


BIODIVERSITY OF FRESHWATER AND ESTUARINE COMMUNITIES IN LOWER PEARL HARBOR, OAHU, HAWAII WITH OBSERVATIONS ON INTRODUCED SPECIES

February 2000

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Cover

From upper left: Photograph taken in 1999 of Waimalu Stream mouth lined with mangroves (*Rhizophora mangle*) as it enters Pearl Harbor. Upper right photograph: taken prior to the introduction of mangroves in 1911 at Kukona fishpond, Waiau, Pearl Harbor (J.F.G. Stokes photograph, CP 3763, Bishop Museum Archives). Plants shown in the 1911 Stokes photograph include a native great bulrush, *Schoenoplectus* (*Scirpus*) *lacustris* subsp. *validus*, coconut trees (*Cocos nucifera*), and pickleweed (*Batis maritima*) in the lower left corner. The native great bulrush community has now been eliminated in Pearl Harbor by mangroves. Lower left photograph: taken in 1930 at Loko Eo fishpond in the Waipio Peninsula of Pearl Harbor (J. Gilbert McAllister photograph, CN 15355, Bishop Museum Archives). The only identifiable plant growing along the fishpond walls in the 1930 McAllister photograph is pickleweed in the bottom foreground area. The Loko Eo fishpond was filled and now is the site of the present-day Ted Makalena golf course. Lower right photograph: Blaisdell Park area in 1999 near the mouth of Waimalu Stream; mangroves on the right side of photograph encroaching on pickleweed.

BIODIVERSITY OF FRESHWATER AND ESTUARINE COMMUNITIES IN LOWER PEARL HARBOR, OAHU, HAWAII WITH OBSERVATIONS ON INTRODUCED SPECIES

Final Report prepared for the U.S. Navy

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EXECUTIVE SUMMARY

Many species of aquatic organisms have been introduced into Pearl Harbor's streams, wetlands, and estuarine areas, altering the species composition of the aquatic fauna. This study, the first comprehensive inventory of the non-marine areas of Pearl Harbor, has found that introduced species comprise the dominant portion of the biota in the estuaries and streams of Pearl Harbor. The lower portions of Pearl Harbor streams, springs, and wetlands are now dominated both in total biomass and in total numbers by introduced species. The effects of introduced species vary widely, with fish species such as mosquitofish, suckermouth catfish, tilapia, and other cichlids suspected of causing the disappearance of many native aquatic species. The effects of introduced species such as dragonflies and damselflies appear to be more benign, as they have not been found to displace native species.

A total of 329 species in 8 phyla were collected and identified in the estuarine and riparian habitats of Pearl Harbor. Of these 329 species, only 21% were native while 60% were introduced with the remainder (19%) being species of undetermined origin. Terrestrial arthropods found in riparian zones adjacent to aquatic habitats were also collected, as these insects are a major dietary component for some fish species. If terrestrial arthropods found in riparian areas are excluded, 192 aquatic species were identified in the lower reaches of Pearl Harbor streams and wetlands. For these aquatic species, introduced species still dominated with 47% of the species recorded, while only 33% were native (endemic or indigenous) and the balance (20%) undetermined.

Arthropods (mainly insects) constituted nearly 61% of the species collected in Pearl Harbor estuarine habitats. Other important groups found in Pearl Harbor estuaries included vertebrates (22%), mollusks (8%), and worms (7%). Minor components of the fauna collectively constituted only 2% of the species found, and included cnidarians, platyhelminthes, nematodes, and sipunculans.

A new species of aquatic mite, *Eupodes* n. sp., was found in Pouhala Marsh during these surveys. In addition, two new introduced species were found during this study--a species of fang-toothed blenny (*Omobranchus ferox*) and an estuarine hydrobiid snail (*Pyrgophorus* cf. *coronatus*) introduced from the Caribbean. A new Oahu Island record was that of an introduced aquatic plant, *Vallisneria americana*. Introduced aquatic vertebrates and invertebrates found in Pearl Harbor have no predominant geographic origin, with species originating fairly evenly from North and South America, Asia and the western Pacific, with smaller numbers of species originating from Africa.

These surveys also found that introduced species already recorded in the Hawaiian Islands are spreading into the lower reaches of Pearl Harbor streams. For example, the first confirmed report in a Pearl Harbor drainage of apple snails (*Pomacea canaliculata*) and a new introduction of an African cichlid (*Hemichromis elongatus*) were recorded. Mangroves continue their encroachment into the Pearl Harbor tidal mudflats. Introduced mangroves are the cause of significant changes in the physical environment of Pearl Harbor. It is difficult to ascertain if the net affects of mangroves in Hawaii are negative or positive. Beneficial effects include increases in water quality and decreased sediment input into the nearshore environment. Adverse effects include the encroachment of mangroves into habitat utilized by some species of endangered Hawaiian waterbirds and the overgrowth of some Hawaiian fishponds. The environmental disturbance associated with mangrove removal combined with the high costs and frequency at which the work must be repeated mean that control efforts should be limited and carefully focused.

An increase in non-native species in the freshwater and estuarine portions Pearl Harbor will probably continue. This is because of the wide variety of sources from which introductions take place. The majority of introduced species appear to have come from three sources: 1) intentional and accidental aquarium releases, 2) intentional biocontrol releases, and 3) intentional food source releases.

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INTRODUCTION

A. Pearl Harbor Biodiversity Project

The Pearl Harbor Biodiversity Project was funded by the Department of Defense Legacy Program, through the U. S. Navy. The project was performed in two phases. Phase I of the study was conducted from November 1995 through June 1997. Phase I involved investigations of the marine organisms of Pearl Harbor, with emphasis on detection of nonindigenous marine organisms that may have become established in the harbor over the past century. Fieldwork for the Phase II investigations commenced in November 1997 and ended in October 1998. Phase II studies investigated the estuarine and freshwater areas of the mouths of streams that enter the harbor's three main lochs.

Summary of Pearl Harbor Legacy Project Phase I Findings

The first major biological survey of Pearl Harbor was conducted from 1970 to 1972 (Evans et al. 1974), and the marine and estuarine invertebrate and fish communities in Pearl Harbor, Oahu, Hawaii were again surveyed at fifteen stations throughout the harbor between January and October, 1996 (Coles et al. 1997, 1999). The Coles et al. (1997) study collected or observed more than 400 species, the highest number of taxa that have been collected in any Pearl Harbor study, with about 22% considered to be introduced or cryptogenic. Cryptogenic species are defined as species of uncertain origin that are most likely introductions (Carlton 1996). The highest numbers of taxa occurred at the channel entrance (ca. 170) and in Rainbow Bay (ca. 140) at the northeast head of East Loch. Lowest taxa numbers (ca. 35) occurred in areas of high sedimentation in West Loch.

Over 1100 marine taxa (algae, invertebrate and fish) have been reported (including those recorded in the present study) from the harbor (Coles et al. 1997). Large increases in the numbers of species were reported for the 1920s to 1930s, and the 1970s and 1990s. However, these peaks are probably related to high levels of sampling activity in those decades. Subsequent analyses (Coles et al. 1999) suggested relatively high introduction rates corresponded to the decades of World Wars I and II when shipping activity in the harbor was probably maximal.

The marine organisms collected in Phase I included 12 new nonindigenous and 12 new cryptogenic (neither demonstrably native nor introduced) species of sponges, bivalve mollusks, crustacea and ascidians. The most prominent new nonindigenous species was the Caribbean barnacle *Chthamalus proteus*, which appears to have been introduced to Hawaii since the early 1970s and is now the most abundant intertidal organism in many other Hawaiian embayments on Oahu, Maui, and Hawaii. It has been found as far west as Midway and Guam (Southward et al. 1998).

Of the 101 introduced species that have been collected from Pearl Harbor since the beginning of the century, 69 species (68%) were found in 1996. Most of the introduced species collected in 1996 and whose geographic origins are known originated in the Indo-West Pacific, although several species originated in the Red Sea and the Caribbean Sea.

The composition of the biological communities in the harbor in 1996 suggested that the environmental conditions in the harbor had improved in 20 years. For example, in 1996 reef corals occurred in the harbor along the ship entrance channel, West Loch and Middle Loch channels, near the entrance to Southeast Loch, and even on the Hawaiian Electric Company's discharge sheet piling and along the shoreline at Rainbow Bay in East Loch (Coles 1999). No corals were found in the extensive studies conducted in the 1970s (Evans et al. 1974). A number of factors may have interacted to produce improved environmental conditions in the harbor, including the ending of Naval shipboard effluent and land based sewage disposal, and a decrease in non-point source runoff in East and Middle Lochs (Grovhoug 1992).

Pearl Harbor Phase II Freshwater and Estuarine Surveys

The lower reaches of each of the streams entering Pearl Harbor were investigated during Phase II. Selected groups of organisms in the fresh and estuarine portions of these streams were sampled. Seventy percent of the natural freshwater discharge into Pearl Harbor originates from a spring complex that is the largest and most significant in the Hawaiian Islands, with an average combined pre-development flow ranging from 176-183 Mgal/d (Million gallons/day) (Nichols et al. 1997). For comparison, the Waiakea springs complex in Hilo is the next largest system in Hawaii, with an average discharge of 146 Mgal/d (Stearns and Macdonald 1946). Although the abundance of fresh water in spring areas within Pearl Harbor has diminished because of upgradient groundwater pumping (Nichols et al. 1997), this area still supports one of the largest freshwater spring systems in the Pacific Islands. Numerous studies and surveys have been conducted in the more marine habitats of Pearl Harbor, but little baseline research has been conducted in the lower reaches of streams and coastal wetlands in the harbor despite the large extent of these habitats. Pearl Harbor also supports the only remaining tidal flat habitat on Oahu (Ducks Unlimited, Inc. 1998), which is now threatened by invasive plants and human encroachment. The large Pearl Harbor spring, coastal wetland, and riverine systems represent an ecologically important and unique natural resource and formerly contained a significant endemic fish and invertebrate fauna (Titcomb 1972). Prior to the present survey little was known about the current status of these areas. This is the first assessment of the biodiversity of the freshwater, estuarine, and coastal wetland regions of Pearl Harbor.

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; and 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 alien 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 commencing in the early 1980s 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, the zebra mussel 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, Eldredge 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 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 to control crayfish depredations, with over 1,417 ha (3500 a) of wetland taro fields treated in Hawaii (Devaney et al. 1982). Amphibians introduced in the Pacific region for biological control purposes such as giant marine toads (*Bufo marinus*) have been shown to have detrimental impacts to native organisms while widely preying on non-target species in Papua New Guinea (Zug et al. 1975). Giant marine toads 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 1999). For example, mosquitofish (*Gambusia affinis*) 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). In southwestern Australia, Morgan et al. (1998) found 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 mosquitofish on native pseudomugilid (blue-eyes) fish species in Australia. Mollusks, such as apple snails 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 are an ever increasing threat to Hawaiian stream, wetland, and anchialine pond ecosystems. Not only do introduced species compete and prey upon native species, but they have also brought with them a complement of disease and parasites to which native species have not evolved resistance (Font and Tate 1994). The severity of alien 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 the full complement of fresh and estuarine water endemic and indigenous fish, crustacean, mollusk, and aquatic insect species (Maciolek 1984, Polhemus 1995). 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 including Pearl Harbor and appear to have been displaced by introduced species (Polhemus 1996, Englund 1999).

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 alien aquatic introductions.

Since 1993 (Englund 1993), three ecologically significant and potentially harmful new introduced species have become established in Waikele Stream and its associated wetlands (results of the present study). These include a new record of an introduced freshwater shrimp species, a range expansion of the introduced apple snail, and another dragonfly introduction. The native freshwater fish *Awaous guamensis* was 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.

D. Vectors for Introductions of Freshwater and Estuarine Species in Pearl Harbor and 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 non indigenous 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).

Introduced aquatic species have been brought into Hawaii both accidentally and intentionally. 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. The first phase of this study (Coles et al. 1997, 1999) 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 phase of the study the natural geographic origin could be determined for all 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.

Two species of freshwater snails found in Pearl Harbor watersheds (during the present study), *Tarebia granifera* and *Melanoides tuberculata* could be recent introductions, but the possibility that they are Polynesian introductions (pre-1778) can not be ruled out (Cowie 1998). Mosquitoes were one of the first and most harmful introduced aquatic species in Hawaii (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 twentieth 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, the 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 in Hawaii (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 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. Mosquitofish have 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).

E. Pearl Harbor Stream and Estuarine Physical Environment

Pearl Harbor Springs and Streams Description

Pearl Harbor is formed from a drowned river system that has been successively flooded and submerged during various glacial epochs, with oyster beds and thin coral reefs flourishing during periods of higher sea level (Stearns 1985). Through wells drilled in the Pearl Harbor area, it was determined that alternating beds of limestone, tuff, alluvium and marine clays now cover the original Koolau volcano land surface by up to 326 m (1069 ft) (Stearns 1985). The lower sections of Pearl Harbor streams, wetlands, and springs now lie largely over a fill of oyster beds, reefs, gravel and mud deposits that have resulted from erosion of the upper elevation areas of the Koolau and Waianae Mountains.

During periods when the sea level was as much as 107 m (351 ft) lower than present, streams entering Pearl Harbor incised deep canyons into basalt, and these streams flowed much further out to sea prior to the submergence of Pearl Harbor (Stearns 1985). These canyons were incised as a result of heavy precipitation in upper elevation areas of Pearl Harbor drainages, and this led to the deposition of calcareous and non-calcareous sediments in lower Pearl Harbor (Stearns and Vaksvik 1935). This long period of sedimentation then formed the cap rock of the Pearl Harbor aquifer, and lowering of the sea level increased stream gradient. Streams in the Pearl Harbor watershed are now removing the cap rock that was left above sea level with artesian springs discharging from bedrock where the cap rock has been removed (Stearns and Vaksvik 1935).

Both surface and sub-surface water for Pearl Harbor springs and streams originates in the Koolau and Waianae Mountains. Groundwater from these two mountain ranges flows down gradient in the Koolau basalt until coastal sediments near Pearl Harbor are encountered. The zone of springs

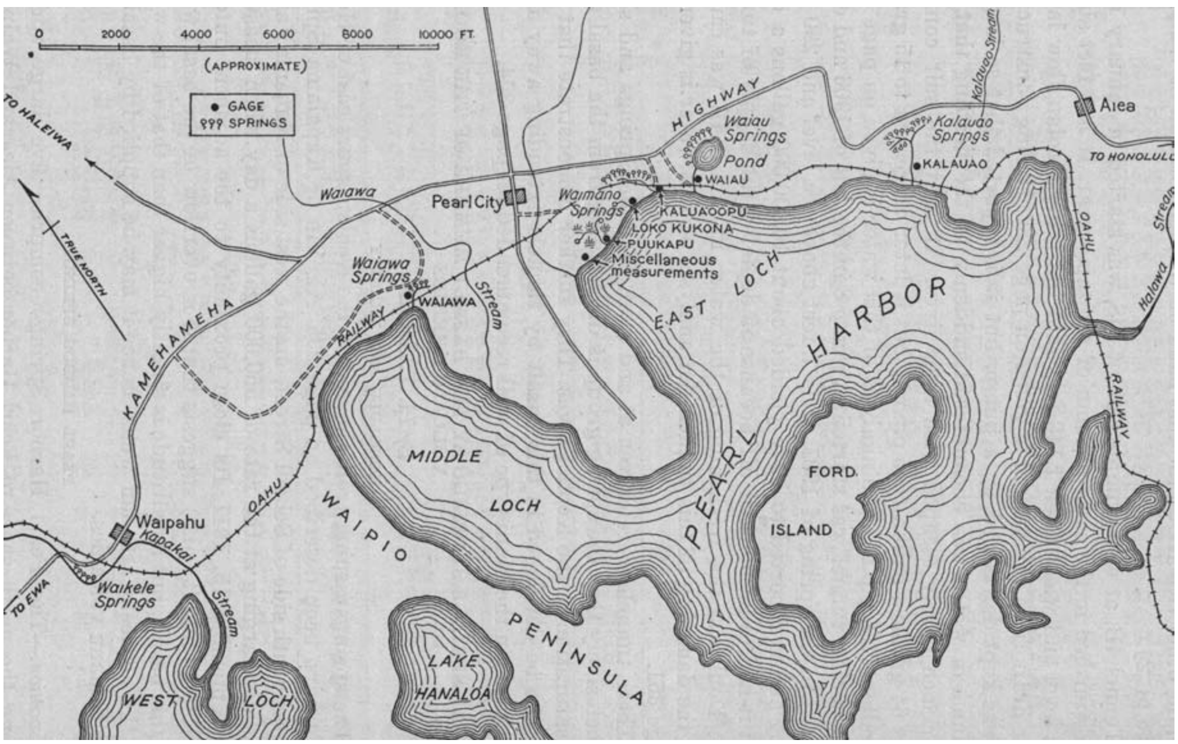

Figure 1. Historic map of the major Pearl Harbor springs in 1935.

along Pearl Harbor is restricted to a narrow strip lying between the inland edge of marine sediments and the caprock at approximately 6.1 m (20 ft) above sea level (Visher and Mink 1964). These springs are fed from breaks or low points in the caprock that allow escape of groundwater; this consequently results in a series of large freshwater releases (Stearns and Vaksvik 1935). Most of the water issues from the inland edge of the caprock where the basalt is exposed (Visher and Mink

1964), for instance at the base of the basalt cliffs of Leeward Community College where Waiawa Springs emerges. Water also emerges seaward of the exposed basalt cliff, through the thin caprock of the Pearl Harbor coastal plain, but in lesser quantities than at the base of the break in the Koolau basalt (Visher and Mink 1964). Figure 1, taken from Stearns and Vaksvik (1935) shows the location and Hawaiian names of the five major spring complexes flowing at the heads of the lochs into Pearl Harbor.

The first development of groundwater (and therefore the first reduction in freshwater spring flow) in the Pearl Harbor area occurred when a well was drilled in Honouliuli in 1879 (Stearns and Vaksvik 1935). Since then, water discharging from the major Pearl Harbor springs has been reduced from an estimated pre-development flow of 176 to 183 Mgal/d to 46 to 48 Mgal/d during 1977-1978 (Nichols et al. 1997). The latest available published data on the combined Pearl Harbor springs discharges indicated a flow of 80 Mgal/d in 1983. Separate flow data for each spring are presented in Table 1. The spring discharges have increased in the past few years because of the cessation of water pumping as sugarcane cultivation on Oahu has ceased (Nance 1998). For example, Waikele Springs used to be almost completely diverted but has not been diverted since 1989 (Englund and Filbert 1999). Table 1 shows the relative sizes of each Pearl Harbor spring complex for the earliest available years on record, 1911-1920.

Table 1. Estimated discharges of the Pearl Harbor Springs from 1911-1920, the first year of available flow data for each spring, and from 1971-1980, the most recent data for each separate spring (from Nichols et al. 1997). Diversions began in 1879.

Pearl Harbor Spring	1911-1920 Discharge (Mgal/d)	1971-1980 Discharge (Mgal/d)
Kalauao	25	12.4
Waiau-Waimano	39.6	25
Waiawa	18	9.2
Waikele	45.1	14.8
Total estimated flow	127.7	61.4

In 1998, Waikele Springs accounted for approximately 80% of the baseflow of Waikele Stream in its lowest reaches (Nance 1998). Above the emergent Pearl Harbor springs, stream flows are usually quite low, especially in the low to middle elevation areas, and consist mainly of surface water runoff. Also, water flow in some streams such as Waimano and Waikele/Kipapa often naturally disappears into the stream channel alluvium during dry periods. The Waianae Mountain tributaries of all Pearl Harbor streams are intermittent, and flow only following heavy rains. Flow is perennial only in the Koolau Mountain headwaters and near the mouth in the area of the basal Pearl Harbor springs. Above the areas of spring influence, Pearl Harbor streams are characterized by high flood peaks and low baseflows, as are other Oahu streams (Nichols et al. 1997). Streamflows are more constant downstream of the Pearl Harbor springs, and have more characteristics of groundwater (low salinity, high silica, high nitrate levels) rather than surface water (Nance 1998).

Pearl Harbor Vegetation

Shoreline vegetation along Pearl Harbor streams, springs, and wetland areas has gone through a substantial change in the past sixty years. The vegetation at the mouth of Waikele Stream was studied by Hosaka from 1931 to 1935 (Hosaka 1937). At that time, Hosaka referred to the Waikele Stream as Kipapa Stream. This study was prior to the successful large-scale establishment of mangroves in Pearl Harbor. Hosaka (1937) characterized the vegetation along the Pearl Harbor shoreline as a *Batis*-*Bulboschoenus (Scirpus) maritimus* (pickleweed-bulrush) community. A representative photograph from the Bishop Museum Archives of the Pearl Harbor shoreline, that was taken at the Pearl City Peninsula between 1900 and 1910, prior to the introduction of mangroves, is reproduced in Figure 2. This photograph and others were analyzed with the assistance of D. Herbst, Bishop Museum, and they provide evidence of native plant species, not mentioned by Hosaka (1937), that were formerly common along Pearl Harbor shorelines prior to the introduction of mangroves. Evidence of Pearl Harbor shorelines containing a native great bulrush, *Schoenoplectus* (*Scirpus*) *lacustris* subsp. *validus*, and *Sesuvium portulacastrum* community are shown in Figure 2. Introduced plant species in this photograph include weeping willow (*Salix babylonica*), bananas (*Musa* x *paradisiaca*), bamboo (*Bambusa vulgaris*), and taro (*Colocasia esculenta*). The presence of the taro and bulrush along the shoreline also indicates the presence of freshwater spring input in these shoreline areas. Other examples of this lost vegetative community include a 1911 photograph (CP 3763 in Bernice P. Bishop Museum (BPBM) Archives) taken at the Kukona fish pond at Waiau, Pearl Harbor (at the Waiau-Waimano Springs complex) showing bulrush (*Schoenoplectus lacustris* subsp. *validus*), coconut trees (*Cocos nucifera*), and pickleweed (*Batis maritima*). A photograph (CN 15356 in BPBM Archives) taken in 1930 at the Pouhala and Kaaukuu fishponds, (the present area of Pouhala Marsh), shows various grasses in the foreground that may possibly include *Brachiaria mutica*, and beyond the grasses a low mat of the native *Sesuvium portulacastrum* lined the banks of the fishpond.

Hosaka (1937) described thick patches of pickleweed along the shore of West Loch growing among *Sesuvium portulacastrum*, and a bulrush, *Bulboschoenus maritimus* subsp. *paludosus*, (as *Scirpus maritimus*) above the high tide level. This bulrush was conspicuous because prior to the introduction of mangroves it was the tallest plant species at the mouth of Waikele Stream (Hosaka 1937). However, the native bulrush *Schoenoplectus lacustris* subsp. *validus* observed in the Pearl Harbor historical photographs attains a height of up to 3 m (10 ft) (Wagner et al. 1990), which is twice the maximum height of *Bulboschoenus maritimus* subsp. *paludosus*, the bulrush species observed by Hosaka (1937) at the mouth of Waikele Stream. It is not known why the taller native

Figure 2. Archival photograph of Pearl Harbor shoreline prior to the introduction of mangroves, circa 1900-1910 (Alonzo Gartley photograph, CP 117,072, Bishop Museum Archives).

bulrush and other species were not observed by Hosaka. However, it is possible these species were either eliminated from Pearl Harbor by the time his study was conducted in the 1930s, or that the species observed in Figure 2 (and other archival photographs) were not found within the portion of the Pearl Harbor area studied by Hosaka. Hosaka (1937) noted that where the soil was drier, *Prosopis pallida* (as *P. chilensis*), *Brachiaria mutica* (as *Panicum purpurascens*), and *Pluchea indica* were the dominant species. All of these species are introduced. Pickleweed was introduced into Hawaii in 1859 (Wagner et al. 1990), and *Bulboschoenus maritimus* subsp. *paludosus* is indigenous to Hawaii.

By the time of the present study, the riparian vegetation surrounding lower stream reaches, wetlands, and spring areas had become dominated by a few introduced species. Mangroves, pickleweed, and *Pluchea indica* and *Pluchea carolinensis* dominated the shoreline areas. Milo (*Thespesia populnea*), a possibly indigenous plant or Polynesian introduction (Wagner et al. 1990), was also commonly interspersed among mangroves. Milo was usually found in slightly drier areas than the mangroves growing in the wetter intertidal regions. Except in areas cleared by humans, drier upland areas, or areas not altered by development, mangroves now form a dense and almost impenetrable monoculture along all Pearl Harbor lochs. The introduction of mangroves has profoundly changed the physical environment of Pearl Harbor estuarine areas (Wester 1981, Allen 1998) from a low shrub and bulrush community to one dominated by nearly impenetrable stands of mangroves.

The first mangroves (*Rhizophora mangle*) in Hawaii were planted in 1902 in the southwestern mudflats of Molokai (Allen 1998). Four species of mangroves from the Philippines (*Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *B. parviflora*, and *Ceriops tagal*) were first planted on the mudflats of Middle and West Loch of Pearl Harbor in 1922, but none of these were successful (McEldowney 1922, Wester 1981). Although not observed in the early 1930s in Pearl Harbor (Hosaka 1937), mangroves apparently have been found in Pearl Harbor since 1917 (Wester 1981), but the steep-sided shorelines provided little suitable habitat for colonization. However, starting in World War II, the mechanical harvesting of sugarcane led to increased sedimentation inputs causing deltas to be built up in the mouth of Pearl Harbor streams (Wester 1981). Aerial photographs (Figures 3-6) show that the Waikele Stream mouth in West Loch was virtually free of mangroves in 1951, but by 1975 a stand of 16 ha (40 a) existed (1951-1975 photographs courtesy Lyndon Wester and Association of Pacific Coast Geographers; from Wester 1981). Since 1981, mangroves have steadily colonized the mudflats of the Waikele Stream estuary and have grown seaward ca. 60 m (200 ft) between 1982 and 1994 (Englund 1998; See Waikele Stream Study Area section of this current report). Currently in Pearl Harbor wetlands and estuaries, mangroves define the area of highest tidal influence. A change in vegetation from mangrove to either hau (*Hibiscus*

Figure 3. Waikele Stream mouth, West Loch Pearl Harbor in 1951.

Figure 4. Waikele Stream mouth, West Loch Pearl Harbor in 1965.

Figure 5. Waikele Stream mouth, West Loch Pearl Harbor in 1975.

Figure 6. Waikele Stream mouth, West Loch Pearl Harbor in 1995.

tiliaceus), Guinea grass (*Panicum maximum*) or *Brachiaria mutica* sharply demarcates the strictly freshwater areas from areas with a saltwater influence.

Because of a lack of native vascular plants occupying the lowest portions of intertidal wetland areas, mangroves generally have not displaced native plant communities in Hawaii (Allen 1998). In Pearl Harbor and elsewhere in Hawaii, large mangrove stands exist in areas of anthropogenically created sediment deposition (Wester 1981, Allen 1998). Allen (1998) described successional changes induced by introductions of saline tolerant plants such as mangrove and pickleweed. This change included the replacement of Hawaiian brackish water communities of indigenous *Ruppia maritima* (ditchgrass), algae, fungi, and sessile animals by pickleweed meadows, which are now being overgrown by mangroves (Allen 1998). Although most fishponds in Pearl Harbor have already been destroyed by human activities, mangrove overgrowth has also damaged a number of others (Wester 1981, Allen 1998). The greatest negative impact to wildlife resources caused by mangrove and pickleweed encroachment is the loss of mudflat and shallow, inshore, and anchialine habitats needed by endangered waterbirds such as the Hawaiian Stilt (Allen 1998, Ducks Unlimited 1998).

It is important to recognize that introduced mangroves may also have had positive impacts. Positive aspects include sediment retention and a resulting improvement in water quality in most estuarine areas (Allen 1998). Mueller-Dombois and Fosberg (1998) believed that mangrove control efforts in Hawaii were usually ill advised and a waste of money as mangroves usually provide positive benefits. In Pearl Harbor, mangroves provide habitats for native Black-Crowned Night-Herons, and native and introduced juvenile fish and crustaceans. They also probably provide these juvenile fishes and crustaceans with a refuge from predation by larger fish, as they do elsewhere in the Pacific (Birkeland and Grosenbaugh 1985). Mangroves may also be correlated to increased fish and crustacean production as in other areas of the Pacific (Birkeland and Grosenbaugh 1985, Baran 1999). High densities of native fish species such as *Mugil cephalus* and *Kuhlia sandvicensis*, and introduced species such as blackchin tilapia (*Sarotherodon melanotheron*), mosquitofish, and *Poecilia mexicana* were often observed in mangrove roots during this study.

METHODS

A. Literature Search

Numerous sources of information on the environmental conditions and biological communities of Pearl Harbor were examined. Literature consulted included published papers in the scientific literature, taxonomy-based monographs and books reporting organisms collected from Pearl Harbor, and unpublished reports of environmental studies in the estuarine regions of Pearl Harbor performed by and for the U.S. Navy, Hawaii Division of Aquatic Resources, and private organizations. Environmental reports and environmental impact statements and assessments were reviewed from AECOS Inc., Bishop Museum, University of Hawaii Library, Hawaiian Electric Co. Environmental Department, and Pacific Aquatic Environmental, Inc. An annotated bibliography of all the literature assembled is presented in Appendix A.

B. Bishop Museum Collections

The Bishop Museum collections of aquatic insects, mollusks, other invertebrates, and fishes were reviewed for all estuarine and freshwater organisms historically collected from Pearl Harbor wetlands, springs, and fresh and estuarine portions of streams entering Pearl Harbor. For the mollusk and fish collections this involved searching the collection catalogs for specimens that were collected from Pearl Harbor 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 Pearl Harbor freshwater and estuarine organisms.

C. Field Surveys- General Methods

Sampling for Phase II of the Pearl Harbor Biodiversity Project began in October 1997 and ended in August 1998. Representative sampling stations were established in each major Pearl Harbor stream and wetland (Figure 7), stations are listed in Table 2. 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 both within sampling stations and throughout the study area. Most sampling stations were generally at or just above sea level.

Insect Sampling

Aquatic insect sampling was conducted according to Polhemus (1995) and Englund et al. (1998). Collections of both immature and adult specimens were made with aerial sweep nets, aquatic dip nets, seines, and by taking benthic samples. Visual observations of aquatic insects were also conducted above the waterbody. In addition, the 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 subsequently transported to the Bishop Museum Entomology Collection for curation and identification. Voucher specimens are currently housed in the Bishop Museum collections.

We also collected and identified the predominant terrestrial insects on vegetation immediately in the vicinity of riparian habitats, as some riparian insects were an important part of fish diet in the lower reaches of Pearl Harbor streams (see Fish Diet Results).

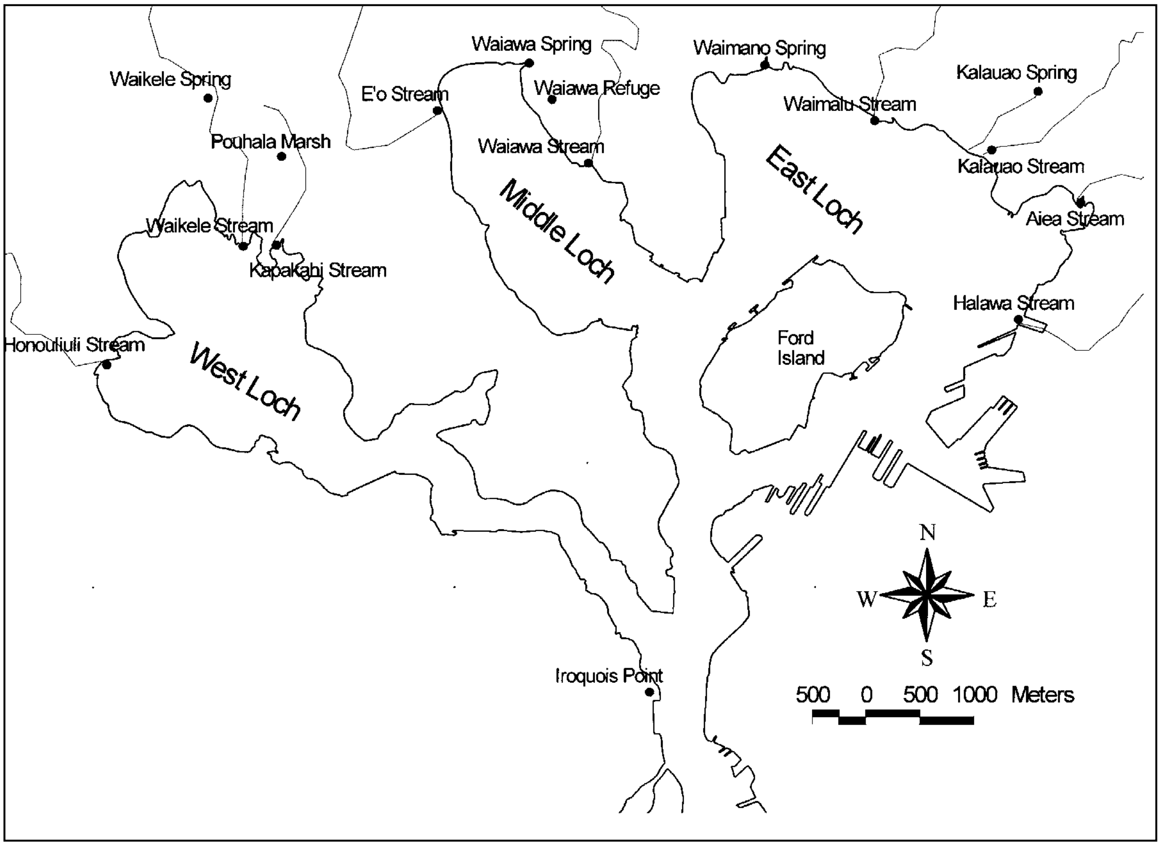

Figure 7. Map of Pearl Harbor with sampling locations.

Benthic Sampling

Bottom communities in the soft-sediment areas of streams were sampled with a Wildco Petite Ponar® 15.2 x 15.2 cm (6 x 6 in) weighted dredge. Three dredge samples were collected at each Pearl Harbor stream mouth and were usually taken from the Chevron petroleum pipeline bridge crossing areas. After collection of the dredge samples, sediments were rinsed out through a fine-meshed 1 x 1 mm (0.04 x 0.04 in) seive. The contents were preserved in 75% ethanol for later laboratory analysis.

Fish, Crustacean, and Mollusk Sampling

Seine netting was the main sampling technique used to assess introduced fish abundance. A fine-mesh, 5 m (16.4 ft) long seine was used to sample stream animals and assess species

Table 2. Sampling details for Phase II of the Pearl Harbor Biodiversity Project.

Station	Sample Dates	Seine/Gill Net/General Collections	Entomology Collection Days	Dredge Samples
Aiea Stream	8 Dec 97;23 Dec 97	2	2	2
E'o Stream	5 Nov 97;24 Dec 97	4	2	3
Halawa Stream	4 Nov 97;8 Dec 97; 23 Mar 98;11May 98; 19 May 98;2 Jun 98; 20 Aug 98	11	2	4
Honouliuli Stream	29 Oct 97;19 Nov 97;20 Nov 97	8	3	7
Iroquois Point	1 May 98;24 Jun 98		2	
Kalauao Stream	23 Dec 97;12 Jan 98	3	2	2
Kalauao Springs	30 Dec 97;12 Jan 98;15 Oct 98;4 Nov 98	4	4	
Kapakahi Stream	15 Dec 97;31 Dec 97; 30 Mar 98;23 Apr 98; 19 May 98	2	2	2
Pouhala Marsh	23 Apr 98;15 June 98;18 Aug 98	4	3	
Waimano Springs	5 Jan 98; 2 June 1998	2	2	
Waiawa Springs	30 Oct 97;16 Dec 97;8 Jan 98;6 Apr 98;9 Apr 98;14 May 98	6	3	
Waiawa Stream	3 Dec 97;16 Dec 97;8 Jan 98;29 Apr 98	4	3	3
Waiawa Wildlife Refuge	16 Dec 97; 26 Aug 98	5	1	
Waikele Springs	5 June 1998; 9 July 1998	2	2	
Waikele Stream	24 Nov 97;1 Dec 97;2 Dec 97;13 Apr 98;18 May 98;26 May 98;20 Aug 98	13	3	2
Waimalu Stream	3 Nov 97; 6 Jan 98; 8 Oct 1998	4	2	2

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. Because of poor water visibility throughout the Pearl Harbor estuaries, snorkeling was used only in the area of the concrete weir at Waikele Stream. In other areas, above-water observations for fish and invertebrates were occasionally possible, although species identification was generally assessed through capture of individuals. Electrofishing in conjunction with the Hawaii Division of Aquatic Resources was attempted but was not successful because most areas sampled during this study had detectable levels of salinity. Even the small amount of salinity at the Waiawa Springs complex (2 to 4 ppt) rendered electrofishing completely ineffective.

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. The estuarine areas of Waikele, Waiawa, and Halawa Streams, and the Waiawa Springs outlet were accessed by kayak. Visual observations and salinity measurements of aquatic biota were also made while kayaking to the tidal flats. 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. Many of the organisms discussed in this report do not have common names. For those species having a common name, a general common name (e.g., moth) is used, and after that the organism is referred to by its scientific name.

Fish Diet Analysis

A small sub-sample of native and introduced fish collected in the lower stream, wetland, and estuarine regions of Pearl Harbor were preserved in 75% ethanol after capture for later stomach content analysis. Fish stomach contents were identified to the lowest possible level, although in many cases identification to the species level of partially digested prey items and smaller crustaceans such as amphipods and ostracods was not possible. Total prey item numbers in each fish stomach were recorded. Head capsules were counted to assess prey item numbers if stomach contents were broken into pieces. The terrestrial or aquatic status was determined for each identifiable prey item found in fish stomachs.

