Biology of Hawaiian Streams and Estuaries. Edited by N.L. Evenhuis & J.M. Fitzsimons. *Bishop Museum Bulletin in Cultural and Environmental Studies* 3: 171–181 (2007).

Hīhīwai (*Neritina granosa* Sowerby) Recruitment in ʻĪao and Honomanū Streams on the Island of Maui, Hawaiʻi

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Abstract

Juvenile *hīhīwai* (*Neritina granosa*), endemic freshwater snails of Hawaiʻi, were collected from ʻĪao and Honomanū Streams on the island of Maui. Each stream has two or three diversions at various elevations which removes most of the stream flow before reaching the ocean. The lack of flow restricts *hīhīwai* to the estuary. Groundwater maintains freshwater habitats for their survival. Both sites were impacted occasionally by large ocean swells and extreme high tides that mixed salt water with fresh or formed berms that blocked stream flow to the ocean. *Hīhīwai* continue to migrate from the ocean. This paper describes their recruitment and reviews some of the conditions found in each stream. Monthly counts were from 0–576 in ʻĪao Stream (1999–2004) while Honomanū Stream counts were from 67–912 (2001–2004). Monthly shell lengths averaged from 1.5–6.1 mm in ʻĪao Stream and 2.2–9.1 mm in Honomanū. The persistence of juvenile *hīhīwai* recruitment confirms the possibility for restoring native stream populations if "natural flow" is restored. Stream restoration should be based on the needs of the slowest migrating animal such as *hīhīwai*. A slow-migrating species like *hīhīwai* may be a good indicator of the adequacy of stream flow during stream restoration programs.

Introduction

ʻĪao Stream is on the northeastern portion of the West Maui Mountains and Honomanū Stream is on the north flank of Haleʻakalā volcano (Fig. 1). Both streams are in windward watersheds. These streams are home to a variety of native fauna including *ʻoʻopu* (fish), *ʻōpae* (shrimp), and *hīhīwai* (snail). During increased stream flows, larvae hatch from eggs and are transported to the ocean. After developing in the ocean for several months, they return to freshwater and migrate upstream as post larvae (Lindstrom & Brown, 1994; Nishimoto & Kuamoʻo, 1997; Radtke *et al.*, 2001). In November 1997, after several weeks of stream flow, about 10 *hīhīwai* (*Neritina granosa*) were seen migrating upstream on the bottom of the concrete run in ʻĪao Stream. The *hīhīwai* traveled more than 500 meters from the ocean. Diversions have reduced stream flow in ʻĪao and Honomanū Streams and greatly reduced the migration success of native stream animals like *hīhīwai*. This paper will quantify the various size classes of *hīhīwai* found in each estuary.

Materials and Methods

Study streams

ʻĪao Stream is a second order stream more than 12 km in length. Puʻu Kukui is the highest point at 1764 m elevation and receives more than 900 cm annual rainfall. Part of ʻĪao Stream was modified with concrete channels for flood control since 1981. Two diversions are connected to Maniania Ditch & ʻĪao-Waikapu Ditch (240 m) and Waiheʻe Ditch (80 m). The third diversion to the Kama Ditch (~123 m) is no longer being used.

Honomanū Stream is a second order stream about 14 km long. Headwaters are about 2700 m elevation. Three diversions are connected to the Lower Kula Pipeline (936 m elevation), Koʻolau/Wailoa Ditch (400 m), and Spreckels Ditch (529 m).

