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Flow Restoration and Persistence of Introduced Species in Waikele Stream, Oʻahu

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Abstract—Unintentional stream flow restoration in Waikele Stream, Oʻahu, Hawaiʻi resulted from the demise of sugar cane cultivation on Oʻahu and subsequent cessation of direct surface water diversions in 1989. Previous artificial stream studies in Hawaiʻi have suggested that increases in the base flow of a diverted stream would displace or reduce introduced fish populations. Surveys of Waikele Stream, conducted in 1993 and 1997–1998 from the Waikele Springs area downstream to the beginning of the tidal reach found that despite an increase in stream flow, introduced fish remained abundant and native species appeared to have declined. In fact, two new introduced aquatic taxa, a dragonfly and a shrimp, had appeared. These results indicate that although restoring hydrological conditions is an important first step in overall restoration of degraded aquatic ecosystems, flow restoration alone is not a panacea, especially in Oʻahu streams with naturally low discharge rates. For stream and wetland restoration to fully succeed, introduced fish and other alien aquatic species must be eradicated by methods other than simply increasing stream base flows.

Introduction

Hawaiʻi has a significant and endemic freshwater fauna that is now seriously threatened. Native Hawaiian stream animals have been adversely affected by the accelerated introduction of non-native species (Devick 1991a), urban development, stream diversions, and stream channelization (Norton et al. 1978, Timbol & Maciolek 1978). In Oʻahu streams, escaped ornamental species are increasingly displacing native organisms. Although the adverse effects associated with introduced freshwater species have been well documented in the Pacific region (Maciolek 1984, Arthington & Lloyd 1989, Crowl et al 1992, Eldredge 1994), reliable solutions to the problem have not been developed. The Hawaiʻi Division of Aquatic Resources has attempted to limit the spread of new introductions through educational advertisements in the media on the harmful effects of introduced species. However, limited efforts have been made to decrease the effects of introduced species already in Hawaiian streams, and success in eliminating or reducing introduced fish in freshwater habitats in Hawaiʻi has been equivocal.

One method, currently under discussion, to reduce the numbers of introduced species in Hawaiian streams involves restoring water flow to natural levels through the removal of agricultural water diversions. Flow restoration has been suggested as an effective way of eliminating or reducing the abundance of introduced animals in historically diverted Hawaiian streams (Fitzsimons & Nishimoto 1996, Fitzsimons et al. 1997). These results were based on laboratory studies conducted in artificial streams. However, it is not obvious how applicable the artificial stream results are to field situations, such as unchannelized streams.

Increases in water velocity associated with increases in flow are believed to displace non-native organisms that have evolved in slow-water environments (Fitzsimons et al. 1997). An obvious problem with this argument, however, is that regardless of flow regime, a stable unchannelized stream will always contain some slow-water habitats (Platts et al. 1983, Helm et al. 1985). In this study we examine Waikele Stream, an Oʻahu catchment that was diverted from prior to 1931 until 1989. Species composition was assessed in this stream four and nine years after the cessation of large-scale agricultural water diversions in 1989. The purpose of this study was to document species composition of native and introduced aquatic animals in the area downstream of a hydrologically restored Oʻahu stream, and to assess the success of flow restoration in regard to the removal or reduction of introduced species.

Study Area

Waikele Stream drains the leeward slope of the Koolau Mountains and the windward slope of the Waiʻanae Mountains in central Oʻahu. From its origin in the Koolau range, the stream flows for 28 km to Pearl Harbor. The Waiʻanae Mountain tributaries of Waikele Stream are intermittent, and flow only following heavy rains. The main channel of Waikele Stream consists of alternating sections of flowing and dry steam except during and after periods of heavy precipitation. This is a natural condition caused by percolation of water into the alluvium. Flow is perennial only in the Koʻolau Mountain headwaters and near the mouth in the area of Waikele Springs. As in many Oʻahu streams, streamflow is characteristically flashy, with high flood peaks and low baseflows (Nichols et al. 1997).

The study area extended from approximately 250 m above Waikele Springs to a concrete weir spanning lower Waikele Stream 1.3 km downstream of the springs (Figure 1). This weir completely separates freshwater from the tidal reach on the downstream side, and the difference in stream levels can range from 1–1.5 m (Nance 1998). The terminal reach of Waikele Stream is mainly fed by a series of large basal springs that are collectively called Waikele Springs. Waikele Springs issue from low points in the cap rock that release groundwater (Stearns & Vaksvik 1935). At base flow, Waikele Springs contribute approximately 80% of the water to the lower Waikele Stream (Nance 1998).

