in the data, or, in the absence of any natural breaks, by the 33rd and 67th percentile, or a combination of the methods, if only 1 natural break was observed. The preliminary Hawaii benthic index of biotic integrity, P-HBIBI, then was calculated as the sum of the metric scores for each site (fig. 6). The P-HBIBI was determined using regression analysis (Proc REG) in an iterative process testing various suites of core metrics to develop the simplest yet most informative group of final metrics with the greatest coefficient of determination (r^2) value. The regression analysis used the linear equation with site impairment as the independent variable and the various metrics values as the dependent variable. The r^2 value is the ratio of the explained sum of squares to the total sum of squares. The final P-HBIBI range of values then was scored using the CDF method, to identify the three impairment categories.

After the P-HBIBI was developed from the calibration set of sites, it was applied to the remaining sites (excluding the multi-year, multi-reach sites at Waihee) and these sites were assigned to an impairment category. The impairment categories assigned by the P-HBIBI then were compared to the impairment categories resolved from a reduced environmental assessment without the contaminants parameters. Regression analysis was used to determine the fit of the P-HBIBI across all the sites. The multi-year, multi-reach sites at Waihee were analyzed independently to examine spatial and temporal patterns. The results of the P-HBIBI analyses then were compared with the results of the site classification analysis for the remaining sites.

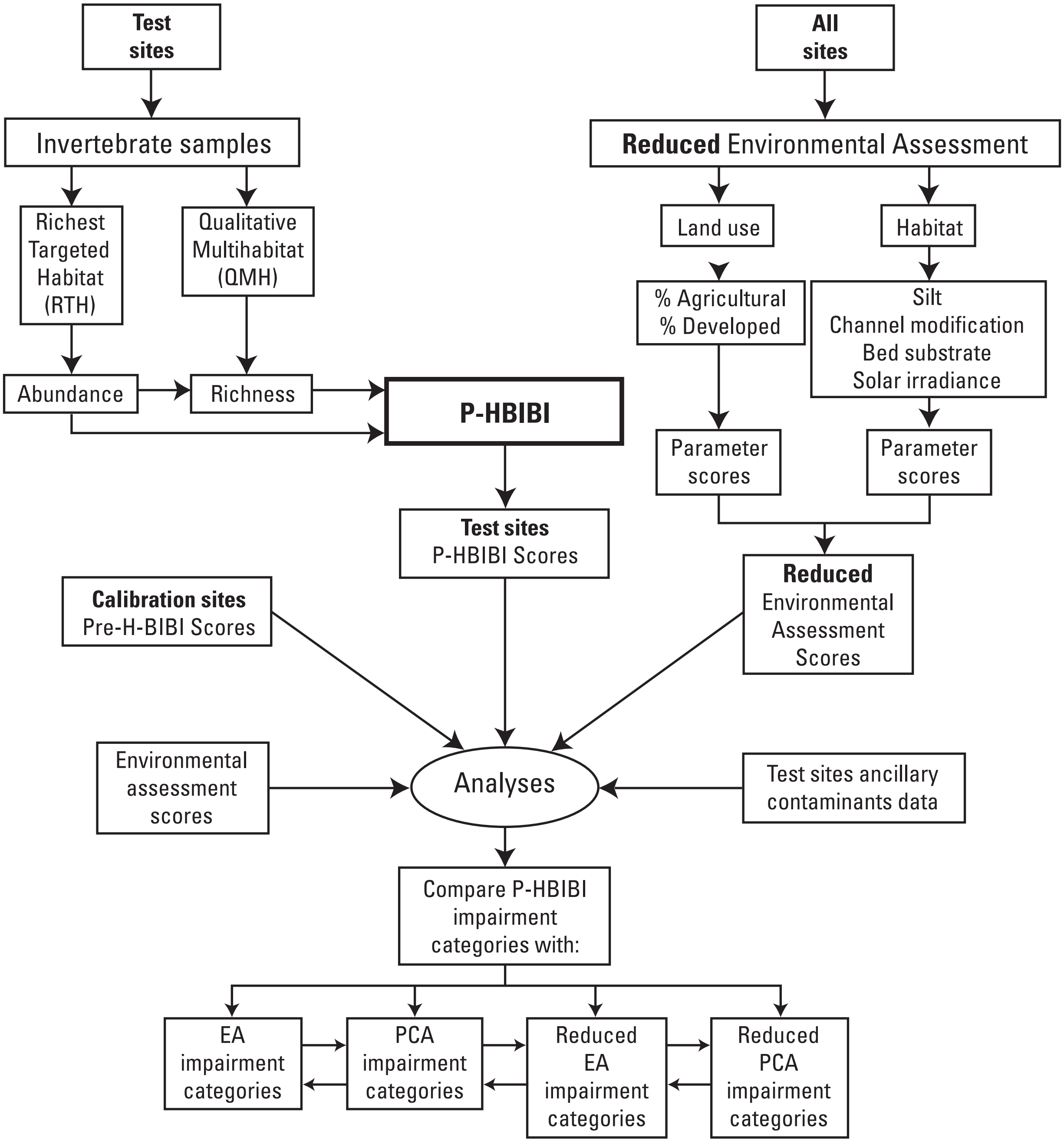


Figure 6. Analytical procedures used to test the preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI).

Results of Data Analyses—Using Benthic Invertebrates as Indicators of Stream Quality

This section includes the results of the environmental assessment analysis and the statistical analysis of the invertebrate data. The results and a discussion pertaining to the development of the P-HBIBI for Hawaiian streams also are included in this section.

Environmental Assessments

A subset of 15 of the 24 sites was used to calibrate the classification of impairment levels of the stream reaches (table 1). The results of the principal components analysis revealed trends common to sites with similar environmental characteristics (fig. 7). The first principal component separated the forested sites from the developed sites along the first axis, with an eigenvalue, the variance of the component, accounting for 46 percent of the total variance (table 12). The second principal component identified the agricultural and commercial sites along the second axis, with an eigenvalue accounting for 19 percent of the total variance. Four groups of sites representing different degrees of environmental impairment were identified using PCA (fig. 7) and Spearman's rank-order correlation analysis.

One group of sites was identified as predominantly forested, having little or no anthropogenic input and relatively undisturbed streams. This group includes the relatively “pristine” forested reference condition sites: LMAH, HNKP, PUNA, and WHOL (see table 1 for explanation of abbreviations for site names). Although none of these forested reference condition sites were sampled for bed sediment or fish tissue contaminants, it was reasoned that these sites would have contaminant concentrations no greater than concentrations recorded from the other less-remote forested site (WHEE) where contaminant samples were collected. This assumption was based on the knowledge that the two Oahu sites, PUNA and WHOL, are completely forested, comparatively distant from the developed coastal land, and reasonably distant from any direct sources of contamination. Both sites, located in more remote areas in the general vicinity of WHEE (windward coast) are affected by the same prevailing winds and atmospheric deposition as WHEE (Armstrong, 1983). Furthermore, in a review of the contaminants data for Oahu sites that were not included in this study, only minor concentrations of a few ubiquitous contaminants were detected at forested sites that were distant from the coast (Brasher and Wolff, 2004). The Kauai “reference sites,” LMAH and HNKP, are both remote sites on the northern side of Kauai. Both of these sites are accessible only by moderately long hikes into the valleys. No local sources of contaminants are at either site. The only anthropogenic inputs would be atmospheric, with the principal sources located to the south. The prevailing northeasterly trade winds blow in the opposite direction and carry any locally derived contaminants away from these sites (Armstrong, 1983). Only two sites on Kauai were sampled for contaminants (NWIL and PUAL); both are in the more-developed southeastern part of the island.

A second group of three sites was identified as consisting predominantly of urban land-use sites. These sites, KANE, MANO, and NUUA, were associated with organochlorine contaminants, residential land use, and channel modification. A third group, WKEL, WKAK, and NWIL, was associated with agricultural and industrial variables including DDT, Hg, semi-volatile organochlorine compounds (SVOC), and siltation. A fourth group, consisting of WAIW, LULU, WAIM, and WKEA, included sites that had agricultural and developed land, but were affected to a lesser degree by contaminants.

Table 12. Eigenvalues and variable loadings for the Principal Components Analysis (PCA) of environmental variables.

[**Abbreviations:** As, arsenic; Hg, mercury; OC, organochlorine compounds; Pb, lead; Zn, zinc; SVOC, semi-volatile organochlorine compounds. Values in **bold** had the most influence on the axis]

Eigenvalues	Axis 1	Axis 2
Eigenvalues	7.354	3.055
Percentage	45.961	19.097
Cumulative percentage	45.961	65.058
PCA variable		
Variable		
Solar	0.085	-0.207
Channel modification	**.329**	.009
Silt	.099	**.386**
Dominant substrate	-.277	-.236
Agricultural land use	.068	**.509**
Developed land use	**.310**	.160
Bed sediment As	.037	.272
Bed sediment Pb	**.322**	-.133
Bed sediment Hg	.105	.287
Bed sediment Zn	**.334**	.133
Bed sediment OC	.271	-.247
Fish tissue total chlordane	**.317**	-.200
Fish tissue total DDT	.138	.090
Fish tissue total dieldrin	**.323**	-.232
Fish tissue total heptachlor	**.315**	-.257
SVOC guideline exceedances	.272	.218

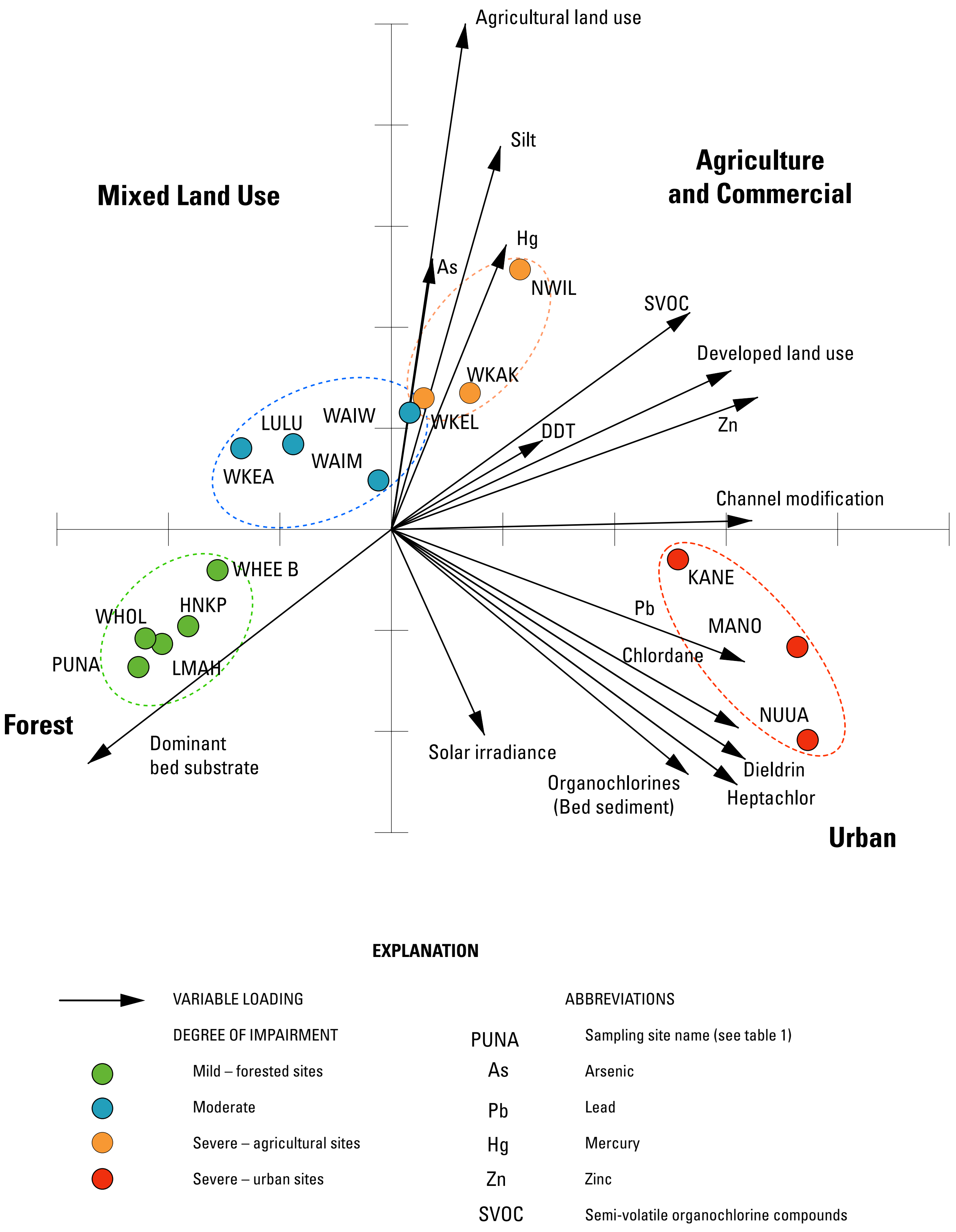


Figure 7. Principal Components Analysis (PCA) using the environmental variables at sampling sites on Hawaiian streams. Clustered sites (same color) display similar environmental conditions or levels of impairment that differ from those at sites in other clusters.

Environmental Assessment Scoring

The total scores for the level 1 land-use categories ranged from a low of 2 for the 100 percent forested sites to a high of 10 for WKEL, the largest drainage in the study as well as having agricultural, residential, and commercial land use (table 13; fig. 8). The total scores for the habitat variables ranged from a low of 4 for the forested, unmodified sites, to a high of 18 at WAIM, a rural residential and agricultural drainage (table 14; fig. 9). The total scores for the trace elements ranged from a low of 1 at the forested sites to a high of 7 at NWIL, an urbanized and agricultural/industrial drainage (table 15). The NWIL site is downstream of a now non-operational sugar cane processing mill. The total scores for organochlorine compounds in bed sediment ranged from a low of 0 for the forested sites as well as LULU, a mixed land-use site, to a high of 13 at MANO, a highly urbanized residential drainage (table 16). The total scores for semi-volatile organochlorine compounds in bed sediment ranged from a low of 0 at the forested sites as well as at WAIM, a rural agricultural drainage, to a high of 11 at WKEL (table 17). The total scores for organochlorine compounds in fish tissue ranked the urban sites MANO, NUUA, and KANE as the most affected (tables 18 and 19). These sites had the highest total concentrations of organochlorine compounds, and three constituents (total chlordane, total dieldrin, and total heptachlor) exceeded NYSDEC guidelines at MANO and NUUA (table 18).

Table 13. Environmental assessment scores for land-use percentages.

[See table 1 for site names]

Site	Developed land		Agricultural land		Total
	Percentage	Score	Percentage	Score	
HNKP	0.00	1	0.00	1	2
LMAH	.00	1	.00	1	2
PUNA	.00	1	.00	1	2
WHEE B-99	1.18	1	.00	1	2
WHOL	.00	1	.00	1	2
NUUA	20.20	3	.00	1	4
WKEA	.15	1	4.23	3	4
KANE	61.75	5	2.68	3	8
LULU	12.62	3	16.88	5	8
MANO	38.36	5	.96	3	8
NWIL	15.61	3	26.29	5	8
WAIM	9.84	3	18.48	5	8
WAIW	10.89	3	15.27	5	8
WKAK	40.49	5	7.27	3	8
WKEL	28.45	5	25.60	5	10

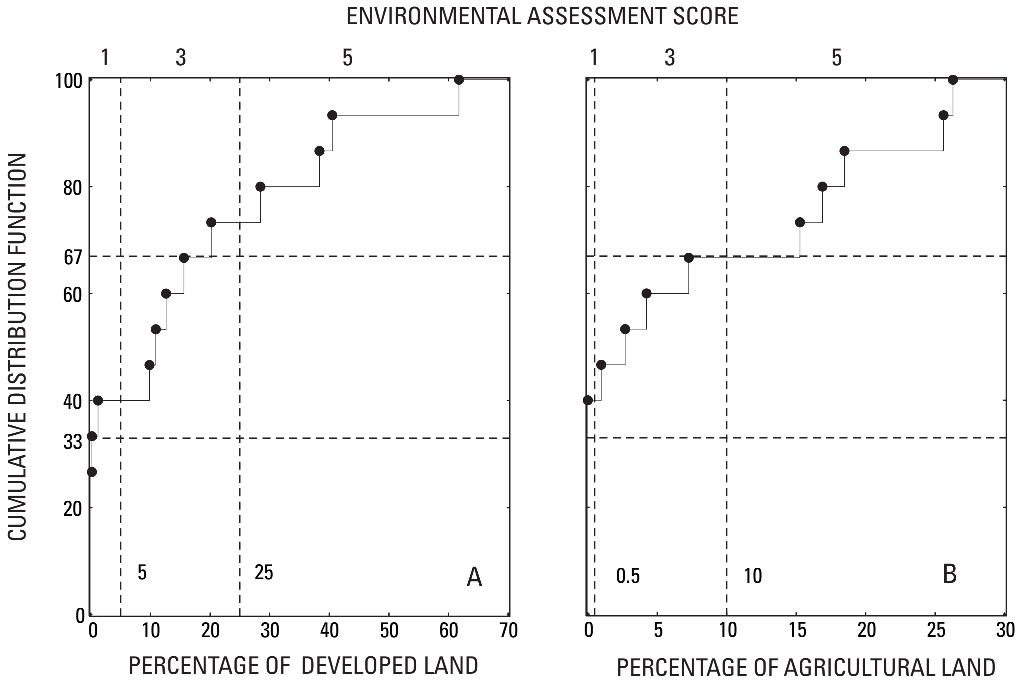


Figure 8. Cut-off values for the scoring range of the land-use variables (A) percentage of developed land; (B) percentage of agricultural land.

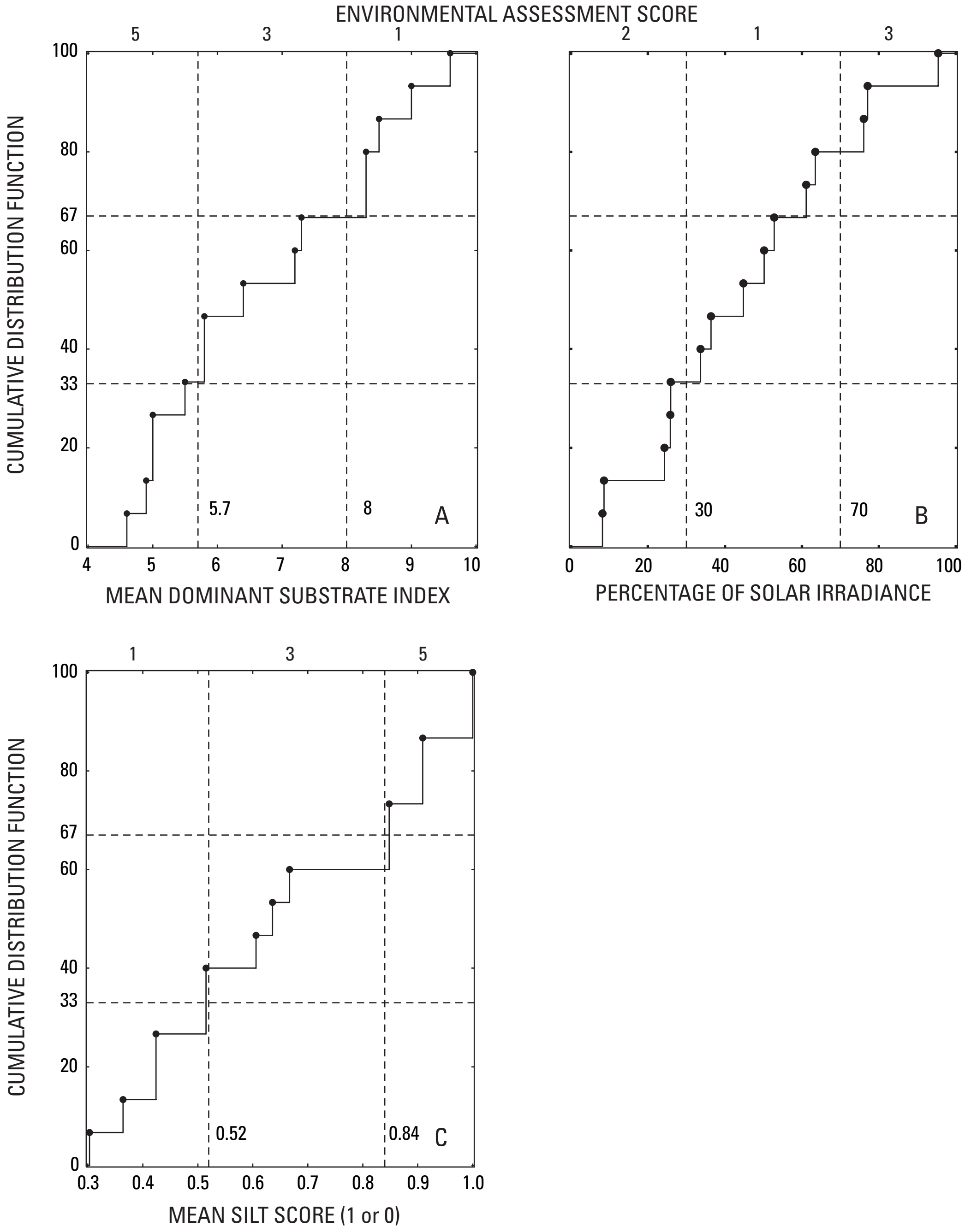


Figure 9. Cut-off values for the scoring range of the habitat variables (A) mean dominant substrate, (B) percent solar irradiance, and (C) mean silt score.

Table 14. Environmental assessment scores for reach-level habitat variables.

[See table 1 for site names]

Site	Percentage of solar irradiance	Solar irradiance rank	Channel modification	Channel modification rank	Mean silt score	Silt rank	Mean dominant bed substrate	Dominant bed substrate rank	Total
HNKP	61.08	1	Not modified	1	0.52	1	8.27	1	4
LMAH	44.75	1	Not modified	1	.42	1	9.61	1	4
PUNA	52.75	1	Not modified	1	.30	1	9.00	1	4
WHOL	36.39	1	Not modified	1	.42	1	8.52	1	4
LULU	8.56	2	Lightly affected	1	.52	1	7.21	3	7
WHEE B-99	24.31	2	Lightly affected	1	.61	3	6.39	3	9
WKEA	25.92	2	Lightly affected	1	.91	5	8.30	1	9
NUUA	50.25	1	Stabilized	5	.36	1	5.45	5	12
WAIW	33.67	1	Channelized, not stabilized	3	.91	5	5.76	3	12
NWIL	8.19	2	Channelized, not stabilized	3	.67	3	4.58	5	13
KANE	63.46	1	Stabilized	5	.64	3	4.88	5	14
WKEL	77.08	3	Channelized, not stabilized	3	1.00	5	7.33	3	14
WKAK	25.83	2	Channelized, not stabilized	3	1.00	5	5.00	5	15
MANO	76.11	3	Concrete lined, stabilized	5	.85	5	5.85	3	16
WAIM	95.42	3	Stabilized	5	.85	5	5.00	5	18

Table 15. Environmental assessment scores for trace elements in bed sediment.

[**Abbreviations:** NA, not analyzed for; S, score; V, value. **Acronyms:** ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999). Concentrations in micrograms per gram dry weight [µg/g] unless otherwise specified. Scores based on exceeding the ISQG (1) or the PEL (2). See table 1 for site names]

PEL ISQG	Arsenic 5.9 17		Lead 35 91.3		Mercury 0.17 0.48		Zinc 123 315		Sum of scores	Final score
Site	V	S	V	S	V	S	V	S		
HNKP	NA		NA		NA		NA		1	1
LMAH	NA		NA		NA		NA		1	1
PUNA	NA		NA		NA		NA		1	1
WHOL	NA		NA		NA		NA		1	1
WAIM	4.8	0	21	0	0.04	0	200	1	1	1
WHEE B-99	1.9	0	6	0	.09	0	160	1	1	1
WAIW	5.4	0	58	1	.12	0	270	1	2	3
WKEL	5.0	0	23	0	.18	1	270	1	2	3
WKAK	4.1	0	59	1	.19	1	290	1	3	3
WKEA	44.0	2	22	0	.15	0	250	1	3	3
KANE	11.0	1	82	1	.12	0	470	2	4	3
LULU	29.0	2	60	1	.08	0	260	1	4	3
MANO	16.0	1	120	2	.17	0	420	2	5	5
NUUA	4.5	0	220	2	.33	1	480	2	5	5
NWIL	29.0	2	58	1	1.50	2	430	2	7	5

Table 16. Environmental assessment scores for organochlorine pesticides in bed sediment.