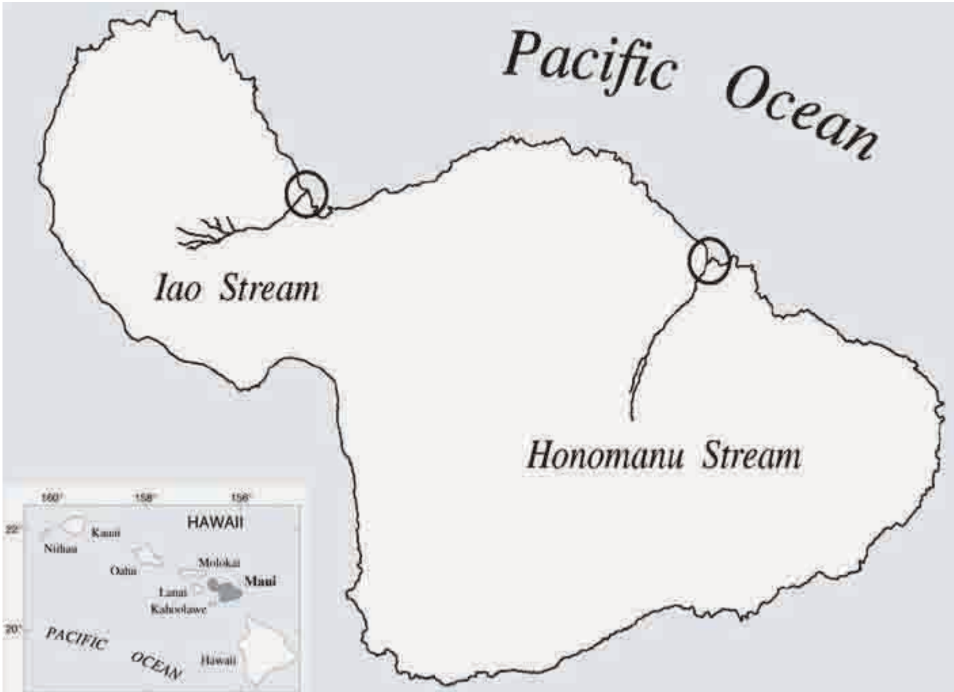

Figure 1. ʻĪao and Honomanū Streams on the island of Maui.

Most of the time, flow is absent in the lower sections of both streams. *Hīhīwai* sampling was initiated to document their presence in the ʻĪao (Fig. 2) and Honomanū (Fig. 3) estuaries. *Hīhīwai* were collected by hand from each stream mouth for up to one hour each month. Rocks were turned over and examined for *hīhīwai* attached to the bottom (Fig. 4). A mask and snorkel was used to collect *hīhīwai* in the deeper Honomanū estuary. A refractometer was used to measure salinity changes in the estuary. Fresh water was present as groundwater seeps at both stream mouths even when surface flow was absent.

Maximum shell lengths of snails were measured with a set of calipers to the nearest 0.1 mm. After *hīhīwai* were identified and measured, they were released in continuous parts of selected streams. Most of the *hīhīwai* collected from ʻĪao Stream were released in ʻĪao State Park (above the ʻĪao Valley intake).

Rainfall information for the Wailuku site came from a rain gauge (WUKH1) located at 55 m elevation while a neighboring Waikamoi rain gauge (#341) at 369 m elevation was used to approximate Honomanū rainfall. The Division of Water Resources Management, Department of Land & Natural Resources, provided monthly rainfall data.

Results

Monthly counts varied from 0 to 576 *hīhīwai* in ʻĪao Stream while Honomanū Stream counts ranged from 67 to 912 (Fig. 5). Monthly counts for both streams increased during June through August. Monthly shell lengths ranged from 1.5 to 6.1 mm for *hīhīwai* from ʻĪao Stream and 2.2 to 9.1 mm in Honomanū Stream (Fig. 6). Due to the intermittent nature of both streams, successful migration was restricted to the estuary. Most *hīhīwai* will not survive beyond the estuary because of dry stream beds and the lack of consistent stream flow.

Figure 2. ʻĪao Stream mouth collection site (groundwater-maintaining freshwater habitat).

Figure 3. Honomanū Stream collection site. *Hīhīwai* moved upstream during large swells and high tides.

Figure 4. *Hīhīwai* recruits (<8 mm shell length) attached to the bottom of a rock.

Size classes were compared annually for ʻĪao and Honomanū Streams (Figs. 7, 8). Most (93%) of the *hīhīwai* measured 5 mm shell length or less and are mostly represented in the first two size classes. Increased survival and limited growth was found in Honomanū Stream.

Total rainfall for January to March was correlated with maximum *hīhīwai* counts in ʻĪao Stream later in the year (R^2 = 0.9289). Total *hīhīwai* counts for July to September were plotted with mean monthly rainfall for January to March (Fig. 9). The increased rainfall at the beginning of each year results in increased larvae transported to the ocean. Juvenile *hīhīwai* return to stream mouths after several months of development and are reflected in the July to September counts for ʻĪao and Honomanū Streams.

Salinity in the ʻĪao estuary ranged from 0–2 ppt up to 14–28 ppt near the ocean during times of large incoming swells and high tides.

