NONINDIGENOUS FRESHWATER AND ESTUARINE SPECIES INTRODUCTIONS AND THEIR POTENTIAL TO AFFECT SPORTFISHING IN THE LOWER STREAM AND ESTUARINE REGIONS OF THE SOUTH AND WEST SHORES OF OAHU, HAWAII

February 2000

Hawaii Biological Survey
Bishop Museum

Cover

From upper left corner: Waikiki in 1886 (A. Mitchell photograph, CPBM 56,428, Bishop Museum Archives) at the mouth of Piinaio Stream where the current Ala Wai Canal or present day Manoa/Palolo Stream empties into the ocean. Upper right photograph: taken at lower Manoa/Palolo stream mouth estuary in the year 2000, from the Date Street Bridge. Lower left photograph: Waikahalulu Falls at Nuuanu Stream in the year 2000 at the mouth of Nuuanu Stream; sampling for Nuuanu Stream began immediately downstream of Waikahalulu Falls. Lower right photograph: taken between 1900-1910 (A. Gartley photograph, CA 1,721, Bishop Museum Archives) at Waikahalulu Falls, Nuuanu Stream, notice lack of vegetation and desert look in this photograph.

NONINDIGENOUS FRESHWATER AND ESTUARINE SPECIES INTRODUCTIONS AND THEIR POTENTIAL TO AFFECT SPORTFISHING IN THE LOWER STREAM AND ESTUARINE REGIONS OF THE SOUTH AND WEST SHORES OF OAHU, HAWAII

Final Report prepared for the Hawaii Department of Land and Natural Resources, Division of Aquatic Resources

R.A. Englund
K. Arakaki
D.J. Preston
S.L. Coles
L.G. Eldredge

Hawaii Biological Survey
Bishop Museum

Bishop Museum Technical Report No. 17

Honolulu, Hawaii
February 2000

Published by
BISHOP MUSEUM
The State Museum of Natural and Cultural History
1525 Bernice Street
Honolulu, Hawai'i 96817-2704, USA

ISSN 1085-455X

Contribution No. 2000-002 to the Hawaii Biological Survey

EXECUTIVE SUMMARY

Surveys of native and nonindigenous species along the south and west shores of Oahu (excluding Pearl Harbor) were funded by a grant from the David and Lucile Packard Foundation with matching Dingell-Johnson funding provided by the Hawaii Department of Natural Resources, Division of Aquatic Resources. This project was performed in two sections. The first section of this project involved investigations of marine organisms in harbors of the south and west shores of Oahu, with an emphasis on the detection of nonindigenous marine organisms. The current study investigated the estuarine and freshwater areas at the mouths of streams and coastal wetlands along the south and west shore of Oahu to investigate the known or potential impacts of introduced species on sportfish. The study area extended from Kaena Point to Makapuu Point.

The first comprehensive biological surveys of south and west shore Oahu coastal wetlands, lower stream reaches, and estuarine areas revealed an ecologically degraded fauna dominated by introduced species in freshwater, but ecosystems that are more intact as waters becomes more marine. During this study the first collection of the introduced jaguar cichlid (*Cichlasoma managuense*) from an Oahu stream (Manoa/Palolo) was made, and this species appears to have spread from the nearby quarry pond at the University of Hawaii. In strictly freshwater areas of the south and west shore of Oahu most taxa identifiable to the species level were introductions. The majority of introduced species appear to be the primarily the result of aquarium releases, intentional biocontrol releases, and intentional food source releases. Although some introduced species may have originated from marine water releases or hull fouling organisms these points of origin probably contributed only a small fraction of overall nonindigenous species introductions in south and west shore Oahu streams, wetlands, and estuaries.

The consumption and pursuit of fresh seafood today is a highly visible part of the local lifestyle and important for a diverse range of cultures in Hawaii. The pursuit of native freshwater species such as gobies, crustaceans, and mollusks still occurs in limited localities in Hawaii such as in the Hanalei River, Kauai, or the north shore of Molokai, but is virtually non-existent on the island of Oahu. Sportfishing has suffered greatly in freshwater and estuarine areas of the south and west shores of Oahu, which includes the large urban area of Honolulu. Because of developments over the last one-hundred years, estuaries, wetlands, and lower reaches of streams have been much more heavily impacted than have the adjacent marine habitats. Nearshore areas covered in the present study include estuaries and the lowest portions of streams along the heavily urbanized south shore of Oahu. This area includes a diverse array of aquatic habitats heavily impacted by urban Honolulu with modifications such as extensive stream channelization, dredging and filling of wetlands, non-point source runoff, and nonindigenous species introductions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A. South and West Shores Oahu Nonindigenous Species Project

Surveys of native and nonindigenous species along the south and west shores of Oahu (excluding Pearl Harbor) were funded by a grant from the David and Lucile Packard Foundation with matching Dingell-Johnson funding provided by the Hawaii Department of Natural Resources, Division of Aquatic Resources. This project was performed in two sections. The first section of this project involved investigations of marine organisms in harbors of the south and west shores of Oahu (Coles et al. 1999a), with an emphasis on the detection of nonindigenous marine organisms. The current study investigated the estuarine and freshwater areas at the mouths of streams and coastal wetlands along the south and west shore of Oahu to investigate the known or potential impacts of introduced species on sportfish. The study area extended from Kaena Point to Makapuu Point. Surveys of Pearl Harbor estuaries and lower streams were done concurrently with surveys of Oahu's south shore, and the results for Pearl Harbor are included in a separate report to the U.S. Navy (Englund et al. 2000).

Summary of Nonindigenous Marine Species Studies in Oahu's South and West Shore Harbors, 1997-98

The marine and estuarine algae, invertebrate and fish communities in Honolulu Harbor, Keehi Lagoon, Kewalo Basin, Ala Wai Yacht Harbor and Barber's Point Deep Draft Harbor were surveyed in 1997-98 (Coles et al. 1999a). Observations and samples were taken at 15 stations in Honolulu Harbor, five in Keehi, four in Kewalo, five in the Ala Wai, and four at Barber's Point, for a total of 32 stations sampled. The harbors support virtually all of the non-military shipping traffic for Oahu and are the major ports of entry for vessels reaching Hawaii, and therefore are the most likely entry points for nonindigenous marine species entering Hawaiian waters. The oldest of these harbors is Honolulu Harbor, which has been in use by ocean going vessels for more than 200 years, and the youngest is the Barber's Point Deep Draft Harbor, which was enlarged to accommodate ocean-going cargo vessels about 25 years ago. The other harbors mostly accommodate sailing and fishing vessels and have existed for 50-80 years.

A total of 728 taxa, including 585 named species, were identified from these surveys for the five harbors. Of these, 604 taxa including 440 species occurred in Honolulu Harbor. Total taxa and species in the other harbors were about one-third the Honolulu Harbor values. A gradient of biota types from coral reef-related organisms near harbor entrances to organisms adapted for eutrophic turbid conditions was noted, especially in Honolulu Harbor where reef corals were common near the main entrance. Dendrographs of station percent similarity based on total invertebrates showed systematic groupings by harbor and by locations within the harbors.

A total of 73 nonindigenous and 27 cryptogenic species were found in the five harbors, comprising about 17% of the 585 named species. Honolulu Harbor had most of these (73 nonindigenous and cryptogenic species) with about 40 to 50 found in the remaining harbors. When viewed as a percentage of the total species found in each harbor, Honolulu had the lowest at 15%, with the other harbors ranging 27-33%. This was not because the other harbors had greater numbers of introduced species but rather to an even distribution of introduced species throughout the harbor system with greater numbers of total species occurring in Honolulu Harbor. Species not previously reported in Hawaii accounted for 13 of the 73 nonindigenous species, while only two new records were designated cryptogenic species. Most of the nonindigenous and cryptogenic species were first reported in these harbors in the 1970s and 1990s. However, analysis indicates that this apparent recent increase in reported introductions is sampling related, and many of these introduced species have occurred in Hawaii for most of the century. With the exception of the intertidal barnacle *Chthamalus proteus*, the sponge *Gellioides fibrosa*, the amphipod *Leucothoe micronesiae* and the bryozoan *Bugula dentata*, recently introduced nonindigenous species occurred only at one or two stations in one or two harbors.

The results of the present study showed a remarkable similarity with the findings of previous surveys of nonindigenous species in Pearl Harbor (Coles et al. 1997, 1999a). Both studies reported about twelve new nonindigenous species out of a total of about 100 nonindigenous and cryptogenic species. Only four of the new nonindigenous species found in Oahu south and west shore harbors also occurred in Pearl Harbor, but 70% of the total nonindigenous and cryptogenic biota occurred in both studies. Introductions into both areas were dominated by species originating in or with a previously reported range in the central Pacific or south and east Asia.

Contrary to many areas in temperate regions in the world, studies of Oahu harbors have shown little indication of recent increases in nonindigenous species introductions, nor of proliferation of species impacting native populations or commercially important species that would constitute a nuisance invasion. Although nonindigenous and cryptogenic species make up a larger component of the total biota of Oahu harbors than has been found in other tropical areas, most of the more common introduced species have been in Hawaiian waters for much of the century, and most recent introductions have remained mostly restricted in their occurrence and are infrequently found.

Surveys of South and West Shore Oahu Freshwater and Estuarine Habitats

The objective of these surveys was to document the composition of native and introduced species occurring in the lower stream reaches and estuaries of the south shore of Oahu. These areas represent some of the most disturbed aquatic and estuarine habitats found in the Hawaiian Islands. Inventories will provide information for resource managers to better manage resources such as fisheries and provide future researchers a baseline of the distributions and abundances of introduced aquatic organisms currently found on Oahu's south and west shores.

B. Estuarine and Freshwater Invasions as a Worldwide Problem

Unintentional translocations of species threaten native ecosystems around the world, and a striking surge of aquatic nonindigenous species introductions has occurred since the 1970s (Carlton 1985, Carlton and Geller 1993, Ruiz et al. 1997). Species invasions have been particularly devastating both environmentally and economically in freshwater systems. In the United States and Canada, the most widespread problem with nonindigenous species began in the Great Lakes and has spread to virtually the all the major lake and river systems of North America (Charlebois et al. 1997, Schneider et al. 1998). A series of mollusk, crustacean, and fish invasions commenced in the early 1980s and led to striking ecosystem alterations and tens of millions of dollars in management costs. The most famous of these species impacts, which single-handedly resulted in federal government legislation on the control of ballast water, is the European zebra mussel *Dreissena polymorpha* (and its sibling species the quagga mussel *Dreissena bugensis*) (Nalepa and Schloesser 1992). A major fouling organism that blocks water pipes and water treatment plants, *D. polymorpha* has led to fundamental alterations in North American freshwater ecosystems. The economic costs of cleaning clogged pipes and water intakes plugged by the uncontrolled growth of populations of this species have been estimated as likely to be between $2 and $3 billion by the end of the century (Ruiz et al. 1995).

The adverse effects associated with introduced freshwater species have been well documented in the Pacific region (Maciolek 1984, Arthington and Lloyd 1989, Crowl et al. 1992, Eldredge 1994, Dove 1998). Introduced freshwater fish, crustaceans, and amphibians now occur in virtually every part of the world, including Australia, New Zealand, and on most Pacific islands with freshwater habitats (Maciolek 1984, Eldredge 1994, 1999). They threaten to displace native aquatic species and disrupt aquatic ecosystems throughout the Pacific region. In Hawaii, introduced crustaceans such as the freshwater crayfish (*Procambarus clarkii*) have caused economic losses to taro farmers because of this species burrowing habits and its consumption of taro corms and roots. Chemical controls, such as the poisoning of taro fields with para-dichloro benzene (PDB) or napthalene, were used from 1940 to 1952 control crayfish depredations, with over 1,417 ha (3500 a) of wetland taro fields treated in Hawaii (Devaney et al. 1982). Amphibians such as *Bufo marinus* introduced in the Pacific region for biological control purposes have detrimental impacts on native organisms while widely preying on non-target species in Papua New Guinea (Zug et al. 1975). *Bufo marinus* have also been shown to be carriers of leptospirosis, a serious human health threat (Everard et al. 1990), and in Australia severely impacted the beekeeping industry by consuming large quantities of honeybees (Tyler 1994).

The negative effects of introduced fish such as poeciliids and blackchin tilapia on other vertebrates and invertebrates have also been widely documented (Hurlbert et al. 1972, Meffe and Snelson 1989, Eldredge

1994, Dove 1998, Englund 1999a). For example, *Gambusia affinis* (western mosquitofish) preys upon eggs, larvae, and fry of sportfish and native fish in areas outside of their native habitat (Courtenay and Meffe 1989). Predation by introduced poeciliids was believed to be a significant cause of extirpation of native fish in Nevada (Courtenay and Meffe 1989) and invertebrates in Australia (Arthington and Lloyd 1989). *Gambusia affinis* also exhibit a wide dietary preference (Miura et al. 1979, Englund et al. 2000) and in California streams were found to prey heavily on native treefrog tadpoles even when mosquito larvae were introduced as alternative prey (Goodsell and Katz 1999). In southwestern Australia, Morgan et al. (1998) found that fin nipping by *G. affinis holbrooki*, the eastern mosquitofish, caused extensive caudal fin damage to native fish species. Howe et al. (1997) documented the negative effects of *Gambusia* on native pseudomugilid (blue-eyes) fish species in Australia. Mollusks, such as apple snails (family Pomacidae) introduced into Hawaii, Taiwan, and the Philippines, have caused widespread damage and severe reductions of rice and taro crop yields (Cowie, in press).

C. Status of Native and Introduced Freshwater Species in Hawaii

Introduced species pose an ever increasing threat to Hawaiian stream, wetland, and anchialine pond ecosystems. Not only do introduced species compete and prey upon native species, they have also brought with them a complement of disease and parasites to which native species have not developed resistance (Font and Tate 1994). The severity of nonindigenous species impacts varies according to island, elevation, and watershed; with adjacent streams often having a significantly different composition of introduced species. Even the most remote areas of the main Hawaiian Islands with freshwater habitats contain introduced aquatic species. However, some relatively pristine stream, wetland, and anchialine pond areas can still be found on Kauai, Maui, Molokai, and Hawaii, with these mostly unimpacted aquatic habitats still having their full complement of fresh and estuarine water endemic and indigenous fish, crustacean, mollusk, and aquatic insect species (Maciolek 1984, Polhemus 1995a). Streams and wetland habitats on Oahu have suffered the greatest impacts, notably aquatic species introductions and habitat disturbances. On Oahu, the rate of aquatic species introductions shows no signs of decreasing. Because of naturally low base flows (Nichols et al. 1997) and watersheds being smaller and shorter, Oahu streams have a lower flushing out capability as compared to the generally larger streams found on other islands such as Kauai and Hawaii. Many formerly common native aquatic insect species, such as damselflies, are now absent or rare in many lower elevation Oahu watersheds and appear to have been displaced by introduced species (Polhemus 1996, Englund 1999a).

By 1991, at least 58 species (excluding aquatic insects) of intentionally and accidentally introduced aquatic organisms had become successfully established throughout Hawaii (Devick 1991a). Waikele Stream in Pearl Harbor is a good example of the rapid pace of indigenous aquatic introductions. Since 1993 three ecologically significant and potentially harmful new introduced species have become established in Waikele Stream and its associated wetlands (Englund and Filbert 1999). These include a new record of an introduced freshwater shrimp species, a range expansion of the introduced apple snail, and a dragonfly. The native freshwater fish *Awaous guamensis* (*'o'opu nakea*) has become rare in the lower reaches of Waikele Stream and Waikele Springs area and may have been displaced by high densities of the numerous introduced species.

Because of the isolation of the Hawaiian Islands from continental areas, relatively few species of native diadromous aquatic organisms were found in Hawaii's lower stream reaches and estuaries. Many species of native aquatic species such as fish, crustaceans, and mollusks in Hawaii are dependent upon the ocean for reproduction and the larvae of the native stream fauna require unimpeded access to the ocean prior to spending the rest of the adult life cycle in freshwater habitats. Excluding arthropods and other invertebrates, only five species of fish, two large crustacean species (excluding amphipods and other smaller crustaceans), and two species of mollusks spend the majority of their life cycle in freshwater habitats in Hawaii. In Hawaii, estuarine habitats are important for a wide variety of native species including several species of culturally important food fish such as striped mullet (*Mugil cephalus*) and aholehole (*Kuhlia sandvicensis*), and crustaceans such as *Macrobrachium grandimanus* and atyid shrimp (*Atyoida bisulcata*) also require estuaries for various stages of their life histories. While Hawaiian streams may not have had a highly diversified freshwater and estuarine macrofauna because the islands are so isolated, the streams and estuaries were highly productive and provided an important food base for the first Polynesian inhabitants (Titcomb 1972).

Although often overlooked in Hawaii because of their small size and innocuous nature, aquatic insects are another important component of the native freshwater fauna as they provide an important food basis for many species of native fish, crustaceans, and mollusks. Many aquatic insects likely arrived in Hawaii by means of a combination of oceanic currents or wind as the majority of insect groups were derived from marine species (Howarth and Polhemus 1991). Aquatic insects differ from the diadromous fish, crustaceans, and mollusks as access to the ocean is not required to complete their life cycle. This also provides an advantage as many insect species are found in high elevation aquatic habitats inaccessible to native fish and crustaceans. Because of the isolation of the Hawaiian Islands many insect orders dominating the stream fauna in continental areas were naturally absent, including mayflies (Ephemeroptera), caddisflies (Trichoptera), stoneflies (Plecoptera), and dobsonflies (Megaloptera). This has led to some unusual speciation patterns in native groups such as the flies (Diptera), damselflies (Odonata), many species of semi-aquatic moths (*Hyposmocoma* sp.), and the world's only aquatic damsel bug, *Nabis gagneorum* (Polhemus 1999).

The mechanism for the success of some introduced species and the failure of others is unclear, however, it is known that some species introduced from continental areas are often generalists and can better compete in disturbed habitats common in the lowlands of Hawaii (Howarth 1985). Even in continental areas freshwater habitats are easily invaded by nonindigenous species, and these invasive species are becoming an increasing economic problem throughout the world. It is clear that native stream vertebrate and invertebrate species do poorly in disturbed aquatic habitats in Hawaii, but there are also numerous examples of introduced aquatic species adapting well to undiverted or nearly pristine aquatic habitats. A selected list of non-indigenous species found in undisturbed freshwater habitats would include a species of aquatic beetle (*Rhantus gutticollis*), three species of damselflies, two species of dragonflies, numerous aquatic flies such as *Cricotopus bicinctus* or *Limonia advena*, and three species of caddis flies. It is quite probable that given the opportunity, many introduced species would thrive or at least persist in 'pristine' aquatic habitats that they currently are unable to access. There is a misconception in Hawaii that introduced species will not become established in Hawaii in healthy or nearly pristine aquatic habitats "but most invading species only do well in altered habitats" (Brown et al. 1999). However, as more introduced species become established in a habitat it becomes more probable that additional species will find a suitable niche (Howarth 1985). For example, numerous species of birds, insects, snails, and other nonindigenous species are abundant in the best preserved high elevation native Hawaiian forests (Howarth et al. 1999). In aquatic systems the large Tahitian prawn (*Macrobrachium lar*) is common in streams on the North shore of Molokai, which are among the most pristine remaining in Hawaii.

Newly established species also often alter an ecosystem by either consuming the resident species or consuming the resources of resident species (Howarth 1985). The introduction of suckermouth catfish and an atyid shrimp (Englund and Cai 1999) into Hawaiian streams are noteworthy examples. The two suckermouth catfish (Loricariidae) species introduced to Hawaii are herbivorous (Sabaj and Englund 1999), as is a native species of freshwater goby, *Sicyopterus stimpsoni*. Extremely high densities of suckermouth catfish in Oahu streams have an obvious impact on available food and habitat resources for the native sportfish *S. stimpsoni*. Although factors such as increased sedimentation and stream urbanization are undoubtedly related to the decline of *S. stimpsoni* on Oahu, this native species distribution is not sympatric with the introduced suckermouth catfish. Native fish such as *S. stimpsoni* are ill-equipped to deal with the much larger and heavily armored suckermouth catfish, species that likely severely reduce available algal resources in a stream. Predation from other introduced fish species, particularly on small returning post-larval native gobiids, is another likely reason for the low numbers of adults observed in urban Oahu watersheds such as Manoa/Palolo or Nuuanu Streams.

Regardless of the mechanism, introduced species in Hawaii have been extremely successful even in undisturbed aquatic habitats and in many cases have nearly or completely displaced native species from those habitats.

Native and Introduced Sportfish in Lower Estuarine Areas of the South and West Shores of Oahu

Although the estuarine and lower stream habitats of the Hawaiian Islands support productive fisheries, because of their isolation there is a low natural diversity of sportfish. A partial listing of important indigenous sportfish in the lower stream reaches includes transient fish found in euryhaline environments such as *Elops hawaiensis*, *Kuhlia sandvicensis*, *Mugil cephalus*, *Neomyxus leuciscus*, *Chanos chanos*, and several species in the family Carangidae. Crustaceans and mollusks are another important component of the sportfishery in Hawaiian fresh and estuarine waters, and some important native species include the large endemic freshwater gastropod *hihiwai* (*Neritina granosa*), and the smaller *hapawai* (*Neritina vespertina* and *Theodoxus cariosus*). Native estuarine crustaceans include the *'opae 'oeha'a* (*Macrobrachium grandimanus*) in the terminal reaches, while the *'opae kuahiwi* (*Atyoida bisulcata*) is generally found in mid- to upper elevation sections of streams. In Hawaii, lower stream and strictly freshwater wetland or spring areas usually have only two resident marine sportfish, the striped mullet (*Mugil cephalus*) and *aholehole* or Hawaiian flagtail (*Kuhlia sandvicensis*). Another smaller native mullet species, *Neomyxus leuciscus*, is found more often in more marine waters and during these surveys was generally found in waters > 26 ppt salinity.

Hawaiian estuaries provide critical nursery habitats for two important native fish species: *Mugil cephalus* and *Kuhlia sandvicensis* (Englund 1998). Other native marine species occurring in Hawaiian estuaries are tolerant to varying degrees freshwater but do not necessarily prefer or select for low-salinity conditions. Although no discrete threshold has been established, juvenile *M. cephalus* appear to prefer water with salinity below 15 ppt (Blabber 1987, Dr. Ken Leber, Mote Marine Lab, Sarasota, Florida, personal communication). When salinity becomes > 15 ppt, juvenile striped mullet will abandon an area (e.g., estuary) and move in search of fresher water. During this movement, juvenile *M. cephalus* become increasingly susceptible to predation and possibly reduced food availability. Adverse effects on juvenile fish can translate into a reduction in fisheries catch. Salinity preferences for *aholehole* are less established than for striped mullet, but the seasonal use of estuaries as nursery habitat by *aholehole* is similar to that of striped mullet and well known in Hawaiian waters (Filbert and Englund 1995, Tate 1997, Englund 1998).

Up to four species of freshwater gobies and one eleotrid species can be found in the lower regions of Hawaiian streams, although adults of two of the four goby species are often mainly found in mid- to upper elevation areas. In lower stream reaches and estuarine areas, three gobies (*Awaous guamensis*, *Sicyopterus stimpsoni*, and *Stenogobius hawaiiensis*) and one eleotrid (*Eleotris sandwicensis*) attain a size large enough size to be considered sportfish. Three out of four of these species and especially *A. guamensis* are considered delicacies, while the euryhaline *S. hawaiiensis* was not considered prime eating by native Hawaiians (Titcomb 1972). Prior to the major disturbances and diversions that occurred in the 20th century, the returning post-larval gobies called *hinana* ascended streams in such great numbers that Hawaiians seasonally captured these small fish at stream mouths in great numbers in woven baskets (Titcomb 1972). Hawaiian royalty also devoted entire fish ponds to the culture of freshwater fish, such as those owned by Ka'ahumanu in Waipio Valley (Titcomb 1972).

The consumption and pursuit of fresh seafood today is still a highly visible part of the local lifestyle and important for a diverse range of cultures in Hawaii (Pooley 1998). Sportfishing for native freshwater species such as gobies, crustaceans, and mollusks still occurs in limited localities such as in the Hanalei River, Kauai, or the north shore of Molokai, but is virtually non-existent on the island of Oahu. Sportfishing in freshwater and estuarine areas has suffered greatly in the south and west shores of Oahu, which includes the large urban area of Honolulu. Because of developments over the last one-hundred years, estuaries, wetlands, and lower reaches of streams have been much more heavily impacted than have the adjacent marine habitats. Nearshore areas covered in the present study include estuaries and the lowest portions of streams along the heavily urbanized south shore of Oahu. This area includes a diverse array of aquatic habitats heavily impacted by urban Honolulu with modifications such as extensive stream channelization, dredging and filling of wetlands, non-point source runoff, and nonindigenous species introductions.

D. Vectors for Introductions of Freshwater and Estuarine Species in Hawaii

Hawaii has a long history of purposefully and accidentally introduced aquatic species (Brock 1960, Devick 1991a, Funasaki et al. 1988). Prior to the arrival of Europeans in the Hawaiian Islands in 1778, the only opportunity for introductions of nonindigenous species to freshwater and estuarine environments in Hawaii was through infrequently arriving Polynesian canoes from the South Pacific. The only way for stream fish, mollusks, or crustaceans to arrive in Hawaii was by the survival and recruitment of the marine stage of amphidromous organisms in freshwater habitats. Thus, only amphidromous freshwater organisms with a relatively long planktonic life cycle were able to naturally colonize and establish self-sustaining populations in Hawaii (Radtke et al. 1988, Kinzie 1991, 1997). In Hawaii, many native aquatic insects have evolved from marine and intertidal species that have secondarily radiated into freshwater habitats (Howarth and Polhemus 1991). Damselflies and dragonflies are a prominent exception to this and likely arrived in Hawaii through aerial dispersal (Polhemus and Asquith 1996).

In many cases the method of introduction into Oahu and geographic origin can be determined, although for some aquatic species the mode of introduction is uncertain. Previous Bishop Museum studies in Pearl Harbor (Coles et al. 1997, 1999b) referred to some marine species of unknown origin as cryptogenic (Carlton 1996) as their natural distribution and origin is difficult to assess. However, in the present freshwater and estuarine study of Oahu's south shore the geographic origin and native or nonindigenous status could be determined for taxa identified to the species level. For this study, aquatic species introductions have been separated into the following categories: governmental biocontrol, intentional food introduction, probable ballast water or hull fouling, accidentally introduced with baitfish, aquarium release, and unknown (if taxa not identifiable to the species level).

Two species of freshwater snails found in south shore Oahu watersheds during the present study, *Tarebia granifera* and *Melanoides tuberculata* may be recent introductions. At least one species (*M. tuberculata*) was recently found in archaeological sites in Kauai wetlands, but only in post-contact (after 1778) deposits (D. Burney, Fordham University, pers. comm.), thus the possibility that these species are Polynesian introductions (pre-1778) (Cowie 1998) appears to be ruled out. Mosquitoes, an early introduced aquatic species in the Hawaiian archipelago, were likely one of the most harmful introductions (Stone and Pratt

1994). In 1826, mosquitoes (*Culex quinquefasciatus*) were introduced into Hawaii, which, prior to that time was mosquito free (Hardy 1960). Mosquito larvae were released into freshwater when whaling ships refilled their freshwater casks, and the mosquitoes quickly spread throughout Hawaii (Hardy 1960). By the start of the 20th century, public health officials in Hawaii grew increasingly concerned that the outbreaks of mosquito-borne diseases (such as yellow fever) occurring during the building of the Panama Canal could affect public health in Hawaii (Van Dine 1908). An effective method to control mosquito populations was sought, as it was believed native freshwater fish species did not impact mosquito populations. David Starr Jordan, one of the pre-eminent ichthyologists of the day, recommended the introduction of fish in the family Poeciliidae into Hawaiian waters to control mosquito populations (Van Dine 1907). In 1905, upon Jordan's recommendation, the Territory of Hawaii imported three species of fish from southern Texas for mosquito control (Van Dine 1907, 1908). At least two of these species, *Gambusia affinis* (western mosquitofish) and *Poecilia latipinna* (sailfin molly), eventually established successful naturally reproducing populations throughout Hawaii. Since these initial fish introductions in the early 1900s (and the prior intentional release of amphibians in 1896), there have been many more species of fish, amphibians, and aquatic insects intentionally released for biological control (Funasaki et al. 1988). By 1991, at least 44 species of introduced freshwater fish had become successfully established in Hawaiian waters (Devick 1991a). These introductions have been intentional by government agencies or were the result of recent accidental aquarium fish releases. Mosquito control, through the introduction of live-bearing fish, has not been proven to be effective, as mosquitoes are still abundant throughout Hawaii. *Gambusia affinis* has since been found to be a poor predator of mosquito larvae in some instances (Arthington and Lloyd 1989) and may actually facilitate an increase in mosquito populations by eliminating other, more effective mosquito predators (Moyle 1976).

METHODS

A. Bishop Museum Collections

The Bishop Museum collections of aquatic insects, mollusks and other invertebrates, and fishes were reviewed for all estuarine and freshwater organisms historically collected from the south shore Oahu. For the mollusk and fish collections this involved searching the collection catalogs for specimens that were collected from south shore Oahu and entering into a database species name, year of collection, and collectors names. The combined data from all sources were assembled into a relational database of South shore Oahu estuarine organisms. The results of the historical searches of the Bishop Collections can be found in Coles et al. 1999.

B. Field Surveys- General Methods

Sampling for Phase II of the South Shore Oahu Biodiversity Project began in January 1998 and ended in June 1999. Representative sampling stations were established in the lowest reaches of each named south and west Oahu stream (Figures 1-3) and sampling stations are listed in Table 1. Sampling locations were somewhat dependent upon the constraints of private property, water depth, sediment depth, and vegetation, but included a complete range of estuarine habitats. Riparian vegetation composition and stream substrate were evaluated at each sampling station. Habitat condition for native aquatic organisms was evaluated at sampling stations. Most sampling stations were generally at or just above sea level.

Insect Sampling

Aquatic insect sampling was conducted according to Polhemus (1995a) and Englund et al. (1998). Collections of both immature and adult specimens were made with aerial sweep nets, aquatic dip nets, seines, and benthic samples. Visual observations of aquatic insects were also conducted above the waterbody. Sampling of damselflies and dragonflies (Odonata) was emphasized, as several of these are currently candidate threatened or endangered species. All insect specimens were stored in 75% ethanol and transported to the Bishop Museum Entomology Collection for curation and identification. Voucher specimens are currently housed in the Bishop Museum collections.

Fish, Crustacean, and Mollusk Sampling

Seine netting was the main sampling technique used to assess introduced fish abundance. A fine-mesh, 5 m long seine was used to sample stream animals and assess species composition, and dip nets were also used to sample areas not accessible to seines. Experimental gill nets of varying sized mesh were also used in areas that were too deep to seine. Salinity was also recorded at least once for each stream location sampled, and, unless otherwise stated, salinities were taken at the surface. Electroshocking was attempted but abandoned as most sampling areas were estuarine and even low salinity levels rendered electrofishing ineffective. Snorkeling was not possible because of poor water clarity and quality throughout many south shore Oahu estuaries. In some areas above-water observations for fish and invertebrates were occasionally possible, although species identification was generally assessed through capture of individuals.

Although some fish, crustacean, and mollusk species were identifiable in the field, many smaller specimens were immediately preserved in 75% ethanol and brought back to the Bishop Museum for further identification. For this report, we used the scientific and common names of fishes published by the American Fisheries Society (American Fisheries Society 1991), crustaceans (American Fisheries Society 1989), and Nishida (1997) for insect names and biogeographic status.

Figure 1. Map of south and west shore Oahu sampling locations, Kaena Point to Pokai Bay.

Figure 2. Map of south and west shore Oahu sampling locations, Maili to Barbers Point.

Figure 3. Map of south shore Oahu sampling locations, Salt Lake to Makapuu Point.

Table 1. Station Locations and sampling dates for Oahu south and west shore estuaries and lowest stream reaches. Longitude and latitude coordinates are in WGS84 datum.

		Latitude			Longitude			
Station	Location	Deg.	Min.	Sec.	Deg.	Min.	Sec.	Sampling Date
1	Makua Stream	21	31	37.4	158	13	40.4	18 Feb 1999
2	Makaha Stream/Wetlands		28	37.3		13	12.9	2 Feb 1998; 23 Feb 1999
3	Kaupuni Stream		26	57.4		11	26.6	9 Mar 1998; 25 Feb 1999
4	Mailiilii Stream		25	45.8		10	53.6	25 Feb 1998
5	Maili Stream		24	31.9		10	38.7	20 Feb 1998
6	Ulehawa Stream		23	33.5		09	25.6	2 Mar 1998; 25 Feb 1999
7	Nanakuli Stream		22	31.0		08	22.3	9 Feb 1998; 25 Feb 1999
8	Ordy's Pond at Barbers Point		18	27.0		03	08.7	26 Jan 1998; 8 June 1999
9	Moanalua Stream		20	40.0	157	53	38.5	15 Jun 1998; 13 Oct 1998; 4 Mar 1999
10	Salt Lake		21	14.5		54	24.1	17 Apr 1998
11	Kalihi Stream		19	57.2		53	13.6	15 Oct 1998; 4 Mar 1999
12	Kapalama Stream		19	23.5		52	18.5	15 Oct 1998; 10 Mar 1999
13	Nuuanu Stream		19	10.9		51	23.0	1 June 1998; 8 June 1998; 25 Mar 1999
14	Makiki Stream		17	43.1		50	11.8	1 May 1999
15	Ala Moana Park		17	30.5		51	13.9	8 Jun 1998
16	Ala Wai Canal		16	30.2		49	03.7	5 Oct 1998; 8 Oct 1998; 1 Apr 1999
17	Manoa/Palolo Stream		17	06.1		49	13.1	8 May 1998; 16 June 1998; 5 Oct 1998; 4 May 1999
18	Waialaenui Stream		16	12.1		46	39.2	4 Jun 1998; 30 Mar 1999
19	Wailupe Stream		16	34.8		45	35.2	10 Jun 1998; 18 Jun 1998; 9 Mar 1999; 3 Mar 1999
20	Niu Stream		16	50.4		44	17.2	18 Jun 1998; 30 Mar 1999
21	Paiko Lagoon		17	04.0		43	22.2	28 Sept 1998; 1 Oct. 1998
22	Kuliouou Stream		17	03.2		43	17.4	13 Apr 1999
23	Kuapa Pond		17	02.6		43	05.2	21 May 1998; 8 June 1998; 13 Apr 1999
24	Awawamalu Stream		17	38.6		39	41.6	18 Mar 1998; 24 Mar 1998; 21 May 1998

C. Data Analysis

Species identification was made to the lowest taxonomic level possible, and the biogeographic status was assessed. Species composition was determined for each stream, and the relationship between salinity and species composition was assessed.