[**Abbreviations:** NA, not analyzed for; S, score; V, value. **Acronyms:** ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999). Concentrations in microgram per kilogram dry weight [µg/kg] unless otherwise specified. Scores based on exceeding the ISQG (1) or the PEL (2). See table 1 for site names]

ISQG PEL	Endrin 2.67 62.4		Total DDD 3.54 8.51		Total DDE 1.42 6.75		Total DDT 1.19 4.77		Total dieldrin 2.85 6.67		Total heptachlor 0.6 2.74		Total PCB 34.1 277		Total chlordane 5.4 8.87		Sum of scores	Final score
Site	V	S	V	S	V	S	V	S	V	S	V	S	V	S	V	S		
HNKP	NA		NA		NA		NA		NA		NA		NA		NA		0	1
LMAH	NA		NA		NA		NA		NA		NA		NA		NA		0	1
PUNA	NA		NA		NA		NA		NA		NA		NA		NA		0	1
WHOL	NA		NA		NA		NA		NA		NA		NA		NA		0	1
LULU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WHEE B-99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WKEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	2	2	3
WAIM	0	0	0	0	2	1	0	0	3	1	0	0	30	0	8	1	3	3
NWIL	0	0	0	0	3	1	0	0	20	2	0	0	0	0	41	2	5	3
WAIW	0	0	0	0	4	1	3	1	2	0	0	0	80	1	12	2	5	3
KANE	0	0	2	0	1	0	0	0	71	2	18	2	0	0	114	2	6	5
WKEL	0	0	4	1	32	2	18	2	2	0	0	0	160	1	12	2	8	5
WKAK	0	0	51	2	13	2	23	2	3	1	0	0	0	0	11	2	9	5
NUUA	3	1	4	1	4	1	3	1	300	2	20	2	950	2	349	2	12	5
MANO	0	0	9	2	9	2	5	2	150	2	8	2	60	1	294	2	13	5

Table 17. Environmental assessment scores for semi-volatile organochlorine compounds in bed sediment.

[**Abbreviations:** NA, not analyzed for; S, score; V, value. **Acronyms:** ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999). Concentrations in microgram per kilogram dry weight [µg/kg]. Scores based on exceeding the ISQG (1) or the PEL (2). See table 1 for site names]

ISQG PEL	Acenaphthene 6.7 89		Acenaphthylene 5.9 128		Anthracene 47 245		Benzo(a) anthracene 32 385		Benzo(a) pyrene 32 782		Chrysene 57.1 862		Dibenzo(a,h) anthracene 6.2 135	
Site	V	S	V	S	V	S	V	S	V	S	V	S	V	S
HNKP	NA		NA		NA		NA		NA		NA		NA	
LMAH	NA		NA		NA		NA		NA		NA		NA	
PUNA	NA		NA		NA		NA		NA		NA		NA	
WHOL	NA		NA		NA		NA		NA		NA		NA	
WAIM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEE B-99	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WKEA	0	0	0	0	0	0	0	0	10	0	0	0	0	0
LULU	0	0	0	0	30	0	50	1	50	1	50	0	0	0
WKAK	0	0	0	0	0	0	40	1	60	1	50	0	20	1
KANE	0	0	0	0	60	1	220	1	250	1	360	1	0	0
NUUA	0	0	0	0	60	1	230	1	260	1	350	1	0	0
MANO	0	0	20	1	320	2	340	1	330	1	420	1	0	0
NWIL	0	0	40	1	50	1	140	1	130	1	180	1	30	1
WAIW	10	1	70	1	60	1	230	1	210	1	310	1	30	1
WKEL	0	0	0	0	70	1	440	2	440	1	620	1	80	1

Table 17. Environmental assessment scores for semi-volatile organochlorine compounds in bed sediment.—Continued

[**Abbreviations:** NA, not analyzed for; S, score; V, value. **Acronyms:** ISQG, Interim Sediment Quality Guidelines; PEL, Probable Effect Level (Canadian Council of Ministers of the Environment, 1999). Concentrations in micrograms per kilogram dry weight [µg/kg]. Scores based on exceeding the ISQG (1) or the PEL (2). See table 1 for site names]

ISQG PEL	Fluoranthene 111 2,355		Naphthalene 35 391		Phenanthrene 41.9 515		Pyrene 53 875		Sum of scores	Final score
Site	**V**	**S**	**V**	**S**	**V**	**S**	**V**	**S**		
HNKP	NA		NA		NA		NA		0	1
LMAH	NA		NA		NA		NA		0	1
PUNA	NA		NA		NA		NA		0	1
WHOL	NA		NA		NA		NA		0	1
WAIM	10	0	0	0	0	0	10	0	0	1
WHEE B-99	0	0	0	0	0	0	0	0	0	1
WKEA	0	0	0	0	0	0	0	0	0	1
LULU	60	0	0	0	30	0	50	0	2	3
WKAK	100	0	0	0	40	0	100	1	4	3
KANE	530	1	0	0	270	1	450	1	7	3
NUUA	580	1	0	0	330	1	520	1	7	3
MANO	700	1	0	0	370	1	620	1	9	3
NWIL	340	1	90	1	160	1	290	1	10	5
WAIW	570	1	0	0	510	1	660	1	10	5
WKEL	1,300	1	0	0	650	2	1,000	2	11	5

Table 18. Environmental assessment scores for fish tissue organochlorine contaminants.

[**Abbreviations:** NA, not analyzed for; S, score; V, value. **Acronym:** NYSDEC, New York State Department of Environmental Conservation guidelines (Newell and others, 1987). Concentrations in micrograms per kilogram wet weight [µg/kg]. Scores based on exceeding the NYSDEC. See table 1 for site names]

Constituent	Total chlordane		Total DDT		Total dieldrin		Total HCH		Total heptachlor		Total PCB		Sum of exceedances scores
NYSDEC	**500**		**200**		**120**		**100**		**200**		**110**		
Site	**V**	**S**	**V**	**S**	**V**	**S**	**V**	**S**	**V**	**S**	**V**	**S**	
HNKP	NA		NA		NA		NA		NA		NA		0
LMAH	NA		NA		NA		NA		NA		NA		0
PUNA	NA		NA		NA		NA		NA		NA		0
WHOL	NA		NA		NA		NA		NA		NA		0
WHEE B-99	0	0	0	0	0	0	0	0	0	0	0	0	0
LULU	19	0	0	0	0	0	0	0	0	0	0	0	0
WKEA	22	0	4	0	0	0	0	0	0	0	0	0	0
WAIM	12	0	18	0	11	0	0	0	0	0	0	0	0
WAIW	15	0	10	0	25	0	0	0	6	0	0	0	0
WKEL	7	0	43	0	10	0	0	0	0	0	0	0	0
WKAK	66	0	361	1	20	0	0	0	4	0	0	0	1
NWIL	191	0	22	0	340	1	0	0	19	0	0	0	1
KANE	745	1	24	0	910	1	0	0	170	0	0	0	2
NUUA	671	1	139	0	1,400	1	0	0	230	1	0	0	3
MANO	1,160	1	40	0	1,700	1	0	0	300	1	0	0	3

Table 19. Final environmental assessment scores for fish tissue organochlorine contaminants.

[**Abbreviation**: NA, not analyzed for. Concentrations in micrograms per kilogram wet weight (µg/kg). Exceedances scores based on exceeding the New York State Department of Environmental Conservation guidelines (NYSDEC) tabulated in table 18. *Xiphophorus helleri*, Green swordtail; *Poecilia sphenops*, Molly. See table 1 for site names]

Site	Fish species	Total concentration	Total score	Sum of exceedances scores	Exceedances scores + total score	Final score
HNKP	NA	NA	1	0	1	1
LMAH	NA	NA	1	0	1	1
PUNA	NA	NA	1	0	1	1
WHOL	NA	NA	1	0	1	1
WHEE B-99	*Xiphophorus helleri*	0	1	0	1	1
LULU	*Xiphophorus helleri*	19	2	0	2	3
WKEA	*Xiphophorus helleri*	26	2	0	2	3
WAIM	*Poecilia sphenops*	31	2	0	2	3
WAIW	*Poecilia sphenops*	56	2	0	2	3
WKEL	*Xiphophorus helleri*	60	2	0	2	3
WKAK	*Xiphophorus helleri*	451	2	1	3	3
NWIL	*Xiphophorus helleri*	572	2	1	3	3
KANE	*Poecilia sphenops*	1,849	3	2	5	5
NUUA	*Poecilia sphenops*	2,440	3	3	6	5
MANO	*Poecilia sphenops*	3,200	3	3	6	5

The total environmental assessment scores show that the forested sites, as identified in the PCA, were the least affected by anthropogenic influences (table 20; fig. 7). These sites scored between 10 and 15. The group of sites identified as “moderate” in the amount of anthropogenic influences scored between 23 and 34. The two groups identified as urban and agricultural/industrial in the PCA scored the highest in the environmental assessment, ranging from 37 to 42. The environmental assessment at NUUA did not correspond to the PCA results. The high levels of organochlorine compounds at NUUA contributed more to the loadings in the PCA. The cut-off values of the environmental assessment scores were determined with the CDF method (fig. 10). Mildly impaired sites scored less than 25, moderately impaired sites scored between 25 and 55, and severely impaired sites scored greater than 55.

The remaining sites (those not used in the calibration exercise) were classified using a reduced environmental assessment, made on the basis of only the land-use data and the habitat data (tables 21 and 22). These scores then were compared to the reduced environmental assessment scores of the calibration set of sites without the contaminants scores (table 23). The CDF plot of the reduced environmental assessment scores put sites UKPA, PUNB, KALU, and MKPA in the mild impairment category (fig. 11). Sites HULA, ULWI, KALA, and LLWI were put in the moderately impaired category and site PUAL was assigned to the severely impaired category.

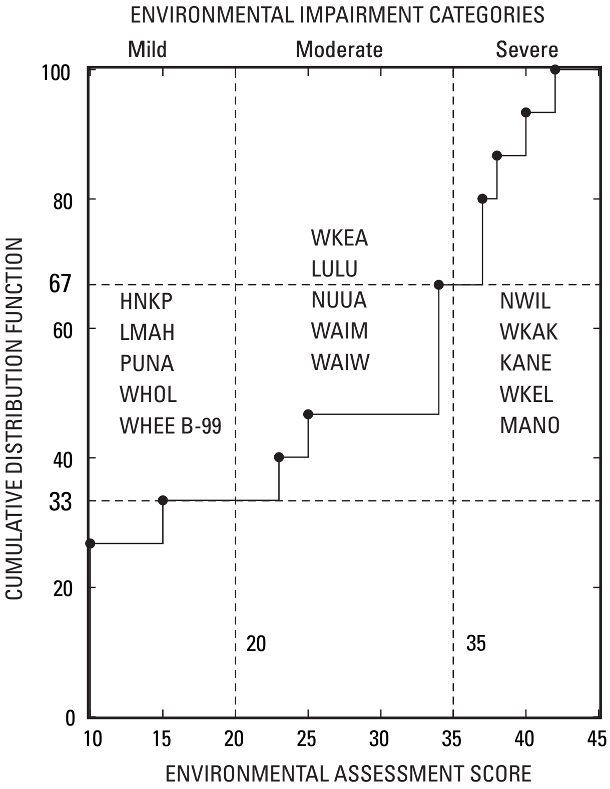


Figure 10. Final environmental assessment scores for the calibration subset of sites.
Vertical divisions demark the cut-off values for the scoring range. See table 1 for site names.

The reduced environmental assessment scores were supplemented by the results of a multivariate analysis using PCA. The ordination plots of the PCA results, using only the land-use and habitat data, illustrated the relations between the calibration sites and the remaining nine sites (fig. 12). The ordination plots facilitated the classification of the nine test sites with the calibration sites that they were most similar to. The first principal component separated the forested sites from the developed sites along the first axis, with an eigenvalue accounting for almost 55 percent of the total variance using the calibration sites and 51 percent using all the sites (tables 24 and 25). The second principal component differentiated the agricultural and commercial sites from the residential sites along the second axis, with an eigenvalue accounting for nearly 22 percent of the total variance using the calibration sites and about 20 percent using all the sites. The sites with mostly forested land were classified as mildly impaired. This included PUNB and KALU on Oahu, and UKPA on Kauai. Sites MKPA, ULWI, LLWI and HULA on Kauai were classified as moderately impaired, while PUAL on Kauai and KALA on Oahu were classified as severely impaired.

Table 20. Individual environmental assessment parameter scores and the final environmental assessment scores.

[See table 1 for site names]

Site	Parameter scores						Final environmental assessment score
	Sum of land use	Sum of habitat	Stream bed sediment			Fish tissue	
			Trace elements	Organochlorines	Semi-volatile organochlorine compounds	Organochlorines	
HNKP	2	4	1	1	1	1	10
LMAH	2	4	1	1	1	1	10
PUNA	2	4	1	1	1	1	10
WHOL	2	4	1	1	1	1	10
WHEE B-99	2	9	1	1	1	1	15
WKEA	4	9	3	3	1	3	23
LULU	8	7	3	1	3	3	25
NUUA	4	12	5	5	3	5	34
WAIM	8	18	1	3	1	3	34
WAIW	8	12	3	3	5	3	34
NWIL	8	13	5	3	5	3	37
WKAK	8	15	3	5	3	3	37
KANE	8	14	3	5	3	5	38
WKEL	10	14	3	5	5	3	40
MANO	8	16	5	5	3	5	42

Table 21. Land use for sites not used in the calibration exercise.

[See table 1 for site names]

Site	Agricultural		Developed		Total
	Percentage	Score	Percentage	Score	
KALU	0.00	1	0.00	1	2
PUNB	.00	1	.00	1	2
UKPA	.33	1	.02	1	2
ULWI	.02	1	.53	1	2
KALA	.00	1	13.24	3	4
MKPA	6.30	3	.35	1	4
HULA	[1]31.97	5	.83	1	6
LLWI	[1]13.79	5	8.82	3	8
PUAL	[1]36.97	5	22.72	3	8

[1] Grassland classified as abandoned agriculture on the basis of personal observations.

Table 22. Habitat characteristics for sites not used in the calibration exercise.

[See table 1 for site names]

Site	Percent solar irradiance	Solar irradiance rank	Channel modification	Channel modification rank	Mean silt score	Silt rank	Mean dominant bed substrate	Dominant bed substrate rank	Total
UKPA	19.11	2	Not modified	1	0.09	1	8.76	1	5
MKPA	9.94	2	Lightly affected	1	.52	1	7.91	3	7
HULA	45.17	1	Channelized, not stabilized	3	.64	3	9.52	1	8
PUNB	49.89	1	Lightly affected	1	.94	5	8.52	1	8
KALU	21.78	2	Not modified	1	.94	5	9.64	1	9
LLWI	51.94	1	Channelized, not stabilized	3	.94	5	6.06	3	12
PUAL	16.28	2	Channelized, not stabilized	3	.79	3	3.12	5	13
ULWI	15.17	2	Channelized, not stabilized	3	.88	5	7.18	3	13
KALA	59.03	1	Stabilized	5	.97	5	4.82	5	16

Table 23. Individual environmental assessment parameter scores and the reduced final environmental assessment scores without the contaminants data.

[Sites in **bold** are from the test group. See table 1 for site names]

Site	Parameter scores		Final reduced environmental assessment scores
	Sum of land use	Sum of habitat	
LMAH	2	4	6
HNKP	2	4	6
WHOL	2	4	6
PUNA	2	4	6
UKPA	**2**	**5**	**7**
PUNB	**2**	**8**	**10**
WHEE B-99	2	9	11
KALU	**2**	**9**	**11**
MKPA	**4**	**7**	**11**
WKEA	4	9	13
HULA	**6**	**8**	**14**
LULU	8	7	15
ULWI	**2**	**13**	**15**
NUUA	4	12	16
KALA	**4**	**16**	**20**
WAIW	8	12	20
LLWI	**8**	**12**	**20**
PUAL	**8**	**13**	**21**
NWIL	8	13	21
KANE	8	14	22
WKAK	8	15	23
MANO	8	16	24
WKEL	10	14	24
WAIM	8	18	26

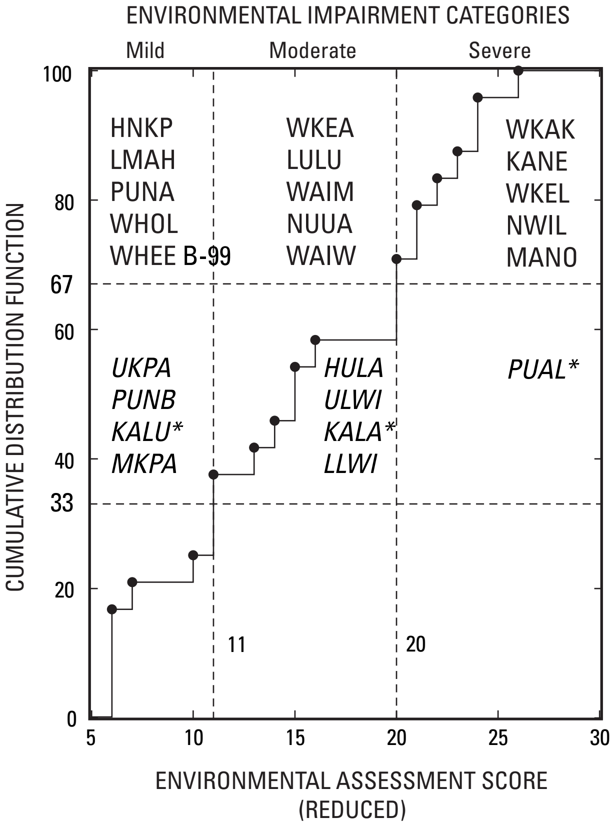


Figure 11. Reduced environmental assessment scores with all sites.
Vertical divisions demark the cut-off values for the scoring range. See table 1 for site names. Sites in italics are from the test group. (*, Sites with ancillary contaminants data)

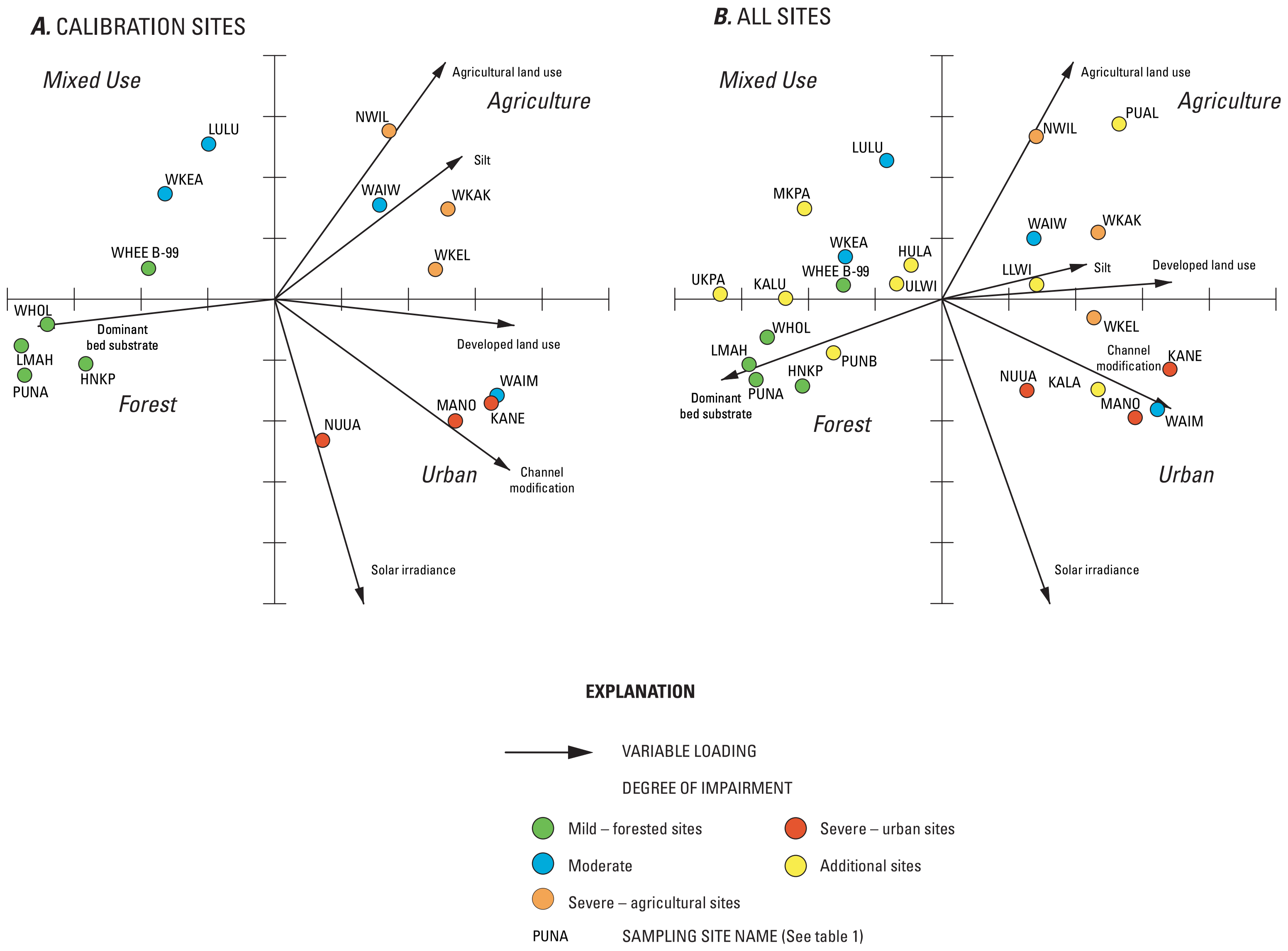


Figure 12. Principal Components Analysis using the environmental variables without the contaminants data set for the subset of calibration sites used to develop the assessment, and the entire set of study sites.
Degree of impairment for calibration sites determined from fig. 7 PCA.

Table 24. Eigenvalues and variable loadings of the Principal Components Analysis (PCA) using land use and habitat variables for the calibration set of study sites.

[Values in **bold** had the most influence on the axis]

Eigenvalues	Axis 1	Axis 2
Eigenvalues	3.269	1.289
Percentage	54.484	21.491
Cumulative percentage	54.484	75.975
PCA variable **Variable**	**Axis 1**	**Axis 2**
Solar	0.181	**-0.682**
Channel modification	**.479**	-.382
Silt	.382	.319
Dominant substrate	**-.483**	-.061
Agricultural land use	.348	**.530**
Developed land use	**.488**	-.058

Table 25. Eigenvalues and variable loadings of the Principal Components Analysis (PCA) using land use and habitat variables for all of the study sites.

[Values in **bold** had the most influence on the axis]

Eigenvalues	Axis 1	Axis 2
Eigenvalues	3.061	1.175
Percentage	51.011	19.579
Cumulative percentage	51.011	70.59
PCA variable **Variable**	**Axis 1**	**Axis 2**
Solar	0.239	**-0.741**
Channel modification	**.507**	-.266
Silt	.32	.085
Dominant substrate	**-.489**	-.196
Agricultural land use	.291	**.577**
Developed land use	**.509**	.041

It should be noted that although KALU is located within Sacred Falls State Park, ancillary contaminants data showed the concentration of arsenic in the bed sediment was above the Interim Sediment Quality Guideline (ISQG), which would shift the site to the moderately impaired category. Furthermore, the KALA basin, which includes 13 percent developed land with 12 percent as residential and 1 percent as commercial, also had the second highest total concentration of organochlorine compounds in the fish tissue sample, second only to MANO, where concentrations of total chlordane, dieldrin, and total heptachlor exceeded the NYSDEC guidelines. Dieldrin was detected in the fish tissue sample from PUAL but did not exceed the guideline. Although samples were not collected for analysis of contaminants, the land-use data indicates that contaminants most likely were present in the ULWI and LLWI basins, both of which include agricultural (pasture) and residential land, and at HULA and PUAL, drainage basins near NWIL that have sizeable proportions of fallow agricultural land (author’s observation).

Macroinvertebrate Metrics

The first step in the development of macroinvertebrate metrics required the application of several diagnostic methods to the data sets to resolve any taxonomic ambiguities and differences in laboratory taxonomic-level designations. Results of the multimetric and multivariate analyses then were used to develop the P-HBIBI. Finally, multiple-year and multiple-reach data were compared to examine any temporal and spatial variability in the P-HBIBI.