D. 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. Fish gut contents were analyzed numerically, and the percent diet was calculated for each species. The percent composition of fish diet was calculated by adding the total number of identifiable prey items and dividing by each prey item category.

RESULTS

A. Station Locations and Descriptions

The following section contains specific sampling locations for Phase II of the study. For each sampling station as much relevant information as possible was included, based upon a literature review and previous studies. Much of the information regarding the hydrology of the Pearl Harbor spring complex and surrounding streams comes from Stearns and Vaksvik (1935), Visher and Mink (1964), Nichols et al. (1997), and Nance (1998). Stream names were derived from the Waipahu USGS quad maps, while spring names were taken from Stearns and Vaksvik (1935). Latitude-longitude coordinates are in WGS84 datum, UTM in Zone 4 Old Hawaiian, and were taken where the stream entered Pearl Harbor.

B. West Loch Pearl Harbor

Honouliuli Stream

Latitude 21°21′58.1′′ N, Longitude 158°01′29.8′′ W

Honouliuli Stream is the westernmost Pearl Harbor watershed and drains an area of 29.8 km^2 (11.5 mi^2), with the watershed extending from West Loch to the crest of the Waianae Mountains. Honouliuli Stream is normally dry except in the low-elevation areas from just above Fort Weaver Road bridge downstream to Pearl Harbor (Nance 1998). Below Fort Weaver Road, a flow of approximately 0.5 Mgal/d, or only 5% of Waikele Stream baseflow, is maintained in Honouliuli Stream by groundwater seepage (Nance 1998). The area of Honouliuli Stream sampled extended from the mangroves at the Pearl Harbor shoreline upstream into the golf course area surrounding the stream. The upstream boundary of sampling was in the golf course area, where drainage channels funnel water into stream channels. Salinities ranged from 32 ppt along the mangroves lining the area of the Honouliuli Stream mouth to 4 ppt in the upstream reaches of the golf course. Above the lowest golfcart bridge riparian vegetation changed from mangroves to grass (*Paspalum* sp.).

Waikele Stream

Latitude 21°22′34.0′′N, Longitude 158°00′46.3′′W

Waikele Stream drains the leeward areas of both the Koolau and Waianae mountain ranges in central Oahu. Tributaries of Waikele Stream draining areas in the Waianae mountains are intermittent and flow only during periods of heavy rains. However, other areas of the Waikele Stream drainage, including the major tributaries of Waikakalaua and Kipapa tributaries have permanent stream flow mainly in upper elevation areas. These tributaries are connected to the ocean during storms and extended periods of wet weather.

From its origin in the Koolau Mountains, the Waikele/Kipapa system flows for 28.2 km (17.5 mi) to the Waikele Stream estuary in Pearl Harbor. Downstream from the junction of Waikele and Kipapa Streams to the southern border of the Kipapa Military reservation, water flow in the stream channel is intermittent, and the channel contains little or no water during drought periods (Englund 1993). From the Waikele/Kipapa Stream junction, Waikele Stream flows 3.2 km (2.0 mi) to its estuary in the West Loch of Pearl Harbor.

A 1.5m (5 ft) high concrete weir ponds up Waikele Stream at the USGS Gaging Station 2130, and the stream spills over the concrete lip of the weir into a 15 m (50 ft) wide concrete-lined channel that begins at the Farrington Highway Bridge. Downstream of the weir is entirely tidal, with no tidal influence occurring in the ponded area upstream of the weir. The bottom of the channel is lined with concrete until downstream of the Farrington Highway Bridge footings. After the bottom concrete channel lining ends, the stream bottom typifies a Pearl Harbor stream, with a fine silt bottom and concrete sides. Eventually the concrete ends, and thick growths of mangroves line the stream banks into the West Loch tidal flats.

At the Waikele Stream mouth, large expanses of tidal mudlflats are exposed at low tide. Tree stumps, shopping carts, tires, abandoned gill-nets, and other urban debris were found strewn throughout this tidal mudflat area. The substrate in the tidal mudflat area consists of thick layers of fine silts, with many areas firm enough to walk on at low tide. However, in some areas it is possible to sink over 1 m (3 ft) deep or more into the fine silt. At low tide, many shallow water pockets are formed in the mudflats near the mangroves, and these extend out several hundred yards into Pearl Harbor. This concentrated the aquatic biota into shallow, isolated pools and allowed for effective sampling conditions.

Dense stands of mangroves line the shoreline of West Loch at the point where Waikele Stream enters Pearl Harbor. Mangroves have extended their growth significantly in the West Loch region of Pearl Harbor (Nance 1998). Between the time of the last USGS Waipahu quad map field check (1982), and aerial photographs taken in 1989 and 1994, mangroves appear to have grown seaward up to ca. 60 m (200 ft) in some areas at the Waikele Stream mouth (Nance 1998).

Stream habitat immediately above the concrete weir in the Waikele Stream area consisted largely of a series of backwater pools formed by the concrete weir, with the pools extending upstream nearly to Waipahu Road. Pools ranged in depth from > 1-1.2 m (3-4 ft) deep to 0.3-1 m (1-3 ft) deep, and were connected by deep, slow-velocity runs. Substrate at this area mainly consisted of find sand/silt in the deep pools, and small cobbles in the limited run habitats. Pools with fine, silty substrate comprise the majority of habitat in Waikele Stream in the vicinity of the Waipahu Plantation Cultural Village. Underwater visibility was quite variable, but in late May 1998, visibility was quite good because of decreasing flows, and was as high as 2.1-2.5 m (7-8 ft). Riparian vegetation in this area consisted entirely of a dense growth of California grass (*Brachiaria mutica*) growing into the stream channel.

Waikele Springs

Latitude 21°22′34.0″N, Longitude 158°00′46.3″W

Although not affected by tidal areas of Pearl Harbor, these springs are only a short distance upstream of the tidal reaches of the Waikele Stream estuary and are the largest single spring system in Pearl Harbor (Table 1). These series of springs provide a significant amount of high quality groundwater input into Pearl Harbor (Nance 1998). Waikele Springs begins approximately 200 m (650 ft) downstream of H-1 Freeway as a large set of springs emergent on the east banks of Waikele Stream. The springs dramatically change the character of the lowest reaches of Waikele Stream and also influence stream and Pearl Harbor water chemistry (Nance 1998). Upstream of these springs Waikele Stream is more turbid, warmer and sluggish, and flow consists mainly of surface water runoff. Spring discharge is clear and cool compared to upstream sections, consequently water clarity in Waikele Stream improves significantly below the emergence of Waikele springs. Thick growths of aquatic macrophytes such as the introduced aquarium plant *Vallisneria americana* lined the streambed where Waikele Springs emerge. This is the first documentation of this aquarium plant successfully becoming established on Oahu (D. Herbst, Bishop Museum, pers. comm.). California grass partially obscures the groundwater tunnel where the springs emerge. Taro (*Colocasia esculenta*) was also growing on both sides of Waikele Stream in the vicinity of the springs, but was more abundant on the west side (near the houses) of the stream, and appeared to be a result of human activity.

At low baseflow these springs contribute 80% of the water flow to the lower Waikele Stream (Nance 1998). Up through July 1989 Oahu Sugar Company in the vicinity of these springs operated a well and pump system for sugar cane irrigation. These irrigation wells extracted variable but often significant amounts of water during periods of low stream flow from Waikele Stream (Nance 1998). Stream habitat in the vicinity of the most upstream (and largest) of the emergent Waikele Springs consisted of high velocity shallow runs 0.3-0.6 m (1-2 ft) deep connecting shallow pools 0.3-0.6 m (1-2 ft) deep. Downstream of the springs, the streambed gradient gradually decreases, and fine substrate dominated pool habitats.

Pouhala Marsh

Latitude 21°23′01.0′′N, Longitude 158°00′34.1′′W

At the northern end of the West Loch, Pouhala Marsh contains an extensive 28.3 ha (70 a) coastal wetland, and is the largest remaining Pearl Harbor wetland (Ducks Unlimited 1998). This large wetland complex is found between Waikele and Kapakahi Streams, with the bermed banks of Kapakahi Stream forming the eastern border of the marsh. A large spring area was observed to issue from the center of Pouhala Marsh, and salinity was measured at 1 ppt near an area of clear water in the center of the marsh; the marsh at this freshwater spring area was dominated by the introduced common cattail (*Typha latifolia*). During our fieldwork, the marsh area also contained several other areas of open water with salinities of 8 to 9 ppt.

Recently a partnership of the U.S. Fish & Wildlife Service, Ducks Unlimited, the State of Hawaii, and the City and County of Honolulu have undertaken a wetland restoration of Pouhala Marsh, and this plan is detailed in the Ducks Unlimited (1998) environmental enhancement plan for the marsh. Pouhala Marsh has been deemed a wetland of critical concern for wildlife protection and habitat enhancement in The Recovery Plan for Hawaiian Waterbirds (U.S. Fish & Wildlife Service 1998). Depending on the season, Pouhala Marsh can contain more than 150 Hawaiian Stilts, which is 10% of the world population of this species (Ducks Unlimited 1998). Currently, nesting success is marginal here for endangered waterbirds because of the proximity of this marsh to urban Waipahu and the high numbers of feral and domestic predators (Ducks Unlimited 1998).

Aquatic habitats in Pouhala Marsh have been degraded in the past few decades, and now only 9.7 ha (24 a) are currently available for endangered Hawaiian waterbirds; an additional 3.2 ha (8 a) were filled, and 15.4 ha (38 a) are presently overgrown with mangroves nearer the ocean and pickleweed in the more upland areas. Pouhala Marsh is classified as a Hawaiian playa wetland, characterized as seasonally filling during the wet winter season and evaporating in the summer (Ducks Unlimited 1998). This area provides an important seasonal wetland resource for endangered Hawaiian Stilts, Hawaiian Duck, Hawaiian Coot, and Hawaiian Moorhen, especially as water levels decline and concentrate aquatic invertebrates in shallow areas.

As mentioned earlier in the Pearl Harbor Vegetation section, an archival photograph of the Pouhala Marsh area taken in 1930 provides evidence that native species of aquatic plants have been largely replaced by introduced species. Nishida and Imada (1997) found the vegetation in this wetland area consisted of mangrove, pickleweed, and other introduced plant species. The only potential native aquatic plant found at Pouhala Marsh by Nishida and Imada (1997) was a small 30 x 15 m (100 x 50 ft) patch of *Schoenoplectus californicus*, however, the native or introduced status of this plant is unknown (Wagner et al. 1990). With the possible exception of the kaluha sedge, the native *Schoenoplectus lacustris* subsp. *validus* and *Sesuvium portulacastrum* riparian community at Pouhala Marsh appears to have been entirely replaced by introduced aquatic plant species.

Kapakahi Stream

Latitude 21°22′34.1′′N, Longitude 158°00′35.3′′W

Kapakahi Stream begins as a 0.5 Mgal/d spring emerging underneath the Shiro's Food parking lot immediately north of Farrington Highway (Nance 1998). Visible water flow for Kapakahi Stream begins on the north side of Farrington Highway, and terminates into an indistinct set of channels flowing through thick stands of mangrove approximately 1.2 km (0.75 mi) downstream into the West Loch of Pearl Harbor. Kapakahi Stream has been channelized but is not lined with concrete. In the area of Farrington Highway the stream channel is shallow and silty. Houses are situated on the west side of the streambanks from Farrington Highway to the old railroad grade and petroleum pipeline. An auto dealership and other industrial properties lined the east side of Kapakahi Stream. Kapakahi Stream is also adjacent to a City and County refuse pickup station next to the Chevron petroleum pipeline crossing. Water clarity was surprisingly high for such a disturbed urban stream, but the channel and banks are lined with trash. A trash dam has built up underneath the old railroad trestle supporting the Chevron petroleum pipeline.

The banks of Kapakahi Stream are bare dirt from Farrington highway to the pipeline, and appear to be frequently sprayed with herbicide. California grass appeared on the streambanks downstream of the Chevron pipeline crossing, while thick growths of honohono grass (*Commelina diffusa*) choked the stream channel in this area. Approximately 100 m (325 ft) downstream of the pipeline mangroves start to line the channel. Mangrove growth eventually becomes so dense that further access to the stream channel is impossible. Salinities in the Kapakahi estuary (on the ocean side of the mangroves, accessed by kayak) ranged from 9 ppt near the shoreline area of the mangroves to 36 ppt further out in Pearl Harbor, while salinities upgradient of the mangroves were measured at 0 ppt. Thick silt (> 1m (3 ft deep)) on the ocean side of the mangroves in the Kapakahi estuary made sampling difficult in this area.

C. Middle Loch Pearl Harbor

E'o Stream

Latitude 21°23′14.0″N, Longitude 157°59′43.8″W

This stream is not named on the USGS topographic maps, and it appears to be entirely artificial and was formed by dredging and draining the former Loko E'o fishpond in Pearl Harbor's middle loch. Located in the Ted Makalena Golf Course, the stream channel is lined with mangroves nearly to the upstream end of the golf course at the uppermost concrete golf-cart bridge crossing. Near the Waipio Point Access Road bridge crossing the stream channel was more marine in character with a hard-bottomed substrate consisting of coral rubble. Thick growths of mangroves line the stream channel throughout the Ted Makalena Golf Course, rendering access difficult for most of the stream course. Toward the upstream end of the golf course the stream channel was lined with concrete but contains a layer of silt deep enough to preclude sampling except along the stream's edge. Sampling took place at the Waipio Point Access Road bridge and near the upstream end of the Ted Makalena Golf Course bridge. Salinities ranged from 35 ppt at the Waipio Point Access Road bridge to 13 ppt at the upstream end of the golf course. Drainage from the upper sections of this artificial stream comes from canals lining a residential area.

Waiawa Springs

Latitude 21°23′28.0″N, Longitude 157°59′13.4″W

Located on the west side of the Pearl City Peninsula, Waiawa Springs emanates from a series of springs lying at the base of the Koolau basalt bluffs below Leeward Community College in Waipahu. Having a partially diverted average flow of 18 Mgal/d between 1911-1920 (Nichols et al. 1997), Waiawa Springs is the smallest of the major Pearl Harbor springs in discharge. Waiawa Springs has the greatest remaining surface area of the main Pearl Harbor springs, and in the early 1960's the active springs totaled 10.1 ha (25 a) in size (Visher and Mink, 1964). During the present survey it appeared that portions of the Waiawa Spring complex near the base of the basalt cliffs were being illegally filled and used as a heavy construction staging area. Watercress is still grown in large quantities in portions of Waiawa Springs, and other areas consist of swampy and silty ponds. Many ponds contained layers of silt greater than 1 m (3 ft) in depth, which hampered sampling in these areas. Numerous irrigation ditches are found at the Waiawa Springs complex, and these shallow areas allowed for effective sampling of aquatic organisms. The altitude of the highest spring orifice is 3.4 m (11 ft) above sea level, while a considerable amount of water issues from the alluvium in the watercress ponds and in the low-lying swampy areas (Visher and Mink 1964). Water can also be seen actively issuing from certain spring areas where the watercress farmers have cleared vegetation. Measured salinities at Waiawa Springs ranged from 3-5 ppt.

Pearl Harbor National Wildlife Refuge

Latitude 21°23′17.4″N, Longitude 157°59′06.0″W

The Pearl Harbor Wildlife National Wildlife Refuge (called Waiawa Refuge in Figure 7) is operated by the U.S. Fish and Wildlife Service as a breeding area for endangered Hawaiian waterbirds and is located in the northwestern corner of the Pearl City Peninsula. The wildlife refuge is separated into two major diked pond areas, and it appears to be hydrologically connected to the Waiawa Springs complex. Water is pumped from the adjacent Waiawa Springs complex through a pump and pipe system into the ponds. The diked ponds vary in depth but have a silty bottom that hindered sampling in the deeper areas. Pickleweed was the dominant plant in and around the ponds. To avoid stressing endangered birds, this area is off-limits during breeding season, thus our sampling time here was limited. Surface salinities were 1.9 ppt at the piped water outlet on the more inshore side of the refuge, while only 3.1 m (10 ft) away from the pipe outlet salinities increased to 5 ppt. Salinities averaged 9 ppt in the upper half of the diked area of the refuge and averaged 24 ppt in the diked portion of the refuge closest to the ocean. Water drains from the ponds to the ocean through a short drainage outlet; this outlet also allows marine fish from Pearl Harbor to access the ponds.

Waiawa Stream

Latitude 21°22′58.1″N, Longitude 157°58′54.3″W

The mouth of Waiawa Stream is located in the western side of the Pearl City peninsula, near the site of an abandoned sewage treatment plant. Mangroves dominate the stream mouth area, and access to the stream mouth is only possible with watercraft because of extremely thick mangrove growth. Substrate at the stream mouth was a mixture of silt and reef rubble, while the stream contained deep layers of silt in the more upstream estuarine reaches. Waiawa Stream was accessed from the stream mouth to the Chevron pipeline area with kayaks. Most of this area was too deep and overgrown by mangroves to effectively sample, although gill nets were used at the mouth of Waiawa Stream. Surface salinity at the sewage outlet measured 34 ppt and at the stream mouth ranged from 8 to 34 ppt.

The lower tidal limit of Waiawa Stream appeared to be near the lower USGS gage area where salinities were measured at 0 ppt. The area around the USGS gage station was directly underneath Kamehameha Highway, and the first riffle of this stream was located here.

D. East Loch Pearl Harbor

Waimano Springs

Latitude 21°23′27.3′′N, Longitude 157°57′57.4′′W

Waimano and Waiau Springs are part of a hydrologically linked spring system separated by a spur of basalt upon which the HECO power plant site is located (Visher and Mink 1964). This large spring complex emerges from cracks in the base of the Koolau basalt. The Waimano Springs area is divided into two sections by the current Chevron gas pipeline/bikepath (the old railroad embankment), with the upper section of springs measuring 243 x 61 m (800 x 200 ft), and the lower section measuring 305 x 91 m (1,000 by 300 ft) (Visher and Mink 1964). During this study, sampling in Waimano Springs occurred on both sides of the Chevron pipeline. A flat, low-lying alluvial area on the ocean side of the Chevron pipeline is currently still cultivated in watercress. Salinities measured 0 ppt both at the HECO plant discharge ponds of Waimano/Waiau Springs and in the cultivated watercress farms.

Most of the water from Waimano Springs is diverted to a storage reservoir for the HECO Waiau Power Plant, with additional water obtained from artesian wells drilled in the power plant area (Visher and Mink 1964). More water for the power plant comes from the Waiau Springs complex. Waiau Springs is located across Kamehameha Highway, but is hydrologically connected to Waimano Springs. This explains why no separate flow data are available for Waiau Springs. Sampling occurred at the vicinity of the HECO Waiau Power Plant and the nearby watercress farm area. The area of Waiau Springs across the road at Kamehameha Highway was not sampled and was filled with water hyacinth plants.

Waimalu Stream

Latitude 21°23′10.8′′N, Longitude 157°57′21.8′′W

The Waimalu Stream estuary is located in the central portion of East Loch of Pearl Harbor. The areas sampled were in Blaisdell Park, near the Chevron pipeline crossing and bridge, and upstream at the upper tidal limit. Mangroves growing along the stream banks and shoreline around Blaisdell Park dominated vegetation in this area, while pickleweed dominated the drier upper tidal and mudflat areas. Kayaks were used to access areas of Waimalu Stream by the H-1 Freeway bridge. Salinities ranged from 32 to 37 ppt near the stream mouth at Blaisdell Park to 0 ppt by the H-1 Freeway bridge. Waimalu Stream has a concrete channel starting from the Kamehameha Highway and extends upstream far past the limit of tidal influence. Tidal influence in Waimalu Stream appeared to extend to the end of a concrete channel where a USGS gaging station is located.

Kalauao Springs

Latitude 21°23′19.4′′N, Longitude 157°56′28.9′′W

Kalauao Springs is one of the five major Pearl Harbor springs located in a crescent shaped alluvial flat approximately five acres in size and lies in a break of weathered basalt (Visher and Mink 1964). The maximum width of the spring area in 1964 was 244 m (800 ft) (Visher and Mink 1964). Currently, Kalauao Springs is the site of the Sumida watercress farm, with the Pearl Ridge Shopping center surrounding Kalauao Springs and the watercress farm on all but the Kamehameha Highway or south side of the spring complex. A small amount of wetland taro is also grown in the north end of the property. The main spring discharges into ditches that lead into a spring outlet channel draining underneath Kamehameha Highway and forms a small channel meandering through another shopping center complex on the edge of Pearl Harbor. This area was sampled both at the Chevron pipeline crossing near the ocean and in the Sumida watercress farm. Salinities measured at Kalauao Springs ranged from 2 to 3 ppt at the watercress farm area to 2 ppt at the Chevron pipeline crossing.

Kalauao Stream

Latitude 21°23′01.4′′N, Longitude 157°56′44.7′′W

Separated from the Kalauao Springs outlet channel by approximately 137 m (450 ft), Kalauao Stream was also sampled in the area near its confluence with Pearl Harbor at the Chevron pipeline crossing near the ocean. Unlike Kalauao Springs, Kalauao Stream begins as a stream at nearly 610 m (2,000 ft) in elevation in the Koolau Mountains. Although no mention (or estimated size) of this spring was found during our literature review, a large spring was observed to emerge from near the west side of Kalauao Stream, underneath a parking structure. The shopping center in this area is on stilts, and was unfortunately built directly over this large spring. The Kalauao Stream channel in this area was lined with mangroves, and surface salinities ranged from ranged from 7 to 12 ppt. Salinities measured at the spring outlet varied from 7 to 9 ppt but increased to 27 ppt at the 0.3 m (1 ft) depth level.

Aiea Stream

Latitude 21°22′45.4′′N, Longitude 157°56′49.9′′W

The terminal reach of Aiea Stream is located in the northeastern corner of Pearl Harbor and empties into Aiea Bay. The lower reaches of the stream lies underneath the Kamehameha Highway bridge, and the sides of this stream mouth are entirely encased in concrete. During our sampling it was apparent that the lower section of stream receives little freshwater flow. Consequently, the stream mouth was more marine in character, and surface salinities ranged from 27 to 30 ppt. Away from the concrete-channel mangroves were the predominant riparian vegetation in the silty areas. As in many areas of Pearl Harbor, thick layers of silt in this area made sampling difficult. There was no distinct fresh and saltwater interface area to sample, as Aiea Stream was almost completely dry during our sampling and channelized with concrete

Halawa Stream

Latitude 21°22′10.1′′N, Longitude 157°56′35.6′′W

Halawa Stream is the easternmost Pearl Harbor drainage, located in the eastern end of East Loch. A long section of Halawa Stream is encased in concrete starting at Salt Lake Boulevard and extending upstream for an indeterminate distance through urban Honolulu. Tidal influence in Halawa Stream extends from the USS Arizona Memorial Visitor's Center upstream to the concrete footings of the Salt Lake Boulevard bridge. Mangroves grow along the length of the tidal reach, both in the tidal mudflats and in the rock fill along portions of the lower shoreline area near the Kamehameha Highway bridge. Stream habitat upstream of the Kamehameha Highway Bridge consisted of a rocky shoreline interspersed with small mangroves, and stream substrate consisted of deep silt covering medium-sized cobble and small boulders. The banks of Halawa Stream have received various forms of fill over the years, and the partially submerged boulder surfaces were coated with thick layers of fine silt. Sampling was effective near the shoreline of the lower stream, but deep silt precluded sampling (except with gill nets) in the mid-channel areas. We were generally unable to visually observe fish at Halawa Stream because of the highly turbid nature of the estuarine habitat.

Sampling in Halawa Stream was concentrated in the area around the Kamehameha Highway Bridge and near the McDonalds® by the Salt Lake Boulevard Bridge. Freshwater flows only intermittently in the Halawa concrete channel section of stream to the beginning of the estuary at the Salt Lake Boulevard. Surface salinities near the Kamehameha Highway bridge in the area of the USS Arizona Memorial ranged between 30 to 37 ppt, while salinities near the Salt Lake Boulevard McDonald's® ranged from 0 ppt in the weakly flowing freshwater channel to 26 to 32 ppt slightly downstream. A pool formed below the Salt Lake Boulevard Bridge provided ideal sampling conditions for fish.

E. Pearl Harbor Fauna Composition

For this study, a total of 329 species in 8 phyla (Figure 8) were collected and identified in estuarine and riparian habitats of Pearl Harbor (see Appendix C). Excluding terrestrial arthropods found in riparian areas, a total 192 aquatic species were identified within the lower reaches of Pearl Harbor streams and wetlands (Table 3). Table 3 includes a summary of all species captured at the sampling stations, including terrestrial riparian insects. The first percentages shown on the left side of Table 3 include the aquatic vertebrates and invertebrates, and terrestrial insects found in the riparian zones. The second column of percentages shown in Table 3 shows the number of strictly aquatic species collected during this study. Including only the aquatic species, introduced species dominated with 47% of the species recorded, while only 33% were native, with the balance

Table 3. Summary of the total number, percent, and biogeographic status of all aquatic species found in Pearl Harbor wetlands, estuaries, stream mouths, and springs.

Biogeographic Status	All species collected, (terrestrial and aquatic invertebrates, and aquatic vertebrates)[1]	Aquatic Species Only
Introduced Species	197 (60%)	91 (47%)
Native Species	69 (21%)	64 (33%)
Undetermined	62 (19%)	36 (19%)
New (undescribed)	1 (< 1%)	1 (<1%)
Total Species	329	192

[1]This includes terrestrial riparian insects collected along shoreline areas.

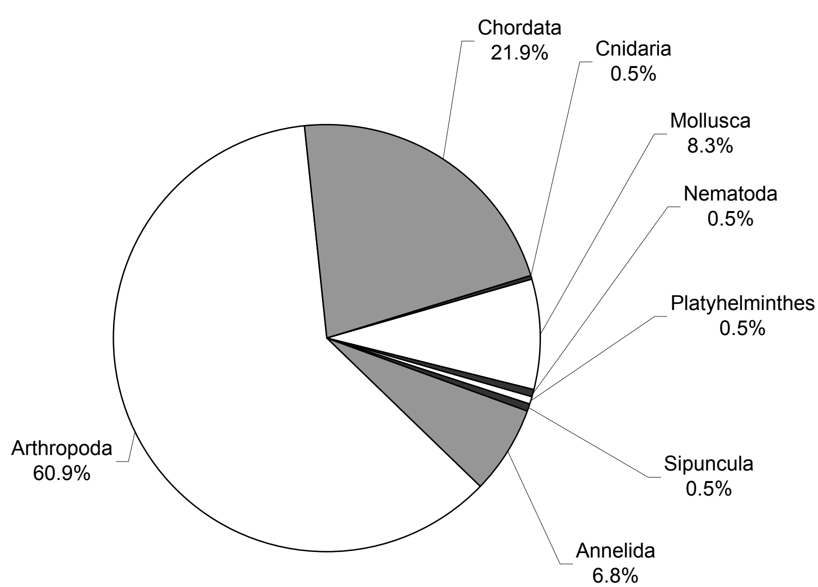

Figure 8. Summary of phyla found in Pearl Harbor estuarine habitats, expressed as a percentage of all known species.

undetermined. We included terrestrial arthropods found in riparian zones adjacent to aquatic habitats, as these insects are a major dietary component of some fish species. The new, undescribed species (Table 3) is a species of aquatic mite (acari), *Eupodes* n. sp., found in salinities ranging from 1 to 9 ppt at Pouhala Marsh. Of these 329 species, 21% were native while

60% were introduced species. Arthropods (mainly insects) composed nearly 61% of the species collected in Pearl Harbor estuarine habitats and were by far the most dominant phylum represented (Figure 8). For the arthropods found in Pearl Harbor there were 89 species of aquatic insects, 26 crustacean and 5 aquatic mite (Arachnida) species. Other important phyla found in Pearl Harbor estuaries included vertebrates (Chordata) at 22%, mollusks (Mollusca) at 8%, and worms (Annelida) at 7%. Minor components of the fauna collectively composed only 2% of the species found, and included Cnidaria, Platyhelminthes, Nematoda, and Sipuncula (Figure 8).

Overall, introduced species appeared to dominate the aquatic fauna of Pearl Harbor wetlands, estuaries, springs, and the lowest reaches of streams entering Pearl Harbor. Of the aquatic organisms that could be identified to the species level, most (47%) were not native to Hawaii. Native species, including both endemic and indigenous biota, accounted for 33% of the aquatic species found in Pearl Harbor. The biogeographic status of 19% of the species found could not be determined primarily because specific determinations could not be made. A further breakdown in biogeographic status of aquatic fauna found in Pearl Harbor estuarine regions is shown in Figure 9. Figure 10 provides the number of species found and the biogeographic status of aquatic fauna in each sampling station.

Sampling effort was not always related to an increased number of species found. For example, sampling effort was far greater at Waikele Stream than compared to Waimalu or Honouliuli Streams (see Table 1), but a similar number of aquatic species were found in all three streams. The Iroquois Point sampling station does not contain any freshwater habitats and is not comparable to other stations. However, sampling this marine shoreline area allowed for an interesting look at changes in the shore insect fauna over time and allowed comparisons to sampling conducted in the 1940s (see Aquatic Insect Results).

F. Aquatic Insect Species Composition

Extensive sampling of the lowest reaches of Pearl Harbor streams and estuaries revealed that introduced insect species dominate Pearl Harbor habitats. Including terrestrial riparian insects, introduced species accounted for 69.1% of the Pearl Harbor fauna, while native species accounted for only 12.7% (Figure 11). A complete listing of aquatic and terrestrial riparian insects associated with Pearl Harbor riparian areas and collected during the present study can be found in Appendix

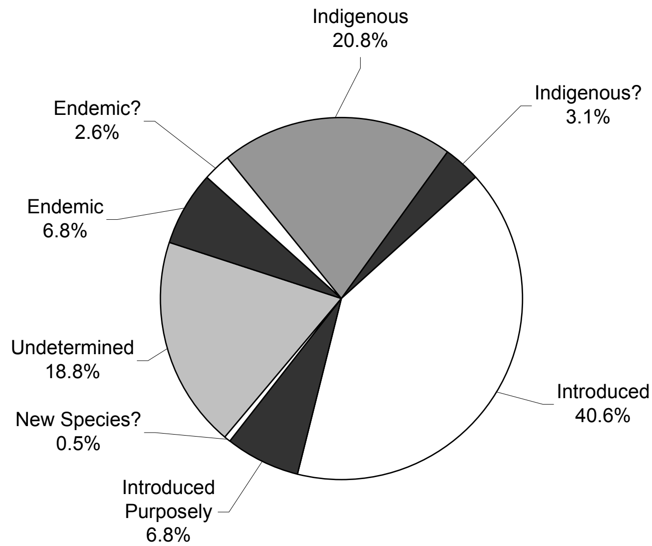

Figure 9. Summary of native and introduced status of aquatic fauna in Pearl Harbor lower stream and estuarine habitats.

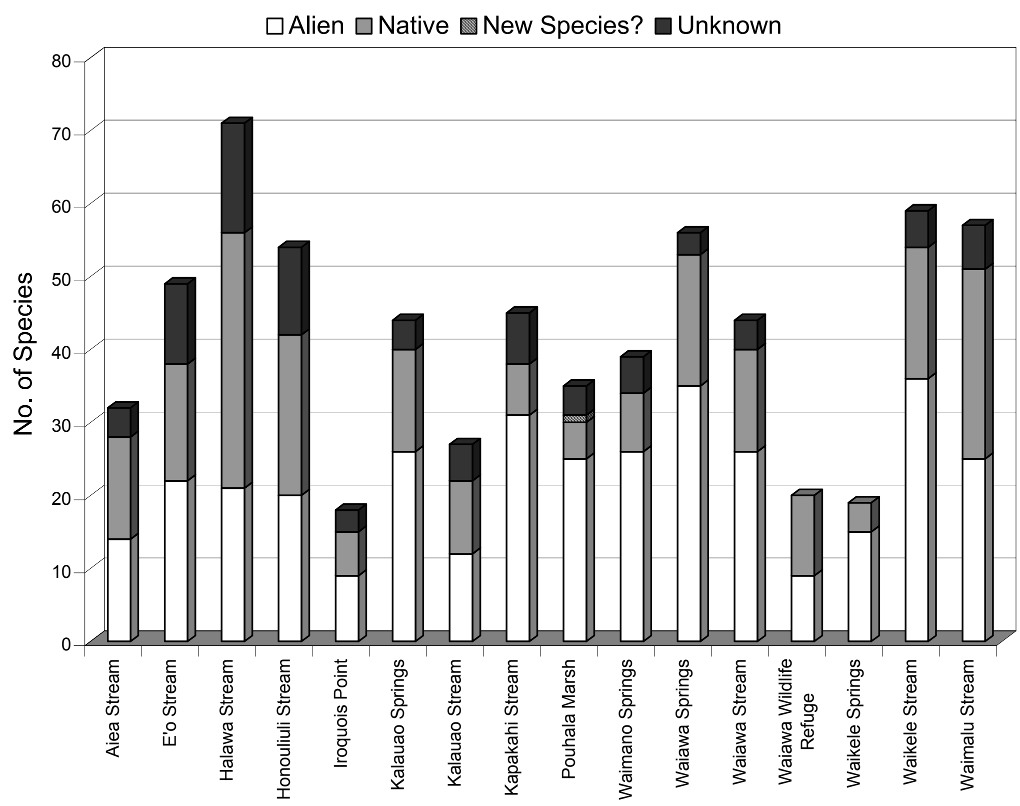

Figure 10. Number of species by stream and biogeographic status for combined aquatic fauna found in estuarine regions of Pearl Harbor.

C. Twenty-two species of native aquatic insects were collected throughout Pearl Harbor estuaries and lower stream reaches. For aquatic insect species, introduced species accounted for nearly 55% of the total, species of currently unknown origin comprised 20%, while only 25% were known or believed to be native (Figure 12). Of the native species of aquatic insects, approximately 14% were endemic or probably endemic, while 10% were indigenous or probably indigenous (Figure 12). 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. Species classified as endemic are found only in the Hawaiian Islands, while indigenous species are native to Hawaii but also native to other areas of the world.

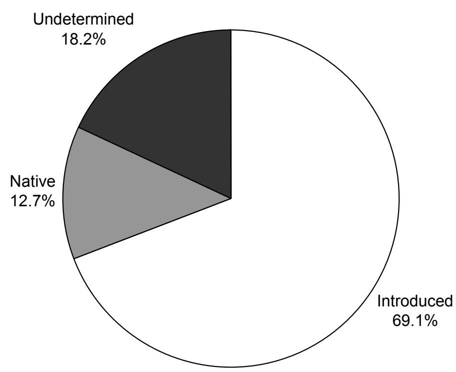

Figure 11. Biogeographic status for all insect species (including terrestrial riparian insects) found in Pearl Harbor lower stream, estuarine, and adjacent riparian areas.

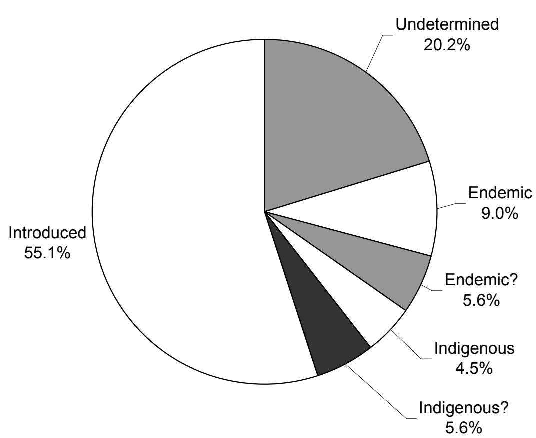

Figure 12. Biogeographic status for aquatic insect species found in Pearl Harbor lower stream and estuarine areas.