Unintentional stream flow restoration resulted from the demise of sugar cane cultivation on Oʻahu and subsequent cessation of direct surface water diversions

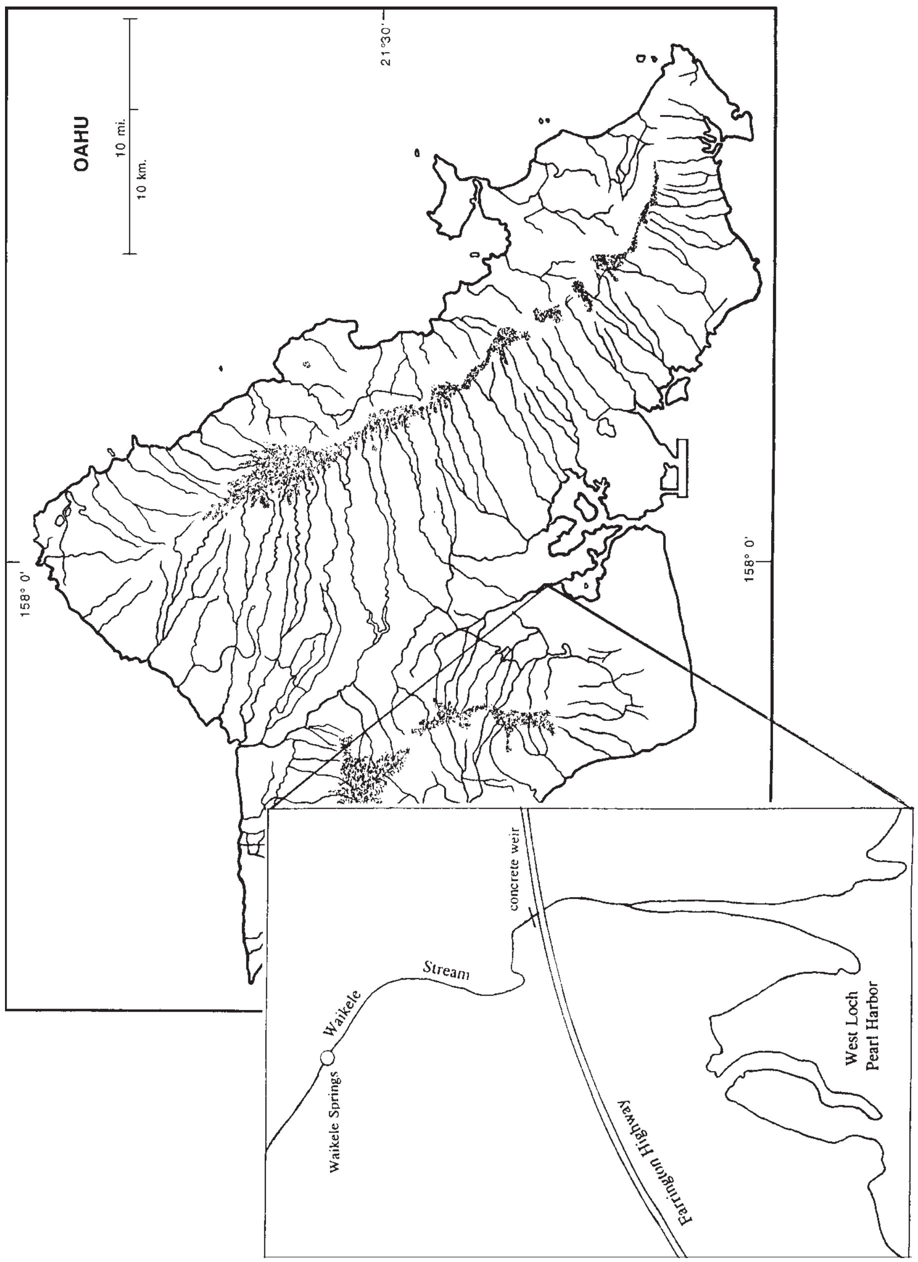

Figure 1. Waikele Stream study area. Study area begins at Waikele Springs and extends downstream to concrete weir at beginning of tidal reach.