Data Sets

The original RTH data set (abundance data) included 102 taxonomic identifications (appendix A). Sixty-six taxonomic identifications remained after the data set was edited to resolve the occurrences of ambiguous taxa and standardized for laboratory taxonomic resolution (appendix B). The original richness data set (RTH, QMH, and other sources) included 141 taxonomic identifications (appendix C). Ninety-seven taxonomic identifications remained after the data set was standardized for laboratory taxonomic resolution (lack of abundance data precluded editing for ambiguity) (appendix D).

The residency status of most of the invertebrates collected in the RTH samples was classified as “undetermined” (table 26). This category included taxa that were not identified to a low enough taxonomical level to ensure either a “native” or “alien” status, and species-level identifications for which the residency status has not yet been determined. Most of the invertebrates in the edited richness data set were alien to Hawaii; only 18 taxa were classified as native.

Thirty percent of the taxa in the edited RTH data set were not common to more than one site, including three of the seven native taxa collected (table 27). *Cricotopus* sp. was the only taxa collected at all the sampling sites. Only 7 non-native taxa were common to 50 percent or more of the samples.

Table 26. Residency status of invertebrate identifications.

[Number of identifications (percentage of total number of identifications). RTH, richest targeted habitat (quantitative). Unedited data corrected for sub-sampling and unit area; edited data corrected for sub-sampling, unit area, and taxonomic resolution and ambiguity]

Data set	Native	Alien	Undetermined	Total
Unedited RTH	14 (14)	35 (34)	53 (52)	102
Edited RTH	7 (11)	20 (30)	39 (59)	66
Raw richness	22 (16)	53 (38)	66 (47)	141
Unedited richness	18 (19)	42 (43)	37 (38)	97

Table 27. Number of sites with occurrences of unique taxa from the edited quantitative (RTH) dataset.

[Number of sites = 28; number of taxa = 66. Percentage occurrence at sites, unique sites/number of sites; percentage collected at sites, occurrence of unique taxa/number of taxa]

Unique sites	Occurrence of unique taxa	Percentage of occurrence at sites	Percentage of taxa			
			Collected at sites	Alien	Native	Undetermined
1	20	3.6	30.3	10.6	4.6	15.2
2	12	7.1	18.2	3.0	1.5	13.6
3	4	10.7	6.1	.0	.0	6.1
4	3	14.3	4.6	3.0	.0	1.5
5	2	17.9	3.0	.0	.0	3.0
6	4	21.4	6.1	.0	1.5	4.6
7	6	25.0	9.1	3.0	1.5	4.6
8	2	28.6	3.0	1.5	.0	1.5
9	2	32.1	3.0	1.5	.0	1.5
10	2	35.7	3.0	1.5	.0	1.5
12	2	42.9	3.0	.0	1.5	1.5
14	1	50.0	1.5	.0	.0	1.5
16	1	57.1	1.5	.0	.0	1.5
25	2	89.3	3.0	3.0	.0	.0
26	1	92.9	1.5	1.5	.0	.0
27	1	96.4	1.5	.0	.0	1.5
28	1	100.0	1.5	1.5	.0	.0

Metrics

A review of the edited data sets resulted in 20 metrics being proposed as candidates based on available taxa (table 28) (see procedural flowchart in fig. 4). Using the data from the subset of calibration sites used to classify the site conditions, each metric value was plotted against the site impairment classification in an XY (scatter) plot to determine the response of each metric to environmental impairment. The candidate metrics that demonstrated an ability to differentiate between reference sites and degraded sites were incorporated into a group of core metrics. The core metrics then were scored using the CDF method discussed in the methods section. Ranges of values associated with the mildly impaired forested sites were scored 1, ranges of values associated with moderately impaired were scored 3, and ranges of values associated with severely impaired were scored 5.

Table 28. List of candidate metrics used to determine core metrics and the final Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) based on the available taxa.

[P/A, presence or absence in samples]

Candidate metrics	Core metrics	Final P-HBIBI
Invertebrate abundance	X	X
Insect abundance	X	
Trichopteran abundance		
Alien mollusc abundance	X	X
Dominant taxa abundance		
Amphipod abundance	X	X
Chironomidae abundance		
Trichopteran-dipteran ratio		
Percentage of trichoptera	X	
Percentage of chironomidae		
Percentage of insecta	X	X
Percentage of oligochaeta	X	
Percentage of alien mollusca	X	
Percentage of amphipoda		
Number of taxa	X	X
Native mountain shrimp P/A	X	X
Crayfish P/A	X	X
Alien prawn richness	X	
Modified family biotic index		
Margelef’s diversity		

After the core metrics were scored, the P-HBIBI was calculated as the sum of the scores for each site. A least squares linear regression (Proc REG) analysis was applied in an iterative process to test various suites of core metrics to develop the simplest yet most biologically informative P-HBIBI with the greatest r^2 value. This process of elimination resulted in the selection of 7 final metrics out of the 12 core metrics examined for inclusion into the P-HBIBI. The XY (scatter) plots for five of the seven final metrics are shown in figure 13. The two metrics based on presence/absence were not plotted. The CDF plots of the five metrics are shown in figure 14. The final P-HBIBI scores were plotted using the CDF method and the ranges of values were ascertained for each impairment category (fig. 15). The final P-HBIBI scores and the environmental assessment scores showed a significant linear relation with an r^2 value = 0.94 (p<0.0001) (fig. 16). This list of core metrics is included (table 29):

- Total invertebrate abundance
- The abundance of alien molluscs
- The abundance of amphipods
- The relative abundance of the class Insecta
- The presence or absence of the native shrimp *Atyoida bisulcata*
- The presence or absence of the alien crayfish *Procambarus clarkii*
- The total number of taxa

Table 29. Conditional scoring for the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) metrics.

[The score of 7 was added to the total abundance metric scoring for samples that did not have the minimum number, 300, of invertebrates counted by the laboratory staff. <, less than; ≤, less than or equal to; >, greater than; ≥, greater than or equal to]

Metric	Condition	Score
Total invertebrate abundance	≤ 200	7
	≤ 700	5
	≤ 3,000	3
	> 3,000	1
Alien mollusc abundance	= 0	1
	≤ 90	3
	> 90	5
Amphipod abundance	= 0	1
	≤ 35	3
	> 35	5
Percentage of Insecta	≤ 75	5
	≤ 90	3
	> 90	1
Native mountain shrimp	Absent	3
	Present	1
Crayfish	Absent	1
	Present	3
Total number of taxa	≥ 30	5
(Taxa richness)	≥ 21	3
	< 21	1
		Impairment category
Final P-HBIBI	≤14	Mild
(Sum of metric scores)	≤22	Moderate
	>22	Severe

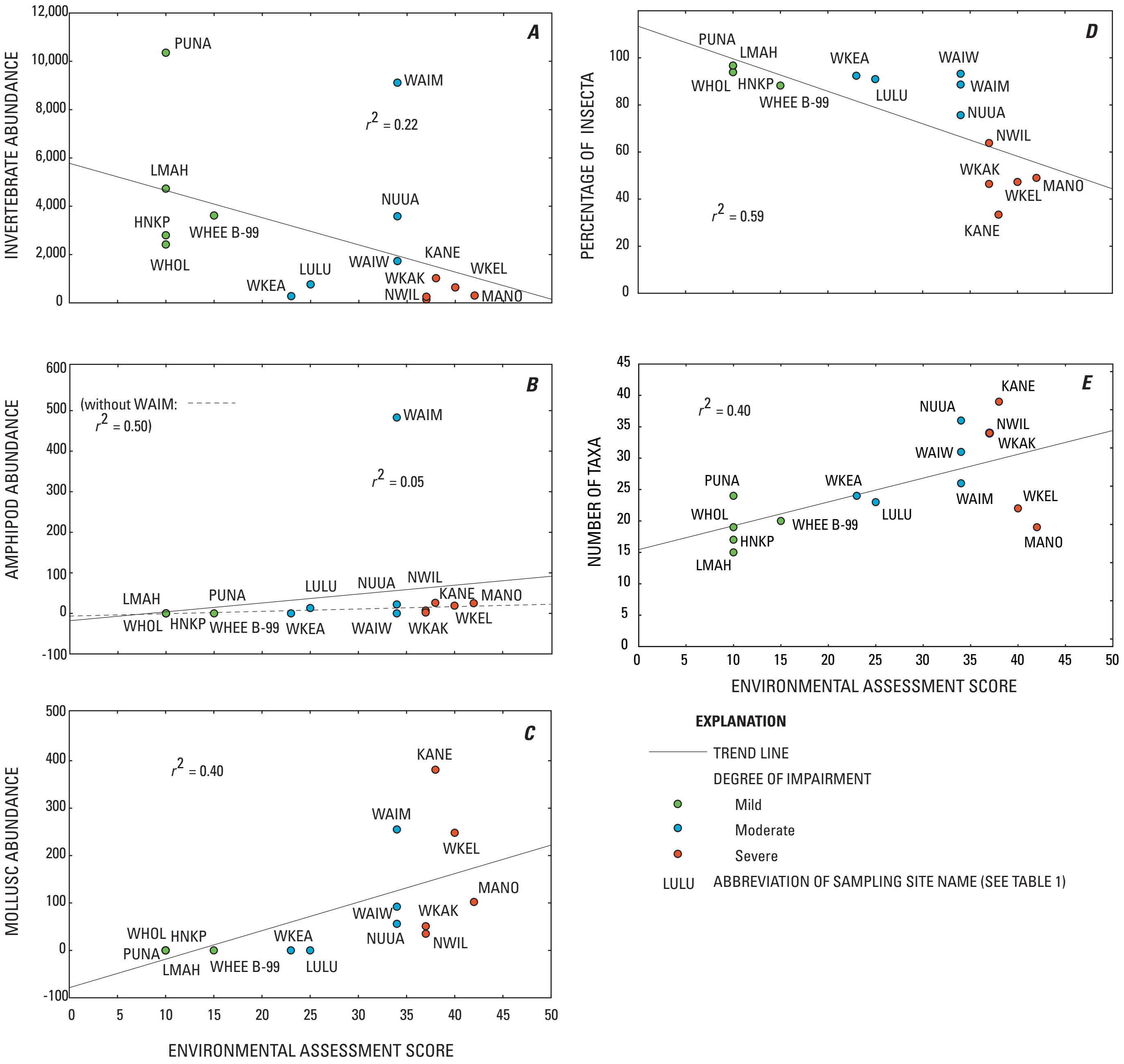


Figure 13. Relation between the final metrics values and the environmental assessment scores for (A) invertebrate abundance, (B) amphipod abundance, (C) mollusc abundance, (D) insect relative abundance, and (E) taxa richness. (r^2, coefficient of determination).

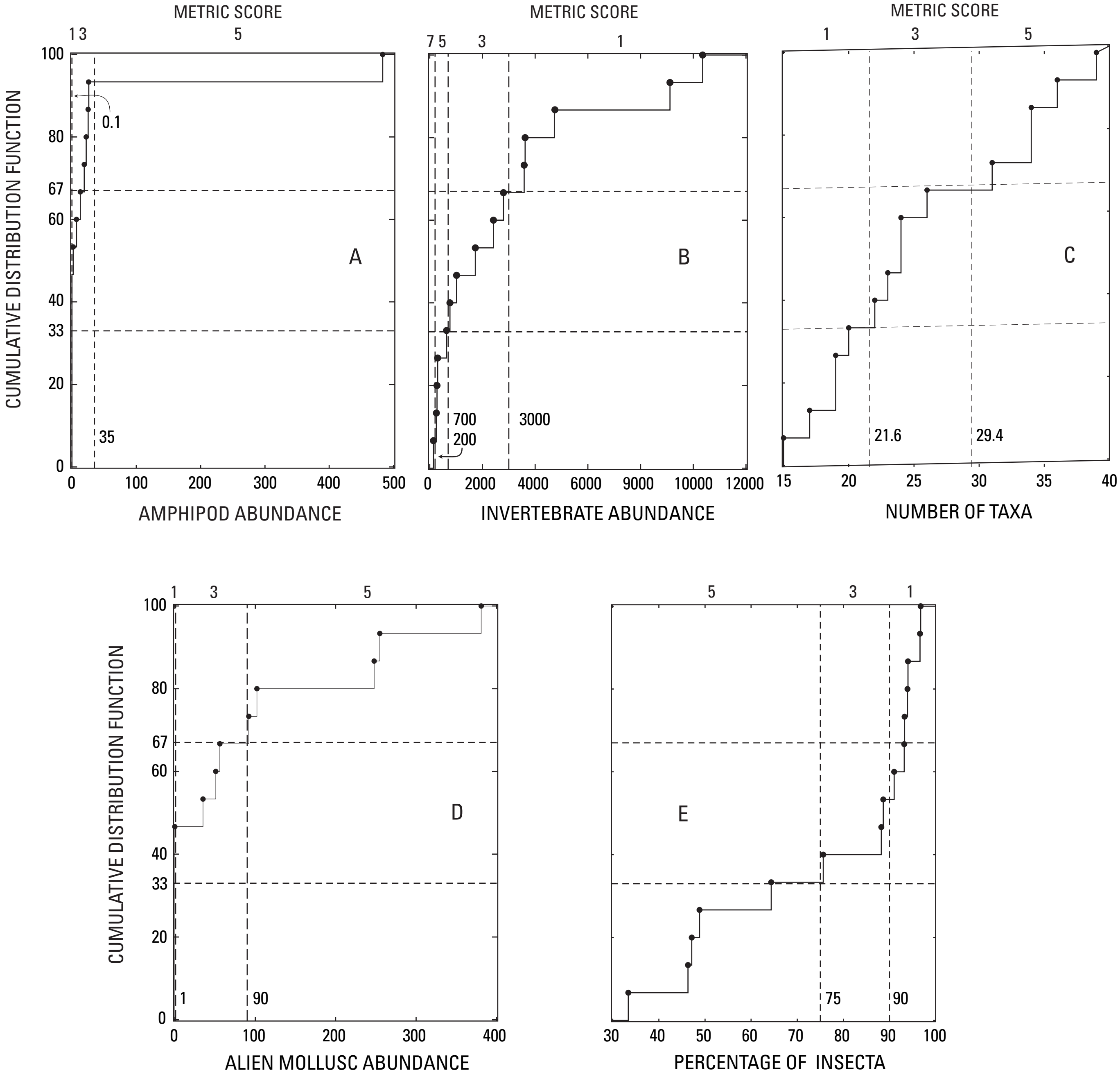


Figure 14. Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) metrics with vertical divisions demarking the cut-off values of the scoring range for (A) amphipod abundance, (B) invertebrate abundance, (C) number of taxa, (D) alien mollusc abundance, and (E) percentage of Insecta.

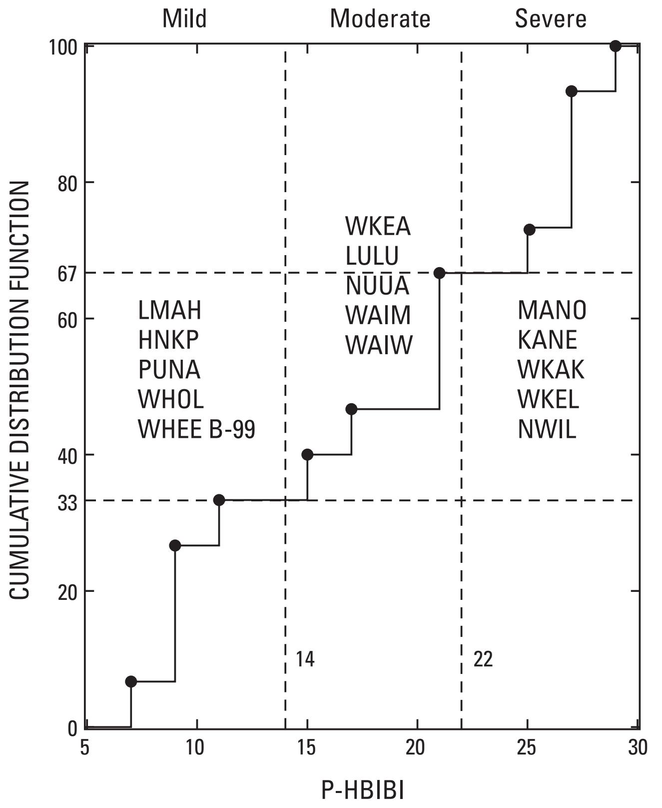


Figure 15. Final Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) core metrics scores for the calibration sites and the vertical divisions demarking the cut-off values of the scoring range for impairment categories.
See table 1 for site names.

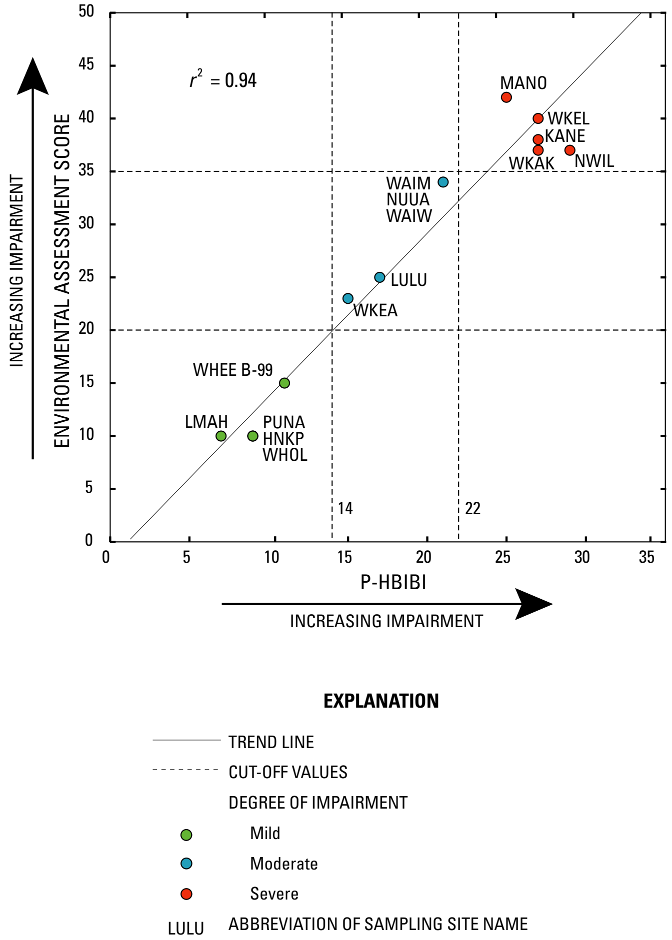


Figure 16. Relationship between the environmental assessment scores and the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) from the calibration sites used to develop the P-HBIBI.
Dashed lines are cut-off values ascertained using the Cumulative Distribution Function (CDF) plots demarking the scoring ranges for impairment categories. See table 1 for site names. (r^2, coefficient of determination)

The P-HBIBI scores ranged from a low of 7 for LMAH, the least impaired site, to a high of 29 for NWIL, identified as the most impaired site (table 30). The data from the test sites that were not used to calibrate the core metrics and the P-HBIBI were then grouped with the data from the calibration sites, and each core metric was re-examined to check for outlying values (fig. 17). This testing did not reveal any values that fell out of the scoring ranges. The test sites then were scored using the P-HBIBI (fig. 18; table 30). Six of the nine test sites were assigned to impairment categories consistent with the reduced environmental assessment. Three sites, KALU, MKPA, and UKPA, were rated as moderately impaired using the P-HBIBI although the reduced environmental assessment rated the sites as only mildly impaired (table 31). The linear relationship between the test sites P-HBIBI scores and the reduced environmental assessment scores had a significant r^2 value = 0.72 (p<0.002) (fig. 19). The relation between the P-HBIBI scores and the environmental

Table 30. Metric scores for final invertebrate metrics and final Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) site scores.

[See table 1 for site names. Sites in **bold**, test sites; sites in i*talics*, multi-year/multi-reach sites. **Abbreviations:** O, collected during fish survey; P/A, presence or absence; Q, present in the qualitative sampling; R, present in the quantitative sampling; S, metric score; V, value. Abundance in number of individuals per square meter]

Site	Richness		Percent Insecta		Amphipod abundance		Invertebrate abundance		Alien mollusc abundance		Crayfish (P/A)		Mountain shrimp (P/A)		P-HBIBI score
	V	S	V	S	V	S	V	S	V	S	V	S	V	S	
LMAH[1]	15	1	97	1	0	1	4,729	1	0	1		1	R	1	7
HNKP[1]	17	1	94	1	0	1	2,799	3	0	1		1	Q,R	1	9
PUNA[1]	24	3	97	1	0	1	10,356	1	0	1		1	O	1	9
WHEE C-00	17	1	99	1	0	1	5,578	1	0	1	Q	3	O	1	9
WHOL[1]	19	1	94	1	0	1	2,415	3	0	1		1	R	1	9
WHEE A-00	23	3	93	1	0	1	10,290	1	0	1	Q	3	Q	1	11
WHEE B-00	21	3	95	1	0	1	6,372	1	0	1	Q	3	Q,R	1	11
WHEE B-99[1]	20	1	88	3	0	1	3,617	1	0	1	Q	3	O	1	11
PUNB	23	3	89	3	0	1	4,145	1	0	1		1		3	13
WHEE B-01	23	3	99	1	0	1	6,131	1	16	3	Q	3	O	1	13
KALU	21	3	22	5	0	1	3,328	1	2	3		1	O	1	15
MKPA	21	3	89	3	0	1	1,331	3	0	1	Q	3	Q,R	1	15
UKPA	26	3	90	3	14	3	877	3	0	1		1	R	1	15
WKEA[1]	24	3	92	1	0	1	276	5	0	1	Q,R	3	O	1	15
LULU[1]	23	3	91	1	13	3	763	3	0	1	Q	3		3	17
LLWI	24	3	93	1	358	5	8,028	1	153	5		1		3	19
ULWI	29	3	75	5	0	1	880	3	3	3	Q	3	R	1	19
HULA	27	3	83	3	391	5	2,603	3	8	3	O	3	O	1	21
KALA	34	5	87	3	0	1	2,207	3	238	5		1		3	21
NUUA[1]	36	5	76	3	22	3	3,583	1	56	3	Q	3		3	21
WAIM[1]	26	3	89	3	483	5	9,115	1	255	5		1		3	21
WAIW[1]	31	5	93	1	0	1	1,729	3	92	5	Q	3		3	21
PUAL	24	3	84	3	10	3	140	7	2	3		1		3	23
MANO[1]	19	1	49	5	25	3	302	5	102	5	Q	3		3	25
KANE[1]	39	5	33	5	26	3	1,018	3	381	5	Q	3		3	27
WKAK[1]	34	5	46	5	2	3	252	5	51	3	Q	3		3	27
WKEL[1]	22	3	47	5	19	3	639	5	248	5	O	3		3	27
NWIL[1]	34	5	64	5	7	3	141	7	35	3	Q	3		3	29

[1] Calibration sites used in the determination of the P-HBIBI and environmental assessment.

assessment scores (without the contaminants scores) for all the sites showed a significant linear relation with an r^2 value = 0.82 (p<0.0001) (fig. 20). Six of the nine test sites were assigned to impairment categories consistent with the reduced principal components analysis. Two test sites, UKPA and KALU, were classified as moderately impaired using the P-HBIBI but grouped with the mildly impaired sites in the ordination plot of the PCA. One site, KALA, was classified as moderately impaired by the P-HBIBI but grouped with the severely impaired sites in the ordination plot. Two calibration sites, WAIM and WAIW, grouped with the severely impaired sites in the PCA ordination plot of the reduced environmental assessment (fig. 12; table 31). These sites were determined to be moderately impaired in the environmental assessment that included the contaminants data and the ordination plot of the full set of environmental data (figs. 7 and 10).