The total number of both terrestrial riparian and aquatic insects collected from each stream area is shown in Figure 13. The total number of insect species (aquatic + terrestrial riparian; Figure 13) found in all sampling sites appeared to be in similar proportions to the numbers of aquatic insect species found at all sampling sites (Figure 14). A high of nearly 70 aquatic and terrestrial insect species were found at Honouliuli Stream (Figure 13), of which 29 species were aquatic insects (Figure 14). The number of aquatic insect species found in each Pearl Harbor stream and estuarine area was fairly uniform with two notable exceptions; (Waikele Springs and the Pearl Harbor

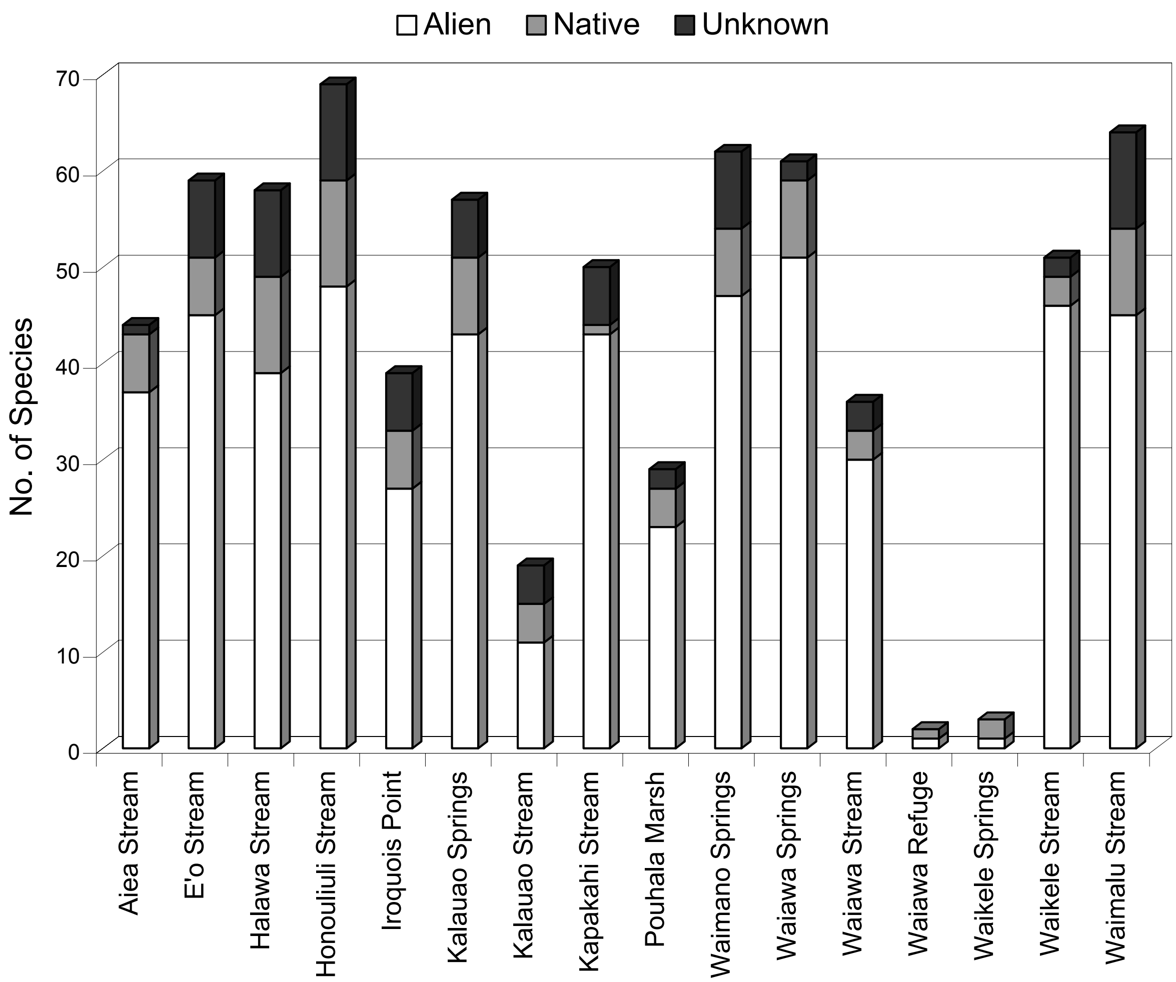

Figure 13. Numbers of riparian terrestrial and aquatic insect species collected in lower stream and estuarine regions of Pearl Harbor with number of species by stream and biogeographic status.

National Wildlife Refuge), ranging from a low of two species at Waiawa Wildlife Refuge to a high of nearly 30 species collected at E'o, Honouliuli, Waiawa and Waimalu Streams, and Waimano and Waiawa Springs (Figure 14). Introduced species predominated in each stream estuary area. The

Pearl Harbor National Wildlife Refuge (Waiawa Refuge in Figure 13) and the Waikele Springs areas had fewer aquatic insects as compared to other stations because of reduced sampling effort (Figure 14). Access to the Pearl Harbor National Wildlife Refuge is strictly controlled, and a reduced number of aquatic insects were observed here because of time constraints in collecting.

We consider Waikele Springs a biological sub-area of Waikele Stream, as most species found immediately above the USGS weir were also found in the Waikele Springs area. Although the Waikele Stream area received the greatest sampling effort, it is significant that other streams were found to have more aquatic arthropods and other aquatic species.

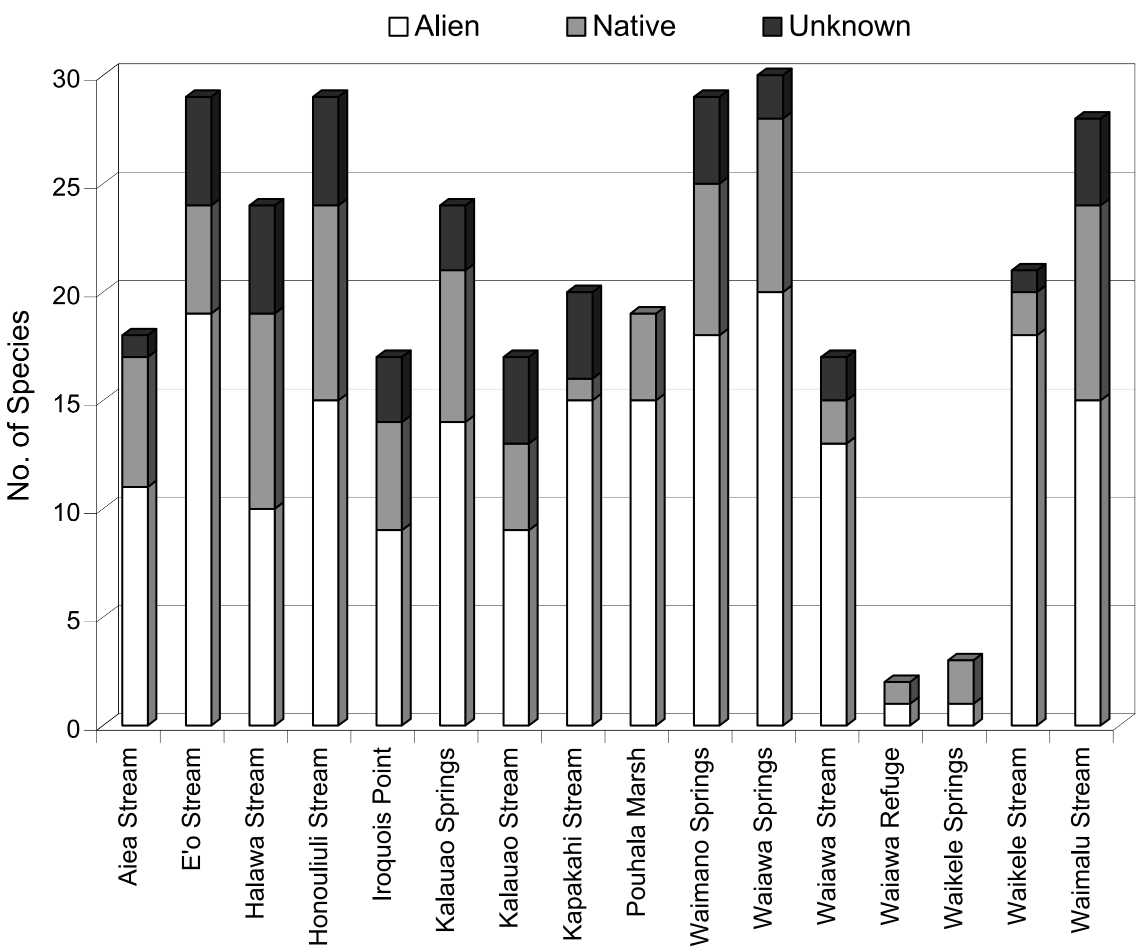

Figure 14. Numbers of aquatic insect species found in lower stream and estuarine regions of Pearl Harbor with number of species by stream and biogeographic status.

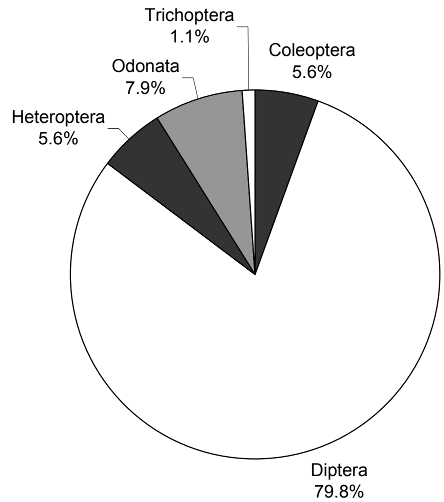

Figure 15. Percent frequency by order of aquatic insect species found in the lower stream and estuarine reaches of Pearl Harbor.

Aquatic Diptera (flies) were by far the most species-rich order found in Pearl Harbor and composed 79.8% of all aquatic insect species (Figure 15), with 46% known to be introduced species, and an additional 27% of unknown origin (Table 4). Odonata (dragonflies and damselflies) were the next most common and comprised 7.9% of species, while 5.6% was composed of aquatic Heteroptera (true bugs) and 5.6% Coleoptera (aquatic beetles), respectively. In the lower regions of Pearl Harbor, introduced caddisflies (Trichoptera) were collected only in a non-tidal section of Waikele Stream, and composed only 1.1% of the sampled aquatic insect fauna. 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.

Because of their small size and the apparent ease of their accidental introduction, a large percentage of aquatic Diptera (27%) 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 complete absence of *Ephydra gracilis*, an aquatic fly in the family Ephydridae that was introduced via seaplanes (Carlton & Eldredge, MS). 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 (Carlton and Eldredge, MS). Intensive sampling of these and other suitable Pearl Harbor wetland areas found numerous species of other native and introduced ephydrid flies, but *Ephydra gracilis* now appears to be absent from Pearl Harbor aquatic habitats.

Another finding of these surveys was the complete absence and extirpation of native *Megalagrion* damselflies in Pearl Harbor stream mouths, wetlands, spring complexes, and estuaries. Three species of introduced damselflies, *Ischnura posita*, *Ischnura ramburii*, and *Enallagma civile* are now abundant in the lower reaches of Pearl Harbor streams and wetlands. Two native and two introduced species of dragonflies were also common during the present study. The indigenous dragonflies *Pantala flavescens* and *Anax junius* were some of the most common native aquatic insects remaining in Pearl Harbor. In contrast to native *Megalagrion* damselflies, of which no adults or larvae were found, larvae of the native dragonfly *Anax junius* were common in areas such as at Waikele Stream or Kalauao Springs outlet and were always collected in the presence of many different species of introduced fish. Other recently introduced dragonflies included *Crocothemis servilia* along with the well-established *Orthemis ferruginea* that were common throughout the aquatic habitats of Pearl Harbor.

A large population of the water strider *Halobates hawaiiensis*, an endemic species of aquatic Heteroptera, was found in Pearl Harbor estuaries and more marine areas of Pearl Harbor. Although

Table 4. Biogeographic status, percent occurrence and total number of species of aquatic Diptera species found in the lower reaches of Pearl Harbor streams. Species recorded as probably endemic/indigenous in Nishida (1997) were assumed to be native for this table.

Family (total # species)	% Endemic/Indigenous	% Introduced	% Unknown
Canacidae (3)	33.3% (1)	66.7% (2)	-
Ceratopogonidae (9)	44.4% (4)	11.1% (1)	44.4% (4)
Chironomidae (10)	10% (1)	30% (3)	60% (6)
Culicidae (2)	0%	100% (2)	-
Dolichopodidae (12)	25% (3)	50% (6)	25% (3)
Empididae (1)	0%	100% (1)	-
Ephydridae (21)	24% (5)	71% (15)	5% (1)
Psychodidae (1)	-	-	100% (1)
Sciaridae (2)	-	-	100% (2)
Tethinidae (5)	60% (3)	20% (1)	20% (1)
Tipulidae (5)	40% (2)	40% (2)	20% (1)
Xenasteiidae (1)	-	-	100% (1)
Total: 72 species	26% (19)	46% (33)	28% (20)

not considered rare, this species is often difficult to locate in Hawaii with populations usually quite localized (D. Polhemus, Smithsonian Institution, pers. comm.) but was common to abundant in localized areas of Pearl Harbor. *Halobates hawaiiensis* was usually found in the shelter of introduced mangroves lining the shores of Pearl Harbor and was observed and collected in large numbers at the mouths of Waimalu and Waiawa Streams and at the outlet of Waiawa Springs. All of these areas had high densities of mangroves. This marine insect species avoided freshwater, and was usually found in areas of water > 34 ppt salinity. For example, salinity measurements were taken at the mouth of Waiawa Stream, one of the areas of highest *Halobates hawaiiensis* density, which indicated that this species was only found in marine waters. At the Waiawa Stream mouth the mixing zone was sharply demarcated 10 m (30 ft) upstream of the stream mouth, where no *Halobates hawaiiensis* were found. No Pearl Harbor collection data are available for this organism prior to the introduction of mangroves. Additional field observations of this species at the mouth of Pearl Harbor near the Hickam Sewage Treatment plant also revealed high densities of *Halobates hawaiiensis*, although this area was completely marine and not in the estuarine study area. On calm days, large swarms of *Halobates hawaiiensis* were observed over the sandy, reef flat area, offshore from the mangroves and the sewage treatment plant. It appears that mangroves do not influence the densities or distributions of this native marine insect species, as it was common both in areas with and without mangroves in Pearl Harbor.

Other aquatic Heteroptera found in Pearl Harbor streams include four common, introduced species. True bugs in the family Saldidae are one of the most common native aquatic insects in higher elevation areas in the Hawaiian Islands with as many as three native species found in a single Oahu stream (Polhemus 1995). However, in the lower areas of Pearl Harbor streams and wetlands only the introduced saldid *Micracanthia humilis*, first collected in 1988 was found, and native saldid species were entirely absent.

Four species of introduced aquatic beetles (Coleoptera) were found in the lower stream and wetland regions of Pearl Harbor. The most recent introduction (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). *Parathroscinus* cf. *murphyi* populations have now exploded, and they were found in extremely high densities throughout Pearl Harbor mudflats. Flying adults often formed thick clouds above the mud. Two other species of introduced water scavenger beetles, *Enochrus sayi* and *Tropisternus salsamentus* were common in areas of still water, especially in areas such as Kapakahi Stream, Pouhala Marsh, and the Waiawa and Waimano Springs complex. Both of these species were saline tolerant and were found in areas of completely freshwater and in salty puddle areas at Waiawa Springs.

G. 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 25 ppt, brackish-marine at 26 to 30 ppt, and marine if >30 ppt (Table 5). Most fish species in Pearl Harbor estuaries and wetlands were found in a wide range of salinities. Important exceptions were the introduced South American loricariid armored catfish and three fish species in the family Poeciliidae. The armored catfish species restricted to freshwater included *Ancistrus temminckii* and *Hypostomus* cf. *watwata*, while *Poecilia reticulata* (guppy), *Xiphophorous helleri* (green swordtail), and *Xiphophorus maculatus* (southern platyfish) were generally restricted to waters having ≤ 3.0 ppt salinity.

Fish species composition in the sampled coastal wetland, spring, and estuarine areas of Pearl Harbor indicated a relatively even mix of native (51.3%) and alien species (46.2%) with unknown species accounting for 2.5%. Most species were from the order Perciformes, which is the most diversified of all fish orders (Nelson 1994). These comprised nearly 44% of the species found in Pearl Harbor estuarine habitats (Figure 16). 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 Pearl Harbor estuarine areas that were comprised solely of introduced species include Characiformes (pacu), Siluriformes (armored catfish), Cyprinodontiformes (poeciliids or mosquitofish), Cypriniformes (carp or koi), and Synbranchiformes (rice paddy eel) (Figure 16). It could not be determined if Dussumieriinae (family Clupeidae) larvae were native or introduced because of their small size and the presence in Hawaii of two species of introduced clupeids (herrings and sardines).

Table 5. Salinity level classification for this study.

Classification for this study	Salinity Level
Freshwater	0-5
Estuarine	6-25
Brackish-Marine	26-30
Marine	>30

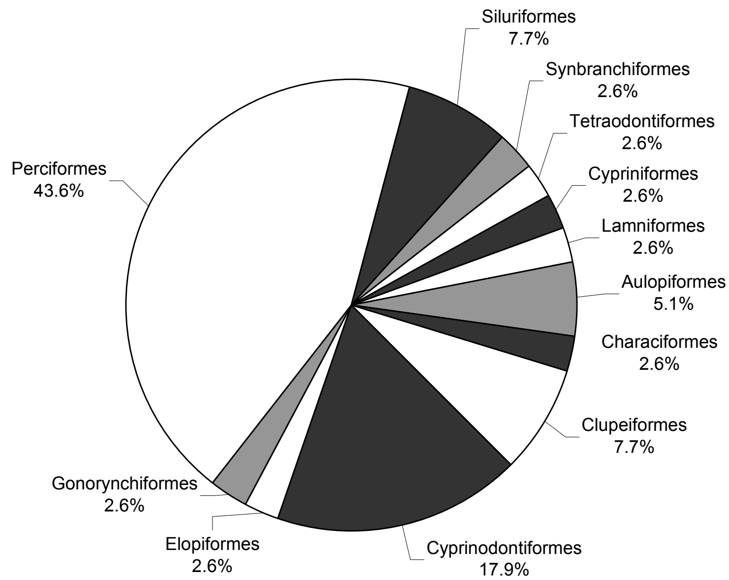

Figure 16. Frequency by Order of fish species found in Pearl Harbor lower stream and estuarine areas.

A total of 39 fish species were collected in all areas of Pearl Harbor estuaries, in salinities ranging from 0 to 37 ppt. Appendix C 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 17). Areas of entirely freshwater contained lower numbers and fewer native species of fish, with 12 native and 16 alien species found in freshwater (0 to 5 ppt), 9 native and 7 alien fish species found in estuarine waters (6 to 25 ppt), 4 alien and 6 native species in brackish-marine (26 to 30 ppt) waters, and 5 alien and 14 native species in marine (> 30 ppt) waters. Sampling effort was slightly lower in strictly marine areas as compared to freshwater and estuarine waters during this study, but the lower number of introduced species found in marine waters likely represents a real trend.

The large Pearl Harbor spring complex including Kalauao and Waiawa Springs had low salinity levels (1 to 4 ppt) and was almost entirely dominated by extremely high densities of introduced fish such as blackchin tilapia and livebearers (such as mosquitofish, *Poecilia latipinna, Poecilia mexicana*, etc.). Along with Waimano Springs complex, the Waikele Springs area was completely freshwater (0 ppt salinity), and no native fish species were observed (Figure 18) in these areas. The number of native and introduced fish species collected or observed at each sampling station is shown in Figure 18.

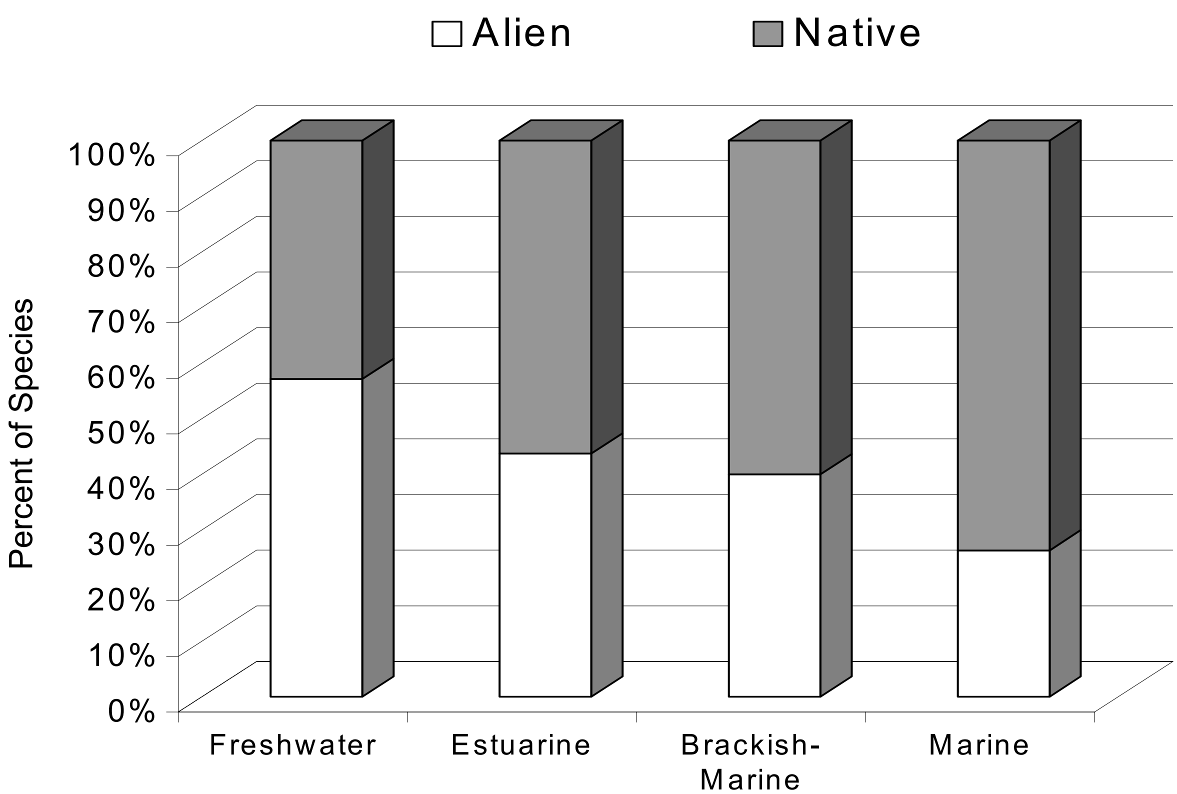

Figure 17. Biogeographic status of fish species and water salinity; freshwater = 0-5 ppt, estuarine = 6-25 ppt, brackish-marine = 26-30, marine >30 ppt salinity.

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 Halawa and Waikele Streams, areas that were both intensively sampled. Halawa Stream contained the most native fish species and was more marine, with little freshwater influence except during storms. Because we sought to assess the range of an introduced fang-toothed blenny (*Omobranchus ferox*), sampling effort was high in Halawa Stream. Sampling effort was similarly high at Waikele Stream (and Waikele Springs area), and also at Kapakahi Stream and Pouhala Marsh, yet these mainly freshwater areas had nearly half the species as compared to Waikele and Halawa Stream. In contrast, effort at Waimalu Stream was lower when compared to Waikele Stream, yet a similar total number of fish species were collected at Waimalu and Waikele Stream (Figure 18).

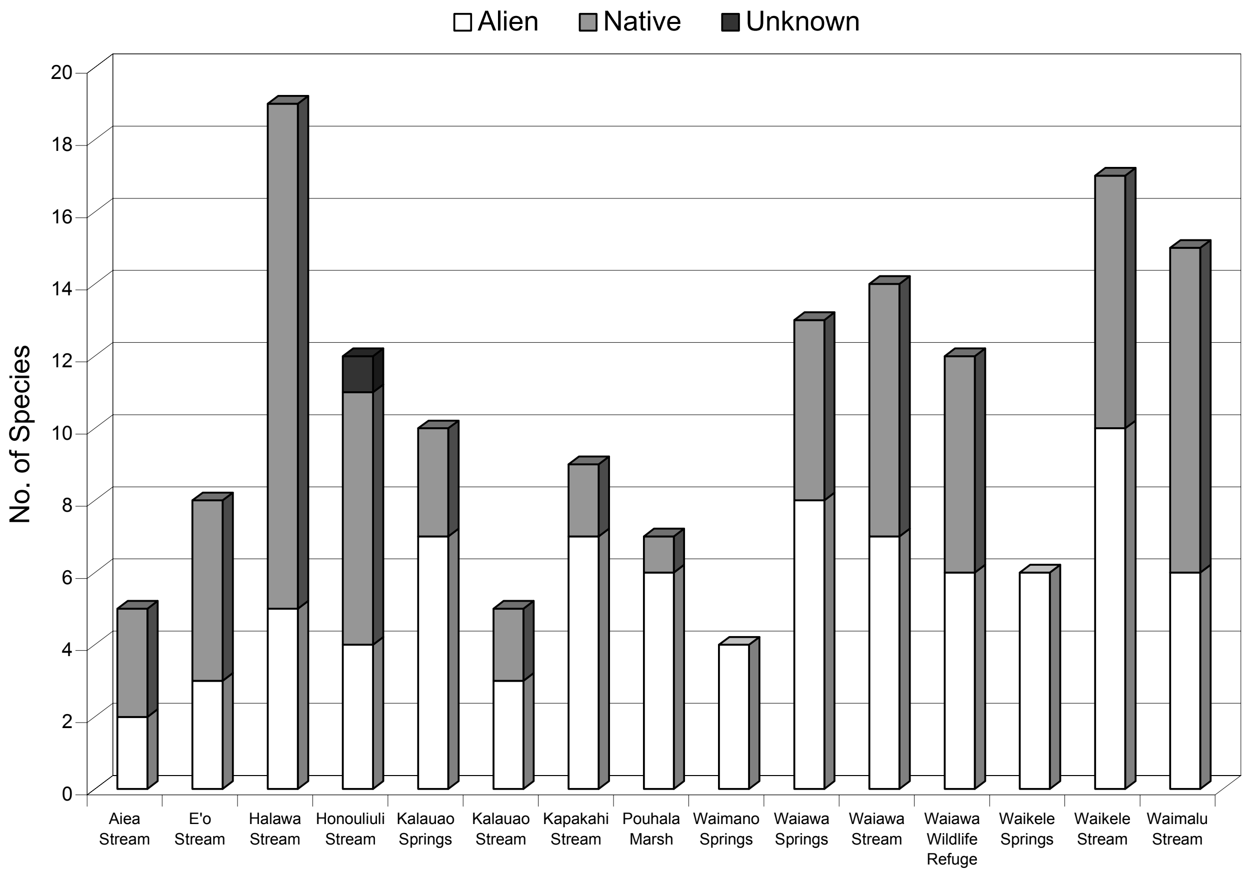

Figure 18. Number of fish species by stream and biogeographic status found in lower stream and estuarine regions of Pearl Harbor.

Although often difficult to capture, because of its benthic nature, one of the most common native Hawaiian stream gobies, *Awaous guamensis*, was relatively uncommon in the lower reaches of streams and wetlands. Sample gear limitations and effectiveness also may have reduced the catch rate of native gobies. Special efforts were also made to visually observe native gobiid fish when visibility conditions were adequate. However, poor water visibility and deep silt often hampered fish collection efforts in many areas, and partially saline conditions prevented the effective use of electrofishing.

Notwithstanding the sometimes-difficult sampling conditions, the introduced goby *Mugilogobius cavifrons* was common and was abundant at most sampling stations. Similar to the native goby species, *Mugilogobius cavifrons* is cryptic and benthic in nature, and our routine capture of this species but not *Awaous guamensis* indicates gear limitations may not have been the reason that native *Awaous guamensis* were so uncommon during this study. For example, *Awaous guamensis*, a significant cultural and food fish for native Hawaiians (Titcomb 1972), was observed or collected in low numbers at only two sampling areas: Waikele and Waimalu 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 Pearl Harbor region and was widely observed and collected in a variety of aquatic habitats. An endemic native gobiid, *Stenogobius hawaiiensis* was less common, and was found in only 6 of 15 sampling stations in the lower reaches of streams.

Blackchin tilapia was the dominant inshore fish species found during this present study of the lower reaches of Pearl Harbor streams and wetlands. Blackchin tilapia were found in high densities in every sampling location. In many areas, such as at the Pearl Harbor National Wildlife Refuge (Waiawa Wildlife Refuge sampling station), it appears that blackchin tilapia have consumed most available resources, as most there were stunted fish only 7.6 to 10 cm (3 to 4 in) in length and in breeding colors. Although blackchin tilapia are often difficult to capture, some situations allowed for effective seining, especially in shallow wetland areas such as at Pouhala Marsh and Waiawa Wildlife Refuge. 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.

Fish Diet Results

The contents of a total of 47 fish stomachs from 9 fish species commonly found in Pearl Harbor estuarine areas were analyzed (Table 6). Contents of 6 native and 3 introduced fish species were examined. Each prey item was identified to the lowest possible taxonomic level, but identification to the species level was usually not possible for fish as they were partially digested. Additionally, most fish stomachs were taken from small (< 90 mm (3.5 in) total length) fish, consequently most prey items were correspondingly small, sometimes making identification difficult. Total prey item numbers in each fish stomach were recorded, and if contents were broken into pieces, head capsules were then counted to assess prey item numbers.

Eleotris sandwicensis, *Kuhlia sandvicensis*, and mosquitofish exhibited the most diverse diets of the analyzed species. As reflected in the general species composition of Pearl Harbor estuarine and riparian fauna, the majority of identifiable prey items in fish stomachs were introduced species. Introduced species comprised 80% of the identifiable taxa in *Eleotris sandwicensis*, 86% in *Kuhlia sandvicensis*, and 100% in mosquitofish stomachs. These three species in particular appear to consume virtually any available aquatic or terrestrial prey item. There were striking differences in fish diet, however, when the consumption of different classes (e.g. insects, crustaceans, fish, mollusks) of prey items were compared among these three fish species (Figures 19-21). For example, while crustaceans amounted to approximately 4.5% (by number) of the diet of the introduced mosquitofish, they accounted for 70% of *Eleotris sandwicensis* and 90.8% of *Kuhlia sandvicensis* diet. Unidentified crustaceans found in mosquitofish guts accounted for 3% of their diet (by number), while copepod crustaceans accounted for 1.5% of diet (Figure 19). Amphipod crustaceans composed 62% of the diet of the native *Eleotris sandwicensis*, while other crustaceans

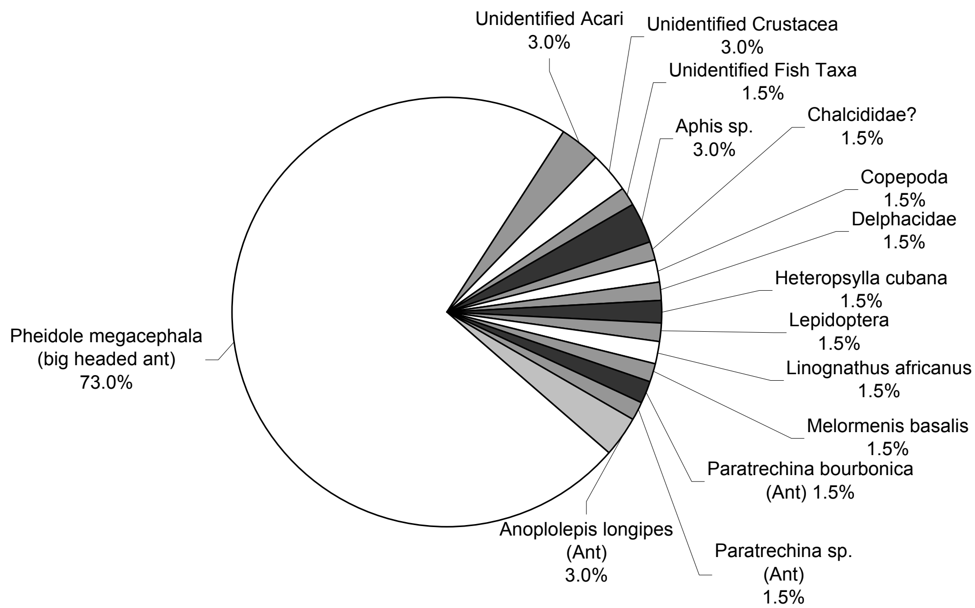

Figure 19. Mosquitofish (*Gambusia affinis*) (n = 8) diet in Pearl Harbor, percentages determined by number of prey items in all stomachs.

combined such as *Macrobrachium grandimanus*, *Neocaridina denticulata sinensis*, and *Palaemon* sp. accounted for 8% of diet (Figure 20). The crustacean component of the diet of *Kuhlia sandvicensis* was dominated by ostracods (48.8%), amphipods and copepods (14% each), unidentified (13.5%), and a small amount (0.5)% of the introduced *Neocaridina denticulata sinensis* (Figure 21). Mosquitofish were found to prey opportunistically on both terrestrial riparian insects and other aquatic species (Figure 19). All mosquitofish found in Pearl Harbor were < 50 mm total length. One of these small fish that measured 46 mm (1.8 in) total length contained over 32 big-headed ants (*Pheidole megacephala*), and ants comprised 79% (numerically) of prey items found in mosquitofish stomachs, with 5 of 8 examined mosquitofish stomachs containing ants. Other prey consumed by mosquitofish included crustaceans (copepods and others), crickets, moths, fish, flatid bugs, mites, and wasps. The endemic *Eleotris sandwicensis* (n = 11) exhibited the widest dietary range, and was found to consume insects (14%), mollusks (6%), and fish (10%) in roughly equivalent proportions. It preyed heavily on ostracods, amphipods, and other unidentified crustaceans (Figure 20). A total of 101 ostracods and 29 amphipods were recovered from the 9 *Kuhlia sandvicensis* stomachs examined (Table 6).

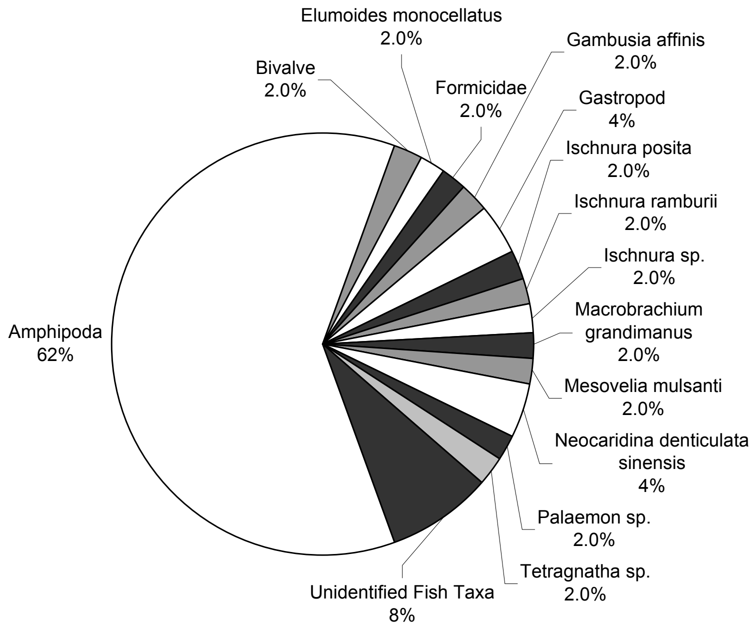

Figure 20. *Eleotris sandwicensis* (n = 11) diet in Pearl Harbor, percentages determined by number of prey items in all stomachs.

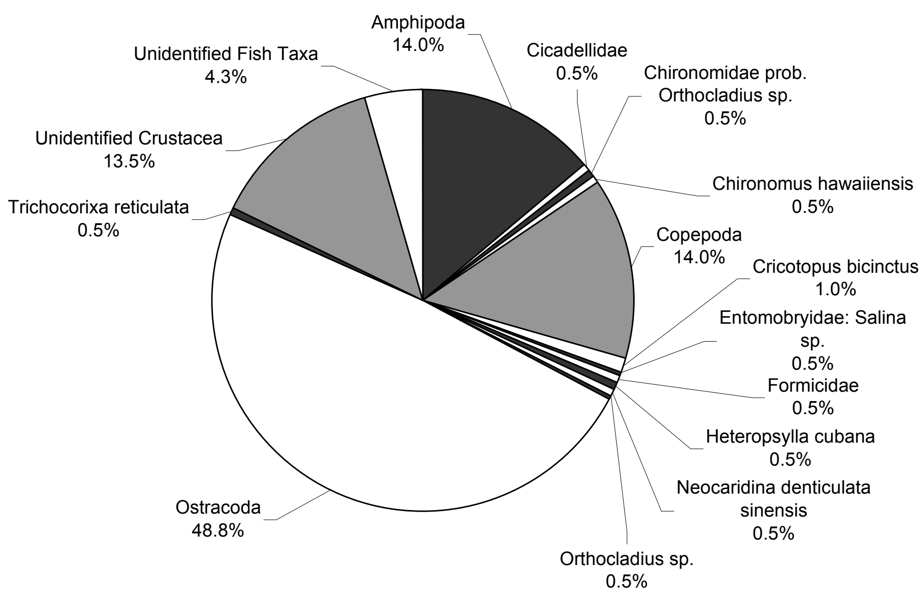

Figure 21. *Kuhlia sandvicensis* (n = 9) diet in Pearl Harbor, percentages determined by number of prey items in all stomachs.

Table 6. Biogeographic status of fish, prey species, total numbers of identifiable species per fish stomach, and % (by using total counts of prey items/fish stomach) in the lower portions of Pearl Harbor streams, estuaries, and wetlands.

Fish Species (# examined) – Biogeographic Status	**Prey Species (Biogeographic status, when known)**	**Total #'s in guts (all fish combined)**	**% Total Diet (by number)**
Bathygobius cocosensis (2) – Indigenous			
	Amphipoda	9	100
Eleotris sandwicensis (11)- Endemic			
	Amphipoda	30	62.0
	Neocaridina denticulata sinensis (Introduced)	2	4.0
	Palaemon sp. (Indigenous)	1	2.0
	Macrobrachium grandimanus (Endemic)	1	1.0
	Bivalve	1	2.0
	Gastropoda	2	4.0
	Formicidae (Introduced)	1	2.0
	Ischnura posita (Introduced)	1	2.0
	Ischnura ramburii (Introduced)	1	2.0
	Ischnura sp. (Introduced)	1	2.0
	Mesovelia mulsanti (Introduced)	1	1.0
	Elumoides monocellatus (Introduced)	1	2.0
	Tetragnatha sp.	1	2.0
	Gambusia affinis (Introduced)	1	2.0
	Unidentified fish	4	8.0
Kuhlia sandvicensis (9)- Endemic			
	Amphipoda	29	14.0
	Ostracoda	101	48.7
	Copepoda	29	14.0
	Neocaridina denticulata sinensis (Introduced)	1	0.5
	Unidentified Crustacea	28	13.5
	Cicadellidae	1	0.5
	Chironomus hawaiiensis (prob. Endemic)	1	0.5
	Cricotopus bicinctus (Introduced)	2	1
	Entomobryidae: *Salina* sp. (Introduced)	1	0.5
	Orthocladius (prob.) sp.	2	1.0
	Formicidae (Introduced)	1	0.5
	Heteropsylla cubana (Introduced)	1	0.5
	Trichocorixa reticulata (Introduced)	1	0.5
	Unidentified fish	9	4.3
Saurida gracilis (6) and *Saurida nebulosa* (2) combined – Indigenous			
	Unidentified crustacea	1	5
	Unidentified fish	19	95
Sphyraena barracuda (5) – Indigenous			
	Palaemon sp. (Indigenous)	2	22

Table 6 (continued).