RESULTS

A. Station Locations

The following section contains specific sampling locations for this study. Sampling along the dry leeward coast (Makua to Barber's Point) of Oahu was mainly conducted during the wetter season (January through April) to maximize the capture of aquatic organisms. Stream names were derived from the USGS quad maps. Latitude-longitude coordinates are in WGS84 datum and were taken where the stream entered the south shore of Oahu.

B. South and West Shore Oahu Sampling Area Descriptions

Makua Stream

Latitude 21°31′37.4′′ N, Longitude 158°13′40.4′′ W

In its lower reaches Makua Stream is normally dry, and salinity measurements of 15-43 ppt were measured at the stream mouth. Makua Stream mouth has a sand bar berm at the ocean and a large stagnant silty-bottomed pool that extends upstream to the Farrington Highway bridge. While pickleweed (*Batis maritima*) was the dominant plant in the mudflats here, other major riparian vegetation at the site included *Paspalum* sp., koa haole (*Leucaena leucocephala*), kiawe (*Prosopis pallida*), *Pluchea* sp., *Chenopodium* sp., and *Bidens pilosa*. Endangered Hawaiian Coots (*Fulica americana alai*) were observed feeding at the Makua Stream mouth.

Makaha Stream and Wetlands

Latitude 21°28′37.3′′ N, Longitude 158°13′12.9′′ W

Sampling took place at the Makaha Stream mouth located at Makaha Beach Park. The mouth of Makaha Stream is adjacent to a large, ephemeral wetland area on the mountain side of Farrington Highway. Many large, round tilapia nests were observed in the large pool formed behind a sandbar at Makaha Beach Park. The Makaha wetlands appear to be created by trapped seawater, as salinities were higher (38-40 ppt) than in the adjacent ocean. The ponds were silty and deep (> 1.5

m) and lined with a monoculture of pickleweed with kiawe growing along the wetland shore. New restroom facilities at Makaha Beach Park were constructed adjacent to the wetlands after field work for this study occurred. Hawaiian stilts (*Himantopus mexicanus knudseni*) were observed foraging at the Makaha Stream mouth and wetlands area.

Kaupuni Stream

Latitude 21°26′57.4′′ N, Longitude 158°11′26.6′′ W

This station was located in the area of Waianae Methodist Church and consists of a large cement channel with no riparian vegetation. Kayaks were used to access the upper areas of the cement channel, and sampling of the surf zone also was conducted near the ocean.

Mailiilii Stream

Latitude 21°25′45.8′′ N, Longitude 158°10′53.6′′ W

This stream mouth was a lined cement channel with some rock rubble lining the channel. No riparian vegetation was found at this site.

Maili Stream

Latitude 21°24′31.9′′ N, Longitude 158°10′38.7′′ W

This station is directly open to the sea and the effects of the constant surf were visible to upstream of the Farrington Highway Bridge. The stream mouth area is not lined with concrete, but sandy reef rubble and sand are found there. Constant grading prevents the build up of sand bar berm at Maili Stream, and native vegetation such as beach naupaka (*Scaevola sericea*) and seaside morning glory (*Ipomoea pescaprae*) was found here despite the constant beach grading.

Ulehawa Stream

Latitude 21°23′33.5′′ N, Longitude 158°09′25.6′′ W

This stream mouth has been channelized and the mouth appears to be regularly dredged for flood control. Large amounts of urban debris were observed behind the wave formed sand bar berm, especially after large rainstorms. No riparian vegetation grows at this channelized stream mouth.

Nanakuli Stream

Latitude 21°22′31.0′′ N, Longitude 158°08′22.3′′ W

This station is located adjacent to Nanakuli Beach Park and is similar in structure to the Makua Stream mouth. Large wetlands that extend upstream of Farrington Highway are formed by a sand bar berm that encloses mudflats lined with pickleweed, *Pluchea* sp., and *Paspalum* sp. grasses.

Ordy's Pond, Barbers Point

Latitude 21°18′27.0′′ N, Longitude 158°03′8.7′′ W

Although this station is not linked to the ocean, sampling occurred at this natural saline lake near the ocean to determine if any remnant native *Megalagrion* damselflies persisted here. Mangroves (*Rhizophora mangle*) line this variably saline sinkhole, with kiawe and bulrush (*Scirpus* sp.) being the other predominant vegetation. Salinity at Ordy's Pond appeared to be related to rainfall, and salinities varied from 12 to 24 ppt.

Moanalua Stream

Latitude 21°20′40.0′′ N, Longitude 157°53′38.5′′ W

The estuary for Moanalua Stream begins at the downstream end of Moanalua Gardens and riparian vegetation consists of mangroves, *Paspalum* sp. grass, pickleweed, with cultivated grasses and various sedges near the park. Moanalua Stream empties a moderate amount of freshwater into Keehi Lagoon, and sampling occurred from Moanalua Gardens to Keehi Lagoon Beach Park.

Salt Lake

Latitude 21°21′14.5′′ N, Longitude 157°54′24.1′′ W

Originally Salt Lake was an evaporation basin fed by seawater seepage at high tides that produced large quantities of salt used for domestic proposes (Maciolek 1982). In 1891 the salinity content of Salt Lake prior to its alteration was measured at 400 ppt (Maciolek 1982), but the hydrology was altered when artesian wells and water drainage from other craters greatly reduced the salinity, allowing it to be used as a commercial fishpond. Much of Salt Lake has been filled and heavily modified by the Honolulu Country Club golf course development. During this study salinities at Salt Lake ranged from 7-8 ppt, and thick layers of silt made sampling difficult in deeper areas. Fish sampling was effective in the shallow marshy areas near the Honolulu Country Club golf course. Riparian vegetation in areas away from the golf course included pickleweed, *Scirpus* sp., and kiawe. Hawaiian Coots were frequently observed swimming in the deeper portions of Salt Lake while Hawaiian Stilts were observed in the mudflat areas.

Kalihi Stream

Latitude 21°19′57.2′′ N, Longitude 157°53′13.6′′ W

This station was located immediately upstream of the Kamehameha Highway Bridge. Kalihi Stream was strongly flowing just above the estuary. The stream banks were completely bare and had no riparian vegetation because of high scouring flows while urban fill debris such as concrete rip-rap lined the south bank. Stream substrate was mainly fine cobble and rubble, and high flows had removed most of the silt in the lower stream area. Mangroves lined the shoreline of the lower estuarine region of the stream, and this area was accessed by kayaking from Keehi Lagoon Beach Park.

Kapalama Stream

Latitude 21°19′23.5′′ N, Longitude 157°52′18.5′′ W

Kapalama Stream maintains a much lesser amount of water flow than adjacent Kalihi and Nuuanu Streams, and occasionally becomes dry in its lowest concrete channelized reaches. This concrete-lined stream flows through urban Honolulu until in the area of the H-1 Highway it flows into a tidal silty mudflat area lined with mangroves and some pickleweed. The Kapalama drainage canal flows through a major business area of Kalihi, and the banks are kept bare. This area was sampled from above the H-1 highway to Dillingham Boulevard.

Nuuanu Stream

Latitude 21°19′10.9′′ N, Longitude 157°51′23.0′′ W

This station was accessed at a park on Kuakini Street and sampled from Waikahalulu Falls downstream to the estuarine area adjacent to Foster Botanical Gardens. Nuuanu Stream is one of largest and most important streams on the south shore Oahu in terms of freshwater flow. The large Waikahalulu Falls are approximately 2.5 m high and provide a sharp contrast between areas of freshwater and the tidally influenced section 150 m downstream of the falls. Tidal influence begins just upstream of the H-1 Highway in an area that has been channelized with concrete.

Makiki Stream

Latitude 21°17′43.1′′ N, Longitude 157°50′11.8′′ W

Tidally influenced areas of Makiki Stream begin downstream of the intersection of Kalakaua Avenue and Philip Street. Flowing into the Ala Wai Canal and similar to Kapalama Stream, Makiki Stream is one of the most degraded and urbanized streams on Oahu. Although permanently flowing in its upper reaches near the Hawaii Nature Center, during dry periods Makiki Stream is often dry at its channelized junction with Nehoa Street. Makiki Stream becomes channelized shortly after leaving the area of the Hawaii Nature Center at Makiki Heights Drive. In its lower reaches Makiki Stream is encased in concrete culverts and channelized, making access difficult to impossible in places. Upstream of Philip Street the stream channel is just slightly more natural having some natural rocks that have been washed into the channel. Tidal influence begins downstream of Philip Street. No riparian vegetation grows in lower Makiki Stream.

Ala Moana Park

Latitude 21°17′30.5″ N, Longitude 157°51′13.9″ W

Sampling at Ala Moana Park took place in the canals lining the circular walkway around the park. There was no sign of freshwater in these canals as salinities were measured at 35 ppt during sampling for the present study. Riparian vegetation consisted of domesticated plants and grasses, and substrate was sand and gravel.

Manoa/Palolo Stream Junction

Latitude 21°17′06.1″ N, Longitude 157°49′13.1″ W

A large amount of freshwater input water comes from the Manoa/Palolo Stream which empties into the Ala Wai Canal. This area was accessed at Kaimuki High School and sampled from above the H-1 Highway bridge downstream to the Date Street bridge. Mangroves start to become common in areas nearer to Date Street, while a variety of introduced plant species line the often dredged shoreline of the stream in the area of Kaimuki High School. Aquatic habitats in this section of the estuary are poor, with deep silt predominating in areas adjacent to the Date Street bridge.

Ala Wai Canal

Latitude 21°16′30.2″ N, Longitude 157°49′03.7″ W

This station is a continuation of the Manoa/Palolo Stream sampling area, where mainly aquatic insects were sampled along the Ala Wai Canal. An extensive history, site description, and study of the sediments and plankton of the Ala Wai Canal can be found in Volume 49 (4) of the journal *Pacific Science* (Glenn and McMurtry 1995, Beach et al. 1995, Glenn et al. 1995). Areas sampled during the current study included the canoe club storage beach region and shoreline up and downstream of this area. Vegetation consisted of mangroves and a variety of cultivated plants.

Waialaenui Stream

Latitude 21°16′12.1″ N, Longitude 157°46′39.2″ W

This station is located at Waialae Beach Park and the area sampled extended to upstream of Kahala Avenue. No riparian vegetation grows along the banks of the stream at this popular beach park, and the stream bottom is mostly sand near the beach. Further upstream above the Kahala Avenue bridge the substrate becomes more silty. There was some freshwater input here as salinities measured between 28-32 ppt during sampling.

Wailupe Stream

Latitude 21°16′34.8″ N, Longitude 157°45′35.2″ W

The mouth of Wailupe Stream is located at Wailupe Beach Park. Salinities at this station ranged from 0-33 ppt, with a small amount of freshwater originating upstream of the beach park from a concrete lined channel. Riparian vegetation consisted of planted grasses and ornamentals.

Niu Stream

Latitude 21°16′50.4″ N, Longitude 157°44′17.2″ W

As salinities were measured at 34 ppt during this study, this station was more marine in character and would have freshwater input only during periods of heavy rain. The mouth of Niu Stream, located downstream of the confluence of Pia and Kupaua Stream, was sandy and lacked riparian vegetation.

Paiko Lagoon

Latitude 21°17′04.0″ N, Longitude 157°43′22.2″ W

This station is located within a State wildlife sanctuary with vegetation consisting mainly of mangroves and pickleweed, with lesser amounts of beach naupaka, kiawe, and milo (*Thespesia populnea*). Substrate at this marine station consisted of sand and reef rubble, and salinities ranged from 37-38 ppt.

Kuliouou Stream

Latitude 21°17′03.2″ N, Longitude 157°43′17.4″ W

Kuliouou Stream was directly adjacent to Paiko Lagoon and was accessed at Kuliouou Beach Park. The stream channel here had concrete retaining walls with a sandy bottom and no riparian vegetation. This station is more marine in character and salinities at the stream mouth measured 34 ppt.

Kuapa Pond

Latitude 21°17′02.6′′ N, Longitude 157°43′05.2′′ W

Collections in the Kuapa Pond area occurred at a variety of stations and habitats. Areas sampled included near the Kalanianaole Highway bridges, at the Hawaii Kai bridge area, and at a spring area. Salinities ranged from 39 ppt inside Kuapa Pond to 8 ppt at the spring-fed pond area near Hahaione School, located near a recreational facility. Bulrushes (*Scirpus* sp.) and *Chenopodium* sp. lined this spring area.

Awawamalu Stream

Latitude 21°17′38.6′′ N, Longitude 157°39′41.6′′ W

This estuarine area is located near Sandy Beach, and there is a relatively large embayment or cove at the Awawamalu Stream estuary. The cove here is the only place sampled along the south shore of Oahu during this study that contained the remnants of undisturbed native lowland coastal riparian vegetation such as ilima (*Sida fallax*), beach naupaka (*Scaevola sericea*) and naio (*Myoporum sandwicense*). Other study sites such as Maili Stream contained some native beach plants, but the constant grading of sand at Maili Stream leaves that area highly disturbed, while the embayment area of Awawamalu estuary is still quite intact. Although Awawamalu Stream is quite small and drains a dry leeward area, there appeared to be a small amount of permanent freshwater flow originating from the Hawaii Kai Country Club golf course, as native dragonfly larvae (*Anax junius*) and mosquitofish (*Gambusia affinis*) were collected. Water flow disappeared into the alluvium on the ocean side of the highway bridge from the small stream starting at the golf but salinities were 0 ppt. This stream did not directly flow into the Awawamalu cove, and salinities in the uppermost portion of the cove were measured at 29 ppt, while other areas were hypersaline and salinities as high as 39 ppt were recorded.

C. South and West Shore Oahu Fauna Composition

For this study 235 aquatic species (Table 2) in 10 phyla (Figure 4) were collected and identified in estuarine and riparian habitats of the south and west shores of Oahu (see Appendix A). Of these 235 species, 51.9% were native while 31.5% were introduced species, with 15.3% were undetermined species (Table 2). Three new undescribed Diptera species (1.3% of total species), two in the family Ephydridae and one in the family Tethinidae, were collected during the present study (Table 2). For Table 2, species considered questionably endemic or indigenous were assumed to be native for the calculations of percent native and percent introduced. The estimates of nonidigenous species are therefore conservative.

Arthropods (mainly insects) composed 58.5% of the species collected in or estuarine habitats and were by far the most dominant phylum represented (Figure 4). Of the 137 arthropod species found along the south and west shore Oahu estuarine areas, 76 were aquatic insects, 60 crustaceans, and 1 a pycnogonid (sea spider). Other important phyla found in south and west shore Oahu estuaries included vertebrates (Chordata) at 21.8%, mollusks (Mollusca) at 6.8%, worms (Annelida) at 6.8%, and echinoderms at 2.1% (Echinodermata). Minor components of the fauna collectively composed only 3% of the species found, and included Hemichordata, Cnidaria, Platyhelminthes, Nematoda, and Sipuncula, with 0.9% undetermined species (Figure 3).

Overall, native species were found in greater percentages than nonindigenous species in the aquatic fauna of south and west shore Oahu estuaries (Figure 5). Figure 6 provides the number of species found and the biogeographic status of aquatic fauna in each sampling station.

Table 2. Summary of the total number, percent, and biogeographic status of all aquatic species found in south shore Oahu wetlands, estuaries, and stream mouths.

Biogeographic Status	Aquatic Species
Introduced Species	74 (31.5%)
Native Species	122 (51.9%)
New Species	3 (1.3%)
Unknown	36 (15.3%)
Total Species	235

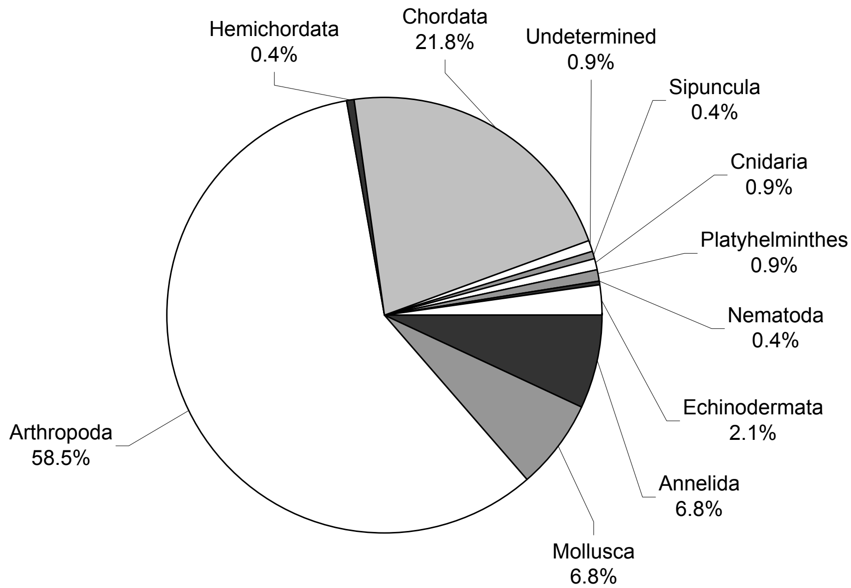

Figure 4. Summary of phyla found in south shore Oahu estuarine habitats, expressed as a percentage of all known species.

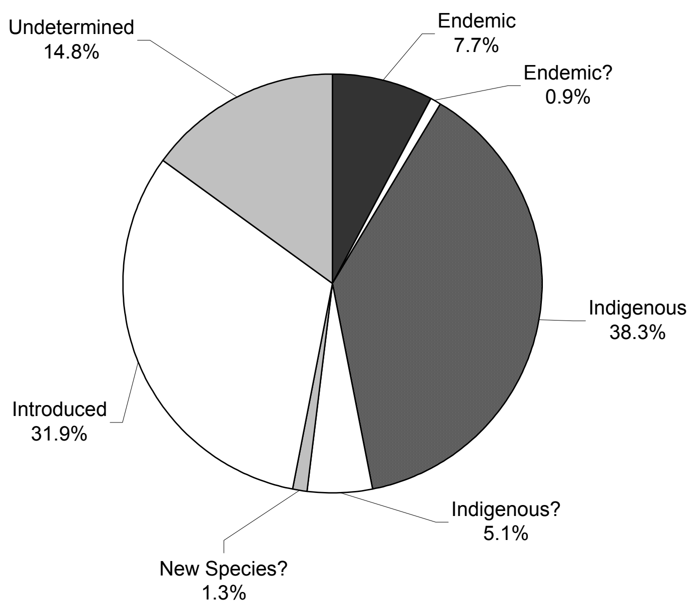

Figure 5. Summary of native and introduced status of aquatic fauna in south shore Oahu lower stream and estuarine habitats.

The sampling station at Wailupe Beach Park at the mouth of Wailupe Stream had the highest number of total and native species (Figure 6). In general, the sampling stations that were more marine in character such as Paiko Lagoon, Kuapa Pond, and Wailupe had the greatest number of

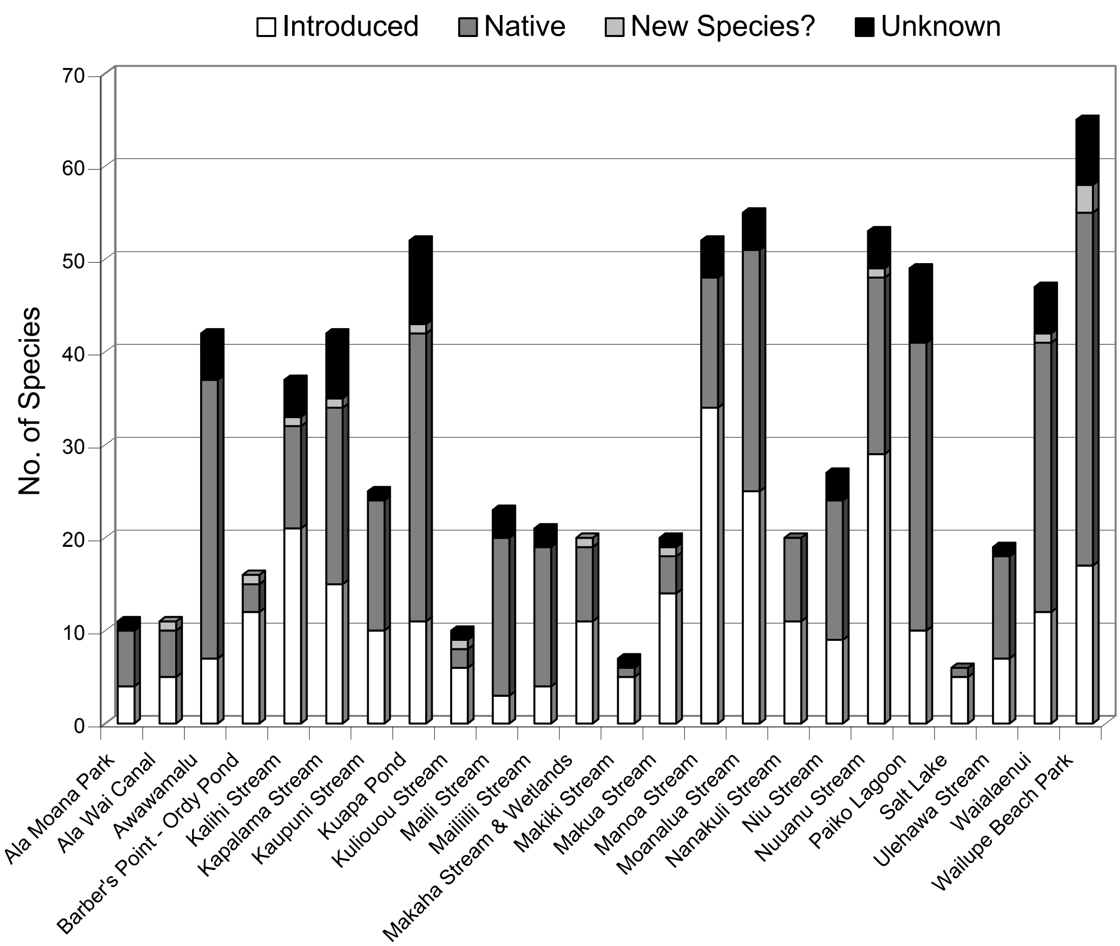

Figure 6. Number of species by stream and biogeographic status for combined aquatic fauna found in estuarine regions of south shore Oahu.

native species. Stations with the greatest amount of freshwater influence such as Manoa, Kalihi, and Nuuanu Streams also had the largest numbers of introduced species (Figure 6).

D. Aquatic Insect Species Composition

Extensive sampling of the lowest reaches of south shore Oahu streams and estuaries revealed that introduced aquatic insect species dominate these habitats, with 76 species being identified. Introduced aquatic species accounted for 60.5% of the south and west shore Oahu fauna, while native species accounted for only 25% (Figure 7). A complete listing of aquatic insects collected during the present study can be found in Appendix A. Nineteen species of native aquatic insects were collected throughout south and west shore Oahu estuaries and lower stream reaches. Of the native species of aquatic insects, 14.4% were endemic or probably endemic, while 10.6% were indigenous or probably indigenous, and 3.9% (n = 3) were new, undescribed species (Figure 8). Nishida (1997) was our reference for the native or introduced status of arthropods, and for this report we assumed that organisms classified as probably endemic or indigenous were native species.

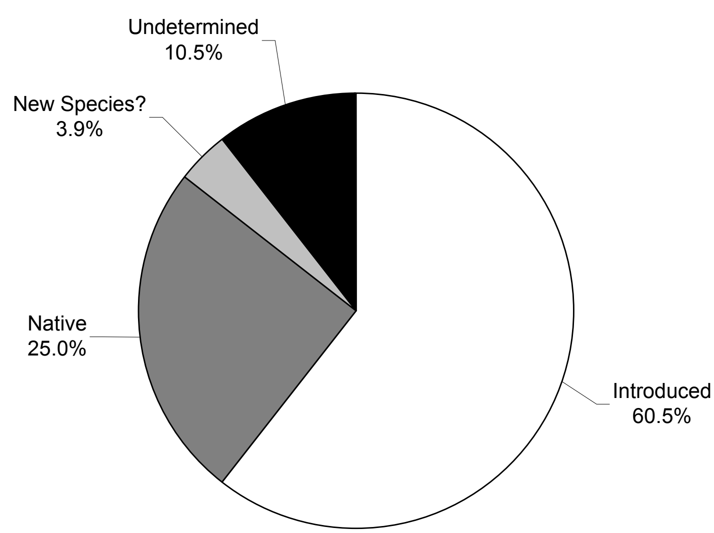

Figure 7. Biogeographic status for aquatic insect species found in south and west shore Oahu lower stream and estuarine areas.

The number of aquatic insect species found in each sampling station was quite variable (Figure 9). Numbers of species from each sample area varied from a low of four at Salt Lake to a high of 27 species at Wailupe and Nuuanu Streams. Introduced aquatic insect species predominated in each stream estuary. One notable exception was Maili Stream, where 5 native species were collected and only one introduced species was found. The lack of freshwater influence at Maili Stream (it flows only intermittently) led to mostly native marine Diptera (flies) being collected at this site.

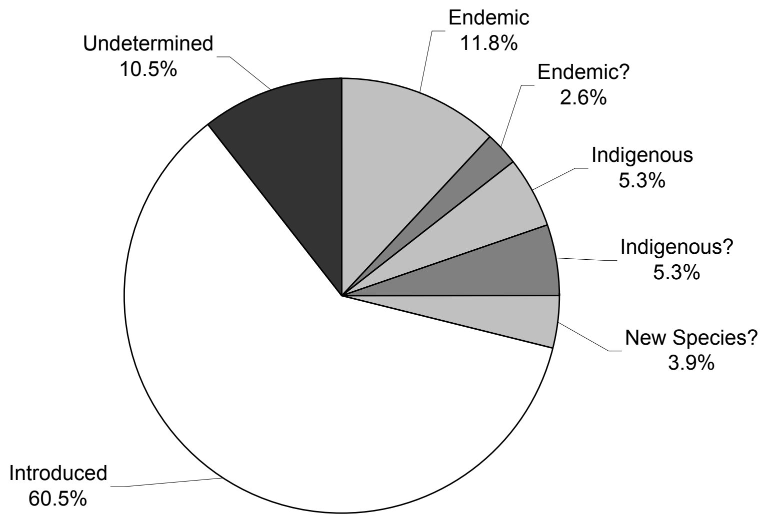

Figure 8. A breakdown of biogeographic status for aquatic insect species found in south and west shore Oahu lower stream and estuarine areas.

Aquatic Diptera (flies) were by far the most species-rich order found, with a total of 59 species collected during the present study. Diptera composed 78.9% of all aquatic insect species (Figure 10), with 27% native, 52.5% introduced, and an additional 20.4% unknown or new species (Table 3). Odonata (dragonflies and damselflies) were the next most common and comprised 10.5% of the aquatic insect fauna, while 5.3% of species were aquatic Heteroptera (true bugs), and 2.6% were Coleoptera (aquatic beetles) (Figure 10). In the lower regions of south and west shore Oahu streams, introduced caddisflies (Trichoptera) were collected only in non-tidal sections of Manoa and Nuuanu Streams, and composed only 2.6% of the sampled aquatic insect species collected. Introduced caddisflies such as *Cheumatopsyche pettiti* are one of the most ubiquitous aquatic insect species found in Hawaiian streams (Kondratieff et al. 1997). However, as most of our collecting effort was conducted in estuarine, wetland, and spring areas with relatively little or no water flow, we collected *Cheumatopsyche pettiti* only at one station, and *Hydroptila arctia*, another caddisfly, was found at two stations.

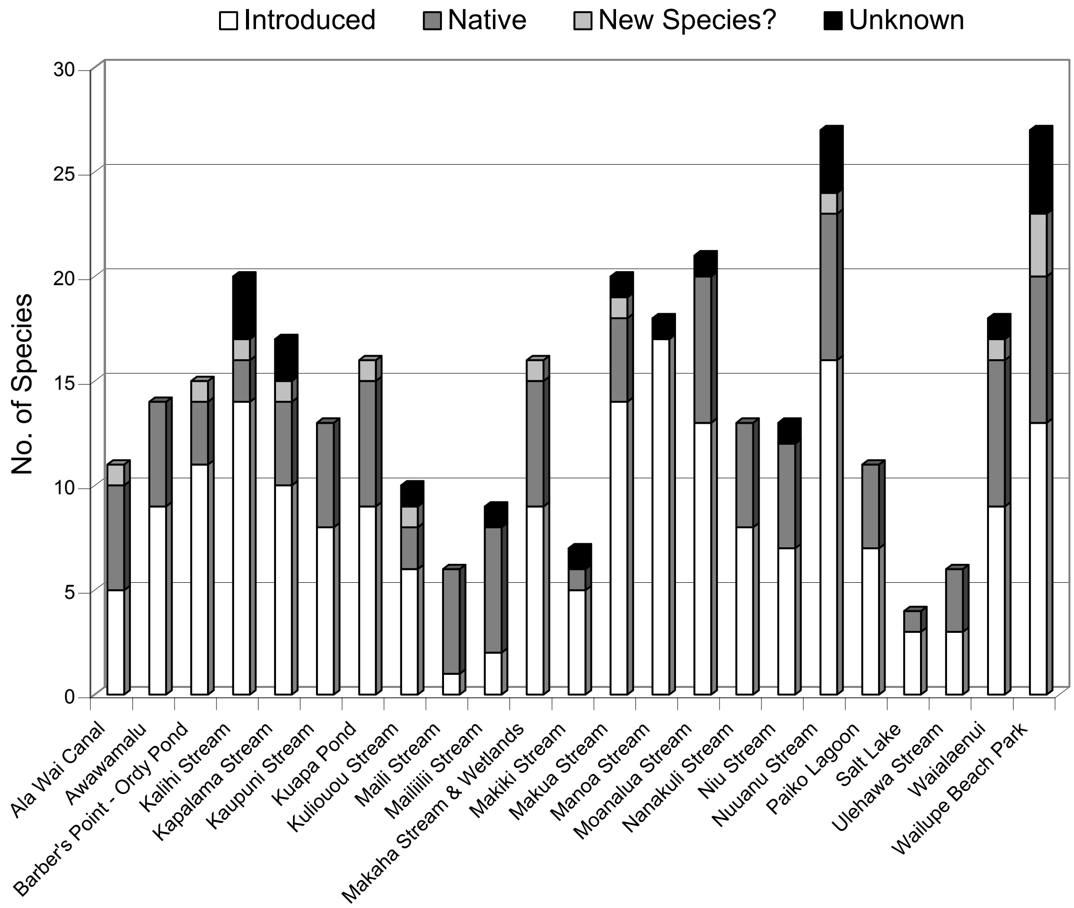

Figure 9. Numbers of aquatic insect species collected in estuarine regions of south and west shore Oahu with number of species by stream and biogeographic status.

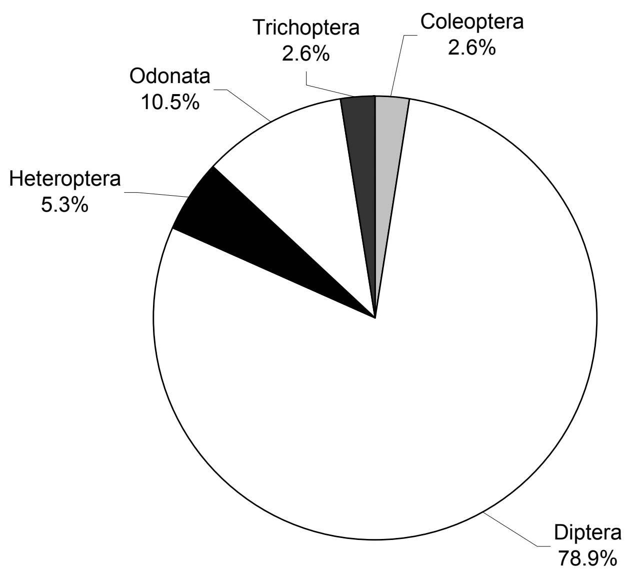

Figure 10. Percent frequency by order of aquatic insect species found in lower stream and estuarine reaches of the south and west shore of Oahu.

Families in the order Diptera dominated aquatic insects found along the south and west shores of Oahu with the marine Ephydridae (shore flies) and Dolichopodidae (long-legged flies) being the most species-rich families (Figure 11). Three introduced and one native dragonfly comprising the family Libellulidae were the most common non-Diptera family, and comprised 5.3% of the species found.