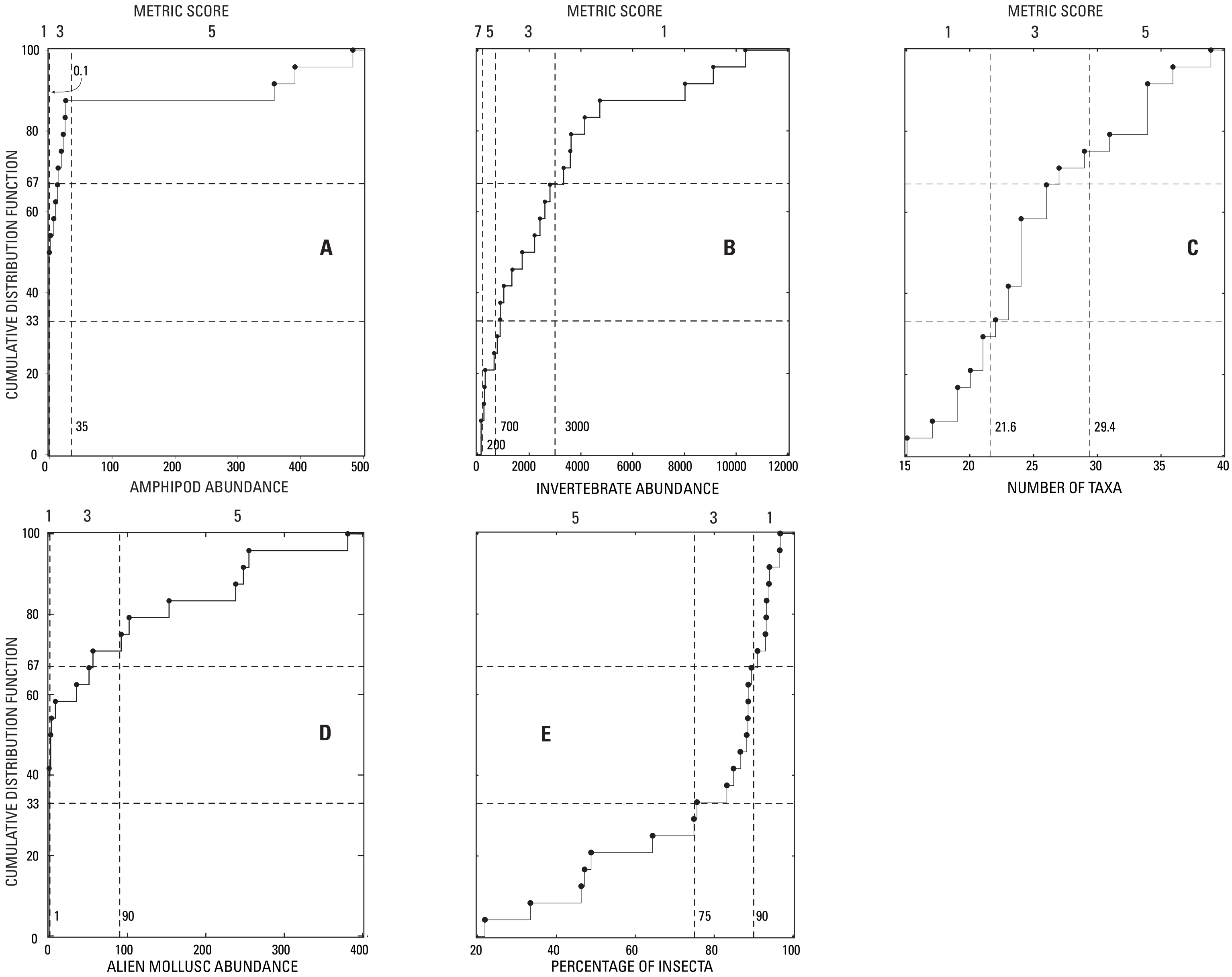


Figure 17. Core metrics using all sites with vertical divisions demarking the cut-off values of the scoring range for amphipod abundance, invertebrate abundance, number of taxa, alien mollusc abundance, and percentage of Insecta.

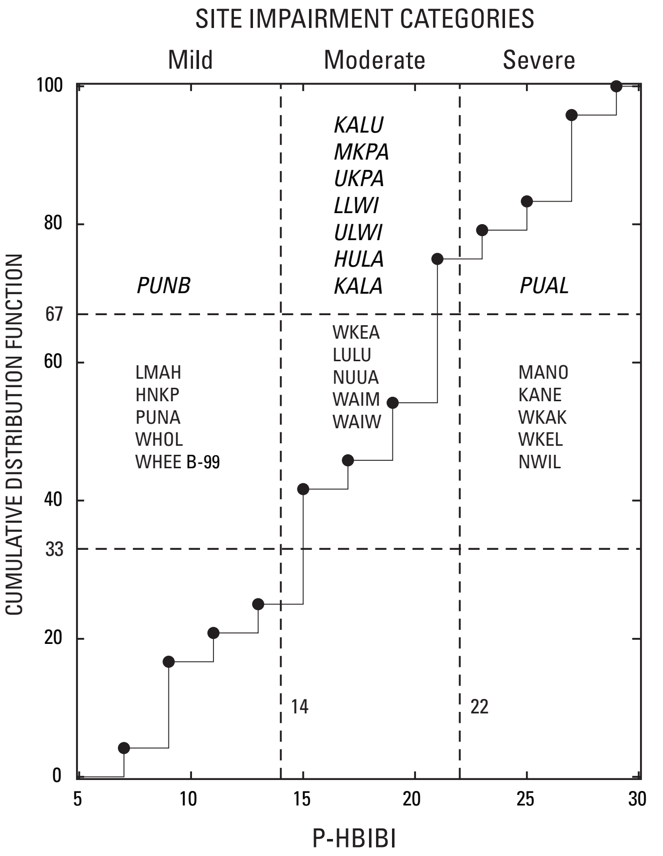


Figure 18. Preliminary Hawaiian Benthic Index of Biotic Integrity Vertical divisions demark the cut-off values marking the high and low ranges of the impairment categories.
Sites not used in the calibration of the P-HBIBI are in italic. See table 1 for site names.

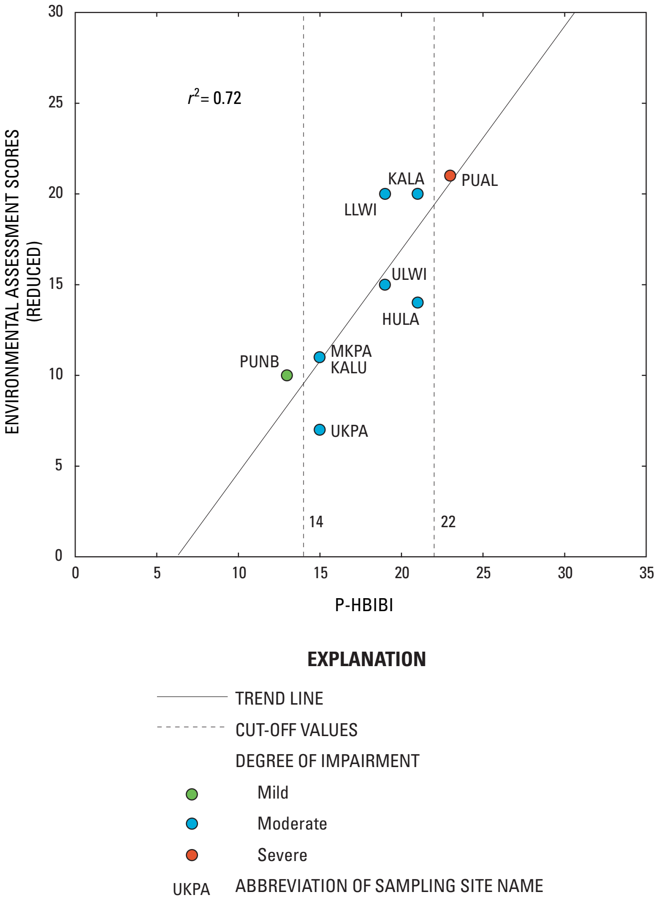


Figure 19. Relationship between the reduced environmental assessment scores and the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) scores for the test sites with vertical divisions demarking the cut-off values of the scoring range for impairment categories.
See table 1 for site names.(r^2, coefficient of determination)

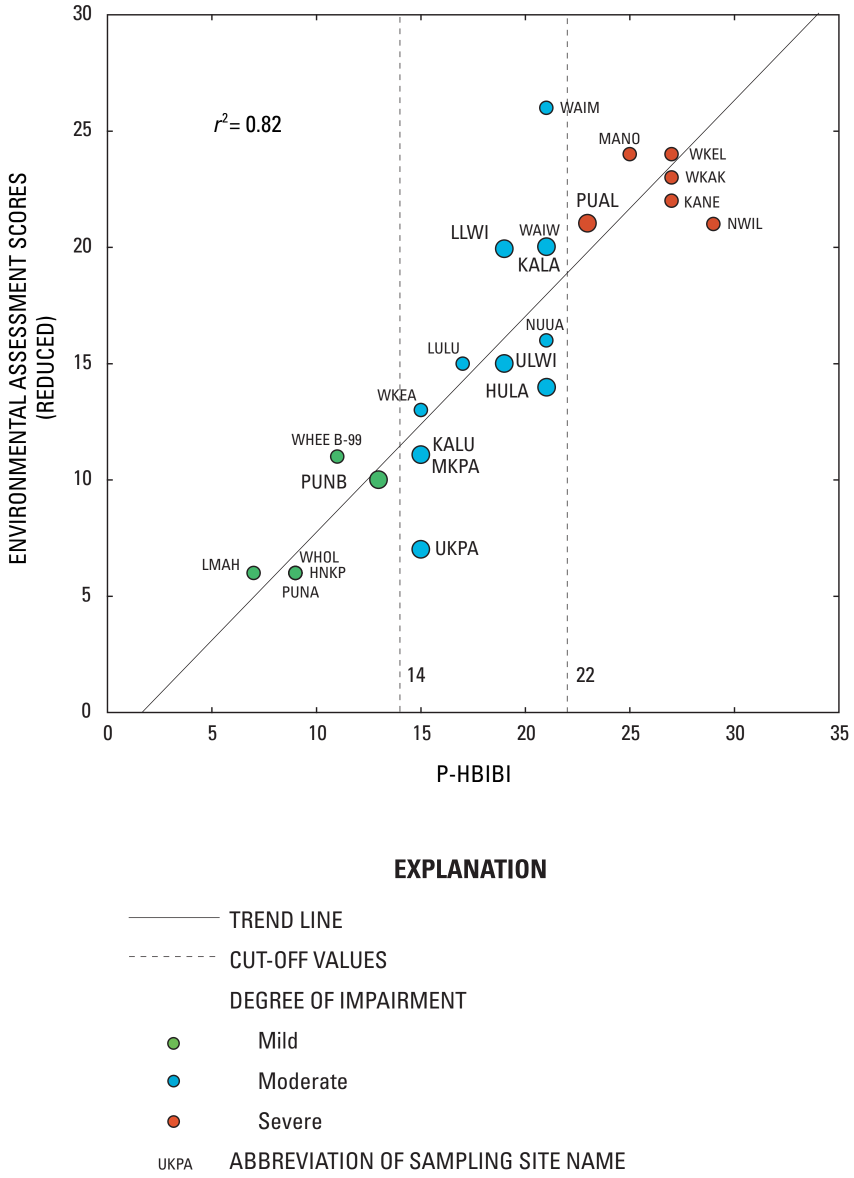


Figure 20. Relationship between the environmental assessment scores and the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) scores for all the sites with vertical divisions demarking the cut-off values of the scoring range for impairment categories. Small markers represent the calibration sites; large markers represent the test sites. See table 1 for site names. (r^2, coefficient of determination).

Table 31. Impairment classifications based on Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) and environmental assessment.

[**Abbreviations:** EA, Environmental Assessment; P-HBIBI, preliminary Hawaiian benthic index of biotic integrity; PCA, principal components analysis;. Reduced, no contaminants data included in analysis. Sites in **bold** are test sites. Sites in i*talics* are multi-year/multi-reach sites. --, not assessed]

Site	EA scores	EA impairment category	PCA impairment category	Reduced EA scores	Reduced EA impairment category	Reduced PCA impairment category	P-HBIBI score	P-HBIBI impairment category
LMAH[1]	10	Mild	Mild	6	Mild	Mild	7	Mild
PUNA[1]	10	Mild	Mild	6	Mild	Mild	9	Mild
HNKP[1]	10	Mild	Mild	6	Mild	Mild	9	Mild
WHOL[1]	10	Mild	Mild	6	Mild	Mild	9	Mild
WHEE C-00	--	--	--	--	--	Mild[2]	9	Mild
WHEE A-00	--	--	--	--	--	Mild[2]	11	Mild
WHEE B-00	--	--	--	--	--	Mild[2]	11	Mild
WHEE B-99[1]	15	Mild	Mild	11	Mild	Mild	11	Mild
WHEE B-01	--	--	--	--	--	Mild[2]	13	Mild
PUNB	--	--	--	10	Mild	Mild	13	Mild
KALU	--	--	--	11	Mild	Mild	15	Moderate
UKPA	--	--	--	7	Mild	Mild	15	Moderate
MKPA	--	--	--	11	Mild	Moderate	15	Moderate
WKEA[1]	23	Moderate	Moderate	13	Moderate	Moderate	15	Moderate
LULU[1]	25	Moderate	Moderate	15	Moderate	Moderate	17	Moderate
LLWI	--	--	--	20	Moderate	Moderate	19	Moderate
ULWI	--	--	--	15	Moderate	Moderate	19	Moderate
NUUA[1]	34	Moderate	Severe	16	Moderate	Severe	21	Moderate
WAIM[1]	34	Moderate	Moderate	26	Severe	Severe	21	Moderate
WAIW[1]	34	Moderate	Moderate	20	Moderate	Severe	21	Moderate
HULA	--	--	--	14	Moderate	Moderate	21	Moderate
KALA	--	--	--	20	Moderate	Severe	21	Moderate
PUAL	--	--	--	21	Severe	Severe	23	Severe
MANO[1]	42	Severe	Severe	24	Severe	Severe	25	Severe
WKAK[1]	37	Severe	Severe	23	Severe	Severe	27	Severe
KANE[1]	38	Severe	Severe	22	Severe	Severe	27	Severe
WKEL[1]	40	Severe	Severe	24	Severe	Severe	27	Severe
NWIL[1]	42	Severe	Severe	21	Severe	Severe	29	Severe

[1] Sites used in the calibration of the P-HBIBI and environmental assessment.

[2] Category assessed using PCA–used to compare temporal and spatial relationships.

Total Invertebrate Abundance

The total abundance of invertebrates typically is predicted to decrease with an increase in human disturbance in continental settings (Fore and others, 1996; Black and MacCoy, 1999) (table 32). Similarly, in Hawaii, decreasing total invertebrate abundances are indicative of increasing human disturbance. This metric makes no differentiation of what taxa are present or more dominant. The reference site PUNA had the greatest abundance of invertebrates (10,356/m^2) and was used to calibrate the range for the lowest metric score (table 33). This was more than twice as many individual organisms as were collected at any of the other reference sites. The total abundance at PUNA was generated by a large number (6,722/m^2) of the dominant taxa, *Hydroptila* sp. (table 33). Because this metric does not

Table 32. Final metrics and predicted responses to increased perturbation.

[P/A, presence or absence in sample; --, no information]

Metric	Predicted response (literature)	Predicted response (Hawaii)
Total number of taxa (taxa richness)	Decrease	Increase
Total invertebrate abundance	Decrease	Decrease
Alien mollusc abundance	Increase	Increase
Amphipod abundance	Increase	Increase
Percent Insecta	--	Decrease
P/A crayfish	--	Present
P/A native mountain shrimp	--	Absent

Table 33. Abundances and proportions of the first and second dominant invertebrate taxa in Hawaii streams.

[Sites in **bold** are test sites; Sites in *italics* are multi-year/multi-reach sites; Sites sorted by P-HBIBI scores in descending order. Abundances in number of individuals per square meter. See table 1 for site names]

Site	Total invertebrate abundance	First dominant taxa			Second dominant taxa		
		Taxa	Abundance	Percent of total	Taxa	Abundance	Percent of total
HNKP[1]	2,799	*Cheumatopsyche pettiti*	862	31	*Eukiefferiella claripennis* gr.	742	27
LMAH[1]	4,729	*Cricotopus* sp.	2,518	53	*Eukiefferiella claripennis* gr.	845	18
PUNA[1]	10,356	*Hydroptila* sp.	6,722	65	*Cheumatopsyche pettiti*	1,615	16
WHOL[1]	2,415	*Cheumatopsyche pettiti*	1,513	63	*Cricotopus* sp.	358	15
WHEE B-01	6,131	*Cheumatopsyche pettiti*	3,147	51	*Hydroptila* sp.	2,016	33
UKPA	877	*Cheumatopsyche pettiti*	291	33	*Eukiefferiella claripennis* gr.	274	31
PUNB	4,145	*Hydroptila* sp.	1,520	37	*Cheumatopsyche pettiti*	1,372	33
WHEE C-00	5,578	*Cheumatopsyche pettiti*	2,983	53	*Hydroptila* sp.	1,999	36
WHEE A-00	10,290	*Hydroptila* sp.	4,581	45	*Cheumatopsyche pettiti*	2,613	25
WHEE B-00	6,372	*Cheumatopsyche pettiti*	2,984	47	*Hydroptila* sp.	1,996	31
KALU	3,328	Naididae	2,542	76	*Cricotopus* sp.	538	16
WHEE B-99[1]	3,617	*Cheumatopsyche pettiti*	1,848	51	*Cricotopus* sp.	828	23
MKPA	1,331	*Cheumatopsyche pettiti*	456	34	*Cricotopus* sp.	357	27
ULWI	880	*Cheumatopsyche pettiti*	310	35	*Ferrissia sharpi*	177	20
HULA	2,603	*Cheumatopsyche pettiti*	967	37	*Cricotopus* sp.	630	24
WKEA[1]	276	*Cheumatopsyche pettiti*	239	87	*Cricotopus* sp. and Naididae	9	3
LLWI	8,028	*Cricotopus* sp.	3,808	47	*Cheumatopsyche pettiti*	3,170	39
PUAL	140	*Cricotopus* sp.	53	38	*Hemerodromia stellaris*	41	29
KALA	2,207	*Cricotopus* sp.	1,660	75	Thiaridae	238	11
LULU[1]	763	*Cheumatopsyche pettiti*	307	40	*Cricotopus* sp.	277	36
WAIM[1]	9,115	*Cheumatopsyche pettiti*	5,317	58	*Hydroptila* sp.	1,557	17
NUUA[1]	3,583	*Cricotopus* sp.	1,602	45	Naididae	594	17
WAIW[1]	1,729	*Polypedilum* sp.	1,101	64	*Cricotopus* sp.	262	15
WKAK[1]	252	Physidae	51	20	Naididae and *Cheumatopsyche pettiti*	28	11
KANE[1]	1,018	Thiaridae	358	35	Naididae	160	16
WKEL[1]	639	*Cricotopus* sp.	265	41	Thiaridae	149	23
NWIL[1]	141	*Cricotopus* sp.	72	51	Thiaridae	26	18
MANO[1]	302	Thiaridae	98	32	*Cricotopus* sp.	78	26

[1] Sites used in the determination of the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) and environmental assessment.

distinguish among the taxa, however, sites may have large numbers of taxa that are tolerant of disturbance. The fewest number of invertebrates were collected in samples at NWIL ($141/m^2$) and PUAL ($140/m^2$) on Kauai. These sites were assigned an extra scoring range of 7 because these abundances were less than the minimum fixed-count conducted by the laboratories (minimum count of 300 organisms; NWIL count = $174/1.25\ m^2$; PUAL count = $172/1.25\ m^2$). At three of the most impaired sites, metric scores were at the high end of the scoring range. The XY plot shows the linear relation between the environmental assessment scores and the total number of invertebrates ($r^2 = 0.22$) (fig. 13A).

Taxa Richness

The number of distinct taxa was predicted to increase with an increase in the level of disturbance (table 32). This prediction is in stark contrast to that of most, if not all, of the studies on continental streams (Kerans and Karr, 1994; Fore and others, 1996; Black and MacCoy, 1999; Weigel and others, 2002; Weigel, 2003). This metric is sensitive to the editing process used to resolve the occurrences of ambiguous taxa and to standardize for laboratory taxonomic resolution discussed earlier. As more of the data is grouped into higher taxonomic categories, fewer number of distinct taxa are counted.

The linear relation between taxa richness and the environmental assessment scores was significant using the calibration sites ($r^2 = 0.40$,F = 8.61 $p < 0.05$, df = 14) (fig. 13E) and all the sites combined with the reduced environmental assessment scores ($r^2 = 0.27$, F = 8.23, $p < 0.01$, df = 23). The reference sites on Kauai, LMAH and HNKP, had a total of 15 and 17 taxa, respectively (table 30). A total of 24 taxa were collected at the Oahu reference site PUNA, including 3 species of Trichoptera, 2 molluscs, and 2 crustaceans not collected at the other reference sites (appendix D). The maximum number of taxa collected at a site was 39, at the urban Oahu site KANE. Six urban and mixed sites had greater than 30 taxa present. Most of the increase in taxa richness at the impaired sites is attributable to the presence of alien molluscs, alien crustaceans, and alien dipterans that have found their way into the stream reaches.

Insect Relative Abundance

The relative abundance of insects (the percentage of the total abundance that comprises insects) was predicted to decrease with an increase in the level of disturbance (table 32). This prediction was made after the data analysis for the NAWQA program report (Brasher and others, 2004). The first and second dominant taxonomic groups of the reference sites were insects of the order Trichoptera or of the family Chironomidae (table 34). Insects accounted for more than 90 percent of the total invertebrate abundances at each of the reference sites (table 30). Conversely, insects accounted for fewer than 65 percent of the total invertebrate abundances at MANO, KANE, WKAK, WKEL, and NWIL. At all of the impaired sites, alien molluscs were either the first or second dominant taxonomical group. At many of the moderately impaired sites, molluscs, annelids, or non-chironomid dipterans were the second dominant taxa. KALU had a curiously high percentage of annelids (family Naididae), they accounted for 76 percent of the total abundance (table 33). There was a significant linear relation between insect relative abundance and the environmental assessments of the calibration sites ($r^2 = 0.59$; $p < 0.0001$; F=19.1; df=14) and between insect relative abundance and the reduced environmental assessment scores using all the sites ($r^2 = 0.24$; $p < 0.05$; F = 6.86; df = 23).

Alien Mollusc Abundance

Abundances of alien molluscs were predicted to increase with increasing disturbance (table 32). The list of molluscs considered alien to Hawaii included the lymnaeid snail *Pseudosuccinea columella*, the Asiatic clam *Corbicula* sp., and species of the families: Physidae, Planorbidae, Thiaridae, and Hydrobiidae. Some of these molluscs were introduced as food sources, others were brought into Hawaii through the aquarium trade, and some are of an unknown source (Devick, 1991; Cowie, 1998). Many of the larger non-native fauna, including fish, molluscs, and crustaceans, are found in the most impaired streams. This is not wholly because they are better equipped to survive in polluted water, but also because people have accidentally or purposefully introduced them to these streams. Unlike most aquatic insects, these animals are rarely transported from stream to stream without assistance. Because more people live in urban areas, one might expect a trend that more aquarium fauna, such as the alien molluscs, would be dumped into urban streams than in streams in other, less developed areas. Consequently, because urban streams tend to be more environmentally impaired, the correlation can be made between an increase in non-native fauna with an increase in impairment. A Spearman's rank-order correlation analysis indicated a significant correlation between alien mollusc abundance and the percentage of developed land use ($r_s = 0.75$, $p < 0.0001$).

Alien molluscs appear to be more tolerant of impaired water quality as they were more abundant, proportionally, in the impaired streams. These molluscs were the dominant taxonomical group at the urban sites MANO and KANE and at the mixed site WKAK, on Oahu, and they were the second dominant taxonomical group at four other urban and mixed sites including KALA, WAIW, WKEL, and NWIL (table 34). No alien molluscs were collected in the RTH samples at the reference sites or at the other mostly forested sites (table 30). Most of the urban land-use sites scored in the upper range of this metric. There was a significant linear relation between the abundance of alien molluscs and the environmental assessment scores for the calibration sites ($r^2 = 0.40$; $p < 0.05$; F = 8.59; df = 14) and for all the sites combined with the reduced environmental assessment scores ($r^2 = 0.46$; $p < 0.0001$; F = 18.94; df = 23).

Amphipod Abundance

The abundance of amphipods typically is predicted to increase with increasing disturbance in continental settings (Weigel, 2003) (table 32). In this study, no amphipods were collected in the RTH or QMH samples at the reference sites. Amphipod abundance was significantly correlated with the categorical variable Channel Modification ($r_s = 0.62$; $p < 0.002$). Channel Modification was significantly correlated with developed land use ($r_s = 0.79$; $p < 0.0001$), dominant bed substrate ($r_s = -0.74$; $p < 0.0001$), and solar irradiance ($r_s = 0.45$; $p < 0.05$). The calibration site WAIM and the test sites LLWI and HULA had comparatively large abundances of amphipods, 483/m^2, 358/m^2, and 391/m^2, respectively (table 30). These sites were assessed as moderately impaired but all three had modified channels and were mixed agricultural and urban land-use sites. Amphipods were present, in lower numbers, at all the severely impaired sites (table 30). Les Watling at the Darling Marine Center identified subsamples of the amphipods as *Hyalella*, close to *H. azteca*.