Fish Species (# examined) – Biogeographic Status	Prey Species (Biogeographic status, when known)	Total #'s in guts (all fish combined)	% Total Diet (by number)
Sphyraena barracuda (continued)	Unidentified crustacea	1	11
	Unidentified fish	6	67
Stenogobius hawaiiensis (1) - Endemic			
	Chironomidae	1	100
Gambusia affinis (8)- Introduced			
	Unidentified crustacea	2	3.0
	Copepoda	1	1.5
	Anoplolepis longipes (Introduced)	2	3.0
	Aphis sp. (Introduced)	2	3.0
	Chalcidae? (Introduced)	1	1.5
	Delphacidae	1	1.5
	Heteropsylla nr. *cubana* (Introduced)	1	1.5
	Lepidoptera	1	1.5
	Linognathanus africanus (Introduced)	1	1.5
	Melormenis basilis (Introduced)	1	1.5
	Paratrechina bourbonica (Introduced)	1	1.5
	Paratrechina sp. (Introduced)	1	1.5
	Pheidole megacephala (Introduced)	48	73.0
	Unidentified Acari	2	3.0
	Unidentified Fish	1	1.5
Mugilogobius cavifrons (2) - Introduced			
	Ostracoda	14	63.0
	Periclimenes cf. *grandis* (Indigenous)	1	5.0
	Unidentified crustacea	4	17.0
	Ceratopogonidae prob. *Forcipomyia* sp.	1	5.0
	Chironomidae	1	5.0
	Hydrophilidae	1	5.0

[1] Prob. = probable identification

Fish Parasitism

Although not a primary objective of this study, it became apparent that the introduced fish parasites were commonly found in both native and introduced fish species in the estuarine areas of Pearl Harbor. Leeches (*Myzobdella lugubris* and *Aestabdella abditovesiculata)* were commonly observed attached to fish immediately after capture and were recovered in the bottom of the voucher sample jars after fish had been placed in ethanol for preservation. Leeches were also recovered from nets and seines after they became dislodged from fish. Both an introduced leech species (*Myzobdella lugubris*) and an introduced camallanid nematode (*Camallanus cotti*) were incidentally found during fish gut content analysis (Table 7). Two *Myzobdella lugubris* were found attached to the inside of the mouth and externally on the abdomen of one preserved individual native *Awaous guamensis* examined during gut analysis (Table 7). The same individual *Awaous guamensis*, captured from lower Waikele Stream below the USGS weir, contained 20 (C*amallanus cotti*) nematode parasites inside the gut cavity. This *Awaous guamensis* was observed to be in a weakened and poor condition when captured at Waikele Stream, and was easily captured with a dip net. The other native stream goby (*Stenogobius hawaiiensis*) and eleotrid species (*Eleotris sandwicensis*), along with the introduced *Poecilia reticulata* (guppy) also contained introduced nematode parasites in their gut cavities (Table 7).

Table 7. Presence of the introduced fish parasites *C. cotti* (nematode) and *M. lugubris* (leech) found in individual fish during gut content analysis in estuarine regions of Pearl Harbor.

Species	Sample Area	Saln (ppt)	Stomach Contents	# *Camallanus cotti*	# *Myzobdella lugubris*
Awaous guamensis	Waikele Stream	0	None	20	2
Eleotris sandwicensis	Waikele Stream	0	1 fish[a]	1	0
Stenogobius hawaiiensis	Waikele Stream	0	None	8	0
Poecilia reticulata	Kalauao Springs	3	None	2	0
Poecilia reticulata	Kapakahi Stream	0	None	3	0
Poecilia reticulata	Waiawa Springs	4.5	None	1	0

[a]Partially digested fish unidentifiable.

H. Crustacean Species Composition

Of the crustacean taxa that were identified to species level, native species comprised 46%, introduced 23%, while 31% were species of unknown origin. At least 25 different crustacea taxa have been determined to varying levels of taxonomic identification. The crustacean species total would be higher if identification to the species level were possible for these taxa. All crustaceans were identified to order, and nearly 60% of the species found in Pearl Harbor estuarine regions were decapods, while isopods (15%) and amphipods (11%) comprised the next most abundant taxa (Figure 22). Less species-rich orders included mysid and copepod (Harpacticoida and Caligidea) 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 C.

Excluding species of unknown status, native crustacean species exceeded the number of introduced species found during the present study (Figure 23). In this study, crustaceans were the only major group of aquatic species where the number of known native species exceed that of introduced species (see Table 8). The number of crustacean species found in each Pearl Harbor stream and estuarine area was highest in Halawa Stream and lowest in Pouhala Marsh (Figure 23). The number of crustacean species collected at each site was not dependent on sample effort. For example, sampling effort was greatest at Waikele Stream, but this area was did not have the greatest number of crustacean species. Sampling effort was also high at Halawa Stream, and native crustacean diversity here was high probably because the lower reach of Halawa Stream was more marine in character, as compared to the Waikele Stream estuary.

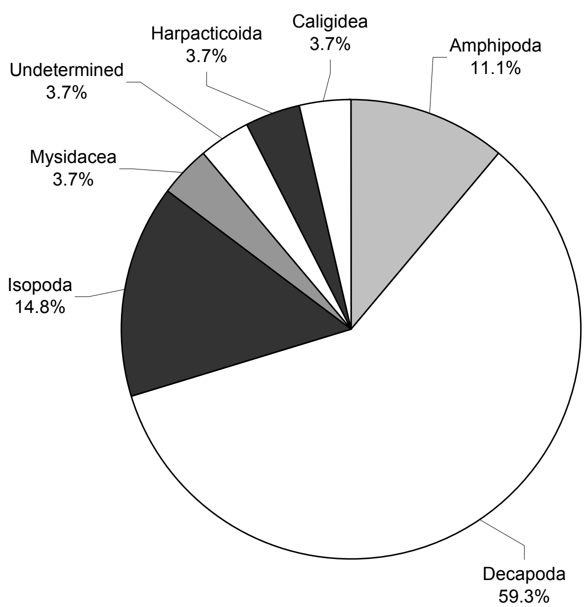

Figure 22. Percent frequency by order of crustacean species found in the lower stream and estuarine reaches of Pearl Harbor.

Native estuarine decapod crustaceans that were abundant and found at most sampling sites in Pearl Harbor include *Periclimenes* cf. *grandis*, *Palaemon debilis*, and *Thalamita crenata*. The native *Macrobrachium grandimanus* was a relatively common decapod crustacean species but was restricted to more freshwater habitats. Two introduced species of freshwater crustaceans, *Macrobrachium lar*, and *Procambarus clarkii*, were also common. Two isopod crustaceans were identified to the species level, the endemic *Ligia hawaiiensis* that is a common marine shoreline species and the widespread *Porcellio laevis*, an introduced species.

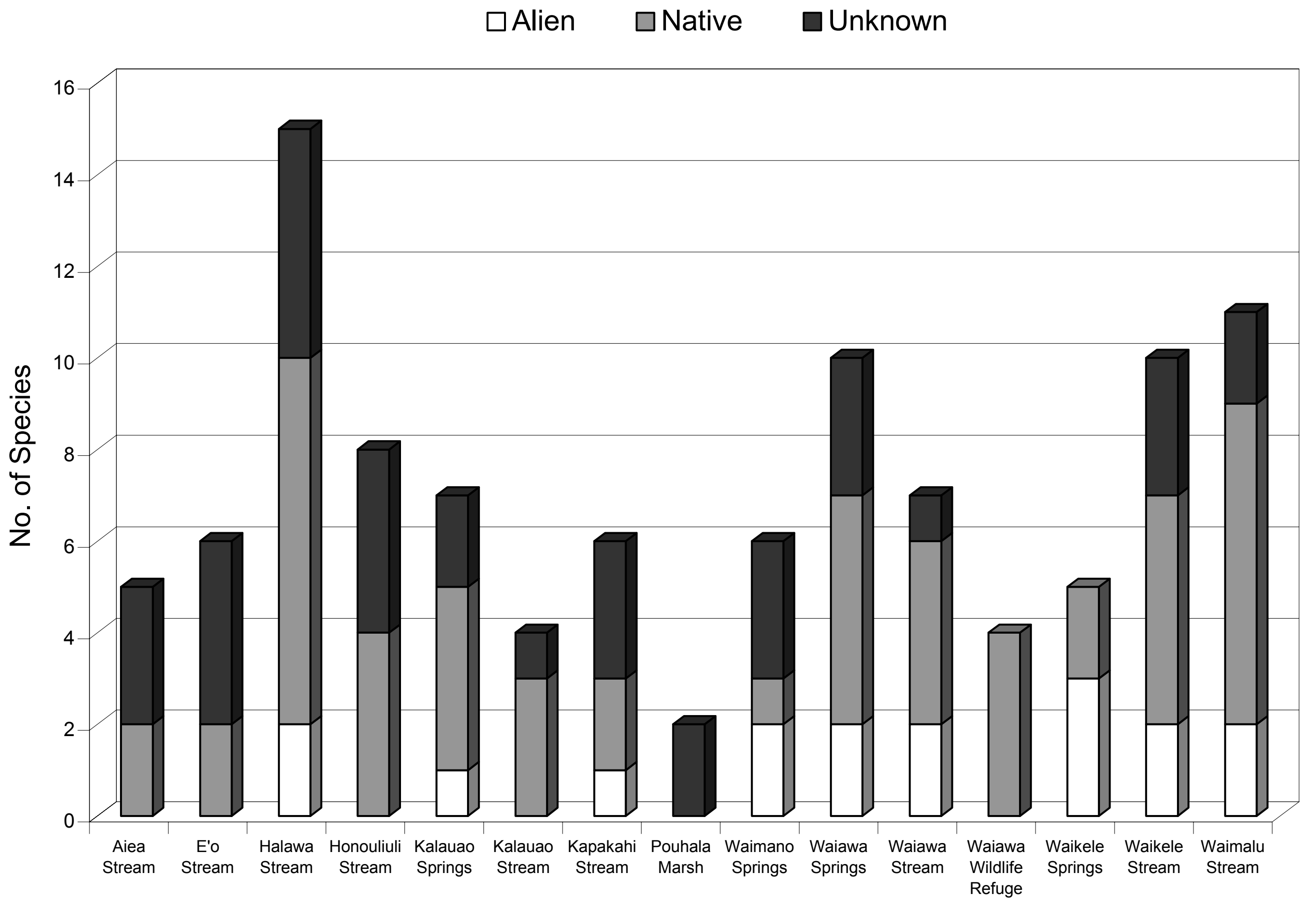

Figure 23. Number of crustacean species by stream and biogeographic status found in estuarine regions of Pearl Harbor.

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. This species was abundant in lower Waikele Stream in 1998 but was absent from the same location in 1993 (Englund 1993). In Waikele Stream, *Neocaridina denticulata sinensis* were common even in areas of higher water velocities that averaged 33 to 52 cm/second but were also found in the clear, cold Waikele Spring areas with velocities as low as 10 cm/second.

I. Mollusk Species Composition

No native freshwater or estuarine mollusks were found in the Pearl Harbor area during these surveys; only introduced mollusks were collected. However, three indigenous (native) species of marine mollusks were found. A complete list of mollusks found is provided in Appendix C. Seventeen species of mollusks were collected throughout Pearl Harbor estuaries, wetlands and lower stream reaches. For mollusks in all habitats, introduced species accounted for 58.8% of the fauna, species of currently unknown origin comprised 23.5%, while only 17.6% were marine mollusks that were known to be native species. The biogeographic status of many species of aquatic Hawaiian snails is unclear (Cowie 1997), especially those found in disturbed or lowland habitats. In some instances this was because species identification could not be determined, and the percentage of introduced mollusks would probably be higher had it been possible to positively identify these species.

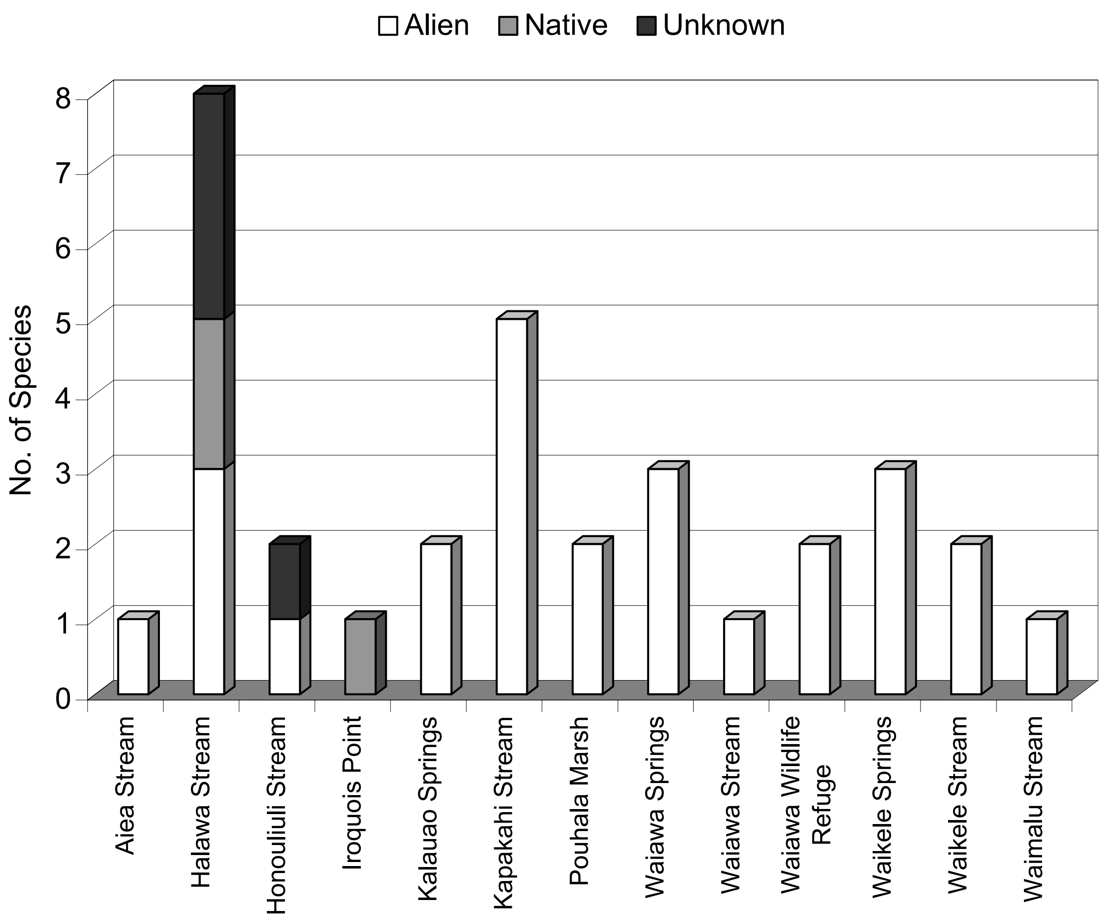

Figure 24. Number of species by stream and biogeographic status for mollusks found in estuarine to marine regions of Pearl Harbor.

The number of mollusk species found in each Pearl Harbor stream and estuarine area was fairly uniform and ranged from a low of one species at several areas to a high of eight species collected at Halawa Stream (Figure 24). Introduced species predominated within all streams and estuary areas. An exception was the finding of two common native species of marine mollusks (*Cerithium nesioticum* and *Ceritihium* cf. *zebrum*) in the lowest reaches of Halawa Stream. Another native mollusk species was also found at the completely marine Iroquois Point station (see Study Area).

The most species-rich snail family found in Pearl Harbor was the Thiaridae, which composed 24% of the total species, and all are likely or known introductions (Cowie 1997).

This study also found two significant species of introduced snails. The first confirmed record of apple snails (*Pomacea canaliculata*) in a Pearl Harbor drainage were collected in Kapakahi Stream (Lach and Cowie 1999). High densities of apple snails were also observed in taro fields in a spring area adjacent to the USGS gaging weir on Waikele Stream at Waipahu Plantation Cultural Village. This area is within 25 m (82 ft) of lower Waikele Stream, however, apple snails were not observed in the stream channel in 1998. The presence of apple snails so close to the stream (and in the floodplain) means that it is highly likely they will soon be in Waikele Stream itself. A new state record was also established for a species of hydrobiid snail, *Pyrgophorus* cf. *coronatus*, found in Pouhala Marsh and Waiawa Springs. The genus *Pyrgophorus* originates in the Caribbean region, and these snails are found in fresh-to-brackish-marine waters in streams and wetlands in their native regions (Cowie 1999). In Pouhala Marsh and Waiawa Springs, *Pyrgophorus* cf. *coronatus* was found in water ranging from 1 to 9 ppt salinity and always on a silty mud bottom. Densities of this newly introduced snail species were high, with numerous individuals incidentally captured in a single fish haul seine.

J. Miscellaneous Species Composition

Three classes of annelids, one species of cnidarian, one species of nematode, and one species of platyhelminthes were also collected in a wide variety of Pearl Harbor estuarine habitats (see Appendix C). Most of these species were collected from sediment samples taken with an Ekman dredge, while leeches (Hirudinea) and aquatic earthworms (Oligochaetes), and flatworms (Platyhelminthes) were found during general collections. Nematodes were found during fish gut content analysis (See Fish Parasite Section). Because of the cosmopolitan nature of many of these sediment dwelling species, the biogeographic status of most of these species is uncertain. However, the biogeographic status of the leeches found in Pearl Harbor was known. The introduced *Myzobdella lugubris* was restricted to freshwater and was commonly observed attached to both native and introduced fish species. Another species of indigenous leech (Eldredge and Miller 1997) *Aestabdella abditovesiculata* was also common on mainly on marine fish, and along with *Myzobdella lugubris* are ectoparasites of fish.

DISCUSSION

A. Continuing Spread of Introduced Species in Lower Pearl Harbor Watersheds

In 1905, the Territory of Hawaii imported three species of fish for mosquito control. These fishes were introduced in the Aiea and Pearl City areas (Van Dine 1907). *Molliensia* [*Poecilia*] *latipinna*, *Fundulus grandis*, and mosquitofish were the first recorded governmental introductions into Pearl Harbor waters, although unrecorded aquatic species introductions undoubtedly occurred earlier. Since that time, many species of aquatic organisms have been accidentally or purposefully introduced into Pearl Harbor's streams, wetlands, and estuarine areas, altering the character of the aquatic fauna. The present study found that introduced species comprise the dominant portion of the biota. The lower portions of Pearl Harbor streams, springs, and wetlands are now dominated by introduced species.

Native species account for a variable percentage of the Pearl Harbor estuarine aquatic fauna (Table 8), ranging from a low of 18% for mollusks to a high of 54% for crustaceans. Overall, for species where biogeographic status could be determined, native species accounted for only 33% of aquatic species in the lower reaches of Pearl Harbor streams and wetlands.

Table 8. Summary of the biogeographic status and total number (percent) of aquatic species found in Pearl Harbor estuarine habitats.

Biogeographic Status	All Aquatic[1] Species	Aquatic Insects	Fish	Crustaceans	Mollusks
Introduced	91 (47%)	49 (55%)	18 (46%)	5 (19%)	10 (59%)
Native	64 (33%)	22 (25%)	20 (51%)	14 (54%)	3 (18%)
Undetermined	36 (19%)	18 (20%)	1 (3%)	7 (27%)	4 (23%)
New	1 (<1%)	0	0	0	0
Total	192	89	39	26	17

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

A trend of decreasing percentages of native species in Pearl Harbor will likely continue as introductions from a wide variety of sources continue to occur. The loss of a major group of native aquatic insects such as the *Megalagrion* damselflies (Polhemus 1995, Liebherr and Polhemus 1997), the lack of native freshwater mollusks, and the scarcity of native fish such as *Awaous guamensis* in the lower stream regions are evidence of this decline. There are no comparable large-scale studies of other large Hawaiian estuarine systems, such as Kaneohe Bay or the Waiakea estuary in Hilo. 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 Pearl Harbor and other areas. Until direct comparisons to other areas in Hawaii can be made, it will not be possible to ascertain whether this is a statewide trend, or a phenomenon restricted to Pearl Harbor. However, based upon the rate of alien 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, Pearl Harbor streams still contain significant reservoirs of native aquatic species, in contrast to the overall finding of 25% native aquatic insects at sea level in Pearl Harbor during the present study (Figure 25). For example, an extensive study in North Halawa Stream (one of the major Pearl Harbor tributaries) from 1991 to 1993 was conducted by the Bishop Museum (Polhemus 1994) which found 73% native aquatic insects in upper North Halawa Stream between 240-300 m (800-1000 ft) elevation. During the current study, we found only 38% of the aquatic insects in the lowest reaches of Halawa Stream were native. The only other available quantitative

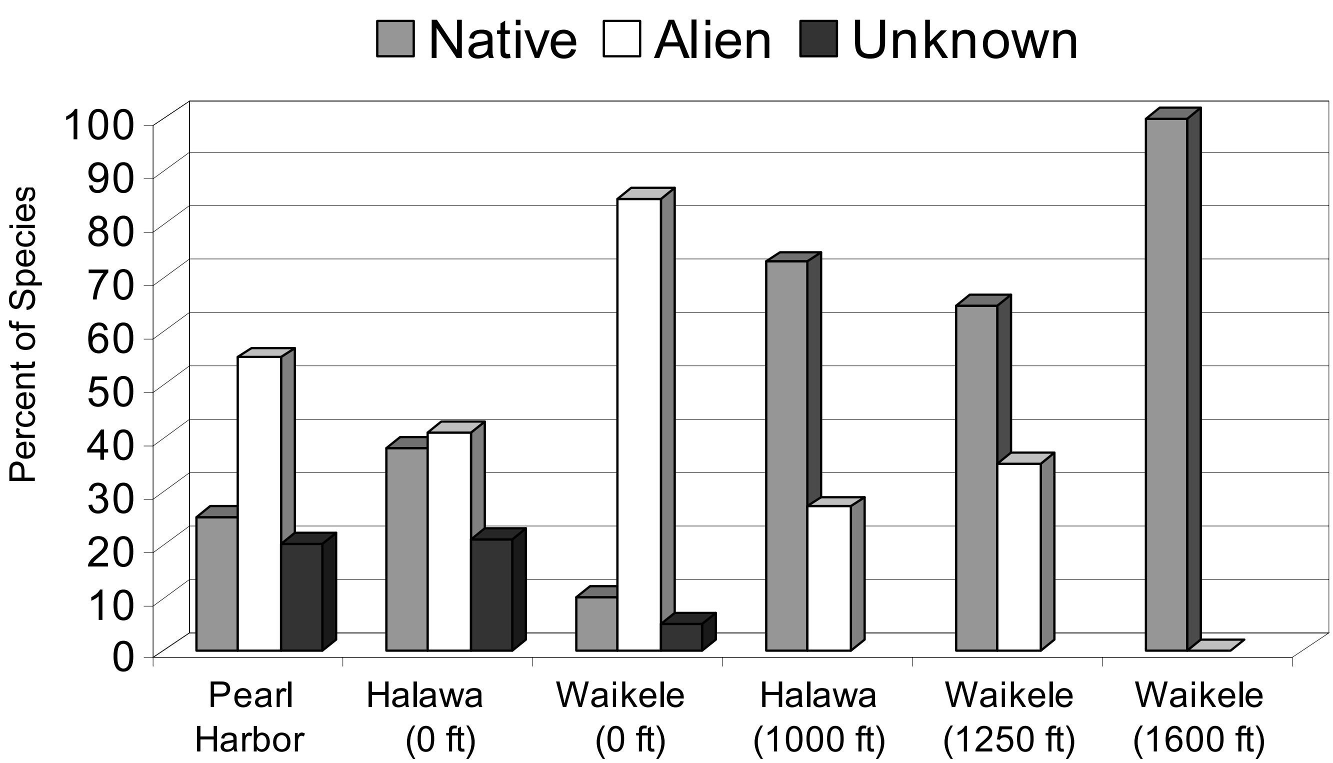

Figure 25. Biogeographic status of aquatic insects at varying elevations on Oahu; upper Halawa data from Polhemus (1994), upper Waikele data from Englund (1993).

survey (Englund 1993) of an upper Pearl Harbor drainage, Waikele Stream, also found a similarly high level of native aquatic species at high elevations, with 65% native aquatic insects at 380 m (1250 ft) elevation, and 100% native aquatic insects at 490 m (1600 ft) elevation. During this study Waikele Stream was perhaps the most thoroughly sampled stream for aquatic insects, yet as it entered Pearl Harbor it contained only 10% native aquatic insect species.

The difference in the abundance of native species of aquatic insects between lower Waikele Stream (10%) and Halawa Stream (38%) is of interest and appears to be because of differences in salinity and habitat diversity between the two sites. Waikele Stream emptied a large amount of water into the West Loch of Pearl Harbor, whereas Halawa Stream was generally dry or contained a minimal amount of waterflow. Because of the lack of freshwater input, Halawa Stream was almost entirely marine (30 to 37 ppt salinity) from the mouth of Pearl Harbor starting at the USS Arizona Memorial area upstream to the end of tidal mudflats at the Salt Lake Boulevard bridge. This was in contrast to a large freshwater plume of $\leq$ 15 ppt salinity in Waikele Stream that extended well out into Pearl Harbor (see Nance 1998). The estuarine reaches of Halawa Stream contained tidal mudflat and rocky shoreline areas with relatively little mangrove growth. Aquatic habitats at Waikele Stream ranged from an impounded freshwater pool at the USGS gaging station, to a riffle formed downstream of this weir, eventually changing to a mixohaline area at the mouth of Pearl Harbor containing thick growths of mangroves and extensive tidal mudflats.

The biogeographic status of many species of Hawaiian aquatic insects in disturbed lowland habitats such as Pearl Harbor is not yet known. For example, 20 aquatic Diptera (flies) taxa (with varying amount of individuals collected for each taxa) could not be identified to the species level, thus rendering determination of biogeographic status impossible. However, the vast majority of these and other undetermined aquatic insects are likely to be new introductions to Pearl Harbor or 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 these lower elevation areas of Pearl Harbor have been described. This would provide further evidence that most of the undetermined aquatic insects found during the Pearl Harbor study are probably introduced species. Thus, if it is assumed that species of unknown status in Pearl Harbor are new introductions, then 75% of the aquatic insects found in Pearl Harbor estuarine regions would be nonindigenous species.

Additionally, 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 1995, Polhemus 1996, Evenhuis 1997, Englund et al. 1998, Englund and Preston 1999). For example, less than 5% of aquatic insects found in the upper (200-550 m (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 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 20% unknown status for Pearl Harbor.

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) have become established in Hawaiian freshwaters from between 1900 to 1991. An average of nearly 6.4 species per decade have become established in Hawaiian freshwaters, if these introductions were assumed to occur starting around 1900.

In the 1990s the trend of nonindigenous species introductions seems to be holding, and perhaps even accelerating in Pearl Harbor watersheds. Three new introduced aquatic species, for example, colonized the lower Waikele Stream area between 1993 and 1998: a dragonfly (*Crocothemis servilia*), an atyid shrimp (*Neocaridina denticulata sinensis),* and the apple snail (*Pomacea canaliculata*). At least two of these species, the atyid shrimp and apple snail could have colonized Waikele Stream (and the directly adjacent Kapakahi Stream) only through human intervention. A species of African cichlid (*Hemichromis elongatus*), previously unknown in Pearl Harbor watersheds and found only in Lake Wilson, Kawainui Marsh drainages, and Nuuanu Stream (M. Yamamoto, HDAR, Personal Communication) was common in the lower portions of Waiawa Stream.

A new Hawaii State record and a potentially harmful species of fish was found during these surveys. Native to the Philippines and South China Sea region, a fang-toothed blenny (*Omobranchus ferox*) was found only in a restricted area of lower Halawa Stream (the east bank, immediately upstream of the Kamehameha Highway bridge). This species appears to have only recently become established, as it was found in approximately 15 m (50 ft) of rocky mangrove habitat lining lower Halawa Stream. Intensive searches for *Omobranchus ferox* in other areas of Halawa Stream and throughout Pearl Harbor failed to locate any additional individuals. The currently restricted range of this species indicates it is a recent Pearl Harbor introduction, however our collection of a wide range of size classes indicates that it is successfully reproducing. In its native habitat, *Omobranchus ferox* inhabits a wide range of shallow estuarine and freshwater habitats, ranging from mangrove swamps to rivers and freshwater lakes in the Philippines (Springer and Gomon 1975). This adaptable species represents a potential threat not only to the ecologically similar indigenous *Oxyurichthys lonchotus* and other native freshwater and estuarine fish and invertebrates.

The freshwater shrimp, *Neocaridina denticulata sinensis,* was found in high densities in the Waikele Springs area. This is the first record for this species in a Pearl Harbor drainage. Unlike the native freshwater atyid shrimp *Atyoida bisulcata*, *N. d. sinensis* does not have an obligate marine phase (Hung et al. 1993) and is restricted to freshwater. Thus, *N. d. sinensis* must have spread into separate watersheds by repeated human introductions. Small feeder aquarium shrimp were purchased at Pet's Plus Petshop on Ward Avenue in Honolulu, and these specimens were identified as *N. d. sinensis*. According to the pet shop owner, these feeder shrimp are regularly purchased from Oahu breeders rearing these shrimp in their backyards in 200 l (55 gal) drums. This is strong evidence that *N. d. sinensis* was introduced to Oahu streams as an escaped or released aquarium species. It is possible that *Neocaridina denticulata sinensis* will compete for food and space with the native atyid shrimp *Atyoida bisulcata*, as they occupy similar habitats and have overlapping elevational distributions (being found up to 237 m (780 ft) elevation on Oahu). *Neocaridina denticulata sinensis* were often found in high densities, and several hundred introduced shrimp were collected in each aquatic dip net sample at the Waikele Springs area. Its native range includes Japan, Taiwan, the Ryukyu Islands, Korea, mainland China, and Vietnam (Hung et al. 1993). This species also has been found in several widely separated windward and leeward Oahu streams (Devick 1991b). However, the Waikele record is the first time it has been found in a Pearl Harbor drainage. [Previously this shrimp was identified from Nuuanu Stream, Oahu, as *Caridina weberi* in Devick (1991b)].

B. Origins and Modes of Introductions of Nonindigenous Species Found in Pearl Harbor Estuarine Regions

The probable origins and mode of introductions of established introduced species of aquatic macrofauna found in lower stream and wetland areas are shown in Table 9. 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 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 9, there is no one geographic region that is a predominant source of aquatic species introductions into the Pearl Harbor area. This reflects the findings of Coles et al. (1997) of Pearl Harbor and Hawaii as the "crossroads of the Pacific Ocean" for species introductions, and also further illustrates, with modern transportation, how easily nonindigenous organisms become established in vulnerable insular tropical island environments. As chronicled in Coles et al. (1997), the Pearl Harbor area has grown from a small, shallow harbor earlier in the century to a large military shipping port with adjacent civilian and military airports, with traffic arriving worldwide. Introduced aquatic vertebrates and invertebrates found in Pearl Harbor have no clear geographic center of origin but appear to be fairly evenly distributed between the western hemisphere, Asia, the western Pacific, with smaller numbers of species originating from Africa.

Resource management decisions involving intentional introductions, mainly those conducted prior to Hawaii statehood in 1959, now appear to have been ill advised. Native damselflies in the genus *Megalagrion* were formerly common in the Pearl Harbor area (Polhemus 1996, Liebherr and Polhemus 1997) but are now absent. For example, Polhemus (1996), Liebherr and Polhemus (1997), and Englund (l999) found that poeciliid fish first introduced for mosquito control now appear to be the major cause for the extinction of endemic *Megalagrion* damselflies in low-elevation areas of Hawaiian streams and wetlands. Especially problematic are biological control and food introductions. Recent food introductions, such as the apple snail and Asiatic clam (*Corbicula fluminea*) (Eldredge 1994), were not sanctioned or introduced by governmental agencies. Apple snails (*Pomacea canaliculata*), first introduced illegally as a food source 1989, are now a major pest threatening the cultivation of an important Hawaiian staple food, taro (Cowie, in press). The Asiatic clam is another food introduction that has caused enormous economic losses similar to that of the Great Lakes zebra mussel infestation (U.S. Congress 1993). In Hawaii, Asiatic clams have clogged irrigation pipes that resulted in economic damage in Maui and elsewhere (Devick 1991a).

Blackchin tilapia first introduced in 1951 for aquatic weed control (and as a baitfish), and are now perceived by U.S. Fish & Wildlife Service biologists to be one of the major causes for the decline of Hawaiian waterbirds (M. 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.). These fish 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. Additionally, migratory waterbirds such as the Northern Pintail (*Anas acuta*) and Northern Shoveler (*Anas clypeata*) have experienced a precipitous decline in numbers since 1953, from 10,000 birds in 1953 to 1,000 birds in 1994 (Ducks Unlimited, 1997). However, the decline in migratory waterfowl since 1953 cannot be explained by feral mammal predation alone, as mammal predation existed well before the introduction of blackchin tilapia.

Table 9. Geographic source (year of introduction) and known (or probably known) mode of introduction of nonindigenous species of aquatic macrofauna found in Pearl Harbor streams and estuaries (References: Van Dine 1907, Brock 1960, Edmondson 1962, Randall 1987, Devick 1991a, Cowie 1997, 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	Accidental with Baitfish
Crustaceans							
Macrobrachium lar	Guam/Tahiti (1957)					X	
Neocaridina denticulata sinensis	China-Taiwan (1991)	X					
Panopeus lacustris	Northwest Atlantic (1947)				X		
Panopeus pacificus	Philippines (1929)				X		
Procambarus clarkii	North America (1923)					X	
Mollusks							
Cipangopaludina chinensis	Southeast Asia (1900)	X					
Corbicula fluminea	Asia (1981)					X	
Planorbella duryi	North America (1994)	X					
Pomacea canaliculata	South America (1989)					X	
Fish							
Ancistrus cf. *temminckii*	South America (1985)	X					
Clarias fuscus	Asia (<1900)					X	
Colossoma macropomum	South America (1987)	X					
Cyprinus carpio	Asia (<1900)					X	
Gambusia affinis	Texas (1905)		X				
Hemichromis elongatus	Africa (1991)	X					
Hypostomus cf. *watwata*	South America (1984)	X					

[1]Or possible seachest fouling

Table 9 (Continued)

Taxa	Geographic Region	Aquarium Release	Intentional Biocontrol	Probable Ballast Water	Probable Ship-Hull Fouling[1]	Intentional Food Introduction	Accidental with Baitfish
Limia vittata	Cuba (1950)	X					
Monopterus albus	Asia (< 1905)					X	
Moolgarda engeli	Marquesas (1955)						X
Mugilogobius cavifrons	Western Pacific (Japan to Indonesia) (1987)			X			
Omobranchus ferox	South Pacific (Philippines to Madagascar) (1998)			X			
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				
Xiphophorus helleri	Central America (1922)		X				
Xiphophorus maculatus	Central America (1922)		X				
<u>Amphibians</u>							
Bufo marinus	South America (1932)		X				
Rana catesbeiana	North America (1902)		X				
Rana rugosa	Japan (1896)		X				
	Percent (number)	30% (9)	30% (9)	6.7% (2)	6.7% (2)	23.3% (7)	3.3% (1)

[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, but this probably occurred after 1930's surveys conducted by G.B. Mainland (1939).

Since Hawaii statehood, government agencies responsible for aquatic resource management have not introduced aquatic macrofauna into Pearl Harbor watersheds (Devick 1991a). Introduction of aquatic organisms through the aquarium trade and from subsistence food introductions are the major threats facing native species in Hawaii. Possible introductions via ballast water and ship hull fouling are other possible vectors for introduced species. However, only 4 of the 30 (13%) species listed in Table 9 are considered likely to have come from these sources. Since 1987, for example, a goby (*Mugilogobius cavifrons*), a fang-toothed blenny (*Omobranchus ferox*), the small mangrove mudflat beetle (*Parathroscinus* cf. *murphyi*) and a brackish-marine water species of aquatic snail (*Pyrgophorus* cf. *coronatus*), were all first observed or collected in Pearl Harbor. This small snail species would not be a food introduction and is also an unlikely aquarium introduction because of its estuarine habitat. Other introduced aquatic insects first sighted in Pearl Harbor before spreading to other areas in Hawaii include the non-biting midge, *Chironomus crassiforceps*, in 1944 (Van Zwaluwenburg 1945), *Cricotopus bicinctus*, in 1955 (Hardy 1956), and the ephydrid flies *Ephydra gracilis* and *Clasiopella uncinata*, both in 1946 (Wirth 1947, Adachi 1952). *Cricotopus bicinctus* is one of the most widespread aquatic insect species in Hawaiian streams and now comprises a substantial portion of invertebrate drift in Hawaiian streams (Kinzie et al. 1997)

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 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 cryptically colored and is not found in the aquarium trade, or used as a potential food source. Although further diet studies for this species are needed, an examination of the stomach contents of two *Mugilogobius cavifrons* (see Table 6) during this study 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.

C. Summary of Important Findings

The first comprehensive biological surveys of Pearl Harbor's freshwater springs, wetlands, and estuarine areas have revealed an ecologically degraded fauna dominated by introduced species.

In nonmarine areas of Pearl Harbor the majority of taxa identifiable to the species level were introductions. A new species of aquatic mite, *Eupodes* n. sp., was found in Pouhala Marsh during these surveys. Two new state records, and one new Oahu Island record for introduced aquatic species were found in Pearl Harbor estuarine regions during the 1997-1998 surveys. The new state records include a species of fang-toothed blenny (*Omobranchus ferox*) and a new record of estuarine hydrobiid snail (*Pyrgophorus* cf. *coronatus*) introduced from the Caribbean. The new Oahu Island record was that of an introduced aquatic plant (*Vallisneria americana*).