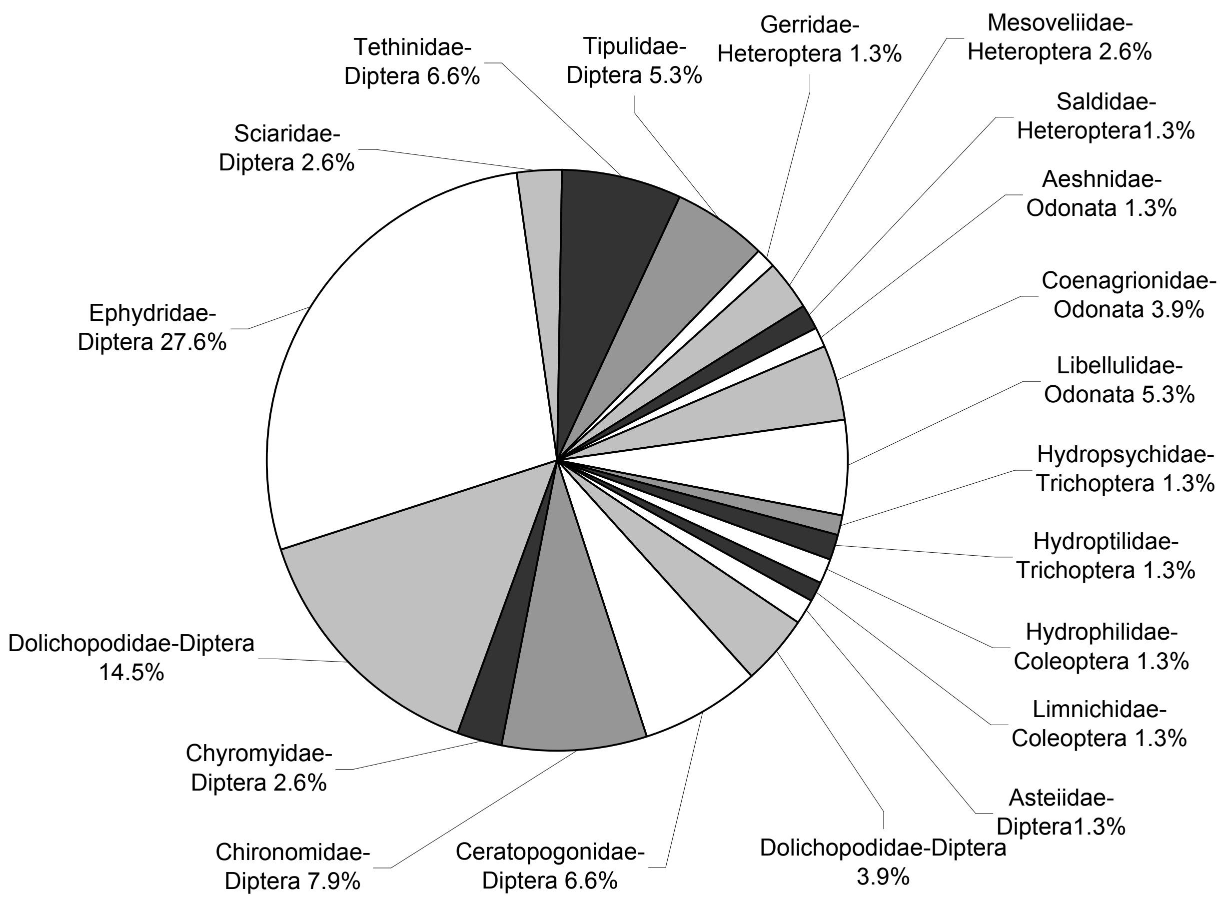

Figure 11. Breakdown of percent composition of aquatic insect families found in the south and west shore Oahu lower stream and estuarine areas.

Because of their small size and the apparent ease of their accidental introduction, a large percentage of aquatic Diptera (20.4%) could not be identified to the species level (or have not yet been described) and thus were of unknown origin. An interesting finding of this study was the finding of *Ephydra gracilis*, an aquatic fly in the family Ephydridae that was introduced via seaplanes (Wirth 1947). Special efforts were made to resample areas where this species was found in 1946 to be “breeding by the millions” in areas such as Moanalua Stream and Salt Lake.

Intensive sampling of these and other suitable areas found numerous species of other native and introduced ephydrid flies during this study. However, *Ephydra gracilis* was uncommon and none were collected in the 1946 collection areas. Only nine individual *Ephydra gracilis* were captured during the present study in two hypersaline areas at Kuapa Pond and the Makaha Stream mouth.

Table 3. Biogeographic status, percent occurrence and total number of species of aquatic Diptera species found in the lower reaches of south and west shore Oahu streams. Species recorded as probably endemic/indigenous in Nishida (1997) were assumed to be native.

Family (total # species)	% Endemic/Indigenous	% Introduced	% Unknown/New
Asteiidae (1)	-	100	-
Canacidae (3)	33.3% (1)	66.7% (2)	-
Ceratopogonidae (5)	40% (2)	20% (1)	40% (2)
Chironomidae (6)	50% (3)	16.7% (1)	33.3% (2)
Chyromyidae (2)	50% (1)	-	50% (1)
Dolichopodidae (11)	18.2% (2)	81.8% (9)	-
Ephydridae (21)	19% (4)	66.7% (14)	14.3% (3)
Sciaridae (2)	50% (1)	-	50% (1)
Tethinidae (5)	40% (2)	20% (1)	40% (2)
Tipulidae (4)	-	75% (3)	25% (1)
Total: species	27.1% (16)	52.5% (31)	20.4% (12)

Another notable finding of these surveys was the absence and extirpation of native *Megalagrion* damselflies in south and west shore Oahu stream mouths, wetlands, and estuaries. Three species of introduced damselflies, *Ischnura posita*, *Ischnura ramburii*, and *Enallagma civile* are now abundant in the lower reaches of south shore Oahu streams and estuarine areas. Two native and two introduced species of dragonflies were also common during the present study. The indigenous *Pantala flavescens* and *Anax junius* were among the most common native aquatic insects remaining in the south shore of Oahu. In contrast to native *Megalagrion* damselflies, of which no adults or larvae were found, larvae of the native *Anax junius* (common green darner dragonfly) were common in areas such as at Awawamalu or Moanalua Streams and were always collected in the presence of many different species of introduced fish. The recently introduced *Crocothemis servilia*, along with the well-established *Orthemis ferruginea*, were also common throughout aquatic habitats in the south shore of Oahu.

A small population of the water strider *Halobates hawaiiensis*, an endemic species of aquatic Heteroptera, was found in the marine estuarine area of Moanalua Stream. Although not considered rare, this species is often difficult to locate in Hawaii, with populations usually quite localized (D. Polhemus, Smithsonian Institution, pers. comm.), but it was common in the area of the Moanalua Stream estuary at Keehi Lagoon. Here *H. hawaiiensis* was found in the shelter of introduced mangroves lining the mouth of Keehi Lagoon. This marine insect species avoided freshwater and occurred in areas of water 36 ppt salinity. Although the Barbers Point Deep Draft Harbor was not part of this study area (as there are no streams or estuaries at this artificial harbor), this area is part of an ongoing Bishop Museum ballast water study, and *H. hawaiiensis* was abundant around large ships and drydocks in the harbor.

Other aquatic Heteroptera found in south and west shore Oahu streams include three common, introduced species: *Mesovelia amoena*, *Mesovelia mulsanti*, and *Micracanthia humilis*. True bugs in the family Saldidae are one of the most common native aquatic insect groups in higher elevation areas in the Hawaiian Islands, with as many as three native species found in a single Oahu stream (Polhemus 1995a). However, in the lower areas of south and west shore Oahu streams, estuaries, and wetlands only the introduced saldid *Micracanthia humilis*, first collected in 1988 was found, and native saldid species were absent. In more pristine stream areas such as the north shore of Molokai native saldid species are still found at or near sea level. Two introduced mesoveliid species were also found along the south and west shore Oahu estuarine areas.

Two species of introduced aquatic beetles (Coleoptera) were found in the lower stream and estuarine regions during the present study. The most recent introduction (in 1996) is the small mangrove mudflat beetle (*Parathroscinus* cf. *murphyi*). This beetle was first recorded in Hawaii during previous Bishop Museum surveys of Pouhala Marsh in 1996 (Nishida and Imada 1997, Samuelson 1998). This beetle has been spreading to other areas on Oahu from the original collecting site at Pearl Harbor and is now found from Koloko Point, which is northeast of Sandy Beach to the West Loch of Pearl Harbor at Honouliuli Stream (Englund et al. 2000). *Parathroscinus* cf. *murphyi* has not yet spread to the western shore of Oahu (from Barbers Point to Kaena Point), as indicated by intensive sampling in suitable habitats in this area. *Parathroscinus* cf. *murphyi* has become one of the most common insects on mudflats where mangrove grows, sometimes moving up along streams where the water is brackish yet tidally influenced. The beetles aggregate in large numbers on exposed mud and take flight when disturbed and generally fly very low to the mud surface

Another species of introduced Coleoptera was the water scavenger beetle, *Tropisternus salsamentus*, common at Ordy's Pond in Barbers Point and perhaps the most common aquatic insect there. Very high numbers of these adult aquatic beetles were collected with high densities of introduced poeciliids such as *Poecilia latipinna* and *Gambusia affinis*. *Tropisternus salsamentus* is saline tolerant and was found at Ordy's Pond in 24 ppt salinity water.

E. Fish Species Composition

For the purposes of this study, aquatic habitats were classified as freshwater if salinities ranged from 0 to 5 ppt, estuarine at 6 to 26 ppt, and marine if >26 ppt. Most fish species in south Oahu estuaries and wetlands were found in a wide range of salinities. Exceptions were the introduced suckermouth catfish species *Ancistrus temminckii* and *Hypostomus* cf. *watwata* that were restricted to freshwater, and *Poecilia reticulata* (guppy) being restricted to waters having ≤ 3.0 ppt salinity.

Fish species composition in the sampled coastal wetland, lower stream, and estuarine areas of the south and west shores of Oahu indicated that more native (73%) fish species were collected than introduced species (23%). Most species were from the order Perciformes, which is the most diversified of all fish orders (Nelson 1994), and these fish comprised 68% of the species found in south and west shore Oahu estuarine habitats (Figure 12). This order includes native and introduced fish including gobies, cichlids (e.g., blackchin tilapia), blennies, and species in the family Mugilidae (mullet). Orders found in south shore Oahu estuarine areas that were comprised solely of introduced species include Siluriformes (suckermouth catfish), Cyprinodontiformes (poeciliids or mosquitofish), and Cypriniformes (dojo loach) (Figure 12). Fish families composed of only

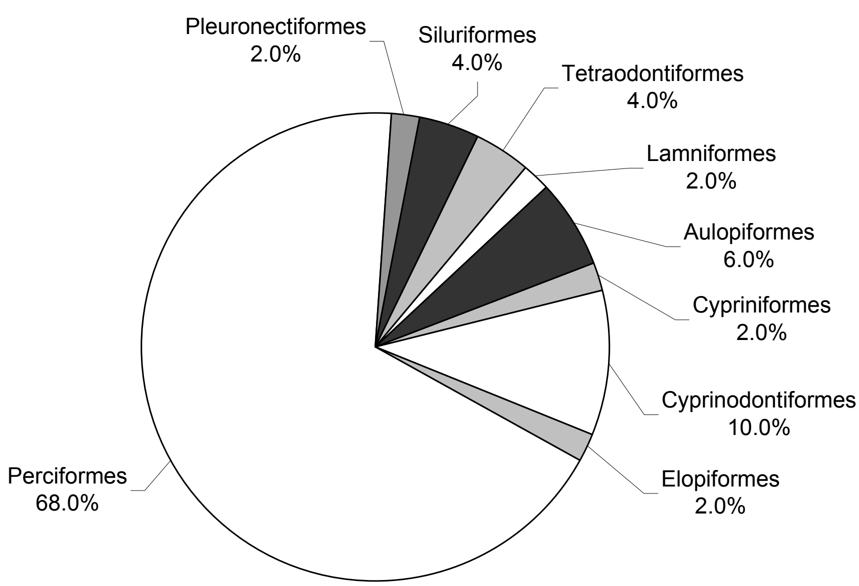

Figure 12. Frequency by Order of fish species found in south and west shore Oahu lower stream and estuarine areas.

introduced species included Cobitidae (1 spp.), Poeciliidae (5 spp.), Cichlidae (4 spp.), Gobiidae (1 spp.), Mugilidae (1 spp.), and Loricariidae (2 spp.).

Fifty fish species were collected in all areas of south shore Oahu lower streams and estuaries, in salinities ranging from 0 to 41 ppt. Appendix A provides a complete listing of each fish species, and streams and habitats where each species was captured. A general trend of the percentage of native fish species increasing as salinities increased was apparent during this study (Figure 13). Areas of entirely freshwater contained lower numbers and fewer native species of fish, with 8 native and 11 introduced species found in freshwater (0 to 5 ppt), 6 native and 6 introduced fish species found in estuarine waters (6 to 26 ppt), and 6 introduced and 29 native species in marine (> 26 ppt) waters.

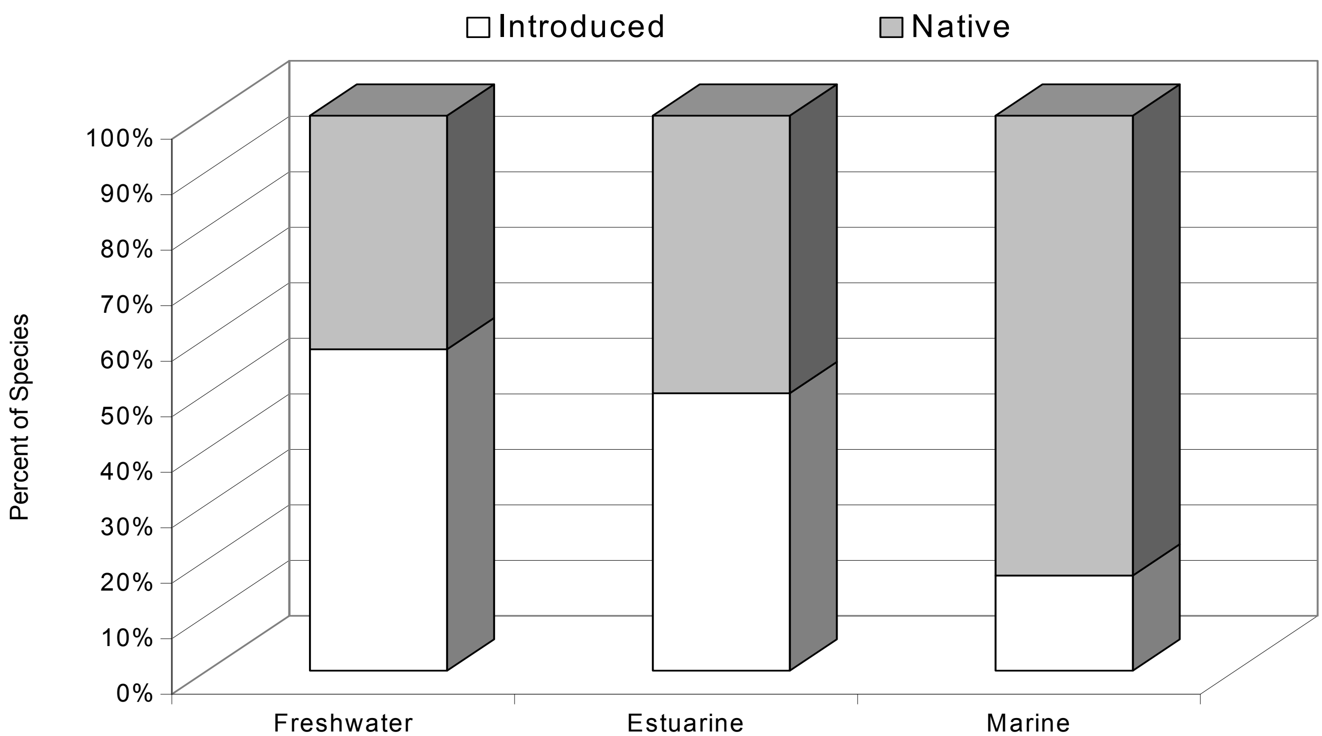

Figure 13. Biogeographic status of fish species and water salinity; freshwater = 0-5 ppt, estuarine = 6-26 ppt, marine >26 ppt salinity.

The largest freshwater streams and estuaries examined during this study included Manoa/Palolo, Nuuanu, and Kalihi Streams, which were dominated by high densities of introduced fish such as blackchin tilapia (*Sarotherodon melanotheron*), livebearers (*Gambusia affinis, Poecilia mexicana*, etc.), and armored catfish (Loricariidae). Although some recruitment was observed for sensitive freshwater native species such as *Sicyopterus stimpsoni*, no adults of this species were captured, and few adults of *Awaous guamensis* were captured or observed in the lower sections of Nuuanu, Manoa/Palolo, and Kalihi Streams.

The number of native and introduced fish species collected or observed at each sampling station is shown in Figure 14. There was no clear relationship between sampling effort and the number of fish species captured in a specific stream, although there were some trends such as more species being collected in areas having more freshwater influence, such as Manoa and Nuuanu Streams, areas that were both intensively sampled (Figure 14). For example, Moanalua Stream and Manoa had the greatest number of fish species even though sample effort was far greater at Manoa Stream.

The largest Hawaiian stream goby and most important native freshwater gobiid sportfish, *Awaous*

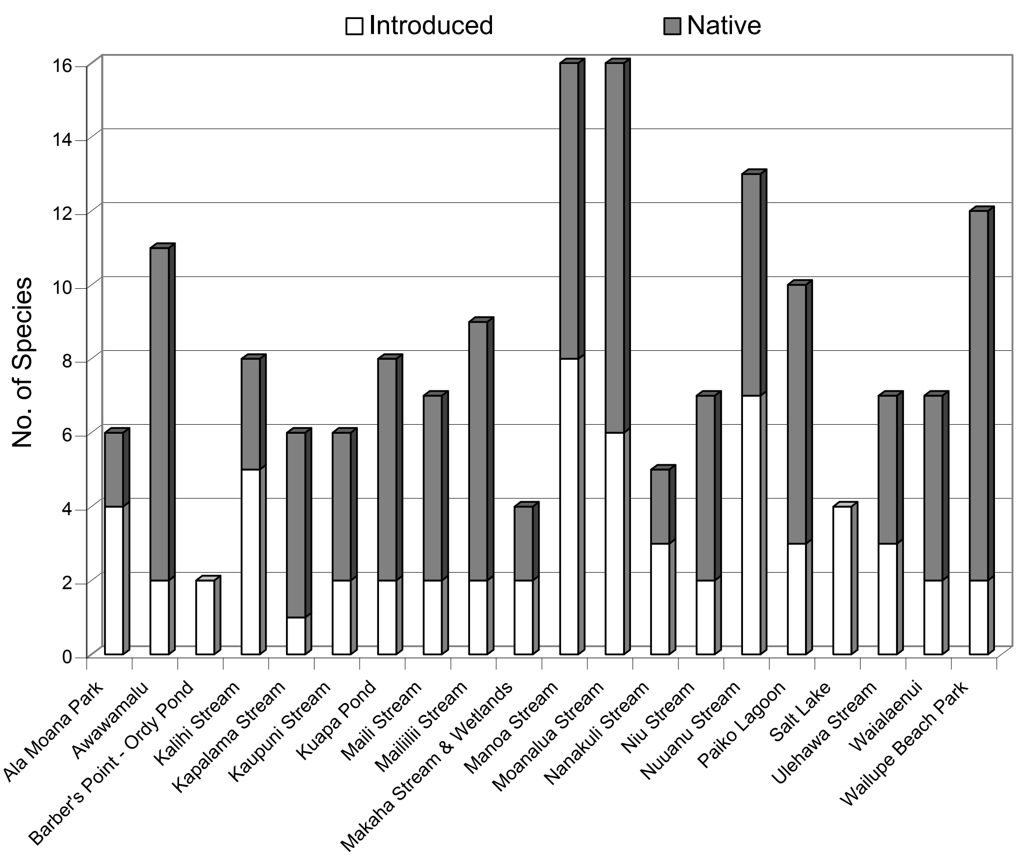

Figure 14. Number of fish species by stream and biogeographic status found in lower stream and estuarine regions of the south and west shore of Oahu.

guamensis, was relatively uncommon in the lower reaches of Oahu streams and wetlands. Sample gear limitations and effectiveness may have reduced the catch rate of native gobies, for example, poor water visibility and deep silt often hampered fish collection efforts in some areas, and partially saline conditions at most sites prevented the effective use of electrofishing. However, the introduced goby *Mugilogobius cavifrons* was found in high numbers, even though it occupies the same difficult to sample lower stream reaches as *A. guamensis*. Although *M. cavifrons* was not captured in any of the more saline Waianae coast sampling stations, this species was found in as many stations as the native *A. guamensis*, but always in greater numbers. Similar to the native goby species, *M. cavifrons* is cryptic and benthic in nature, and our capture of this species at an equal number of stations (including Manoa/Palolo, Ala Moana Park, and Kalihi Stream) as compared to *A. guamensis* indicates gear limitations may not have been the reason that *A. guamensis* were so uncommon during this study. *Awaous guamensis*, a significant cultural and food fish for native Hawaiians (Titcomb 1972), was observed or collected in low numbers at only three sampling areas: Makiki, Nuuanu, and Manoa/Palolo Streams.

Other native gobiid estuarine fish found include *Oxyurichthys lonchotus*, and *Stenogobius hawaiiensis*. *Eleotris sandwicensis* was the most common native stream fish remaining in the south shore of Oahu and was observed and collected in a variety of aquatic habitats. The endemic native gobiid, *S. hawaiiensis* was less common and was found in only 5 of 24 sampling stations in the lower reaches of streams.

Blackchin tilapia (*Sarotherodon melanotheron*) was the dominant inshore fish (in terms of numbers) found during this present study of the lower reaches of Oahu streams and wetlands. Blackchin tilapia were found in high densities in nearly every sampling location. Although blackchin tilapia are often difficult to capture, some situations allowed for effective seining, especially in turbid areas of lower Manoa/Palolo Streams and channelized areas of Moanalua Stream. In these areas, large quantities of stunted blackchin tilapia were often captured during each seine haul. Poeciliids were the only other fish commonly captured during these seine hauls.

Other threats facing sportfish and native biota include chemical spills such as the spill that occurred in upper Nuuanu Stream between Kimo Drive and Dow Street during this study on February 6, 1999. Thousands of fish were killed, mainly introduced aquarium fish and sportfish such as smallmouth bass (*Micropterus dolomieu*) (M. Yamamoto, HDAR, pers. comm.). The fish poison apparently did not affect the lowest reaches of Nuuanu Stream as sampling shortly after the chemical spill revealed healthy populations of two species of poeciliids, armored catfish, tilapia, native striped mullet, and jewel cichlids (*Hemichromis elongatus*).

F. Crustacean Species Composition

Native species comprised 65% of the crustacean species found in south and west shore Oahu estuaries and introduced species accounted for only 8% of the fauna, while 27% were species of unknown origin. At least 60 different crustacea taxa (of which 1 species is undetermined) have been determined to varying levels of taxonomic identification during the present study. Sixteen crustacean taxa were not identifiable to the species level. All crustaceans were identified to order, and nearly 55% of the species found in south and west shore Oahu estuarine regions were decapods, while amphipods (20%) and isopods (8.3%) and comprised the next most abundant taxa (Figure 15). Less species-rich orders included tanaid, mysid, stromatopodid, copepod (Harpacticoida and Caligidea), and other crustaceans, although large numbers of specimens from each of these orders were found in certain sampling areas. A complete listing of crustaceans found in each stream is provided in Appendix A.

Excluding species of unknown status, native crustacean species well exceeded the number of introduced species found during the present study (Figure 16). In this study crustaceans were the major group of aquatic species with the lowest percentage of known introductions (see Table 6). The number of crustacean species was highest at Paiko Lagoon and lowest at the Nanakuli Stream

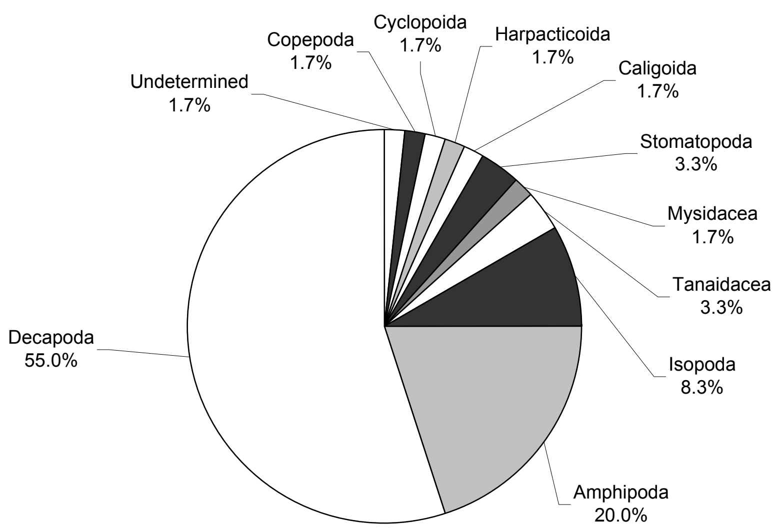

Figure 15. Percent frequency by order of crustacean species found in the lower stream and estuarine reaches of south and west shore Oahu.

mouth (Figure 16), and the number of crustacean species collected at each site was not dependent on sampling effort. For example effort was greatest at the Manoa/Palolo Stream station, but this area did not have the greatest number of crustacean species. Instead, crustacean diversity appeared to be inversely correlated with freshwater input. Marine areas such as Paiko Lagoon (37 ppt saln) and Kuapa Pond (39 ppt saln) had the greatest crustacean diversity. The only stations with introduced freshwater crustaceans were Manoa/Palolo, Nuuanu, and Moanalua Streams; all areas with large freshwater inputs. Nuuanu Stream had the greatest number of introduced crustaceans with *Macrobrachium lar*, *Procambarus clarkii*, and *Neocaridina denticulata sinensis* found directly above areas of tidal influence. *Scylla serrata* (Samoan crab) and *Panopeus pacificus* were the only nonindigenous marine crustaceans found along the south and west shores of Oahu.

Native estuarine decapod crustaceans that were abundant and found at most sampling sites along the south of Oahu and include *Periclimenes* cf. *grandis*, *Palaemon debilis*, and three species in the genus *Thalamita*. The native *Macrobrachium grandimanus* was a relatively common decapod

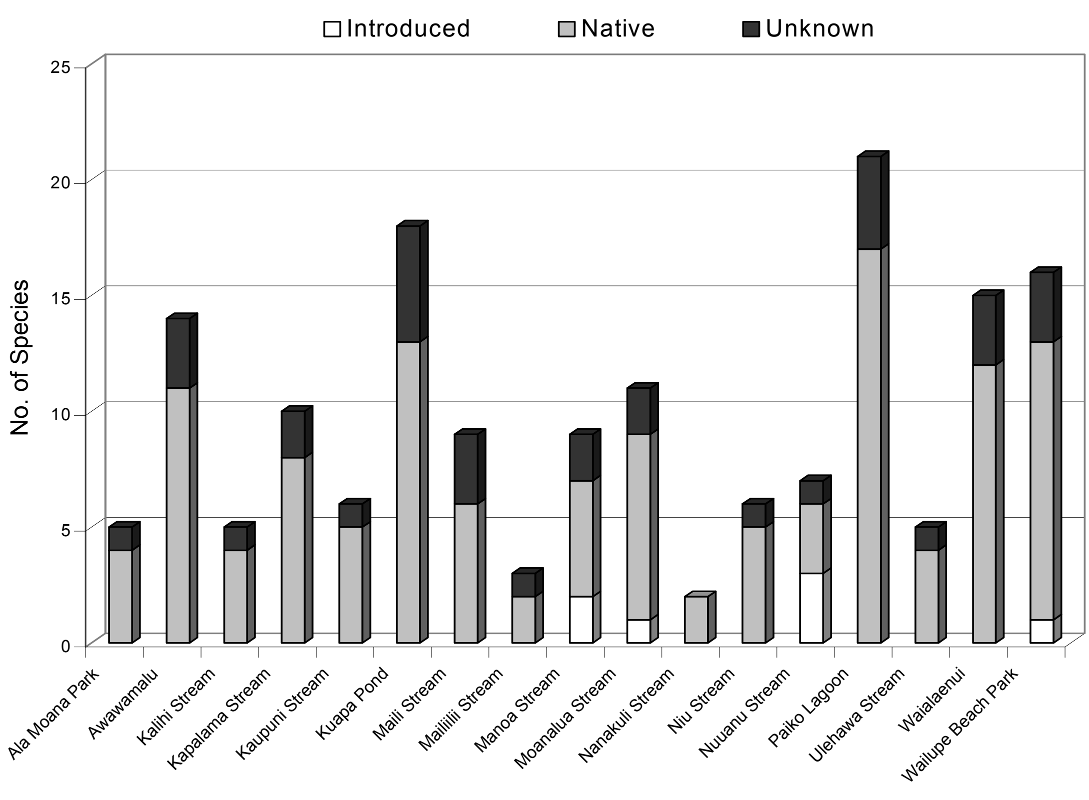

Figure 16. Number of crustacean species by stream and biogeographic status found in estuarine regions of south shore Oahu.

crustacean species and was found in a wide range of habitats. An introduced freshwater shrimp species previously reported as *Caridina weberi* by Devick (1991b) proved to be *Neocaridina* *denticulata sinensis*, a subspecies previously known only from the Chinese mainland and Taiwan (Englund and Cai 1999). During the present study this species was abundant in Nuuanu Stream from Nuuanu Reservoir (elevation ca. 240 m) downstream to the just above the estuary, and was also common in Manoa Stream. Although elevations above the study area were not in the scope of this study, the native freshwater atyid shrimp *Atyoida bisulcata* was not observed or collected in areas of upper Nuuanu Stream with high densities of *Neocaridina denticulata sinensis*.

A wide range of both marine and freshwater amphipod species were also collected during the present study with 11 amphipod species amounting to 20% of the total crustacean species diversity. The endemic freshwater amphipod *Hyalella azteca* was common in aquatic vegetation in strongly flowing freshwater areas such as Manoa and Moanalua Streams. This species is still widespread throughout Oahu. *Bemlos macromanus* and *Maera insignis* were two widespread marine amphipods found in this study and are likely native species, but could be considered cryptogenic as the origins of these species is not certain. Other amphipods found during this study were known or probable indigenous species inhabiting estuarine to marine environments. Anchialine shrimp species such as *Halocaridina rubra* found by Bailey-Brock et al. (1999) in the area of the Niu Stream mouth were not found during the present study. Bailey-Brock et al. (1999) found the anchialine shrimp species after periods of heavy rains and our sampling occurred during dry weather.

G. Mollusk Species Composition

The number of mollusk species found in each south and west shore Oahu lower stream and estuarine area was fairly uniform and ranged from a low of one species at Maili Stream to a high of six species at Awawamalu Stream estuary, in the area near the Hawaii Kai golf course (Figure 16). Introduced species predominated within streams containing permanent water flow such as Manoa, Nuuanu and Moanalua Streams, while the more marine Wailupe Stream (an intermittent stream) contained only native marine mollusk species (Figure 17). Mollusks were not found at all sampling stations, reflected by the few stations shown in Figure 17.

Of the 16 mollusk species collected during the present study, introduced species accounted for 31% (5 species) of the fauna, while 69% (11 species) were native species. A list of mollusks found is provided in Appendix A. Two endemic species and important sportfish species found in fresh to brackish water (*Neritina granosa* and *Neritina vespertina*), one endemic marine species (*Nerita picea*) and eight widespread indigenous mollusk species were found during the present study. *Nerita picea* is the dominant nerite snail found along Hawaiian shorelines (Kay 1979). The only other nerite found during this survey was *Neritina granosa*, with small (5-10 mm) recruiting settlement larvae collected in one small area of Nuuanu Stream, just above the upper limit of tidal influence in an area of concrete channelization (filled with small rocks) below the H-1 Highway bridge. *Neritina granosa* and *Neritina vespertina* were found attached to the loose rock substrate in this channelized area of Nuuanu Stream, and this was the only location during the present study where any *Neritina granosa* were collected. Attempts were made to collect *Neritina granosa* individuals above the H-1 Highway bridge and upstream to above the Waikahalulu Falls area,

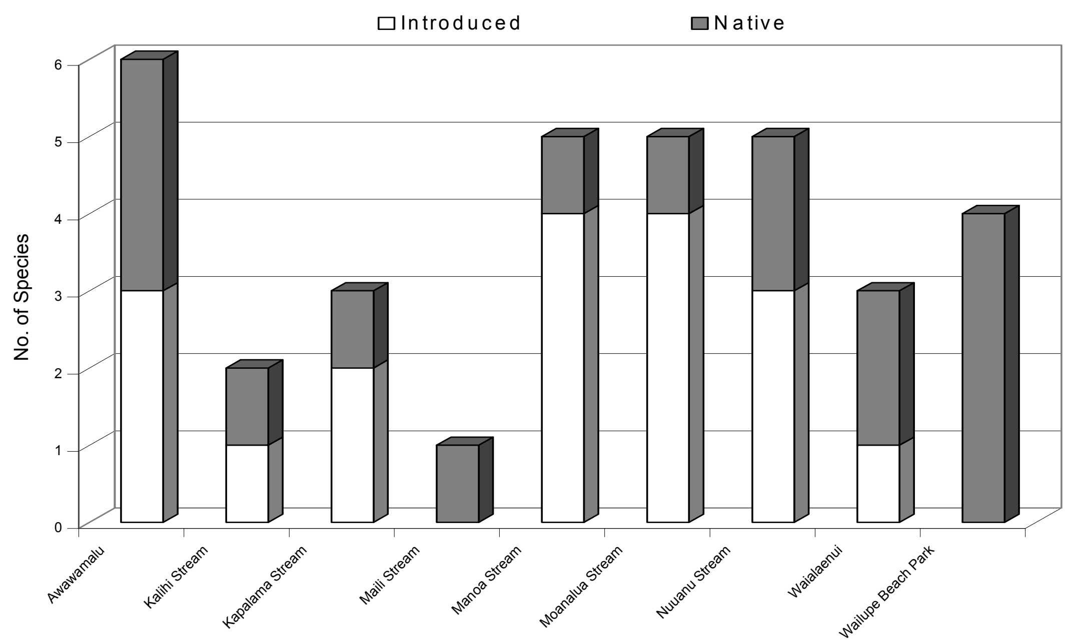

Figure 17. Number of species by stream and biogeographic status for mollusks found in lower stream and estuarine regions of south and west Oahu shores.

but no observable recruitment of this species was observed. *Neritina vespertina* appears to be more tolerant of disturbed conditions. Large numbers of egg cases, juveniles, and adults were collected in probably the most disturbed estuarine area of Hawaii, at the lower Manoa/Palolo stream junction by Kaimuki High School. Other areas where *Neritina vespertina* were common included estuarine areas of strongly flowing stream areas such as lower Kalihi and Moanalua Stream.