in 1989, and groundwater well pumping between 1994 and 1995 (Nance 1998). The earliest recorded diversion of Waikele Springs was conducted in 1931 by the Oahu Sugar Company and consisted of 0.1 m^3/s (Stearns & Vaksvik 1935). Although it is known that diversions occurred prior to 1931, records are not available for these early diversions. From 1951 to 1989 flow diversion averaged 0.19 m^3/s (Nance 1998). Diversions greater than 0.6 m^3/s frequently occurred during droughts. Direct diversions from the Waikele Springs ceased in July 1989. The last groundwater pumping that could have affected flow in the Waikele Springs occurred in 1995 (Nance 1998). It is not known to what extent these wells affected Waikele Stream flow, but it appeared to be insignificant compared to direct diversions that occurred prior to 1989 (T. Nance, personal communication, 1998).

During this study, habitat downstream of the Waikele Springs input consisted of high-velocity runs (0.3–0.6 m in depth) connecting shallow pools (0.2–0.6 m in depth) with stream widths of 4–8 m. Unlike many low-elevation sections of O‘ahu streams, Waikele Stream is not lined with concrete or channelized in the area of Waikele Springs. The natural stream channel is maintained from above Waikele Springs downstream for 1.3 km until the stream is impounded by the concrete weir.

Methods

Stream animals were sampled during two periods: March 1993, and December 1997 to April–August 1998. Sampling effort in 1997 and 1998 was close enough in time to be considered one sampling period. In 1993, sampling methods consisted of snorkeling, netting, and above-water observations. Quantitative fish sampling was not conducted in 1993, but relative abundance and fish species composition were noted. In 1998, one quantitative seine haul was used to characterize the relative abundance of introduced fish immediately below Waikele Springs.

A fine-mesh, 5 m long seine was used to sample stream animals and assess species composition. Snorkeling and above-water observation were also used, especially in fast-water habitats. During both periods aquatic insect collection focused on dragonflies and damselflies (Odonata). Odonata were captured with both aerial and dip nets, and dip nets were also used to sample areas not accessible to seines. Water velocity was measured with a Swoffer 2100 current meter in the main channel downstream of Waikele Springs. Velocity measurements were collected at 0.6 to 1.2 m intervals along transects that were perpendicular to stream flow. Three transects were established in areas of relatively laminar flow: 4, 18, and 33 m downstream of the beginning of the Waikele Springs input. Water velocities were measured at the water’s surface and six tenths of total stream depth below the stream surface. The latter measurement location corresponds to the location of average velocity in an ideal channel (Nielson & Johnson 1983).

Sampling effort in March 1993 consisted of approximately 50 hours of observations and organism collection in the study area. In 1997–1998, sampling effort increased to approximately 100 hours, with similar proportions of time spent snorkeling and netting. In both sampling periods observations were also made directly below the weir.

Results

Water velocity measurements for each transect are shown in Table 1. In 1998, relatively high average water velocities (33–52 cm/s) were encountered downstream of the restored Waikele Springs. Water velocities as low as 10 cm/s were recorded near the streambanks.

In 1997–1998, two previously unrecorded introduced species were collected in Waikele Stream (Table 2). Only three of the five freshwater fish species known from Hawaiian streams (*Stenogobius hawai'iensis, Awaous guamensis,* and *Eleotris sandwicensis*) were captured. Most observations of native fish species occurred in the tidal reach below the 1.5 m high concrete weir in lower Waikele Stream. Native fish such as *Kuhlia sandvicensis, Mugil cephalus,* and *E. sandwicensis,* were common but found only downstream of this weir which precluded their upstream movement. The weir did not prevent upstream movement by native stream gobies. However, neither *Sicyopterus stimpsoni* nor *Lentipes concolor* were encountered during this or previous surveys.

The stream gobies *A. guamensis* and *S. hawai'iensis* appear to have declined since 1993 in the study area. In 1993, high densities of post-larvae of both of these species were observed and collected below the weir (Figure 1). Although adults of both of these species were observed in 1998, post-larvae were not observed in that same location during extensive sampling conducted in 1997–1998. While not common, *S. hawai'iensis* was collected both up and downstream in the vicinity of the weir, but was not observed upstream near Waikele Springs in 1998, in contrast to 1993. Despite greater sampling effort than in 1993, only a few *A. guamensis* were observed just below the concrete weir in 1997–1998. Additionally, native fish were not observed in the vicinity of Waikele Springs in 1998, despite intensive sampling effort. In 1993, native gobies were common at the Waikele Springs area, with 12 *A. guamensis* in a wide range of size classes netted, including relatively recent recruits as small as 24 mm total length (Englund 1993).