Discussion

Amphidromy and Stream Flow

Maciolek (1978) and Ford (1979) discussed the amphidromous life cycle that involves an obligatory period of larval development in the sea. Similar to fish larvae, there appears to be a limited window of opportunity for *hīhīwai* larvae to reach saltwater. Veligers held in fresh water died within six days (Ford, 1979). *Hīhīwai* larvae were found to occur twice a year in drift collections in Palauhulu Stream in Keʻanae (Hau *et al.*, 1992), about 2.3 km east of Honomanū Stream. *Hīhīwai* larvae was present three to five months prior to juvenile recruitment upstream (Unpublished).

The first major stream flow often triggers reproduction and the release of larvae for development in the ocean (Maciolek, 1978; Ford, 1979). During low flow conditions, *hīhīwai* populations are often found in pool and run areas. The first major freshet after a period of low flow often causes a sudden decrease in water temperature and an increase in dissolved oxygen. This scouring flow

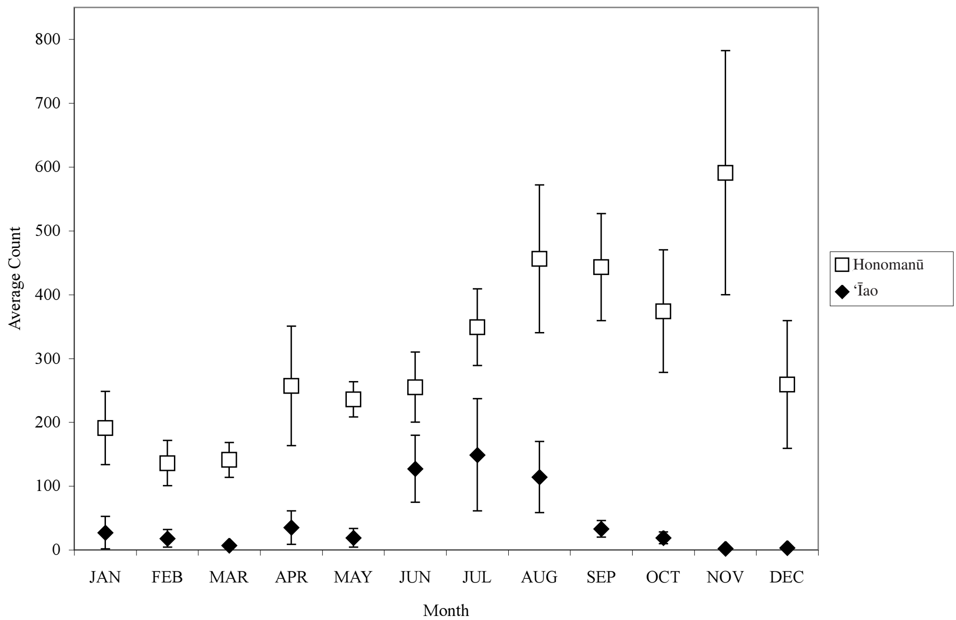

Figure 5. Monthly average counts for *hīhīwai* in ʻĪao (1999–2004) and Honomanū (2001–2004) Streams.