Crayfish Presence or Absence

The presence of the crayfish *Procambarus clarkii* metric has similarities with the alien mollusc metric in that this species was deliberately introduced, as early as 1923, as a food source (Brock, 1960; Devick, 1991). Intentional releases occurred in the 1920's and 1930's and the species is now established on the major islands. Commonly called the Louisiana crayfish, *P. clarkii* is now considered a pest species in Hawaii because it burrows into stream banks, thereby increasing rates of erosion and sedimentation. Like the alien molluscs, the presence of the crayfish in impaired streams is not wholly because they are better equipped to survive in polluted waters, but also because they were released into those waters. There is no evidence that the crayfish would not thrive if released into "pristine" waters.

Table 34. Abundances and proportions of the first, second, and third dominant invertebrate taxa groups.

[Sites in **bold**, test sites; Sites in i*talics*, multi-year/multi-reach sites; Sites sorted by P-HBIBI scores in descending order; Diptera group includes non-chironomid dipterans; Mollusca group does not include native species. See table 1 for site names]

Site	Invertebrate abundance	First dominant	First dominant abundance	First dominant (percent)	Second dominant	Second dominant abundance	Second dominant (percent)	Third dominant	Third dominant abundance	Third dominant (percent)	Sum of percentages
HNKP[1]	2,799	Chironomidae	1,544	55	Trichoptera	973	35	Annelida	119	4	94
LMAH[1]	4,729	Chironomidae	3,363	71	Trichoptera	1,013	21	Diptera	199	4	97
PUNA[1]	10,356	Trichoptera	8,337	81	Chironomidae	1,210	12	Diptera	458	4	97
WHOL[1]	2,415	Trichoptera	1,788	74	Chironomidae	382	16	Diptera	94	4	94
WHEE B-01	6,131	Trichoptera	5,163	84	Chironomidae	725	12	Diptera	145	2	98
UKPA	877	Chironomidae	465	53	Trichoptera	291	33	Mollusca	42	5	91
PUNB	4,145	Trichoptera	2,892	70	Chironomidae	494	12	Annelida	323	8	89
WHEE C-00	5,578	Trichoptera	4,982	89	Chironomidae	500	9	Acari	48	1	99
WHEE A-00	10,290	Trichoptera	7,194	70	Chironomidae	1,935	19	Annelida	581	6	94
WHEE B-00	6,372	Trichoptera	4,980	78	Chironomidae	1,008	16	Annelida	222	3	97
KALU	3,328	Annelida	2,553	77	Chironomidae	538	16	Trichoptera	101	3	96
WHEE B-99[1]	3,617	Trichoptera	2,296	63	Chironomidae	851	24	Platyhelminthes	280	8	95
MKPA	1,331	Trichoptera	584	44	Chironomidae	448	34	Diptera	137	10	88
ULWI	880	Trichoptera	310	35	Chironomidae	307	35	Mollusca	180	20	91
HULA	2,603	Trichoptera	1,374	53	Chironomidae	638	25	Amphipoda	391	15	92
WKEA[1]	276	Trichoptera	239	87	Annelida	15	5	Chironomidae	9	3	95
LLWI	8,028	Chironomidae	3,962	49	Trichoptera	3,502	44	Amphipoda	358	4	97
PUAL	140	Chironomidae	56	40	Diptera	42	30	Trichoptera	15	11	81
KALA	2,207	Chironomidae	1,707	77	Mollusca	262	12	Diptera	158	7	96
LULU[1]	763	Chironomidae	312	41	Trichoptera	309	40	Diptera	69	9	90
WAIM[1]	9,115	Trichoptera	6,874	75	Diptera	590	6	Chironomidae	536	6	88
NUUA[1]	3,583	Chironomidae	1,647	46	Annelida	649	18	Trichoptera	616	17	81
WAIW[1]	1,729	Chironomidae	1,408	81	Mollusca	98	6	Trichoptera	96	6	93
WKAK[1]	252	Mollusca	73	29	Chironomidae	69	27	Annelida	50	20	76
KANE[1]	1,018	Mollusca	420	41	Trichoptera	187	18	Annelida	174	17	77
WKEL[1]	639	Chironomidae	265	41	Mollusca	252	39	Trichoptera	35	5	86
NWIL[1]	141	Chironomidae	74	52	Mollusca	37	26	Diptera	12	9	87
MANO[1]	302	Mollusca	102	34	Chironomidae	80	26	Trichoptera	66	22	82

[1] Sites used in the determination of the Preliminary Hawaiian Benthic Index of Biotic Integrity (P-HBIBI) and environmental assessment.

Crayfish were present at 17 sites (including the WHEE sites). They were collected in 16 QMH samples, 1 RTH sample (also in QMH), and at 1 site where it was not collected in QMH or RTH sampling, the collection was supplemented with electrofishing data (table 30). *Procambarus clarkii* prefers slower water than the riffle habitat sampled for RTH. No crayfish were collected at any of the reference sites. Crayfish were not present above the diversion at PUNA or below the diversion at PUNB, but crayfish have been observed in Punaluu Stream farther downstream, where the stream channel had been modified.

Native Mountain Shrimp (*Atyoida bisulcata*) Presence or Absence

The presence of *Atyoida bisulcata*, the endemic mountain shrimp commonly called opae kalaole, is an indicator of higher water quality (Kido and Smith, 1997; Kido and others, 1999b). As an amphidromous species, *A. bisulcata* larvae wash out into the ocean, where they spend time metamorphosing, returning to freshwater as post-larvae, and migrating upstream as juveniles (Kinzie, 1990). This species of crustacean is more commonly found at higher elevations in the more “pristine” streams; however, juveniles have been observed and collected from the lower reaches of these streams, most often in the channel margins, during the upstream migration. If downstream conditions are impaired to the point at which post-larvae or juveniles are unable to survive, adult *A. bisulcata* may not be present at the less-impaired upstream sites.

The mountain shrimp was collected at all of the reference sites, at all of the WHEE sites, and at most of the sites with predominantly forested basins. Unpredictably, none were collected below the diversion at PUNB; however, the effects of this diversion also were evident in other aspects of the invertebrate assemblage (Brasher and others, 2004). Invertebrate assemblages in Hawaii have been observed to vary considerably between sites above and below diversions (Kinzie and others, 1997; McIntosh and others, 2002). No *A. bisulcata* were collected at any of the impaired sites. Capture of the shrimp varied by collection technique among the different sites. The shrimp was collected at 6 sites using the RTH collection method in riffles; at 4 sites using the QMH D-net method (3 sites overlapping with RTH); and at 7 sites the list was supplemented with data collected using electrofishing methods (table 30).

Temporal and Spatial Variability

The multi-year, multi-reach samples collected from Waihee Stream (WHEE) were analyzed separately to examine temporal and spatial variability in the P-HBIBI. The multi-year samples were collected at reach B on Waihee Stream over a 3-year period. The multi-reach samples were collected from three adjacent reaches (A, B, and C) in 2000. A total of five samples were analyzed along with five sets of reach-level habitat data. Because the land-use data and the contaminants data for the Waihee sites were identical, these sites were assessed using only the reach-level environmental variables. The results of a PCA using the environmental variables show that the Waihee sampling sites were more similar to each other than to sites on other streams (fig. 21A). The environmental assessment methods described earlier classified WHEE B-99 (reach B sampled in 1999) as a “mild” impairment site; consequently, the other Waihee sites were also assessed as “mild” sites (table 31). A detrended correspondence analysis (DCA) of the invertebrate data, log (x+1) transformed prior to analysis, shows that the invertebrate communities at the Waihee sites also were more similar to each other than to sites on other streams (fig. 21B). The P-HBIBI scoring for the Waihee sites range from 9 to 13, with the single 2001 sample scoring the highest. All the scores were within the range of the “mild” impairment category (table 31).

Total invertebrate abundance ranged from a low of 3,617/m^2 at WHEE B-99 to a high of 10,290/m^2 at WHEE A-00, with a mean of 6,398/m^2 for the 5 sites (table 33). The high abundance at WHEE A-00 was due to a large number of the trichopteran *Hydroptila* sp. (4,581/m^2), the dominant taxa for that sample (table 33). The trichopteran *Cheumatopsyche pettiti* was the dominant taxa in the four other WHEE samples. In all five samples, *C. pettiti*, *Hydroptila* sp., and *Cricotopus* sp. were the dominant taxa although not always in the same order. Insects accounted for more than 90 percent of individuals in the four samples from 2000 and 2001 and accounted for 88 percent of the total abundance in the 1999 sample. Alien molluscs were not collected in the RTH samples from 1999 or 2000, but were present in the QMH sample from 1999 and were collected in the RTH sample from 2001. No amphipods were collected in any sample. The native mountain shrimp *Atyoida bisulcata* was present in all the QMH samples as was the alien crayfish *Procambarus clarkii*.

Relations between Land Use, Contaminants, and Habitat

The environmental assessments in this study made use of the data collected as part of the Oahu NAWQA study. One of the goals of the NAWQA study was to describe the relation between land use and a range of environmental variables. Many associations were found between land use and variables including contaminants and habitat (Brasher and others, 2004). Drainage basins with large percentages of urban land were commonly associated with contaminants such as chlordane, dieldrin (a metabolite of the pesticide aldrin), and polycyclic aromatic hydrocarbons (PAHs) (Brasher and Anthony, 2000; Brasher and Wolff, 2004). Predominantly agricultural drainages were associated with DDT and its degradation products DDD and DDE. Mixed land-use basins were associated with both groups of contaminants. The organochlorine pesticides chlordane, aldrin, dieldrin, and DDT were banned in the United States in the 1970s and 1980s but persist in the soils of the areas in which they were applied. Land use also was associated with habitat variables determined at the reach or transect scale. Urban residential sites were associated with an increase in channel modification and decreased canopy cover, agricultural sites were associated with higher levels of silt and embeddedness, and urban commercial sites were associated with semi-volatile organic compounds (Brasher and others, 2004). Levels of trace-element concentrations create another challenge in Hawaiian stream sediments and site assessments. First, studies have to differentiate between anthropogenic input and naturally occurring elevated levels of such elements in the rocks of the Hawaiian Islands (De Carlo and Anthony, 2002; De Carlo and others, 2004). Secondly, non-point sources of these contaminants may not be indicated by land use. For example, sources of arsenic (As) have been associated with agricultural fertilizers, yet the small percentage (4.2) of agricultural land in the WKEA basin is the most likely source of the highest concentration of As detected in bed sediments at any of the sites in this study (table 15).

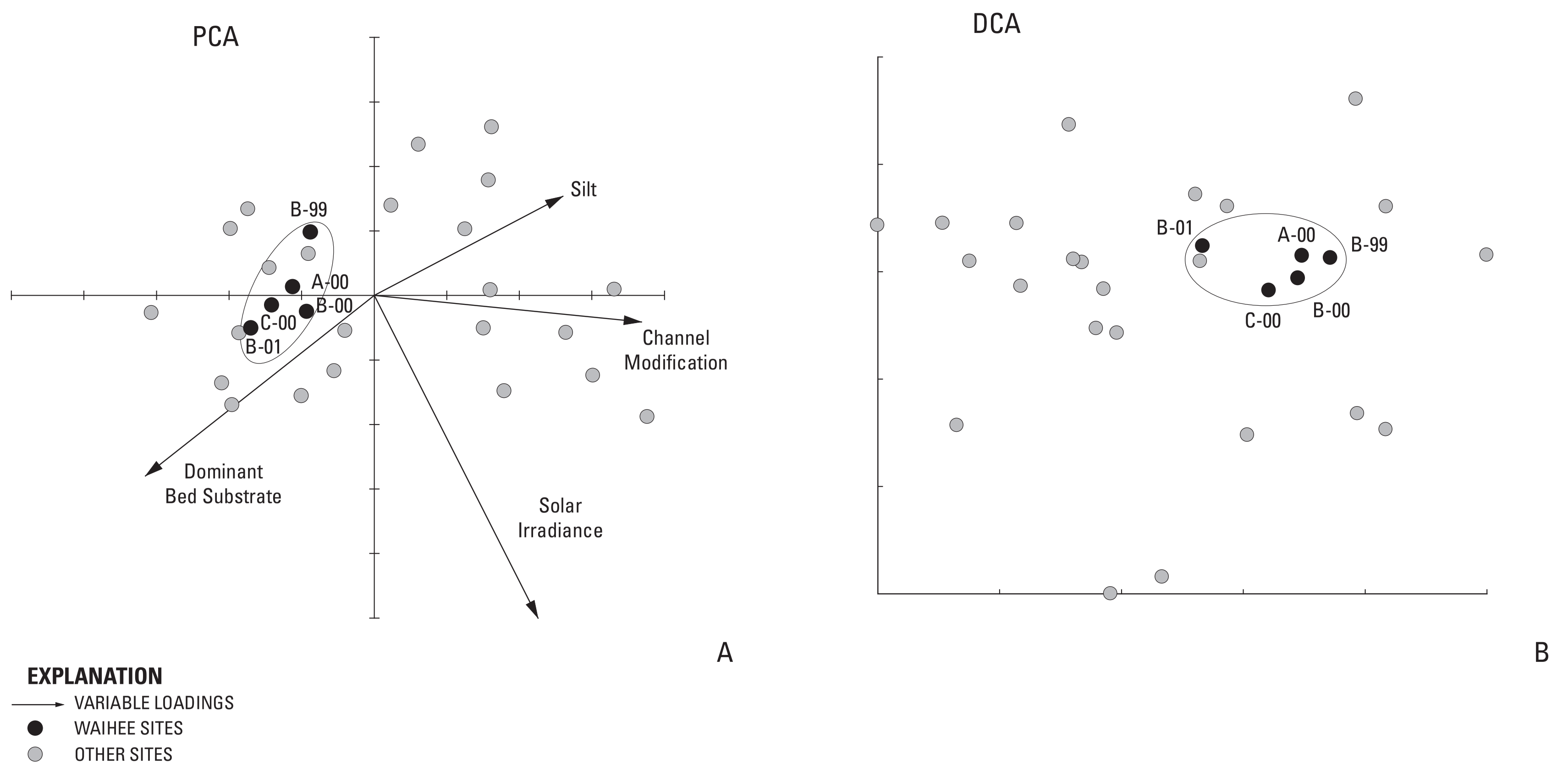


Figure 21. Comparison of multi-year and multi-reach samples collected at Waihee Stream at reach B in 1999, 2000, and 2001, and at reaches A and C in 2000. Ordination plots of (A) Principal Components Analysis (PCA) of the habitat variables (B) Detrended Correspondence Analysis (DCA) of the invertebrate data. Clustered sites display similar conditions that differ from those at other sites.

The environmental assessments conducted in this study attempted to differentiate among the sites by compounding the effects of the various levels of these environmental variables. By examining the level 1 land-use percentages and the contaminants and habitat characteristics that were associated with these percentages, it was possible to distinguish levels of impairment among the study reaches, and to extrapolate these results to sites where less data were available. Sites that scored the highest in the assessments were the most affected by anthropogenic activities (table 20). These sites had lower percentages of forested land in their drainage basins, a greater number of detectable contaminants, higher concentrations of these contaminants, and usually had structurally modified stream channels and reduced or nonexistent riparian zones. Sometimes the effects at the reach scale were confounded by restoration of the riparian vegetative zones and stream channels artificially filled with boulder/cobble substrate. Such was the case at Nawiliwili Stream (NWIL), a site downstream of an abandoned sugar cane processing mill, where boulders were placed in the modified stream channel adjacent to recent residential development. Similarly, at Nuuanu Stream (NUUA), an urban Oahu site located within the Queen Liliuokalani Botanical Garden, the riparian zone is well maintained by the park staff; only a few meters downstream, however, the channel is lined with concrete as it extends through downtown Honolulu. These restorative techniques can enhance the scenic beauty of a site and create habitat for biota, but also can superficially mask the effects of degraded water quality.

Land use in Hawaii has undergone significant changes in the last century. The growing population and increased operational costs have resulted in a conversion from large-scale agriculture to urban residential and commercial development (Oki and Brasher, 2003). This changing landscape creates new projects such as construction, utilities, infrastructure, and waste disposal. These projects put added pressures on the streams that drain the basins under development by increasing sediment input, increasing amounts of impervious surfaces and storm drains, dewatering, and increased public access and usage. Land-use and land-cover information needs to be continually updated to reflect these changes.

Relations between Benthic Index of Biotic Integrity and Environmental Assessments

The goal of a benthic index of biotic integrity (BIBI) for Hawaiian streams is to provide a quick way to assess the biological integrity of stream reaches and provide managers with a tool to prioritize their efforts. An effective BIBI should be able to discern impairment levels of stream reaches based on the invertebrate assemblages at the reaches and the deviation of these assemblages from reference site assemblages. The individual metrics that comprise the BIBI also should differentiate between reference sites and impaired sites, although each metric may differentiate these sites for dissimilar reasons. It is when the metrics are compiled into an index that the metric-specific details are replaced with the overall impairment level. The calibration of the individual metrics depends on the quality of the reference condition. The results of the environmental assessments in this study provided an objective analysis to determine the most and least impaired sites. These least-impaired reference sites were determined to be HNKP and LMAH on Kauai and PUNA and WHOL on Oahu. The most impaired sites were determined to be KANE, WKEL, and MANO (table 20). The individual metrics were therefore calibrated to demonstrate deviation from the invertebrate assemblages at the reference sites with increases in human disturbance. Secondarily, the metrics were calibrated to demonstrate the greatest of these deviations that were observed at the most severely impaired sites. A between-island comparison of the reference site assemblages is discussed below.

Reference Condition and Between-Island Comparisons

One of the goals of this study was to assess the viability of a statewide BIBI for all streams in Hawaii. The environmental assessments developed in this study were designed to establish a range of conditions, from mildly impaired to severely impaired, based on our knowledge of what the least impaired site conditions are. This methodology uses the “reference condition” as a standard against which all other sites are compared. Genuine, statewide reference conditions are thought to exist only in remote streams on the less populated islands. Kido (2002) used remote “pristine” streams on Kauai as the reference conditions for developing the Hawaii Stream Bioassessment Protocol (HSBP) with the understanding that biologically pristine streams are in reality “minimally impacted” streams in Hawaii. The NAWQA program was limited to studying streams on Oahu, with reference condition sites chosen as those that had the least amount of human disturbance (Brasher and others, 2004). After the reference condition sites are chosen, the biological assemblages of those sites become the standard to which all others are compared with metrics designed to score sites according to deviation from the reference condition.

The state of Hawaii comprises 8 main islands that range in age from about 5.5 million years (Kauai) to less than 1 million years (Hawaii) (Armstrong, 1983). The state of Hawaii was not included in Omernik’s framework of ecoregions (Omernik, 1987), geographic regions with similar geology, soils, vegetative cover, and climate. Ecoregions have been used for comparing biological communities based on the concept that the biological assemblages within the same homogenous ecoregion are similar, the natural variations among these biological assemblages are predictable, and responses to disturbance can be observed by comparison with a reference site in the same ecoregion (Hughes and Larsen, 1988; Hughes, 1989; Omernik and Bailey, 1997). The State of Hawaii often has been regionalized by island, and each island has traditionally been regionalized as leeward or windward. The HSBP reference condition is applied statewide for the native fish, mollusc, and crustacean assemblages because their amphidromous life histories allow them to inhabit all the islands (Kido, 2002). This study investigated whether or not there are differences in the invertebrate assemblages between the islands of Kauai and Oahu.

The environmental assessment scored two Kauai sites, HNKP and LMAH, and two Oahu sites, PUNA and WHOL as the least impaired sites, all scoring the low score of 10 (table 20). These 100 percent forested sites had natural stream channels and were assumed to have minimal concentrations of contaminants. The plot of the results of the PCA of the environmental data grouped these sites very near to one another, indicating that the sites had similar habitats (fig. 7). Access to these sites is limited, though some allow entry to hikers and hunters. Because these sites were selected as the reference condition sites, the P-HBIBI was compiled from metrics that scored these sites as having the highest biotic integrity. Other candidate metrics that demonstrated considerable differences between the invertebrate assemblages at the reference sites were omitted from the final index.

The invertebrate assemblages collected at reference sites on the two islands displayed a number of differences. Taxa richness was higher at PUNA than at the other reference sites. One possible contributing factor for this difference could be the randomn sub-sampling and the lack of replicate samples. Taxa that are not numerous in the main body of the sample have less chance of being included in the randomly chosen sub-sample. Another possible factor is that the more urban and populated island of Oahu has a greater chance of having more alien introductions than Kauai because of the greater amount of international traffic on Oahu. The total taxa abundance was much higher at PUNA due to a large number of *Hydroptila* in the sample (table 35). The PUNA sample had more than twice the total abundance of invertebrates than the second most abundant reference site sample from LMAH, and more than three times the total abundance of invertebrates from WHOL and HNKP. The total invertebrate abundances at reference sites are controlled more by population dynamics than by water-quality limitations.

The most obvious difference between the islands was the dominant taxa at the reference sites. On Oahu, the dominant taxonomic group was the insect order Trichoptera; while on Kauai the dominant taxonomic group was the insect family Chironomidae (table 35). At the genus level, the trichopteran *Hydroptila* sp. was the dominant taxa at PUNA (65 percent), the trichopteran *Cheumatopsyche pettiti* was dominant at WHOL (63 percent) and HNKP (31 percent) and the chironomid *Cricotopus* sp. was dominant at LMAH (53 percent). The PUNA sample had a very high abundance of *Hydroptila* (6,722/m^2) compared to all the other samples. The second dominant genus in the LMAH sample was also a chironomid midge, *Eukiefferiella*. Although four of these taxa were collected at all the reference sites, the abundances and proportions varied. Large proportions of chironomids are typically indicators of degraded water quality in continental settings; however, because the LMAH site is a “pristine” stream reach, the large abundance of chironomids must be attributable to other factors.

Other notable differences in the macroinvertebrate assemblages among the reference sites included:

- A much larger abundance of the dipteran insect *Hemerodromia stellaris* (family: Empididae) was collected at the PUNA site. Proportionally, *H. stellaris* abundance was similar at PUNA (4.2 percent), WHOL (3.6 percent), and LMAH (3.6 percent) but was much lower at HNKP (0.6 percent).

- The endemic dipteran insect genus *Procanace* (family: Canacidae) was collected only in the samples from HNKP and PUNA. This sensitive taxon was suggested as a possible indicator species, but it was rare in the samples. Other recommended sensitive indicator taxa, *Telmatogeton* and *Scatella*, were not collected in any samples.

Table 35. Abundances and proportions of the trichopterans and chironomids from the reference condition sites.

[**Abbreviation**: A, abundance in -number of individuals per square meter; Pct, percent of site total. Numbers in **Bold** indicate the dominant genus. See table 1 for site names]

Site	Total	Trichoptera						Chironomidae					
				Cheumatopsyche pettiti		*Hydroptila* sp.				*Cricotopus* sp.		*Eukiefferiella* sp.	
	A	A	Pct	A	Pct	A	Pct	A	Pct	A	Pct	A	Pct
HNKP	2,799	973	35	**862**	**31**	111	4	1,544	55	683	24	742	27
LMAH	4,729	1,013	21	430	9	583	12	3,363	71	**2,518**	**53**	845	18
PUNA	10,356	8,337	81	1,615	16	**6,722**	**65**	1,210	12	1,109	11	101	1
WHOL	2,415	1,788	74	**1,513**	**63**	275	11	382	16	358	15	24	1

Integrating Macroinvertebrates and Existing Bioassessment Protocols

The purpose of applying rapid bioassessment techniques is to identify stream quality problems and document long-term regional changes in a cost-effective way (Lenat and Barbour, 1994; Resh and Jackson, 1993). Thus it would be beneficial to streamline the sampling protocols so the Hawaii Department of Health (HDOH) staff could reduce the time and cost for sampling and processing the macroinvertebrate samples. A streamlined sampling protocol would enable personnel with moderate training to collect and process invertebrate samples for stream monitoring. The sampling and processing protocols used in this study followed the NAWQA protocols (Cuffney and others, 1993; Moulton and others, 2000) with some slight modifications for Hawaiian streams (Brasher and others, 2004). The invertebrate sampling and on-site habitat assessments required a minimum of three personnel, although a field crew of four was optimal. The final crew consisted of an aquatic biologist with expertise in invertebrates, while the other members of the field crew were trained hydrologic technicians. One full day was required to collect and field-process the invertebrate samples and the habitat data for each site. After all the samples were collected, they were packed and shipped to the laboratory in compliance with all state and federal regulations. A number of governmental and private laboratories employ expert taxonomists that specialize in this type of work, including the USGS National Water Quality Laboratory (NWQL) Biological Unit, and EcoAnalysts, Inc., the two laboratories used during this study. The turnover time of the laboratory depended on the number of samples sent and the laboratory workload but generally took 3 to 6 months. The laboratory results were returned in spreadsheet form and a statistician/aquatic ecologist interpreted the data. The fundamental costs incurred during this study included those for field materials, labor, travel, shipping, and a per-sample analysis charge (varied among laboratories).