Introduced fish were common throughout the study area. Tilapia (*Sarotherodon melanotheron*) were found both upstream and downstream of

Table 1. The range and mean water velocities (± standard error) recorded in the transects downstream of Waikele Springs.

Distance from start of restored Waikele Springs outlet (stream width–m)	Surface Velocity (range–cm/s)	Mid-Channel Velocity (range–cm/s)	Mean Mid-Channel Velocity (cm/s)
4m (7.9 m wide)	10–67	10–67	33±7
18 m (7.0 m wide)	25–92	16–93	52±7
33 m (5.2 wide)	10–80	13–65	48±6

Table 2. Introduced and native species found in Waikele Stream, O'ahu in 1993 and 1997–1998 from 250 m above Waikele Springs downstream to concrete weir. O'ahu introduction dates from Beardsley (1980), Devick (1991a), Cowie (1995), Polhemus & Asquith (1996), Randall (1996), Cowie (1998).

Taxon	1993	1998	Biogeographic Status	Year of O'ahu Introduction or Discovery
Fish				
Awaous guamensis	X	X	Indigenous	
Stenogobius hawai'iensis	X	X	Endemic	
Eleotris sandwicensis	X	X	Endemic	
Mugilobius cavifrons	X	X	Introduced	
Kuhlia sandvicensis	X	X	Endemic	
Mugil cephalus	X	X	Indigenous	
Moolgarda engeli	X	X	Introduced	1955
Ancistris cf. temminckii	X	X	Introduced	1985
Sarotherodon melanotheron	X	X	Introduced	1951
Poecilia reticulata	X	X	Introduced	1922
P. mexicana	X	X	Introduced	1960
Gambusia affinis	X	X	Introduced	1905
Xiphorphous helleri	X	X	Introduced	1922
Crustaceans				
Macrobrachium grandimanus	X	X	Endemic	
Procambarus clarki	X	X	Introduced	1923
Macrobrachium lar	X	X	Introduced	1957
Neocaridina denticulata sinensis		X	New Introduction	1991
Mollusks				
Corbicula fluminea	X	X	Introduced	1988
Pomacea canaliculata		X	New Introduction[1]	1990
Tarebia granifera	X	X	Introduced	1856
Damselflies/dragonflies (Odonata)				
Ischnura ramburi	X	X	Introduced	1973
Ischnura posita	X	X	Introduced	1936
Enallagma civile		X	Introduced	1936
Pantala flavescens	X	X	Indigenous	
Anax junius	X	X	Indigenous	
Crocothemis servilia		X	New Introduction	1994
Orthemis ferruginea	X	X	Introduced	1977
Amphibians				
Bufo marinus	X	X	Introduced	1932
Rana catesbeiana	X	X	Introduced	1867

[1]Apple snails not directly found in stream, but in taro fields 25 m away from stream channel.

Waikele Springs. Bristle-nosed or armored catfish (*Ancistris cf. temminckii*) were extremely abundant in runs and riffles downstream of Waikele Stream. Two species of alien fish known to inhabit lower Waikele Stream, Chinese catfish (*Clarias fuscus*) and the rice paddy eel (*Monopterus albus*) (Hawaiʻi Division of Aquatic Resources, personal communication, 1998), were not observed at this location in 1993 or 1997–1998. This is likely due to their wariness, or to gear limitations, since electrofishing is the most effective means of sampling these species.

As in 1993, large numbers of introduced poeciliids such as *Gambusia affinis, Poecilia mexicana, P. reticulata,* and *Xiphophorus helleri* were observed in the Waikele Springs area downstream to the tidal reach. Densities of poeciliids remained high in 1997–1998. Using a haul seine (in a pool) in 1998 we found densities of 2.2/m^2 for *G. affinis,* 1.5/m^2 for *P. reticulata,* 0.4/m^2 for *P. mexicana,* and 0.2/m^2 for *X. helleri,* for a total of 4.3/m^2 for all poeciliids combined.