Four introduced species of freshwater to estuarine snails were also collected along the south and west shores of Oahu. The introduced snail species *Planorbella duryi* was restricted to freshwater (0 ppt saln), while *Melanoides tuberculata*, *Tarebia granifera*, and *Physa* sp. were found in waters of up to 31 ppt saln. The biogeographic status of many species of freshwater Hawaiian snails is unclear (Cowie 1997), especially those found in disturbed or lowland habitats. Introduced apple snails (*Pomacea canaliculata*) were not found in any south and west shore Oahu stream estuarine areas during the present study, although they were recently found in lower Pearl Harbor drainages

(Englund et al. 2000) and are abundant elsewhere, particularly on windward Oahu (Lach and Cowie 1999)

H. Miscellaneous Species Composition

Three classes of annelids, two species of cnidarian, five echinodermata species, one species of sipuncula, two species of platyhelminthes, and one nematode species were also collected in a wide variety of south shore Oahu estuarine habitats (Table 4). The vast majority of identifiable species were native, while only 7% of were introduced species. Because of the cosmopolitan nature of some of these sediment dwelling species, the biogeographic status of 29% of these species is uncertain.

However, the biogeographic status of the leeches (Annelida: Hirudinea) found during the present study was known. The indigenous leech *Glossiphonia weberi lata* was restricted to freshwater. Introduced fish parasites were commonly found in both native and introduced fish species in the

Table 4. Miscellaneous groups found in south and west shore Oahu lower stream and estuarine areas.

Phylum	Class	Introduced Species	Native Species	Undetermined Species
Annelida	Hirudinea	-	2 (100%)	-
	Oligochaeta	-	-	1 (100%)
	Polychaeta	-	8 (67%)	4 (33%)
Arthropoda	Pycnogonida	-	1 (100%)	-
Cnidaria	Anthozoa	-	1 (100%)	-
	Scyphozoa	1 (100%)	-	-
Echinodermata	Holothuroidea	-	2 (100%)	-
	Ophiuroidea	-	3 (100%)	-
Hemichordata	Enteropneusta	-	1 (100%)	-
Nematoda		-	-	1 (100%)
Platyhelminthes	Turbellaria	1 (50%)	-	1(50%)
Sipuncula		-	-	1 (100%)
Total		2 (7%)	18 (64%)	8 (29%)

estuarine areas of the south and west shore of Oahu. The indigenous leech *Aestabdella abditovesiculata* was commonly observed attached to fish immediately after capture and were also recovered in the bottom of the voucher sample jars after fish had been placed in ethanol for preservation. *Aestabdella abditovesiculata* exhibited a wide salinity tolerance, being found in 31 ppt in lower Kapalama Stream, and 2-24 ppt in Kalihi Stream. This species was also recovered in nets and seines after becoming dislodged from fish. *Glossiphonia weberi lata* was not found attached to fish, but rather was picked off rocks in fast flowing sections of lower Nuuanu and Kalihi Streams. *Glossiphonia weberi lata* species was found in sections of stream just above areas of tidal influence in waters of 0 ppt saln.

DISCUSSION

A. Influence of Nonindigenous Species on the South Shore Oahu Estuarine Sportfishery

For this report, sportfish are defined as marine or freshwater species regulated by the State of Hawaii in the *Hawaii Fishing Regulations* handbook published annually by the Department of Land and Natural Resources, Division of Aquatic Resources (Division of Aquatic Resources 1999). The Hawaii Division of Aquatic resources regulates a wide variety of native and nonindigenous marine and freshwater fish, crustaceans, and mollusks in their annual *Hawaii Fishing Regulations* handbook (Division of Aquatic Resources 1999). We define the recreational sport fishery as the non-commercial recreational pursuit of sportfish including fish, crustaceans, and mollusks in Hawaii for home consumption. The consumption or take of some species is not regulated in *Hawaii Fishing Regulations* but nevertheless represent culturally important foods for native Hawaiians. Thus species found in the present survey that were recorded by Titcomb et al. (1978) as eaten by native Hawaiians were included as sportfish in Table 5, and an example would include the common box crab or *pokipoki* (*Calappa hepatica*).

Some economically and culturally important sport fish found during this study were relatively common and include aholehole (*Kuhlia sandvicensis*), ‘o’opu akupa (*Eleotris sandwicensis*) striped mullet (*Mugil cephalus*), moi (*Polydactylus sexfilis*), papio (*Caranx ignobilis*), and Samoan crabs (*Scylla serrata*) (Table 5). Some common marine species such as *Abudefduf abdominalis* and *Scarus rubroviolaceus* were classified as rare in Table 5 because these species venture into estuarine areas only occasionally. Other species in Table 5 were common at the stations where they were collected, such as *Penaeus marginatus* or *Neomyxus leuciscus*, but were also considered uncommon during this study because these species are normally found in more marine habitats. Although not considered a prime sportfish by many (and not listed in the *Hawaii Fishing Regulations* handbook), tilapia (*Sarotherodon melanotheron*) was included in Table 5 as many people pursue this fish for food. For example, tilapia are currently the main species caught by anglers fishing in the Ala Wai Canal.

In general this study found lesser impacts of species introductions and habitat disturbance on native species as salinities increased. For example, at the sandy mouth of Niu Stream over 700 *K.*

sandvicensis were collected during a short 30 m long haul seine. Salinities at this Niu Stream sampling station were 34 ppt. Areas with the greatest number of introduced aquatic species included Nuuanu, Manoa/Palolo, Kalihi, and Moanalua Stream--all areas with large amounts of freshwater inflow.

The native goby species *Awaous guamensis* was uncommon, and only one small post-larval *Sicyopterus stimpsoni* was collected during this study in Nuuanu Stream. Adults of the native *S. stimpsoni* are abundant in the lowest reaches of nearly pristine streams such as Nualolo or Hanakapiai Streams, Kauai (Fitzsimons et al. 1993), or Wailau and Waikolu Stream, Molokai (Englund and Puleloa, pers. observ.). The near absence of this species, and *Lentipes concolor*, another native freshwater goby sensitive to disturbance in the lowest areas of south and west shore Oahu streams indicates these habitats have been heavily impacted by a combination of habitat alterations and introductions of nonindigenous species.

Blackchin tilapia (*Sarotherodon melanotheron*), first introduced in 1951 for aquatic weed control (and as a baitfish), are now perceived by U.S. Fish & Wildlife Service biologists to be one of the major causes for the decline of Hawaiian waterbirds (Mike Silbernagle, U.S. Fish & Wildlife Service, pers. comm.). Similar to carp (*Cyprinus carpio*), which have significant negative impacts on turbidity and algal production (King et al. 1997), blackchin tilapia consume virtually all available aquatic vegetation and invertebrate resources in wetland areas, leaving little invertebrate forage left for native species (A. Engilis, Ducks Unlimited, pers. comm.). Tilapia heavily impact sportfish in lower stream and estuary areas through predation and competition for resources. Randall (1987) mentioned that tilapia aggressively compete with *M. cephalus* for the same food source of soft algae and detritus. Other competitors with *M. cephalus* found during this study include *Moolgarda engeli*, now one of the most common inshore fish species in the Hawaiian Islands. Because of its small size this species is commercially worthless (Hoover 1996). *Moolgarda engeli* has proliferated in Hawaii and may be displacing the recreationally and culturally important food fish *Mugil cephalus* (Hoover 1996). During this study we found overlapping distributions of both *M. engeli* and *M. cephalus*, although the former species was sometimes found in waters having higher salinities and rarely ascended streams for any appreciable distance.

Other potential or known impacts of introduced species on native sportfish species in Oahu estuaries include a wide range of complex interactions between predation, disease, and competition for resources. Some examples are the introduced freshwater shrimp *Neocaridina denticulata sinensis* excluding the native *Atyoida bisulcata* as these species do not occur sympatrically (Englund and Cai 1999), the introduced loricariid catfish competing with the native *Sicyopterus stimpsoni* for food and space (Sabaj and Englund 1999), and the mosquitofish and introduced goby *Mugilogobius cavifrons* consuming native palaemonid shrimp and any other fish it

Table 5. Native and introduced sportfish species observed in 24 sampling stations along the south shore of Oahu during the present study. Titcomb et al. (1978) was used for marine invertebrates. See text for explanation of this table.

Sportfish Species	% Sampling Stations Collected	Status in South and West Shore Estuarine[1] Habitats	Biogeographic Status
Mollusks			
Nerita picea	8.3	Common	Endemic
Neritina granosa	4.2	Rare	Endemic
Neritina vespertina	16.7	Common	Indigenous
Crustaceans			
Atyoida bisulcata	0	Absent	Endemic
Calappa hepatica	12.5	Common	Indigenous
Macrobrachium grandimanus	21	Common	Endemic
Macrobrachium lar	8.3	Common	Introduced
Metopograpsus messor	25	Abundant	Indigenous
Ocypode ceratophthalama	4.2	Uncommon	Indigenous
Penaeus marginatus	4.2	Uncommon	Indigenous
Portunus sanguinolentus	12.5	Common	Indigenous
Procambarus clarkii	8.3	Common	Introduced
Scylla serrata	12.5	Common	Introduced
Fish			
Abudefduf abdominalis	4.2	Rare	Endemic
Awaous guamensis	12.5	Uncommon	Indigenous
Caranx ignobilis	4.2	Uncommon	Indigenous
Eleotris sandwicensis	30	Common	Endemic
Elops hawaiensis	4.2	Rare	Indigenous
Kuhlia sandvicensis	63	Abundant	Endemic
Mugil cephalus	54	Abundant	Indigenous
Neomyxus leuciscus	8.3	Uncommon	Indigenous
Polydactylus sexfilis	8.3	Uncommon	Indigenous
Sarotherodon melanotheron	83.3	Abundant	Introduced
Scarus rubroviolaceus	4.2	Rare	Indigenous
Sicyopterus stimpsoni	4.2	Rare	Endemic
Sphyraena barracuda	8.3	Common	Indigenous
Stenogobius hawaiiensis	21	Common	Endemic

[1]Includes lowest portions of surveyed south and west shore Oahu streams, wetlands, and estuaries

is able to swallow (Englund et al. 2000). Introduced poeciliids have been documented to transmit parasites to Hawaiian sport fish for which native fish have no evolutionary resistance (Font and Tate 1994). Randall (1987) aptly concluded that four of the seven planned introductions of marine fish into Hawaii have had harmful consequences and that "further introductions of fishes to the Hawaiian Islands should, in general, be discouraged".

B. Continuing Spread of Introduced Species in Lower South and West Shore Oahu Watersheds

In 1905, the Territory of Hawaii imported three species of fish for mosquito control. In the south shore of Oahu (excluding Pearl Harbor) these fishes were introduced in the general vicinity of Honolulu (Van Dine 1907). *Molliensia* [*Poecilia*] *latipinna*, *Fundulus grandis*, and *Gambusia affinis* were the first recorded purposeful governmental introductions of fish into Oahu waters, although other aquatic species introductions such as frogs and toads occurred earlier (Bryan 1932). The present study found that introduced species comprise the dominant portion of the biota in areas of freshwater. The lower portions of Oahu south and west shore streams and wetlands are now dominated by introduced species. Native species of fish, crustaceans, mollusks, and other invertebrates start to predominate as salinity increases and estuarine conditions become more marine in character.

Native species account for a variable percentage of the south and west shore Oahu estuarine aquatic fauna, ranging from a low of 25% for aquatic insects to a high of 72% for fish and 69% for mollusks (Table 6). Englund et al. (2000) found an identical level of 25% native aquatic insect species during a study of Pearl Harbor estuarine habitats conducted in the same time period as the present study. Overall, for species where biogeographic status could be determined, native species accounted for 52% of aquatic species in the lower reaches of Oahu south and west shore streams and wetlands.

Table 6. Summary of the biogeographic status and total number (percent) of aquatic species found in south shore Oahu estuarine habitats.

Biogeographic Status	All Aquatic[1] Species	Aquatic Insects	Fish	Crustaceans	Mollusks
Introduced	74 (31%)	45 (59%)	14 (28%)	5 (8%)	5 (31%)
Native	122 (52%)	19 (25%)	36 (72%)	39 (65%)	11 (69%)
Undetermined	36 (15%)	9 (12%)	0	16 (27%)	0
New	3 (1%)	3 (4%)	0	0	0
Total	235	76	50	60	16

[1]Miscellaneous species such as Annelida, Echinodermata, Nematoda, and Cnidaria are included in this total.

One of the major findings of both studies was a direct correlation of native species predominating as the environment becomes more marine in character. The present study also found that many native aquatic species have been displaced from the lower reaches of freshwater systems of the south shore of Oahu. The loss of a major group of native aquatic insects such as the *Megalagrion* damselflies (Liebherr and Polhemus 1997, Englund 1999a) and native aquatic saldids, the near lack of native freshwater mollusks, the scarcity of native fish such as *Awaous guamensis*, and the absence or near-absence of the fish *Lentipes concolor* and *Sicyopterus stimpsoni* in the lower stream reaches are evidence of this decline. With the exception of the present study and previous Bishop Museum studies in Pearl Harbor (Coles et al. 1997, 1999b; Englund et al. 2000), there are no comparable large-scale biodiversity studies of other large Hawaiian estuarine systems, such as Kaneohe Bay or the Waiakea estuary in Hilo Bay. Comparisons therefore cannot be made on the extent of biological degradation (as defined by the percentage of introduced species) and the loss of native biodiversity between Oahu's south and west shores and windward Oahu or other Hawaiian Islands. Until direct comparisons to other regions in Hawaii can be made, it will not be possible to ascertain whether this is a statewide trend, or a phenomenon restricted to Oahu. However, based upon the rate of introductions worldwide as discussed in the introduction, it is likely that all Hawaiian estuaries have experienced similar alterations in native flora and fauna.

At high elevation areas, some Oahu streams still contain significant reservoirs of native aquatic species, in contrast to the overall finding of 25% native aquatic insects at sea level areas during the present study of south and west shore Oahu (Figure 18). For example, an extensive study in Makaha Stream (Polhemus 1995a) found 80-89% native aquatic insects in the upper elevation areas (Figure 18). During the current study, we found that only 38% of the aquatic insects in the lowest reaches of Makaha Stream were native. Native aquatic insect species found at Makaha Stream and at other more marine sampling stations included mainly marine shore and beach flies and also native dragonflies such as *Pantala flavescens* and *Anax junius*. Lack of freshwater influence was the likely reason that the percentage of native species in the lowest reaches of Makaha Stream and wetland areas was higher than the average (25%) native species percentages found throughout the south shore Oahu. The difference in the abundance of native species of aquatic insects between lower Manoa (0% native) and Kalihi (10% native) and Makaha Stream (38%) appears to be because of differences in salinity and habitat diversity among the three sites. Both Manoa and Kalihi Streams released relatively large amounts of water into the south shore of Oahu, whereas the Makaha Stream estuary and wetlands were hypersaline (38-40 ppt saln) and were formed from salt water seepage.

During this study the biogeographic status of 12% of Hawaiian aquatic insects found in the disturbed lowland habitats of the south shore Oahu could not be determined. For example, 12 species of aquatic Diptera (flies) could not be identified to the species level, thus rendering determination of biogeographic status impossible. However, the majority of these and other undetermined aquatic insects are likely to be new introductions to the south shore of Oahu and the

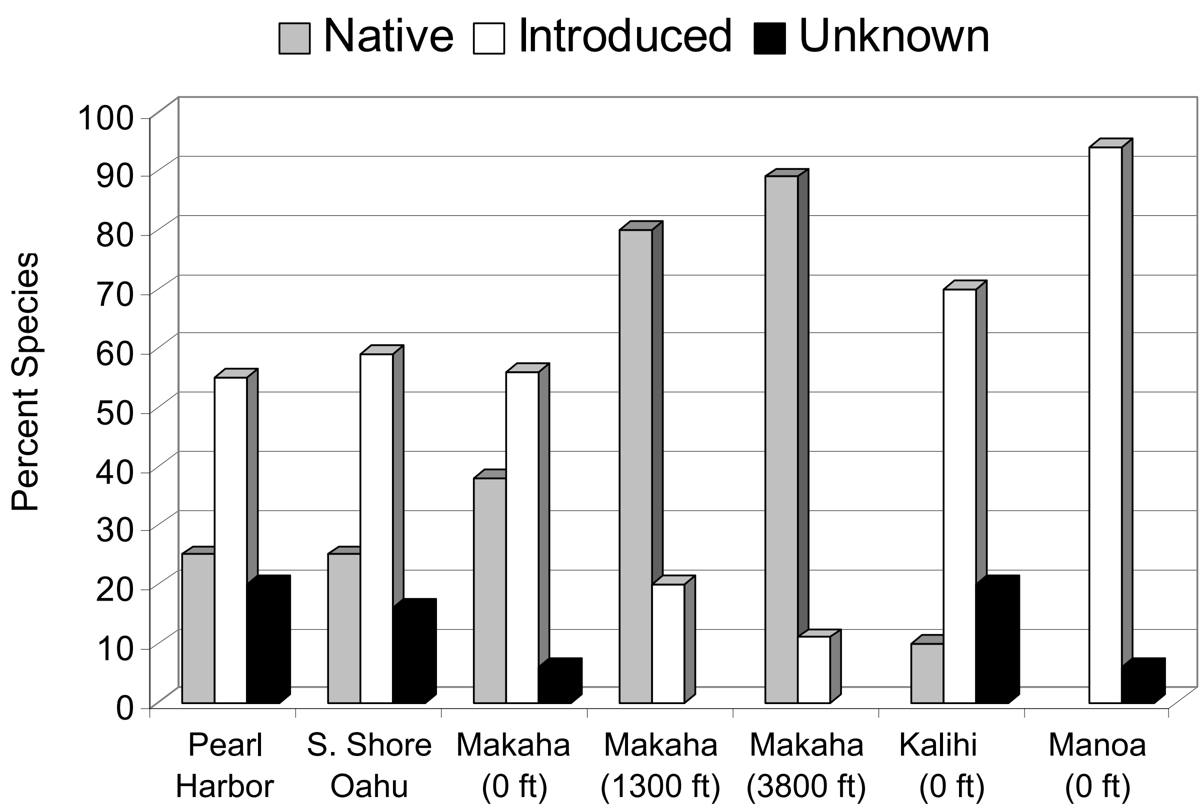

Figure 18. Biogeographic status of aquatic insects at varying elevations on Oahu; upper Makaha data from Polhemus (1995a), Pearl Harbor data from Englund et al. (2000).

State of Hawaii, since introduced insect species predominate in lowland stream and coastal marsh areas on Oahu (G. Nishida, Bishop Museum, pers. comm.). The native Hawaiian insect fauna in accessible lowland areas has been relatively well studied since the 1880s, starting with early collectors such as Blackburn and Perkins (Liebherr and Polhemus 1997). Thus it would seem reasonable to assume that most native aquatic insect species in the lower elevation areas of south Oahu have been described. This would provide further evidence that most of the undetermined aquatic insects found during the present study are probably introduced species. If it is assumed that aquatic insect species of unknown status found during the present study are new introductions, then 71% of the aquatic insects found in south shore Oahu estuarine regions would be introduced species.

Extensive surveys in upper elevation areas of the Hawaiian Islands in the 1990s have generally yielded either known native and introduced species, or undescribed native species of aquatic insects (Evenhuis and Polhemus 1994, Polhemus 1995a, Polhemus 1996, Evenhuis 1997, Englund et al. 1998, Englund and Preston 1999). For example, less than 5% of aquatic insects found in the upper 650-1800 ft elevations of Waipio River, Hawaii Island were of an unknown biogeographic status (Englund and Preston 1999). Only one aquatic insect of undetermined origin was found during extensive Bishop Museum surveys of the nearly pristine stream systems in the upper Alakai plateau on Kauai between 1997-1999 (Englund et al. 1998). A review of these surveys indicates far fewer undetermined aquatic insect species in upper elevation areas, compared to the 16% unknown status for the south shore of Oahu.

C. Origins and Modes of Introductions of Nonindigenous Species Found in South Shore Oahu Estuarine Regions

Cowie (1998) found an average of four species of terrestrial and aquatic snails became established per decade in Hawaii during the twentieth century. A review of Hawaiian freshwater introductions by Devick (1991a) found at least 58 species of aquatic organisms (excluding aquatic insects) to have been established in Hawaiian freshwaters from between 1900 to 1991, or an average of nearly 6.4 species per decade if these introductions started around 1900. Aquarium introductions appear to be the most important current mode of introduction in Oahu stream and estuarine habitats, although ballast water introductions are another problematic source (Englund et al. 2000).

The probable modes of introduction for nonindigenous aquatic insects in south and west shore Oahu habitats is shown in Figure 19. Aquatic plants were the most important known vector for aquatic insect introduction, while airplanes and shipping played important but lesser roles. Because of the uncertainty of many aquatic insect introductions into Hawaii, a large number of introductions were from unknown causes (Figure 19). However, it is likely that most aquatic insect introductions were through the transport of aquarium plants and aquatic plants sold at nurseries. Aquatic plants are an important vector for the introduction of other aquatic organisms as well. For example, the nonindigenous freshwater leech *Placobdelloides bdellae* was recently found in an aquatic plant container on Kauai (Englund 1999b).

The probable origins and mode of introductions of established introduced species of aquatic species (excluding aquatic insects) found in lower stream and wetland areas are shown in Table 7. Only organisms identified to the species level and having a definite or probable mode of introduction were included in this table. Aquatic insects were not included in this table because

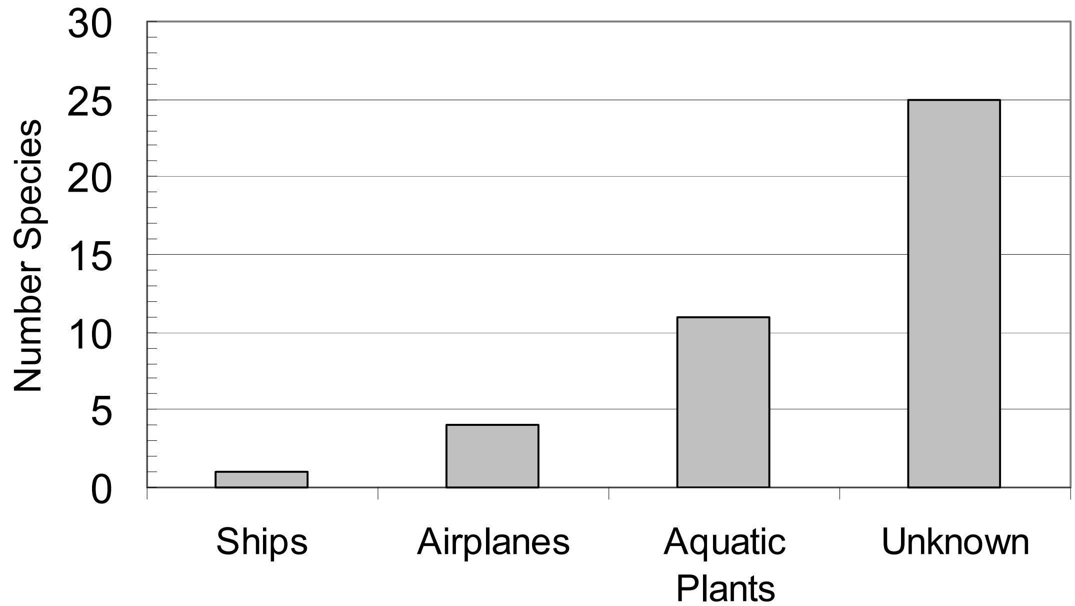

Figure 19. Vectors of introduced aquatic insects collected in south and west shore Oahu estuarine habitats during the present study.

many new introduced species could not yet be identified to the species level, and this precluded any attempt to determine region of origin. Also, determining the mode of aquatic insect transport into Hawaii is often highly speculative because of the inconspicuous nature of most insect introductions.

As is evident in Table 7, there is no one geographic region that is a predominant source of aquatic species introductions into the south and west shores of Oahu. Introductions appear to be somewhat evenly distributed between the western hemisphere, Asia, the western Pacific, with smaller numbers of species originating from Africa. This reflects the findings of Coles et al. (1997) of Hawaii as the “crossroads of the Pacific Ocean” for species introductions, and further illustrates how, with modern transportation nonindigenous organisms become established in vulnerable insular tropical island environments.

Resource management decisions involving intentional introductions, mainly conducted prior to Hawaii statehood in 1959, appear to have been ill advised. For example, Polhemus (1996), Liebherr and Polhemus (1997), and Englund (I999a) believed that poeciliid fish first introduced for mosquito control now appear to be the major cause of extinction of the endemic *Megalagrion* damselflies in low-elevation areas of Hawaiian streams and wetlands. Especially problematic are recent food introductions, such as the Asiatic clam (*Corbicula fluminea*) (Eldredge 1994) which were not sanctioned by governmental agencies. The Asiatic clam has caused enormous economic losses in the U.S. mainland similar to the zebra mussel infestation of the U.S. Great Lakes (U.S.

Table 7. Geographic source (year of introduction) and known (or probably known) mode of introduction of nonindigenous species of aquatic macrofauna found in South Oahu streams and estuaries, excluding Pearl Harbor (References: Van Dine 1907, Bryan 1932, Brock 1960, Edmondson 1962, Tinker 1965, Randall 1987, Devick 1991a, Cowie 1997, Fuller et al. 1999, M. Yamamoto, pers. comm.,).

Taxa	Geographic Region (Year first released/found)	Aquarium Release	Intentional Biocontrol	Probable Ballast Water	Probable Ship-Hull Fouling[1]	Intentional Food Introduction	Baitfish
Crustaceans							
Macrobrachium lar	Guam/Tahiti (1957)					X	
Neocaridina denticulata sinensis	China-Taiwan (1991)	X					
Panopeus pacificus	Philippines (1929)				X		
Procambarus clarkii	North America (1923)					X	
Scylla serrata	Samoa (1920s)					X	
Mollusks							
Corbicula fluminea	Asia (1981)					X	
Planorbella duryi	North America (1994)	X					
Fish							
Ancistrus cf. *temminckii*	South America (1985)	X					
Cichlasoma managuense	South America (1992)	X					
Cichlasoma nigrofasciatum	South America (1983)	X					
Gambusia affinis	Texas (1905)		X				
Hemichromis elongatus	Africa (1991)	X					
Hypostomus cf. *watwata*	South America (1984)	X					
Limia vittata	Cuba (1950)	X					
Misgurnus anguillicaudatus	Eastern Asia (< 1900)						X
Moolgarda engeli	Marquesas (1955)						X
Mugilogobius cavifrons	Western Pacific (Japan to Indonesia) (1987)			X			

[1]Or possible seachest fouling

Table 7 (Continued)

Taxa	Geographic Region	Aquarium Release	Intentional Biocontrol	Probable Ballast Water	Probable Ship-Hull Fouling[1]	Intentional Food Introduction	Baitfish
Poecilia latipinna	Texas (1905)		X				
Poecilia mexicana[2]	North America (1940-1950)	X					
Poecilia reticulata	South America (1922)		X				
Tilapia (*Sarotherodon*) *melanotheron*	Africa (1951)		X				
<u>Amphibians</u>							
Bufo marinus	South America (1932)		X				
Rana catesbeiana	North America (1902)		X				
	Percent (number)	39% (9)	26% (6)	4.3% (1)	4.3% (1)	17.4% (4)	9% (2)

[1]Or possible seachest fouling
[2]*P. mexicana* possibly hybridized before introduced to Hawaii, however, the source of these fish is thought to be from Mexico or the southern U.S. Randall (1987) believed they were released before 1950 with releases likely occurred after 1930's surveys conducted by G.B. Mainland (1939).

Congress 1993). In Hawaii, Asiatic clams have clogged irrigation pipes resulting in economic damage in Maui and elsewhere (Devick 1991a).

Introduction of aquatic organisms through the aquarium trade and from subsistence food introductions are the major new threats currently facing native aquatic species in Hawaii. Introductions via ballast water and ship hull fouling are other major vectors for introduced species as 2 of the 23 (9%) species listed in Table 7 are considered likely to have come from ballast water and hull fouling.

Based on what has occurred on Oahu, it is highly likely that once an organism is introduced into a stream or adjacent wetland it will spread to other aquatic habitats throughout Oahu, and potentially to the other Hawaiian Islands. For example, the introduced dragonfly *Crocothemis servilia* was first observed in the Hawaiian Islands on Oahu in 1994 (Polhemus 1995b) and has now recently spread to the island of Kauai. The introduced goby *Mugilogobius cavifrons* was first observed in 1987 in Waimalu Stream at Blaisdell Park in Pearl Harbor (Randall et al. 1993) and is now common in estuarine areas throughout windward and leeward Oahu. This small (< 50 mm (2 in)) estuarine goby species is crypticallly colored and is not used in the aquarium trade or as a potential food source. Although further diet studies for this species are needed, an examination of the stomach contents of two *Mugilogobius cavifrons* from Pearl Harbor (Englund et al. 2000) found native crustaceans (*Periclimenes*) and native aquatic flies (*Forcipomyia*). Aquarium observations of *Mugilogobius cavifrons* also indicate this species is highly carnivorous and will consume virtually any prey item smaller than itself. The impacts of predation by *Mugilogobius cavifrons* on native biota are unknown, but the fact that it was documented to prey on native species in this study should be cause for concern, especially as this species was much more abundant than any native stream goby in the lower reaches of Pearl Harbor streams and wetlands (Englund et al. 2000).

D. Summary of Important Findings

The first comprehensive biological surveys of south and west shore Oahu coastal wetlands, lower stream reaches, and estuarine areas have revealed an ecologically degraded fauna dominated by introduced species in freshwater, but ecosystems that are more intact as waters becomes more marine. During this study the first collection of the introduced jaguar cichlid (*Cichlasoma managuense*) from an Oahu stream (Manoa/Palolo) was made, and this species appears to have spread from the nearby quarry pond at the University of Hawaii. In strictly freshwater areas of the south and west shore of Oahu most taxa identifiable to the species level were introductions. The majority of introduced species appear to be the primarily the result of aquarium releases, intentional biocontrol releases, and intentional food source releases. Although some introduced species may have originated from marine water releases or hull fouling organisms these points of origin probably contributed only a small fraction of overall nonindigenous species introductions in south and west shore Oahu streams, wetlands, and estuaries.

REFERENCES

Arthington, A.H. and L.N. Lloyd. 1989. Introduced poeciliids in Australia and New Zealand. In *Ecology and evolution of livebearing fishes (Poeciliidae)*, (G.K. Meffe and F.F. Snelson, Jr., eds), pp. 333-348. Prentice Hall, Englewood Cliffs.

American Fisheries Society. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. American Fisheries Society Special Publication 17. Bethesda. 77 pp.

American Fisheries Society. 1991. Common and scientific names of fishes from the United States and Canada, Fifth Edition. American Fisheries Society Special Publication 20. Bethesda. 183 pp.

Bailey-Brock, J.H., V.R. Brock and R.E. Brock. 1999. Intrusion of anchialine species in the marine environment: the appearance of an endemic Hawaiian shrimp, Halocaridina rubra, on the south shore of Oahu (Hawaiian Islands). *Pac. Sci.* 53: 367-369.

Beach, K.S. R. Harris, M. Holsomback, M. Rabago and C.M. Smith. 1995. Net phytoplankton of the Ala Wai Canal, Oahu, Hawaii. *Pac. Sci.* 49: 332-340.

Blaber, S.J.M. 1987. Factors affecting recruitment and survival of mugilids in estuaries and coastal waters of southeastern Africa. *American Fisheries Society Symposium* 1: 507-518, 1987.

Bryan, E.H. 1932. Frogs in Hawaii. *The Mid-Pacific Magazine* 43: 1: 61-64.

Brock, V.E. 1960. The introduction of aquatic animals into Hawaiian waters. *Internat. Rev. Ges. Hydrobiol.* 45: 463-480.

Brown, L.R., A.M. Brasher, B.C. Harvey and M. Matthews. 1999. Success and failure of nonindigenous aquatic species in stream systems: case studies from California and Hawaii. R. Claudi and J.H. Leach (eds.) *In*: Nonindigenous freshwater organisms: vectors, biology, and impacts, pp. 415-430. CRC Press.

Carlton, J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanogr. Mar. Biol. Annu. Rev.* 23: 313-371.

Carlton, J.T. 1996. Biological invasions and cryptogenic species. *Ecology* 77: 1653-1655.

Carlton, J.T. and J.B. Geller. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. *Science* 261: 78-82.

Charlebois, P.M., J.E. Marsden, R.G. Goettel, R.K. Wolfe, D.J. Jude and S. Rudnika. 1997. The round goby, *Neogobius melanostomus* (Pallas), a review of European and North American literature. Illinois-Indiana Sea Grant Program and Illinois Natural History Survey. INHS Special Publication No. 20. 76 pp.

Coles S.L., R.C. DeFelice, L.G. Eldredge and J.T. Carlton 1997. Biodiversity of marine communities in Pearl Harbor, Oahu, Hawaii with observations on introduced exotic species. *Bishop Mus. Tech. Rep.* 10.

Coles, S.L., R.C. DeFelice, L.G. Eldredge and J.T. Carlton. 1999a. Nonindigenous marine species introductions in the harbors of the south and west shores of Oahu, Hawaii. *Bishop Mus. Tech. Rep.* 15.

Coles, S.L., R.C. DeFelice, L.G. Eldredge and J.T. Carlton. 1999b. Historical and recent introduction of nonindigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands. *Mar. Biol.* 135:147-158.