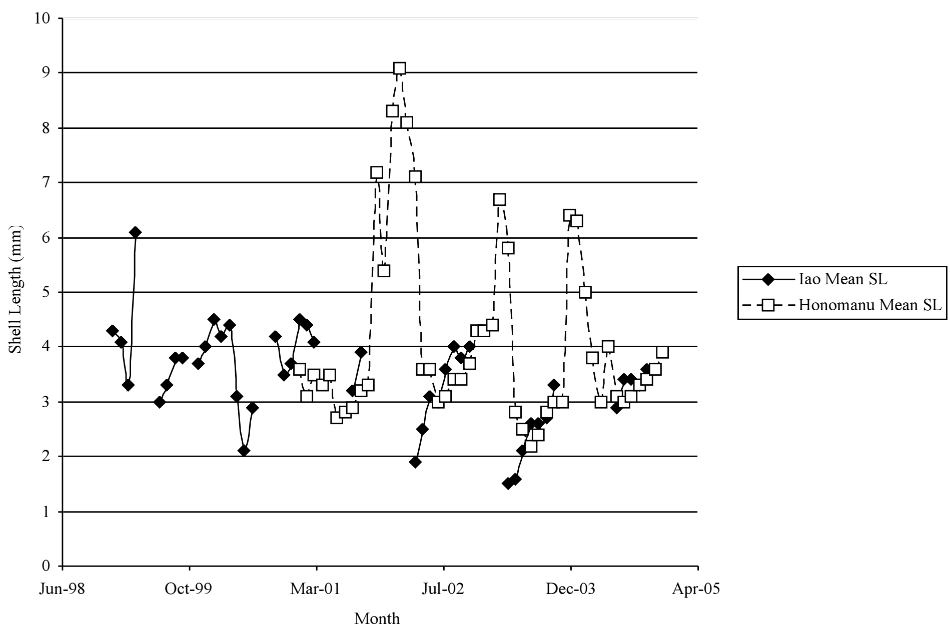

Figure 6. Comparison of mean monthly shell lengths of *hīhīwai* from ʻĪao and Honomanū Streams.

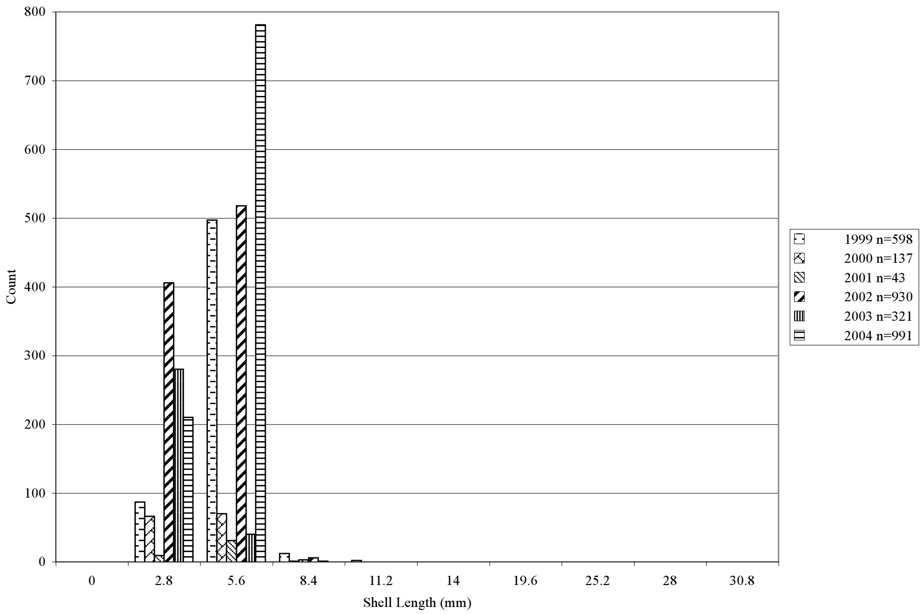

Figure 7. *Hīhīwai* size classes for ʻĪao Stream (1999 to 2004).

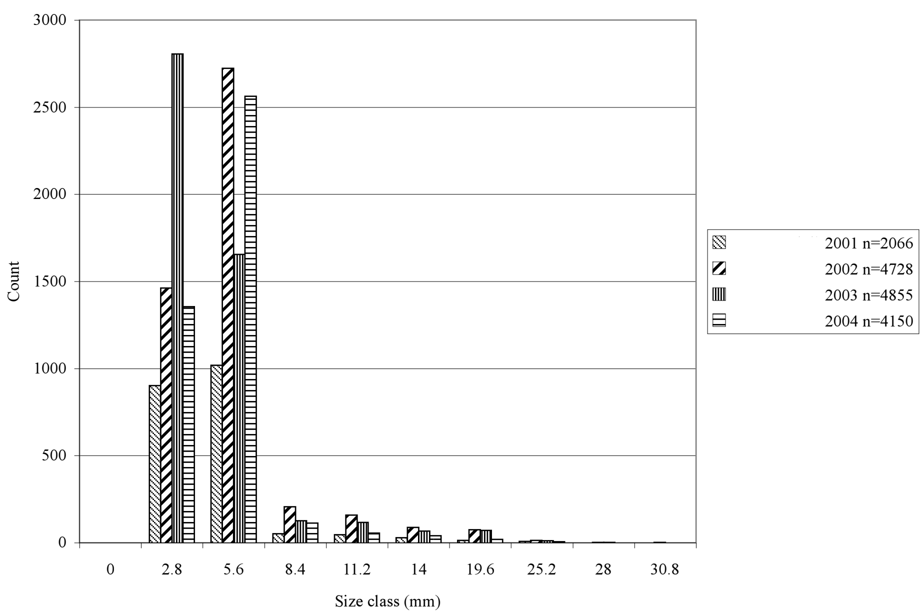

Figure 8. *Hīhīwai* size classes for Honomanū Stream (2001 to 2004).

provides optimum conditions for *hīhīwai* egg cases to be laid on hard substrate and the transport of hatched larvae to the ocean as quickly as possible.