Introduced dragonflies and damselflies dominated the aquatic insect fauna of Waikele Stream. All damselfly species were introduced (Table 2). Native *Megalagrion* damselflies were not observed in lower Waikele Stream in 1993 or 1998. The indigenous dragonfly *Anax junius* was common around Waikele Springs, and the introduced dragonfly *Crocothemis servilla* was absent in 1993, but common in 1998.

The introduced freshwater shrimp, *Neocaridina denticulata sinensis*, was abundant in 1998 but was not found in 1993. Introduced apple snails (*Pomacea canaliculata*) were observed in taro fields in a separate and lower spring area that is adjacent to their weir below Waikele Springs. This area was within 25 m of the stream, but apple snails were not observed within the stream channel.

Discussion

In the last five years, two new species, a dragonfly and a shrimp, have become established in lower Waikele Stream, and an additional species of introduced aquatic snail was found within 25 m of the stream. At the same time, native stream animals have become less common despite flow restoration.

The dragonfly *C. servilia* was first collected around taro fields in Waiahole Stream, Oʻahu in 1994 (Polhemus 1995). The rapid spread of this dragonfly across Oʻahu was expected because of its vagility, thus its appearance at Waikele Stream is not surprising. Moreover, this dragonfly is suited to the disturbed, lowland aquatic habitats common on Oʻahu. The long-term effects of this introduced dragonfly on native aquatic organisms are unknown. However, its distribution overlaps with the native dragonfly *A. junius*, suggesting a potential for negative interactions.

The freshwater shrimp, *N. d. sinensis,* was probably introduced to Oʻahu streams as an escaped or released ornamental species. Its native range includes Taiwan, the Ryukyu Islands, Korea, mainland China, and Vietnam (Hung et al. 1993). Recently this species has been found in several widely separated windward and leeward Oʻahu streams (Devick 1991b). However, the Waikele record is the first time it has been found in a Pearl Harbor stream. Previously this shrimp was incorrectly identified from Nuʻuanu Stream, Oʻahu, as *Caridina weberi* (Devick 1991b). It is possible that *N. d. sinensis* could compete with the native atyid shrimp *Atyoida bisulcata.*

High densities of adult and immature apple snails were seen in an area of taro fields less than 25 m from Waikele Stream and within the floodplain. 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.

Introduced poeciliids were abundant in the unchannelized and restored flow areas of Waikele Stream. Total poeciliid densities in Waikele Stream were equal to or greater than those found in other similarly degraded Oʻahu streams. For example, poeciliid densities in low elevation areas of Kawa Stream (0–1.5 m above sea level) ranged from 1.6 to 2.9/m^2 (Filbert & Englund 1995), compared to 4.3/m^2 found in Waikele Stream. The high poeciliid densities appear not to support predictions made from artificial stream research. Using species found in Hawaiʻi, Fitzsimons et al. (1997) found strong water flows displaced introduced poeciliids in an artificial stream, and then applied these displacement velocities to natural stream channels. Fitzsimons et al. (1997) concluded that, "…a stream with a base flow of 20 cm/second or greater will be ideal for native fishes and will eliminate or at least suppress non-native poeciliids and the copepod [parasite] intermediate hosts…". Water velocities in the restored Waikele Stream ranged from 33 to 52 cm/second (Table 1). Although the average mid-column and surface water velocities in Waikele Stream (below Waikele Springs) now far exceed 20 cm/s, poeciliids and other alien fish remain abundant in areas of high water velocities. Armored catfish (*A. cf. temminckii*) appear to preferentially select areas of highest water velocities, and were less common in pool habitats. The likely reason that introduced poeciliids were not displaced by the >20 cm/s water velocities in Waikele Stream may be due to the habitat complexity found in natural, unchannelized streams. Large rocks, downed trees, side channels, and aquatic vegetation all offer a velocity refuge to introduced fish (such as poeciliids or tilapia) which favor slower water velocities than do the native stream gobies. Additionally, many Oʻahu streams are small, and naturally have low water velocities at the stream mouth or in other low-elevation sections of the stream.