Courtenay, W.R., and G.K. Meffe. 1989. Small fishes in strange places: a review of introduced poeciliids. *In* G.K. Meffe and F.F. Snelson, Jr. (eds.), Ecology and evolution of livebearing fishes (Poeciliidae), pp. 319-331. Prentice Hall, Englewood Cliffs.

Cowie, R.H. 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. *Bishop Mus. Occas. Pap.* 50: 66 pp.

Cowie, R.H. 1998. Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. *Biodiv. Conserv.* 7: 349-368.

Cowie, R.H. In Press. Apple snails as agricultural pests: their biology, impacts and management. In: Molluscs as Crop Pests (ed. G.M. Barker). CABI, London.

Crowl, T.A., A.R. Townsend and A.R. McIntosh. 1992. The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Rev. Fish Biol. and Fish.*. 2: 217-241.

Division of Aquatic Resources. 1999. Hawaii fishing regulations. Department of Land and Natural Resources, 1151 Punchbowl Street, Room 330, Honolulu, Hawaii 96813.

Devaney, D.M., M. Kelly, P.J. Lee, L.S. Motteler. 1982. Kaneohe a history of change. Bess Press, Honolulu, Hawaii. 271 pp.

Devick, W.S. 1991a. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. In: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems, Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii*, pp. 189-213. Hawaii Division of Aquatic Resources, Honolulu.

Devick, W.S. 1991b. Job progress report F-14-R-15 [Fresh water fisheries and surveys]. Disturbances and fluctuations in the Wahiawa Reservoir Ecosystem. Hawaii Division of Aquatic Resources, Honolulu.

Dove, A.D.M. 1998. A silent tragedy: parasites and the exotic fishes of Australia. *Proc. Roy. Soc. Queens.* 107: 109-113.

Edmondson, C.H. 1962. Xanthidae of Hawaii. *Bishop Mus. Occas. Pap.* 22: 215-309.

Eldredge, L.G. 1994. Perspectives in aquatic exotic species management in the Pacific Islands: Volume I, Introductions of commercially significant aquatic organisms to the Pacific Islands. South Pacific Commission, Noumea, New Caledonia. 127 pp.

Eldredge, L.G. 1999. Nonindigenous freshwater fishes, amphibians, and crustaceans of the Pacific and Hawaiian Islands. South Pacific Regional Environmental Programme (SPREP), Apia, Samoa. 28 pp.

Englund, R.A. 1999a. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on Oahu Island, Hawaii. *J. Insect Conserv.* 3: 225-243.

Englund, R.A. 1999b. New records and range extensions of native Odonata (Coenagrionidae) and introduced aquatic species in the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 59: 15-19.

Englund, R.A and Y. Cai. 1999. The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 58: 58-65.

Englund, R.A. and R.B. Filbert. 1999. Flow restoration and persistence of introduced species in Waikele Stream, Oahu. *Micronesica* 31(2): 143-154.

Englund, R.A., D.A. Polhemus and D.J. Preston. 1998. Assessment of the suitability of Kokee State Park streams as habitat for year-round catch and release fishing for rainbow trout without annual stocking. Contribution No. 1998-001 to the Hawaii Biological Survey, Bishop Museum. 37 pp.

Englund, R.A. and D.J. Preston. 1999. Biological Assessment of the Lower Hamakua Ditch on the Hawaiian Stream Fly (*Sigmatineurum meaohi*) and other aquatic insects. Contribution No. 1999-003 to the Hawaii Biological Survey, Bishop Museum. 31 pp.

Englund, R.A., D.J. Preston, R. Wolff, S.L. Coles, L..G. Eldredge and K. Arakaki. 2000. Biodiversity of freshwater and estuarine communities in lower Pearl Harbor, Oahu, with observations on introduced species. *Bishop Mus. Tech. Rep. in prep.*

Evenhuis, N.L. and D.A. Polhemus. 1994. Review of the endemic Hawaiian genus *Sigmatineurum* Parent (Diptera: Dolichopodidae). *Bishop Mus. Occas. Pap.* 37: 1-19.

Evenhuis, N.L. 1997. The genus *Sigmatineurum* Parent in Hawaii (Diptera: Dolichopodidae), with a revised key to species. *Bishop Mus. Occas. Pap.* 47: 66-73.

Everard, C.O.R., D.G. Carrington, H. Korver, R.Burke, J.D. Everard and C. Gravekamp. 1990. Leptospires in the whistling frog (*Eleutherodactylus johnstonei*) on Barbados. *J. Trop. Med. Hygiene* 93:140-145.

Filbert, R.B., and R.A. Englund. 1995. Waiahole Ditch Water Contested Case: Biological Assessments of Windward and Leeward Oahu Streams (including Appendix 1). Report for The Kamehameha Schools/Bishop Estate. Pacific Aquatic Environmental, Honolulu, Hawaii. 156 pp.

Fitzsimons, J.M., R.T. Nishimoto and D.A. Polhemus. 1993. Assessments of the impact of Hurricane Iniki on stream biota and ecosystems on Kauai. Hawaii Division of Aquatic Resources, Honolulu. 88 pp.

Font, W.F. and D.C. Tate. 1994. Helminth parasites of native Hawaiian freshwater fishes: an example of extreme ecological isolation. *J. Parasit.* 80: 682-688.

Fuller, P.L., L.G. Nico and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, Maryland. 613 pp.

Funasaki, G.Y., P.Y. Lai, L.M. Nakahara, J.W. Beardsley and A.K. Ota. 1988. A review of biological control introductions in Hawaii: 1890 to 1985. *Proc. Hawaii. Entomol. Soc.* 28: 105-160.

Glenn, C.R. and G.M. McMurtry. 1995. Scientific studies and history of the Ala Wai Canal, an artificial tropical estuary in Honolulu. *Pac. Sci.* 49: 307-318.

Glenn, C.R., S. Rajan, G.M. McMurtry and J. Benaman. 1995. Geochemistry, mineralogy, and stable isotopic results from Ala Wai estuarine sediments: records of hypereutrophication and abiotic whitings. *Pac. Sci.* 49: 367-399.

Goodsell, J.A. and L.B. Katz. 1999. Effect of introduced mosquitofish on Pacific treefrogs and the role of alternative prey. *Conserv. Biol.* 13: 921-924.

Hardy, D.E. 1960. Insects of Hawaii, Volume 10, Diptera:Nematocera-Brachycera. University of Hawaii Press. 368 pp.

Hoover, J.P. 1996. Hawaii's Fishes: a guide for snorkelers divers and aquarists. Mutual Publishing, Honolulu, Hawaii. 183 pp.

Howarth, F.G. 1985. Impacts of alien land arthropods and mollusks on native plants and animals in Hawaii. In: *Hawaii's terrestrial ecosystems: preservation and management*. (C.P. Stone and J.M. Scott, eds), pp. 149-179. Cooperative National Park Resources Studies Unit, University of Hawaii, Honolulu.

Howarth, F.G., R.H. Cowie, D.J. Preston, R.A. Englund, R.J. Rundell, F.D. Stone and S.L. Montgomery. 1999. Proposed new Hawaii Island correctional facility, Waiakea, South

Hilo, Island of Hawaii: Assessment of potential impacts on invertebrates (snails, insects, and other arthropods) of proposed improvements to Stainback Highway. Hawaii Biological Survey, Bishop Museum, Honolulu. 90 pp.

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

Howe, E., C. Howe, R. Lim and M. Burchett. 1997. Impact of the introduced poeciliid *Gambusia holbrooki* (Girard, 1859) on the growth and reproduction of *Pseudomugil signifer* (Kner, 1865) in Australia. *Mar. Freshwater Res.* 48: 425-434.

Hurlbert, S.H., J. Zedler and D. Fairbanks. 1972. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. *Science* 175: 639-41.

Kay, E.A. 1979. Hawaiian marine shells. Reef and Shore Fauna of Hawaii, Section 4. Bishop Museum Special Publication 64(4). Bishop Museum Press, Honolulu, Hawaii. 653 pp.

King, A.J., A.I. Robertson and M.R. Healey. 1997. Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. *Mar. Freshwater Res.* 48: 435-443.

Kinzie, R.A. 1991. Hawaiian freshwater ichthyofauna. In: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems, Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii*, pp. 18-39. Hawaii Division of Aquatic Resources, Honolulu.

Kinzie, R.A. 1997. Evolution and life history patterns in freshwater gobies. *Micronesica* 30: 27-40.

Kondratieff, B.C., R.J. Bishop and A.M. Brasher. 1997. The life cycle of an introduced caddisfly, *Cheumatopsyche pettiti* (Banks) (Trichoptera: Hydropsychidae) in Waikolu Stream, Molokai, Hawaii. *Hydrobiologia* 350: 81-85.

Lach, L. and R.H. Cowie. 1999. The spread of *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae), an introduced freshwater apple snail, on Oahu, Hawaii. *Bishop Mus. Occas. Pap.* 58: 66-72.

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

Maciolek, J.A. 1982. Lakes and lake-like waters of the Hawaiian archipelago. *Bishop Mus. Occas. Pap.* 25: 1-14.

Maciolek, J.A. 1984. Exotic fishes in Hawaii and other islands of Oceania. *In*: Distribution, Biology, and Management of Exotic Fishes, Ed. By W.R. Courtenay, Jr. and J.R. Stauffer, Jr., John Hopkins University Press, Baltimore and London, pp. 131-161.

Meffe, G.K. and F.F. Snelson. 1989. An ecological overview of poeciliid fishes. *In* G.K. Meffe and F.F. Snelson, Jr. (eds.), Ecology and evolution of livebearing fishes (Poeciliidae), pp. 13-31. Prentice Hall, Englewood Cliffs.

Miura, T., R.M. Takahashi and R.J. Stewart. 1979. Habitat and food selection by the mosquitofish, Gambusia affinis. *Proc. Calif. Mosq. Vect. Contr. Assoc.* 47: 46-50.

Morgan, D.L., H.S. Gill and I.C. Potter. 1998. Distribution, identification and biology of freshwater fishes in south-western Australia. *Records of the Western Australian Museum*, supplement 56, 97 pp.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley.

Nalepa, T.F. and D.W. Schloesser, (eds.). 1992. Zebra Mussels: Biology, Impacts, and Controls. Lewis Publishers, Ann Arbor. 810 pp.

Nelson, J.S. 1994. Fishes of the world, third edition. John Wiley and Sons, New York. 600 pp.

Nichols, W.D., P.J. Shade and C.D. Hunt. 1997. Summary of the Oahu, Hawaii, regional aquifer-system analysis. *U.S. Geological Survey Professional Paper* 1412-A. 61 pp.

Nishida, G.M. 1997. Hawaiian terrestrial arthropod checklist, 3rd Edition. Hawaii Biological Survey. *Bishop Mus. Tech. Rep.* 12. 263 pp.

Nishida, G.M. and C.T. Imada. 1997. A reconnaissance survey of the plants and animals of Pouhala Marsh, Pearl Harbor, Oahu. Report to Ducks Unlimited, Inc. Bishop Museum, Hawaii Biological Survey. 15 pp.

Pooley, S.G. 1998. Fisheries. *In* S.P. Juvik and J.O. Juvik (eds.), *Atlas of Hawaii* pp. 252-254. University of Hawaii Press, Honolulu, Hawaii.

Polhemus, D.A. 1995a. A survey of the aquatic insect faunas of selected Hawaiian streams. Report for the Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawaii. Department of Natural Sciences, Bishop Museum. Hawaii Biological Survey No. 1995-008. 128 pp.

Polhemus, D.A. 1995b. New Heteroptera and Odonata (Insecta) records and range extensions in the Hawaiian Islands. *Bish. Mus. Occ. Pap.* 42: 42-43.

Polhemus, D.A. 1996. The orangeblack Hawaiian damselfly *Megalagrion xanthomelas* (Odonata: Coenagrionidae): clarifying the current range of a threatened species. *Bish. Mus. Occ. Pap.* 45: 30-53.

Polhemus, D.A. 1999. A new species of riparian Nabidae (Heteroptera) from the Hawaiian Islands. *Proc. Entomol. Soc. Wash.* 101:868-874.

Polhemus, D.A. and A. Asquith. 1996. Hawaiian damselflies: a field identification guide. Bishop Museum Press, Honolulu. 122 pp.

Radtke, R.L., R.A. Kinzie and S. D. Folsom. 1988. Age at recruitment of Hawaiian freshwater gobies. *Env. Biol. Fish.* 23: 205-213.

Randall, J.E. 1987. Introduction of marine fishes to the Hawaiian Islands. *Bull. Mar. Sci.* 41: 490-502.

Randall, J.E., J.L. Earle, T. Hayes, C. Pittman, M. Severns, and R.J.F. Smith. 1993. Eleven new records and validations of shore fishes from the Hawaiian Islands. *Pac. Sci.* 47: 222-239.

Ruiz, G.M, J.T. Carlton, E.D. Grosholz and A.H. Hines. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent and consequences. *Am. Zool.* 37: 621-632.

Ruiz, G.M., A.H. Hines, L.D. Smith, and J.T. Carlton. 1995. An historical perspective on invasions of North American waters by nonindigenous species. *Aquatic Nuisance Digest* 1: 11.

Sabaj, M.H. and R.A. Englund. 1999. Preliminary identification and current distribution of two suckermouth catfishes (Loricariidae) introduced to O'ahu streams. *Bishop. Mus. Occas. Pap*. 59: 50-55.

Schneider, D.W., C.D. Ellis and K.S. Cummings. 1998. A transportation model assessment of the risk to native mussel communities from zebra mussel spread. *Conserv. Biol.* 12: 788-800.

Stone, C.P. and L.W. Pratt. 1994. Hawaii's plants and animals. Hawaii Natural History Association, Distributed by University of Hawaii Press, Honolulu, Hawaii. 399 pp.

Tate, D.C. 1997. The role of behavioral interactions of immature Hawaiian stream fishes (Pisces: Gobiodei) in population dispersal and distribution. *Micronesica* 30: 51-70.

Tinker, S.W. 1965. Pacific crustacea. Charles E. Tuttle Company, Rutland, Vermont. 134 pp.

Titcomb, M. 1972. Native use of fish in Hawaii. Second Edition. University of Hawaii Press, Honolulu, Hawaii. 175 pp.

Titcomb, M., D.B. Fellows, M.K. Pukui and D.M. Devaney. 1978. Native use of marine invertebrates in old Hawaii. *Pac. Sci.* 32: 325-385.

Tyler, M.J. 1994. Australian frogs. Second Edition. Reed Books, Chatswood, New South Wales. 192 pp.

U.S. Congress, Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. OTA-F-565. Washington, DC: U.S. Government Printing Office, September 1993.

Van Dine, D.L. 1907. The introduction of top-minnows (natural enemies of mosquitoes) into the Hawaiian Islands. *Hawaiian Agricultural Experiment Station Press Bulletin* 20: 1-10.

Van Dine, D.L. 1908. Mosquitoes. Annual Report of the Hawaii Agricultural Experiment Station for 1907, pp. 38-39.

Wirth, W. W. 1947. *Ephydra gracilis* Packard, a recent immigrant fly in Hawaii (Diptera: Ephydridae). *Proc. Hawaii. Ent. Soc*. 13: 141-142.

Zug, G.R.E., E. Lingren and J.R. Pipet. 1975. The distribution and ecology of the marine toad, *Bufo marinus*, in Papua New Guinea. *Pac. Sci.* 29(1): 31-50.

APPENDIX A

Stream and Wetland Records for Invertebrates and Fishes Collected or Observed in the South and West Shore Oahu Dingell-Johnson Project Surveys

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiili Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Sipuncula																										
Undetermined Sipunculid?	E,M	?			X																					
Cnidaria																										
Anthozoa																										
Undetermined Zooantharia	E,M	Ind?																								X
Scyphozoa																										
Rhizostomae																										
Cassiopeidae																										
Cassiopea medusa Light, 1914	E,M	Intro																						X		
Platyhelminthes																										
Undetermined Platyhelminthes	E,M	?								X																
Turbellaria																										
Tricladida																										
Planariidae																										
Dugesia cf. *tigrina* (Girard)	F,E	Intro																X			X					
Nematoda																										
Undetermined Nematoda	E,M	?						X																		
Echinodermata																										
Holothuroidea																										
Actinopoda																										
Holothuridae																										
Holothuria sp.	E,M	Ind																								X
Paractinopoda																										
Synaptidae																										
Chiridota rigida (Semper, 1868)	E,M	Ind			X																					X
Ophiuroidea																										
Gnathophiurida																										
Amphiuridae																										
Amphipholis squamata (Delle Chiaje, 1828)	E,M	Ind			X					X																X
Ophiactis modesta? Brock, 1888	E,M	Ind			X					X																
Ophiactis savignyi (Müller & Troschel, 1842)	E,M	Ind			X																					
Annelida																										
Undetermined Annelida	E,M	?			X					X												X				
Hirudinea																										
Rhynchobdellida																										
Glossiphoniidae																										
Glossiphonia weberi lata Oka, 1910	F	Ind					X														X					
Piscicolidae																										
Aestabdella abditovesiculata (Moore, 1952)	F,E,M	Ind						X									X	X								X
Oligochaeta																										
Oligochaeta																										
Undetermined Oligochaeta	F,E,M	?															X	X				X				
Eunicidae																										
Marphysa cf. *sanguinea* Montagu, 1815	E,M	?																				X			X	
Polychaeta																										
Undetermined Polychaeta	E,M	?						X		X																
Nereididae																										
Namalycastis abiuma (Müller, in Grube, 1872)	E	?															X									
Undetermined Nereididae	E,M	?																							X	
Polynoidae																										
Paralepidonotus ampulliferus (Grube, 1878)	E,M	Ind								X																
Syllidae																										

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Typosyllis variegata? (Grube, 1860)	E,M	Ind								X																
Phyllodocida																										
Amphinomidae																										
Eurythoe complanata (Pallas, 1766)	E,M	Ind								X																X
Cirratulidae																										
Cirratulidae?	E,M	?																				X				
Capitellida																										
Capitellidae																										
Capitella capitata (Fabricius, 1780)	E,M	Ind								X																
Undetermined Capitellidae	E,M	?						X		X																
Spionida																										
Spionidae																										
Malacoceros sp?	E,M	Ind																				X			X	
Streblospio benedicti Webster, 1879	E,M	Ind						X																	X	
Mollusca																										
Gastropoda																										
Archaeogastropoda																										
Neritidae																										
Nerita picea (Récluz, 1841)	E,M	End			X																					X
Neritina granosa Sowerby, 1825	F	End																			X					
Neritina vespertina Sowerby, 1825	F,E	End					X										X	X			X					
Basommatophora																										
Physidae																										
Physa sp.	F	Intro			X			X										X			X					
Planorbidae																										
Planorbella duryi (Wetherby, 1879)	F	Intro			X												X	X								
Siphonariidae																										
Siphonaria normalis Gould, 1846	E,M	Ind			X																				X	
Thiaridae																										
Melanoides tuberculata (Müller, 1774)	F,E,M	Intro			X		X	X									X	X			X					
Tarebia granifera (Lamarck, 1816)	F,E,M	Intro															X	X							X	
Mesogastropoda																										
Cerithiidae																										
Cerithium sp. cf. *zebrum* Kiener, 1841	E,M	Ind																							X	
Mesogastropoda																										
Littorinidae																										
Littorina pintado (Wood, 1828)	E,M	Ind			X																					
Neogastropoda																										
Columbellidae																										
Anachis sp. cf. *miser* (Sowerby, 1844)	E,M	Ind										X														
Muricidae																										
Muricodrupa funiculus (Wood, 1828)	E,M	Ind																								X
Sacoglossa																										
Elysia sp?	E,M	Ind																								X
Pelecypoda																										
Heterodonta																										
Corbiculidae																										
Corbicula fluminea Müller, 1774	F	Intro															X				X					
Taxodonta																										
Isognomonidae																										
Isognomon cf. *incisum* (Conrad, 1837)	E,M	Ind						X																		
Isognomon perna (Linnaeus, 1767)	E,M	Ind																								X

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Arthropoda																										
Insecta																										
Coleoptera																										
Hydrophilidae																										
Tropisternus salsamentus Fall, 1901	E	Intro				X																				
Limnichidae																										
Parathroscinus cf. *murphyi*	F,E,M	Intro		X			X	X	X	X	X				X		X	X			X	X			X	X
Diptera																										
Asteiidae																										
Sigaloessa sp.	F,E	Intro					X														X					
Canacidae																										
Canaceoides angulatus Wirth, 1969	F,E,M	Intro		X				X	X	X		X	X					X		X					X	X
Canaceoides hawaiiensis Wirth, 1969	E,M	End										X	X											X		
Procanace williamsi Wirth, 1951	F,E,M	Intro		X			X	X		X	X				X		X	X		X		X				X
Ceratopogonidae																										
Atrichopogon sp. not *jacobsoni*	F,E,M	Intro					X										X			X	X					X
Dasyhelea calvescens Macfie, 1938	F,E,M	Ind?		X				X	X	X			X		X			X		X					X	X
Dasyhelea digna Borkent, 1996	F,E,M	End																X			X					
Forcipomyia sp.	F,E	?																			X					
Undetermined Ceratopogonidae	F,E	?																								X
Chironomidae																										
Cricotopus bicinctus (Meigen, 1818)	F,E,M	Intro						X									X				X					X
Orthocladius oahuensis/wirthi?	E,M	End				X														X					X	
Orthocladius sp.	F,E,M	?					X	X							X		X				X					X
Orthocladius williamsi (Hardy, 1960)	F,E	End																			X					
Polypedilum sp. [not *nubiferum*]	E,M	Intro?											X													
Thalassomya setosipennis Wirth, 1947	F,E,M	End		X					X	X	X	X	X							X					X	X
Chyromyidae																										
Aphaniosoma minuta Hardy, 1980	E,M	End												X					X							
Undetermined Chyromyidae	E,M	?									X															
Dolichopodidae																										
Asyndetus carcinophilis Parent, 1937	E,M	End																		X		X				
Chrysosoma globiferum (Wiedemann, 1830)	F	Intro															X									
Chrysotus longipalpus Aldrich, 1896	F,E,M	Intro					X									X	X	X			X					X
Condylostylus longicornis (Fabricius, 1775)	F	Intro															X				X					
Dolichopus exsul Aldrich, 1922	F,E,M	Intro												X							X				X	
Medetera grisescens Meijere, 1916	F,E,M	Ind?																			X	X				X
Pelastoneurus lugubris Loew 1861	F,E	Intro					X										X				X					X
Syntormon flexibile Becker, 1922	F,E,M	Intro				X	X	X	X						X					X	X				X	X
Thambemyia acrosticalis (Parent, 1937)	E,M	End							X	X	X	X								X				X	X	
Thinophilus hardyi Grootaert & Evenhuis, 1996	E,M	Intro				X										X			X			X				
Ephydridae																										
Atissa oahuensis Cresson, 1948	F,E,M	End		X		X		X		X			X	X		X			X						X	X
Brachydeutera hebes Cresson, 1926	F,E	End																			X					
Brachydeutera ibari Ninomiya, 1930	F	Intro																			X					
Ceropsilopa coquilletti Cresson, 1922	E,M	Intro				X		X			X			X		X			X							
Chlorichaeta tuberculosa Becker, 1993	E,M	Intro														X			X							
Clasiopella uncinata Hendel, 1914	M	Intro						X						X		X			X							
Discocerina mera Cresson, 1939	F,E,M	Intro						X	X	X			X					X				X		X	X	X
Donaceus nigronotatus Cresson, 1943	F,E,M	Intro					X	X							X	X	X	X			X					X
Ephydra gracilis Packard, 1871	M	Intro								X				X												
Ephydra milbrae Jones, 1906	E,M	Intro												X		X										

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Hecamede granifera (Thomson, 1896)	E,M	Intro									X			X		X			X	X		X		X	X	
Mosillus tibialis Cresson, 1916	E,M	Intro														X						X				
Nostima sp.	F,E	New?																			X					X
Ochthera circularis Cresson, 1926	F	Intro					X										X									
Placopsidella marquesana (Malloch, 1933)	E,M	Intro								X	X							X	X						X	
Psilopa girschneri Von Roeder, 1889	E,M	Intro				X								X		X		X	X	X						
Scatella bryani (Cresson, 1926)	F,E	End?																			X					
Scatella sexnotata Cresson, 1926	F,E,M	Ind		X		X	X	X	X				X	X		X		X	X				X	X	X	X
Scatella stagnalis (Fallen, 1813)	F,E,M	Intro		X		X	X	X		X					X	X	X	X			X				X	X
Typopsilopa sp.	F,E	New?																								X
Undetermined Ephydridae	F,E	?					X														X					
Sciaridae																										
Bradysia molokaiensis? (Grimshaw, 1901)	F,E	End																			X					
Undetermined Sciaridae	F,E,M	?					X											X		X					X	X
Tethinidae																										
Dasyrhicnoessa vockerothi Hardy & Delfinado, 1980	E,M	Ind?							X			X														
Dasyrhinoessa insularis (Aldrich, 1931)	F,E,M	Ind?		X			X	X		X			X	X		X		X		X		X			X	X
Dasyrhinoessa sp. [small orange]	F,E,M	New?		X		X	X	X		X	X			X		X									X	X
Tethina sp. [not *variseta*]	E,M	?						X								X										
Tethina variseta (Melander, 1951)	E,M	Intro							X		X			X		X			X					X	X	
Tipulidae																										
Erioptera bicornifer Alexander, 1921	F	Intro																			X					
Limonia sp.	F,E	?																								X
Limonia advena Alexander, 1954	F	Intro															X				X					
Limonia perkinsi (Grimshaw, 1901)	F	Intro					X																			
Heteroptera																										
Gerridae																										
Halobates hawaiiensis Usinger, 1938	M	Ind																X								
Mesoveliidae																										
Mesovelia amoena Uhler, 1894	F,E	Intro																								X
Mesovelia mulsanti White, 1879	F,E	Intro															X	X								X
Saldidae																										
Micracanthia humilis (Say, 1832)	F,E,M	Intro		X												X	X									
Odonata																										
Aeshnidae																										
Anax junius (Drury, 1770)	F,E,M	Ind			X									X		X		X	X			X				
Coenagrionidae																										
Enallagma civile (Hagen, 1862)	E	Intro				X																				
Ischnura posita (Hagen, 1862)	F	Intro					X																			
Ischnura ramburii (Selys-Longchamps, 1850)	F,E,M	Intro			X	X	X		X							X	X	X			X					
Libellulidae																										
Crocothemis servilia (Drury, 1770)	F,E	Intro				X	X		X	X								X					X			
Orthemis ferruginea (Fabricius,1775)	F,E,M	Intro			X	X			X	X				X				X								
Pantala flavescens (Fabricius,1798)	F,E,M	Ind			X					X		X		X				X	X		X	X				X
Tramea lacerata Hagen, 1862	E	Intro				X																				
Trichoptera																										
Hydropsychidae																										
Cheumatopsyche pettiti (Banks, 1908)	F	Intro															X				X					
Hydroptilidae																										
Hydroptila arctia Ross	F	Intro															X				X					
Pycnogonida																										
Ammothella biunguiculata fusca Hilton, 1942	E,M	Ind?																				X				

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Crustacea																										
Undetermined Ostracoda	F,E,M	?						X										X								
Copepoda																										
Copepoda	F,E,M	?	X		X					X								X				X		X		
Cyclopoida																										
Undetermined Cyclopoid Copepoda	E,M	Ind?																				X				
Harpacticoida																										
Undetermined Harpacticoid Copepoda	F,E,M	Ind?	X		X			X		X								X				X				
Caligoida																										
Caligidae																										
Caligus rapax Edwards, 1840	F,E,M	Ind							X			X					X					X		X		
Stomatopoda																										
Squillidae																										
Pseudosquilla ciliata (Fabricius, 1787)	E,M	Ind			X					X																X
Pseudosquilla oculata (Brullé, 1837)	E,M	Ind																								X
Mysidacea																										
Undetermined Mysidacea	E,M	?																				X				
Tanaidacea																										
Apseudidae																										
Apseudes tropicalis Miller, 1940	E,M	Ind								X																
Tanaidae																										
Leptochelia dubia (Krøyer)	E,M	?						X	X	X		X										X				X
Isopoda																										
Undetermined Isopoda	F,E	?					X										X									
Cirolanidae																										
Undetermined Cirolanidae sp.1	E,M	?								X												X				
Undetermined Cirolanidae sp.2	E,M	?			X																					
Gnathiidae																										
Gnathia sp.	E,M	New?						X																		
Munnidae																										
Munna acarina? Miller, 1941	E,M	Ind								X												X				
Amphipoda																										
?																										
Undetermined Amphipods	E,M	?			X			X	X			X	X				X			X	X	X				X
Aoridae																										
Bemlos macromanus (Shoemaker, 1925)	M	?								X																
Caprellidae																										
Caprella acutifrons Latreille	E,M	?			X																	X				
Caprella cf. *danilevskii* Czerniavski	E,M	Ind																				X				
Caprella scaura Templeton, 1836	E,M	?										X										X			X	
Hemiaegina minuta? Mayer, 1890	E,M	Ind																				X				
Corophidae																										
Undetermined Corophidae	M	?										X														
Gammaridae																										
Maera insignis (Chevreus, 1901)	M	?																							X	
Melita sp.	M	?								X																
Hyalellidae																										
Hyalella azteca (Saussure, 1858)	F,E	End																X			X					
Talitridae																										
Orchestia sp.	M	?										X														
Decapoda																										
Penaeidae																										

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Penaeus marginatus Randall	E,M	Ind																							X	
Alpheidae																										
Alpheus gracilipes Stimpson, 1860	E,M	Ind?																								X
Alpheus lobidens de Haan	E,M	Ind?								X												X			X	
Alpheus mackayi Banner, 1959	E,M	Ind			X													X								
Atyidae																										
Neocaridina denticulata sinensis (de Haan, 1844)	F	Intro															X				X					
Processidae																										
Undetermined Processidae	E,M	?																								X
Cambaridae																										
Procambarus clarkii (Girard, 1852)	F	Intro(p)															X				X					
Palaemonidae																										
Macrobrachium grandimanus (Randall, 1840)	F,E,M	Ind					X										X	X	X		X					
Macrobrachium lar (Fabricius, 1798)	F	Intro(p)																X			X					
Palaemon debilis? (Dana, 1852)	F,E,M	Ind	X		X		X	X	X								X	X		X	X	X		X	X	X
Palaemon sp.	E,M	Ind																							X	
Pontoniinae																										
Periclimenes cf. *grandis* Simpson	E,M	Ind	X					X									X	X						X		
Paguridae																										
Undetermined Paguridae	E,M	?																							X	
Calappidae																										
Calappa hepatica (Linnaeus)	E,M	Ind			X																	X				X
Majidae																										
Simocarcinus simplex (Dana, 1758)	E,M	Ind																								X
Grapsidae																										
Grapsus longitarsis Dana, 1852	E,M	Ind																							X	
Metopograpsus messor Forskål, 1900	E,M	Ind			X		X	X	X										X			X				
Metopograpsus thukuhar (Owen, 1839)	E,M	Ind			X			X										X							X	
Ocypodidae																										
Ocypode ceratophthalma (Pallas, 1900)	E,M	Ind																		X						
Portunidae																										
Portunus cf. *granulatus* (Edwards, 1899)	E,M	Ind										X														
Portunus longispinosus (Dana, 1852)	E,M	Ind			X					X										X					X	X
Portunus oahuensis (Edmonson, 1954)	E,M	End										X														X
Portunus sanguinolentus (Herbst, 1796)	E,M	Ind											X									X			X	
Scylla serrata (Forskål, 1755)	F,E	Intro (p)					X		X								X									
Thalamita crenata Latreille, 1900	E,M	Ind	X		X			X		X			X					X		X		X		X	X	X
Thalamita edwardsi Borradaile, 1900	E,M	Ind			X					X															X	X
Thalamita integra Dana, 1852	E,M	Ind						X		X		X								X		X			X	X
Xanthidae																										
Actaea sp.	E,M	Ind?								X																
Chlorodopsis cf. *areolata* (Milne Edwards, 1873)	E,M	Ind								X																
Panopeus cf. *herbstii* Milne Edwards, 1930	E,M	Ind																				X				
Panopeus pacificus Edmonson, 1931	E,M	Intro																								X
Undetermined Xanthidae	E,M	Ind?								X																
Undetermined Megalopa	E,M	?										X													X	
Hemichordata																										
Enteropneusta																										
Ptychoderiida																										
Ptychodera cf. *flava* Spengel	E,M	Ind			X																					
Chordata																										
Chondrichthyes																										