The HDOH already makes use of two stream assessment protocols created for Hawaiian streams on the basis of on-site habitat measurements and visual observations of stream fish, molluscs, and crustaceans (Burr, 2001; Burr, 2003; Henderson, 2003; Paul and others, 2004). The Hawaii Stream Bioassessment Protocol (HSBP) consists of a detailed habitat assessment and a multimetric assessment of the stream macrofauna (Smith, 1998; Kido and others, 1999b; Kido, 2002). A field crew of three trained personnel is recommended to complete the assessment in approximately 3 hours. The biological metrics assess the native macrofaunal communities and native fish species in comparison to the alien macrofaunal communities. The observations of macrofauna are made using snorkeling surveys, or electrofishing where snorkeling is not feasible. These metrics include:

- Number of native amphidromous macrofauna
- Percentage of contribution native taxa
- Percentage of sensitive native taxa
- Sensitive native fish density
- Sensitive native fish size
- *Awaous guamensis* (oopu nakea) size
- Total native fish density
- Community weighted average
- Number of alien taxa
- Percentage of tolerant alien fish
- Percentage of diseased native fish

The second assessment protocol is the Hawaii Stream Visual Assessment Protocol (HSVAP) developed by the U.S. Department of Agriculture National Research Conservation Service (NRCS) (Kelley, 2001). Like the HSBP, the HSVAP already is being used by the HDOH (Burr, 2001; Henderson, 2003; Paul and others, 2004). The HSVAP was designed as a basic water quality evaluation technique centered on on-site habitat parameters so that minimally trained conservationists could conduct the survey. This protocol does not require any special biological training or even entering the water. A very descriptive set of conditions and a range of scores for each condition are used to assess each of the following parameters:

- Stream turbidity
- Plant growth
- Channel condition
- Channel flow alteration
- Percentage of embeddedness
- Bank stability
- Canopy/shade
- Riparian condition
- Habitat available for native species
- Litter/trash

The first steps in streamlining the protocols of this study would be to use the habitat evaluation of either the HSBP or HSVAP. There is a great deal of overlap in the habitat parameters being measured in all three protocols (HSBP, HSVAP, and NAWQA protocols). The hydrologic parameters determined in the NAWQA protocol require specialized equipment and training and this level of scientific information may not be necessary for the HDOH for its evaluations of site conditions. Many habitat parameters also are correlated with each other and therefore a measurement of one parameter may suffice for a group of associated parameters.

The major difference between the P-HBIBI for Hawaii and the HSBP is that the invertebrates incorporated into the HSBP include only the larger molluscs and crustaceans (Kido, 2002). The HSBP does not include any of the other invertebrates, such as insects, found in Hawaiian streams. The results of this study are in agreement with the HSBP that the presence of *Procambarus clarkii* is an indicator of impaired biotic integrity, while the presence of *Atyoida bisulcata* is an indicator of better biotic integrity. The data for these two P-HBIBI metrics can be collected simultaneously with the HSBP. A third P-HBIBI metric, the abundance of alien molluscs, also can be estimated simultaneously with the HSBP, when using snorkeling surveys, with some training and taxonomical knowledge of what the alien molluscs look like. When in doubt, samples of the molluscs could be collected and identified by experienced taxonomists. Rough estimates of the abundance of these molluscs within a square meter should not be difficult. When snorkeling surveys cannot be conducted, a D-frame kick net can be used to collect alien molluscs from wadeable areas within a stream reach. An excellent source of information and photographs of these macrofauna are available in Yamamoto and Tagawa (2000).

The more difficult P-HBIBI metrics to accomplish are those dealing with estimates of abundance of very small taxa. These metrics include the total invertebrate abundance, the abundance of amphipods, the relative abundance of insects, and the total number of taxa. Because these metrics are abundance based, the densities (number of individuals/unit area) need to be estimated per unit area, in this case square meters. The data for two of these metrics, the percentage abundance of insects and the total number of taxa, also require a higher level of taxonomic knowledge. Comprehensive taxonomic keys include:

- Merritt and Cummins (1984) aquatic insects
- Usinger (1971) aquatic insects
- Thorp and Covich (1991) aquatic invertebrates
- Peckarsky and others (1990) aquatic invertebrates
- Insects of Hawaii - University of Hawaii Press (17 volumes)

Need for Additional Information

The study described in this report was the first attempt in the Hawaiian Islands at developing and testing the quantifiable attributes of benthic invertebrate assemblages to understand the effects of degraded water quality on the biotic integrity of those assemblages. The study was limited to the islands of Kauai and Oahu and relied a great deal on the invertebrate data collected specifically as part of the Oahu NAWQA study. The results of this study cannot, with confidence, be extrapolated to streams on the other islands of Hawaii without sampling an assortment of streams, and testing and refining the P-HBIBI developed in this study.

The number of sites sampled was relatively small in comparison to the number sampled in many of the studies on continental streams. More samples, including replicate samples, would be required to develop a better understanding of the variability in the assemblages. Additionally, most of the streams sampled in this study were sampled at only one or at most two locations. Many streams in Hawaii begin in the steep, mountainous, forested conservation districts and continue downstream through agricultural land, and finally flow through coastal urban areas before discharging into the ocean. Sampling sites should be located at various points along this continuum to determine how the invertebrate assemblages are affected by changes in elevation and land use. This same concept should be applied to streams that are completely within conservation districts to ascertain the effects of elevation and distance on the invertebrate assemblages under reference conditions. Further refinement of the BIBI would make it a more robust indicator of water quality and therefore a better management tool.

Summary and Conclusions

Environmental variables at sampling sites on streams in Hawaii, including land use, contaminants, and reach-level parameters, and benthic macroinvertebrate assemblages, were evaluated. Macroinvertebrates were collected from 19 sites on 14 streams on the island of Oahu and from 9 sites on 7 streams on the island of Kauai. The sites were selected to represent a range of land use including conservation, urban, agricultural, and mixed land-use watersheds. Invertebrates were collected at each site using both qualitative and quantitative sampling methods. Environmental variables were determined at a range of spatial scales including basin, reach, transect, and point.

The 1972 Federal Clean Water Act requires states to restore and maintain the biological integrity of the Nation’s surface waters. The Hawaii Department of Health (HDOH) is required to submit to the U.S. Environmental Protection Agency a list of all waterbodies (estuaries, harbors, coastal waters, and streams) that do not meet state water quality standards. The HDOH is required to rank and prioritize the list of impaired waters according to the severity of the impairment and the instream and offstream uses of the waters. HDOH currently uses two site evaluation protocols, the Hawaii Stream Visual Assessment Protocol (HSVAP), based on habitat parameters, and the Hawaii Stream Bioassessment Protocol (HSBP), based on habitat characteristics and macrofauna metrics, including fish, crustaceans, and molluscs. The goal of this study was to evaluate the possibility of developing a multimetric-based index of biotic integrity (BIBI) for Hawaiian streams based on attributes of the benthic macroinvertebrate assemblages. In the future, a BIBI could be incorporated into the HDOH site evaluations to better enable the HDOH to prioritize the list of impaired waters.

Site conditions were evaluated using various environmental criteria to classify the stream reaches from the most "pristine" reference conditions to the most severely degraded conditions. Sites were scored and classified using a combination of seven land-use, seven contaminant, and four habitat parameters. There was a relation between increasing urban and agricultural land use with an increase in the number of detections and the concentrations of contaminants. Habitat quality decreased with a decrease in forested land, and with increasing urbanization and agriculture in the watersheds. Watersheds with large percentages of urban land were associated with contaminants such as chlordane, dieldrin, and polycyclic aromatic hydrocarbons. DDT and its degradation products DDE and DDD were associated with predominantly agricultural watersheds, whereas both groups of contaminants were found in mixed land-use watersheds. Decreased canopy cover and increased channel modification were associated with urban residential sites, semi-volatile organic compounds were associated with urban commercial sites, and higher levels of silt and embeddedness were associated with agricultural sites. The most impaired sites were determined to be Waikele Stream (WKEL), Nawiliwili Stream (NWIL), and Manoa Stream (MANO) while the reference condition sites were Limahuli Stream (LMAH) and Hanakapiai Stream (HNKP) on Kauai and Punaluu Stream above the diversion (PUNA) on Oahu.

Macroinvertebrate assemblages were examined and various metrics were tested to determine the degree to which these attributes could distinguish between reference conditions and severely impaired conditions. The preliminary Hawaiian benthic index of biotic integrity (P-HBIBI) comprises seven core metrics that were calibrated as the best collection of metrics for distinguishing between site conditions. These metrics were: total invertebrate abundance, taxa richness, insect relative abundance, amphipod abundance, crayfish presence or absence, and native mountain shrimp presence or absence.

Total invertebrate abundance (total number of individuals) was lower at urban and mixed land-use sites than at forested sites. In contrast, taxa richness (the number of different taxa) was higher at urban and mixed land-use sites. The majority of invertebrates identified during this study were alien introductions. In a "pristine" Hawaiian stream, taxa richness is expected to be inherently low, while in the more degraded streams, the pollution-tolerant alien taxa flourish.

Insect relative abundance decreased with an increase in the level of disturbance. Reference sites were predominantly (greater than 90 percent of total abundance) insects of the order Trichoptera or of the family Chironomidae, while insects accounted for less than 65 percent of the total abundance at impaired sites. Alien mollusc abundance increased with increasing levels of disturbance. Molluscs such as the Asiatic clam *Corbicula* sp., and species of the families Physidae, Planorbidae, and Thiaridae appeared to be more tolerant of impaired water quality.

The abundance of amphipods increased with increasing levels of disturbance. No amphipods were collected at the reference sites, but they were present at all of the severely impaired sites, whereas three moderately impaired mixed land-use sites had extremely high abundances. No crayfish were collected at any of the reference sites but they were present at most of the impaired sites. The mountain shrimp *Atyoida bisulcata* was collected at all reference sites and at most forested sites, but none were collected at the severely impaired sites.

The P-HBIBI was calibrated using attributes that were similar among the invertebrate assemblages at the reference condition sites. A comparison of the invertebrate assemblages from the reference sites indicated some differences between the islands assemblages. Although insects were dominant at the reference sites (greater than 90 percent of the total abundance) the taxa that comprised the Insecta component varied among the sites. The dominant taxonomic group on Oahu was the insect order Trichoptera while the dominant taxonomic group on Kauai was the insect family Chironomidae. At a lower taxonomic resolution, on Oahu, the trichopteran *Hydroptila* sp. was the dominant taxa at Punaluu Stream above the diversion (PUNA), while the trichopteran *Cheumatopsyche pettiti* was dominant at Waiahole Stream (WHOL). On Kauai, *C. pettiti* was dominant at Hanakapiai Stream (HNKP) while the chironomid *Cricotopus* sp. was dominant at Limahuli Stream (LMAH). Additional information is required to resolve this difference in the preference of dominant taxa at "pristine" sites.

Temporal and spatial variability was analyzed using multiple year and multiple reach samples collected from adjacent reaches in Waihee Stream on Oahu. Although there were some differences among the samples, the P-HBIBI scored all the sites as only "mildly" impaired. Multivariate analysis also showed that the invertebrate assemblages at these sites were similar to each other and to other "mildly" impaired sites by grouping these sites close to each other in the ordination plot.

This study provides valuable information needed for an integrated assessment of stream quality in Hawaii and the development of appropriate monitoring and management strategies. The ability of the P-HBIBI developed to discern levels of impairment in Hawaiian streams could provide the HDOH one more tool in their stream assessment toolbox. Further refinement and calibration would make the Hawaii Stream BIBI a more robust resource for monitoring programs to rely on. Future refinements may reveal the forces that shape the invertebrate communities and lead to predictive models that could be used to forecast the effects of anthropogenic activities.

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Appendixes A–D

Appendix A. Unedited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.

[Abundances computed for sub-sampling and for an area of 1 square meter. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; -,not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
																				WHEE										
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA	PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Porifera	**Porifera**	N	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes																														
Turbellaria	**Turbellaria**	U	34	-	-	-	34	-	61	-	12	77	56	-	1	81	115	-	-	-	6	280	65	40	16	-	14	-	1	-
Nematoda	**Nematoda**	U	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	215	-	-	-	-	-	-	-	-	-	-
Nemertea	**Nemertea**	U	-	-	8	-	-	-	-	-	-	-	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hoplonemertea																														
	***Prostoma* sp.**	A	-	-	-	-	9	-	-	-	10	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	5	2	23
Annelida																														
Aphanoneura																														
Aeolosomatidae																														
	***Aeolosoma* sp.**	U	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	**Hirudinea**	U	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchobdellida																														
Glossiphoniidae	**Glossiphoniidae**	N	-	-	-	-	14	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	**Oligochaeta**	U	-	8	8	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lumbricina	**Lumbricina**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Megadrile	**Megadrile**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	1	13	-	-	-	-	1	-	-	-	1	6	3	2	-
Tubificida																														
Enchytraeidae	**Enchytraeidae**	U	17	-	-	11	-	-	-	-	-	-	11	2	-	-	11	-	-	54	-	-	-	-	-	16	-	-	1	2
Naididae	**Naididae**	U	-	-	-	2542	160	-	-	-	3	4	-	-	-	269	299	-	-	-	-	134	581	222	16	32	67	28	9	23
	Allonais inaequalis	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
	***Nais* sp.**	U	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Nais communis	U	17	-	-	-	-	-	-	13	-	4	-	-	2	-	-	5	14	-	-	-	-	-	-	-	-	-	-	-
	Nais elinguis	U	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Nais pardalis	U	9	31	8	-	-	26	77	-	-	17	415	1	2	-	-	21	11	-	-	-	-	-	-	-	-	-	-	-
	Nais variabilis	U	9	-	-	-	-	-	-	-	-	26	34	-	-	-	-	5	3	-	6	-	-	-	-	-	-	-	-	-
	***Pristina* sp.**	U	-	-	-	-	-	-	-	10	-	-	67	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-
	Pristina breviseta	U	-	-	-	-	-	-	-	-	-	4	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pristina leidyi	U	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pristinella jenkinae	U	68	-	-	-	-	-	-	-	-	-	-	-	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
	Slavina appendiculata	U	-	-	-	-	-	-	-	3	-	-	56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tubificidae	**Tubificidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	1	-
	Tubificidae w/ cap setae	U	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tubificidae w/o cap setae	U	-	-	-	-	-	-	-	3	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix A. Unedited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

[Abundances computed for sub-sampling and for an area of 1 square meter. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; -,not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
																				WHEE										
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA	PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Polychaeta																														
Errantia																														
Nereididae																														
	Namalycastis abiuma	N	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	5	2	2
Mollusca																														
Gastropoda	**Gastropoda**	U	-	-	-	-	-	-	-	-	-	-	-	9	2	-	-	-	-	107	-	-	-	-	-	16	-	2	-	10
Basommatophora																														
Ancylidae																														
	Ferrissia sharpi	N	9	-	24	11	39	102	-	-	-	-	11	2	2	-	-	42	177	-	-	-	-	-	-	-	-	22	-	4
Lymnaeidae																														
	Pseudosuccinea columella	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	57	-	-	-	-	-	-	-	-	-	-
Physidae	**Physidae**	A	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51	-	-
Planorbidae	**Planorbidae**	A	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thiaridae	**Thiaridae**	A	-	-	24	2	358	-	-	-	98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	149
	Melanoides tuberculata	A	-	-	184	-	-	77	-	-	-	-	-	19	-	-	-	-	-	11	76	-	-	-	-	-	-	-	-	-
	Tarebia granifera	A	-	-	32	-	-	26	-	-	-	-	-	6	-	-	-	-	-	80	8	-	-	-	-	-	-	-	-	-
Mesogastropoda																														
Hydrobiidae	**Hydrobiidae**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-
Pelecypoda																														
	Bivalvia	A	-	-	-	-	3	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90
Venerioda																														
Corbiculidae																														
	***Corbicula* sp.**	A	-	8	-	-	17	51	-	-	3	-	45	-	-	-	-	-	3	-	2	-	-	-	-	-	-	-	-	9
Veneroida																														
Lymnaeidae																														
	Pseudisidora producta	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-
Arthropoda																														
Insecta	**Insecta**	U	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coleoptera	**Coleoptera**	U	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrophilidae																														
	***Limnoxenus* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	6	-	-	-	-	-	-	-	-	-
Collembola	**Collembola**	U	-	-	-	22	3	-	-	3	-	-	-	-	3	-	11	-	-	-	-	-	32	-	-	-	6	2	2	-
Sminthuridae	**Sminthuridae**	U	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diptera																														
	Brachycera	U	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-

Appendix A. Unedited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

[Abundances computed for sub-sampling and for an area of 1 square meter. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; -,not present. See table 1 for site names]

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Canacidae																														
	***Canace* sp.**	U	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Procanace* sp.**	N	51	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	**Ceratopogonidae**	U	-	-	32	22	3	-	-	-	-	-	146	-	-	-	46	-	-	107	-	-	-	-	-	-	-	4	-	-
	Ceratopogoninae	U	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Dasyhelea* sp.**	U	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	54	-	-	-	-	-	-	-	-	-	-
Chironomidae	**Chironomidae**	U	-	-	-	-	26	-	-	-	-	9	-	-	-	-	58	-	-	-	-	-	65	101	16	145	6	4	1	-
	Chironominae	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-
	***Ablabesmyia* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
	***Apedilum* sp.**	A	51	-	8	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-
	***Chironomus* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-
	***Cricotopus* sp.**	A	683	599	1628	537	37	3808	2518	276	51	350	1255	72	53	887	357	191	23	376	237	762	1548	706	387	532	302	14	9	262
	***Cricotopus bicinctus* gr.**	A	-	31	32	-	50	-	-	-	27	-	347	-	-	-	-	-	-	27	26	-	-	-	-	-	-	2	-	2
	***Cricotopus/Orthocladius* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	226	141	16	32	-	-	-	-
	***Endotribelos* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Eukiefferiella* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	81	11	-	-	-	-	11	-	-	-	-	20	1	-	-
	***Eukiefferiella claripennis* gr.**	A	743	-	-	-	-	26	845	18	-	90	-	2	-	-	-	273	174	-	13	-	-	-	-	-	-	-	-	-
	Orthocladiinae	U	-	-	-	45	20	-	-	-	3	-	-	-	-	242	126	-	-	-	-	67	162	162	97	16	60	4	-	19
	***Orthocladius* Complex**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	134	-	-	-	-	-	-	-	-	-	-
	***Orthocladius* sp.**	N	68	-	-	-	-	-	-	13	-	-	45	-	1	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
	***Paratanytarsus* sp.**	A	-	-	40	-	-	128	-	3	1	-	-	-	1	-	-	-	108	-	26	11	-	-	-	16	-	18	-	-
	***Polypedilum* sp.**	A	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	5	-	-
	***Polypedilum illinoense* gr.**	A	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	1101	-	-	-	-	-	-	-	-	-
	***Pseudosmittia* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Tanytarsus* sp.**	A	-	-	-	-	9	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
	***Thienemanniella* sp.**	A	-	15	-	-	-	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Empididae	**Empididae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hemerodromia stellaris	A	17	138	79	11	15	-	169	69	3	128	258	12	41	430	81	29	43	403	77	22	419	40	16	129	88	4	-	-
Ephydridae	**Ephydridae**	U	17	8	-	11	-	-	15	-	-	-	-	-	-	-	126	-	-	-	-	11	-	-	-	16	-	1	-	-
	***Neoscatella* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Psychodidae	**Psychodidae**	U	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-
Tipulidae	**Tipulidae**	U	-	-	8	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Limonia* sp.**	U	-	-	16	11	-	-	15	-	-	-	-	-	-	27	23	-	-	27	-	-	-	-	-	-	6	-	-	-
Ephemeroptera																														
Caenidae																														
	Caenis nigropunctata	A	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix A. Unedited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

[Abundances computed for sub-sampling and for an area of 1 square meter. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; -,not present. See table 1 for site names]

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																				WHEE									
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Hemiptera																														
Corixidae																														
	Trichocorixa reticulata	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mesoveliidae																														
	Mesovelia amoena	A	-	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54	-	11	-	-	-	-	-	-	1	-
Veliidae																														
	Microvelia vagans	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	-	-	-	-
Lepidoptera	**Lepidoptera**	U	26	8	-	11	-	-	-	-	-	-	-	-	2	-	-	-	-	-	6	-	-	-	-	-	-	-	-	2
Odonata																														
Coenagrionidae	**Coenagrionidae**	U	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	-	-	-	1	-	-
	Enallagma civile	A	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Megalagrion* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
	Megalagrion nigrohamatum	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Trichoptera																														
Hydropsychidae																														
	Cheumatopsyche pettiti	A	862	967	-	90	93	3169	430	307	-	456	202	2	13	1615	1372	291	310	5317	77	1848	2613	2984	2983	3147	1513	28	240	9
Hydroptilidae																														
	***Hydroptila* sp.**	A	111	407	40	11	73	332	583	3	57	119	415	2	2	6399	1428	-	-	1557	19	426	4387	1915	1983	2016	255	3	-	23
	Hydroptila arctia	A	-	-	-	-	11	-	-	-	-	-	-	-	-	323	69	-	-	-	-	22	162	81	16	-	20	-	-	-
	Hydroptila icona	A	-	-	-	-	9	-	-	-	9	9	-	-	-	-	22	-	-	-	-	-	32	-	-	-	-	-	-	2
Arachnida																														
Acari	**Acari**	U	-	-	-	22	14	-	-	-	1	-	-	-	-	-	-	-	-	-	-	11	-	-	-	16	-	5	1	-
	Oribatidae	U	-	-	8	-	-	-	-	-	-	13	-	2	-	-	-	-	-	27	-	-	32	40	48	-	-	-	-	-
Crustacea																														
Isopoda	**Isopoda**	A	-	-	-	-	-	-	-	3	-	-	-	3	30	-	-	-	-	-	6	-	-	-	-	-	-	-	-	-
Tanaidacea	**Tanaidacea (order)**	U	-	-	-	-	-	-	-	-	-	-	56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	**Ostracoda**	U	-	8	-	-	-	-	-	8	-	-	179	4	2	-	-	-	17	430	-	-	-	-	-	-	-	-	-	-
Amphipoda	**Amphipoda**	U	-	392	-	-	-	358	-	13	-	-	22	7	10	-	-	13	-	483	-	-	-	-	-	-	-	-	-	-
Decapoda	**Decapoda**	U	-	-	-	2	-	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	32	40	-	-	-	-	1	16
Atyidae																														
	Atyoida bisulcata	N	9	-	-	-	-	-	15	-	-	9	-	-	-	-	-	3	3	-	-	-	-	2	-	-	58	-	-	-
	Neocaridina denticulata sinensis	A	-	-	-	-	-	-	-	26	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Cambaridae																														
	Procambarus clarkii	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Palaemonidae																														
	Macrobrachium lar	A	-	-	-	-	-	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix B. Edited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.