The streams occasionally experience heavy rains and flash flooding which temporarily establishes the *mauka-makai* connection (from the mountain to the ocean) that is vitally important for amphidromous animals migrating between the ocean and fresh water. The connection is maintained intermittently after storms with flows that exceed diversion capacities. Many papers have documented post larval migration of hinana or juvenile fishes (Gobiidae) and ʻ*ōpae* or shrimp (*Atyoida bisulcata*) in response to increased flow (Lindstrom & Brown, 1994; Nishimoto & Kuamoʻo, 1997; Tate, 1997).

Hīhīwai still attempt to migrate into ʻĪao and Honomanū estuaries even though both streams have been diverted for more than 100 years. Water collected by diversions is transported to agricultural lands by a comprehensive system of irrigation ditches and reservoirs (Wilcox, 1996). These diversions may also be carrying *hīhīwai* larvae away from the ocean.

Dewatering can inhibit upstream migration of postlarvae, which are critical to the life cycles of many native species (Brasher, 2003). The removal of water through diversions (Fig. 10) reduces stream discharge, lowers flow velocity, decreases water depth, and increases water temperature. The amount of run, riffle, and pool habitats are reduced for stream organisms like *hīhīwai*. An insect study in Kinihapai Stream (tributary of ʻĪao Stream) suggest that torrential flows are a factor regulating habitat availability for *Telmatogeton torrenticola* and the reduced discharge could significantly reduce the amount of useable habitat for this and other stream fauna (Benbow *et al.*, 1996).

For diverted streams, the requirement for two or more flows are often overlooked and are needed to allow post larvae *hīhīwai* and other stream animals sufficient space and time to migrate upstream. Depending on the duration of the rainy season, these later flows may need to exceed diversion capacities and be able to break open a natural berm built up by large winter swells (>10 m) generated from the North Pacific. Substrate, which naturally moves downstream, blocks the stream from flowing into the ocean. On the other hand, with consistent rainfall, there is sufficient flow to prevent this build up and a continuous stream connection to the ocean is maintained.

The maintenance of median flow with prolonged periods of elevated discharge has been shown to be important for successful reproduction of *ʻoʻopu alamoʻo* (*Lentipes concolor*) (Way *et al.*, 1998). The diversion of Waikolu Stream on the island of Molokaʻi dampened the natural seasonal discharge cycle, exacerbated natural low flow conditions, and increased the likelihood of prolonged periods of extremely low flow. Although *ʻoʻopu alamoʻo* appears to be capable of reproducing throughout the year, the speciesʻ gonadal activity is correlated with monthly periods of high water flow. Fish from Waikolu Stream had a ʻboom or bustʻ reproductive pattern, and the population had reduced or no reproduction when stream flow conditions reached extreme low levels (Way *et al.*, 1998).

Groundwater

At both study sites, springs and groundwater becomes much more important in maintaining the freshwater stream habitat near the shore. *Hīhīwai* juveniles and adults are restricted to fresh waters and not found in brackish water environments (Ford, 1979). During November 1975, the population of neritids in the lower 90-m reach of Waiohue Stream on Maui was subjected to seawater inundation during periods of extremely high surf (Ford, 1979). The influence of large ocean swells and seasonal high tides reaching the estuary can increase salinity and cause *hīhīwai* to migrate upstream, away from brackish water. There could be an unknown mortality of juvenile *hīhīwai* caused by increased salinity. Depending on tides, *hīhīwai* was often the only snail migrating upstream while *hapawai (Neritina vespertina*) and *pipiwai* (*Theodoxus cariosus*) remained in the estuary (Maciolek, 1978; Titcomb, 1978). *Hīhīwai* was periodically absent at the mouth but located more than 50–75 m upstream in the ʻĪao and Honomanū estuaries.

Groundwater emerging from several springs in the Honomanū basalt near the shoreline is estimated to be 1.4 mgd (2.2 cfs) of flow (Gingerich, 1999). The Honomanū estuary is much larger and covers over 200 m in length, over 10 m in width, and a maximum depth of 2 m. This larger area of stable aquatic habitat results in significantly higher *hīhīwai* counts and allows recruits to grow to larger sizes (>20 mm).