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Lamniformes																										
Sphyrnidae																										
Sphyrna lewini Griffith & Smith, 1834	E,M	Ind																				X				
Osteichthyes																										
Aulopiformes																										
Synodontidae																										
Saurida gracilis Quoy & Gaimard, 1824	E,M	Ind			X																					
Saurida nebulosa Valenciennes, 1849	E,M	Ind						X										X				X				
Synodus dermatogenys Fowler, 1912	E,M	Ind										X														
Cypriniformes																										
Cobitidae																										
Misgurnus anguillicaudatus (Cantor 1842)	F	Intro															X									
Cyprinodontiformes																										
Poeciliidae																										
Gambusia affinis Baird & Girard, 1853	F,E,M	Intro(p)	X		X	X	X										X				X		X	X		
Poecilia latippina LeSeur, 1821	E,M	Intro(p)				X																	X			
Limia cf. *vittata* Guichenot, 1853	E	Intro								X													X			
Poecilia mexicana Steindachner, 1863	F,E,M	Intro	X				X	X		X				X			X	X	X		X	X	X	X	X	
Poecilia reticulata Peters, 1859	F	Intro(p)																			X					
Elopiformes																										
Elopidae																										
Elops hawaiensis Regan, 1909	E	Ind							X																	
Perciformes																										
Acanthuridae																										
Acanthurus triostegus sandvicensis (Linnaeus, 1758)	E,M	Ind			X																			X	X	
Apogonidae																										
Foa brachygramma Jenkins, 1903	E,M	Ind						X		X								X							X	X
Blenniidae																										
Entomacrodus marmoratus (Bennett, 1828)	E,M	Ind											X													
Carangidae																										
Undetermined Carangidae	E,M	Ind																X								
Caranx ignobilis (Forsskål, 1775)	E,M	Ind																X								
Cichlidae																										
Cichlasoma managuense (Günther,1867)	F,E	Intro															X									
Cichlasoma nigrofasciatum (Günther,1867)	F,E	Intro																X			X					
Hemichromis elongatus (Guichenot in Duméril, 1861)	F	Intro																			X					
Sarotherodon melanotheron Rüppell, 1852	F,E,M	Intro	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X
Creediidae																										
Crystallodytes cookei Fowler, 1923	E,M	Ind										X														
Eleotridae																										
Eleotris sandwicensis Vaillant & Sauvage, 1875	F,E,M	End						X									X	X	X		X			X		X
Gobiidae																										
Asterropteryx semipunctatus Rüppell, 1830	E,M	Ind								X																X
Awaous guamensis Valenciennes, 1837	F,E	End													X		X				X					
Bathygobius coalitus (Benner, 1832)	F,E,M	Ind								X			X													X
Bathygobius cocosensis Bleeker, 1854	E,M	Ind	X		X			X		X		X	X							X		X		X	X	X
Mugilogobius cavifrons Weber, 1909	F,E,M	Intro	X				X										X									
Oxyurichthys lonchotus Jenkins, 1903	E,M	Ind							X								X									X
Priolepis eugenius (Jordan & Evermann, 1903)	E,M	Ind								X																
Sicyopterus stimpsoni (Gill, 1860)	F	End																			X					
Stenogobius hawaiiensis Watson, 1991	F,E	Ind					X								X		X	X			X					
Larval Marine Gobiidae	E,M	Ind								X										X						

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

Oahu South and West Shore Estuarine Species List

Phylum / **Class** / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Ala Moana Park	Ala Wai Canal	Awawamalu	Barber's Point - Ordy Pond	Kalihi Stream	Kapalama Stream	Kaupuni Stream	Kuapa Pond	Kuliouou Stream	Maili Stream	Mailiilii Stream	Makaha Stream & Wetlands	Makiki Stream	Makua Stream	Manoa/Palolo Stream	Moanalua Stream	Nanakuli Stream	Niu Stream	Nuuanu Stream	Paiko Lagoon	Salt Lake	Ulehawa Stream	Waialaenui	Wailupe Beach Park
Kuhliidae																										
Kuhlia sandvicensis Steindachner, 1876	F,E,M	End			X		X		X			X	X	X			X	X	X	X	X	X		X	X	X
Labridae																										
Stethojulis balteata (Quoy & Gaimard, 1824)	E,M	Ind																								X
Mugilidae																										
Moolgarda engeli Bleeker, 1858	E,M	Intro			X		X		X			X	X				X	X	X	X		X			X	X
Mugil cephalus Linnaeus, 1758	F,E,M	Ind	X		X		X		X			X	X	X			X	X			X	X			X	X
Neomyxus leuciscus Günther, 1871	E,M	Ind																		X						
Mullidae																										
Larval Mullidae	E,M	Ind																		X						
Mulloidichthys sp.	E,M	Ind											X													
Mulloidichthys flavolineatus (Lacepède, 1801)	E,M	Ind											X													
Polynemidae																										
Polydactylus sexfilis (Valenciennes, 1831)	E,M	Ind															X					X				
Pomacentridae																										
Abudefduf abdominalis (Quoy & Gaimard, 1825)	E,M	Ind			X																					
Scaridae																										
Scarus dubius? Bennet, 1828	E,M	Ind																								X
Scarus rubroviolaceus Bleeker, 1849	E,M	Ind			X																					
Sphyraenidae																										
Sphyraena barracuda Walbaum, 1792	E,M	Ind																X				X				
Pleuronectiformes																										
Bothidae																										
Bothus pantherinus (Rüppell,1830)	E,M	Ind			X																					
Siluriformes																										
Loricariidae																										
Ancistrus temminckii Valenciennes, 1840	F	Intro															X				X					
Hypostomus cf. *watwata* Hancock, 1828	F	Intro					X										X				X					
Tetraodontiformes																										
Tetraodontidae																										
Arothron hispidus Linnaeus, 1758	E,M	Ind			X			X										X								
Arothron sp.	F,E	Ind															X									
Amphibia																										
Anura																										
Bufonidae																										
Bufo marinus (Linnaeus, 1758)	F,E	Intro(p)					X										X				X					
Ranidae																										
Rana catesbeiana Shaw, 1802	F	Intro(p)															X				X					

[1]F=Freshwater (saln:0-5ppt); E=Estuarine (saln:6-26ppt); M=Marine (saln: >26ppt)

[2]End=Endemic; Ind=Indigenous; Intro=Introduced; (p)=Purposely; New=New Species; ?=Undetermined

APPENDIX B

A Description of Introduced Aquatic and Estuarine Species Collected in the South and West Shore Oahu Dingell-Johnson Project Surveys

INSECTA: COLEOPTERA

Family Hydrophilidae

Tropisternus salsamentus Fall, 1901

Common Name:	Water scavenger beetle
First Record:	ca. 1968, Maui
Mechanism:	Overseas transport
Origin:	North America (California)

Older Hawaiian records beginning with the earliest (Maui: Hanaula, 1,220 m, July 1968) were cited by Hansen (1995). New records include abundant specimens found at Ordy's Pond, Barbers Point, in 24 ppt saln waters. This species of *Tropisternus* was the most recent to become established in Hawaii. It follows *Tropisternus lateralis humeralis* Motschulsky, which became established on Oahu in the late 1940s. *Tropisternus salsamentus* has been reported from stagnant water and sometimes collected at lights. *Tropisternus salsamentus* was exceptionally abundant in aquatic vegetation lining the shore of Ordy's pond.

Family Limnichidae

Parathroscinus cf. *murphyi* (Wooldridge 1990)

Common Name:	Mangrove mudflat beetle
First Record:	1996, Oahu
Mechanism:	Possibly shipborne
Origin:	Southeast Asia

This beetle is a recent arrival to Hawaii and is currently restricted to Oahu. The original state record was taken in 1996 from Pearl Harbor on the mudflats of Pouhala Marsh, which is between Waikele Stream and Kapakahi Stream (Samuelson 1998). It has since been collected from many shore sites along the south shore of Oahu and was common to extremely abundant at these sites. *Parathroscinus* cf. *murphyi* often formed dense clouds as these small beetles flew just above the exposed tidal mudflats. Numerous specimens have been collected from virtually every stream estuary containing tidal mudflats including the Ala Wai Canal, Kalihi, Kapalama Streams, Kuapa Pond, Kuliouou, Makiki, Manoa, Moanalua, Nuuanu Streams, Wailaenui, and Wailupe Streams.

Larval collections of this species have been made from Pearl Harbor streams (Englund et al. 2000) by collecting mud samples and extracting larvae from the mud in the laboratory. One pupa was also collected in mud samples. This beetle has been spreading to other areas on Oahu and is now found from Koloko Point northeast of Sandy Beach to the West Loch of Pearl Harbor (Honouliuli Stream). *Parathroscinus* cf. *murphyi* is still not found in the area from Barbers Point to Kaena Point, despite intensive sampling in suitable habitats on the Waianae coast. *Parathroscinus* cf. *murphyi* has become one of the most common insects on mudflats where mangrove grows; sometimes moving up along streams where the water is still brackish and affected by the tides. These beetles aggregate in large numbers on exposed mud and take flight when disturbed. This species keys to *P. murphyi* Wooldridge (1990) from Singapore. Furthermore, the habits of *P. murphyi* and the Hawaiian introduction are similar in that they are associated with mangrove environments and that both readily fly low over mudflats when disturbed.

INSECTA: DIPTERA

Family Canacidae

Canaceoides angulatus Wirth, 1969

Common Name:	Beach fly
First Record:	1922
Mechanism:	?
Origin:	U.S. west coast and South America

Wirth described this species in 1969 (Wirth 1969) with the type specimen collected in Waimea, Oahu. The earliest record was a female from Wawamalu Beach near Koko Crater in 1922. The paratype series includes materials collected in Mexico, Baja California, Gulf of California, Galapagos Archipelago, and Peru. *Canaceiodes angulatus* was collected from most areas sampled during this study. Recent materials collected from shoreline habitats of the south and west shore of Oahu include Ala Wai Canal, Kapalama and Kaupuni Streams, Kuapa Pond, Maili, Mailiilii, Moanalua, Niu, Waialaenui, and Wailupe Stream. The method of introduction into Hawaii is unknown, but canacids are normally intertidal and saline tolerant species breeding in algae covered rocks (Hardy and Delfinado 1980).

Procanace williamsi Wirth, 1951

Common Name:	Beach fly

First Record: 1944, Oahu I.
Mechanism: Plane?
Origin: Japan

Description of *Procanace williamsi* was based on male and female specimens collected in Hawaii (Wirth 1951). The first collection of this species (the paratype female) from Hawaii was from a plane in 1944. Unlike the endemic canacid beach fly *Canaceiodes hawaiiensis* that was collected in only two sampling sites, the two introduced canacid species *Procanace williamsi* and *Canaceiodes angulatus* (see above) were abundant throughout most south shore Oahu sampling stations. *Procanace williamsi* is one of the most common beach flies currently found on Oahu, and was found in most south shore sampling stations.

Recent materials collected from shoreline habitats of the south shore of Oahu include the muddy banks of the Ala Wai Canal, Kalihi and Kapalama Streams, Kuapa Pond, Kuliouou, Makiki, Manoa, Moanalua and Niu Streams, Paiko Lagoon, and Wailupe Stream. Miyagi (1965) reported *Procanace williamsi* from Honshu, Shikoku and Kyushu, extending its range into Japan.

Family Chironomidae

Cricotopus bicinctus (Meigen, 1818)

Common Name: Non-biting midge
First Record: 1955, Oahu
Mechanism ?
Origin: Widespread, Afrotropical and Holarctic

Hardy (1956) first reported *Cricotopus bicinctus* as being taken in 1955 from a light trap in Waipio [Pearl Harbor], Oahu, and near Kipapa Gulch [a Pearl Harbor tributary], Oahu, in that same year. *Cricotopus bicinctus* is now one of the most ubiquitous introduced aquatic insects in the Hawaiian archipelago, being found from disturbed low-elevation areas to nearly pristine high elevation (> 1,220 m) sections of Hawaiian streams (Englund et al. 1998). This species has a widespread Afrotropical and Holarctic distribution (Evenhuis 1989). On Oahu, *C. bicinctus* is abundant in areas of flowing freshwater but is highly adaptable and also found in estuarine condtions. During this study *C. bicinctus* was collected while sweeping *Batis maritima* at Kapalama stream (34 ppt saln), Manoa/Palolo Stream (0 ppt saln), Nuuanu (0 ppt saln), and while sweeping mud near a grassy area of Wailupe Stream (9 ppt saln).

Family Dolichopodidae

Chrysosoma globiferum Weidemann, 1830

Synonym:	*Chrysotus fraternum* Van Duzee, 1933
Common Name:	Long-legged fly
First Record:	1915, Kona
Mechanism	possibly with greenhouse plants and/or soil
Origin:	China, Taiwan

Originally collected in 1915 in Kona, this species was originally thought to be a native species Van Duzee (1933) but was later determined to be introduced from the Oriental region (Evenhuis 1989). Collected only along the vegetation and mud banks of lower Manoa/Palolo Stream, this dolichopodid species was uncommon along the south and west shores of Oahu.

Chrysotus longipalpus Aldrich, 1896

Synonym:	*Chrysotus pallidipalpus* Van Duzee, 1933
Common Name:	Long-legged fly
First Record:	1930, Oahu
Mechanism	possibly with greenhouse plants and/or soil
Origin:	West Indies

Van Duzee (1933) described *Chrysotus pallidipalpus* from specimens collected in Honolulu, Oahu, and Waialua, Oahu. Evenhuis (1996) found *Chrysotus pallidipalpus* to be conspecific with *Chrysotus longipalpus* Aldrich, 1896, which was described from the West Indies. This species was quite common along the south shore of Oahu and during this study was found in Kalihi, Makua, Manoa, Moanalua, Nuuanu, and Waialaenui Streams.

Condylostylus longicornis (Fabricius, 1775)

Common Name:	Long-legged fly
First Record:	1996, Oahu
Mechanism:	?
Origin:	Southern U.S., Neotropics to French Polynesia

Grootaeart and Evenhuis 1997 [*in*: Evenhuis (1997a)] reported this species was taken in 1996 from a freshwater marsh at Barber's Point, Oahu. *Condylostylus longicornis* is native to the southern United States and the Neotropical region but has also been reported from the

Marquesas, Society Islands, Tuamotus and Austral Islands in French Polynesia [probably all introductions] (Bickel 1994). Specimens collected during the present surveys include Manoa Stream (0 ppt saln) and Nuuanu Stream (0 ppt saln).

Dolichopus exsul Aldrich, 1922

Common Name:	Long-legged fly
First Record:	1930, Oahu
Mechanism	possibly with greenhouse plants and/or soil
Origin:	West Indies

Dolichopus exsul is readily recognizable from other Hawaiian Dolichopodidae by the very large ornate genitalia of the males (Hardy 1964). This predatory species is found in a wide variety of aquatic habitats, and has been found in nearly pristine upland aquatic habitats sympatrically with rare native aquatic insect species such as *Sigmatineurum meaohi* in upper Waipio Valley, Hawaii Island (Englund and Preston 1999). During the present study we found *Dolichopus exsul* in both hypersaline environments of Makaha Stream and wetland (38 ppt saln) area, and at Nuuanu Stream (0 ppt saln), and along the concrete channel area at the Waialaenui Stream mouth (32 ppt saln).

Medetera grisescens Meijere, 1916

Synonyms:	*M. hawaiiensis* VanDuzee, 1933
	M. atrata van Duzee, 1933
	M. cilifemorata van Duzee, 1933
	M. palmae Hardy, 1939
Common Name:	Long-legged fly
First Record:	1914, Oahu
Mechanism:	?
Origin:	Oriental region

The earliest record of *Medetera hawaiiensis* is from specimens collected from Honolulu in 1914 (Van Duzee 1933). This species was incorrectly identified and actually was *Medetera grisescens* (Bickel 1987). Bickel (1987) examined specimens from the Indian Ocean, the Indian subcontinent, south-east Asia, southern China, the Ryukyu Islands, coastal Australia and many Pacific islands. Evenhuis (1989) stated *Medetera grisescens* was known throughout the Oriental and southern Pacific. This species appears to be an introduction, and the endemic status, as listed in Nishida (1997) should be changed to reflect the wide distribution of this species.

Specimens were collected at Nuuanu Stream (0 ppt saln), Paiko Lagoon (38 ppt saln), and Wailupe Stream (4 ppt saln).

Pelastoneurus lugubris Loew, 1861

Common Name:	Long-legged fly
First Record:	1994, Oahu
Mechanism	?
Origin:	North America

Reported by Evenhuis (1996) as a new state record, with the first specimens collected at the University of Hawaii, Manoa, in 1994, and also has been found in north Halawa and Halona Valleys, and at Lualualei Naval Magazine (Evenhuis 1997b). This species is native to eastern United States and south to Mexico. During the south and west shore Oahu surveys specimens were taken at Kalihi Stream (0 ppt saln), Manoa Stream (0 ppt saln), Nuuanu Stream (0 ppt saln), and at Wailupe Stream (4 ppt saln).

Syntormon flexibile Becker, 1922

Synonym:	*Syntormon distortitarsis* Van Duzee, 1933
Common Name:	Long-legged fly
First Record:	1917, Kauai
Mechanism:	?
Origin:	Taiwan, Australia, Bonin Islands, St. Helena

This species was first collected in Hawaii in 1917 in Mana, Kauai (Van Duzee 1933), and is widespread throughout the Pacific, and from Australia to Taiwan. *Syntormon flexible* was the most common native or introduced dolichopodid fly found during the present study and was collected in a wide range of freshwater and estuarine habitats at nine stations. This species was present at Ordy's Pond at Barbers Point (24 ppt saln), Kalihi Stream (0 ppt saln), Kapalama Stream (34 ppt saln), Kaupuni Stream (36 ppt saln), Makiki Stream (0 ppt saln), Niu Stream (37 ppt saln), Nuuanu Stream (0 ppt saln), Waialaenui Stream (32 ppt saln), and Wailupe Stream (4 ppt).

Thinophilus hardyi Grootaert & Evenhuis, 1997

Common Name:	Long-legged fly
First Record:	1996, Oahu

Mechanism ?
Origin: Australasia

This apparently marine dolichopodid species was originally found at Shark's Cove, Oahu, in a porous lava bench that occasionally was inundated with sea water (Grootaert and Evenhuis 1997). *Thinophilus hardyi* was moderately common along the south shore of Oahu, and was collected while sweeping over mud at the edge of Ordy's Pond (24 ppt saln), Makua Stream (15-43 ppt saln), Nanakuli Stream (42 ppt saln), and Paiko Lagoon (38 ppt saln).

Family Ephydridae

Brachydeutera ibari Ninomya, 1930

Common Name: Shore fly
First Record: 1980, Kahoolawe
Mechanism: ?
Origin Oriental region?

Evenhuis (1986) reported *Brachydeutera ibari* as a new State record from a specimen collected at Becks Cove, Kahoolawe Island, February 1980. This introduced species was uncommon and only four specimens were collected during the present study. During the south shore surveys these specimens were collected only in freshwater areas of the lowest reaches of Nuuanu Stream (0 ppt saln).

Ceropsilopa coquilletti Cresson, 1922

Common Name: Shore fly
First Record: 1946, Oahu
Mechanism: ?
Origin: Nearctic (Described from California)

First records of this species are from Adachi (1952) with specimens collected at the edge of a pond at Ewa, Oahu, in 1946. Little is known about the biology of this species, but it may be phytophagous as it has been reared from various plants coastal plants and is found along pond margins on sedges and grasses (Tenorio 1980). Recent materials collected during the south and west shore Oahu surveys include Ordy's Pond at Barbers Point (24 ppt saln), Kapalama Stream (34 ppt saln), Makaha Stream and wetlands (38 ppt saln), Makua Stream (15-43 ppt saln), and Nanakuli Stream (42 ppt saln).

Clasiopella uncinata Hendel, 1914

Common Name:	Shore fly
First Record:	1946, Oahu
Mechanism:	Airplane
Origin:	Taiwan, Australasian Region

Adachi (1952) first described *Clasiopella uncinata* in Hawaii from many specimens collected from an airplane window at the Honolulu, Oahu, Naval Air Station in 1946. *Clasiopella uncinata* is widely distributed, with Cresson (1945) reporting specimens collected in planes on Guam and Midway Island. Cresson (1946) also reported a specimen captured in Florida on a plane arriving from the West Indies. This species was found along the dry Waianae coast stream mouths and saline areas of the Kapalama Stream estuary. Materials collected from south and west shore Oahu habitats include Kapalama Stream (34 ppt saln), Makaha Stream (38 ppt saln), Makua Stream (43 ppt saln) and Nanakuli Stream (42 ppt saln).

Discocerina mera Cresson, 1939

Common Name:	Shore fly
First Records:	1948, Oahu
Mechanism:	?
Origin:	Pacific distribution

The first record of *Discocerina mera* was from Honolulu, Oahu, 1948 (Adachi 1952), and little is known about the biology of this species. *Discocerina mera* was collected mostly in saline estuarine habitats during the present study. Areas where this species were collected while sweeping muddy and rocky banks include Kapalama Stream (34 ppt saln), Kaupuni Stream (36 ppt saln), Kuapa Pond (39 ppt saln), wet sand on the side Mailiilii Stream channel, sweeping mangroves and sandy/rocky shoreline at Moanalua Stream (34 ppt saln), Ulehawa Stream (37 ppt saln) Waialaenui Stream (32 ppt saln), Wailupe Stream (10-33 ppt saln).

Donaceus nigronotatus Cresson, 1943

Common Name:	Shore fly
First Record:	1958, Oahu I.
Mechanism:	Airplane
Origin:	Oriental Region (Described from Taiwan)

Donaceus nigronotatus was first collected from John Rogers Airport, Oahu, in 1958, and this suggests the possibility of dispersal of this species to the Hawaiian Islands aboard airplanes. This generalist species is quite adaptable and in Hawaii is found from sea level to over 1220 m, and breeds in the muddy margins of a wide range of water bodies (Tenorio 1980). Recent materials collected from shoreline habitats of Oahu's south and west shore include Kalihi Stream (0 ppt saln), Kapalama Stream (34 ppt saln), Makiki Stream (0 ppt saln), Makua Stream (15 ppt saln), Manoa Stream (0 ppt saln), Moanalua Stream (34 ppt saln), Nuuanu Stream (0 ppt saln), Wailupe Stream (4 ppt saln).

Ephydra gracilis Packard, 1871

Synonyms:	*Ephydra cinerea* Jones, 1906
Common Name:	Brine fly
First Record:	1946, Oahu
Mechanism:	Seaplanes
Origin:	North America (western saline lakes)

Larvae in the genus *Ephydra* are aquatic and are most abundant in strongly saline or alkaline waters, with adults congregating in high densities on the surface of the water, vegetation, and in shoreline areas of water bodies (Tenorio 1980). Tenorio (1980) stated the species reported by Wirth (1947) was *Ephydra cinerea* Jones, 1906, however, Mathis and Zatwarnicki (1990) later synonomized this species with *E. gracilis* Packard, 1871. This species was first collected from Hickam Field in 1946 and found to be "breeding by the millions" in salt water ponds (Wirth 1947) that are no longer in existence opposite Moanalua Gardens. Up to the time its discovery in 1947, the mode of introduction of *E. gracilis* can be more definitely attributed to aircraft transport than can any other immigrant insect species (Wirth 1947). Several important factors led to the successful introduction of *E. gracilis* into Hawaii. These include the close proximity of favorable breeding habitats at the California World War II seaplane bases, the large number of adults produced in areas such as the Salton Sea or the Great Salt Lake near air bases, the huge numbers of adults emerging at times, and their habit of swarming into moving vehicles (where they are pests in trains crossing the Great Salt Lake), and most importantly, suitable saline habitats near the Oahu seaplane bases (Wirth 1947). These combination of factors provided for favorable conditions for the transplantation of this marine fly. From Oahu this species spread to Kauai (Nishida 1997) and is likely found on other Hawaiian Islands.

This species is fond of hypersaline conditions both on Oahu and in its native range of the saline lakes of western North America (Wirth 1947). *Ephydra gracilis* was collected in low numbers on

Oahu with one specimen captured while sweeping the sand at the mouth of Makaha Stream (38 ppt saln) and eight specimens at Kuapa Pond (38 ppt saln). Special efforts were made to resample areas where this species was found in 1946 to be "breeding by the millions" in areas of Pearl Harbor such as Hickam Field and Iroquois Point (Englund et al. 2000), and in Moanalua Stream and Salt Lake during the present study. Intensive sampling of these and other suitable Pearl Harbor wetland areas found numerous species of other native and introduced ephydrid flies, but *E. gracilis* was absent from all sampled Pearl Harbor aquatic habitats (Englund et al. 2000). This species is now uncommon on Oahu, and despite over one year of intensive sampling of the entire south shore of Oahu, including Pearl Harbor, only 9 individuals were captured, and none in areas where the species was originally found. The phenomena of an insect species population exploding shortly after its introduction and then being found in low numbers decades later is not unusual but has rarely been documented to such an extent as in the Hawaiian Islands.

Ephydra millbrae Jones, 1906

Common Name:	Brine fly
First Record:	1950, Oahu
Mechanism:	?
Origin:	North America (west coast)

The first record of this species was a collection from the Ala Wai Canal, Oahu in 1950 (Hardy 1952). This species was originally misidentified as *Ephydra riparia* Fallen. *Ephydra millbrae* is a common established marine ephydrid species in the Hawaiian islands. This species ranges from the coast of British Columbia to Mexico (Wirth 1971). This species was only found along the dryer leeward coast of Oahu. Recent materials collected from shoreline habitats of the south and west shore of Oahu include Makaha Stream and wetlands (38 ppt saln), Makua Stream (15-43 ppt saln).

Hecamede granifera Thomson, 1869

Synonyms:	*Hecamede persimilis*, Hendel, 1913
	Hecamede femoralis Malloch, 1930
	Hecamede inermis Malloch, 1933
Common Name:	Shore fly
First Record:	1923, Oahu
Mechanism	?
Origin:	Pacific region

Hecamede granifera was first collected in 1923 from Mokapu, Oahu (Adachi 1952). This is widespread marine ephydrid species is found throughout the Pacific (Evenhuis 1989). During the present study materials were collected by sweeping mud and rocks from the south shore of Oahu. Areas where *Hecamede granifera* were collected include mainly dry leeward areas or intermittent stream mouths with little freshwater influence. This species breeds on dead seaweed and other marine debris washed onto the beach by waves (Tenorio 1980). Specimens were collected at the following locations during the present study: Kuliouou Stream (34 ppt saln), Makaha Stream and wetlands (38 ppt saln), Makua Stream (15-43 ppt saln), Nanakuli Stream (42 ppt saln), and Niu Stream (37 ppt saln), Paiko Lagoon (38 ppt saln), Ulehawa Stream (37 ppt saln), and Waialaenui Stream (32 ppt saln).

Mosillus tibialis Cresson, 1916

Common Name:	Shore fly
First Record:	1944, Molokai
Mechanism:	?
Origin:	U.S.

The first record of this species in Hawaii was reported by Adachi (1952) and was collected at Mapulehu, Molokai, in 1944. Other specimens in the Bishop Museum collection were taken at Waipahu, Oahu in 1958. This introduced marine ephydrid species appears to tolerate poor water quality conditions and was previously collected in a polluted section of Enchanted Lakes, Oahu (Tenorio 1980). During the present study specimens were collected by sweeping mud and rocks at the shoreline of Makua Stream (43 ppt saln) and Paiko Lagoon (38 ppt). *Mosillus tibialis* originated from the United States (Evenhuis 1989).

Ochthera circularis Cresson, 1926

Common Name:	Shore fly
First Record:	1982, Oahu
Mechanism:	?
Origin:	Oriental and eastern Palaearctic regions

Hardy (1985b) reported specimens of *Ochthera circularis* which were first collected from Moanalua Stream, Oahu in 1982. *Ochthera circularis* has large and unusual raptorial forelegs that are well- suited for a predatory lifestyle along streams and other bodies of water that attract an abundance of other insects to prey upon. The effects of introduced predatory fly on native Hawaiian insects are unknown. During the south shore surveys this species was restricted to areas above tidal influence around flowing areas of streams and was found in Manoa (0 ppt saln) and Kalihi (0 ppt saln) Streams. *Ochthera circularis* were collected while sweeping along rocks at the edge of the stream.

Placopsidella marquesana (Malloch, 1933)

Common Name: Shore fly

First Record: 1951, Oahu

Mechanism: ?

Origin: Pacific

The first specimen was collected from Hanauma Bay, Oahu on rocks in 1951 (Adachi 1952) but was misidentified as *Placopsidella cynocephala*. This species has a Pacific-wide distribution (Evenhuis 1989), and is common in seaweed and debris on beaches (Tenorio 1980). Other Oahu records include Kailua and Waimanalo Beaches (Tenorio 1980). Recent materials collected from the south and west shore of Oahu include areas with relatively little or no freshwater input such as Kuapa Pond (39 ppt), Kuliouou (34 ppt saln), Moanalua (34 ppt saln), Nanakuli (42 ppt saln), and Waialaenui Streams.

Psilopa girschneri Röder, 1889:54

Synonyms: *Psilopa olga* Cresson, 1922

Common Name: Shore fly

First Record: Oahu, 1952

Mechanism: ?

Origin: Holarctic

Hardy (1952) first reported specimens from Oahu in 1952. *Psilopa girschneri* is found along the margins of muddy pond areas and according to Tenorio (1980) inhabits waters that are "stagnant and odoriferous". This ephydrid species has been recorded from throughout the Holarctic region and also from Kiribati, where it was also likely introduced (Evenhuis 1989). *Psilopa girschneri* appears to favor more saline environments. During this study it was collected at stream mouth areas having little or no freshwater influence. Recent materials collected from shoreline habitats of the south and west shore of Oahu include Ordy's Pond at Barbers Point (24 ppt saln), Makaha Stream and wetlands (38 ppt saln), Makua Stream (15-43 ppt saln), Moanalua Stream (34 ppt saln), Nanakuli Stream (42 ppt saln), and Niu Stream (37 ppt saln).

Scatella stagnalis (Fallen, 1913)

Common Name: Shore fly
First Record: 1967, Oahu
Mechanism: ?
Origin: Holarctic

Tenorio (1980) reported *Scatella stagnalis* was first collected on Oahu in 1967. This species has a widespread Holarctic distribution (Evenhuis 1989), and is found from fresh to brackish standing water habitats. *Scatella stagnalis* is found where vegetation is growing along the margins of backyard fishponds. By 1980 *S. stagnalis* had become one of the most widespread fly species in Hawaii despite its recent immigrant status at that time (Tenorio 1980). This species still remains one of the most common aquatic fly species on Oahu and was collected from almost every sampling station along the south shore of Oahu. Prior to this study Tenorio (1980) found *S. stagnalis* was abundant in Salt Lake and the Ala Wai canal area of Oahu's south shore.

Some areas where *S. stagnalis* were collected during the current study include the Ala Wai canal (28 ppt saln), Ordy's Pond at Barbers Point (24 ppt saln), Kalihi Stream (0 ppt saln), Kapalama Stream (34 ppt saln), Kuapa Pond (8-39 ppt saln), Makiki Stream (0 ppt saln), Makua Stream (15-43 ppt saln), Manoa Stream (0 ppt saln), Moanalua Stream (34 ppt saln), Nuuanu Stream (0 ppt saln), Waialaenui Stream (32 ppt saln), Wailupe Stream (4 ppt saln).

Family Tethinidae

Tethina variseta (Melander, 1951)

Common Name: -
First Record: 1947, Oahu
Mechanism: ?
Origin: U.S.

Wirth (1947) first reported this species was collected from Waianae, Oahu in 1946, misidentified as *Tethina albula* (Loew). However, Hardy and Delfinado (1980) corrected the identification to *T. variseta*. *Tethina variseta* is associated with maritime habitats, and originated from the United States (Evenhuis 1989). Specimens were collected sweeping mud and rocks mainly along the drier coast of leeward Oahu streams that have little or no flowing water, such as at Kaupuni (36 ppt saln), Kuliouou (34 ppt saln), Makaha (38 ppt saln), Makua (15-43 ppt saln), Nanakuli (42 ppt saln), Ulehawa (37 ppt saln), and Waialaenui (32 ppt saln) Streams.

Family Tipulidae

Erioptera bicornifer Alexander, 1921

Common Name:	Crane fly
First Record:	1931, Honolulu
Mechanism:	?
Origin:	Eastern Asia (Siberia to Japan)

This species was first collected in Honolulu by F.X. Williams in 1931 (Alexander 1941). Little is known about the habitats of this cranefly in Hawaii, except that is moderately common in disturbed, low elevation aquatic habitats. *Erioptera bicornifer* is found on Oahu and Hawaii Islands (Nishida 1997) but is probably found throughout the archipelago. During the present study this species was collected in freshwater habitats of Nuuanu Stream (0 ppt saln), just above areas of tidal influence.

Limonia advena Alexander, 1954

Common Name:	Crane fly
First Record:	1952, Honolulu
Mechanism:	?
Origin:	Canada to Argentina

First described from Honolulu in 1952 (Hardy 1960), *Limonia advena* occurs throughout the Hawaiian archipelago (Englund 1999b). Both Hardy (1960) and Alexander (1954) believed that *L. advena* was an introduction because it is closely allied with species ranging from Canada to Argentina. Several other factors may corroborate that this large cranefly species is a non-indigenous species. *Limonia advena* was first collected in 1952 after 6 decades of intensive entomological collections throughout Oahu and is a generalist species found from disturbed low elevation aquatic habitats at sea level to upper elevation areas that still relatively intact. This cranefly species is found around seeps and riffle habitats in a wide range of elevations ranging from sea level to 1,220 m on Kauai (Hardy 1960) and in disturbed and nearly pristine aquatic habitats throughout Hawaii (Englund 1999b). Larvae are often found in mossy areas of waterfalls, with only the posterior protruding (Hardy 1960). During this present study this species was found in areas above tidal influence at Manoa and Nuuanu Streams, in waters of 0 ppt saln.

Limonia perkinsi Grimshaw, 1901

Common Name:	Crane fly
First Record:	1901, Kona
Mechanism:	Nursery or aquatic plants?
Origin:	Marquesas, Fiji, Society Islands, Tahiti, Samoa

Limonia perkinsi is a highly adaptable species with larvae that can develop in decaying wood, leaf bases of trees, tree holes, in potted ferns, and in muddy pockets of water in a stream bed (Williams 1943). In Hawaii this species feeds upon decaying plant tissues, algae, and diatoms, and the pupa are highly mobile which likely helps this species adjust to changing water levels (Williams 1943). Although the type specimen of *L. perkinsi* was collected in Kona, Hardy (1960) believed it was introduced because it has such a widespread distribution.

This cranefly species is in fact common throughout the Hawaiian Islands even though it was found only at Kalihi Stream (0 ppt saln) during the present surveys.

INSECTA: HETEROPTERA

Family Mesoveliidae

Mesovelia amoena Uhler, 1894

Common Name:	Water treader
First Record:	1971, Kauai
Mechanism:	?
Origin:	?

Gagne and Howarth (1975) first reported specimens from Kauai at Waikanaloa Cave, Haena, August 1971 and Limestone Quarry Cave, sea level, Koloa, June 1973 and on Oahu along Waimea River, October 1971; Salt Lake, June 1973 and Palolo Stream, January 1974. During this study specimens were taken on the water surface on the mauka side of Kalanianaole Highway at Wailupe Stream (4 ppt saln).