It is too early to ascertain negative impacts from these new introductions, but they reflect the continuing influx of alien species into the Hawaiian Islands. These surveys also recorded introduced species spreading into Pearl Harbor drainages. For example, the first confirmed record of apple snails (*Pomacea canaliculata*), (Lach and Cowie 1999), and a new introduction of an African cichlid, (*Hemichromis elongatus*), in Pearl Harbor drainages were found during this study. Additional collections and observations of apple snails in Pearl Harbor drainages were recorded in a spring area adjacent to Waikele Stream at Waipahu Plantation Cultural Village. Mangroves continue their encroachment into the Pearl Harbor tidal mudflats as illustrated by the aerial photographs shown in Figure 3-6. Introduced mangroves are the cause of significant changes in the physical environment of Pearl Harbor. The majority of introduced species appear to be the result of aquarium releases, intentional biocontrol releases and intentional food source releases. Although some introduced species may have originated from ballast water releases or hull fouling organisms these points of origin probably contributed only a small fraction of overall alien introductions in Pearl Harbor streams, wetlands and estuaries.

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

Van Zwaluwenburg, R.H. 1945. Notes. *Proc. Hawaii. Ent. Soc*. 12: 228.

Visher, F.N. and J.F. Mink. 1964. Ground-water resources in southern Oahu, Hawaii. Geological Survey Water-Supply Paper 1778. 133 pp.

Wagner, W.L., D.L. Herbst and S.H. Sohmer. 1990. Manual of the flowering plants of Hawaii. University of Hawaii Press and Bishop Museum Press, Honolulu. 2 vols. 1,853 pp.

Wester, L. 1981. Introduction and spread of mangroves in the Hawaiian Islands. *Assoc. Pac. Coast Geog. Year.* 43:125-137.

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.

APPENDICES

APPENDIX A

Annotated Bibliography of Literature for Pearl Harbor Streams and Estuarine Areas

AECOS (1991). Survey of lower Waiawa Stream and impacts assessment for flood retention basins at the Waiawa Ridge development project. AECOS, Inc., Kailua.

This report assessed the potential impacts of the Waiawa Ridge Development Project on stream ecology. A brief qualitative survey resulted in a very short list of freshwater organisms found in Waiawa Stream, as well as water quality data. Sailfin mollies are reported as the most common fish found in the sampled areas of Waiawa Stream, but this may be based on a misidentification.

AECOS (1992). Assessment of aquatic and riparian habitats on intermittent tributaries of Kipapa and Waikakalaua Streams at Mililani Mauka, Oahu. AECOS, Inc., Kailua.

A brief reconnaissance of Kipapa and Waiakakalaua Streams was conducted as part of the Mililani Mauka developments. All surveyed areas were dry, thus no aquatic biota were reported. Previous Dames & Moore surveys were cited in a review of biological surveys, but no new information was presented.

AECOS (1994). Waiawa Stream water quality monitoring program. AECOS, Inc., Kailua, HI.

This report presents water quality data for lower Waiawa Stream collected during monitoring for the Waiawa Ridge Development Project. The report also contains a list of stream organisms and locality data or organisms observed in lower Waiawa Stream in 1994.

AECOS (1995). Summary final report: Wailani Stream Monitoring Program. AECOS, Inc., Kailua.

Water quality was monitored at Wailani Stream (which is not on USGS topographic maps) in Waipahu during construction of Wailani Stream channel improvements.

AECOS (1996). Final report and water quality assessment: Waimano drainage channel reconstruction, Pearl City, Oahu. AECOS, Inc., Kailua, HI.

Water quality was sampled at three stations in Waiau Stream for the Waimano drainage channel reconstruction project. Pre- and post-construction water quality readings of temperature, dissolved oxygen, pH, conductivity, turbidity, total suspended solids, nitrates, and phosphorus.

Allen, J.A. (1998). Mangroves as alien species: the case of Hawaii. Global Ecology and Biogeography Letters 7: 61-71.

Documents the spread and effects of mangrove introductions into the Hawaiian Islands. The mainly negative impacts of mangroves are discussed, including the loss of habitat for endangered waterbirds such as the Hawaiian Stilt, the overgrowth of Hawaiian cultural sites, and the loss of native species in anchialine pool areas. Positive effects, although fewer, are discussed, and include the use of *Bruguiera gymnorrhiza* flowers for leis, and the beneficial water quality effects attributed to mangroves elsewhere (sediment retention, organic matter export). Barnacles and oysters can be found in mangroves in Pearl Harbor, but are missing from mangroves at Heeia Swamp in Kaneohe Bay.

Anonymous (1916). A possible enemy of the mosquito. California Fish and Game 2(4): 1-4.

This early paper documents predation by topminnows on aquatic insects such as mosquitoes and other chironomid insects. A brief mention of the success of topminnows in reducing mosquitoes in Hawaii is also made.

Anonymous (1990). Hawaii Stream Assessment. Prepared for Commission on Water Resource Management, State of Hawaii, Honolulu, HI.

Although this report did not conduct any new studies, data existing prior to 1990 on Hawaiian streams were compiled into a large report. Areas examined include fish, crustacean, mollusk, and riparian vegetation resources, and a thorough documentation of water diversions. Streams on each island are examined, along with references to previously conducted stream surveys in each island.

Aoyama, S.S. and R.H.F. Young (1974). A study of the effects of secondary effluent on Waimano and Waiawa Streams. OWRR Project No. A-027-HI.

This study examined water quality changes in Waiawa and Waimano Stream and the effect of the addition of chlorinated sewage effluent from the Pacific Palisades sewage treatment plant. Physical, chemical, and bacteriological characteristics of Waiawa and Waimano Streams were monitored for nine months in selected stations. This study found the water quality of Waimano and Waiawa Stream was significantly altered by the addition of effluent from the Pacific Palisades sewage treatment plant.

Coles, S.L. (1979) A description of the wetlands adjacent to the Waiau generating station, Oahu, Hawaii, and a history of its land utilization. Hawaiian Electric Company Report.

This report provides a description of conditions in aquatic habitats at the site of the HECO Waiau generation station. Included are descriptions of aquatic biota including plants, fish, crustaceans, and birds found at the wetlands here. A history of land ownership and use is also provided.

COMPACNAVFACENGCOM (1971). Pearl Harbor Pollution Model Study. OICC, MICPAC, and DCE (COMFOURTEEN) staffs, Pearl Harbor 90 pp.

Identification and compilation of all significant sources of pollution contributing to the degradation of Pearl Harbor as of 1971, including major streams.

Cox, D.C. and C. Lao (1967). Development of deep monitoring station in the Pearl Harbor ground water area on Oahu. Water Resources Research Center, Honolulu.

Deep wells at Puuloa and Ewa Beach were drilled to sample water quality characteristics. Indications of a possible existence of a thin layer of fresher water floating on seawater in the deep aquifer were found, with a tidal fluctuation of about 15%.

Devick, W.S. (1991). Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. Proceedings of the 1990 symposium on freshwater stream biology and fisheries management. Department of Land and Natural Resources, Division of Aquatic Resources Honolulu.

This paper documents the spread of introduced species into Hawaiian streams and reservoirs. Year of introduction and geographic origin of introduced freshwater fish, crustaceans, mollusks, and amphibians are discussed. Some of the adverse impacts caused by introduced freshwater species are given.

Ducks Unlimited (1998). Environmental and Enhancement Plan for Pouhala Marsh, Oahu, Hawaii. Rancho Cordova, California.

The Pouhala Marsh restoration project is a multi-cooperator effort that aims to secure and restore nearly 70 acres of wetlands in Pearl Harbor's West Loch. Pouhala Marsh lies between the delta of Waikele and Kapakahi Streams, and contains both permanently flooded and seasonal wetlands. The project has been undertaken through a partnership of Ducks Unlimited, Inc., the State of Hawaii, the U.S. Fish & Wildlife Service, and the City and County of Honolulu. This document details the physical, natural and archaeological features of the marsh. Bird, insect, vegetation, and hydrological surveys were conducted within the Pouhala Marsh area.

Englund, R. (1993). A survey of the fish and aquatic insect fauna of the Waikele/Kipapa Streams Oahu, Hawaii. BHP Environmental Technologies International, Honolulu 47pp.

A survey of the Waikele/Kipapa Stream from Pearl Harbor to 1800 ft elevation in the Koolau Mountains was conducted in 1993. Fish, crustaceans, and aquatic insects were assessed.

Englund, R. and R. Filbert (1996). Non-overlapping distributions of introduced live-bearing fishes and endemic damselflies on Oahu. Pacific Entomology Conference, Ala Moana Hotel, Honolulu, (Abstr.)

Native and introduced fish were sampled by snorkeling and seining on the island of Oahu, while native *Megalagrion* spp. damselflies were collected with aerial and aquatic nets. Only one native damselfly, *Megalagrion nigrohamatum nigrolineatum*, was regularly found on Oahu, and only at high elevations. There was virtually no overlap between the distribution of introduced fish in the family Poeciliidae and Oahu endemic damselflies.

Englund, R. (1997). Biological assessment of Kipapa Stream, Oahu, adjacent to the Kipapa fuel storage annex. Pacific Aquatic Environmental, Inc., Honolulu, HI.

A biological assessment of Kipapa Stream, a tributary of Waikele Stream, was conducted to characterize stream fauna up and down gradient of the U.S. Air Force fuel tank storage area.

Englund, R.A. (1998). Biological assessment and the effects of water withdrawals on Waikele Stream, Oahu aquatic biota. Bernice P. Bishop Museum, Honolulu, Hawaii.

The Hawaii Biological Survey of the Bishop Museum conducted a preliminary assessment of the effects of water withdrawal on Waikele Stream and the surrounding estuary area in the West Loch of Pearl Harbor. A surface water diversion of 4.6 Mgal/d was proposed in the area of the USGS gauging station immediately upstream of Farrington Highway. This study assessed the potential effects that long-term water withdrawal would have on native and estuarine aquatic biota in Waikele Stream. Additionally, a complete biological survey was conducted from Waikele Springs (a large spring system in the area of H-1 freeway) downstream to the mouth of Waikele Stream in the West Loch of Pearl Harbor.

Filbert, R. and R. Englund (1995). Waiahole ditch water contested case: biological assessments of windward and leeward streams. Pacific Aquatic Environmental, Inc., Honolulu, HI.

Pacific Aquatic Environmental conducted stream assessments of all drainages influenced by the Waiahole ditch. Streams on both the leeward and windward sides of Oahu were surveyed. Areas examined that entered into Pearl Harbor streams included Waiawa Stream, and Ekahanui, Huliwai, Poliwai, and Punakauahi Gulches.

Giambelluca, T.W. (1983). Water Balance of the Pearl Harbor-Honolulu Basin 1946-1975. Ph.D. Thesis, Dept. Geography., University of Hawaii, Honolulu.

The water balance of the Pearl Harbor -Honolulu Basin was computed for 258 discrete zones at a monthly interval over the period 1946-1975. The average recharge rate of the Pearl Harbor region was found to be 268 Mgal/d, of which 68 Mgal/d was from the return of applied irrigation water. The groundwater resources of the basin are sufficient to support a population increase of approximately 450,000, should sugarcane and pineaple cultivation be discontinued.

Harland, B.A. (1958). Pearl Harbor regional drainage study. U.S. Naval District Public Works Office, Honolulu.

Comprehensive engineering investigation of the Pearl Harbor drainage system describing rainfall, surface runoff, flood conditions and recommendations for remedial measures to prevent or minimize future floods.

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

The first observations of the introduced damselfly *Ischnura ramburii* in 1974 are mentiioned in this paper. This species was first observed on Hawaii Island and then in Pearl Harbor shortly thereafter.

Hirashima, G.T. (1971). Availability of streamflow for recharge of the basal aquifer in the Pearl Harbor area, Hawaii. U.S. Geological Survey, Washington.

Description of rainfall, stream flows, and basal aquifer recharge for the Pearl Harbor watershed.

Honolulu Board of Water Supply (1981). Municipal water use plan, Pearl Harbor water control area. Honolulu Board of Water Supply, Honolulu.

Detailed account of water sources and usage in the Pearl Harbor watershed and planning for sustained use.

Hosaka, E.Y. (1937). Ecological and floristic studies in Kipapa Gulch, Oahu. Bishop Museum Occasional Papers 13(17): 175-232.

In 1933 a thorough investigation of the vegetation in Kipapa Gulch (Waikele Stream) was undertaken, providing a quantitative measure plant abundance and diversity in this Pearl Harbor tributary. This study began at the stream mouth and continued to the uppermost reaches of Kipapa Stream.

Howarth, F.G. (1994). Natural History of Halawa Valley, report to Hawaii State Department of Transportation, H-3 project. Hawaii Biological Survey, Bishop Museum, Honolulu, Hawaii.

This report includes faunal surveys by the Hawaii Biological Survey of the Bishop Museum as part of an environmental impact statement for upper North Halawa Valley and stream, a tributary to Halawa Stream that enters into Pearl Harbor. Complete surveys at the 300 m elevation level were conducted in North Halawa Stream, with assessments of native and introduced species.

Howarth, F.G. and D.A. Polhemus (1991). A review of the Hawaiian stream insect fauna. Proceedings of the 1990 symposium on freshwater stream biology and fisheries management, Honolulu, HI, Department of Land and Natural Resources, Division of Aquatic Resources.

Between 100 and 150 native insect species occur in the running waters of the Hawaiian archipelago. The native biota is characterized by the absence of many major continental aquatic insect groups. Native aquatic insects are predominately composed of Diptera (flies) and Odonata (dragonflies and damselflies), with minor representations by Coleoptera (beetles), Heteroptera (true bugs), Lepidoptera (moths), and Hymenoptera (wasps).

Hufen, T.H., P. Eyre, et al. (1980). Underground residence times and chemical quality of basal groundwater in Pearl Harbor and Honolulu aquifers, Oahu, Hawaii. Univ. Hawaii Water Resources Research Center, Honolulu.

Movement and origin of groundwater in the Pearl Harbor systems and five other systems on southern Oahu were determined using natural isotopic and chemical compositions of water samples. Basal water in the western inland portion of the Pearl Harbor system is similar in

underground residence time to that of the Kalihi, Beretania and Moiliili systems, but water in the eastern and seaward portions is characterized by short residence times and in many cases, the presence of young water. Many regions in this basal water system and, in particular, the eastern part, show the presence of transition zone water, return irrigation water and caprock water.

Jordan, D.S. and B.W. Evermann (1903). Part 1, The shore fishes, the aquatic resources of the Hawaiian islands. U.S. Government Printing Office, Washington, D.C.

Provides many original descriptions of native stream and estuarine fish, and their distributions in 1901-1902. Describes number of specimens taken from each locality (e.g. Honolulu), unfortunately specific locality data for streams and estuarine areas are not included.

Mainland, G.B. (1939). Gobioidea and fresh water fish on the island of Oahu. M.A. Thesis, Dept. Zoology. University of Hawaii, Honolulu, 50 pp.

Provides the first distribution records of introduced fish in Hawaiian waters. Also, some of the earliest distribution records for individual streams for native freshwater stream fish are included. Earlier collections by Jordan and Evermann did not include anything more than general location data, such as which island the fish was captured on. A detailed map with sampling areas is provided, and the Pearl Harbor tributaries sampled from 1937 to 1939 include Halawa Stream. High quality black and white photographs were included of all extant native freshwater fish, and can verify fish species identification. Of further importance are the specific dates and names of people responsible for early freshwater fish introductions.

McEldowney, G.A. (1922). Report (letter) to HSPA on Mangrove and other tree plantings. Experiment Station of the Hawaiian Sugar Planters Association, Honolulu.

This letter documents a shipment of 14,000 mangrove seedlings received by the HSPA and planted in the salt marshes of Oahu. The areas receiving mangrove plantings included: Kuapa Pond, Maunalua Bay, Kaloaloa Pond, Kalihi, Middle Loch and West Loch Pearl Harbor, Waialua Bay, Kawailoa Swamp, Hauula, Mokapu Peninsula and Kaneohe Bay. Four mangrove species were included in this shipment: *Rhizophora mucronata, Bruguiera gymnorrhiza, Bruguiera parviflora,* and *Ceriops tagal*.

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

This book will provide a historical overview and summary of current native and introduced fish species distribution. Provides a useful summary of introduced freshwater fish.

Nance, T. (1998). Effect of the proposed use of the WP-18 pump station on Waikele Stream and West Loch. Consultants Report by Tom Nance Water Resource Engineering, Honolulu, HI. 39 pp + appendices.

This report presents an analysis of the effects of withdrawing 4.6 Mgal/d from Waikele Stream. It is focused on the stream itself and the very shallow upper end of Pearl Harbor's West Loch, the receiving body of water. The analysis is based on the assumption that the withdrawal would be at a constant year-round rate of 4.6 MGD. Supplemental groundwater sources may be developed to supply dry-period irrigation requirements, which exceed 4.6 MGD, but this is not considered. The contribution of freshwater input from other Pearl Harbor streams such Honouliuli and Kapakahi Stream is also assessed.

Nichols, W.D., P.J. Shade, et al. (1997). Summary of the Oahu, Hawaii, regional aquifer-system analysis. U.S. Geological Survey.

A thorough description of changes in water use on Oahu is given. The decline in freshwater output since 1910 from the Pearl Harbor spring system is documented, as is the increase in the number of groundwater wells. Water budgets and groundwater recharge rates for the Pearl Harbor drainage basin are given.

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.

This inventory survey of the aquatic insects and plants of Pouhala Marsh was conducted for Ducks Unlimited in December 1996 by the Hawaii Biological of the Bishop Museum. The first sighting of the mangrove mudflat beetle in the State of Hawaii was recorded during these surveys.

Norton, S. E., A. S. Timbol, et al. (1978). Stream channel modification in Hawaii. Part B: effect of channelization on the distribution and abundance of fauna in selected streams. Hawaii Cooperative Fishery Research Unit, University of Hawaii, Honolulu, Hawaii.

This report assessed the influence of channelization on native stream biota, finding detrimental effects in several Oahu Streams. An assessment of biological conditions in two altered and one unaltered stream was also made.

PacDiv (1974). Monitoring results and evaluation of the receiving water quality of Pearl Harbor, Hawaii. PacDiv Nav. Fac. Eng. Com., Honolulu.

Water quality data taken in support of NUC 1971-74 biological study with significant findings and recommendations.

Pangelinan, A.A. (1997). Demography and life history of the orangeblack Hawaiian damselfly (*Megalagrion xanthomelas*) (Selys-Longchamp, 1876) on Oahu, Hawaii. M.S. Thesis, Biology Department, University of Guam. 44 pp.

A translocation and mark-recapture study of *Megalagrion xanthomelas* was conducted in the last remaining 95 m of Oahu stream habitat where this damselfly is found. Damselflies were translocated to mitigation ponds near the stream, and life history studies were conducted. This damselfly species was historically the most common Oahu damselfly, and is mainly found in lowland habitats.

Park, E.I. (1983). Pearl Harbor brackish water study. Board of Water Supply, Honolulu.

Study to identify sources of brackish water in the Ewa District that were available for development. Best potential sources were found at Palailai, Waikele, Ewa Beach, Barbers Point, Pearl Harbor Springs and Waiawa Springs.

Perkins, R. C. L. (1913). Introduction to Fauna Hawaiiensis. Fauna Hawaiiensis. D. Sharp. Cambridge, Cambridge University Press.

Perkins noted that *Megalagrion xanthomelas* was a common insect in Honolulu gardens, and in lowland districts generally.

Polhemus, D. (1996). The orangeblack Hawaiian damselfly, *Megalagrion xanthomelas* (Odonata: Coenagrionidae): clarifying the current range of a threatened species. Bishop Museum Occasional Papers 45: 30-53.

This article describes the decline and threats faced by the orangeblack Hawaiian damselfly. This research indicated that the *Megalagrion xanthomelas* damselfly was the most common large aquatic insect in the Pearl Harbor area. With the introduction of alien fish species, these damselflies have nearly become extinct on Oahu. Surveys of the major spring complexes entering Pearl Harbor confirmed the extirpation of this species from the Pearl Harbor region.

Polhemus, D.A. and A. Asquith (1996). Hawaiian damselflies: a field identification guide. Honolulu, HI, Bishop Museum Press.

This book provides a general synopsis of Hawaiian damselfly ecology and the status of damselflies in Hawaii. Current and historical distributions for native damselflies are given, as well as a summary of the current threats facing damselfly populations.

Polhemus, D.A. and J.K. Liebherr (1997). Comparisons to the century before: the legacy of R. C. L. Perkins and *Fauna Hawaiiensis*as the basis for a long-term ecological monitoring program. Pacific Science 51(4): 490-504.

As a means of assessing the impacts of 100 years of development, comparisons were made to collections made by Perkins in the 1890s and early 1900s and present day damselfly distributions. Distributions of native damselflies inhabiting Pearl Harbor 100 years ago were compared with present-day distributions.

Samuelson, G.A. (1998). New records for Hawaiian coleoptera. Bishop Museum Occasional Papers 56: 27-33.

This paper discusses the first finding of the mangrove mudflat beetle, an introduced species, in Pearl Harbor. This estuarine beetle is native to Asia.

Schuyler, J.D. and G.F. Allardt (1889). Culture of Sugar Cane: Report on Water Supply for Irrigation on the Honouliuli and Kahuku Ranchos, Island of Oahu, Hawaiian Islands. , Oakland, California.

D.F. Dillingham hired two civil engineers to assess the potential water resources for the two large ranch areas he owned. This report on the water supply for irrigation quantified spring and stream flow for Pearl Harbor streams, and also for the Kahuku area. Also included is a map of the Hawaiian fish ponds occurring in Pearl Harbor in 1889, and historical place names, some of which have changed. Of interest are quantified discharges of Pearl Harbor springs prior to urbanization and well development.

Shafland, P.L. (1991). Management of introduced freshwater fishes in Florida (Appendix II). Proceedings of the 1990 symposium on freshwater stream biology and fisheries management, Honolulu, HI, Department of Land and Natural Resources, Division of Aquatic Resources.

This paper documents the effects of introduced crayfish, and experience in Florida in attempts to introduce *Procambarus clarkii* (red swamp crayfish) for aquaculture. Some of the adverse impacts caused by introduced crayfish are discussed.

Souza, W.R. and W. Meyer (1995). Numerical simulation of regional changes in ground-water levels and in the freshwater saltwater interface induced by increased pumpage at Barbers Point shaft, Oahu, Hawaii. U.S. Geological Survey.

This report estimated regional changes in ground-water levels and the freshwater-saltwater interface that could occur in the ground-water system of southern Oahu as a result of increasing ground-water withdrawal at the U.S. Navy's Barbers Point shaft. Specifically, the Koolau aquifer in the Pearl Harbor area was examined.

Stearns, H.T. and K.N. Vaksvik (1935). Geology and ground-water resources of the island of Oahu, Hawaii. Wailuku, Hawaii, Maui Publishing Company, Limited.

This book provides baseline data on the springs discharging into Pearl Harbor prior to large scale development. Data such as location, spring volume, groundwater pumpage, and a discussion of the Pearl Harbor aquifer are given, along with detailed maps. Excellent source of data for Pearl Harbor aquifer and springs prior to large-scale urbanization on Oahu.

Stearns, H.T. (1940). Supplement to geology and ground-water resources of the island of Oahu, Hawaii. Honolulu, Hawaii, Advertiser Publishing Co., Ltd.

This reference includes a discussion of groundwater pumping tests and borings conducted in the Pearl Harbor navy yard in 1938. The rate of water pumped during tests is given, as were the effects of droughts on water well levels in the Pearl Harbor aquifer.

Stearns, H. T. (1985). Geology of the State of Hawaii. Palo Alto, California, Pacific Books.

This book is a revised version of Stearns' general geology of the State of Hawaii, containing descriptions of the geological structure and aquifer of the Pearl Harbor area.

Timbol, A.S. and J.A. Maciolek (1978). Stream channel modification in Hawaii. Part A: statewide inventory of streams, habitat factors and associated biota. Hawaii Cooperative Fishery Research Unit, Honolulu, Hawaii.

This report summarized the amount and impacts of stream channelization in Hawaii. Streams entering Pearl Harbor were included such as Waikele and Waiawa Streams.

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

This article documents the unfortunate introductions of top minnows (although poeciliids are not top minnows but are classified as live bearers) into Hawaii to control mosquitoes. With advice from David Starr Jordan several species of introduced fish were widely spread into all lowland Hawaiian waters.

Van Dine, D.L. (1908). Annual Report of the Hawaii agricultural experiment station for 1907. U.S. Department of Agriculture.

This report gives specific locations of fish introductions (*Molliensia latipinna*, *Fundulus grandis*, *Gambusia affinis*) on each island, and states that the fish are breeding so successfully that no further importations are necessary.

Visher, F.N. and J.F. Mink (1964). Ground-Water Resources in Southern Oahu, Hawaii. Washington, D.C., United States Government Printing Office.

This book provides an authoritative reference on groundwater springs in Pearl Harbor, and how they affect stream flow. Also, flow estimates for the five major Pearl Harbor springs are provided, as are estimates of the impacts of groundwater pumping on springs and streams. A valuable reference to any investigation of fresh and brackish water areas of the Pearl Harbor region and southern Oahu.

Wester, L. (1981). Introduction and spread of mangroves in the Hawaiian Islands. Association of Pacific Coast Geographers Yearbook 43:125-137.

Description of how mechanization of sugar cane harvest during and following WW II increased sedimentation and deposition of the delta at the mouth of Waikele Stream in Pearl Harbor, providing a substratum for mangrove (*Rhizophora mangle*) recruitment. Aerial photos show rapid extension of mangroves from virtually none in 1951 to over 40 acres in 1981.

Williams, F. X. (1931). Handbook of the insects and other invertebrates of Hawaiian sugar cane fields, Experiment Station of the Hawaiian Sugar Planters' Association.

This text mentions that *Megalagrion xanthomelas* was widespread throughout the islands. *Megalagrion xanthomelas* is virtually extinct from Oahu and declining on all islands, but this book documents that it was common throughout Hawaii.

Williams, F.X. (1936). Biological studies in Hawaiian water-loving insects. Proceedings of the Hawaiian Entomological Society 9: 235-349.

This article discusses how *Megalagrion xanthomelas* was commonly found in the low-lands of Oahu until the introduction of topminnows into sugarcane ponds. Extensive treatment on many important native aquatic insects, including beetles, dragonflies, and damselflies. Extensive treatment of many important native aquatic insects, including beetles, dragonflies, and damselflies.

Zimmerman, E.C. (1948). Insects of Hawaii: Volume 2, Apterygota toThysanoptera. Honolulu.

This book provides keys for dragonflies and damselflies found in Hawaii as of 1948, including the native damselflies, many of which are extirpated from Oahu. Also included are habitat types and ranges of the native Odonata. Zimmerman also discusses the effects of introduced on some native damselfly species such as *Megalagrion xanthomelas*. Provides a valuable reference for dates of introduced species and original distributions of native species.

APPENDIX B

Listing of Occurrences of Freshwater and Estuarine Organisms Collected or Observed in Pearl Harbor from All Available Sources

Kingdom: Animalia
- *Amblyseius* sp. nr. *oahuensis/coniferus*
1998 - Current Project

Phylum: Porifera
- *Heteromyenia baileyi*
1992 - HDAR-OBS
Class: Demospongiae
Order: Hadromerida
Family: Suberitidae
- *Suberites* cf. *zeteki* de Laubenfels **(Introduced)**
1948 - BPBM-C 201

Phylum: Cnidaria
Class: Anthozoa
Order: Actiniaria
Family: Isophelliidae
- *Epiphellia humilis* (Verrill, 1928)
1997 - Current Project

Phylum: Platyhelminthes
Class: Turbellaria
Order: Tricladida
Family: Planariidae
- *Dugesia* sp. (Introduced)
1997 - Current Project

Phylum: Nematoda
Class: Secernentea
Order: Camallanida
Family: Camallanidae
- *Camallanus cotti* Fujita, 1927 **(Introduced)**
1997 - Current Project
1998 - Current Project

Phylum: Annelida
Class: Polychaeta
- Unidentified Polychaeta
1997 - Current Project
1998 - Current Project
Order: Phyllodocida
Family: Amphinomidae
- Unidentified Amphinomidae?
1997 - Current Project
Family: Nereididae
- *Neanthes* sp.
1997 - Current Project
- Unidentified Nereididae
1931 - BPBM-R 1488
- *Perinereis* sp.
1929 - BPBM-R 1502
Order: Spionida
Family: Spionidae
- *Minuspio* sp.?
1997 - Current Project
- Unidentified Spionidae

1997 - Current Project
- *Streblospio benedicti* Webster, 1879 **(Introduced)**
1997 - Current Project
1998 - Current Project
Order: Cirratulida
Family: Cirratulidae
- *Cirratulus* sp.
1929 - BPBM-R 1451
Order: Opheliida
Family: Opheliidae
- *Armandia intermedia* Fauvel, 1902
1997 - Current Project
Order: Capitellida
Family: Capitellidae
- *Capitella capitata* (Fabricius, 1780)
1997 - Current Project
1998 - Current Project
Order: Terebellida
Family: Polynoidae
- Unidentified Polynoidae
1997 - Current Project
Order: Cossurida
Family: Cossuridae
- *Cossura coasta* Kitamori, 1960
1997 - Current Project
1998 - Current Project
Class: Oligochaeta
- Unidentified Oligochaeta
1998 - Current Project
Order: Rhynchobdellida
Family: Piscicolidae
- *Aestabdella abditovesiculata* (Moore, 1952)
1997 - Current Project
1998 - Current Project
- *Myzobdella lugubris* Leidy, 1851 **(Introduced)**
1997 - Current Project
1998 - Current Project

Phylum: Mollusca
Class: Gastropoda
Order: Archaeogastropoda
Family: Stomatellidae
- *Syncera giffardi* Dall
Unknown - BPBM-MO 65725
Order: Mesogastropoda
Family: Ampullariidae
- *Pomacea canaliculata* (Introduced)
1997 - Current Project
1997 - HDAR-OBS
1998 - Current Project
Family: Cerithiidae
- *Cerithium nesioticum* Pilsbry & Vanatta, 1905
1998 - Current Project
- *Cerithium* sp. cf. *zebrum* Kiener, 1841
1998 - Current Project

Family: Hydrobiidae
- *Pyrgophorus* cf. *coronatus* Pfeiffer, 1840 **(Introduced)**
1998 - Current Project
Family: Littorinidae
- *Littoraria scabra* (Linnaeus, 1758)
1997 - Current Project
Family: Thiaridae
- *Melanoides* sp.
1964 - HDAR-OBS
- *Melanoides tuberculata* (Müller, 1774)
1992 - HDAR-OBS
1993 - Englund, R. A., 1993 (Recorded as *Thiaria tuberculata*.)
1998 - Current Project
- *Tarebia granifera* (Lamarck, 1816)
1997 - Current Project
1998 - Current Project
- *Thiara* cf. *indefinata* (Lea & Lea, 1851) **(Introduced)**
1997 - Current Project
- Unidentified Thiaridae
1997 - Current Project
Family: Viviparidae
- *Cipangopaludina chinensis* (Sykes, 1900)
1998 - Current Project
Order: Neogastropoda
Family: Terebridae
- Unidentified Terebridae?
1998 - Current Project
Order: Basommatophora
Family: Ellobiidae
- *Melampus castaneus* Montfort
1923 - BPBM-TH 1
Family: Lymnaeidae
- *Lymnaea reticulata*
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
Family: Physidae
- *Physa* sp.
1997 - Current Project
1998 - Current Project
Family: Planorbidae
- *Planorbella duryi* (Wetherby, 1879)
1997 - Current Project
1998 - Current Project
Order: Stylommatophora
Family: Pupillidae
- *Gastrocopta lyonsiana*
1921 - BPBM-MO 33730
Family: Subulinidae
- Unidentified Subulinidae
1998 - Current Project
Order: Archaeopulmonata
Family: Melampodidae
- *Allochroa bronnii*
Unknown - BPBM-MO 64832
- *Laemodonta octanfracta*

Unknown - BPBM-MO 64874
Unknown - BPBM-MO 64875
1923 - BPBM-MO 67478
1923 - BPBM-TH 17
1932 - BPBM-MO 199241
1932 - BPBM-MO 199242

- *Plectotrema* sp.
1932 - BPBM-MO 199243

Class: Polyplacophora
Order: Ischnochitonida
Family: Ischnochitonidae
- *Ischnochiton petaloides* Gould
1931 - BPBM-TH 78

Class: Bivalvia
Order: Arcoida
Family: Isognomonidae
- *Isognomon* cf. *californicum* (Conrad, 1837)
1998 - Current Project

Order: Veneroida
Family: Corbiculidae
- *Corbicula fluminea* Müller, 1774
1989 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project

Class: Pelecypoda
- Unidentified Pelecypoda
1997 - Current Project

Phylum: Arthropoda
Family: Hyalellidae
- *Hyalella azteca* (Saussure, 1858)
1997 - Current Project
1998 - Current Project

Class: Arachnida
Order: Acari
Family: Ascidae
- Unidentified Ascidae
1998 - Current Project

- *Lasioseius* sp. (Introduced)
1998 - Current Project

Family: Bdellidae
- *Bdella distincta* Baker & Balock, 1944 **(Introduced)**
1998 - Current Project

Family: Eupodidae
- *Eupodes n.sp.*
1998 - Current Project

Order: Araneae
Family: Clubionidae
- *Cheiracanthium mordax* L. Koch **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997

Family: Heteropodidae
- *Heteropoda venatoria* (Linnaeus) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997

Family: Tetragnathidae
- *Tetragnatha mandibulata* Walkennaer **(Introduced)**
1997 - Current Project
Class: Insecta
Order: Odonata
Family: Aeshnidae
- *Anax junius* (Drury, 1770)
1993 - Englund, R. A., 1993
1994 - Polhemus, 1994
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Anax strenuus* Hagen, 1867
1993 - Englund, R. A., 1993
1994 - Polhemus, 1994
Family: Libellulidae
- *Crocothemis servilia* (Drury, 1770) **(Introduced)**
1997 - Current Project
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
1998 - Current Project
- *Nesogonia blackburni* (McLachlan, 1883)
1994 - Polhemus, 1994
- *Orthemis ferruginea* (Fabricius, 1775)
1993 - Englund, R. A., 1993
1997 - Current Project
- *Pantala flavescens* (Fabricius, 1798)
1993 - Englund, R. A., 1993
1994 - Polhemus, 1994
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
Order: Zygoptera
Family: Coenagrionidae
- *Enallagma civile* (Hagen, 1862) **(Introduced)**
1997 - Current Project
- *Ischnura posita* (Hagen, 1862)
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project
- *Ischnura ramburii* (Sely-Longchamps, 1850) **(Introduced)**
1993 - Englund, R. A., 1993 (Recorded as Ischnura ramburi.)
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Megalagrion hawaiiense* (McLachlan)
1994 - Polhemus, 1994
- *Megalagrion koelense* (Blackburn)
1994 - Polhemus, 1994
- *Megalagrion leptodemas* Perkins
1994 - Polhemus, 1994
- *Megalagrion nigrohamatum nigrolineatum* (Blackburn)
1994 - Polhemus, 1994
- *Megalagrion oahuense* (Blackburn)
1994 - Polhemus, 1994

Order: Heteroptera
Family: Anthocoridae
- *Paratriphleps laeviusculus* Champion, 1901 **(Introduced)**
    1998 - Current Project
Family: Coreidae
- Unidentified Coreidae
    1998 - Current Project
Family: Corixidae
- *Trichocorixa reticulata* (Guerin-Meneville, 1857) **(Introduced)**
    1998 - Current Project
Family: Gerridae
- *Halobates hawaiiensis* Usinger, 1938
    1997 - Current Project
    1998 - Current Project
    1998 - Current Project
Family: Lygaeidae
- *Nysius* sp.
    1998 - Current Project
- *Nysius caledoniae* Distant, 1920 **(Introduced)**
    1998 - Current Project
Family: Mesoveliidae
- *Mesovelia amoena* Uhler, 1894 **(Introduced)**
    1993 - Englund, R. A., 1993
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project
- *Mesovelia mulsanti* White, 1879 **(Introduced)**
    1997 - Current Project
    1998 - Current Project
Family: Rhopalidae
- *Liorhyssus hyalinus* (Fabricius, 1794) **(Introduced)**
    1998 - Current Project
Family: Saldidae
- *Micracanthia humilis* (Say, 1832) **(Introduced)**
    1998 - Current Project
- *Saldula exulans*
    1993 - Englund, R. A., 1993
    1994 - Polhemus, 1994
- *Saldula procellaris* (Kirkaldy)
    1994 - Polhemus, 1994
Family: Tingidae
- *Corythucha morrilli* Osborn & Drake, 1917 **(Introduced)**
    1998 - Current Project
- *Leptodictya tabida* (Herrich-Schaeffer, 1840) **(Introduced)**
    1998 - Current Project
Family: Veliidae
- *Microvelia vagans* White
    1993 - Englund, R. A., 1993
    1994 - Polhemus, 1994
Order: Coleoptera
Family: Anobiidae
- *Tricorynus sharpi* (Pic, 1912)
    1998 - Current Project
Family: Anthribidae
- *Araecerus* sp. (Introduced)
    1997 - Current Project
    1998 - Current Project