[Data has been corrected for sub-sampling, taxonomic resolution and ambiguity, and unit area. #, abundance; (#), percent of total site abundance; N, native species; A, alien species; U, undetermined status; <, less than; -, not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA
Porifera	**Porifera**	U	-	-	-	-	1 (<1.0)	-	-	-	-	-	-	-	-	-
Platyhelminthes																
Turbellaria	**Turbellaria**	U	34 (1.2)	-	-	-	34 (3.3)	-	62 (1.3)	-	12 (4)	77 (5.8)	56 (1.6)	-	1 (<1.0)	81 (<1.0)
Nematoda	**Nematoda**	U	-	-	-	11 (<1.0)	-	-	-	-	-	-	-	-	-	-
Nemertea	**Nemertea**	U	-	-	8 (<1.0)	-	-	-	-	-	-	-	78 (2.2)	-	-	-
Hoplonemertea																
	***Prostoma* sp.**	U	-	-	-	-	9 (<1.0)	-	-	-	10 (3.3)	-	-	-	-	-
Annelida																
Aphanoneura																
Aeolosomatidae																
	***Aeolosoma* sp.**	U	-	-	-	-	-	-	-	-	-	-	22 (<1.0)	-	-	-
Hirudinea	**Hirudinea**	U	-	-	1 (<1.0)	-	-	-	-	-	-	-	-	-	-	-
Rhynchobdellida																
Glossiphoniidae	**Glossiphoniidae**	U	-	-	-	-	14 (1.4)	-	-	-	-	-	-	-	-	-
Oligochaeta	**Oligochaeta**	U	-	8 (<1.0)	8 (<1.0)	-	-	-	-	-	-	-	22 (<1.0)	-	-	-
Lumbricina	**Lumbricina**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megadrile	**Megadrile**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)
Tubificida																
Enchytraeidae	**Enchytraeidae**	U	17 (<1.0)	-	-	11 (<1.0)	-	-	-	-	-	-	11 (<1.0)	2 (1.4)	-	-
Naididae	**Naididae**	U	102 (3.6)	30 (1.2)	8 (<1.0)	2542 (76.4)	160 (15.7)	26 (<1.0)	77 (1.6)	28 (3.7)	3 (<1.0)	54 (4.1)	594 (16.6)	1 (<1.0)	5 (3.6)	269 (2.6)
Tubificidae	**Tubificidae**	U	-	-	-	-	-	-	-	2 (<1.0)	-	-	-	1 (<1.0)	2 (1.4)	-
Polychaeta																
Errantia																
Nereididae																
	Namalycastis abiuma	N	-	-	-	-	-	-	-	-	1 (<1.0)	-	-	1 (<1.0)	-	-
Mollusca																
Gastropoda	**Gastropoda**	U	-	-	-	-	-	-	-	-	-	-	-	9 (6.4)	2 (1.4)	-
Basommatophora																
Ancylidae																
	Ferrissia sharpi	N	9 (<1.0)	-	24 (1.1)	11 (<1.0)	39 (3.8)	26 (<1.0)	-	-	-	-	11 (<1.0)	2 (1.4)	2 (1.4)	-
Lymnaeidae																
	Pseudosuccinea columella	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix B. Edited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

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Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA
Planorbidae	**Planorbidae**	A	-	-	-	-	3 (<1.0)	-	-	-	-	-	-	-	-	-
Thiaridae	**Thiaridae**	A	-	-	238 (10.8)	2 (<1.0)	358 (35.2)	102 (1.3)	-	-	98 (32.5)	-	-	26 (18.4)	-	-
Mesogastropoda			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrobiidae	**Hydrobiidae**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pelecypoda																
Venerioda																
Corbiculidae																
	***Corbicula* sp.**	A	-	8 (<1.0)	-	-	20 (2)	51 (<1.0)	-	-	4 (1.3)	-	45 (1.3)	-	-	-
Veneroida																
Lymnaeidae																
	Pseudisidora producta	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arthropoda																
Insecta																
Coleoptera	**Coleoptera**	U	-	-	-	-	-	-	-	2 (<1.0)	-	-	-	-	-	-
Curculionidae	**Curculionidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrophilidae																
	***Limnoxenus* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Staphylinidae	**Staphylinidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Collembola	**Collembola**	U	-	-	-	22 (<1.0)	3 (<1.0)	-	-	2 (<1.0)	-	9 (<1.0)	-	-	3 (2.1)	-
Diptera																
	Brachycera (suborder)	U	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
Canacidae																
	***Canace* sp.**	U	-	-	-	-	-	-	-	-	-	-	22 (<1.0)	-	-	-
	***Procanace* sp.**	U	51 (1.8)	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)
Ceratopogonidae	**Ceratopogonidae**	U	-	-	55 (2.5)	22 (<1.0)	3 (<1.0)	-	-	-	-	-	146 (4.1)	-	-	-
	***Dasyhelea* sp.**	U	-	-	-	-	-	-	-	-	-	-	11 (<1.0)	-	-	-
Chironomidae																
	***Ablabesmyia* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Apedilum* sp.**	A	51 (1.8)	-	8 (<1.0)	-	6 (<1.0)	-	-	-	-	-	-	-	-	-
	***Chironomus* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Cricotopus* sp.**	A	683 (24.4)	630 (24.2)	1660 (75.2)	538 (16.2)	107 (10.5)	3808 (47.4)	2518 (53.2)	277 (36.3)	78 (25.8)	357 (26.8)	1602 (44.7)	72 (51.1)	53 (37.9)	1109 (10.7)
	***Eukiefferiella* sp.**	A	-	-	-	-	-	-	-	18 (2.4)	-	-	-	-	-	101 (<1.0)
	***Eukiefferiella claripennis* gr.**	A	742 (26.5)	-	-	-	-	26 (<1.0)	845 (17.9)	-	-	91 (6.8)	-	2 (1.4)	-	-

Appendix B. Edited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

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Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA
	Orthocladiinae	U	68 (2.4)	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
	***Orthocladius* Complex**	U	-	-	-	-	-	-	-	13 (1.7)	-	-	45 (1.3)	-	-	-
	***Paratanytarsus* sp.**	A	-	-	39 (1.8)	-	-	128 (1.6)	-	2 (<1.0)	1 (<1.0)	-	-	-	1 (<1.0)	-
	***Polypedilum* sp.**	U	-	8 (<1.0)	-	-	-	-	-	2 (<1.0)	-	-	-	-	-	-
	***Pseudosmittia* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
	***Tanytarsus* sp.**	U	-	-	-	-	9 (<1.0)	-	-	-	1 (<1.0)	-	-	-	-	-
Empididae																
	Hemerodromia stellaris	A	17 (<1.0)	138 (5.3)	79 (3.6)	11 (<1.0)	15 (1.5)	-	169 (3.6)	69 (9)	2 (<1.0)	128 (9.6)	258 (7.2)	12 (8.5)	41 (29.3)	430 (4.2)
Ephydridae	**Ephydridae**	U	17 (<1.0)	8 (<1.0)	-	11 (<1.0)	-	-	15 (<1.0)	-	-	-	-	-	-	-
Psychodidae	**Psychodidae**	U	-	-	-	-	-	-	-	-	-	9 (<1.0)	-	-	-	-
Tipulidae	**Tipulidae**	U	-	-	8 (<1.0)	-	-	-	-	-	-	-	11 (<1.0)	-	-	-
	***Limonia* sp.**	U	-	-	16 (<1.0)	11 (<1.0)	-	-	15 (<1.0)	-	-	-	-	-	-	27 (<1.0)
Ephemeroptera																
Caenidae																
	Caenis nigropunctata	A	-	-	-	-	3 (<1.0)	-	-	-	-	-	-	-	-	-
Hemiptera																
Mesoveliidae																
	Mesovelia amoena	A	-	-	8 (<1.0)	-	-	-	-	-	-	-	-	-	-	-
Veliidae																
	Microvelia vagans	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidoptera	**Lepidoptera**	U	26 (<1.0)	8 (<1.0)	-	11 (<1.0)	-	-	-	-	-	-	-	-	2 (1.4)	-
Odonata																
Coenagrionidae	**Coenagrionidae**	U	-	-	-	-	7 (<1.0)	-	-	-	-	-	-	-	-	-
	Megalagrion nigrohamatum	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichoptera																
Hydropsychidae																
	Cheumatopsyche pettiti	A	862 (30.8)	967 (37.1)	-	90 (2.7)	93 (9.1)	3170 (39.5)	430 (9.1)	307 (40.2)	-	456 (34.3)	202 (5.6)	2 (1.4)	13 (9.3)	1615 (15.6)
Hydroptilidae																
	***Hydroptila* sp.**	A	111 (4)	407 (15.6)	39 (1.8)	11 (<1.0)	94 (9.2)	332 (4.1)	583 (12.3)	2 (<1.0)	66 (21.9)	128 (9.6)	414 (11.6)	2 (1.4)	2 (1.4)	6722 (64.9)
Arachnida																
Acari																
	Oribatidae	U	-	-	8 (<1.0)	22 (<1.0)	14 (1.4)	-	-	-	1 (<1.0)	13 (<1.0)	-	2 (1.4)	-	-

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Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA
Crustacea																
Amphipoda																
Hyalellidae																
	***Hyalella* sp.**	U	-	391 (15)	-	-	26 (2.6)	358 (4.5)	-	13 (1.7)	25 (8.3)	-	22 (<1.0)	7 (5)	10 (7.1)	-
Decapoda	**Decapoda**	U	-	-	-	2 (<1.0)	-	-	-	-	-	-	-	-	-	-
Atyidae																
	Atyoida bisulcata	N	9 (<1.0)	-	-	-	-	-	15 (<1.0)	-	-	9 (<1.0)	-	-	-	-
	Neocaridina denticulata sinensis	A	-	-	-	-	-	-	-	26 (3.4)	-	-	-	-	-	-
Cambaridae																
	Procambarus clarkii	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palaemonidae																
	Macrobrachium lar	A	-	-	-	-	-	1 (<1.0)	-	-	-	-	-	-	-	-

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Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
								WHEE								
			PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Porifera	**Porifera**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes																
Turbellaria	**Turbellaria**	U	115 (2.8)	-	-	-	6 (<1.0)	280 (7.7)	65 (<1.0)	40 (<1.0)	16 (<1.0)	-	14 (<1.0)	-	1 (<1.0)	-
Nematoda	**Nematoda**	U	-	-	-	214 (2.3)	-	-	-	-	-	-	-	-	-	-
Nemertea	**Nemertea**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hoplonemertea																
	***Prostoma* sp.**	U	11 (<1.0)	-	-	-	-	-	-	-	-	-	-	5 (2)	2 (<1.0)	23 (3.6)
Annelida																
Aphanoneura																
Aeolosomatidae																
	***Aeolosoma* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	**Hirudinea**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhynchobdellida																
Glossiphoniidae	**Glossiphoniidae**	U	-	-	3 (<1.0)	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	**Oligochaeta**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lumbricina	**Lumbricina**	U	-	-	3 (<1.0)	-	-	-	-	-	-	-	-	-	-	-
Megadrile	**Megadrile**	U	13 (<1.0)	-	-	-	-	1 (<1.0)	-	-	-	1 (<1.0)	6 (<1.0)	3 (1.2)	2 (<1.0)	-
Tubificida																
Enchytraeidae	**Enchytraeidae**	U	11 (<1.0)	-	-	54 (<1.0)	-	-	-	-	-	16 (<1.0)	-	-	1 (<1.0)	2 (<1.0)
Naididae	**Naididae**	U	299 (7.2)	34 (3.9)	32 (3.6)	-	13 (<1.0)	134 (3.7)	581 (5.6)	222 (3.5)	16 (<1.0)	32 (<1.0)	67 (2.8)	28 (11.1)	9 (3.3)	23 (3.6)
Tubificidae	**Tubificidae**	U	-	-	-	-	-	-	-	-	-	-	-	14 (5.6)	1 (<1.0)	-
Polychaeta																
Errantia																
Nereididae																
	Namalycastis abiuma	N	-	-	-	-	-	-	-	-	-	1 (<1.0)	-	5 (2)	2 (<1.0)	2 (<1.0)
Mollusca																
Gastropoda	**Gastropoda**	U	-	-	-	107 (1.2)	-	-	-	-	-	16 (<1.0)	-	-	-	-
Basommatophora																
Ancylidae																
	Ferrissia sharpi	N	-	42 (4.8)	177 (20.1)	-	-	-	-	-	-	-	-	22 (8.7)	-	4 (<1.0)
Lymnaeidae																
	Pseudosuccinea columella	A	-	-	-	57 (<1.0)	-	-	-	-	-	-	-	-	-	-
Physidae	**Physidae**	A	-	-	-	-	-	-	-	-	-	-	-	51 (20.2)	-	-

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Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
								WHEE								
			PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Planorbidae	**Planorbidae**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thiaridae	**Thiaridae**	A	-	-	-	91 (<1.0)	84 (4.9)	-	-	-	-	-	-	-	-	149 (23.3)
Mesogastropoda			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrobiidae	**Hydrobiidae**	A	-	-	-	-	6 (<1.0)	-	-	-	-	-	-	-	-	-
Pelecypoda																
Venerioda																
Corbiculidae																
	***Corbicula* sp.**	A	-	-	3 (<1.0)	-	2 (<1.0)	-	-	-	-	-	-	-	-	99 (15.5)
Veneroida																
Lymnaeidae																
	Pseudisidora producta	N	-	-	-	-	6 (<1.0)	-	-	-	-	-	-	-	-	-
Arthropoda																
Insecta																
Coleoptera	**Coleoptera**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Curculionidae	**Curculionidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
Hydrophilidae																
	***Limnoxenus* sp.**	N	-	-	-	27 (<1.0)	6 (<1.0)	-	-	-	-	-	-	-	-	-
Staphylinidae	**Staphylinidae**	U	-	-	-	-	6 (<1.0)	-	-	-	-	-	-	-	-	-
Collembola	**Collembola**	U	11 (<1.0)	-	-	-	-	-	32 (<1.0)	-	-	-	6 (<1.0)	2 (<1.0)	2 (<1.0)	-
Diptera																
	Brachycera (suborder)	U	-	-	-	-	-	-	-	-	-	-	-	5 (2)	-	-
Canacidae																
	***Canace* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Procanace* sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	**Ceratopogonidae**	U	46 (1.1)	-	-	107 (1.2)	-	-	-	-	-	-	-	4 (1.6)	-	-
	***Dasyhelea* sp.**	U	-	-	-	54 (<1.0)	-	-	-	-	-	-	-	-	-	-
Chironomidae																
	***Ablabesmyia* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	2 (<1.0)	-	-
	***Apedilum* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	14 (5.6)	-	-
	***Chironomus* sp.**	U	-	-	-	-	6 (<1.0)	-	-	-	-	-	-	-	-	-
	***Cricotopus* sp.**	A	479 (11.6)	191 (21.8)	22 (2.5)	402 (4.4)	262 (15.2)	828 (22.9)	1935 (18.8)	1008 (15.8)	500 (9)	705 (11.5)	358 (14.8)	20 (7.9)	9 (3.3)	265 (41.5)
	***Eukiefferiella* sp.**	A	15 (<1.0)	-	-	-	13 (<1.0)	12 (<1.0)	-	-	-	-	24 (<1.0)	1 (<1.0)	-	-
	***Eukiefferiella claripennis* gr.**	A	-	274 (31.2)	174 (19.8)	-	-	-	-	-	-	-	-	-	-	-

Appendix B. Edited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

[Data has been corrected for sub-sampling, taxonomic resolution and ambiguity, and unit area. #, abundance; (#), percent of total site abundance; N, native species; A, alien species; U, undetermined status; <, less than; -, not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
								WHEE								
			PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
	Orthocladiinae	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Orthocladius **Complex**	U	-	-	-	134 (1.5)	-	-	-	-	-	-	-	-	-	-
	Paratanytarsus **sp.**	A	-	-	108 (12.3)	-	26 (1.5)	11 (<1.0)	-	-	-	20 (<1.0)	-	22 (8.7)	-	-
	Polypedilum **sp.**	U	-	-	3 (<1.0)	-	1101 (63.7)	-	-	-	-	-	-	6 (2.4)	-	-
	Pseudosmittia **sp.**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Tanytarsus **sp.**	U	-	-	-	-	-	-	-	-	-	-	-	4 (1.6)	-	-
Empididae																
	Hemerodromia stellaris	A	81 (2)	29 (3.3)	42 (4.8)	402 (4.4)	77 (4.5)	22 (<1.0)	419 (4.1)	40 (<1.0)	16 (<1.0)	129 (2.1)	88 (3.6)	4 (1.6)	-	-
Ephydridae	**Ephydridae**	U	126 (3)	-	-	-	-	11 (<1.0)	-	-	-	16 (<1.0)	-	1 (<1.0)	-	-
Psychodidae	**Psychodidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	2 (<1.0)	-
Tipulidae	**Tipulidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Limonia **sp.**	U	23 (<1.0)	-	-	27 (<1.0)	-	-	-	-	-	-	6 (<1.0)	-	-	-
Ephemeroptera																
Caenidae																
	Caenis nigropunctata	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiptera																
Mesoveliidae																
	Mesovelia amoena	A	-	-	-	54 (<1.0)	-	11 (<1.0)	-	-	-	-	-	-	1 (<1.0)	-
Veliidae																
	Microvelia vagans	N	-	-	-	-	-	-	-	-	-	16 (<1.0)	-	-	-	-
Lepidoptera	**Lepidoptera**	U	-	-	-	-	6 (<1.0)	-	-	-	-	-	-	-	-	2 (<1.0)
Odonata																
Coenagrionidae	**Coenagrionidae**	U	-	-	-	-	13 (<1.0)	-	-	-	-	-	-	1 (<1.0)	-	-
	Megalagrion nigrohamatum	N	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
Trichoptera																
Hydropsychidae																
	Cheumatopsyche pettiti	A	1372 (33.1)	291 (33.2)	310 (35.2)	5317 (58.3)	77 (4.5)	1848 (51.1)	2613 (25.4)	2984 (46.8)	2983 (53.5)	3147 (51.3)	1513 (62.7)	28 (11.1)	239 (86.6)	9 (1.4)
Hydroptilidae																
	Hydroptila **sp.**	A	1520 (36.7)	-	-	1557 (17.1)	19 (1.1)	448 (12.4)	4581 (44.5)	1996 (31.3)	1999 (35.8)	2016 (32.9)	275 (11.4)	3 (1.2)	-	26 (4.1)
Arachnida																
Acari																
	Oribatidae	U	-	-	-	27 (<1.0)	-	11 (<1.0)	32 (<1.0)	40 (<1.0)	48 (<1.0)	16 (<1.0)	-	5 (2)	1 (<1.0)	-

Appendix B. Edited richest targeted habitat (RTH, quantitative sampling) invertebrate abundance data set.—Continued

[Data has been corrected for sub-sampling, taxonomic resolution and ambiguity, and unit area. #, abundance; (#), percent of total site abundance; N, native species; A, alien species; U, undetermined status; <, less than; -, not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site													
								WHEE								
			PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Crustacea																
Amphipoda																
Hyalellidae																
	***Hyalella* sp.**	U	-	14 (1.6)	-	483 (5.3)	-	-	-	-	-	-	-	2 (<1.0)	-	19 (3)
Decapoda	**Decapoda**	U	23 (<1.0)	-	-	-	-	-	32 (<1.0)	40 (<1.0)	-	-	-	-	1 (<1.0)	16 (2.5)
Atyidae																
	Atyoida bisulcata	N	-	2 (<1.0)	3 (<1.0)	-	-	-	-	2 (<1.0)	-	-	58 (2.4)	-	-	-
	Neocaridina denticulata sinensis	A	-	-	-	1 (<1.0)	-	-	-	-	-	-	-	-	-	-
Cambaridae																
	Procambarus clarkii	A	-	-	-	-	-	-	-	-	-	-	-	-	1 (<1.0)	-
Palaemonidae																
	Macrobrachium lar	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix C. Unedited invertebrate richness data set.

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
																				WHEE									
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA	PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Porifera	**Porifera**	N	-	-	-	-	R	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes																														
Turbellaria	**Turbellaria**	U	QR	-	Q	-	R	-	QR	-	R	QR	R	-	QR	QR	QR	-	-	-	R	QR	QR	QR	QR	-	QR	-	R	-
Nematoda	**Nematoda**	U	-	Q	-	R	-	-	-	-	-	Q	-	-	Q	-	-	Q	-	QR	-	-	-	-	-	-	-	-	-	-
Nemertea	**Nemertea**	U	-	-	R	-	-	Q	-	-	-	-	R	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-	-
Hoplonemertea																														
	***Prostoma* sp.**	A	-	-	-	-	R	-	-	-	QR	-	-	-	-	Q	QR	-	-	-	-	-	-	-	-	-	-	R	R	R
Annelida																														
Aphanoneura																														
Aeolosomatidae																														
	***Aeolosoma* sp.**	U	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	**Hirudinea**	U	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pharyngobdellida																														
Erpobdellidae	**Erpobdellidae**	U	-	-	Q	-	-	-	Q	-	-	-	-	-	-	Q	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-
Rhynchobdellida																														
Glossiphoniidae	**Glossiphoniidae**	N	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	**Oligochaeta**	U	-	R	QR	-	-	-	-	Q	-	-	R	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lumbricina	**Lumbricina**	U	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-
Lumbriculida																														
Lumbriculidae	**Lumbriculidae**	U	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megadrile	**Megadrile**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	R	-	-	-	-	R	Q	Q	Q	R	QR	R	R	-
Tubificida																														
Enchytraeidae	**Enchytraeidae**	U	R	-	-	R	-	-	-	-	-	-	R	QR	Q	-	R	-	Q	QR	-	-	-	-	-	R	-	-	R	R
Naididae	**Naididae**	U	-	-	-	QR	R	-	-	-	QR	R	-	-	-	QR	QR	-	Q	-	-	R	R	QR	R	R	QR	QR	QR	R
	Allonais inaequalis	U	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-
	***Dero* sp.**	U	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dero furcata	U	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dero pectinata	U	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Nais* sp.**	U	-	-	-	-	-	-	-	-	-	-	R	Q	Q	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-
	Nais communis	U	QR	-	Q	-	-	-	-	QR	-	QR	-	Q	QR	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-
	Nais elinguis	U	-	-	-	-	-	-	-	-	-	-	-	Q	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Nais pardalis	U	QR	QR	QR	-	-	QR	QR	Q	-	R	QR	QR	QR	-	-	QR	QR	-	Q	-	-	-	-	-	-	-	-	-

Appendix C. Unedited invertebrate richness data set.—Continued

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
																				WHEE								
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	Nais variabilis	U	R	-	-	-	-	-	-	-	-	QR	R	Q	Q	-	-	QR	R	-	R	-	-	-	-	-	-	-	-	-
	***Pristina* sp.**	U	-	-	Q	-	-	-	-	R	-	-	R	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
	Pristina breviseta	U	-	-	-	-	-	-	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pristina leidyi	U	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pristinella jenkinae	U	QR	-	-	-	-	-	-	-	-	-	-	Q	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-
	Slavina appendiculata	U	-	-	-	-	-	-	-	R	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tubificidae	**Tubificidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	Q	-	-	QR	R	-
	Tubificidae w/ cap setae	U	-	-	Q	-	-	-	-	-	-	-	Q	R	R	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-
	Tubificidae w/o cap setae	U	-	-	-	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
	Branchiura sowerbyi	U	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q
Polychaeta																														
Errantia																														
Nereididae																														
	Namalycastis abiuma	N	-	-	-	Q	Q	-	-	-	QR	-	Q	R	Q	-	-	-	Q	-	-	Q	Q	-	-	R	-	QR	R	QR
Mollusca																														
Gastropoda	**Gastropoda**	U	-	Q	Q	-	-	-	-	-	-	-	-	QR	QR	-	-	-	-	QR	-	Q	-	-	-	R	-	QR	Q	QR
Archaeogastropoda																														
Neritidae																														
	Neritina granosa	N	Q	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Basommatophora																														
Ancylidae																														
	Ferrissia sharpi	N	R	-	QR	R	QR	QR	-	-	Q	-	QR	QR	R	-	-	R	QR	-	-	-	-	-	-	-	-	R	-	R
Lymnaeidae																														
	Pseudosuccinea columella	A	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-
Physidae	**Physidae**	A	-	-	Q	-	-	Q	-	-	-	-	R	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
	***Physella* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-
Planorbidae	**Planorbidae**	A	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Planorbella* sp.**	A	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-
	Planorbella druryi	A	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
Thiaridae	**Thiaridae**	A	-	-	R	QR	QR	-	-	-	QR	-	Q	Q	-	Q	-	-	-	-	Q	Q	-	-	-	-	-	-	-	QR
	Melanoides tuberculata	A	-	-	QR	-	-	QR	-	-	-	-	Q	QR	-	-	-	-	-	QR	QR	-	-	-	-	-	-	-	-	-
	Tarebia granifera	A	-	-	QR	-	-	QR	-	-	-	-	Q	R	-	-	-	-	-	QR	QR	-	-	-	-	-	-	-	-	-
	***Thiara* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-