The negative effects of introduced poeciliids on other vertebrates and invertebrates have been widely documented (Hurlbert et al. 1972, Meffe & Snelson 1989). For example, *G. affinis* prey upon eggs, larvae, and fry of sportfish and native fish in areas outside of their native habitat (Courtenay & Meffe 1989). Predation by introduced poeciliids was believed to be a significant cause of extirpation of native fish in Nevada (Courtenay & Meffe 1989) and invertebrates in Australia (Arthington & Lloyd 1989). In south-western Australia, Morgan et al. (1998) found fin nipping by *G. affinis holbrooki,* the eastern mosquitofish, caused extensive caudal fin damage to native fish species.

The persistence of poeciliids in Waikele Stream after flow restoration will also likely prohibit the recolonization of this area by native stream breeding

Megalagrion damselflies. Polhemus & Asquith (1996) believed the presence of introduced poeciliids was responsible for the absence of native *Megalagrion* species in areas where they co-occurred. These authors found a complete absence of native damselflies in low elevation areas similar to Waikele Stream where introduced poeciliids were found.

Additionally, bristle-nosed catfish densities were high, and may also be contributing to the absence of *A. guamensis* in the study area in 1998. Native stream gobies are undoubtedly adversely affected by loricariid catfish through competition for food and space. The species of loricariid catfish found on O‘ahu are primarily algivores, but will also readily consume fish eggs (J. Armbruster, personal communication, 1998). Native stream gobies are rare in low elevation areas of O‘ahu streams containing very high densities of introduced armored catfish (Kawa Stream, Filbert & Englund 1995; Manoa Stream, Bishop Museum unpublished databade).

Flow restoration between 1989 and 1998 appears to have had little beneficial effect on native stream animals. Our surveys in 1993 and 1997–1998 indicate native animals are rare to non-existent and introduced species are more abundant. This suggests that elements other than flow may be important to the rehabilitation of native stream communities in Hawai‘i. However, there may be situations in which flow restoration alone has had a beneficial effect on native organisms. Flow restoration in an unnamed stream at Tripler Army Medical Center (O‘ahu) led to an increased abundance of a rare native damselfly (*Megalagrion xanthomelas*). After ten months of flow restoration, adult damselfly observations increased from 17 to 162 adults per monitoring period (Englund 1998). The absence of introduced fish in this stream likely explains the success of flow restoration in this case. In the presence of an introduced fish damselfly abundance would likely have not increased (Polhemus & Asquith 1996).

The results of this study corroborate other field observations that flow restoration alone will not reduce the numbers of alien species. On O‘ahu, recovery of native freshwater vertebrates and invertebrates will not occur until it is understood that alien species now dominate the system in low elevation aquatic habitats. For stream and wetland restoration to succeed, introduced fish and other harmful aliens must first be eradicated. Introduced poeciliids occur in almost every major wetland in the Hawaiian archipelago. Even if it were possible to flush introduced fish out of an Hawaiian stream, adjoining wetlands or side-channel habitats would still provide low velocity refugia. This would limit the recolonization of streams by native aquatic insects such as *Megalagrion* damselflies.

Introduced freshwater fish now occur in many parts of the world, including Australia, New Zealand, and on most Pacific islands with freshwater habitats (Maciolek 1984, Eldredge 1994). They threaten the biodiversity of aquatic ecosystems throughout the Pacific region. Restoring hydrological conditions is an important first step in restoring degraded aquatic ecosystems but flow restoration is not a panacea, especially in areas having streams with a naturally low baseflow discharges such as those on O‘ahu. To preserve native fish and invertebrate biodiversity in Hawai‘i and the Pacific region, creative management solutions must be found, including the elimination of introduced species. Every step should also be taken to ensure that new species introductions do not occur in pristine aquatic habitats.

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References

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

Beardsley, J.W. 1980. New record of *Orthemis ferruginea* (Fabricius) from O‘ahu. Proceedings of the Hawaiian Entomological Society for 1977, 23: 83.

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

Crowl, T.A., A.R. Townsend & A.R. McIntosh. 1992. The impact of introduced brown and rainbow trout on native fish: the case of Australasia. Reviews in Fish Biology and Fisheries. 2: 217–241.

Cowie, R.H. 1995. Identity, distribution and impacts of introduced Ampullariidae and Viviparidae in the Hawaiian Islands. Journal of Medical and Applied Malacology 5: 61–67.

Cowie, R.H. 1998. Patterns of introductions of non-indigenous non-marine snails and slugs in the Hawaiian Islands. Biodiversity and Conservation 7: 349–368.