- *Araecerus fasciculatus* (DeGeer) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
Family: Bruchidae
- *Algarobius bottimeri* Kingsolver, 1972 **(Introduced)**
1998 - Current Project
- *Mimosestes amicus* (Horn, 1873) **(Introduced)**
1998 - Current Project
- *Stator limbatus* (Horn, 1873) **(Introduced)**
1998 - Current Project
- *Stator pruininus* (Horn, 1873) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
Family: Cerambycidae
- *Prosoplus bankii* (Fabricius, 1775) **(Introduced)**
1998 - Current Project
- *Sybra alternans* (Wiedemann, 1825) **(Introduced)**
1998 - Current Project
Family: Chrysomelidae
- *Chaetocnema confinis* Crotch, 1873 **(Introduced)**
1998 - Current Project
Family: Coccinellidae
- *Azya orbigera* Mulsant, 1850 **(Introduced)**
1998 - Current Project
- *Brumoides suturalis* (Fabricius, 1798) **(Introduced)**
1998 - Current Project
- *Coccinella septempunctata* Linnaeus **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
- *Coelophora inaequalis* (Fabricius, 1775) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Curinus coeruleus* (Mulsant, 1850) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Diomus notescens* (Blackburn, 1889) **(Introduced)**
1998 - Current Project
- *Olla v-nigrum* (Mulsant) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
- *Scymnus loewii* Mulsant, 1850 **(Introduced)**
1998 - Current Project
- *Sticholotis rufipes* Weise, 1902 **(Introduced)**
1998 - Current Project
Family: Cucujidae
- *Cryptamorpha desjardinsi* (Guerin-Meneville, 1844) **(Introduced)**
1998 - Current Project
Family: Curculionidae
- *Myllocerus* sp. (Introduced)
1997 - Nishida, G. M.; Imada, C. T., 1997
Family: Dytiscidae
- *Copelatus parvulus* (Boisduval)
1994 - Polhemus, 1994
Family: Histeridae
- *Xerosaprinus fimbriatus* (Le Conte, 1851) **(Introduced)**
1998 - Current Project
Family: Hydrophilidae
- *Enochrus sayi* Gundersen, 1977 **(Introduced)**
1998 - Current Project

- ***Tropisternus* cf. *salsamentus*** Fall, 1901 **(Introduced)**
    1998 - Current Project
- ***Tropisternus lateralis humeralis*** Motschulsky, 1859 **(Introduced)**
    1997 - Current Project
- ***Tropisternus salsamentus*** Fall, 1901 **(Introduced)**
    1998 - Current Project

Family: Limnichidae
- **Unidentified Limnichidae**
    1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Parathroscinus* cf. *murphyi*** Wooldridge, 1990 **(Introduced)**
    1997 - Current Project
    1998 - Current Project
    1998 - Samuelson, G.A., 1998

Family: Nitidulidae
- **Unidentified Nitidulidae (Introduced)**
    1998 - Current Project

Family: Scirtidae
- ***Scirtes* sp. (Introduced)**
    1998 - Current Project

Order: Megaloptera

Family: Coniopterygidae
- ***Coniocompsa zimmermani*** Kimmins, 1953 **(Introduced)**
    1998 - Current Project

Family: Hemerobiidae
- ***Micromus timidus*** Hagen, 1853 **(Introduced)**
    1998 - Current Project

Order: Trichoptera

Family: Hydropsychidae
- ***Cheumatopsyche pettiti*** (Banks, 1908)
    1993 - Englund, R. A., 1993
    1994 - Polhemus, 1994
    1998 - Current Project

Family: Hydroptilidae
- ***Oxyethira maya*** Deming
    1994 - Polhemus, 1994

Order: Lepidoptera

Family: Crambidae
- ***Herpetogramma licarsisalis*** (Walker, 1859) **(Introduced)**
    1997 - Current Project
    1998 - Current Project
- ***Spoladea recurvalis*** (Fabricius) **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997

Family: Danaidae
- ***Danaus plexippus*** (Linnaeus, 1758) **(Introduced)**
    1997 - Current Project
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project

Family: Geometridae
- ***Macaria abydata*** Guenée, 1857 **(Introduced)**
    1997 - Current Project
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project

Family: Lycaenidae
- ***Brephidium exilis*** (Boisduval, 1852) **(Introduced)**

1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project

Family: Nymphalidae

- *Agraulis vanillae* (Linnaeus, 1758) **(Introduced)**
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project

- *Papilio xuthus* (Linnaeus, 1767) **(Introduced)**
1997 - Current Project

Order: Diptera

Family: Agromyzidae

- *Amauromyza maculosa* (Malloch, 1913) **(Introduced)**
1998 - Current Project

- *Liriomyza sativae* Blanchard, 1938 **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project

- *Liromyza* sp. (Introduced)
1998 - Current Project

- *Melanagromyza splendida* Frick, 1953 **(Introduced)**
1998 - Current Project

Family: Asteiidae

- *Loewimyia orbiculata* Hardy, 1980
1998 - Current Project

- *Sigaloessa* sp.? (Introduced)
1998 - Current Project

Family: Calliphoridae

- *Chrysomya megacephala* (Fabricius, 1794) **(Introduced)**
1998 - Current Project

- *Melinda pusilla* (Villeneuve, 1927) **(Introduced)**
1998 - Current Project

Family: Canaceidae

- *Canaceoides angulatus* Wirth, 1969 **(Introduced)**
1998 - Current Project

- *Canaceoides hawaiiensis*? Wirth, 1969
1998 - Current Project

- *Procanace williamsi* Wirth, 1951 **(Introduced)**
1997 - Current Project
1998 - Current Project

Family: Cecidomyiidae

- *Cecidomyiidae Gen. 1* sp.
1998 - Current Project

Family: Ceratopogonidae

- *Atrichopogon jacobsoni* (de Meijere, 1907)
1994 - Polhemus, 1994
1998 - Current Project

- *Atrichopogon* sp. not *jacobsoni* (Introduced)
1998 - Current Project

- *Dasyhelea calvescens* Macfie, 1938
1998 - Current Project

- *Dasyhelea digna* Borkent, 1996
1998 - Current Project

- *Dasyhelea hawaiiensis*? Macfie, 1934
1998 - Current Project

- *Dasyhelea sp. 1*
1998 - Current Project

- ***Dasyhelea sp. 2***
  1998 - Current Project
- ***Forcipomyia* sp.**
  1998 - Current Project
- ***Forcipomyia hardyi*** Wirth & Howarth, 1982
  1994 - Polhemus, 1994
  1997 - Current Project
- ***Forcipomyia kaneohe*** Wirth & Howarth
  1994 - Polhemus, 1994
- ***Forcypomyia sp. nr. hardyi***
  1997 - Nishida, G. M.; Imada, C. T., 1997

Family: Chironomidae

- ***Chironomus* sp.**
  1997 - Nishida, G. M.; Imada, C. T., 1997 (Recorded as *Chironomus* sp.)
- ***Chironomus crassiforceps*** (Keiffer, 1916) **(Introduced)**
  1998 - Current Project
- ***Chironomus hawaiiensis*** Grimshaw, 1901
  1997 - Current Project
  1998 - Current Project
- ***Cricotopus bicinctus*** (Meigen, 1818)
  1993 - Englund, R. A., 1993
  1994 - Polhemus, 1994
  1998 - Current Project
- ***Goeldichironomus holoprasinus*** (Goeldi, 1905) **(Introduced)**
  1998 - Current Project
- ***Orthocladius* sp.**
  1997 - Current Project
- ***Orthocladius sp. 1***
  1998 - Current Project
- ***Orthocladius sp. 2***
  1998 - Current Project
- ***Orthocladius sp. 3***
  1998 - Current Project
- ***Orthocladius sp. 4***
  1998 - Current Project
- ***Orthocladius sp. 5***
  1998 - Current Project

Family: Chloropidae

- ***Cadrema pallida*** (Loew, 1865) **(Introduced)**
  1998 - Current Project
- ***Gaurax* sp.?**
  1998 - Current Project
- ***Liohippelates collusor*** (Townsend, 1895) **(Introduced)**
  1998 - Current Project
- ***Monochaetoscinella anonyma*** (Williston, 1896) **(Introduced)**
  1998 - Current Project
- ***Rhodesiella sauteri*?**
  1998 - Current Project
- ***Rhodesiella scutellata*** (Meijere, 1908) **(Introduced)**
  1998 - Current Project
- ***Semaranga dorsocentralis*** Becker, 1911 **(Introduced)**
  1998 - Current Project

Family: Chyromyidae

- ***Chyromyidae Gen. 1* sp.**
  1998 - Current Project

Family: Culicidae
- ***Aedes* sp. (Introduced)**
  1998 - Current Project
- ***Aedes albopictus*** (Skuse, 1984) **(Introduced)**
  1994 - Polhemus, 1994
  1997 - Current Project
  1997 - Nishida, G. M.; Imada, C. T., 1997

Family: Dolichopodidae
- ***Asyndetus carcinophilus*** Parent, 1937
  1998 - Current Project
- ***Campsicnemus gloriosus*** Van Duzee
  1994 - Polhemus, 1994
- ***Campsicnemus miritibialis*** Van Duzee
  1993 - Englund, R. A., 1993
  1994 - Polhemus, 1994
- ***Chrysosoma globiferum*** (Wiedemann) **(Introduced)**
  1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Chrysotus longipalpus*** Aldrich, 1896 **(Introduced)**
  1998 - Current Project
- ***Chrysotus paliidipalpus***
  1993 - Englund, R. A., 1993
- ***Chrysotus sp. 1***
  1998 - Current Project
- ***Condylostylus longicornis*** (Fabricius, 1775) **(Introduced)**
  1998 - Current Project
- ***Dolichopodidae Gen. 1* sp.**
  1998 - Current Project
- ***Hydrophorus pacificus*** van Duzee, 1933
  1998 - Current Project
- ***Medetera grisescens*** Meijere, 1916
  1998 - Current Project
- ***Pelastoneurus lugubris*** Loew 1861 **(Introduced)**
  1998 - Current Project
- ***Syntormon flexibile*** Becker, 1922 **(Introduced)**
  1997 - Current Project
  1997 - Nishida, G. M.; Imada, C. T., 1997
  1998 - Current Project
- ***Tachytrechus angustipennis*** Loew, 1862 **(Introduced)**
  1998 - Current Project
- ***Thambemyia* sp.**
  1998 - Current Project
- ***Thinophilus hardyi*** Grootaert & Evenhuis, 1996 **(Introduced)**
  1997 - Current Project
  1998 - Current Project

Family: Drosophilidae
- **Unidentified Drosophilidae**
  1998 - Current Project

Family: Empididae
- ***Hemerodromia stellaris*?** Melander, 1947 **(Introduced)**
  1998 - Current Project

Family: Ephydridae
- ***Atissa oahuensis*** Cresson, 1948
  1998 - Current Project
- ***Brachydeutera ibari*** Ninomiya, 1930 **(Introduced)**
  1998 - Current Project
- ***Ceropsilopa coquilletti*** Cresson, 1922 **(Introduced)**

1998 - Current Project
- ***Clasiopella uncinata*** Hendel, 1914 **(Introduced)**
1998 - Current Project
- ***Discocerina mera*** Cresson, 1939 **(Introduced)**
1997 - Current Project
1998 - Current Project
- ***Donaceus nigronotatus*** Cresson, 1943 **(Introduced)**
1998 - Current Project
- ***Ephydra milbrae*** Jones, 1906 **(Introduced)**
1998 - Current Project
- ***Hecamede granifera*** (Thomson, 1896) **(Introduced)**
1998 - Current Project
- ***Hydrellia williamsi*** Cresson, 1936 **(Introduced)**
1998 - Current Project
- ***Lytogaster gravida*** (Loew, 1863) **(Introduced)**
1998 - Current Project
- ***Mosillus tibialis*** Cresson, 1916 **(Introduced)**
1998 - Current Project
- ***Nannodastia horni*** Hendel, 1930 **(Introduced)**
1998 - Current Project
- ***Neoscatella hawaiiensis***
1993 - Englund, R. A., 1993
- ***Neoscatella warreni***
1993 - Englund, R. A., 1993
- ***Notiphila insularis*** Grimshaw, 1901
1998 - Current Project
- ***Ochthera circularis*?** Cresson, 1926 **(Introduced)**
1998 - Current Project
- ***Paratissa pollinosa*** (Williston, 1896) **(Introduced)**
1998 - Current Project
- ***Placopsidella marquesana*** (Malloch, 1933) **(Introduced)**
1998 - Current Project
- ***Psilopa girschneri*** Von Roeder, 1889 **(Introduced)**
1998 - Current Project
- ***Scatella* sp.**
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Scatella bryani*** (Cresson, 1926)
1998 - Current Project
- ***Scatella hawaiiensis*** (Grimshaw)
1994 - Polhemus, 1994
- ***Scatella sexnotata*** Cresson, 1926
1997 - Current Project
1998 - Current Project
- ***Scatella sp. nr. bryani*** (Cresson)
1997 - Current Project
1998 - Current Project
- ***Scatella stagnalis*** (Fallen, 1813) **(Introduced)**
1998 - Current Project

Family: Lauxaniidae
- ***Homoneura unguiculata*** (Kertesz, 1901) **(Introduced)**
1998 - Current Project

Family: Lonchaeidae
- ***Lonchaea* sp.**
1998 - Current Project

Family: Milichiidae
- *Desmometopa* sp.
1998 - Current Project
- *Leptometopa* sp.
1998 - Current Project
Family: Muscidae
- *Atherigona reversura* Villeneuve, 1936 **(Introduced)**
1998 - Current Project
- *Hydrotaea chalcogaster* (Wiedemann, 1824) **(Introduced)**
1998 - Current Project
Family: Neriidae
- *Teleostylinus lineolatus* (Wiedemann, 1830) **(Introduced)**
1998 - Current Project
Family: Otitidae
- *Euxesta annonae* (Fabricius) **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997
- *Notogramma cimiciforme* Loew, 1867 **(Introduced)**
1998 - Current Project
Family: Phoridae
- *Megaselia* sp.
1998 - Current Project
- Unidentified Phoridae
1997 - Current Project
Family: Platystomatidae
- *Scholastes bimaculatus* Hendel, 1914 **(Introduced)**
1998 - Current Project
Family: Psychodidae
- *Clogmia albipunctata* (Williston)
1994 - Polhemus, 1994
- *Psychoda* sp.
1994 - Polhemus, 1994
- *Psychoda sp.1*
1998 - Current Project
Family: Sarcophagidae
- *Gressittomyia gressitti* (Hall & Bohart, 1948) **(Introduced)**
1998 - Current Project
- *Tricharaea occidua* (Fabricius, 1794) **(Introduced)**
1998 - Current Project
Family: Scatopsidae
- *Holoplagia guamensis* (Johannsen, 1946) **(Introduced)**
1998 - Current Project
- *Rhegmoclemina parvula*? Hardy, 1956 **(Introduced)**
1998 - Current Project
Family: Scenopinidae
- *Scenopinus papuanus* (Kroeber, 1912) **(Introduced)**
1998 - Current Project
Family: Sciaridae
- *Sciara* sp.
1997 - Current Project
- *Sciaridae Gen. 1* sp.
1998 - Current Project
Family: Sphaeroceridae
- *Coproica hirtula* (Rondani, 1880) **(Introduced)**
1998 - Current Project
- *Leptocera abdominiseta* (Duda, 1925) **(Introduced)**
1998 - Current Project

- ***Leptocera fuscipennis*** (Haliday, 1933) **(Introduced)**
    1998 - Current Project
- ***Pterogramma brevivenosum*** (Tenorio, 1968)
    1998 - Current Project

Family: Stratiomyidae

- ***Evaza javanensis*** Meijere, 1911 **(Introduced)**
    1998 - Current Project
- ***Hermetia illucens*** (Linnaeus, 1758) **(Introduced)**
    1997 - Current Project
- ***Wallacea albiseta*** Meijere, 1907 **(Introduced)**
    1998 - Current Project

Family: Syrphidae

- ***Allograpta exotica*** (Wiedemann, 1830) **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project
- ***Allograpta obliqua*** (Say, 1823) **(Introduced)**
    1998 - Current Project
- ***Ornidia obesa*** (Fabricius, 1775) **(Introduced)**
    1997 - Current Project
    1998 - Current Project
- ***Syritta orientalis*** Macquart **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Toxomerus marginatus*** (Say, 1823) **(Introduced)**
    1998 - Current Project

Family: Tachinidae

- ***Archytas cirphis*** Curran **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Lespesia archippivora*** (Riley) **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Lixophaga sphenophori*** (Villeneuve) **(Introduced)**
    1997 - Nishida, G. M.; Imada, C. T., 1997
- ***Trichopoda pilipes*** (Fabricius, 1805) **(Introduced)**
    1998 - Current Project

Family: Tephritidae

- ***Acinia picturata*** (Snow, 1894) **(Introduced)**
    1998 - Current Project
- ***Ensina sonchi*** (Linnaeus, 1767) **(Introduced)**
    1998 - Current Project
- ***Neotephritis* sp.**
    1997 - Current Project

Family: Tethinidae

- ***Dasyrhicnoessa* sp.**
    1998 - Current Project
- ***Dasyrhicnoessa insularis*** (Aldrich, 1931)
    1998 - Current Project
- ***Dasyrhicnoessa* prob. *insularis*?** (Aldrich, 1931)
    1998 - Current Project
- ***Dasyrhicnoessa vockerothi*** Hardy & Delfinado, 1980
    1998 - Current Project
- ***Tethina variseta*** (Melander, 1951) **(Introduced)**
    1998 - Current Project

Family: Tipulidae

- ***Limonia (Dicranomyia)***
    1998 - Current Project
- ***Limonia advena*** (Alexander, 1954)
    1998 - Current Project

- ***Limonia hawaiiensis*** (Grimshaw)
    1994 - Polhemus, 1994
- ***Limonia jacoba*** (Alexander)
    1993 - Englund, R. A., 1993
    1994 - Polhemus, 1994 (Recorded as Limonia jacobus.)
- ***Limonia perkinsi*** (Grimshaw)
    1994 - Polhemus, 1994
- ***Limonia stygipennis*** (Alexander)
    1993 - Englund, R. A., 1993
    1994 - Polhemus, 1994
- ***Limonia swezeyi*** (Alexander, 1919)
    1998 - Current Project
- ***Styringomyia didyma*** Grimshaw, 1901 **(Introduced)**
    1998 - Current Project
- ***Symplecta pilipes*** (Fabricius, 1787) **(Introduced)**
    1998 - Current Project

Family: Xenasteiidae
- ***Xenastia sabroskyi*?** Hardy, 1980
    1998 - Current Project

Order: Hymenoptera

Family: Agaonidae
- ***Philotrypesis* sp. (Introduced)**
    1998 - Current Project

Family: Anthophoridae
- ***Ceratina* sp.? (Introduced)**
    1998 - Current Project
- ***Pithitis smaragdula*** (Fabricius, 1787) **(Introduced)**
    1998 - Current Project
- ***Xylocopa sonorina*** F. Smith, 1874 **(Introduced)**
    1997 - Current Project
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project

Family: Aphelinidae
- ***Coccophagus ceroplastae*?** (Howard, 1895) **(Introduced)**
    1998 - Current Project

Family: Apidae
- ***Apis mellifera*** Linnaeus, 1758 **(Introduced)**
    1997 - Current Project
    1997 - Nishida, G. M.; Imada, C. T., 1997
    1998 - Current Project

Family: Chalcididae
- ***Brachymeria* sp.**
    1998 - Current Project

Family: Dryinidae
- **Unidentified Dryinidae**
    1998 - Current Project

Family: Elasmidae
- ***Elasmus* sp.**
    1998 - Current Project

Family: Eucoilidae
- **Unidentified Eucoilidae**
    1997 - Current Project

Family: Eupelmidae
- ***Anastatus koebelei*** Ashmead, 1901
    1998 - Current Project

Family: Evaniidae
- *Evania appendigaster* (Linnaeus, 1758) **(Introduced)**
1998 - Current Project
Family: Formicidae
- *Cardiocondyla* sp. nr. *nuda* (Introduced)
1997 - Nishida, G. M.; Imada, C. T., 1997
- Unidentified Formicidae (Introduced)
1997 - Current Project
1998 - Current Project
Family: Halictidae
- *Lasioglossum* sp. (Introduced)
1998 - Current Project
Family: Ichneumonidae
- Unidentified Ichneumonidae
1997 - Current Project
Family: Megachilidae
- *Megachile gentilis* Cresson, 1872 **(Introduced)**
1998 - Current Project
Family: Pteromalidae
- Unidentified Pteromalidae
1998 - Current Project
Family: Sphecidae
- *Sceliphron caementarium* (Drury, 1770) **(Introduced)**
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Trypoxylon* sp. nr. *philippinense* (Introduced)
1997 - Nishida, G. M.; Imada, C. T., 1997
Family: Torymidae
- *Torymus* sp.
1998 - Current Project
Family: Vespidae
- *Delta campaniforme campaniforme* (Fabricius, 1775) **(Introduced)**
1997 - Current Project
- *Delta curvata* (Saussure, 1854) **(Introduced)**
1997 - Current Project
- *Delta pyriformis philippinense* (Bequaert, 1928) **(Introduced)**
1997 - Current Project
- *Pachodynerus nasidens* (Latreille, 1832) **(Introduced)**
1997 - Current Project
1998 - Current Project
- *Polistes aurifer* Saussure, 1853 **(Introduced)**
1997 - Current Project
1997 - Nishida, G. M.; Imada, C. T., 1997
1998 - Current Project
- *Polistes exclamans* Viereck, 1906 **(Introduced)**
1998 - Current Project
- *Polistes olivaceus* (DeGeer, 1773) **(Introduced)**
1997 - Current Project
1998 - Current Project
Class: Chilopoda
Order: Scolopendrida
Family: Scolopendridae
- *Scolopendra subspinipes* Leach **(Introduced)**
1997 - Nishida, G. M.; Imada, C. T., 1997

Order: Caligoida
Family: Caligidae
- *Caligus rapax* Edwards, 1840
1998 - Current Project
Class: Maxillopoda
Order: Thoracica
Family: Balanidae
- *Balanus* sp.
1975 - BPBM-B 565
- *Balanus amphitrite* Darwin
1922 - BPBM-B 247
1975 - BPBM-B 568
- *Balanus amphitrite amphitrite* Darwin, 1854 **(Introduced)**
Unknown - BPBM-B 332
1915 - BPBM-B 233
1929 - BPBM-B 268
1931 - BPBM-B 276
- *Balanus eburneus* Gould, 1841 **(Introduced)**
1929 - BPBM-B 271
1948 - BPBM-B 349
1950 - BPBM-B 368
1975 - BPBM-B 567
- *Balanus trigonus* Darwin, 1854
1948 - BPBM-B 345
1948 - BPBM-B 350
Order: Harpacticoida
Family: Miracidae
- *Miracia* sp.
1998 - Current Project
Class: Malacostraca
Order: Mysidacea
- Unidentified Mysidacea Boas, 1883
1997 - Current Project
1998 - Current Project
Order: Amphipoda
- Unidentified Amphipoda Latreille, 1816
1997 - Current Project
1998 - Current Project
Family: Caprellidae
- *Caprella scaura* Templeton, 1836 **(Introduced)**
1929 - BPBM-S 5251
1929 - BPBM-S 5252
Family: Talitridae
- Unidentified Talitridae
1997 - Current Project
1998 - Current Project
Order: Isopoda
- Unidentified Isopoda Latreille, 1817
1998 - Current Project
1998 - Current Project
Family: Armadillidiidae
- Unidentified Armadillidiidae
1997 - Current Project
1998 - Current Project
Family: Ligiidae
- *Ligia hawaiensis* (Dana)

1997 - Nishida, G. M.; Imada, C. T., 1997

- *Ligia hawaiiensis* (Dana, 1853)

1997 - Current Project

1998 - Current Project

Family: Oniscidae

- *Porcellio laevis* Latreille, 1804 **(Introduced)**

1998 - Current Project

Order: Decapoda

- Unidentified Caridea Dana, 1852

1997 - Current Project

1998 - Current Project

Family: Alpheidae

- *Alpheus crassimanus* Heller, 1865

1929 - BPBM-S 8928

1938 - BPBM-S 6442

- *Alpheus mackayi* Banner & Banner, 1974

1997 - Current Project

1998 - Current Project

- *Alpheus pacificus* Dana, 1852

1947 - BPBM-S 5302

1947 - BPBM-S 5317

1948 - BPBM-S 5337

- *Leptalpheus pacificus* Banner & Banner, 1974

1972 - BPBM-S 8550

Family: Atyidae

- *Neocaridina denticulata sinensis* (Kemp, 1918) **(Introduced)**

1997 - Current Project

1998 - Current Project

Family: Calappidae

- *Cryptosoma granulosum* Alcock

Unknown - BPBM-S 1500

Family: Cambaridae

- *Procambarus clarkii* (Girard, 1852)

1992 - HDAR-OBS

1993 - Englund, R. A., 1993

1997 - Current Project

1998 - Current Project

Family: Grapsidae

- *Metapograpsus messor* (Forsskål, 1900)

1998 - Current Project

- *Metapograpsus thukuhar* Owen, 1839

1929 - BPBM-S 3157

1948 - BPBM-S 5331

- *Plagusia depressa tuberculata* Lamarck, 1818

1947 - BPBM-S 5306

Family: Hippolytidae

- *Hippolysmata* sp.

1948 - BPBM-S 6079

- *Hippolysmata vittata*

1936 - BPBM-S 4222

1947 - BPBM-S 5316

1948 - BPBM-S 5330

1948 - BPBM-S 5338

- *Lysmata acicula* Rathbun

1948 - BPBM-S 5329

- *Spirontocaris marmoratus*

1950 - BPBM-S 5634

Family: Palaemonidae

- *Macrobrachium grandimanus* (Randall, 1840)
1922 - BPBM-S 717
1991 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project

- *Macrobrachium lar* (Fabricius, 1798)
1991 - HDAR-OBS
1993 - Englund, R. A., 1993
1998 - Current Project

- *Macrobrachium rosenbergi* (de Man, 1879)
1991 - HDAR-OBS

- *Palaemon debilis* (Dana, 1852)
Unknown - BPBM-S 3265
1934 - BPBM-S 3833
1997 - Current Project
1998 - Current Project

- *Palaemonella tenuipes* Dana, 1852
1948 - BPBM-S 5339

- *Periclimenes* cf. *grandis* Simpson
1997 - Current Project
1998 - Current Project

Family: Portunidae

- *Podophthalmus vigil* (Weber, 1795)
1997 - Current Project
1998 - Current Project

- *Portunus oahuensis* (Edmonson, 1954)
1997 - Current Project

- *Thalamita crenata* Latreille, 1900
Unknown - Current Project
1997 - Current Project
1998 - Current Project

- *Thalamita edwardsi*? Borradaile, 1900
1948 - BPBM-S 5335
1997 - Current Project

- *Thalamita integra* Dana, 1852
Unknown - Current Project
1915 - BPBM-S 1590
1922 - BPBM-S 1597
1922 - BPBM-S 718
1922 - BPBM-S 724
1929 - BPBM-S 3155
1931 - BPBM-S 3343
1938 - BPBM-S 4418
1947 - BPBM-S 5305
1947 - BPBM-S 5312
1948 - BPBM-S 5332
1948 - BPBM-S 5334

- *Thalamita medipacifica* Edmondson, 1954
1923 - BPBM-S 3210

Family: Xanthidae

- *Etisus electra* (Herbst, 1801)
1937 - BPBM-S 4382

- *Etisus laevimanus* Randall, 1839
1931 - BPBM-S 3342
- *Glabropilumnus seminudus* (Miers, 1884) **(Introduced)**
1950 - BPBM-S 5640
- *Panopeus herbstii* Milne-Edwards **(Introduced)**
1947 - BPBM-S 5314
- *Panopeus lacustris* Desbonne, 1867 **(Introduced)**
1998 - Current Project
- *Panopeus pacificus* Edmondson, 1931 **(Introduced)**
Unknown - Current Project
1930 - BPBM-S 5298
1937 - BPBM-S 4397
1948 - BPBM-S 5333
1948 - BPBM-S 5336
- *Pilumnus oahuensis* Edmondson, 1931
1931 - BPBM-S 3433
1932 - BPBM-S 3852
1947 - BPBM-S 5303
1950 - BPBM-S 5613
1950 - BPBM-S 6131
- *Platypodia eydouxii* (A. Milne Edwards, 1865)
1929 - BPBM-S 3156
1931 - BPBM-S 3344
Class: Ostracoda
- Unidentified Ostracoda Latreille, 1806
1998 - Current Project

Phylum: Sipuncula
Class: Sipunculida
- Unidentified Sipunculida?
1997 - Current Project
1998 - Current Project

Phylum: Chordata
Class: Ascidiacea
Order: Stolidobranchia
Family: Styelidae
- *Styela partita*? Stimson, 1852
1929 - BPBM-Y 102
1976 - BPBM-Y 239
Class: Chondrichthyes
Order: Carchariniformes
Family: Sphyrnidae
- *Sphyrna lewini* (Griffith & Smith, 1834)
1997 - Current Project
Class: Osteichthyes
Order: Synbranchiformes
Family: Synbranchidae
- *Monopterus albus* (Zouiev, 1787) **(Introduced)**
1998 - Current Project
Order: Perciformes
Family: Acanthuridae
- *Acanthurus xanthopterus* Valenciennes in Cuvier & Valenciennes, 1835
1997 - Current Project
1998 - Current Project

Family: Apogonidae
- ***Foa brachygramma*** (Jordan & Seale, 1905)
  1997 - Current Project
  1998 - Current Project
  1998 - Current Project

Family: Blenniidae
- ***Omobranchus ferox*** Herre, 1927 **(Introduced)**
  1998 - Current Project
  1998 - Current Project

Family: Carangidae
- ***Scomberoides lysan*** (Forsskål, 1775)
  1997 - Current Project
  1997 - Current Project

Family: Cichlidae
- ***Cichlasoma nigrofasciatus*** Günther, 1867
  1991 - HDAR-OBS
- ***Hemichromis elongatus*** (Guichenot in Duméril, 1861) **(Introduced)**
  1998 - Current Project
- ***Oreochromis mossambicus*** (Peters, 1852) **(Introduced)**
  1991 - HDAR-OBS
- ***Sarotherodon melanotheron*** Rüppell, 1852 **(Introduced)**
  1993 - Englund, R. A., 1993 (Recorded as *Tilapia* (*Sarotherodon*) *melanotheron*.)
  1997 - Current Project
  1997 - Current Project
  1998 - Current Project
  1998 - Current Project
- ***Tilapia* sp.** Smith, 1840
  1989 - HDAR-OBS
  1997 - HDAR-OBS
- ***Tilapia melanotheron*** Ruppell, 1852
  1991 - HDAR-OBS
  1992 - HDAR-OBS

Family: Eleotridae
- ***Eleotris sandwicensis*** Vaillant & Sauvage, 1875
  1992 - HDAR-OBS
  1993 - Englund, R. A., 1993
  1997 - Current Project
  1997 - HDAR-OBS
  1998 - Current Project
  1998 - Current Project

Family: Gobiidae
- ***Awaous guamensis*** (Valenciennes in Cuvier & Valenciennes, 1837)
  1961 - HDAR-OBS
  1986 - HDAR-OBS
  1991 - HDAR-OBS
  1992 - HDAR-OBS
  1993 - Englund, R. A., 1993
  1993 - HDAR-OBS
  1997 - Current Project
  1998 - Current Project
- ***Bathygobius cocosensis*** (Bleeker, 1854)
  1998 - Current Project
- ***Lentipes concolor*** (Gill, 1860)
  1961 - HDAR-OBS
  1989 - HDAR-OBS
- ***Mugilogobius* sp.** Smitt, 1900

1992 - HDAR-OBS
1997 - HDAR-OBS
- *Mugilogobius cavifrons* (Weber, 1909) **(Introduced)**
1993 - Englund, R. A., 1993
1997 - Current Project
1997 - Current Project
1998 - Current Project
1998 - Current Project
- *Oxyurichthys lonchotus* (Jenkins, 1903)
1997 - Current Project
1998 - Current Project
1998 - Current Project
- *Stenogobius hawaiiensis* Watson, 1991
1991 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project
1998 - Current Project
Family: Kuhliidae
- *Kuhlia sandvicensis* (Steindachner, 1876)
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1997 - Current Project
1998 - Current Project
1998 - Current Project
Family: Mugilidae
- *Moolgarda engeli* (Bleeker, 1858) **(Introduced)**
1997 - Current Project
1998 - Current Project
1998 - Current Project
- *Mugil cephalus* Linnaeus, 1758
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project
1998 - Current Project
- *Neomyxus leuciscus* (Günther, 1872)
1997 - Current Project
1998 - Current Project
Family: Sphyraenidae
- *Sphyraena barracuda* (Walbaum, 1792)
1997 - Current Project
1997 - Current Project
1998 - Current Project
1998 - Current Project
Order: Tetraodontiformes
Family: Tetraodontidae
- *Arothron hispidus* (Linnaeus, 1758)
1997 - Current Project
1998 - Current Project
Order: Elopiformes
Family: Elopidae
- *Elops hawaiensis* Regan, 1909
1998 - Current Project

Order: Clupeiformes
Family: Clupeidae
- Unidentified Dussumieriinae
1997 - Current Project
Family: Engraulidae
- *Encrasicholina purpurea* (Fowler, 1900)
1997 - Current Project
- Unidentified Engraulidae?
1997 - Current Project
Order: Gonorynchiformes
Family: Chanidae
- *Chanos chanos* (Forsskål, 1775)
1997 - Current Project
1998 - Current Project
Order: Cypriniformes
Family: Cobitidae
- *Misgurnus anguillicaudatus* Cantor, 1842 **(Introduced)**
1961 - HDAR-OBS
1991 - HDAR-OBS
1993 - Englund, R. A., 1993
Family: Cyprinidae
- *Cyprinus carpio* Linnaeus, 1758 **(Introduced)**
1998 - Current Project
Order: Characiformes
Family: Characidae
- *Colossoma macropomus* (Cuvier, 1816) **(Introduced)**
1998 - Current Project
Order: Siluriformes
Family: Clariidae
- *Clarias fuscus* (Lacepède, 1803) **(Introduced)**
1989 - HDAR-OBS
1993 - Englund, R. A., 1993
1998 - Current Project
Family: Loricariidae
- *Ancistrus* sp. Kner, 1854 **(Introduced)**
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
- *Ancistrus temminckii* Valenciennes in Cuvier & Valenciennes, 1840 **(Introduced)**
1997 - Current Project
1998 - Current Project
- *Hypostomus* cf. *watwata* Hancock, 1828 **(Introduced)**
1998 - Current Project
1998 - Current Project
Order: Aulopiformes
Family: Synodontidae
- *Saurida gracilis* (Quoy & Gaimard, 1824)
1997 - Current Project
1997 - Current Project
1998 - Current Project
1998 - Current Project
- *Saurida nebulosa* Valenciennes in Cuvier & Valenciennes, 1850
1998 - Current Project
Order: Cyprinodontiformes
Family: Poeciliidae
- *Gambusia affinis* (Baird & Girard, 1853) **(Introduced)**

1989 - HDAR-OBS
1997 - Current Project
1997 - Current Project
1997 - HDAR-OBS
1998 - Current Project
1998 - Current Project

- *Limia* cf. *vittata* Guichenot, 1853 **(Introduced)**
1998 - Current Project
1998 - Current Project

- *Poecilia* sp. Bloch & Schneider, 1801
1961 - HDAR-OBS
1989 - HDAR-OBS
1991 - HDAR-OBS

- *Poecilia latipinna* (Lesueur, 1821) **(Introduced)**
1991 - HDAR-OBS
1998 - Current Project
1998 - Current Project

- *Poecilia mexicana* Steindachner, 1863 **(Introduced)**
1985 - HDAR-OBS
1989 - HDAR-OBS
1993 - Englund, R. A., 1993 (Recorded as Poecilia sphenops.)
1997 - Current Project
1997 - Current Project
1998 - Current Project
1998 - Current Project

- *Poecilia reticulata* Peters, 1859 **(Introduced)**
1961 - HDAR-OBS
1989 - HDAR-OBS
1991 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1997 - Current Project
1997 - HDAR-OBS
1998 - Current Project
1998 - Current Project

- *Poecilia sphenops* Valenciennes in Cuvier & Valenciennes, 1846
1992 - HDAR-OBS
1997 - HDAR-OBS

- *Poecilia velifera* Regan, 1914
1997 - HDAR-OBS

- *Xiphophorus helleri* Heckel, 1848 **(Introduced)**
1986 - HDAR-OBS
1989 - HDAR-OBS
1991 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project
1998 - Current Project

- *Xiphophorus maculatus* (Günther, 1866) **(Introduced)**
1998 - Current Project

Class: Amphibia
Order: Anura
Family: Bufonidae

- *Bufo marinus* (Linnaeus, 1758) **(Introduced)**

1991 - HDAR-OBS
1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project

Family: Ranidae

- *Rana catesbeiana* Shaw, 1802

1992 - HDAR-OBS
1993 - Englund, R. A., 1993
1997 - Current Project
1998 - Current Project

- *Rana rugosa* Schlegel, 1838

1993 - Englund, R. A., 1993
1998 - Current Project

Class: Reptilia

Order: Testudines

Family: Emydidae

- *Chrysemys scripta elegans*

1992 - HDAR-OBS
1993 - Englund, R. A., 1993

APPENDIX C

Stream and Wetland Records for Invertebrates and Fishes Collected or Observed in Pearl Harbor Legacy Project Surveys