The family of water treaders is represented in the island fauna by three species in two genera. *Mesovelia amoena* is found along stream and pond margins, and is apparently parthenogenetic in Hawaii; only females have ever been captured (D. Polhemus, Smithsonian, pers. comm.).

Mesovelia mulsanti White, 1879

Common Name:	Water treader
First Record:	1933, Oahu
Mechanism:	Aquatic plants?
Origin:	North and South America

First found by Williams (1933) in a reservoir at Waipio, Oahu, 1933 and is abundant in the freshwater ponds and streams of Oahu. For this survey *Mesovelia mulsanti* was found in Manoa Stream (0 ppt saln), Moanalua Stream (0 ppt saln), and sympatrically with the other introduced mesoveliid, *Mesovelia amoena*, at Wailupe Stream (4 ppt saln) on the water surface. Winged and apterous forms were observed moving across the water surface, lily pads, algal masses and other aquatic vegetation. Eggs are laid in aquatic plant tissue.

Family Saldidae

Micracanthia humilis (Say, 1832)

Common Name:	Shore bug
First Record:	1988, Oahu
Mechanism:	?
Origin:	North America
Status:	Introduced

First specimens of this widely distributed North American species were collected from Kawainui Marsh in July 1988 and July 1989 by Strazanac (1992). Saldidae are represented in the Hawaiian fauna by *Micracanthia humilis* and eight endemic species in the genus *Saldula*. Saldids are predaceous bugs found along margins of streams, ponds, lakes, and marshes. A few of the endemic *Saldula* live an arboreal lifestyle, residing in the rain forests on shrubs, or on damp mosses and lichen.

The introduced *M. humilis* appears to be more saline tolerant than the endemic stream saldids, and is found along the entire south and west shore of Oahu. During this study, recent specimens of *M. humilis* were taken along the south shore of Oahu along the lower Ala Wai Canal (28 ppt saln), Makua Stream (15 ppt saln), and at Manoa Stream (0 ppt saln) on the surface of mud, above the area of tidal influence.

INSECTA: ODONATA

Family Coenagrionidae

Enallagma civile (Hagen, 1862)

Common Name:	Familiar bluet
First Record:	1936, Oahu
Mechanism:	Probably with aquarium plants
Origin:	Western North America

Williams (1937) first collected *Enallagma civile* in Manoa Valley, Oahu in 1936. This species is locally common in coastal wetlands because of its ability to tolerate brackish waters (Polhemus and Asquith 1996). This species is now widespread and found throughout Oahu, and prefers slow-water sections of streams, and irrigation pond areas such as the leeward Waiahole Ditch (Filbert and Englund 1995). During the present study this adults of this species were found at Ordy's Pond, Barber's Point, with salinities of 24 ppt.

Ischnura posita (Hagen, 1862)

Common Name:	Fragile forktail
First Record:	1936, Oahu
Mechanism:	Probably with aquarium plants
Origin:	Canada to Central America

First found in a Punahou lily pond in 1936 (Hoyt 1937), *Ischnura posita* is now a common introduced damselfly found throughout low to high-elevation sections of all Hawaiian streams and wetlands. This species has been found in nearly pristine high elevation (1250+ m) sections of streams found in Kokee State Park but co-exists with many currently rare native *Megalagrion* damselfly species (Polhemus 1996). *Ischnura posita* is the smallest of the introduced damselflies, and being mainly found in freshwater habitats does not have the wide ranging salinity tolerances of the other introduced Odonata such as *Ischnura ramburii*. During the south and west shore surveys this species was found in Kalihi Stream immediately above the area of tidal influence in waters of 0 ppt saln.

Ischnura ramburii (Selys-Longchamps, 1850)

Common Name:	Rambur's forktail
First Record:	1973, Hawaii Island
Mechanism:	Possible aircraft stowaway/aquatic plants
Origin:	Maine to Chile

First observed at Hilea, Hawaii Island in 1973, and shortly thereafter on Oahu, it is impossible to determine if this species first became established on Oahu or Hawaii Island (Harwood 1976). Fertilized females may seek shelter in aircraft, and Odonata in general are resistant to insecticides, thus this species likely could survive as a stowaway (Harwood 1976). However, it is just as likely that it also came in with a shipment of aquatic plants. Currently this is the most abundant and widespread introduced Zygoptera species on Oahu and also one of the most common aquatic insects in lowland areas of Oahu streams and coastal wetlands. *Ischnura ramburii* also has the distinction for being the most saline tolerant introduced damselfly with adults observed around water of up to 32 ppt salinity.

Family Libellulidae

Crocothemis servilia (Drury, 1770)

Common Name:	Scarlet skimmer
First Record:	1994, Oahu
Mechanism:	Aquatic or aquarium plants
Origin:	Middle East, Asia to Australia

Crocothemis servilia was first collected around taro fields in Waiahole Stream, Oahu in December 1994 (Polhemus 1995a). The rapid spread of *C. servilia* across Oahu was expected because of its vagility, and thus its presence is not surprising as this dragonfly is especially suited to disturbed, lowland aquatic habitats common on Oahu. The long-term effects of this introduced dragonfly on native aquatic organisms are unknown, and its distribution overlaps with the native dragonfly *Anax junius*. This species was common throughout low elevation aquatic habitats along the south shore of Oahu in areas of standing or stillwater, and in many estuarine regions such as at the mouth of Manoa/Palolo Stream.

Orthemis ferruginea (Fabricius. 1775)

Common Name:	Roseate skimmer
First Record:	1977, Oahu
Mechanism:	Aquatic or aquarium plants
Origin:	South America to Florida

This large, bright lavender dragonfly is one of the most conspicuous components of the aquatic insect fauna on Oahu. First collected at Haleiwa, Oahu, in 1977 (Beardsley 1980), *O. ferruginea* now appears to be established throughout the Hawaiian archipelago. Prior to this, Nishida (1997) had recorded this species from Kauai and Oahu, while Englund (1999b) found *O. ferruginea* occurs on all other main Hawaiian Islands. *Orthemis ferruginea* was abundant throughout disturbed lowland areas of Oahu and is often observed some distance from aquatic habitats and also flying above estuarine and marine habitats. The species is difficult to capture but easy to identify while flying because it is large and has a unique color, thus visual observations were the usual form of identification. The method of introduction of *O. ferruginea* into Hawaiian waters is unknown, but it is highly likely that the immature larval stage was brought in with imported aquatic plants. The native range of this species is from the Florida Keys to Central and South America (Dunkle 1989).

Tramea lacerata Hagen, 1862

Common Name:	Black-mantled glider
First Record:	1873, Oahu
Mechanism:	Unknown
Origin:	North America (Ontario to Cuba)

This species ranges from Ontario to Cuba, Bermuda, and the Bahamas (Dunkle 1989). First recorded from Hawaii in 1873, *T. lacerata* is one of the earliest introduced insect species to be reported from the Hawaiian Islands (Zimmerman 1948). This dragonfly species likely has little if any impact on native aquatic insects because of its overall scarcity and its restriction to low elevation coastal wetland areas. Native damselflies also have appeared to suffer few ill-effects from this species. Perkins conducted extensive insect surveys in the 1890s and early 1900s (Liebherr and Polhemus 1997) prior to the introduction of many aquatic species but long after the introduction of *T. lacerata*. These early surveys found many species of native damselflies that are now extirpated formerly had overlapping elevational distributions with *T. lacerata*. The only Oahu location where *T. lacerata* were locally common was at Ordy's Pond at Barbers Point Naval Base. This species is apparently saline tolerant, as females were seen ovipositing in the 24 ppt saln water of Ordy's Pond and is also likely unaffected by introduced poeciliid fish, as extremely high densities of *Poecilia latipinna* and *Gambusia affinis* were present at Ordy's Pond.

INSECTA: TRICHOPTERA

Family Hydropsychidae

Cheumatopsyche pettiti (Banks, 1908)

Common Name:	Caddisfly
First Record:	1965
Mechanism:	Aquatic plants
Origin:	Western North America

The caddisfly *Cheumatopsyche pettiti* was first collected at light traps in 1965 in various locations throughout Oahu (Denning and Beardsley 1967). Species in this genus are found in lotic habitats or fast-flowing areas of streams (Usinger 1968, Merritt and Cummins 1996), thus it seems possible that this species could have inadvertently been introduced into Hawaii during unsuccessful attempts to establish several species of mayfly [Ephemeroptera] to serve as forage for sport fish, as described in Usinger (1972). However, Beardsley (pers. comm.) believes it is more likely that the eggs of this species were transported into Hawaii on aquatic vegetation or some aquatic substrate. Adult caddisflies are short-lived and would likely not survive transport as would the eggs or larvae.

Along with *Cricotopus bicinctus*, Kinzie et al. (1997) found *C. pettiti* comprised a dominant portion of the aquatic insect drift in Wainiha Stream, Kauai. The diet of *C. pettiti* larvae in Molokai streams was found to consist of 50% detritus with diatoms and algae composing the remainder (Kondratieff et al. 1997). In Wainiha Stream, Kauai, Kido et al. (1993) found *C. pettiti* comprised 23.1% (by number) of the diet of the native goby *Awaous guamensis*. Because of its great abundance in Hawaiian streams *C. pettiti* has undoubtedly influenced native aquatic invertebrate populations, perhaps through competition for space and resources. Because sampling efforts during this study concentrated mainly on tidal estuarine areas and coastal wetlands this species was found only at one sampling station. In south shore Oahu streams, *Cheumatopsyche pettiti* was found in completely freshwater (0 ppt saln) sections of Manoa/Palolo Stream, above areas of tidal influence.

Family Hydroptilidae

Hydroptila arctia Ross, 1938

Common Name:	Caddisfly
First Record:	1968
Mechanism:	Aquatic plants
Origin:	Western North America

The first specimen of *Hydroptila arctia* was collected in a light trap at the Honolulu International Airport in May 1968 (Joyce 1969). This small caddisfly was the third caddis species to become established in the Hawaiian Islands and is now found throughout the archipelago. Because of its small size *H. arctia* is more difficult to collect than the larger *Cheumatopsyche pettiti* and is easily overlooked. Larvae of this species inhabit small, light tan purse-like cases about 3 mm long (Beardsley 1971). In Wainiha Stream, Kauai, Kido et al. (1993) found *H. arctia* comprised 8.9% (by number) of the diet of the native goby *Awaous guamensis*.

This species is ubiquitous and is found from disturbed low elevation stream mouth areas such as the Manoa/Palolo Stream junction in this study (0 ppt saln) to high elevation (762-1220 m) sections of nearly pristine streams on Kauai (Englund et al. 1998) and Oahu (Polhemus 1995a).

PELECYPODA: HETERODONTA

Family Corbiculidae

Corbicula fluminea (Muller, 1774)

Common Name:	Asiatic clam
First Record:	1982, Kauai
Mechanism:	Intentional (food) introduction
Origin:	California (via native range of Philippines or Southeast Asia)

The first specimens of *Corbicula fluminea* or the Asiatic clam found in Hawaii were introduced from California (Eldredge 1994) and now this species is widespread in lowland stream areas on Oahu. *Corbicula fluminea* was first observed on Oahu in 1988 in Waikele Stream (Devick 1991a). Worldwide this species has adversely impacted power plant intake systems through clogging of pipes, and estimated losses in the U.S. alone were $1 billion annually in the 1980s (U.S. Congress 1993). This species has spread widely throughout the United States and Europe (Swinnen et al. 1998). Negative effects of this introduction have occurred in California, where reservoir fish populations have declined because of competition for food resources and in Hawaii as this species has clogged irrigation pipes (Devick 1991a).

Corbicula fluminea was restricted to freshwater in south and west shore Oahu streams and was common in Nuuanu and Manoa Streams (0 ppt saln). This species was not found in more streams as it avoids estuarine areas and most sample effort during this study was in areas of tidal influence.

GASTROPODA: BASOMMATOPHORA

Family Planorbidae

Planorbella duryi (Wetherby, 1879)

Common Name:	Ram's horn snail
First Record:	1994, Kauai
Mechanism:	Aquarium introduction
Origin:	North America (Florida)

Although 1994 is the first literature record of this species in Hawaii, photographs of a *Planorbis* sp. from Hawaii were published in 1940 (Alicata 1940). Because of the difficulty of identifying species of Planorbidae it is possible that the 1940 record is in fact *Planorbella duryi* and that it may have been present in Hawaii since 1940 or earlier. Planorbids in Hawaii may belong to a single morphologically variable species, although it is possible that there may indeed be more than one species present (Cowie 1997).

Planorbella duryi is a snail commonly encountered in most Oahu streams, in areas upstream of tidal influence. During these surveys this species was more restricted to freshwater than were the thiarid snails. *Planorbella duryi* was found in 0 ppt saln in Moanalua Stream and Manoa Stream.

Family Thiaridae

Melanoides tuberculata (Muller, 1774)

Common Name:	Freshwater snail
First Record:	1994, Hawaiian Islands

Mechanism: ?

Origin: Asia or the Middle East and Africa

Along with *Tarebia granifera*, *Melanoides tuberculata* is one of the most common aquatic snails in Hawaii. Although 1994 is the first literature record in Hawaii, it appears to have been present here for some time, as evidenced by its widespread distribution throughout Hawaii (Cowie 1997). Other closely related species, of which there are many specimens in the Bishop Museum Malacology Collection, may be synonymized with either *Melanoides tuberculata* or *Tarebia granifera* in the future with species such as *Melania indefinita*, first collected in Hawaii in 1856 (Cowie 1997). Therefore, *M. tuberculata* has been present in Hawaii for many years. This species was recently found in archaeological sites in Kauai wetlands, but only in post-contact (after 1778) deposits (D. Burney, Fordham University, pers. comm.).

The taxonomy of the mainly freshwater Thiaridae family of aquatic snails in Hawaii is problematic, likely because of their clonal mode of reproduction, which causes extensive morphological variations (Cowie 1997). Future genetic analysis of thiarid snails may also be difficult because of the clonal form of reproduction. Many thiarids have been widely introduced throughout the Pacific by humans, as appears to be the case for species in this family found in Hawaii (Cowie 1997).

Melanoides tuberculata appears to be even more saline tolerant than *Tarebia granifera* and was found in a wide range of disturbed habitats during these Oahu surveys, being found from freshwater (0 ppt saln) in Nuuanu Stream, to 15-23 ppt in Moanalua Stream, to 31 ppt in Kapalama Stream to tidal areas of lower Manoa/Palolo Stream ranging from 14-34 ppt saln.

Tarebia granifera (Lamarck, 1816)

Common Name: Freshwater snail

First Record: 1856, Hawaiian Islands

Mechanism: Unknown

Origin: Unknown (possible Polynesian introduction?)

Tarebia granifera appears to have been established in Hawaii for a long period of time and may have been transported in the roots of wetland plants such as taro brought with the colonizing Polynesians (Cowie 1998). The record of thiarids being found in Hawaii as early as 1856 (Cowie 1997), prior to the majority of Hawaiian aquatic organism introductions, lends some weight to this hypothesis. This snail was abundant in the lower reaches of a wide variety of south shore Oahu freshwater and estuarine habitats, and is saline tolerant. *Tarebia granifera* was found in Manoa

Stream (0 ppt) just above the area of tidal influence and also was abundant at Moanalua Stream (15 ppt salinity) and Waialaenui Stream (30 ppt salinity).

In Hawaii, the effects of this species on native mollusks is unknown. Thiarid snails, including both *T. granifera* and *Melanoides tuberculata*, have successfully been used in the Caribbean as a biological control to eliminate the intermediate host of schistosomiasis, the native snail *Biomphalaria glabrata* (Pointier et al. 1994). Introduced *T. granifera* also appeared to have eliminated native snails that were hosts of schistosomiasis in 29 rivers in Venezuela (Pointier et al. 1994).

DECAPODA: CARIDEA

Family Atyidae

Neocaridina denticulata sinensis (Kemp, 1918)

Common Name:	Atyid shrimp
First Record:	1991, Oahu
Mechanism:	Aquarium release
Origin:	Taiwan and Southern China

This species was originally found in Nuuanu Stream, Oahu, in 1991 and reported as *Caridina weberi* (Devick 1991b). During the Oahu surveys *Neocaridina denticulata sinensis* was found in high densities in Manoa and Nuuanu Streams, just above areas of tidal influence. The genus *Neocaridina* is found throughout Japan, Taiwan, the Ryukyu Islands, Korea, mainland China, and Vietnam (Englund and Cai 1999). The native range of this subspecies found in Hawaii is Taiwan and southern China (Hung et al. 1993). *Neocaridina denticulata sinensis* is now found in high densities in widely separated windward and leeward Oahu drainages but is restricted to freshwater habitats (Englund and Cai 1999).

Unlike the native freshwater atyid shrimp *Atyoida bisulcata*, *N. d. sinensis* does not have an obligatory marine phase (Hung et al. 1993). Thus, *N. d. sinensis* must have spread into separate Oahu watersheds by repeated human introductions. Additionally, specimens of *N. d. sinensis* were purchased as feeder shrimp at Pet's Plus Petshop on Ward Avenue in Honolulu. This is strong evidence that *N. d. sinensis* was introduced to Oahu streams as an escaped or released aquarium species. It is possible that *N. d. sinensis* could compete with the native atyid shrimp *Atyoida bisulcata*, as they occupy similar habitats.

Family Cambaridae

Procambarus clarkii (Girard, 1852)

Common Name: Red swamp crayfish
First Record: 1923, Oahu
Mechanism: Governmental (Food)
Origin: Louisiana

First introduced into taro patches near Ahuimanu Stream, Oahu in 1923 (Brock 1960), *Procambarus clarkii* have become established throughout Hawaii. Crayfish are abundant in freshwater along the south shore of Oahu, but were only collected near areas of tidal influence in Nuuanu and Manoa/Palolo Streams. Crayfish populations apparently exploded after their introduction into Hawaii, and by 1940 they had become serious pests to taro cultivation (Devaney et al. 1982). In Hawaii, crayfish have been documented to consume taro, prey on insects and snails, and their burrows can cause the draining of taro fields (Devaney et al. 1982). Chemical controls, such as the treatment of taro fields with para-dichloro benzene (PDB) or napthalene were used from 1940 to 1952 to control crayfish depredations with over 1,417 ha of wetland taro fields treated in Hawaii (Devaney et al. 1982). Crayfish are still abundant throughout aquatic habitats on Oahu, and there has been no active Hawaii control program since 1952. In California, the introduction of *P. clarkii* and other introduced crayfish species has caused the displacement of native species (Shafland 1991). Although not studied in Hawaii, the effects on native fish and other species may be profound. *Procambarus clarkii* is also a vector for several harmful human parasites (Alicata 1969, Shafland 1991) including the lung fluke, *Paragonimus westermani*, and the rat lungworm *Angiostrongylus cantonensis*.

Family Palaemonidae

Macrobrachium lar (Fabricius, 1798)

Common Name: Tahitian prawn
First Record: 1956, Molokai
Mechanism: Governmental (Food)
Origin: South Pacific (Guam and Tahiti)

Macrobrachium lar was first introduced into Pelekunu Stream, Molokai in 1956 (Devick 1991a). Because of its amphidromous life-cycle this species is now found in virtually every Hawaiian stream. *Macrobrachium lar* is found in virtually stream on Oahu but was collected during this study only near the estuary of Nuuanu and Moanalua Streams, in areas of freshwater. In Hawaii, this species directly competes with the native *Macrobrachium grandimanus* (Eldredge 1994), and it is not uncommon to observe *M. lar* preying on native freshwater mollusks such as *Neritina granosa* and native stream gobies. Although quantitative studies on the impacts of this species in Hawaiian waters have not been conducted, *M. lar* is assumed to have detrimental impacts, mainly through predation and competition to native species (Devick 1991a). Additionally, *M. lar* has been documented to be a vector for the harmful human parasite, the rat lungworm, *Angiostrongylus cantonensis,* which is the cause of eosinophilic meningoencephalitis (Alicata 1969).

OSTEICHTHYES: CYPRINIFORMES

Family Cobitidae

Misgurnus anguillicaudatus (Cantor 1842)

Common Name: Dojo loach
First Record: Prior to 1900, Oahu
Mechanism: Food/bait introduction
Origin: Eastern Asia

Dojo loaches (*Misgurnus anguillicaudatus*) are one of the earlier aquatic species introductions into Hawaii (Brock 1960). Mainland (1939) recorded this species from Nuuanu, Manoa, Palolo Streams, and in the taro patches around Kaneohe. Dojo loaches are considered a cool water species (Fuller et al. 1999), and on Kauai are found up to 1070 m elevation on Kawaikoi Stream, where they were introduced as baitfish by trout fishermen (Englund et al. 1998).

Because the current study was examining only estuarine and areas just above the influence of the tide we found dojo loaches only in lower Manoa/Palolo Streams in waters of 0 ppt saln. Little is known about the effects of this species on native Hawaiian stream biota, but dojo loaches may be one of the more innocuous Hawaiian stream introductions. Sections of high elevation streams on Kauai containing dojo loaches have a diverse and full complement of native insects, and biologically are some of the best remaining streams in the Hawaiian Islands (Englund et al. 1998). Based on their preferred diet of aquatic insects and their densities, Maciolek (1984) characterized dojo loaches as having an intermediate impact on Hawaiian streams.

CYPRINODONTIFORMES

Family Poeciliidae

Gambusia affinis Baird & Girard, 1853

Common Name:	Western mosquitofish
First Record:	1905, Oahu
Mechanism:	Governmental Biocontrol
Origin:	South Texas

Gambusia affinis grows to only 56 mm, and along with *Poecilia reticulata*, are the smallest of the introduced live-bearing poeciliids found on Oahu. This species was first introduced into the Pearl Harbor drainages of Aiea and Pearl City spring areas in 1905 for mosquito control (Van Dine 1908). Because of a salinity tolerance second only to *Poecilia mexicana*, *Gambusia affinis* is found throughout Oahu. This species is highly carnivorous (Meffe and Snelson 1989) and when transplanted out of its native range has been shown to completely transform aquatic ecosystems (Hurlbert et al. 1972, Rees 1979, Walters and Legner 1980). In the presence of mosquitofish, declines in Odonata populations were found in California rice fields (Farley and Younce 1977).

Most of the published research on the negative effects of poeciliids has been attributed to *Gambusia affinis* and *Xiphophorus helleri*. *Gambusia affinis* were mainly found in extremely high densities in the lower reaches of Oahu streams and always in the presence of *Poecilia mexicana*. *Gambusia affinis* were found to have a wide salinity tolerance and along the south and west shore of Oahu were usually in salinities of <16 ppt during this study but were found in salinities of up to 41 ppt in Nanakuli Stream.

Limia cf. *vittata* Guichenot, 1853

Common Name:	Cuban limia
First Record:	1950
Mechanism:	Aquarium release
Origin:	Cuba and Isle of Pines

Brock (1960) stated that the origin and date of the introduction into Hawaii was not known, but its presence in Hawaii was known by 1950 (Devick 1991a). This poeciliid species was relatively uncommon and similar to *Poecilia latipinna* and preferred still-water habitats. Although Brock (1960) reported *Limia vittata* was found in the lower portions of several streams flowing through Honolulu, none were collected during this study in flowing stream habitats within Honolulu. *Limia* cf. *vittata* was abundant in the still water habitats of Salt Lake (7-8 ppt saln) and Kuapa Pond (8 ppt saln). Except for its preference of slightly brackish wetland and still water habitats, relatively little is known about the ecology of this species in Hawaii.

Poecilia latipinna LeSueur, 1821

Common Name:	Sailfin molly
First Record:	1905
Mechanism:	Governmental (biocontrol)
Origin:	Southern Texas

Poecilia latipinna was first introduced to Oahu in 1905 for mosquito control (Van Dine, 1907) and in 1950 three buckets were taken from Kapalama Canal, Oahu and planted in Port Allen and Nawiliwili, Kauai as a baitfish, but apparently none survived (Randall 1987). This species is also established on Molokai and Maui (Randall 1987). *Poecilia latipinna* was not found in Kapalama Canal during this study but was abundant there in 1950. Randall (1987) noted that *P. latipinna* has become less abundant in recent years, perhaps because of competition with tilapia (*Sarotherodon melanotheron*).

During this study, *P. latipinna* was found only in the stillwater habitat of Ordy's Pond at Barbers Point and maintained extremely high densities at this site. Ordy's Pond lacked tilapia and was a still water pond with no inlet or outlet. *Poecilia latipinna* is considered to be primarily herbivorous (Meffe and Snelson 1989) and thus seems an inappropriate choice for mosquito control. However, *P. latipinna* is highly flexible in its diet and was found to be cannibalistic in the laboratory (Meffe and Snelson 1989) and to have undesirable effects on native fish (Courtenay and Meffe 1989). In California, *P. latipinna* is responsible for the decline for the desert pupfish (*Cyprinodon macularius*) (Fuller et al. 1999).

In Hawaii, Hiatt (1947) analyzed the stomachs of 22 specimens of *P. latipinna* from mullet ponds. The adult (50-65 mm SL) fish were found to feed mainly on the microbenthos such as bluegreen algae and detritus. *Poecilia latipinna* can adapt to a wide range of environmental conditions and exhibited a wide salinity tolerance, being found in waters ranging from 5 to 24 ppt saln at Ordy's Pond. This species was also common in Salt Lake in still waters of 7-8 ppt saln.

Poecilia mexicana Steindachner, 1863

Common Name:	Shortfin molly
First Record:	Before 1950, Hawaiian Islands

Mechanism: Possible aquarium release
Origin: Mexico or Central America

The mechanism of introduction of this species to Hawaii is not known, but Randall (1987) believed it to be a possible aquarium release that occurred prior to 1950. Specimens from Oahu and Maui streams and estuaries were recently examined by W.W. Fink and R.R. Miller of the University of Michigan Museum of Zoology. This species appears to have hybridized prior to introduction into Hawaii and did not key out to any described species (W.W. Fink, pers. comm.). However, the morphological characteristics of this species have stabilized, and it is a distinctive form that appears to not interbreed with other poeciliid species in Hawaii (W.W. Fink, pers. comm.). During the present study of south shore Oahu, *Poecilia mexicana* was found in water ranging from 0-41 ppt saln, and can withstand salinities of up to 135 ppt (Randall 1987). *Poecilia mexicana* was one of the most common fish found in lower stream and estuarine areas of the south and west shores of Oahu, with only tilapia being found in correspondingly high densities. This species is the largest (up to 115 mm) of the introduced Hawaiian livebearers.

Poecilia mexicana is likely one of the most detrimental introduced fish found in fresh and brackish water habitats in Hawaii because of its large size and the high numbers in which it is found. Filbert and Englund (1995) found this species readily consumed returning native post-larval gobies in experimental aquarium observations. Additionally, *P. mexicana* is often heavily infested with ectoparasites such as the leech *Myzobdella lugubris*, and ick or *Ichthyophthirius* (Filbert and Englund 1995), and nematode parasites such as *Camallanus cotti* (Font and Tate 1994). A parasitic copepod (*Pseudocaligus* sp.) was also introduced into Hawaii with *P. mexicana* (Hoffman and Schubert 1984). None of these introduced fish parasites are found in streams containing only native fish species. The impacts of these parasites upon native stream fish are likely great, as native species have not co-evolved defenses as have the introduced poeciliids (Font and Tate 1994).

Poecilia reticulata Peters, 1859

Common Name: Guppy
First Record: 1920, Oahu
Mechanism: Government Biocontrol
Origin: South America

This species was introduced into Hawaii between 1920 to 1922 by Dr. C. Montague Cooke for the purposes of mosquito control (Mainland 1939). *Poecilia reticulata* are quite similar in size and ecological requirements to *Gambusia affinis*, attaining a maximum length of 55 mm. In contrast to

G. affiinis, we found guppies were restricted to mainly to freshwater in slightly brackish water of ≤ 5 ppt salinity. Less research has been conducted on the negative impacts of *P. reticulata* on native communities as compared to *G. affinis*. However, *P. reticulata* and *Xiphophorus helleri* may have played a role in the decline of the Utah Sucker (*Catostomus ardens*) in a thermal spring in Wyoming (Courtenay and Meffe 1989). Arthington and Lloyd (1989) were concerned that the introduced and widespread carnivorous *P. reticulata* would likely have impacts on native aquatic biota similar to that of *G. affinis*.

Poecilia reticulata is abundant in low to mid-elevation reaches of nearly every perennial Oahu stream (Englund 1999a), and is a probable vector for the spread of several harmful (Font and Tate 1994) introduced parasites in Hawaiian streams. In Pearl Harbor, *P. reticulata* were found to contain the introduced nematode parasite *Camallanus cotti* in their guts (Englund et al. 2000). Font and Tate (1994) found the introduced Asian tapeworm (*Bothriocephalus acheilognathi*) in *P. reticulata* in Wainiha Stream, Kauai. During the present survey, however, this species was found only in sections of Nuuanu and Manoa Streams above areas of tidal influence.

PERCIFORMES

Family Gobiidae

Mugilogobius cavifrons Weber, 1909

Common Name:	Goby
First Record:	1988, Oahu
Mechanism:	Probable Ballast Water
Origin:	Japan to Indonesia

First observed in Pearl Harbor in 1987 (Randall et al. 1993) and reported as *Mugilogobius parvus*, this introduced goby is now common throughout Oahu. *Mugilogobius cavifrons* was probably inadvertently introduced to Hawaii in the ballast water of ships or possibly attached on the hulls of ships (Randall et al. 1993, Mundy in press). It is also possible that this goby came to Hawaii with aquacultural shipments as it was found in aquaculture research ponds in 1990 (Randall 1993). However, aquaculture material from Asia to Hawaii is monitored, while there has been no monitoring (until recently) of shipping traffic between the western Pacific and Hawaii (Mundy in press).

This species was found in the lowest sections of streams, and inhabits water from 0-36 ppt salinity. Unlike native stream gobies, *M. cavifrons* displays little climbing ability. South shore

Oahu collection locations include the drainage canal at Ala Moana Park and lower Kalihi Stream. The effects of *M. cavifrons* on native species are unknown, but native crustacean species have been found in their stomachs (Englund et al. 2000). In aquaria, this species was observed to be highly aggressive and predaceous, and readily consumed native *Awaous guamensis* post-larvae.

Family Cichlidae

Cichlasoma managuense (Gunther, 1867)

Common Name:	Jaguar guapote cichlid
First Record:	1992, Oahu
Mechanism:	Aquarium introduction
Origin:	Central America

The impacts this introduced cichlid will have upon native aquatic organisms are unknown but they undoubtedly will be negative upon native species. This cichlid is considered aggressive and was considered a potential threat as a predator on native fish in the Virgin River, Utah system, but has now been eradicated from Utah (Fuller et al. 1999). According to Fuller et al. (1999), the only location where *Cichlasoma managuense* was established in Hawaii was in a pond at the University of Hawaii. This species may now also be established in Oahu streams as a large adult specimen in a tidal section of lower Manoa/Palolo Stream was found during the current study. This species has apparently either escaped from the campus quarry pond at the University of Hawaii, perhaps during heavy rains that can cause flooding into nearby Manoa Stream, or alternatively had been intentionally released there.

Cichlasoma nigrofasciatum (Gunther, 1867)

Common Name:	Convict cichlid
First Record:	1983, Oahu
Mechanism:	Aquarium introduction
Origin:	Central America

Cichlasoma nigrofasciatum were first recorded on Oahu in an irrigation ditch near Haleiwa in 1983 (Devick 1991a) and have since spread to many leeward and windward streams on Oahu. In aquaria this fish is extremely aggressive and will usually kill or eat most other species of fish and crustaceans. Although the impacts of convict cichlids on native aquatic stream species have not been studied, they are undoubtedly negative. In combination with other introduced fish species

C. nigrofasciatum were implicated in the extermination of the native speckled dace *Rhinichthys osculus* in Lake Mead, Nevada and are cited as a threat to the survival of endangered fish found in White River, Nevada (Fuller et al. 1999). Although numerous other introduced fish species always occur sympatrically with *C. nigrofasciatum*, on Oahu, native aquatic species are non-existent to rare where in areas where this species occurs. During the present surveys this species was common in Nuuanu Stream (0 ppt saln) in areas upstream of tidal influence.

Hemichromis elongatus (Guichenot in Dumeril, 1861)

Common Name: Jewel cichlid
First Record: 1991, Oahu
Mechanism: Aquarium introduction
Origin: Western Africa

This large (to 30 cm length) and colorful species of African cichlid was found in the lower reaches of Nuuanu Stream. *Hemichromis elongatus* was found in non-tidal areas (0 ppt saln) of Nuuanu Stream and was common in slower pool habitats. In Hawaii, *H. elongatus* was first collected in Lake Wilson, Oahu in 1991 and is currently also found in Kawainui Marsh drainages (Mike Yamamoto, Hawaii Division of Aquatic Resources, pers. comm.), and Waiawa Stream (Englund et al. 2000). The impacts this introduced cichlid will have upon native aquatic organisms are unknown in Hawaii, but this species has a reputation as an aggressive predator on fish, shrimp, and insects (Fuller et al. 1999). The highly aggressive *H. elongatus* undoubtedly has negative impacts upon native Hawaiian stream organisms.

Sarotherodon melanotheron Ruppell, 1852

Common Name: Blackchin tilapia
First Record: 1951, Hawaiian Islands
Mechanism: Governmental (Biocontrol/Food)
Origin: Africa

First introduced into Hawaii in 1951 for tuna bait and weed control (Randall 1987), blackchin tilapia (*Sarotherodon melanotheron*) are now the dominant estuarine fish on the island of Oahu. Alpha-level taxonomy for tilapiines is complex and unresolved, especially as numerous species have been transplanted and hybridized in Hawaii (Dr. M. Stiassny, American Museum of Natural History, pers. comm.). Hybridization usually results when different tilapia species are mixed together (Philippart and Ruwet 1982). Along the south and west shores of Oahu we assumed all tilapia were *S. melanotheron*, as obviously breeding males had the distinctively colored ‘black chin', and specimens sent to Dr. Stiassny were identified as *S. melanotheron*. We found extremely high densities and biomass of blackchin tilapia in most low-elevation aquatic habitats sampled, in water ranging from 0 to 41 ppt saln. Blackchin tilapia display little ability to colonize upstream into higher elevation areas and prefer still waters of low elevation streams, estuaries, and wetlands.