Appendix C. Unedited invertebrate richness data set.—Continued

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

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																					WHEE									
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Mesogastropoda																														
Hydrobiidae	**Hydrobiidae**	A	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	Q	QR	-	-	-	-	-	-	-	-	-
Pelecypoda																														
	Bivalvia	A	-	-	-	-	R	-	-	-	R	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-	-	-	R
Venerioda																														
Corbiculidae																														
	***Corbicula* sp.**	A	-	QR	Q	-	QR	QR	-	-	QR	-	QR	-	Q	-	-	-	R	Q	QR	-	-	-	-	-	-	-	-	R
Sphaeriidae																														
	***Musculium* sp.**	A	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Pisidium* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
Veneroida																														
Lymnaeidae																														
	Pseudisidora producta	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Arthropoda																														
Insecta																														
Coleoptera	**Coleoptera**	U	-	-	Q	-	-	-	-	R	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
Hydrophilidae	**Hydrophilidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-
	***Limnoxenus* sp.**	N	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	QR	R	-	-	-	-	-	-	-	-	-
	Limnoxenus semicylindricus	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	Q	-	-	-	-	-	-	-	-	-
Collembola	**Collembola**	U	-	-	-	R	R	-	-	QR	-	-	Q	-	R	-	R	-	-	-	Q	-	QR	-	-	-	R	QR	R	-
Sminthuridae	**Sminthuridae**	U	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diptera																														
	Brachycera (suborder)	U	-	-	-	-	-	-	-	-	-	-	Q	-	R	-	-	Q	-	-	-	-	-	-	-	-	Q	R	Q	-
Canacidae																														
	***Canace* sp.**	U	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Procanace* sp.**	N	R	-	-	-	-	-	-	-	-	-	-	-	-	R	-	Q	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	**Ceratopogonidae**	U	-	-	QR	QR	R	-	-	-	-	-	QR	-	-	-	R	-	-	QR	Q	-	-	-	-	-	-	R	-	-
	Ceratopogoninae	U	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Dasyhelea* sp.**	U	-	-	Q	-	-	Q	Q	-	-	-	R	Q	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-
	***Forcipomyia* sp.**	U	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-

Appendix C. Unedited invertebrate richness data set.—Continued

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
																				WHEE								
			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA	PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Chironomidae	**Chironomidae**	U	-	-	-	-	QR	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	QR	QR	QR	QR	R	R	R	-
	Chironominae	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	QR	-	-
	***Ablabesmyia* sp.**	A	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
	***Apedilum* sp.**	A	QR	Q	QR	-	R	-	Q	-	-	-	Q	Q	-	-	-	Q	Q	-	Q	-	Q	-	-	-	-	QR	-	-
	***Chironomus* sp.**	U	-	-	Q	-	Q	-	-	-	-	Q	Q	Q	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-
	***Corynoneura* sp.**	A	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Cricotopus* sp.**	A	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR
	***Cricotopus/Orthocladius* sp.**	U	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	QR	QR	R	R	-	Q	-	-
	***Cricotopus bicinctus* gr.**	A	-	QR	QR	-	QR	Q	-	-	QR	-	QR	Q	Q	-	-	-	Q	QR	QR	-	-	-	-	-	-	QR	-	R
	***Endotribelos* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Eukiefferiella* sp.**	A	-	-	-	Q	-	-	-	-	-	-	-	-	-	QR	QR	-	-	-	-	QR	-	-	-	Q	QR	R	-	-
	***Eukiefferiella claripennis* gr.**	A	QR	-	-	-	-	R	QR	QR	-	QR	-	R	-	-	-	QR	QR	-	QR	-	-	-	-	-	-	-	-	-
	***Goeldichironomus* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-
	Goeldichironomus holoprasinus	A	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-
	***Micropsectra* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
	***Micropsectra/Tanytarsus* sp.**	U	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Orthocladiinae	U	-	-	-	QR	R	-	-	-	R	-	-	-	-	QR	R	-	-	-	-	R	QR	QR	R	R	R	R	-	R
	***Orthocladius* (*Eudactylo.*) sp.**	N	QR	-	-	-	-	-	-	R	-	-	QR	-	R	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-
	***Orthocladius* Complex**	N	-	Q	Q	-	-	Q	Q	Q	-	-	Q	Q	Q	-	-	Q	Q	R	-	-	-	-	-	-	-	-	-	-
	***Paratanytarsus* sp.**	A	-	Q	QR	-	-	QR	-	R	R	-	-	Q	QR	-	-	Q	QR	Q	QR	QR	-	Q	-	R	-	QR	-	-
	***Polypedilum* sp.**	A	-	QR	-	-	-	Q	-	-	-	-	-	Q	-	-	-	-	QR	-	-	-	-	-	-	-	-	QR	-	-
	***Polypedilum illinoense* gr.**	A	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-
	***Pseudosmittia* sp.**	U	-	-	Q	-	-	-	-	-	-	-	-	Q	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Stempellinella* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-
	***Tanytarsus* sp.**	A	-	-	-	-	QR	Q	-	-	R	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
	***Thienemanniella* sp.**	A	-	QR	-	-	-	QR	-	-	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
Dixidae																														
	Dixa longistyla	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	Q	Q	-	Q	-	-	-
Empididae	**Empididae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hemerodromia stellaris	A	QR	QR	QR	R	R	Q	QR	QR	R	QR	QR	QR	QR	QR	R	QR	QR	QR	R	QR	QR	QR	R	QR	QR	QR	-	-

Appendix C. Unedited invertebrate richness data set.—Continued

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

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Ephydridae	**Ephydridae**	U	R	R	-	R	-	-	QR	-	-	Q	-	-	-	-	QR	-	-	-	-	R	-	-	-	R	-	QR	Q	-
	***Neoscatella* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	Q	-	-	-	-	-	-	-	-	-	-	-
Psychodidae	**Psychodidae**	U	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
	***Pericoma/Telmatoscopus* sp.**	U	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Psychoda* sp.**	U	-	-	-	-	-	-	-	-	-	Q	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-
Stratiomyidae	**Stratiomyidae**	A	-	-	-	-	Q	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Syrphidae	**Syrphidae**	U	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	**Tipulidae**	U	-	-	QR	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-
	***Limonia* sp.**	U	Q	-	R	QR	Q	-	QR	Q	-	-	Q	Q	-	R	R	-	-	R	-	-	-	Q	-	Q	QR	-	-	-
Ephemeroptera																														
Caenidae																														
	Caenis nigropunctata	A	-	-	-	-	R	-	-	Q	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
Hemiptera																														
Corixidae																														
	Trichocorixa reticulata	A	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mesoveliidae																														
	Mesovelia amoena	A	-	-	R	-	-	-	-	Q	-	-	Q	Q	-	-	Q	-	-	QR	Q	QR	-	Q	-	Q	-	-	QR	-
	Mesovelia mulsanti	A	-	-	-	-	Q	-	-	-	-	-	-	-	-	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
Veliidae																														
	Microvelia vagans	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-
Lepidoptera	**Lepidoptera**	U	QR	QR	-	R	Q	-	-	-	-	-	-	Q	QR	-	-	Q	Q	-	R	-	Q	Q	-	-	-	-	-	R
Odonata																														
Aeshnidae																														
	***Anax* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
Coenagrionidae	**Coenagrionidae**	U	-	Q	Q	-	QR	-	-	-	-	-	-	-	Q	-	-	-	-	-	QR	-	-	-	-	-	-	R	-	-
	Enallagma civile	A	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Ischnura* sp.**	A	-	Q	-	-	Q	Q	-	-	-	-	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
	***Megalagrion* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-
	Megalagrion nigrohamatum	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-

Appendix C. Unedited invertebrate richness data set.—Continued

[Compiled from the quantitative richest targeted habitat (RTH) data set and the qualitative multihabitat (QMH) data set. Unedited data are data prior to correction for taxonomic resolution and ambiguity. N, native species; A, alien species; U, undetermined status; Q, collected in QMH sample; R, collected in RTH sample; -, not present; gr., group; sp., species. See table 1 for site names]

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Libellulidae																														
	Orthemis ferruginea	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
	Pantala **sp.**	N	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pantala flavescens	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	Q	-	-
Trichoptera																														
Hydropsychidae																														
	Cheumatopsyche pettiti	A	QR	QR	-	QR	QR	QR	QR	QR	-	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	R
Hydroptilidae																														
	Hydroptila **sp.**	A	QR	QR	QR	R	QR	QR	QR	QR	QR	QR	QR	R	QR	QR	QR	Q	Q	QR	QR	QR	QR	QR	QR	QR	QR	R	-	R
	Hydroptila arctia	A	-	-	-	-	R	-	-	-	-	-	-	-	-	QR	QR	-	-	-	-	R	QR	QR	QR	-	R	-	-	-
	Hydroptila icona	A	-	Q	-	-	R	Q	-	Q	R	R	-	-	-	Q	R	-	-	-	-	-	R	-	-	-	-	-	-	R
	Hydroptila potosina	A	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oxyethira **sp.**	A	-	Q	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	-
	Oxyethira maya	A	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arachnida																														
Acari	**Acari**	U	-	-	-	R	R	-	-	-	R	-	-	-	-	-	-	-	-	-	-	R	-	-	-	R	-	QR	R	-
	Oribatidae	U	-	-	QR	-	-	-	-	-	-	QR	-	QR	Q	-	-	Q	Q	R	-	-	R	R	R	-	-	-	-	-
Pseudoscorpiones	**Pseudoscorpiones**	U	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea																														
Isopoda	**Isopoda**	A	-	Q	-	-	-	-	-	QR	-	-	-	QR	QR	-	-	-	Q	-	R	-	-	-	-	-	-	-	-	-
Tanaidacea	**Tanaidacea (order)**	U	-	Q	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ostracoda	**Ostracoda**	U	-	QR	Q	-	-	Q	-	QR	-	-	QR	QR	QR	-	-	-	QR	QR	Q	-	-	-	-	-	-	-	-	-
Copepoda	**Copepoda**	U	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda	**Amphipoda**	U	-	QR	Q	-	-	QR	-	QR	-	-	QR	QR	QR	-	-	R	Q	QR	-	-	-	-	-	-	-	-	-	-
Hyalellidae																														
	Hyalella azteca	N	-	-	-	-	QR	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	QR
Decapoda	**Decapoda**	U	-	-	-	QR	Q	-	-	-	-	-	Q	-	-	Q	R	-	-	-	-	-	R	R	-	Q	Q	Q	QR	QR
Atyidae																														
	Atyoida bisulcata	N	QR	-	-	-	-	-	R	-	-	QR	-	-	-	-	-	R	R	-	-	-	Q	QR	-	-	R	-	-	-
	Neocaridina denticulata sinensis	A	-	-	-	-	-	-	-	QR	-	-	Q	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-
Cambaridae																														
	Procambarus clarkii	A	-	-	-	-	Q	-	-	Q	Q	Q	Q	Q	-	-	-	-	Q	-	Q	Q	Q	Q	Q	Q	-	Q	QR	-
Palaemonidae																														
	Macrobrachium grandimanus	N	-	-	-	-	-	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Macrobrachium lar	A	-	-	-	-	-	R	Q	-	-	-	-	Q	Q	Q	-	-	-	Q	Q	-	-	-	Q	-	-	-	-	-

Appendix D. Edited invertebrate richness data set.

[Combined qualitative and quantitative data sets with supplementary data from a concurrent macrofaunal study. Data has been corrected for resolution and ambiguity. R, from RTH sampling; Q, from QMH sampling; O, from other sampling; N, native species; A, alien species, U, undetermined status; -, not present. See table 1 for site names]

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Porifera	**Porifera**	N	-	-	-	-	R	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Platyhelminthes																														
Turbellaria	**Turbellaria**	U	QR	-	Q	-	R	-	QR	-	R	QR	R	-	QR	QR	QR	-	-	-	R	QR	QR	QR	QR	-	QR	-	R	-
Nematoda	**Nematoda**	U	-	Q	-	R	-	-	-	-	-	Q	-	-	Q	-	-	Q	-	QR	-	-	-	-	-	-	-	-	-	-
Nemertea																														
Hoplonemertea																														
	***Prostoma* sp.**	A	-	-	R	-	R	Q	-	-	QR	-	R	-	-	Q	QR	Q	-	Q	-	-	-	-	-	-	-	R	R	R
Annelida																														
Aphanoneura																														
Aeolosomatidae																														
	***Aeolosoma* sp.**	U	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hirudinea	**Hirudinea**	U	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pharyngobdellida																														
Erpobdellidae	**Erpobdellidae**	U	-	-	Q	-	-	-	Q	-	-	-	-	-	-	Q	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-
Rhynchobdellida																														
Glossiphoniidae	**Glossiphoniidae**	N	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	**Oligochaeta**	U	-	R	QR	-	-	-	-	Q	-	-	R	Q	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-
Megadrile	**Megadrile**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	R	-	-	-	-	R	Q	Q	Q	R	QR	R	R	-
Tubificida																														
Enchytraeidae	**Enchytraeidae**	U	R	-	-	R	-	-	-	-	-	-	R	QR	Q	-	R	-	Q	QR	-	-	-	-	-	R	-	-	R	R
Naididae	**Naididae**	U	QR	QR	QR	QR	R	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	-	QR	R	R	QR	R	R	QR	QR	QR	R
Tubificidae	**Tubificidae**	U	-	-	Q	-	-	-	-	R	-	-	Q	R	R	-	Q	Q	-	-	Q	-	-	-	Q	-	-	QR	R	-
	Branchiura sowerbyi	U	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q
Polychaeta																														
Errantia																														
Nereididae																														
	Namalycastis abiuma	N	-	-	-	Q	Q	-	-	-	QR	-	Q	R	Q	-	-	-	Q	-	-	Q	Q	-	-	R	-	QR	R	QR
Mollusca																														
Gastropoda	**Gastropoda**	U	-	Q	Q	-	-	-	-	-	-	-	-	QR	QR	-	-	-	-	QR	-	Q	-	-	-	R	-	QR	Q	QR
Archaeogastropoda																														
Neritidae																														
	Neritina granosa	N	Q	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix D. Edited invertebrate richness data set.—Continued

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Basommatophora																														
Ancylidae																														
	Ferrissia sharpi	N	R	-	QR	R	QR	QR	-	-	Q	-	QR	QR	R	-	-	R	QR	-	-	-	-	-	-	-	-	R	-	R
Lymnaeidae																														
	Pseudosuccinea columella	A	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-
Physidae	**Physidae**	A	-	-	Q	-	-	Q	-	-	-	-	R	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
Planorbidae	**Planorbidae**	A	-	Q	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	Q	-	-	-
Thiaridae	**Thiaridae**	A	-	-	QR	QR	QR	QR	-	-	QR	-	Q	QR	-	Q	-	-	-	QR	QR	Q	-	-	-	-	-	-	-	QR
Mesogastropoda																														
Hydrobiidae	**Hydrobiidae**	A	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	Q	QR	-	-	-	-	-	-	-	-	-
Pelecypoda																														
	Bivalvia	A	-	-	-	-	R	-	-	-	R	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-	-	-	R
Venerioda																														
Corbiculidae																														
	***Corbicula* sp.**	A	-	QR	Q	-	QR	QR	-	-	QR	-	QR	-	Q	-	-	-	R	Q	QR	-	-	-	-	-	-	-	-	R
Sphaeriidae																														
	***Musculium* sp.**	A	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Pisidium* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
Lymnaeidae																														
	Pseudisidora producta	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Arthropoda																														
Insecta																														
Coleoptera	**Coleoptera**	U	-	-	Q	-	-	-	-	R	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
Hydrophilidae	**Hydrophilidae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-
	***Limnoxenus* sp.**	N	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	QR	R	-	-	-	-	-	-	-	-	-
	Limnoxenus semicylindricus	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	Q	-	-	-	-	-	-	-	-	-
Collembola	**Collembola**	U	-	-	-	R	R	-	-	QR	-	R	Q	-	R	-	R	-	-	-	Q	-	QR	-	-	-	R	QR	R	-
Diptera																														
	Brachycera (suborder)	U	-	-	-	-	-	-	-	-	-	-	Q	-	R	-	-	Q	-	-	-	-	-	-	-	-	Q	R	Q	-
Canacidae	**Canacidae**	U	R	-	-	-	-	-	-	-	-	-	R	-	-	R	-	Q	-	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	**Ceratopogonidae**	U	-	-	QR	QR	R	Q	Q	-	-	-	QR	Q	-	-	R	-	-	QR	Q	-	-	-	-	-	-	QR	-	-

Appendix D. Edited invertebrate richness data set.—Continued

[Combined qualitative and quantitative data sets with supplementary data from a concurrent macrofaunal study. Data has been corrected for resolution and ambiguity. R, from RTH sampling; Q, from QMH sampling; O, from other sampling; N, native species; A, alien species, U, undetermined status; -, not present. See table 1 for site names]

Phylum Class Order Family	Genus, species, or lowest taxonomic designation	Status	Site																											
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			HNKP	HULA	KALA	KALU	KANE	LLWI	LMAH	LULU	MANO	MKPA	NUUA	NWIL	PUAL	PUNA	PUNB	UKPA	ULWI	WAIM	WAIW	B-99	A-00	B-00	C-00	B-01	WHOL	WKAK	WKEA	WKEL
Chironomidae	**Chironomidae**	U	-	-	-	-	QR	-	-	-	-	R	-	-	-	-	R	-	-	-	-	-	QR	QR	QR	QR	R	R	R	-
	Chironominae	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	QR	-	-
	***Ablabesmyia* sp.**	A	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
	***Apedilum* sp.**	A	QR	Q	QR	-	R	-	Q	-	-	-	Q	Q	-	-	-	Q	Q	-	Q	-	Q	-	-	-	-	QR	-	-
	***Chironomus* sp.**	U	-	-	Q	-	Q	-	-	-	-	Q	Q	Q	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-
	***Corynoneura* sp.**	A	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Cricotopus* sp.**	A	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR
	***Endotribelos* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Eukiefferiella* sp.**	A	QR	-	-	Q	-	R	QR	QR	-	QR	-	R	-	QR	QR	QR	QR	-	QR	QR	-	-	-	Q	QR	R	-	-
	***Goeldichironomus* sp.**	A	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	Q	-	Q	-	-	-	-	-	-	Q	-	-
	***Micropsectra* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
	***Micropsectra/Tanytarsus* sp.**	U	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Orthocladiinae	U	QR	Q	Q	QR	R	Q	Q	QR	R	-	QR	Q	QR	QR	R	QR	Q	R	-	R	QR	QR	R	R	R	R	-	R
	***Paratanytarsus* sp.**	A	-	Q	QR	-	-	QR	-	R	R	-	-	Q	QR	-	-	Q	QR	Q	QR	QR	-	Q	-	R	-	QR	-	-
	***Polypedilum* sp.**	A	-	QR	-	-	-	Q	-	QR	-	-	-	Q	-	-	-	-	QR	-	QR	-	-	-	-	-	-	QR	-	-
	***Pseudosmittia* sp.**	U	-	-	Q	-	-	-	-	-	-	-	-	Q	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Stempellinella* sp.**	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-
	***Tanytarsus* sp.**	A	-	-	-	-	QR	Q	-	-	R	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-
	***Thienemanniella* sp.**	A	-	QR	-	-	-	QR	-	-	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-
Dixidae																														
	Dixa longistyla	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	Q	Q	-	Q	-	-	-
Empididae	**Empididae**	U	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hemerodromia stellaris	A	QR	QR	QR	R	R	Q	QR	QR	R	QR	QR	QR	QR	QR	R	QR	QR	QR	R	QR	QR	QR	R	QR	QR	QR	-	-
Ephydridae	**Ephydridae**	U	R	R	-	R	-	-	QR	-	-	Q	-	-	-	-	QR	-	-	-	-	R	-	-	-	R	-	QR	Q	-
	***Neoscatella* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	Q	-	-	-	-	-	-	-	-	-	-	-
Psychodidae	**Psychodidae**	U	-	-	-	-	-	-	-	-	-	QR	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	R	-
Stratiomyidae	**Stratiomyidae**	A	-	-	-	-	Q	-	-	-	-	Q	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Syrphidae	**Syrphidae**	U	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	**Tipulidae**	U	-	-	QR	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-
	***Limonia* sp.**	U	Q	-	R	QR	Q	-	QR	Q	-	-	Q	Q	-	R	R	-	-	R	-	-	-	Q	-	Q	QR	-	-	-

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Ephemeroptera																														
Caenidae																														
	Caenis nigropunctata	A	-	-	-	-	R	-	-	Q	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
Hemiptera																														
Corixidae																														
	Trichocorixa reticulata	A	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mesoveliidae																														
	Mesovelia amoena	A	-	-	R	-	-	-	-	Q	-	-	Q	Q	-	-	Q	-	-	QR	Q	QR	-	Q	-	Q	-	-	QR	-
	Mesovelia mulsanti	A	-	-	-	-	Q	-	-	-	-	-	-	-	-	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
Veliidae																														
	Microvelia vagans	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-
Lepidoptera	**Lepidoptera**	U	QR	QR	-	R	Q	-	-	-	-	-	-	Q	QR	-	-	Q	Q	-	R	-	Q	Q	-	-	-	-	-	R
Odonata																														
Aeshnidae																														
	***Anax* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
Coenagrionidae	**Coenagrionidae**	U	-	Q	Q	-	QR	-	-	-	-	-	-	-	Q	-	-	-	-	-	QR	-	-	-	-	-	-	R	-	-
	Enallagma civile	A	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	***Ischnura* sp.**	A	-	Q	-	-	Q	Q	-	-	-	-	-	Q	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-
	***Megalagrion* sp.**	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	QR	-	-	-	-	-	-	-	-	-	-	-	-
	Megalagrion nigrohamatum	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Libellulidae																														
	Orthemis ferruginea	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-
	***Pantala* sp.**	N	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pantala flavescens	N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	Q	-	-

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Trichoptera																														
Hydropsychidae																														
	Cheumatopsyche pettiti	A	QR	QR	-	QR	QR	QR	QR	QR	-	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	R
Hydroptilidae																														
	***Hydroptila* sp.**	A	QR	QR	QR	R	QR	QR	QR	QR	QR	QR	QR	R	QR	QR	QR	Q	Q	QR	QR	QR	QR	QR	QR	QR	QR	R	-	R
	Hydroptila arctia	A	-	-	-	-	R	-	-	-	-	-	-	-	-	QR	QR	-	-	-	-	R	QR	QR	QR	-	R	-	-	-
	Hydroptila icona	A	-	Q	-	-	R	Q	-	Q	R	R	-	-	-	Q	R	-	-	-	-	-	R	-	-	-	-	-	-	R
	Hydroptila potosina	A	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oxyethira maya	A	-	Q	-	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	Q	-	-	-	-	-	-
Arachnida																														
Acari	**Acari**	U	-	-	QR	R	R	-	-	-	R	QR	-	QR	Q	-	-	Q	Q	R	-	R	R	R	R	R	-	QR	R	-
Pseudoscorpiones	**Pseudoscorpiones**	U	-	-	-	-	-	-	-	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Crustacea																														
Isopoda	**Isopoda**	A	-	Q	-	-	-	-	-	QR	-	-	-	QR	QR	-	-	-	Q	-	R	-	-	-	-	-	-	-	-	-
Copepoda	**Copepoda**	U	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipoda																														
Hyalellidae																														
	***Hyalella* sp.**	U	-	QR	Q	-	QR	QR	-	QR	QR	-	QR	QR	QR	-	-	R	Q	QR	-	-	-	-	-	-	-	R	-	QR
Decapoda	**Decapoda**	U	-	-	-	QR	Q	-	-	-	-	-	Q	-	-	Q	R	-	-	-	-	-	R	R	-	Q	Q	Q	QR	QR
Atyidae																														
	Atyoida bisulcata	N	QR	O	-	O	-	-	R	-	-	QR	-	-	-	O	-	R	R	-	-	O	Q	QR	O	O	R	-	O	-
	Neocaridina denticulata sinensis	A	-	-	-	-	-	-	-	QR	-	-	Q	-	-	-	-	-	-	QR	-	-	-	-	-	O	-	O	O	O
Cambaridae																														
	Procambarus clarkii	A	-	O	-	-	Q	-	-	Q	Q	Q	Q	Q	-	-	-	-	Q	-	Q	Q	Q	Q	Q	Q	-	Q	QR	O
Palaemonidae																														
	Macrobrachium grandimanus	N	-	-	-	-	O	Q	-	-	-	-	Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O
	Macrobrachium lar	A	-	O	-	O	-	R	Q	O	-	O	O	Q	Q	Q	O	O	O	Q	Q	O	O	O	Q	O	O	-	O	O

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Wolff

Feasibility of Using Benthic Invertebrates as Indicators of Stream Quality in Hawaii

SIR 2005–5079