Pearl Harbor Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Aiea Stream	E'o Stream	Halawa Stream	Honouliuli Stream	Iroquois Point	Kalauao Springs	Kalauao Stream	Kapakahi Stream	Pouhala Marsh	Waimano Springs	Waiawa Springs	Waiawa Stream	Waiawa Wildlife Refuge	Waikele Springs	Waikele Stream	Waimalu Stream
Cnidaria																		
Anthozoa																		
Actiniaria																		
Isophellidae																		
Epiphellia humilis (Verrill, 1928)	E	Ind								X								
Platyhelminthes																		
Turbellaria																		
Tricladida																		
Planariidae																		
Dugesia sp.	F	Intro						X										
Nematoda																		
Secernentea																		
Spirurida																		
Camallanidae																		
Camallanus cotti Fujita, 1927	F	Intro						X		X			X				X	
Sipuncula																		
Undetermined Sipunculid?	E,M	?	X	X	X													X
Annelida																		
Hirudinea																		
Rhynchobdellida																		
Piscicolidae																		
Aestabdella abditovesiculata (Moore, 1952)	F,M	Ind			X									X			X	X
Myzobdella lugubris Leidy, 1851	F	Intro											X				X	
Oligochaeta																		
Oligochaeta																		
Undetermined Oligochaeta	F,M	?			X									X				
Polychaeta																		
Undetermined Polychaeta	M	?		X	X													
Nereididae																		
Neanthes sp.	F,E	?		X													X	
Capitellida																		
Capitellidae																		
Capitella sp.	F,E,M	?	X	X	X	X			X								X	
Cossurida																		
Cossuridae																		
Cossura coasta Kitamori, 1960	E	Ind												X				X
Opheliidae																		
Opheliida																		
Armandia intermedia Fauvel, 1902	F,E,M	?	X	X	X					X							X	
Phyllodocida																		
Amphinomidae																		
Undetermined Amphinomidae?	F,E,M	?			X	X											X	
Spionida																		
Spionidae																		
Minuspio sp.	F,E	?		X						X							X	
Undetermined Spionidae	E	?				X												
Streblospio benedicti Webster, 1879	F,E,M	Intro	X	X	X	X								X			X	X
Terebellida																		
Polynoidae																		
Undetermined Polynoidae	M	?			X													

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

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

Pearl Harbor Estuarine Species List

Phylum / Class / Order / Family / Taxon and Author	Sampled Habitat[1]	Status[2]	Aiea Stream	E'o Stream	Halawa Stream	Honouliuli Stream	Iroquois Point	Kalauao Springs	Kalauao Stream	Kapakahi Stream	Pouhala Marsh	Waimano Springs	Waiawa Springs	Waiawa Stream	Waiawa Wildlife Refuge	Waikele Springs	Waikele Stream	Waimalu Stream
Mollusca																		
Gastropoda																		
Subulinidae																		
Undetermined Subulinidae	R	?			X													
Cerithiidae																		
Cerithium nesioticum Pilsbry and Vanatta, 1905	M	Ind			X													
Cerithium sp. cf. *zebrum* Kiener, 1841	M	Ind			X													
Littorinidae																		
Littoraria scabra (Linnaeus, 1758)	M	Ind	X															X
Physidae																		
Physa sp.	F	Intro			X					X								
Planorbidae																		
Planorbella duryi (Wetherby, 1879)	F	Intro						X		X			X					
Terebridae?																		
Undetermined Terebridae?	M	?			X													
Mesogastropoda																		
Ampulariidae																		
Pomacea canaliculata	F	Intro								X						X		
Hydrobiidae																		
Pyrgophorus cf. *coronatus* Pfeiffer, 1840	F	Intro									X		X		X			
Thiaridae																		
Melanoides tuberculata (Müller, 1774)	F	Intro								X	X			X			X	
Tarebia granifera (Lamarck, 1816)	F,E,M	Intro			X			X								X		
Thiara cf. *indefinata* (Lea & Lea, 1851)	E	Intro				X												
Undetermined Thiaridae	E	?				X												
Viviparidae																		
Cipangopaludina chinensis (Sykes, 1900)	F	Intro			X													
Pelecypoda																		
Undetermined Pelecypoda	M	?			X													
Taxodonta																		
Isognomonidae																		
Isognomon cf. *californicum* (Conrad, 1837)	M	Ind					X											
Veneroida																		
Corbiculidae																		
Corbicula fluminea Müller, 1774	F	Intro								X			X		X	X	X	
Arthropoda																		
Arachnida																		
Acari																		
Ascidae																		
Undetermined Ascidae	F	?									X							
Lasioseius sp.	F	Intro									X							
Bdellidae																		
Bdella distincta Baker and Balock, 1944	F	Intro									X							
Eupodidae																		
Eupodes n. sp.	F	New?									X							
Phytoseiidae																		
Amblyseius sp. nr. *oahuensis/coniferus*	F	?									X							
Araneae																		
Tetragnathidae																		
Tetragnatha mandibulata Walckennaer, 1841	R	Intro				X				X			X					X

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

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

Pearl Harbor Estuarine Species List

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Insecta																		
Coleoptera																		
Anobiidae																		
Tricorynus sharpi (Pic, 1912)	R	End					X											
Anthribidae																		
Araecerus sp.	R	Intro	X	X	X	X		X		X		X	X				X	X
Bruchidae																		
Algarobius bottimeri Kingsolver, 1972	R	Intro					X											
Mimosestes amicus (Horn, 1873)	R	Intro					X											
Stator limbatus (Horn, 1873)	R	Intro						X					X					
Stator pruininus (Horn, 1873)	R	Intro	X				X											
Cerambycidae																		
Prosoplus bankii (Fabricius, 1775)	R	Intro				X												
Sybra alternans (Wiedemann, 1825)	R	Intro	X	X			X											X
Chrysomelidae																		
Chaetocnema confinis Crotch, 1873	R	Intro								X		X		X				
Coccinellidae																		
Azya orbigera Mulsant, 1850	R	Intro	X		X		X											
Brumoides suturalis (Fabricius, 1798)	R	Intro									X		X					
Coelophora inaequalis (Fabricius, 1775)	R	Intro(P)					X											
Curinus coeruleus (Mulsant, 1850)	R	Intro(P)			X		X						X	X			X	
Diomus notescens (Blackburn,1889)	R	Intro(P)												X				
Scymnus loewii Mulsant, 1850	R	Intro(P)										X		X			X	
Sticholotis ruficeps Weise, 1902	R	Intro(P)												X				
Cucujidae																		
Cryptamorpha desjardinsi (Guerin-Meneville, 1844	R	Intro												X				
Histeridae																		
Xerosaprinus fimbriatus (Le Conte, 1851)	R	Intro(P)					X											
Hydrophilidae																		
Enochrus sayi Gundersen, 1977	F,E	Intro								X	X		X	X				X
Tropisternus cf. salsamentus Fall, 1901	F,E	Intro								X			X					
Tropisternus lateralis humeralis Motschulsky, 1859	F	Intro												X			X	
Tropisternus salsamentus Fall, 1901	F	Intro								X	X		X					
Limnichidae																		
Parathroscinus cf. *murphyi* Wooldridge, 1990	F,E,M	Intro	X	X	X	X		X	X	X		X	X				X	X
Nitidulidae																		
Undetermined Nitidulidae	R	Intro									X							
Scirtidae																		
Scirtes sp.	M	Intro	X															
Diptera																		
Agromyzidae																		
Amauromyza maculosa (Malloch, 1913)	R	Intro												X				
Liriomyza sp. prob. *sativae* Blanchard, 1938	R	Intro					X											X
Liromyza sp.	R	Intro												X				
Melanagromyza splendida Frick, 1953	R	Intro				X		X	X	X		X						X
Asteiidae																		
Loewimyia orbiculata Hardy, 1980	M	End				X												
Sigaloessa? sp.	F,M	Intro											X	X				
Calliphoridae																		
Chrysomya megacephala (Fabricius, 1794)	R	Intro				X												
Melinda pusilla (Villeneuve, 1927	R	Intro												X				

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Canacidae																		
Canaceoides angulatus Wirth, 1969	M	Intro	X	X			X					X						X
Canaceoides hawaiiensis? Wirth, 1969	M	End						X										
Procanace williamsi Wirth, 1951	F,E,M	Intro	X	X	X	X		X	X			X	X				X	X
Cecidomyiidae																		
Undetermined Cecidomyiidae Genus 1	R	?																X
Ceratopogonidae																		
Atrichopogon jacobsoni (Meijere, 1907)	E	Intro																X
Atrichopogon sp. not *jacobsoni*	F,M	Intro					X	X						X				
Dasyhelea calvescens Macfie, 1938	F,E,M	Ind?	X	X				X				X	X					X
Dasyhelea digna Borkent, 1996	F,M	End				X		X										X
Dasyhelea hawaiiensis? Macfie, 1934	F	End							X			X	X					X
Dasyhelea sp. 1	F	?							X			X						X
Dasyhelea sp. 2	F	?								X				X				X
Forcipomyia hardyi Wirth & Howarth, 1982	M	End			X													
Forcipomyia sp.	E,M	?				X	X					X						
Chironomidae																		
Chironomus crassiforceps (Kieffer, 1916)	F	Intro								X	X							
Chironomus hawaiiensis Grimshaw, 1901	E,M	End?		X	X	X												X
Cricotopus bicinctus (Meigen, 1818)	F	Intro						X		X		X		X			X	
Goeldichironomus holoprasinus (Goeldi, 1905)	F	Intro		X						X		X	X					
Orthocladius sp.	M	?			X													
Orthocladius sp. 1	F	?						X		X								
Orthocladius sp. 2	F,M	?				X		X		X								
Orthocladius sp. 3	M	?					X											
Orthocladius sp. 4	F,E,M	?	X	X	X	X		X	X			X						X
Orthocladius sp. 5	F,E,M	?										X						
Chloropidae																		
Cadrema pallida (Loew, 1865)	R	Intro	X	X		X	X					X						X
Gaurax ? or near	R	?		X			X	X										
Liohippelates collusor (Townsend, 1895)	R	Intro				X						X						
Monochaetoscinella anonyma (Williston, 1896)	R	Intro						X		X							X	X
Rhodesiella scutellata (Meijere, 1908)	R	Intro		X										X			X	X
Rhodesiella sp. 1	R	?										X					X	
Semaranga dorsocentralis Becker, 1911	R	Intro		X														X
Chyromyidae																		
Undetermined Chyromyidae Gen. 1	R	?			X	X												
Nannodastia horni Hendel, 1930	R	Intro											X					
Culicidae																		
Aedes albopictus (Skuse, 1984)	M	Intro			X													
Aedes sp.	M	Intro		X														
Dolichopodidae																		
Asyndetus carcinophilus Parent, 1937	M	End?					X											
Chrysotus longipalpus Aldrich, 1896	F,E	Intro		X				X				X					X	
Chrysotus sp. 1	F	?							X					X				
Condylostylus longicornis (Fabricius, 1775)	F,E	Intro		X		X				X				X				
Undetermined Dolichopodidae Gen. 1	F	?							X				X					
Hydrophorus pacificus van Duzee, 1933	F	End?											X					
Medetera grisescens Meijere, 1916	M	Ind?			X													
Pelastoneurus lugubris Loew 1861	F	Intro						X										
Syntormon flexibile Becker, 1922	F,E,M	Intro	X	X	X	X	X	X	X		X	X	X				X	

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Tachytrechus angustipennis Loew, 1862	F	Intro												X			X	
Thambemyia sp.	E,M	?		X			X											
Thinophilus hardyi Grootaert & Evenhuis, 1996	F,E,M	Intro				X					X	X	X					X
Drosophilidae																		
Undetermined Drosophilidae	R	?		X														
Empididae																		
Hemerodromia prob. *stellaris* Melander, 1947	F	Intro															X	
Ephydridae																		
Atissa oahuensis Cresson, 1948	F,E,M	End	X		X	X	X		X		X	X	X					X
Brachydeutera ibari Ninomiya, 1930	F,M	Intro		X													X	
Ceropsilopa coquilletti Cresson, 1922	F,E,M	Intro		X	X	X			X		X							X
Clasiopella uncinata Hendel, 1914	F,E,M	Intro				X			X									X
Discocerina mera Cresson, 1939	F,E,M	Intro	X		X	X	X		X			X	X					X
Donaceus nigronotatus Cresson, 1943	F,E,M	Intro		X	X			X		X		X	X				X	
Ephydra milbrae Jones, 1906	F,E,M	Intro	X	X		X					X		X					
Hecamede granifera (Thomson, 1869)	M	Intro					X											X
Hydrellia williamsi Cresson, 1936	F	Intro										X						
Lytogaster gravida (Loew, 1863)	F	Intro										X						
Mosillus tibialis Cresson, 1916	M	Intro		X														
Notiphila insularis Grimshaw, 1901	F	End						X									X	
Ochthera prob. *circularis* Cresson, 1926	F,E	Intro		X				X			X						X	
Paratissa pollinosa (Williston, 1896)	F,M	Intro					X										X	
Placopsidella marquesana (Malloch, 1933)	F,E,M	Intro	X	X	X		X					X	X					
Psilopa girschneri Von Roeder, 1889	F,M	Intro		X		X					X		X					X
Scatella bryani (Cresson, 1926)	F	End?										X						
Scatella sexnotata Cresson, 1926	F,E,M	Ind	X	X	X	X			X		X	X	X			X		X
Scatella sp. *cilipes* or *warreni*	F	?															X	
Scatella sp. nr. *bryani* (Cresson)	M	End			X	X												
Scatella stagnalis (Fallen, 1813)	F,E,M	Intro	X	X	X	X	X	X	X	X	X	X	X	X			X	X
Lauxaniidae																		
Homoneura unguiculata (Kertesz, 1913)	R	Intro																X
Lonchaeidae																		
Lonchaea sp.	R	?		X										X				
Milichiidae																		
Desmometopa sp.	R	?				X												
Leptometopa sp.	R	?									X							
Muscidae																		
Atherigona reversura Villeneuve, 1936	R	Intro		X	X												X	
Hydrotaea chalcogaster (Wiedemann, 1824)	R	Intro		X		X												
Neriidae																		
Teleostylinus lineolatus (Wiedemann, 1830)	R	Intro												X				
Otitidae																		
Notogramma cimiciforme Loew, 1867	R	Intro								X								
Phoridae																		
Megaselia sp.	R	?						X										
Undetermined Phoridae	R	?						X										
Platystomatidae																		
Scholastes bimaculatus Hendel, 1914	R	Intro	X															
Psychodidae																		
Psychoda sp.1	E,M	?		X	X	X												
Sarcophagidae																		

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Gressittomyia gressitti (Hall & Bohart, 1948)	R	Intro				X	X											
Tricharaea occidua (Fabricius, 1794)	R	Intro										X						
Scatopsidae																		
Holoplagia guamensis (Johannsen, 1946)	R	Intro						X										
Rhegmoclemina parvula? Hardy, 1956	R	Intro			X													
Scenopinidae																		
Scenopinus papuanus (Kroeber, 1912)	R	Intro					X											
Sciaridae																		
Sciara sp.	M	?			X													
Undetermined Sciaridae	R	?								X								X
Sphaeroceridae																		
Coproica hirtula (Rondani, 1880)	R	Intro																X
Leptocera abdominiseta (Duda, 1925)	R	Intro		X										X				X
Leptocera fuscipennis (Haliday, 1933)	R	Intro			X	X	X				X							X
Pterogramma brevivenosum (Tenorio, 1968)	R	End		X				X									X	
Stratiomyidae																		
Evaza javanensis Meijere, 1911	R	Intro												X				
Hermetia illucens (Linnaeus, 1758)	R	Intro			X					X								
Wallacea albiseta Meijere, 1907	R	Intro		X														
Syrphidae																		
Allograpta exotica (Wiedemann, 1830)	R	Intro											X	X				
Allograpta obliqua (Say, 1823)	R	Intro				X												
Ornidia obesa (Fabricus, 1775)	R	Intro	X	X	X	X		X		X		X	X				X	X
Toxomerus marginatus (Say, 1823)	R	Intro						X				X	X					
Tachinidae																		
Trichopoda pilipes (Fabricius,1805)	R	Intro(P)															X	
Tephritidae																		
Acinia picturata (Snow, 1894)	R	Intro(P)																X
Ensina sonchi (Linnaeus, 1767)	R	Intro										X						
Neotephritis sp.	R	End				X												
Tethinidae																		
Dasyrhicnoessa insularis (Aldrich, 1931)	F,E,M	Ind?	X		X	X	X	X	X		X	X	X					X
Dasyrhicnoessa prob. *insularis* (Aldrich, 1931)	M	Ind?			X													
Dasyrhicnoessa sp.	F,E,M	?		X	X	X							X					
Dasyrhicnoessa vockerothi Hardy & Delfinado, 1980	F,E,M	Ind?					X				X							
Tethina variseta (Melander, 1951)	F,E,M	Intro	X				X											X
Tipulidae																		
Limonia (Dicranomyia) sp.	E,M	?		X														
Limonia advena (Alexander, 1954)	F	End?														X		
Limonia swezeyi (Alexander, 1919)	F,E	End				X												
Styringomyia didyma Grimshaw, 1901	F	Intro										X						
Symplecta pilipes (Fabricius, 1787)	F	Intro									X							
Xenasteiidae																		
Xenastia sabroskyi? Hardy, 1980	E,M	?					X											X
Heteroptera																		
Anthocoridae																		
Paratriphleps laeviusculus Champion, 1901	R	Intro											X					X
Coreidae																		
Undetermined Coreidae	R	?										X						
Corixidae																		
Trichocorixa reticulata (Guerin-Meneville, 1857	F, E	Intro									X		X					

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Gerridae																		
Halobates hawaiiensis Usinger, 1938	E,M	Ind	X				X							X	X			X
Lygaeidae																		
Nysius caledoniae Distant, 1920	R	Intro								X			X					
Nysius sp.	R	?			X	X	X			X	X	X						X
Mesoveliidae																		
Mesovelia amoena Uhler, 1894	F,E	Intro								X	X			X				
Mesovelia mulsanti White, 1879	F,E	Intro						X		X	X	X	X	X			X	
Miridae																		
Trigonotylus sp.	R	?										X						
Rhopalidae																		
Liorhyssus hyalinus (Fabricius, 1794)	R	Intro								X		X						
Saldidae																		
Micracanthia humilis (Say, 1832)	F	Intro											X	X				
Tingidae																		
Corythucha morrilli Osborn & Drake, 1917	R	Intro												X				
Leptodictya tabida (Herrich-Schaeffer, 1840)	R	Intro															X	
Homoptera																		
Cicadellidae																		
Balclutha sp.	R	?								X								
Carneocephala sagittifera (Uhler, 1895)	R	Intro						X										
Draeculacephala sp.	R	Intro						X		X			X					
Empoasca sp.	R	Intro								X	X							
Protalebrella brasiliensis (Baker, 1899)	R	Intro						X										
Spanbergiella quadripunctata Lawson, 1932	R	Intro						X										
Clastopteridae																		
Clastoptera xanthocephala Germar, 1839	R	Intro						X			X		X					
Flatidae																		
Melormenis basalis (Walker, 1851)	R	Intro	X	X	X	X		X	X	X	X							
Tropiduchidae																		
Undetermined Tropiduchidae	R	Intro	X		X	X					X	X						
Hymenoptera																		
Agaonidae																		
Philotrypesis sp.	R	Intro?																X
Anthophoridae																		
Ceratina? sp.	R	Intro					X											
Pithitis smaragdula (Fabricius, 1787)	R	Intro					X						X					
Xylocopa sonorina Smith, 1874	R	Intro	X	X	X	X		X		X		X	X				X	X
Aphelinidae																		
Coccophagus ceroplastae? (Howard, 1895)	R	Intro				X												
Apidae																		
Apis mellifera Linnaeus, 1758	R	Intro(P)	X	X	X	X		X		X		X	X				X	X
Chalcididae																		
Brachymeria sp.	R	?				X												
Dryinidae																		
Undetermined Dryinidae	R	?			X													
Elasmidae																		
Elasmus sp.	R	?				X												
Eucoilidae																		
Undetermined Eucoilidae	R	End?			X													
Eupelmidae																		
Anastatus koebelei Ashmead, 1901	R	End												X				

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Evaniidae																		
Evania appendigaster (Linnaeus, 1758)	R	Intro															X	
Formicidae																		
Undetermined Formicidae	R	Intro	X	X	X	X		X		X		X	X				X	X
Halictidae																		
Lasioglossum sp.	R	Intro	X				X											
Ichneumonidae																		
Undetermined Ichneumonidae	R	?			X													
Megachilidae																		
Megachile gentilis Cresson, 1872	R	Intro					X											
Pteromalidae																		
Undetermined Pteromalidae	R	?																X
Sphecidae																		
Sceliphron caementarium (Drury, 1770)	R	Intro			X		X											
Torymidae																		
Torymus sp.	R	?																X
Vespidae																		
Delta campaniforme campaniforme (Fabricius,1775)	R	Intro						X										
Delta curvata Saussure, 1854	R	Intro			X	X												
Delta pyriformis philippinense (Bequaert, 1928)	R	Intro				X												
Pachodynerus nasidens (Latreille, 1832)	R	Intro	X	X	X	X		X		X		X	X				X	X
Polistes aurifer Saussure, 1853	R	Intro	X	X	X	X		X		X		X	X				X	X
Polistes exclamans Viereck, 1906	R	Intro									X							
Polistes olivaceus (DeGeer, 1773)	R	Intro	X	X	X	X		X		X		X	X				X	X
Lepidoptera																		
Crambidae																		
Herpetogramma licarsisalis (Walker, 1859)	R	Intro	X	X	X	X		X		X		X	X				X	X
Geometridae																		
Macaria abydata Guenee, 1857	R	Intro	X	X	X	X		X		X		X	X				X	X
Lycaenidae																		
Brephidium exilis (Boisduval, 1852)	R	Intro	X	X	X	X		X		X		X	X				X	X
Nymphalidae																		
Agraulis vanillae (Linnaeus, 1758)	R	Intro(P)	X	X	X	X		X		X		X	X				X	X
Danaus plexippus (Linnaeus, 1758)	R	Intro	X	X	X	X		X		X		X	X				X	X
Papilionidae																		
Papilio xuthus (Linnaeus, 1767)	R	Intro			X	X												
Pieridae																		
Pieris rapae (Linnaeus, 1758)	R	Intro	X	X	X	X		X		X		X	X				X	X
Neuroptera																		
Coniopterygidae																		
Coniocompsa zimmermani Kimmins, 1953	R	Intro				X												
Hemerobiidae																		
Micromus timidus Hagen, 1853	R	Intro(P)												X			X	
Odonata																		
Aeshnidae																		
Anax junius (Drury, 1770)	F,E,M	Ind	X	X	X	X		X		X		X	X				X	X
Coenagrionidae																		
Enallagma civile (Hagen, 1862)	F	Intro				X											X	
Ischnura posita (Hagen, 1862)	F	Intro						X	X	X				X			X	
Ischnura ramburii (Selys-Longchamps, 1850)	F,E,M	Intro	X	X	X	X		X		X		X	X	X	X		X	X
Libellulidae																		
Crocothemis servilia (Drury, 1770)	F,E	Intro	X	X		X		X	X	X	X	X	X	X			X	X

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

Pearl Harbor Estuarine Species List

Phylum **Class** Order Family Taxon and Author	Sampled Habitat[1]	Status[2]	Aiea Stream	E'o Stream	Halawa Stream	Honouliuli Stream	Iroquois Point	Kalauao Springs	Kalauao Stream	Kapakahi Stream	Pouhala Marsh	Waimano Springs	Waiawa Springs	Waiawa Stream	Waiawa Wildlife Refuge	Waikele Springs	Waikele Stream	Waimalu Stream
Orthemis ferruginea (Fabricius,1775)	F	Intro				X							X					
Pantala flavescens (Fabricius,1798)	F,E,M	Ind		X		X		X					X	X				
Orthoptera																		
Acrididae																		
Oedaleus abruptus (Thunberg, 1815)	R	Intro											X					
Schistocerca nitens (Thunberg, 1815)	R	Intro											X					
Pyrgomorphidae																		
Atractomorpha sinensis Bolivar, 1905	R	Intro								X		X						
Tetrigidae																		
Paratettix mexicanus (Saussure, 1861)	R	Intro										X					X	
Tettigoniidae																		
Conocephalus saltator (Saussure, 1859)	R	Intro	X	X	X	X		X		X		X	X				X	X
Elimaea punctifera (Walker, 1869)	R	Intro	X	X	X	X		X		X		X	X				X	X
Euconocephalus nasutus (Thunberg, 1815)	R	Intro			X												X	
Xiphidiopsis lita Hebard, 1922	R	Intro	X	X	X	X		X		X		X	X				X	X
Trichoptera																		
Hydropsychidae																		
Cheumatopsyche pettiti (Banks, 1908)	F	Intro														X		
Arthropoda																		
Crustacea																		
Undetermined Ostracoda	F	?									X			X				
Amphipoda																		
Undetermined Amphipoda	F,E,M	?	X	X	X	X				X	X						X	
Hyalellidae																		
Hyalella azteca (Saussure, 1858)	F	End						X				X				X		
Talitridae																		
Undetermined Talitridae	F,E,M	?	X	X	X	X		X		X		X	X				X	X
Caligoida																		
Caligidae																		
Caligus rapax Edwards, 1840	F	Ind															X	
Harpacticoida																		
Miraciidae																		
Miracia sp.	M	Ind?			X													
Decapoda																		
Undetermined Caridea	E	?		X					X									
Alpheidae																		
Alpheus mackayi Banner, 1959	E,M	Ind			X									X				
Atyidae																		
Neocaridina denticulata sinensis (de Haan, 1844)	F	Intro														X	X	
Cambaridae																		
Procambarus clarkii (Girard, 1852)	F	Intro(P)						X		X		X	X	X		X	X	
Palaemonidae																		
Macrobrachium grandimanus (Randall, 1840)	F,E,M	Ind			X	X		X					X	X		X	X	
Macrobrachium lar (Fabricius, 1798)	F	Intro(P)										X	X	X		X		
Palaemon debilis? (Dana, 1852)	F,E,M	Ind			X	X		X	X				X	X	X		X	X
Pontoniinae																		
Periclimenes cf. *grandis* (Stimpson, 1860)	F,E,M	Ind	X	X	X	X		X	X						X		X	X
Grapsidae																		
Metopograpsus messor Forskål, 1900	F	Ind											X					
Portunidae																		
Podophthalmus vigil Weber, 1795	E,M	Ind			X					X								X
Portunus oahuensis (Edmonson, 1954)	F	End											X					

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Thalamita crenata Latreille, 1900	F,E,M	Ind	X	X	X	X			X	X			X		X		X	X
Thalamita edwardsi Borradaile, 1900	M	Ind													X			X
Thalamita integra Dana, 1852	M	Ind																X
Xanthidae																		
Panopeus lacustris Desbonne, 1867	M	Intro			X													
Panopeus pacificus Edmonson, 1931	M	Intro																X
Isopoda																		
Undetermined Isopoda	F,M	?			X							X	X					
Armadillidae																		
Undetermined Armadillidae	F,E,M	?	X	X	X	X		X		X		X	X				X	X
Ligiidae																		
Ligia hawaiiensis (Dana, 1853)	R	End			X									X				X
Porcellionidae																		
Porcellio laevis Latreille, 1804	R	Intro			X													X
Mysidacea																		
Undetermined Mysidacea	E,M	?			X	X												
Chordata																		
Chondrichthyes																		
Lamniformes																		
Sphyrnidae																		
Sphyrna lewini Griffith & Smith, 1834	E	Ind												X				
Osteichthyes																		
Aulopiformes																		
Synodontidae																		
Saurida gracilis Quoy & Gaimard, 1824	F,E,M	Ind	X	X	X	X				X				X	X		X	X
Saurida nebulosa Valenciennes, 1849	M	Ind			X													
Characiformes																		
Characidae																		
Colossoma macropomum (Cuvier, 1818)	F	Intro											X					
Clupeiformes																		
Clupeidae																		
Undetermined Dussumieriinae	F	?				X												
Engraulidae																		
Encrasicholina purpurea Fowler, 1900	F	Ind				X												
Undetermined Engraulidae? larvae	F,M	Ind	X										X					
Cypriniformes																		
Cyprinidae																		
Cyprinus carpio Linnaeus, 1758	F	Intro(P)						X										
Cyprinodontiformes																		
Poeciliidae																		
Gambusia affinis Baird & Girard, 1853	F,E,M	Intro(P)			X	X		X	X	X	X	X	X	X	X	X	X	X
Limia cf. *vittata* Guichenot, 1853	F,E	Intro								X	X		X		X		X	
Poecilia latipinna LeSueur, 1821	F,E	Intro(P)									X				X			
Poecilia mexicana Steindachner, 1863	F,E,M	Intro	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Poecilia reticulata Peters, 1859	F	Intro(P)						X		X			X	X		X	X	X
Xiphophorus helleri Heckel, 1848	F	Intro(P)						X				X				X	X	X
Xiphophorus maculatus (Günther, 1866)	F	Intro(P)								X	X							
Elopiformes																		
Elopidae																		
Elops hawaiensis Regan, 1909	M	Ind			X													
Gonorynchiformes																		

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Chanidae																		
Chanos chanos Forsskål, 1775	E,M	Ind													X			X
Perciformes																		
Acanthuridae																		
Acanthurus xanthopterus Cuvier & Valenciennes, 1835	M	Ind		X	X													
Apogonidae																		
Foa brachygramma Jenkins, 1903	M	Ind	X	X	X													
Blenniidae																		
Omobranchus ferox Herre, 1927	M	Intro			X													
Carangidae																		
Scomberoides lysan Forsskål, 1775	F,E	Ind				X								X				
Cichlidae																		
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
Eleotridae																		
Eleotris sandwicensis Vaillant & Sauvage, 1875	F,E,M	End			X	X		X	X	X	X			X			X	X
Gobiidae																		
Awaous guamensis Valenciennes, 1837	F	End															X	X
Bathygobius cocosensis Bleeker, 1854	M	Ind			X													
Mugilogobius cavifrons Weber, 1909	F,E,M	Intro						X		X			X				X	X
Oxyurichthys lonchotus Jenkins, 1903	F,E,M	Ind			X								X					X
Stenogobius hawaiiensis Watson, 1991	F,M	Ind			X	X							X	X			X	X
Kuhliidae																		
Kuhlia sandvicensis Steindachner, 1876	F,E,M	End			X	X		X					X	X	X		X	
Mugilidae																		
Moolgarda engeli Bleeker, 1858	F,E,M	Intro	X	X	X	X									X		X	
Mugil cephalus Linnaeus, 1758	F,E,M	Ind		X	X	X			X				X		X		X	X
Neomyxus leuciscus Günther, 1871	F,M	Ind			X										X			
Sphyraenidae																		
Sphyraena barracuda Walbaum, 1792	F,E,M	Ind		X	X			X						X	X		X	X
Siluriformes																		
Clariidae																		
Clarias fuscus (Lacepede, 1803)	F	Intro(P)											X					
Loricariidae																		
Ancistrus temminckii Valenciennes, 1840	F	Intro														X	X	
Hypostomus cf. *watwata* Hancock, 1828	F	Intro												X			X	
Synbranchiformes																		
Synbranchidae																		
Monopterus albus Zuiew, 1793	F	Intro(P)												X				
Tetraodontiformes																		
Tetraodontidae																		
Arothron hispidus Linnaeus, 1758	M	Ind			X													X
Chordata																		
Amphibia																		
Anura																		
Bufonidae																		
Bufo marinus (Linnaeus, 1758)	F,M	Intro(P)			X					X		X		X		X	X	X
Ranidae																		
Rana catesbeiana Shaw, 1802	F	Intro(P)								X		X		X				
Rana rugosa Schlegel, 1838	F	Intro(P)														X		

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APPENDIX D

A Description of Introduced Aquatic and Estuarine Species Collected in Pearl Harbor

INSECTA: COLEOPTERA

Family Hydrophilidae

Enochrus sayi Gundersen, 1977

Common Name:	Water scavenger beetle
First Record:	1931, Oahu
Mechanism:	Possibly boat or airplane
Origin:	Eastern North America

Older Hawaiian records were cited by Hansen (1995). New records from Pearl Harbor include: Kapakahi Stream, mangrove area, 0 m, June 1998; Pouhala wetlands near Kapakahi Stream, 0 m, April 1998; Waimalu Stream area (Blaisdell Park), May 1998, dip netting in *Batis maritima* patch 0 m; Waiawa Stream June 1998, in algal growth in stream; Waiawa Springs, June 1998, 0-1 m, in shallow pools mostly covered by grass.

Enochrus sayi is an aquatic species that is sometimes attracted to light and appears to be restricted to Oahu. Throughout Pearl Harbor it was collected in various situations: pools in a marsh, shallow seepages, and in quiet eddies of running streams. In streams, individuals were associated with algae, leaves, and various debris floating on the surface in relatively still water at the edge of the stream. Adults of both *Enochrus sayi* and *Tropisternus salsamentus* tend to be attracted to lights at night, and individuals of either species may have been attracted to lights on ships or planes while they were being loaded and thereby carried into new areas. *Enochrus sayi* was saline tolerant and found in waters of up to 16 ppt salinity in puddles around the Waiawa Springs complex and also common in Pouhala Marsh were salinities ranged from 1 to 9 ppt.

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 Pearl Harbor records include: Kapakahi Stream, 0 m, June 1998, on grass in water; Waiawa Springs, 0-1 m, June 1998, in shallow pools mostly covered by grass.

This was the newest species of *Tropisternus* 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 collected in clear estuarine water and freshwater seepages, both adjacent to Pearl Harbor. This species was also saline tolerant, and in Pearl Harbor were often found sympatrically with *Enochrus sayi* in waters of up to 16 ppt salinity in puddles in the Waiawa Springs complex and in completely freshwater in Kapakahi Stream.

Tropisternus lateralis humeralis Motschulsky, 1859

Common Name:	Water scavenger beetle
First Record:	1948, Oahu
Mechanism:	Probably with aquatic plants
Origin:	Pacific Coast of North America (California to British Columbia)

First recorded in Nuuanu Valley in 1948 (Hansen 1995), *Tropisternus lateralis humeralis* is another introduced aquatic beetle inhabiting a wide range of habitats from freshwater ponds to irrigation ditches. Nishida (1997) lists this species as having been introduced to Kauai and Oahu. This species has been divided into a number of subspecies with Hansen (1995) providing the currently used taxonomic revision for the Hawaiian introductions. In the lower Pearl Harbor region *Tropisternus lateralis humeralis* was found in Waiawa Stream and Waikele Stream (both 0 ppt saln), in slow-moving areas of freshwater.

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 Pearl Harbor and was common to extremely abundant at these sites. *Parathroscinus* cf. *murphyi* sometimes formed dense clouds as these small beetles flew just above the exposed tidal mudflats. Numerous specimens have been collected from Aiea, Halawa, Honouliuli, Kalauao, Waimano-Waiau Springs (HECO Power Plant), and Waiawa Springs. Larval collections were made at the Halawa and Honouliuli sampling stations 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 from Pearl Harbor and is now found up to Koloko Point, which is northeast of Sandy Beach.

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. They generally fly very low to the mud surface. 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: HETEROPTERA

Family Corixidae

Trichocorixa reticulata (Guerin-Meneville, 1857)

Common Name:	Water boatman
First Record:	1878, Hawaiian Islands
Mechanism:	Unknown
Origin:	Americas (described from Cuba)

An inhabitant of brackish pools and stillwater ponds, *Trichocorixa reticulata* was one of the earliest known aquatic insect introductions, and was first noted to occur in Hawaii by Blackburn in 1878, although no locality information were given (Zimmerman 1948). The diet of this species consists of plant materials, including filamentous algae and diatoms, and is also predatory on small aquatic animals. Specimens were collected at Pouhala Marsh wetlands near Kapakahi Stream, 23 April, 1998, dip netting pond near salt flats, 8 to 9 ppt salinity; Waiawa Springs, 3 June, 1998, in puddles with grass.

Family Mesoveliidae

Mesovelia amoena Uhler, 1894

Common Name:	Water treader
First Record:	1971, Kauai
Mechanism:	Unknown
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. Recent specimens were taken at Kapakahi Stream, June 1998; Pouhala wetlands (1-9 ppt saln) and Waiawa Stream June 1998.

The family of water treaders is represented in the island fauna by three species in two genera. The endemic *Cavaticovelia aaa* (Gagne and Howarth 1975) from the island of Hawaii was the first known troglobitic heteropteran from Hawaii. *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. For this survey *Mesovelia mulsanti* was found inhabiting Waikele Stream, on surface of water; Kapakahi Stream, on surface at mangrove and on water lettuce; Pouhala Marsh wetlands (1-9 ppt saln), dip netting along edge of 2nd pond; Waiau (Hawaiian Electric Power Plant), near dam at lower end of pond, on surface, 2 m and makai of bike path, 0-1 m; Kalauao ponds, on surface of water; Waiawa Stream, on surface of water on algae mat, surface along edge; Waiawa Springs (4.5 ppt saln), on surface of puddle.

Mesovelia mulsanti is abundant in freshwater ponds and streams in the Pearl Harbor area. 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:	Unknown

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). Recent specimens were taken in the Pearl Harbor area along Waiawa Stream, 16, June, 1998 and Waiawa Springs, on surface of mud, algae puddles of dirt road, 3 June, 1998.

Saldidae are represented in the Hawaiian fauna by *M. 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.

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. Recent materials collected from shoreline habitats of Pearl Harbor include: Iroquois Point near Okiokiolepe pond, rocks at splash zone, 35 ppt salinity, June 1998; Iroquois Point (boulders at splash zone; on dead eel; tree stump in shallows; sweeping over water in mangrove area). June 1998; Waiau, open rocky shoreline, 30 ppt salinity, June 1998; Waimalu, Blaisdell Park, on wet sand or mud on shore, June 1998; Aiea Bay, (rocky shoreline, mangrove-*Batis maritima*; mud flats) June 1998.

Procanace williamsi Wirth, 1951
Common Name: Beach fly
First Record: 1944, Oahu I.
Mechanism: Plane?