The blackchin tilapia is one of the most harmful introduced fish in low-elevation areas of Hawaiian streams, wetlands, and estuaries, and likely has caused more negative ecosystem effects in Hawaiian streams and wetlands than any other introduced aquatic species. Tilapia thrive in wetland or marsh areas as they are cut off from predators such as papio (*Caranx* spp.) and barracuda (*Sphyraena barracuda*), and eventually consume all plant and invertebrates, thus reducing or eliminating available food for endangered Hawaiian waterbirds (Kubota 1996). After eliminating aquatic plants and invertebrates in Hawaiian wetlands and marshes, tilapia can then switch to filtering small food particles through mud (Kubota 1996), and their air breathing abilities allow them to inhabit waters containing very little dissolved oxygen (Philippart and Ruwet 1982). Tilapia also decrease food availability for young endangered Hawaiian waterbirds such as the Hawaiian Stilt (*Himantopus mexicanus knudseni*) and Hawaiian Moorhen (*Gallinula chloropus sandwicensis*) and probably contribute to poor survivorship and recruitment in endangered waterbird populations. Even in areas with intensive predator control on Oahu, such as the Pearl Harbor National Wildlife Refuge or the James Campbell National Wildlife Refuge, young waterbird survival is poor, with food resources now apparently the limiting factor for young waterbirds.

In Lake Kinkony in Madagascar, introduced tilapia destroyed 3,000 ha of aquatic macrophytes and eliminated a valuable indigenous fish (Philippart and Ruwet 1982). Numerous examples exist in the destruction of native species and fisheries caused by tilapia, and Eldredge (1994), Nelson and Eldredge (1991), and Maciolek (1984), documented some of the negative impacts tilapia have had throughout the Pacific and Hawaii. Tilapia are omnivorous and consume a wide variety of food including epilithic blue-green algae, fine benthic sediments, insect larvae, crustaceans, and mollusks (Philippart and Ruwet 1982). In Hawaii, tilapia compete with the valuable native striped mullet (*Mugil cephalus*) for the same soft algae and detritus food source, and have also failed as a tuna baitfish in Hawaii (Randall 1987).

For this report we adapted the Trewavas system scientific name (Kendall 1997), which is accepted by the American Fisheries Society (AFS). However, *Tilapia melanotheron*, used in the Thys system, is also currently accepted by the AFS (Kendall 1997).

Moolgarda engeli Bleeker, 1858

Common Name:	Mullet
First Record:	1955, Oahu
Mechanism:	Accidentally introduced with baitfish.
Origin:	Marquesas

This small mullet (formerly known as *Valamugil engeli*) was unintentionally introduced into the Hawaiian Islands from Nuku Hiva in 1955 with a shipment of Marquesan sardines (*Sardinella marquesensis*) to be used for baitfish (Randall 1987). The sardines were captured in a seine and several non-target species including *Moolgarda engeli* were also captured and then transported in the livewell of the research vessel *Hugh M. Smith*. Upon reaching Hawaii, fishery biologists from the Bureau of Commercial Fisheries (now the National Marine Fisheries Service) failed to sort the sardines from the non-target catch of mullet and the entire contents of the livewell were released (Randall 1987).

Moolgarda engeli are now one of the most common inshore fish species in the Hawaiian Islands, and because of its small size is commercially worthless (Hoover 1996). Hoover (1996) also mentions that *Moolgarda engeli* has proliferated in Hawaii and is displacing the commercially and culturally important food fish *Mugil cephalus*. During this study we found overlapping distributions of both *Moolgarda engeli* and *Mugil cephalus*, although the former species was sometimes found in waters having higher salinities and rarely ascended streams for any appreciable distance. In contrast, *Mugil cephalus* juveniles in Hawaii are usually found to the first substantial waterfall of a stream, which can often be a considerable distance. In the south and west shores of Oahu this species was ubiquitous and captured at Awawamalu, Kalihi, Kaupuni, Maili, Mailiilii, Manoa/Palolo junction, Moanalua, Nanakuli, Niu, Wailaenui, and Wailupe Streams, and Paiko Lagoon. *Moolgarda engeli* was found in salinities ranging from 0 ppt saln at the Manoa/Palolo junction to 40 ppt in Nanakuli Stream.

Family Loricariidae

Ancistrus cf. *temminckii* Valenciennes, 1840

Common Name:	Bristle-nosed catfish
First Record:	1985, Oahu
Mechanism:	Aquarium release
Origin:	South America

Ancistrus cf. *temminckii* was first found on Oahu in 1985 (Devick 1991a). Species in the genus *Ancistrus* are distinctive because of their prominent snout tentacles occurring in both sexes, with the tentacles having the greatest development in breeding males (Sabaj et al. in press). The largest *Ancistrus* cf. *temminckii* specimen collected in Manoa Stream was 78 mm. This species appeared to preferentially select high velocity riffle and run habitats, and was less common in pool habitats. In Manoa Stream, bristle-nosed catfish densities were high and may also be in part contributing to the near absence of the native gobiid *Awaous guamensis* during this study. Native stream gobies are undoubtedly adversely affected by loricariid catfish through competition for food and space, and introduced parasites. Loricariid catfish found in Oahu streams are primarily algivores but will also readily consume fish eggs (Sabaj and Englund 1999). Although habitat disturbance and other introduced fish are factors, native gobies such as *Awaous guamensis* were rare in the lowest sections of south shore Oahu streams containing very high densities of introduced suckermouth catfish such as Manoa and Nuuanu Streams.

Hypostomus cf. *watwata* Hancock, 1828

Common Name:	Armored catfish
First Record:	1984, Oahu
Mechanism:	Aquarium release
Origin:	South America

In the south shore of Oahu, *Hypostomus* cf. *watwata* was found in Kalihi, Manoa/Palolo and Nuuanu Streams. *Hypostomus* cf. *watwata* can attain a much larger size (of nearly 300 mm in length) than the other suckermouth catfish species found on Oahu (*Ancistrus* cf. *temminckii*). Densities of this fish in Nuuanu and Manoa Streams currently are astonishingly high. During this study it was it was easy to catch over 10 kg of this species with a small Hawaiian opae net in less than 20 m of Manoa Stream (by Kaimuki High School). After a suckermouth catfish species becomes established it is difficult to eradicate, and electrofishing has proven to be an ineffective control method in Hawaiian streams (Fuller et al. 1999). It is also doubtful that rotenone would be an effective control method as these suckermouth catfish are facultative air-breathers.

Additionally, differentiation of this species of from *Ancistrus* cf. *temminckii* is simplified by the lack of snout tentacles on *Hypostomous* (Sabaj and Englund 1999). This species of *Hypostomus* is restricted to the lowest portions of freshwater of streams but appears to be intolerant of salt or brackish water. Potential negative impacts on native stream animals would likely be similar as cited above for *Ancistrus* cf. *temminckii*.

AMPHIBIA: ANURA

Family Bufonidae

Bufo marinus (Linneaus, 1758)

Common Name:	Cane toad
First Record:	1932, Oahu
Mechanism:	Biological control release
Origin:	S. America to Texas

Introduced from Puerto Rico to Hawaii in 1932 (Pemberton 1933, Pemberton 1934), the cane toad (*Bufo marinus*) was then released into the rest of Oceania. Cane toads were originally introduced into Puerto Rico in 1920 to control a serious beetle pest, *Phyllophaga vandinei*, that was causing serious losses to banana, coconut, breadfruit, and sugar cane crops (Tyler 1994). An examination of cane toad stomachs several years after their introduction into Puerto Rico found 41% of their diet consisted of *Phyllophaga* and a second crop pest *Diaprepes*. This led the journal *Nature* in 1934 to proclaim 'Toads save sugar crop' and not surprisingly cane toads were immediately imported into many countries (Tyler 1994).

Originally intended to control the sugar cane beetle pest *Anomala orientalis* cane toads have been found to consume a wide variety of non-target species in Hawaii including insects. Another 50 non-target dogs are also estimated to be killed each year in Hawaii after consuming cane toads (Otani et al. 1969). The impacts of these toads on native biota have not been studied in Hawaii. Many native species of snakes, lizards, birds, and mammals in Australia have been documented to have been killed after consuming cane toads (Tyler 1994). Cane toads are ubiquitous along the south shore of Oahu, and they only require freshwater for breeding. They are commonly encountered thoughout urban Honolulu, and during this study we collected tadpoles in Nuuanu and Manoa/Palolo Streams.

Family: Ranidae

Rana catesbeiana Shaw, 1802

Common Name:	Bullfrog
First Record:	1902, Oahu
Mechanism:	Biological control release
Origin:	Eastern United States

Frogs have been introduced into Honolulu as early as 1857 in a taro patch near Nuuanu (Bryan 1932) although what species were imported is uncertain. Bullfrogs (*Rana catesbeiana*) were first imported into Hawaii in 1902 for the control of Japanese beetles, but by 1905 the supplying of San Francisco markets with frog legs from Hawaii had become minor industry (Bryan 1932). Bullfrogs are common in wetlands and streams throughout the State of Hawaii, however, this aquatic species is not nearly as terrestrial as are cane toads. The adverse impacts of bullfrogs have been well documented in the continental United States.

In Hawaii, adult bullfrogs have been documented to consume endangered waterbird chicks such as the Hawaiian Moorhen (*Gallinula chloropus sandvicensis*) at Hanalei National Wildlife Refuge, and taro farmers there commented that this was not an unusual event (Mike Silbernagle, U.S. Fish & Wildlife Service, pers. comm.). Bullfrogs will consume virtually anything (including mice) that will fit into their mouth (Weidenbach 1995, McKeown 1996). During these surveys frogs were found sympatrically with cane toads and adults or tadpoles were collected above areas of tidal influence in Manoa/Palolo and Nuuanu Streams.

APPENDIX B REFERENCES

Adachi, M.S. 1952. Notes. *Proc. Hawaii. Ent Soc*. 14: 353-354.

Alexander, C.P. 1941. New or little-known Tipulidae from the Hawaiian Islands (Diptera). *Proc. Hawaii. Ent Soc.* 11: 23-24.

Alexander, C.P. 1954. An undescribed crane-fly from the Hawaiian Islands (Diptera: Tipulidae). *Proc. Hawaii. Ent Soc.* 15: 297-298.

Alicata, J.E. 1940. Life history and control of the liver fluke of cattle in the Hawaii. *Bernice P. Bishop Mus. Spec. Publ.* 35: 8.

Alicata, J.E. 1969. Parasites of man and animals in Hawaii. S. Karger Press, Basel, Switzerland and New York. 190 pp.

Arthington, A.H. and L.N. Lloyd. 1989. Introduced poeciliids in Australia and New Zealand. In *Ecology and evolution of livebearing fishes (Poeciliidae)*, (G.K. Meffe and F.F. Snelson, Jr., eds), pp. 333-348. Englewood Cliffs, New Jersey: Prentice Hall.

Beardsley, J.W. 1971. Notes: *Hydroptila arctia*. *Proc. Hawaii. Ent. Soc*. 21: 15.

Beardsley, J.W. 1980. New record of *Orthemis ferruginea* (Fabricius) from Oahu. *Proc. Hawaii. Ent. Soc*. 23: 183.

Bickel, D.J. 1987. A revision of the Oriental and Australian Medetera (Diptera: Dolichopodidae). *Rec. Austr. Mus.* 39: 195-259.

Bickel, D.J. 1994. The Australian Sciapodinae (Diptera: Dolichopodidae), with a Review of the Oriental and Australasian Faunas, and a World Conspectus of the Subfamily. *Rec. Austr. Mus. Suppl.* 21: 1-394.

Brock, V.E. 1960. The introduction of aquatic animals into Hawaiian waters. *Internat. Rev. Ges. Hydrobiol.* 45: 463-480.

Bryan, E.H. 1932. Frogs in Hawaii. The Mid-Pacific Magazine 43: 1: 61-64.

Courtenay, W.R. and G.K. Meffe. 1989. Small fishes in strange places: a review of introduced poeciliids. *In* G.K. Meffe and F.F. Snelson, Jr. (eds.), Ecology and evolution of livebearing fishes (Poeciliidae), pp. 319-331. Prentice Hall.

Cowie, R.H. 1995. Identity, distribution and impacts of introduced Ampullariidae and Viviparidae in the Hawaiian Islands. *J. Med. Appl. Malacol.* 5(1993): 61-67.

Cowie, R.H. 1997. Catalog and bibliography of the nonindigenous nonmarine snails and slugs of the Hawaiian Islands. *Bishop Mus. Occas. Pap.* 50: 66 pp.

Cowie, R.H. 1998. Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. *Biodiv. Conserv.* 7: 349-368.

Cresson, E.T., Jr. 1945. A systematic annotated arrangement of the genera and species of the Indo-Australian Ephydridae (Diptera). I. The subfamily Psilopinae. *Trans. Am. Ent. Soc*. 71: 47-75.

Cresson, E.T., Jr. 1946. A systematic annotated arrangement of the genera and species of the Neotropical Ephydridae (Diptera). *Trans. Am. Ent. Soc*. 71: 129-163.

Denning, D.G., and J.W. Beardsley. 1967. The collection of *Cheumatopsyche analis* in Hawaii. *Proc. Ent. Soc. Wash.* 69: 56-57.

Devaney, D.M., M. Kelly, P.J. Lee, L.S. Motteler. 1982. Kaneohe a history of change. Bess Press, Honolulu, Hawaii. 271 pp.

Devick, W.S. 1991a. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. In: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems, Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii*, pp. 189-213. Hawaii Division of Aquatic Resources. Honolulu: Hawaii.

Devick, W.S. 1991b. Job progress report F-14-R-15 [Fresh water fisheries and surveys]. Disturbances and fluctuations in the Wahiawa Reservoir Ecosystem. Hawaii Division of Aquatic Resources.

Dunkle, S.W. 1989. Dragonflies of the Florida Peninsula, Bermuda and the Bahamas. Scientific Publishers, Gainesville-Washington. 155 pp.

Eldredge, L.G. 1994. Perspectives in aquatic exotic species management in the Pacific Islands: Volume I, Introductions of commercially significant aquatic organisms to the Pacific Islands. South Pacific Commission, Noumea, New Caledonia. 127 pp.

Englund, R.A. 1998. Biological assessment and the effects of water withdrawals on Waikele Stream, Oahu aquatic biota. Contribution No. 1998-011 to the Hawaii Biological Survey, Bishop Museum. 22 pp.

Englund, R.A. 1999a. The impacts of introduced poeciliid fish and Odonata on endemic *Megalagrion* (Odonata) damselflies on Oahu Island, Hawaii. *J. Insect Conserv.* 3: 225-243.

Englund, R.A. 1999b. New records and range extensions of native Odonata (Coenagrionidae) and introduced aquatic species in the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 59: 15-19.

Englund, R.A and Y. Cai. 1999. The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 58: 58-65.

Englund, R.A., D.A. Polhemus, and D.J. Preston. 1998. Assessment of the suitability of Kokee State Park streams as habitat for year-round catch and release fishing for rainbow trout without annual stocking. Contribution No. 1998-001, Hawaii Biological Survey, Bishop Museum. 37 pp.

Englund, R.A. and D.J. Preston. 1999. Biological Assessment of the Lower Hamakua Ditch on the Hawaiian Stream Fly (*Sigmatineurum meaohi*) and other aquatic insects. Contribution No. 1999-003 to the Hawaii Biological Survey, Bishop Museum. 31 pp.

Englund, R.A., D.J. Preston, R. Wolff, S.L. Coles, L..G. Eldredge and K. Arakaki. 2000. Biodiversity of freshwater and estuarine communities in lower Pearl Harbor, Oahu, with observations on introduced species. *Bishop Mus. Tech. Rep. in prep.*

Evenhuis, N.L. 1986. Notes. *Proc. Hawaii. Ent Soc*. 27: 4.

Evenhuis, N.L. 1989. Catalog of the diptera of the Australasian and Oceanian regions. Bishop Museum Special Publication 86. Bishop Museum Press and E.J. Brill. 1155 pp.

Evenhuis, N.L. 1996. New records and synonymies of Hawaiian diptera. *Bishop Mus. Occas. Pap*. 46: 27-28.

Evenhuis, N.L. 1997a. New records and synonymies and range extensions of two-winged flies (Diptera) from the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 49: 29-32.

Evenhuis, N.L. 1997b. Diversity of insects and related arthropods of the Naval Magazine. Lualualei, Headquarters Branch, Oahu, Hawaii. Final report prepared for the U.S. Navy. *Bishop Mus. Tech. Rep. 9*. 170 pp.

Farley, D.G. and L.C. Younce. 1977. Stocking density versus efficacy of *Gambusia affinis* in Fresno County rice fields. *Proc. Pap. Annu. Conf. California Mosq. Vector Control Assoc.* 45: 83-86.

Font, W.F., and D.C. Tate. 1994. Helminth parasites of native Hawaiian freshwater fishes: an example of extreme ecological isolation. *J. Parasitol.* 80: 682-688.

Filbert, R.B., and R.A. Englund. 1995. Waiahole Ditch Water Contested Case: Biological Assessments of Windward and Leeward Oahu Streams (including Appendix 1). Report for The Kamehameha Schools/Bishop Estate. Pacific Aquatic Environmental, Honolulu, Hawaii. 156 pp.

Fuller, P.L., L.G. Nico and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society, Special Publication 27, Bethesda, Maryland. 613 pp.

Funasaki, G.Y., P.Y. Lai, L.M. Nakahara, J.W. Beardsley and A.K. Ota. 1988. A review of biological control introductions in Hawaii: 1890 to 1985. *Proc. Hawaii. Entomol. Soc.* 28: 105-160.

Gagne, W.C. and Howarth, F.G. 1975. The cavernicolous fauna of Hawaiian lava tubes 6. Mesoveliidae or water treaders (Heteroptera). *Pac. Ins*. 16(4): 399-413.

Grootaert, P., and N.L. Evenhuis. 1997. A new species of *Thinophilus* (Diptera: Dolichopodidae) from the Hawaiian Islands. *Bishop Mus. Occas. Pap*. 48: 74-77.

Hansen, M. 1995. A review of the Hawaiian Hydrophilidae (Coleoptera). *Pac. Sci.* 49: 266-288.

Hardy, D.E. 1952. Additions and corrections to Bryan's checklist of the Hawaiian Diptera. *Proc. Hawaii. Ent. Soc.* 14(3): 443-484.

Hardy, D.E. 1956. Notes. *Proc. Hawaii. Ent. Soc*. 16(1): 15.

Hardy, D.E. 1960. Insects of Hawaii, Volume 10, Diptera:Nematocera-Brachycera. University of Hawaii Press.

Hardy, D.E. 1964. Dolichopodidae, p. 13-256. *In:* Zimmerman, E.C., *Insects of Hawaii*. Volume 11, Diptera: Brachycera, family Dolichopodidae. Cyclorhapha, series Aschiza, families Lonchopteridae, Phoridae, Pipunculidae, and Syrphidae. Univ. Hawaii Press, Honolulu.

Hardy, D.E. 1985b. Notes. *Proc. Hawaii. Ent. Soc*. 25: 12.

Hardy, D.E. and M.D. Delfinado. 1980. Diptera: Cyclorrahapha III. Series Schizophora, Acalypterae, Exclusive of Family Drosophilidae. *Insects of Hawaii.* 13: 1-451.

Harwood, P.D. 1976. Dragonflies (Odonata) observed in Hawaii in 1973 and 1974. *Proc. Hawaii. Ent. Soc*. 22:251-254.

Hiatt, R.W. 1947. Food chains and food cycle in Hawaiian fish ponds. Part II. Biotic interaction. *Trans. Amer. Fish. Soc.* 74: 262-280.

Hoffman, G.L. and G. Schubert. 1984. Some parasites of exotic fishes. *In*: Distribution, Biology, and Management of Exotic Fishes, Ed. By W.R. Courtenay, Jr. and J.R. Stauffer, Jr., John Hopkins University Press, Baltimore and London, pp. 233-261.

Hoover, J.P. 1996. Hawaii's fishes: a guide for snorkelers divers and aquarists, 3rd edition. Mutual Publishing, Honolulu, Hawaii. 183 pp.

Hoyt, C. 1937. Exhibition and discussion of local material. *Proc. Hawaii. Ent. Soc*. 9(3): 370.

Hung, M.S., T.Y. Chan, and H.S. Yu. 1993. Atyid shrimps (Decapoda: Caridea) of Taiwan, with descriptions of three new species. *J. Crust. Biol.* 13: 481-503.

Hurlbert, S.H., J. Zedler, & D. Fairbanks. 1972. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. *Science* 175: 639-41.

Joyce, R.C. 1969. Notes. *Proc. Hawaii. Ent. Soc.* 20(2): 275.

Kendall, R.L. 1997. Corrections and additions to published American Fisheries Society Books. *Fisheries* 22: 21-22.

Kido, M.H., P. Ha and R.A. Kinzie. 1993. Insect Introductions and diet changes in an endemic Hawaiian amphidromous goby, *Awaous stamineus* (Pisces: Gobiidae). *Pac. Sci.* 47: 43-50.

Kinzie, R.A., C. Chong, J. Devrell, D. Lindstrom, D. Moser and R. Wolff. 1997. Final report on effect of flow regimes on productivity in Hawaiian stream ecosystems. Contract report for the Hawaii Division of Aquatic Resources, Honolulu. 40 pp.

Kondratieff, B.C., R.J. Bishop and A.M. Brasher. 1997. The life cycle of an introduced caddisfly, *Cheumatopsyche pettiti* (Banks) (Trichoptera: Hydropsychidae) in Waikolu Stream, Molokai, Hawaii. *Hydrobiologia* 350: 81-85.

Kubota, G.T. 1996. Tilapia's appetite affects endangered birds. Honolulu Star-Bulletin, May 5.

Lawler, S.P., D. Dritz, T. Strange and M. Holyoak. 1999. Effects of introduced mosquitofish and bullfrogs on the threatened California red-legged frog. *Conserv. Biol.* 13: 613-622.

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

Maciolek, J.A. 1984. Exotic fishes in Hawaii and other islands of Oceania. *In*: Distribution, Biology, and Management of Exotic Fishes, Ed. By W.R. Courtenay, Jr. and J.R. Stauffer, Jr., John Hopkins University Press, Baltimore and London, pp. 131-161.

Mainland, G.B. 1939. Gobioidea and fresh water fish on the island of Oahu. Unpublished Masters Thesis, University of Hawaii.

Mathis, W.N. and T. Zatwarnicki. 1990. Taxonomic notes on Ephydridae (Diptera). *Proc. Biol. Soc. Wash.* 103: 891-906.

McKeown, S. 1996. A field guide to reptiles and amphibians in the Hawaiian Islands. Diamond Head Publishing. Los Osos, California. 172 pp.

Meffe, G.K. and F.F. Snelson. 1989. An ecological overview of poeciliid fishes. *In* G.K. Meffe and F.F. Snelson, Jr. (eds.), Ecology and evolution of livebearing fishes (Poeciliidae), pp. 13-31. Prentice Hall.

Merritt, R.W. and K.W. Cummins. 1996. An introduction to the aquatic insects of North America. Third Edition. Kendall Hunt Publishing Company, Dubuque Iowa. 862 pp.

Miyagi, I. 1965. On the Japanese species of the genus Procanace Hendel, with descriptions of seven new species. *Insecta Matsum.* 27(2): 85-98.

Mundy, B. In press. A checklist of fishes of the Hawaiian Archipelago. Bishop Museum Press, Honolulu, Hawaii.

Nelson, S.G. and Eldredge, L.G. 1991. Distribution and status of introduced cichlid fishes of the genera *Oreochromis* and *Tilapia* in the islands of the South Pacific and Micronesia. *Asian Fish. Sci.* 4: 11-22.

Nishida, G.M. 1997. Hawaiian Terrestrial Arthropod Checklist, 3rd Edition. Hawaii Biological Survey. *Bishop Mus. Tech. Rep.* 12, iv + 263 pp.

Otani, A., Palumbo, N. and G. Read. 1969. Pharmacodynamics and treatment of mammals poisoned by *Bufo marinus* toxin. *Amer. J. Vet. Res.* 30: 1865-1872.

Pemberton, C.E. 1933. Introduction to Hawaii of the tropical American toad Bufo marinus. *Hawaiian Planters' Rec.* 37: 15-16.

Pemberton, C.E. 1934. Local investigations on the introduced tropical American toad *Bufo marinus*. *Hawaiian Planters' Rec*. 38:186-192.

Philippart, J.Cl. and J.Cl. Ruwet. 1982. Ecology and distribution of tilapias, p. 15-59. *In:* The biology and culture of tilapias, R.S.V. Pullin and R.H. Lowe-McConnell (eds.). ICLARM Conf. Proc. 7. International Center for Living Aquatic Resources Management, Manila, Philippines.

Pointier, J.P., R.N. Incani, C. Balzan, P. Chrosciechowski and S. Prypchan. 1994. Invasion of the rivers of the littoral central region of Venezuela by *Thiara granifera* and *Melanoides tuberculata* (Mollusca: Prosobranchia: Thiaridae) and the absence of *Biomphalaria glabrata*, snail host of *Schistosoma mansoni*. *The Nautilus* 107: 124-128.

Polhemus, D.A. 1995a. A survey of the aquatic insect faunas of selected Hawaiian streams. Report for the Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawaii. Department of Natural Sciences, Bishop Museum. Hawaii Biological Survey No. 1995-008. 128 pp.

Polhemus, D.A. 1995b. New Heteroptera and Odonata (Insecta) records and range extensions in the Hawaiian Islands. *Bish. Mus. Occ. Pap.* 42: 42-43.

Polhemus, D.A. 1996. The orangeblack Hawaiian damselfly *Megalagrion xanthomelas* (Odonata: Coenagrionidae): clarifying the current range of a threatened species. *Bish. Mus. Occ. Pap.* 45: 30-53.

Polhemus, D.A. and A. Asquith. 1996. Hawaiian damselflies: a field identification guide. Bishop Museum Press, Honolulu, Hawaii. 122 pp.

Randall, J.E. 1987. Introduction of marine fishes to the Hawaiian Islands. *Bull. Mar. Sci.* 41:490-502.

Randall, J.E., J.L. Earle, T. Hayes, C. Pittman, M. Severns, and R.J.F. Smith. 1993. Eleven new records and validations of shore fishes from the Hawaiian Islands. *Pac. Sci.* 47: 222-239.

Rees, J.T. 1979. Community development in freshwater microcosms. *Hydrobiologica* 63: 113-128.

Rosen, P.C. and C.R. Shwalbe. 1996. Bullfrog impacts on sensitive wetland herpetofauna, and herpetology of the San Bernardino National Wildlife Refuge. Final Report to the Arizona Game & Fish Department Heritage Fund and U.S. Fish & Wildlife Service. 47 pp.

Sabaj, M.H. and R.A. Englund. 1999. Preliminary identification and current distribution of two suckermouth catfishes (Loricariidae) introduced to O'ahu streams. *Bishop. Mus. Occas. Pap*. 59: 50-55.

Sabaj, M.H., J.W. Armbruster, and L.M. Page. In press. Spawning in *Ancistrus* (Siluriformes: Loricariidae) with comments on the evolution of snout tentacles as a novel reproductive strategy: larval mimicry. *Ichthyol. Explor. Freshwaters*.

Samuelson, G.A. 1998. New records for Hawaiian Coleoptera. *Bishop Mus. Occas. Pap.* 56: 27-33.

Shafland, P.L. 1991. Management of introduced freshwater fishes in Florida. In: *New directions in research, management, and conservation of Hawaiian freshwater stream ecosystems, Proceedings of the 1990 Symposium on Freshwater Stream Biology and Management, State of Hawaii*, pp. 213-238. Hawaii Division of Aquatic Resources. Honolulu: Hawaii.

Swinnen, F., M. Leynen, R. Sablon, L. Duvivier and R. Vanmaele. 1998. The Asiatic clam *Corbicula* (Bivalvia: Corbiculidae) in Belgium. Bulletin De L'Institut Royal Des Sciences Naturelles De Belgique 68: 47-53.

Strazanac, J.S. 1992. Notes. *Proc. Hawaii. Ent. Soc.* 31: 23.

Tenorio, J.A. 1980. Family Ephydridae. *Insects of Hawaii* 13: 251-351.

Tyler, M.J. 1994. Australian frogs. Second Edition. Reed Books, Chatswood, New South Wales. 192 pp.

U.S. Congress, Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. OTA-F-565. Washington, DC: U.S. Government Printing Office, September 1993.

Usinger, R.L. 1968. Aquatic insects of California. University of California Press. 508 pp.

Usinger, R.L. 1972. Robert Leslie Usinger: an autobiography of an entomologist. Pacific Coast Entomological Society, California Academy of Sciences. San Francisco, California. 330 pp.

Van Dine, D.L. 1908. Mosquitoes. Annual Report of the Hawaii Agricultural Experiment Station for 1907, pp. 38-39.

Van Duzee, M.C. 1933. New Dolichopodidae from the Hawaiian Islands (Diptera). *Proc. Hawaii. Ent. Soc*. 8(2):307-357.

Walters, L.L. and E.R. Legner. 1980. Impact of the desert pupfish, Cyprinodon macularius, and *Gambusia affinis* on fauna in pond ecosystems. *Hilgardia* 48: 1-18.

Weidenbach, R.P. 1995. Freshwater pond life: a guide to the animals and plants of Hawaii's freshwater aquaculture ponds. State of Hawaii, Aquaculture Development Program, Department of Land and Natural Resources. 84 pp.

Williams, F.X. 1933. Notes. *Proc. Hawaii. Ent. Soc*. 8(3): 378.

Williams, F.X. 1937. Exhibition and discussion of local material. *Proc. Hawaii. Ent. Soc*. 9(3): 368.

Williams, F.X. 1943. Biological studies in Hawaiian water-loving insects. Part III. Diptera or Flies. C, Tipulidae and Psychodidae. *Proc. Hawaii. Ent. Soc*. 11(3): 313-338.

Wirth, W. W. 1947. *Ephydra gracilis* Packard, a recent immigrant fly in Hawaii (Diptera: Ephydridae). *Proc. Hawaii. Ent. Soc*. 13: 141-142.

Wirth, W.W. 1951. A revision of the dipterous family Canaceidae. *Occas. Pap. Bernice P. Bishop Mus.* 20: 245-75.

Wirth, W.W. 1969. The shore flies of the genus *Canaceoides* Cresson (Diptera: Canaceidae). *Proc. Calif. Acad. Sci.* (4) 36: 551-70

Wirth, W.W. 1971. The brine flies of the genus ephydra in North America (Diptera: Ephydridae). *Ann. Ent Soc. Am.* 62(2): 357-377.

Zimmerman, E.C. (1948) *Insects of Hawaii*. Volume 2. Apterygota to Thysanoptera inclusive. Honolulu: University of Hawaii Press.

APPENDIX C

List of Authors, Taxonomic Consultants and Acknowledgements of Assistance

This study was conducted through the facilities of the Bishop Museum Department of Natural Sciences by:

R.A. Englund, K. Arakaki, D.J. Preston, S.L. Coles, L.G. Eldredge

Other Bishop Museum Department of Natural Sciences staff contributing to this study included:

R.C. DeFelice, K.S. Kami, R.L. Pyle, G.A. Samuelson, A.Y. Suzumoto

TAXONOMIC CONSULTANTS

Taxonomic expertise for identifying organisms was provided by the following individuals, and their efforts and contributions to this project are gratefully acknowledged.

Amphibians: Ms. Carla Kishinami, Bishop Museum
Arachnida and Acari: Dr. Sabina Swift, Bishop Museum
Cichlid and Poeciliid Fish: Mr. Mike Yamamoto, Hawaii Division of Aquatic Resources
Copepods: Ms. April Davis, University of Hawaii
Diptera: Dr. Neal Evenhuis, Bishop Museum
Decapod Crustaceans: Dr. Brian Kensley, Smithsonian Institution , Mr. Cai Yixiong, National University of Singapore
Decapods, Amphipods: Dr. David Muir, Bishop Museum, Dr. James Thomas, Nova Southeastern University
Fish: Dr. Jack Randall, Bishop Museum
Gastropods: Dr. Robert Cowie, and Ms. Regie Kawamoto, Bishop Museum
Heteroptera: Dr. Dan Polhemus, Smithsonian Institution
Hirudinea: Dr. Mark Siddall, American Museum of Natural History
Isopods: Dr. Francis Howarth, Bishop Museum, Dr. Stefano Taiti, Centri di Studio per la Faunistica ed Ecologia Tropicali
Loricariid Fish: Mr. Mark Sabaj, Illinois Natural History Survey, Dr. John Armbruster, University of Auburn
Poeciliid Fish: Dr. David Greenfield, University of Hawaii, Dr. William Fink and Dr. Robert Miller, University of Michigan

ACKNOWLEDGEMENTS

Many thanks to Mr. Michael Yamamoto and Ms. Annette Tagawa of the Hawaii Division of Aquatic Resources for assisting in fish species identifications, distributional data, and providing sampling assistance and advice. Dr. Jack Randall assisted in the identification and photography of many different fish species. Dr. Neal Evenhuis, Dr. Francis G. Howarth, Dr. Jim Carlton, and Dr. Dan Polhemus provided critical manuscript reviews. Bishop Museum librarians Ms. B.J. Short and Ms. Patty Belcher patiently provided very helpful support to researchers involved in this project. Mr. Desoto Brown and Mr. Ron Schaeffer of the Bishop Museum Archives provided invaluable assistance in tracking down historical south shore Oahu photos. We especially would like to thank Ms. Tracie Mackenzie for her administrative support.