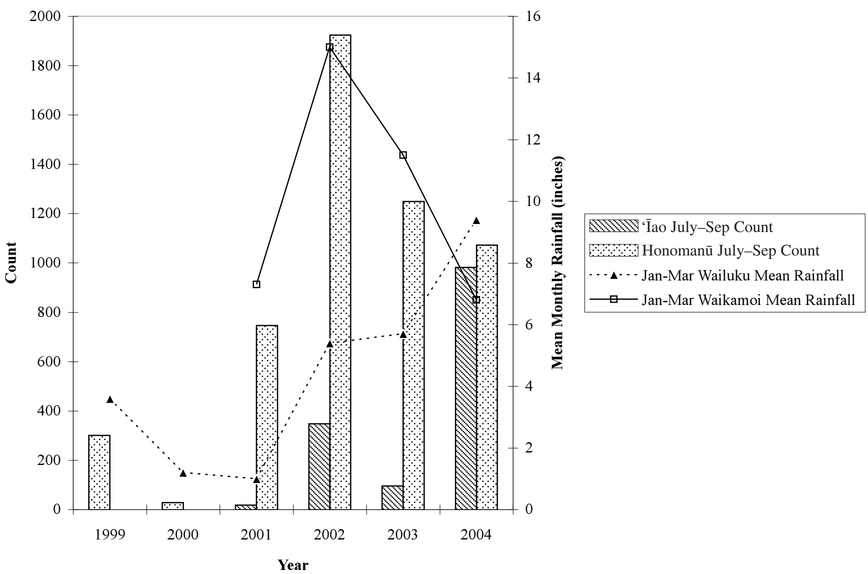

Figure 9. Total *hīhīwai* counts (July to September) in ‘Īao and Honomanū Streams plotted with mean monthly rainfall (January to March).

Flow is reduced in ‘Īao Stream from water tunnels and diversions. Lower ‘Īao Stream often lacks stream flow (Yamamoto & Tagawa, 2000). ‘Īao Stream is subject to prolonged dry periods, which reduces the amount of aquatic habitat to less than 100 m^2, and water depths are often less than 0.3 m. During rainy periods, the ‘Īao estuary can be greater than 100 m in length, more than 20 m in width, and about 0.5 m in depth. The concrete channel and flood control modifications help to shunt stream flow directly to the ocean resulting in shallow runs, riffles, and pools.

From July 1993 to June 2003, ‘Īao Stream discharge averaged 59.9 cfs (38.7 mgd) (U.S. Geological Survey Water-Data ‘Īao Stream Gauge No. 16604500). Based on water declarations, estimated stream flow was reduced from 80% in FY1993 to 96% in FY2003. The Spreckels Ditch, Kama Ditch, and ‘Īao Valley intakes were identified as major diversions. Together with private declarations a total of 129.6 cfs (83 mgd) were reported (Tagomori, 1991). Total water declarations exceed actual stream flow by more than two times.

Upstream Migration

The upstream movement of *hīhīwai* appears to be influenced by several factors. In general, there is limited upstream movement in diverted streams because of intermittent stream flows. Similar to migrating *hinana* and *‘ōpae, hīhīwai* will die after being stranded when flow stops and the streams dry.

Migration lines appear to be an efficient way to move en masse during times of increasing stream flow. The tendency of *hīhīwai* to aggregate and form lines and mucus trails was observed in both ‘Īao and Honomanū Streams. After a passing storm on 13 April 2004, I encountered snails starting to form lines (up to 7.5 cm) at the Honomanū Stream mouth. I also found several migrating *hīhīwai* carrying smaller ones. Small one-mm *hīhīwai* were found on larger ones with shells between 2 to 5 mm. This “hitchhiking” behavior was also reported for *Cochliopina tryoniana* migrating with *Neritina latissima* in the Rio Claro in Costa Rica (Schneider & Lyons, 1993); smaller *C. tryoniana* sometimes attached to larger *N. latissima*.