Origin: Oriental Region?

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.

Recent materials collected from shoreline habitats of Pearl Harbor include Honouliuli, (moist mud flats; on sponge/mud edge of mangrove), June 1998; Waikele stream, sweeping along rocks at stream edge; E'o canal, waterline near bridge foundation, June 1998; Waiau, Hawaiian Electric Power Plant, open rocky shoreline at ewa end, 30 ppt salinity, June 1998; Waimalu, Blaisdell Park shoreline, sweeping mud and rocks, May 1998; sweeping Waimalu stream exposed bank, May 1998; Kalauao stream, mud bank near *Batis maritima* patch, 0 ppt salinity, June 1998; Kalauao pond, mud and rock shoreline [of Pearl Harbor] Ewa of Kalauao stream, 0 ppt salinity, June 1998; Aiea stream, (mangrove; rocky shoreline, mangrove and *Batis maritima*), June 1998; Halawa Stream, (sweeping over mud; sweeping over mud bar in stream), June 1998. Miyagi (1965) reported *Procanace williamsi* from Honshu, Shikoku and Kyushu, extending its range into Japan.

Family Ceratopogonidae

Atrichopogon jacobsoni (Meijere, 1907)
Common Name: Biting midge
First Record: 1958, Oahu
Mechanism: ?
Origin: Oriental and Pacific Regions

Joyce (1959) first reported a specimen taken at Fort Armstrong, Honolulu, August 1958 and additional specimens at Honolulu International Airport in 1959, (Joyce 1960). A single specimen was collected at Blaisdell Park by sweeping under mangroves along Waimalu stream.

Family Chironomidae

Chironomus crassiforceps (Kieffer, 1916)
Synonym: *Chironomus esakii* Tokunaga, 1940
Common Name: Non-biting midge
First Record: 1944, Oahu
Mechanism: Airplane

Origin: Pacific and Oriental regions

Van Zwaluwenberg (1945) reported a new *Chironomus* sp. collected at the Naval Air Station, Honolulu, July 1944. Hardy (1956) determined this *Chironomus* sp. to be *Chironomus esakii* Tokunaga. This species was collected by sweeping nets over areas of open water and pickleweed (*Batis maritima*) at Pouhala Marsh in the nearly freshwater pond (1 ppt salinity) in, April 1998; and in Kapakahi Stream, along stream edge, and in mangroves at Pouhala Marsh in June 1998.

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).

During Pearl Harbor surveys, *C. bicinctus* was collected in June 1998 at Waikele Stream, near the Waipahu Plantation Cultural Village, sweeping along rocks at stream edge, on algae covered rocks at waterline, on primrose willow (*Ludwigia octovalis*) and on exposed rocks in stream. Also collected at Kapakahi Stream, along stream edge; Waiawa Stream, stream edge and tall grass on bank; Waiau HECO power plant (Waiau-Waimano Springs), pond makai of bike path, 0-1 m elevation, 0 ppt salinity; Kalauao Springs, 0-1 m elevation, along pond edge, 0 ppt salinity.

Goeldichironomus holoprasinus (Goeldi, 1905)

Common Name: Non-biting midge

First Record: 1969, Oahu

Mechanism: ?

Origin: North and South America (Described from Brazil)

The first published report of *Goeldichironomus holoprasinus* occurring in Hawaii came from records of this species caught in light trap material at University of Hawaii campus in 1969 (Hardy 1970). However, the first specimens in Hawaii actually came from the Bishop Museum courtyard in 1966, but this record never was published (J. Martin, Latrobe University, Melbourne, Australia, pers. comm. to N. Evenhuis, Bishop Museum).

Specimens collected at the following Pearl Harbor sites: Kapakahi Stream, mangrove, June 1998; Kapakahi Stream, stream edge, June 1998; E'o Canal, Ted Makalena Golf Course, sweeping under mangrove, July 1998; Waiau Hawaiian Electric Power Plant (Waimano-Waiau Springs), mangrove near dam at lower end of pond, 0-2 m, June 1998. This species has not yet been recorded from the other main islands.

Family Dolichopodidae

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.

During this study, collections were made from E'o Stream, sweeping in mangrove in canal, June 1998; Waikele Stream, near Cultural Garden, sweeping tall grass at stream edge, June 1998; Kalauao ponds, 0-1 m elevation, stream from watercress farm, 0 ppt salinity, June 1998; Waiau Hawaiian Electric Power Plant (Waimano-Waiau Springs), mangorve near dam at lower end of pond, 0-2 m, June 1998; Kalauao Springs, 0-1 m elevation, grass and sedges near edge of water, June 1998. A series of aberrant *Chrysotus sp.* with palps broad and rounded differing from the tapered palps of *C. longipalpus* were collected at Waiawa Stream, in tall grass along stream, June 1998; Kalauao Stream, mud bank near *Batis maritima*, 0 ppt salinity, June 1998 and Kalauao ponds, along pond edge, 0 ppt salinity, June 1998.

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 in Pearl Harbor include Honouliuli Stream, spring near rocky mud flats, June 1998; Kapakahi Stream, near pipeline on cucurbit plant on upper bank, June 1998; E'o Stream (18 ppt saln), sweeping in mangrove in canal, June 1998; Waiawa Stream (0 ppt saln), on grass in stream, June 1998.

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. A specimen was collected at Halawa Stream (32-37 ppt saln), bridge area, 0-1 m elevation, sweeping over mud along stream, 2 June 1998.

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 Pearl Harbor surveys two specimens were taken at Kalauao Springs, in grass and sedges along the edge of the watercress farms in June 1998.

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

Van Duzee (1933) described *Syntormon distortitarsis* from a series of specimens first collected in 1917 in Mana, Kauai. This species is widespread throughout the Pacific and from Australia to Taiwan. In Pearl Harbor, specimens were collected from Iroquois Point, at the edge of fishpond, sweeping over water at shore in sheltered mangrove thicket, June 1998; Waikele Stream, near Cultural Garden, on algae covered rocks at waterline; sweeping along rocks at stream edge; on exposed rocks in stream, June 1998; Pouhala Marsh wetlands near Kapakahi Stream, sweeping over water and *Batis maritima*; April 1998; E'o Canal, Ted Makalena Golf Course, sweeping under mangrove, July 1998; Middle Loch, near Waiawa Springs, sweeping shoreline, mud, sand, rocks and decaying seaweed, May 1998; Waiau Hawaiian Electric Power Plant, mangorve near dam at lower end of pond; open rocky shoreline at ewa end, June 1998; Kalauao Stream, 0-1 m, mangrove trail to mud bank, 0 ppt salinity, June 1998; Aiea Bay, Aiea Stream mouth, mangrove and mud flats, June 1998; Halawa Stream (lower), sweeping mud bank under bridge - Aiea side; bridge area, 0-1 m, sweeping over mud along stream, June 1998;

Tachytrechus angustipennis Loew, 1862

Common Name: Long-legged fly
First Record: 1993, Kauai
Mechanism ?
Origin: North and South America

Evenhuis (1996) first reported this species as *Tachytrechus* sp. from specimens collected at Hanakapiai Stream, Kauai in 1993. Additional specimens collected from Oahu include the Waianae Mountains, Puhawai Falls, in 1996, from a splash zone on vertical cliff near falls, and stream east of Puhawai Spring, in 1996 (Evenhuis 1996). *Tachytrechus angustipennis* is distributed throughout North America and as far south as Chile. Recent materials from Pearl Harbor were specimens taken at Waikele Stream, near Waipahu Cultural Garden, on exposed rocks in stream, June 1998, and Waiawa Stream, June 1998.

Family Empididae

Hemerodromia stellaris Melander, 1947
Common Name: Dance fly
First Record: 1985, Oahu
Mechanism: ?
Origin: Southwest U.S.

Hardy (1985a) identified adults first collected from Makiki Stream, in December 1982. These individuals were first identified as *Hemerodromia* sp. Subsequently, specific identification was provided in Hardy (1992). Specimens collected at Waikele Stream, on primrose willow (*Ludwigia octovalis*); June 1998. This species was previously known only from southwestern Texas (Hardy 1995).

Family Ephydridae

Brachydeutera ibari Ninomiya, 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. During the Pearl Harbor surveys specimens were collected at Waikele Springs, at the Waipahu Cultural Garden in algae on surface of a shallow pond, June 1998; and also at E'o Stream, Ted Makalena Golf Course, on exposed barnacles at the golf course bridge footing, July 1998.

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 reported from Ewa, Oahu, in 1946. Recent materials collected during the Pearl Harbor surveys include Honouliuli Stream, sweeping in mangroves, along mud banks, over *Batis maritima;* Pouhala Marsh wetlands, beating *Pluchea indica*; E'o Stream, sweeping *Batis maritima,* July 1998; Waimalu Stream area, Blaisdell Park, on wet sand or mud on shore; Kalauao Stream, mud bank near *Batis* patch; Halawa Stream, sweeping rocky shoreline. All specimens were collected in June 1998 except where noted.

Clasiopella uncinata Hendel, 1914

Common Name: Shore fly
First Record: 1946, Oahu
Mechanism: Airplane
Origin: ?

Adachi (1952) first described *Clasiopella uncinata* from specimens collected at an airplane window at the Honolulu, Oahu, Naval Air Station in 1946. Materials collected from Pearl Harbor include shoreline habitats at the Honouliuli Stream area, around mangrove, in June 1998, and at Waimalu stream, Blaisdell Park, May 1998; also at Kalauao Stream, sweeping *Batis maritima*, June 1998. *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.

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). *Discocerina mera* was collected during this study from shoreline habitats of Pearl Harbor. Areas where this species were collected include Iroquois Point, Okiokiolepe Pond, in mangroves in a sheltered cove, June 1998; Honouliuli Stream in the ponds along golf course, June 1998; Waiau-Waimano Spring areas, along rocky shoreline of peninsula, June 1998; Blaisdell Park, sweeping Waimalu Stream exposed bank, June 1998; Kalauao Stream, mud bank near *Batis maritima*, June 1998; Middle Loch near Waiawa Springs, sweeping shoreline - mud, sand, rocks and decaying seaweed, June 1998; Aiea Stream, mangrove, mud bank, June 1998; Halawa Stream, sweeping rocky shoreline and bridge area, sweeping over mud, June 1998.

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. Recent materials collected from shoreline habitats of Pearl Harbor: Waikele Stream, sweeping along rocks at stream edge; Kapakahi Stream; E'o Stream, Ted Makalena Golf Course, sweeping mud in mangrove, July 1998; Waiau-Waimano Springs, in mangroves at lower end of pond; Waiawa Springs; Kalauao Springs, along pond edge; Halawa Stream, sweeping mud bank under bridge. All specimens collected in June 1998, except where noted.

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 an established species in the Hawaiian islands. This species ranges from the coast of British Columbia to Mexico (Wirth 1971). Recent materials collected from shoreline habitats of Pearl

Harbor. Honouliuli, June 1998 (dead on surface of stagnant pool); Pouhala wetlands, April and June 1998; Waiawa Springs, June 1998 (on surface of mud algae & puddles on dirt road); Aiea Bay, June 1998 (pools in dry stream bed, 44 ppt salinity).

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 a widespread species found throughout the Pacific (Evenhuis 1989). Materials collected from seashore habitats of Pearl Harbor include Iroquois Point, (on dead eel; on dead puffer fish; at splash zone), June 1998; Blaisdell Park shoreline, sweeping mud and rocks, May 1998.

Hydrellia williamsi Cresson, 1936

Common Name:	Shore fly
First Record:	1931, Molokai
Mechanism:	Leaves of aquatic plant?
Origin:	Australia, New Zealand

Cresson (1936) described the species based on specimens collected by Williams from Kukuiala Valley, Waianae Mountains, taken from *Lemna* in 1936. The earliest specimens at were collected in 1931 at Kanoa, Molokai (Williams 1938). The species probably arrived in Hawaii via importation of aquatic plants. *Hydrellia williamsi* larvae are leaf miners of aquatic plants, which probably accounts for their introduction into Hawaii. A single specimen was collected at Waimano-Waiau Springs at the Hawaiian Electric Power Plant, sweeping along a ditch, 0 ppt salinity, June 1998. *Lemna* filled the freshwater ditch were this species was collected.

Lytogaster gravida (Loew, 1863)

Common Name:	Shore fly
First Record:	1937, Oahu
Mechanism:	?

Origin: U.S.

The first specimen was collected on Tantalus trail, Oahu in 1937 and identified as *Lytogaster willistoni* Cresson, (Williams 1938) and subsequently the species name was changed to *Lytogaster gravida*. The origin of this species is the United States (Evenhuis 1989). Two specimens collected in freshwater pond makai of bike path at Waiau, Hawaiian Electric Power Plant, June 1998.

Mosillus tibialis Cresson, 1916

Commom 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, August 25, 1944. Other specimens in the Bishop Museum collection were taken at Waipahu, Oahu in 1958. During the Pearl Harbor surveys, a single specimen was collected by sweeping mud and rocks at shoreline of E’o Canal, Ted Makalena Golf Course, June 1998. *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* were first collected from Maunaluha 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. Specimens from the Pearl Harbor area collected at Waikele stream, resting on floating plant debris, on surface of seepage crossing road, and sweeping along rocks at stream edge; at Pouhala marsh, and E’o Canal, Ted Makalena Golf Course, sweeping puddle on fairway, July 1998; Kalauao pond, along stream from watercress farm. All specimens were collected in June 1998, except where noted.

Paratissa pollinosa (Williston, 1896)

Common Name:	Shore fly
First Record:	1945, Oahu
Mechanism:	?
Origin:	Neotropics

The earliest records of *Paratissa pollinosa* were taken in 1945 from the intertidal zone of beach rocks from Lanikai, Oahu. During the Pearl Harbor surveys specimens were collected at Iroquois Point and taken off a dead eel in June 1998. This species is native to the Neotropics (Evenhuis 1989).

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). This species has a Pacific-wide distribution (Evenhuis 1989). Recent materials collected from shoreline habitats from Pearl Harbor include Iroquois Point at Pearl Harbor entrance, (mud-sand shore with rocks; sandy beach), June 1998; Waiau-Waimano Springs area, (along rocky shoreline; open rocky shoreline, 30 ppt salinity; in mangrove), June 1998; Middle Loch near Waiawa springs, shoreline - mud, sand, rocks and decaying seaweed, May 1998; Aiea Bay, rocky shoreline, mangrove and *Batis maritima*, June 1998; Halawa stream, (sweeping rocky shoreline; sweeping over mud along stream), June 1998.

Psilopa girschneri Van Roeder, 1889

Synonyms:	*Psilopa olga* Cresson, 1922
Common Name:	Shore fly
First Record:	prior to 1952
Mechanism:	?
Origin:	Holarctic

Hardy (1952) reported specimens in the U.S. National Museum collection "from Hawaii" with no date given. This species has been recorded from throughout the Holarctic region and also from Kiribati, where it was also likely introduced (Evenhuis 1989). Recent materials collected from shoreline habitats of Pearl Harbor include Honouliuli, (mud flats; sweeping *Batis maritima*; beating *Scaevola* and mangrove), June 1998; Pouhala wetlands, sweeping over water and *Batis maritima*, June 1998; Blaisdell Park shoreline, (sweeping over saline puddle; sweeping Waimalu stream exposed bank), May 1998; Waiawa springs, on surface of mud, algae and puddles on dirt road, June 1998; Middle Loch shoreline near Waiawa spring, mud, sand, rocks and decaying seaweed, May 1998.

Scatella stagnalis (Fallen, 1913)

Common Name:	Shore fly
First Record:	1946, 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). Recent materials collected from shoreline habitats of Pearl Harbor include Honouliuli, mangrove bank, June 1998; Waikele stream, along rocks at stream edge, June 1998; Pouhala wetlands, April and June 1998; Kapakahi stream, June 1998; Waiau, June 1998; Blaisdell Park, sweeping exposed bank Waimalu stream, May 1998; Kalauao stream, June 1998; near Kalauao ponds, mud and rock shoreline, June 1998; Waiawa stream, June 1998; near Waiawa spring sweeping shoreline - mud, sand, rocks and decaying seaweed, May 1998; Aiea stream, mud bank, June 1998; Aiea Bay, (mangrove and mud flats; pools in dry stream bed, park area, 44 ppt salinity), June 1998; Halawa stream, mud bar in stream, June 1998.

Family Tethinidae

Tethina variseta (Melander, 1951)

Common Name:	-
First Record:	1946, 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 at Iroquois Point, beach strand, and on dead eel and puffer fish on beach June 1998; Blaisdell Park shoreline, sweeping mud and rocks, May 1998; Aiea Bay, rocky shoreline, mangrove and *Batis maritima*, in June 1998.

Family Tipulidae

Symplecta pilipes (Fabricius, 1787)

Common Name:	Crane fly
First Record:	1892, Hawaiian Islands
Mechanism:	?
Origin:	Tropical cosmopolitan species

Grimshaw (1901) described specimens from Hawaii Island first collected from Kaawaloa in 1892, as *Trimicra lateralis* Edwards (1921). The species identification was later changed to *Symplecta pilipes* by Williams (1943). Specimens in Bishop Museum collection were collected at Honaunau, Hawaii, in 1919 and in Kaimuki, Oahu, 1921. During the Pearl Harbor surveys a single specimen was collected at Pouhala Marsh in June 1998, over mud and shallow pools was covered with mites. Williams (1943) noted that *S. pilipes* breeds in mud. This species has a widespread distribution, and is found in the Afrotropic, Holarctic, and Neotropic regions (Evenhuis 1989).

Styringomyia didyma Grimshaw, 1901

Common Name:	Crane fly
First Record:	1896, Oahu
Mechanism:	?
Origin:	Australasia

Grimshaw (1901) described this new species based on specimen collected from Oahu, Honolulu, November 1896, however, this species was later found to widely distributed throughout the Pacific and is likely an introduction (Hardy 1960). *Styringomyia didyma* is believed to be an introduction as there are nearly 100 species in the genus yet only one widespread immigrant species is found in Hawaii (Hardy 1960). The earliest Bishop Museum specimens for *Styringomyia didyma* include is from Waialua, Oahu, in 1906. In Pearl Harbor, specimens were collected at the Waimano-Waiau Springs of the Hawaiian Electric Power Plant at the lower end of the ponds, 0-2 m elevation, 30 June 1998.

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 due to its ability to tolerate brackish waters (Polhemus and Asquith 1996). This species is now widespread and found throughout Pearl Harbor and Oahu, and prefers slow-water sections of streams, and irrigation pond areas of the leeward Waiahole Ditch (Filbert and Englund 1995). Found in Waikele Stream above USGS weir in pool habitats (0 ppt salinity), and Honouliuli Stream (16 ppt salinity).

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). A common introduced damselfly found throughout low-elevation sections of Oahu streams and wetlands. The smallest of the introduced damselflies was mainly found in freshwater but was also collected in 3 ppt salinity in the watercress farm at Kalauao Springs, near Pearl Ridge mall. Also found in Kapakahi Stream (0 ppt salinity) and at Waikele Springs (0 ppt salinity) area of Waikele Stream.

Ischnura ramburii (Selys-Longchamps, 1850)

Common Name:	Rambur's forktail
First Record:	1973, Hawaii Island
Mechanism:	Possible aircraft stowaway
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 insecticide, thus this species likely could survive as a stowaway (Harwood 1976). The earliest Pearl Harbor record for this species was one mating pair in Pearl Harbor collected in 1974 (Harwood 1976). Currently this is the most abundant and widespread Zygoptera species found in Pearl Harbor, and 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. This species was ubiquitous and was found in the lower areas of all Pearl Harbor streams and wetland areas.

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 1995). The rapid spread of *Crocothemis servilia* across Oahu was expected because of its vagility, and thus its presence within Pearl Harbor habitats is not surprising, as this dragonfly is especially suited to the disturbed, lowland aquatic habitats common on Oahu. The long-term effects of this introduced dragonfly on native aquatic organisms are unknown. However, its distribution overlaps with the native dragonfly *Anax junius*, suggesting a potential for negative interactions. This species was especially common at the very slightly brackish-water ponds of Waiawa Springs (2-4 ppt salinity), and also in areas of standing or stillwater.

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 insect fauna in Pearl Harbor. 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 (1999) found this species also occurs on all other main Hawaiian Islands. *Orthemis ferruginea* was abundant throughout disturbed lowland areas of Oahu, and was common in still-water areas of Pearl Harbor coastal wetlands and springs, and was captured in areas of < 5 ppt salinity. The species is difficult to capture but easy to identify while flying due to its unique color, and visual observations were the usual form of observation. The method of introduction of *O. ferruginea* into Hawaiian waters is unknown, but it is highly likely the immature larval stage was brought in with imported aquatic plants sold at nurseries and pet stores. The native range of this species is from the Florida Keys to Central and South America (Dunkle 1989).

INSECTA: TRICHOPTERA

Family Hydropsychidae

Cheumatopsyche pettiti (Banks, 1908)

Common Name:	Caddis fly
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 Pearl Harbor, *C. pettiti* was found in (0 ppt saln) flowing sections of Waikele Stream, above the USGS gaging station weir, but not found in the completely freshwater Waimano-Waiau Springs complex, or other wetland areas.

HIRUDINEA: RHYNCHOBDELLIDA

Family Piscicolidae

Myzobdella lugubris Leidy, 1851

Common Name:	Leech
First Record:	1994, Hawaiian Islands
Mechanism:	Arrived with introduced fish or blue crabs
Origin:	Probably Gulf of Mexico States (U.S.)

The first record of *Myzobdella lugubris* occurring in Hawaii was published in 1994 (Font 1994). This species likely has been in the Hawaiian Islands for a long time, and could possibly have been imported as early as 1905 when several poeciliid species such as *Gambusia affinis* were intentionally introduced (Van Dine 1907, 1908), or in the 1920s when *Poecilia reticulata*, *Xiphophorus helleri* and other species were introduced (Mainland 1939). This leech was commonly found attached to native and introduced fishes in wetlands and lower areas of Pearl Harbor streams. Although possibly introduced into Hawaii with the importation of blue crabs (*Callinectes sapidus*), the blue crab is not required for this leech to reproduce (Font 1997). In the Hawaiian Islands, *Myzobdella lugubris* is found only in stream and wetland areas containing introduced fish, and its presence on native stream fish is obvious. Font (1994) found this leech the second most abundant parasite in Hakalau Stream, Hawaii, and identified this species as an important vector for disease transmission to native fish. See the Fish Parasitism section of this report for more information regarding the occurrence of this parasite during fish gut analysis.

SECERNENTEA: SPIRURIDA

Family Camallanidae

Camallanus cotti Fujita, 1927

Common Name:	Nematode
First Record:	1994, Hawaiian Islands
Mechanism:	Likely came in with *Poecilia reticulata*
Origin:	Japan or Oriental region

The freshwater nematode *Camallanus cotti* was found in the intestines of four species (*Awaous guamensis*, *Eleotris sandwicensis*, *Stenogobius hawaiiensis*, and *Poecilia reticulata*) of fish during gut content analysis (See Fish Parasitism Section). In Pearl Harbor, six individual fish (of 47 analyzed) examined during gut content analysis contained this introduced parasite. These fish were collected at four different Pearl Harbor locations. Small crustaceans such as copepods become infected with nematode parasites and serve intermediate hosts for the nematode parasite *C. cotti*. Fish are infected with *C. cotti* by feeding on the intermediate hosts such as small crustaceans (Kennedy et al. 1987). *Camallanus cotti* survive by feeding on fish blood and partially ingesting sections of the intestinal wall (Kennedy et al. 1987). Small numbers of *C. cotti* have no apparent effect on fish species that have co-evolved with this parasite (such as *Poecilia reticulata*), but large numbers are fatal (Kennedy et al. 1987).

Although *C. cotti* has likely been in Hawaiian streams for a substantial period of time since the introduction of poeciliids for mosquito control, this parasite was only first reported in the literature in 1994 by Font (1994). This species was brought in with introduced aquarium fish, possibly *Poecilia reticulata* and has a low host specificity (Rigby et al. 1997). The source of this parasite in Europe was found to be poeciliid aquarium fish imported from Singapore and Malaysia (Font 1994). *Camallanus cotti* is by far the most widespread and harmful introduced parasite found in native freshwater fishes, and in Hawaii is found only in streams containing introduced fish species (Font 1997). Prior to this study *C. cotti* was found in the intestines of following Hawaiian stream fish: *P. reticulata*, *Xiphophorus helleri*, *Awaous guamensis*, *Eleotris sandwicensis*, *Lentipes concolor*, and *Stenogobius hawaiiensis* (Rigby et al. 1997); *Poecilia mexicana,* and *Gambusia affinis* (Font 1997).

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) and was abundant in this stream during this study. World wide 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 been widely introduced 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).

This species was restricted to freshwater in Pearl Harbor streams and wetlands, and was common in Kapakahi and Waikele Streams and in the most freshwater sections of the Waiawa Wildlife Refuge wetlands. *Corbicula fluminea* was also found in the watercress farm area of Waiawa Springs complex.

GASTROPODA: MESOGASTROPODA

Family Ampullariidae

Pomacea canaliculata Lamarck, 1804

Common Name:	Apple snail
First Record:	1990, Oahu
Mechanism:	Intentional (food) introduction
Origin:	South America

First found on Oahu in 1990 (Cowie 1995), apple snails (*Pomacea canaliculata*) are now found in two Pearl Harbor drainages, Waikele and Kapakahi Streams. These are the first confirmed record of apple snails in Pearl Harbor streams and wetlands (Lach and Cowie 1999). Apple snails had been recorded from the Waipahu area in 1991 (Cowie 1995), but locality data were incomplete, and the origin of these specimens is unknown. In the Pearl Harbor area apple snails were restricted to freshwater habitats. High densities of adult and immature apple snails were observed in taro fields in a separate and lower spring area that is adjacent to the weir below Waikele Springs. This area was within 25 m of the stream, but apple snails were not observed within the stream channel. The presence of apple snails within 25 m of the stream means that it is highly likely they will soon be in Waikele Stream itself. Egg clusters and adult apple snails were also collected in Kapakahi Stream during this study.

Apple snails are highly destructive to wetland crops such as taro and rice and are considered a significant detrimental species (Cowie 1995). Apple snails have been implicated in the decline native snails in southeast Asia and they destroy aquatic vegetation (Cowie 1995). Ampullariid snails are also significant vectors of disease in humans, but in Hawaii this potential problem has not yet been studied (Cowie 1995).

GASTROPODA: BASOMMATOPHORA

Family Thiaridae

Tarebia granifera (Lamarck, 1816)

Common Name:	Freshwater snail
First Record:	1856, Hawaiian Islands
Mechanism:	Unknown
Origin:	Unknown (possible Polynesian introduction?)

The taxonomy of the mainly freshwater Thiaridae family of aquatic snails in Hawaii is problematic, likely due to their clonal mode of reproduction, which causes extensive morphological variations (Cowie 1997). Many thiarids have been widely introduced throughout the Pacific by humans as is probably the case for species in this family found in Hawaii (Cowie 1997). *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 most Pearl Harbor streams, springs and wetlands. *Tarebia granifera* was found in Halawa Stream (0 ppt) just above the area of tidal influence, and also was abundant at Kalauao (3 ppt salinity), Waiau (0 ppt salinity), and Waikele (0 ppt salinity) Spring areas. In Hawaii, the effects of this species on native mollusks is unknown. Thiarid snails 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

Originally found in Nuuanu Stream, Oahu, since 1991 and reported as *Caridina weberi* (Devick 1991b), *Neocaridina denticulata sinensis* was found in high densities in Waikele Stream. 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. In lower Waikele Stream, this species was most abundant in high water velocity areas such as run and riffles and was also common in aquatic vegetation and stream side-margins. 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 *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. In lower Waikele Stream at the Waikele Springs area, several hundred introduced shrimp were collected in a single aquatic dip net scoop. *Neocaridina denticulata sinensis* was likely recently introduced into Waikele Stream, since it was not found between 85-91m elevation in the main Kipapa tributary of Waikele Stream during surveys conducted in April 1997 (Englund 1997).

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. In aquatic habitats in lower Pearl Harbor, crayfish were abundant mainly in freshwater but were also found in 3 ppt salinity at Kalauao Springs. *Procambarus clarkii* were collected at Waiau, Waiawa, and Waikele Springs; Kapakahi, Waiawa, and Waikele Streams. Crayfish populations apparently exploded shortly after being introduced 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 control crayfish depredations, with over 1,417 ha of wetland taro fields treated in Hawaii (Devaney et al. 1982). Crayfish are still currently abundant in Pearl Harbor aquatic habitats and throughout Oahu, and there has been no active Hawaii control program since 1952. In California, the introduction of *P. clarkii* and other alien 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. Additionally, *P. clarkii* is also a potential 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. In Pearl Harbor, *M. lar* was found in areas of freshwater, or just slightly (2-3 ppt salinity or less) saline waters, including Waiau Springs, Waiawa Springs, Waiawa Stream, and Waikele Springs. In Hawaii, this species directly competes with the native *Macrobrachium grandimanus* (Eldredge 1994), and biologists have also observed this species 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: CYPRINODONTIFORMES

Family Poeciliidae

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 Pearl Harbor streams and estuaries were 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.). In Pearl Harbor waters *Poecilia mexicana* was found in water ranging from 0-36 ppt salinity 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 Pearl Harbor, with only tilapia being found in correspondingly high densities. This species is the largest (up to 115 mm) of the introduced Hawaiian livebearers. This species is likely is 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 1994). None of these 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 1994).

Xiphophorus helleri Heckel, 1848

Common Name:	Green swordtail
First Record:	1922, Oahu
Mechanism:	Governmental biocontrol
Origin:	Central America

Xiphophorus helleri in Pearl Harbor estuarine areas appeared to have a low salinity tolerance and were generally found in areas of flowing water with salinities < 3.5-4.0 ppt. Kalauao Springs (the watercress farm area at Pearl Ridge shopping mall) was another aquatic habitat having measurable salinities where *X. helleri* was collected, with salinities at Kalauao Springs ranging from 2 to 3 ppt. *Xiphophorus helleri* were introduced in 1922 for the purposes of mosquito control (Brock 1960) and have successfully established populations in the low elevation areas of virtually every Oahu stream. *Xiphophorus helleri* can attain a size of up to 105 mm, which is much larger than that of *Poecilia reticulata* and *Gambusia affinis*. In Pearl Harbor, *X. helleri* were found in Kalauao Springs, Waiau Springs, and Waikele Stream and Waikele Springs area, and Waimalu Stream.

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 in Pearl Harbor. This species was first introduced into Pearl Harbor drainages of Aiea and Pearl City spring areas in 1905 for mosquito control (Van Dine 1908). Due to a salinity tolerance second only to *Poecilia mexicana*, *Gambusia affinis* is now found in virtually all wetland and lower stream areas of Pearl Harbor. 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, Hurlbert and Mulla 1981). 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 in Pearl Harbor were usually in salinities of <16 ppt during this study but have been found in salinities of up to 40 ppt on Oahu.

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 *Gambusia 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* was common in Pearl Harbor streams and wetlands, and was found at Kalauao Springs, Kapakahi Stream, Waiawa Springs, Waiawa Stream, Waikele Springs and Waikele Stream, and Waimalu Stream.

Poecilia latipinna LeSueur, 1821
Common Name: Sailfin molly
First Record: 1905
Mechanism: Governmental (biocontrol)
Origin: Southern Texas

Although *Poecilia latipinna* was first introduced to Hawaii in 1905 for mosquito control, this species was only locally common and was restricted to stillwater habitats such as Pouhala Marsh. *Poecilia latipinna* has a wide salinity tolerance, and was found at Pouhala Marsh in salinities ranging from 1 to 9 ppt. This species 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).

Limia cf. *vittata* Guichenot, 1853
Common Name: Cuban limia
First Record: 1950
Mechanism: Aquarium release
Origin: Greater Antilles

This poeciliid species was relatively uncommon and similar to *Poecilia latipinna* as it preferred still-water habitats. *Limia vittata* was most abundant at Pouhala Marsh and the large pool areas at Waiawa Springs, and much less common in lotic habitats. Except for its preference of wetland and still water habitats, relatively little is known about the ecology of this species in Hawaii.

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) this introduced goby is now common throughout Pearl Harbor and 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 most Pearl Harbor streams, spring areas, and wetlands, and inhabits water from 0-36 ppt salinity. Unlike native stream gobies, *M. cavifrons* displays little climbing ability, and its distribution in Waikele Stream was limited to areas below the 1.5 m high concrete weir. Pearl Harbor collection locations include Kalauao, Waiawa Springs; and Kalauao, Waikele, Waimalu, and Waiawa Streams. The effects of *M. cavifrons* on native species are unknown, but during this study native crustacean species were found in their stomachs (See Fish Diet Section). In aquaria, this species was observed to be highly aggressive and predaceous, and readily consumed native *Awaous guamensis* post-larvae.

Family Blennidae

Omobranchus ferox Herre, 1927

Common Name:	Fang-toothed blenny
First Record:	1998, Oahu
Mechanism:	Possible ballast water

Origin: Native range from South Africa to Philippines

A new island and state distributional record was established for *Omobranchus ferox*, and this species appears to have become established in Pearl Harbor. All fish were captured during several months of sampling using aquatic dip nets and small hand-seines. Nine individual *Omobranchus ferox* ranging in size from 25 to 90 mm have been captured in the lower tidal reaches of Halawa Stream. Extensive surveys of all stream mouth, estuarine, and spring areas in the East, Middle, and West Lochs of Pearl Harbor have failed to locate additional populations of *O. ferox*. All individuals were found within a small 15 m shoreline region of Halawa Stream. *Omobranchus ferox* habitat consisted of a rocky shoreline interspersed with small mangroves (*Rhizophora mangle*), and stream substrate consisted of deep silt covering cobble and small boulder. Fish were usually captured in the vicinity of mangrove roots, and also on the partially submerged surface of boulders that were coated with thick layers of fine silt. We were unable to visually observe these fish at Halawa Stream due to the highly turbid nature of this estuarine habitat. In Halawa Stream, *O. ferox* were found in salinities ranging from 35-36 ppt. *Omobranchus ferox* was also usually captured along with the introduced molly, *Poecilia mexicana*, the most commonly occurring fish in this section of Halawa Stream. The native estuarine goby *Oxyurichthys lonchotus* was the main native fish species commonly captured with *O. ferox* at Halawa Stream.

Although the transport mechanism for this species into Pearl Harbor is unknown, it is likely a recent introduction due to its extremely restricted distribution during this study. *Omobranchus ferox* has apparently been introduced into other regions such as Mozambique (Springer and Gomon 1975). In its native range O*mobranchus ferox* inhabits shallow near-shore waters and has been collected mainly in mangrove swamps, river estuaries, and lakes in the Philippines (Springer and Gomon 1975). There is a potential for negative impacts on native species if this species becomes more widespread in Hawaiian estuarine and freshwater habitats. In Apra Harbor Guam, three species of blennies, including *Omobranchus elongatus*, were collected from the hull of a U.S. Navy drydock that was towed from Subic Bay, Philippines (R.F. Meyer, University of Guam, June 10, 1992 letter, pers. comm.). None of the blennies found on the drydock were native to Guam. *Omobranchus elongatus* is closely related to the *Omobranchus* species collected in Pearl Harbor during this study and inhabits stream mouth areas, having a brackish water habitat preference similar to that of *Omobranchus ferox* (Springer and Gomon 1975).

Family Cichlidae

Hemichromis elongatus (Guichenot in Dumeril, 1861)

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

This large (to 30 cm length) and colorful species of African cichlid was found in the lower reaches of Waiawa Stream. *Hemichromis elongatus* was found only in areas of freshwater in Waiawa Stream just above areas of tidal influence and was common in slow pool habitats above and below the Kamehameha Highway bridge. In Hawaii, *Hemichromis elongatus* or the jewel cichlid, was first collected in Lake Wilson, Oahu in 1991 and is currently also found in Kawainui Marsh drainages, and Nuuanu Stream (Mike Yamamoto, Hawaii Division of Aquatic Resources, pers. comm.). Collections of *H. elongatus* during this study were the first record of this species being collected in a Pearl Harbor drainage. The impacts this introduced cichlid will have upon native aquatic organisms are unknown.

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 in Pearl Harbor (and 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). In Pearl Harbor, 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 every low-elevation aquatic habitat sampled, in water ranging from 0 to 36 ppt salinity in Pearl Harbor estuaries and wetlands. 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 lower Pearl Harbor streams and wetlands than any other introduced aquatic species. In Hawaii, tilapia thrive in wetland or marsh areas as they are cut off from predators such as papio and 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).

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 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).

SILURIFORMES: Family Loricariidae

Ancistrus cf. *temminckii* Valenciennes, 1840

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

Currently found only in Waikele Stream in the Pearl Harbor drainages, this species has occurred in Waikele Stream since at least 1993 (Englund 1993), and was first found on Oahu in 1985. Species in the genus *Ancistrus* are distinctive due to 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 Waikele Stream was 74.1 mm.

This species appeared to preferentially select high velocity riffle and run habitats, and was less common in pool habitats. In lower Waikele Stream, bristle-nosed catfish densities were high, and may also be in part contributing to the near absence of the native gobiid *A. 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 Pearl Harbor 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 lower sections of Pearl Harbor streams (Waiawa and Waikele) containing very high densities of introduced armored catfish such as Waikele Stream.

Hypostomus cf. *watwata* Hancock, 1828

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

In the Pearl Harbor region, *Hypostomus* cf. *watwata* was found only in lower Waiawa Stream. *Hypostomus* cf. *watwata* can attain a much larger size (of nearly 300 mm in length) than the other armored catfish species found in Pearl Harbor (*Ancistrus* cf. *temminckii*). 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*.

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APPENDIX E

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:

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