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

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

Eldredge, L.G. 1994. Perspectives in aquatic species management in the Pacific islands. Volume 1, introductions of commercially significant aquatic organisms to the Pacific Islands. South Pacific Commission, Noumea, New Caledonia. 127 pp.

Englund, R.A. 1993. A survey of the fish and aquatic insect fauna of the Waikele/Kipapa streams, Oʻahu, Hawaiʻi. BHP Environmental Technologies report prepared for Halekua Development Corp., Honolulu. 20 pages.

Englund, R.A. 1998. Response of the Orangeblack Hawaiian Damselfly (*Megalagrion xanthomelas*), a Candidate Threatened Species, to increases in stream flow. Bishop Museum Occasional Papers 56: 19–24.

Filbert, R.B. & R.A. Englund. 1995. Assessment of the freshwater macrofauna of Kawa Stream, Oʻahu. Pacific Aquatic Environmental report prepared for Pacific Atlas Hawaiʻi, Inc. 19 pages.

Fitzsimons, J.M. & R.T. Nishimoto. 1996. Recovery of three Kauai streams from Hurricane Iniki and implications for the restoration and regeneration of freshwater ecosystems in Hawaiʻi. *In* Will Stream Restoration Benefit Freshwater, Estuarine, and Marine Fisheries? Proceedings of the October 1994 Hawaiʻi Stream Restoration Symposium.

Fitzsimons, J.M., H.L. Schoenfuss & T.C. Schoenfuss. 1997. Significance of unimpeded flows in limiting the transmission of parasites from exotics to Hawaiian stream fishes. Micronesica 30: 117–125.

Helm, W.T., P. Brouha, M. Aceotima, C. Armour, P. Bisson, J. Hall, G. Holton & M. Shaw. 1985. Glossary of stream habitat terms. Western Division, American Fisheries Society. 34 pp.

Hung, M.S., T.Y. Chan & H.S. Yu. 1993. Atyid shrimps (Decapoda: Caridea) of Taiwan, with descriptions of three new species. Journal of Crustacean Biology 13: 481–503.

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

Maciolek, J.A. 1984. Exotic fishes in Hawaiʻi and other islands of Oceania. *In* W.R. Courtenay, Jr. & J.R. Stauffer, Jr. (eds), Distribution, biology, and management of exotic fishes, pp. 131–161. Johns Hopkins University Press, Baltimore.

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

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

Nance, T. 1998. Effect of the proposed use of the WP-18 pump station on Waikele Stream and West Loch. Tom Nance Water Resource Engineering, 680 Ala Moana Boulevard, Suite 406. 39 pages + appendices.

Nichols, W.D., P.J. Shade & C.D. Hunt, Jr. 1997. Summary of the Oʻahu, Hawaiʻi, regional aquifier-system analysis. U.S. Geological Survey Professional Paper 1412-A. 61 pp.

Nielsen, L.A. & D.L. Johnson. 1983. Fisheries Techniques. American Fisheries Society. 468 pp.

Norton, S.E., A.S. Timbol & J.D. Parrish. 1978. Stream channel modification in Hawaiʻi. Part B: effect of channelization on the distribution and abundance of fauna in selected streams. FWS/OBS-78/17. USFWS National Stream Alteration Team, Columbia, Missouri. 47 pp.

Platts, W.S., W.F. Megahan & G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. Intermountain Forest and Range Experiment Station. U.S. Forest Service, Ogden, Utah. 70 pp.

Polhemus, D.A. 1995. New Heteroptera and Odonata (Insecta) records and range extensions in the Hawaiian Islands. Bishop Museum Occasional Papers 42: 42–43.

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

Randall, J.E. 1996. Shore Fishes of Hawaiʻi. Natural World Press. 216 pp.

Stearns, H.T. & K.N. Vaksvik. 1935. Geology and ground-water resources of the island of Oʻahu, Hawaiʻi. Territory of Hawaiʻi, Department of Public Lands, Division of Hydrography, Bulletin 1, 479 p.

Timbol, S.A. & J.A. Maciolek. 1978. Stream channel modification in Hawaiʻi, Part A: Statewide inventory of streams, habitat factors and associated biota. FWS/OBS-78-16. USFWS National Stream Alteration Team, Columbia, Missouri. 157 pp.

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