Longer migration lines appear in runs and riffles further upstream. On 8 May 2004, after heavy

Figure 10. `Īao Stream Diversion (below USGS Stream Gauge No. 16604500). Most stream flow is diverted into irrigation ditches.

rains, I found *hīhīwai* traveling along trails up to 60 cm long on the rocky streambed that is normally dry below the Honomanū highway bridge. A total of 315 *hīhīwai* measured from 2.3–5.9 mm and averaged 3.4 mm shell length (S.E. = 0.03). The mucus trail appears to reduce friction and "grease" the way for other *hīhīwai* to follow. These trails seem to reduce time spent in exploring other directions. As flow decreases in certain habitat conditions, some *hīhīwai* appear to independently stop migrating.

Dry streambeds, concrete channels, or multiple diversions impede and prevent upstream migration of *hīhīwai* beyond the estuary. During July 1991, Hodges (1992) found *hīhīwai* in wet gravel under large cobbles and boulders in the middle of the dry intermittent Honomanū streambed. On one occasion, he observed tens of thousands of young *hīhīwai* (up to 10 mm shell length) in a migrating column over a meter and downstream for 500 m. It appears this observation was during an exceptional rainy period with continuous stream flow that allowed *hīhīwai* to migrate upstream. When stream flow stops, similar to drought conditions, *hīhīwai* are forced initially into standing pools that eventually dries leaving moist areas under boulders and wet gravel.

In Pua‘alu‘u Stream, snails did not occur above 185 m in windward East Maui (Ford, 1979). The diversion at 390 m significantly restricted *hīhīwai* to a short reach immediately above the head of the estuary (Ford, 1979). This same condition exists for ‘Īao and Honomanū Streams. On Maui, *hīhīwai* was recorded at 140 m in continuous ‘Alelele Stream (Division of Aquatic Resources Surveys September 1994).

The majority of migrating *hīhīwai* found in ‘Īao and Honomanū Streams are less than five mm shell length. When present, *hīhīwai* from ‘Īao Stream appears to be represented by two size classes with few growing larger than 5 mm. The ‘Īao estuary has been impacted by droughts at various times of the year. Honomanū Stream appears to be a better nursery with significantly more *hīhīwai* growing to larger size classes. The increased groundwater helps to insure a stable freshwater environment.

Water recharge estimates in the ʻĪao watershed have continued to decrease with the loss of agriculture (Meyer & Presley, 2001). More water recharge is necessary to sustain healthy groundwater flow. Water diversion projects have had enormous impacts on streams after the degrading of Hawaiian forests and the introduction of grazing animals. Perennial streams became intermittent and springs dried up (Wilcox, 1996). In the Wailuku watershed, increasing development and changes in land use activities including urbanization have increased impervious surfaces and drainage runoff.

ʻĪao and Honomanū Streams represent many other streams in Hawaiʻi that have been diverted. Restricted stream flows have resulted in smaller estuaries and prevented *hīhīwai* from migrating to higher elevations. Unless the animals reach adequate freshwater stream habitats, they are unable to grow into healthy reproducing populations. In Honomanū and ʻĪao Streams, the diversion of over 90% of the stream flow results in intermittent stream conditions, which limit the average growth of *hīhīwai* to less than 10 mm. The recruitment of *hīhīwai* and other amphidromous species requires consistent stream flows.

Groundwater plays a very important role in maintaining freshwater stream habitats near the ocean. Similar to *Neritina punctulata* in Puerto Rico which requires estuary connections for larval development (Pyron & Covich, 2003), the connections between the estuary and upstream reaches need to be maintained to avoid local extinctions of *hīhīwai*. The persistence of *hīhīwai* recruitment confirms the possibility for restoring native stream populations if "natural flow" is restored. Stream restoration should be based on the needs of the slowest migrating animal such as *hīhīwai*. A slow-migrating species like *hīhīwai* may be a good indicator of the adequacy of stream flow during stream restoration programs. Future attention should be focused on the flow requirements for sustaining reproducing populations of *hīhīwai* and other amphidromous species and not just on their mere presence. Native stream animals need successful spawning, larval development, and recruitment for each island (Radtke *et al.*, 2001).

Acknowledgments

Many thanks to Isabella A. Abbott, Darrell G.K. Kuamoʻo, Robert T. Nishimoto, Glenn R. Higashi, Wesley Hau, Lori L. Ohta, Norman Yoshioka, Matt Wong, Stephen B. Gingerich, Richard Fontaine, J. Michael Fitzsimons, David Higa, Neal D. Fujii, and Alison Sherwood who provided assistance, support, and kind words of encouragement. Special thanks to Ivor D. Williams & Thierry M. Work who reviewed my raw data and offered helpful comments. Thanks also to Luis E. Menoyo (USGS) for getting copies of their excellent maps showing my study sites. I especially wish to recognize two *kupuna*, Sarah Kaʻaaumo and Luther Kanae, Sr., who shared their stories and observations from earlier times before their passing.

Literature cited

Benbow, **M**.**E**., **A**. **J Burky & C**.**M Way**. 1996. Habitat specificity of the endemic Hawaiian midge, *Telmatogeton torrenticola* (Telmatogetoninae). *Bulletin of the North American Benthological Society* **13**: 136–137.

Brasher, **A**.**M**. 2003. Impacts of human disturbances on biotic communities in Hawaiian streams. *BioScience* **53**: 1052–1060.

Ford, **J**.**I**. 1979. Biology of a Hawaiian fluvial gastropod *Neritina granosa* Sowerby (Prosobranchia: Neritidae). M.S. Thesis, University of Hawaii, Honolulu, Hawaii: 94 p.

Gingerich, **S**.**B**. 1999. Ground-water occurrence and contribution to streamflow, Northeast Maui, Hawaii. *United States Geological Survey Water-Resources Investigations Report* 99-4090. 69p.

Hau, **S**., **C**.**M**. **Way & A**.**J**. **Burky**. **1992**. *Life cycle of the endemic limpet* Neritina granosa *(Sowerby), in Palauhulu Stream, Maui. 43rd Annual Meeting of American Institute of Biological Sciences*. Ecological Society of America, 9–13 August, Honolulu, Hawaii (abstract).

Hodges, **M.H.-D**. 1992. Population biology and genetics of the endemic Hawaiian stream gastropod *Neritina granosa* (Prosobranchia: Neritidae): implications for conservation. Honors Thesis, Wildlife Biology Program University of Montana, Missoula, Montana, July 1992.

Lindstrom, **D.P. & C.L. Brown**. 1994. Early development and biology of the amphidromous Hawaiian stream goby *Lentipes concolor*. *Proceedings of the Fourth Indo-Pacific Fish Conference, Systematics and Evolution of Indo-Pacific Fishes*, 28 November–4 December, 1993, Bangkok, Thailand, p. 397–409.

Maciolek, **J.A**. 1978. Shell character and habitat of nonmarine Hawaiian neritid snails. *Micronesica* **14**: 209–214.

Meyer, **W. & T.K. Presley**. 2001. The response of the ʻĪao Aquifer to ground-water development, rainfall, and land-use practices between 1940 and 1998, Island of Maui, Hawaii: *United States Geological Survey Water-Resources Investigations Report* **00-4223**, 60 p.

Nishimoto, **R.T. & D.G.K. Kuamoʻo**. 1997. Recruitment of goby postlarvae into Hakalau stream, Hawaii Island. *Micronesica* **30**:41–49.

Pyron, **M. & A.P. Covich**. 2003. Migration patterns, densities, and growth of *Neritina punctulata* snails in Rio Espiritu Santo and Rio Mameyes, Northeastern Puerto Rico, *Caribbean Journal of Science* **39**: 338–347.

Radtke, **R.L.**, **R.A. Kinzie III & D.J. Shafer**. 2001. Temporal and spatial variation in length of larval life and size at settlement of the Hawaiian amphidromous goby *Lentipes concolor*. *Journal of Fish Biology* **59**: 928–938.

Schneider, **D.W. & J. Lyons**. 1993. Dynamics of upstream migration in two species of tropical freshwater snails. *Journal of the North American Benthological Society* **12**: 3–16.

Tagomori, **M**. 1991. Division of Water Resource Management. [Letter to Mr. Henry Sakuda, Administrator, Division of Aquatic Resources. January 29, 1991.]

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

Titcomb, **M**. 1978. Native use of marine invertebrates in old Hawaii. *Pacific Science* **32**: 325–375.

Way, **C.M.**, **A.J. Burky**, **J.M. Harding**, **S. Hau & W.K.L.C. Puleloa**. 1998. Reproductive biology of the endemic goby, *Lentipes concolor*, from Makamakaʻole Stream, Maui and Waikolu Stream, Molokaʻi. *Environmental Biology of Fishes* **51**: 53–65.

Wilcox, **C**. 1996. *Sugar water: Hawaii's plantation ditches*. University of Hawaiʻi Press, Honolulu, Hawaii. 191 p.

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