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Recruitment of Goby Postlarvae into Hakalau Stream, Hawai'i Island[1]

ROBERT T. NISHIMOTO AND DARRELL G.K. KUAMO'O

Division of Aquatic Resources
Department of Land & Natural Resources
P.O. Box 936
Hilo, Hawai'i 96721-0936

Abstract—Native Hawaiian stream fishes are diadromous and re-enter streams as either clear, opaque or pigmented postlarvae after their oceanic larval phase. Recruiting postlarvae were sampled hourly over a 24-hour period for 19 consecutive months (December 1993 to June 1995) with a passive trap set at the stream mouth. Postlarvae of all native stream fish species were collected and the mean fish size at entry into Hakalau stream did not vary over the sample period. There were two size classes: *hinana, Sicyopterus stimpsoni,* 23.61 mm SL and *ahina, Awaous guamensis,* 15.95 mm SL, *Lentipes concolor,* 14.43 mm SL, *Stenogobius hawaiiensis,* 14.09 mm SL, *Eleotris sandwicensis,* 13.46 mm SL. *L. concolor* and *S. stimpsoni* recruited most heavily immediately after sunrise while *S. hawaiiensis* and *E. sandwicensis* were most common after dark and during the rising tide. *A. guamensis* occurred throughout the 24-hour period but with recruitment peaks around the high tides. Postlarval recruitment into streams was greatest after periods of heavy rainfall and subsequent freshets.

Introduction

In comparison to US mainland streams, Hawaiian freshwater ecosystems are quite small and less obvious than their marine counterpart. Except for 5 naturally occurring small lakes, freshwater habitats consist of 376 small, precipitous mountain streams (Hawaii Stream Assessment 1990) that originate in rainforest watersheds, flow directly downslope, and enter the ocean via a terminal waterfall or a sandbar berm fronting the estuary. The flow of water in streams depends upon the islands' receiving persistent orographic rainfall associated with trade winds and seasonal storms. Consequently, perennial streams are limited to the windward side of the main Hawaiian Islands (Fig. 1). These streams are characterized by having flashy flows dependent on rainfall patterns. The onset of a freshet flow is as abrupt as its return to normal flow.

The fish fauna occupying Hawaiian streams have low species diversity and high degree of endemism, characteristic of island ecosystems (Fitzsimons &

[1]ASIH symposium on freshwater gobies.

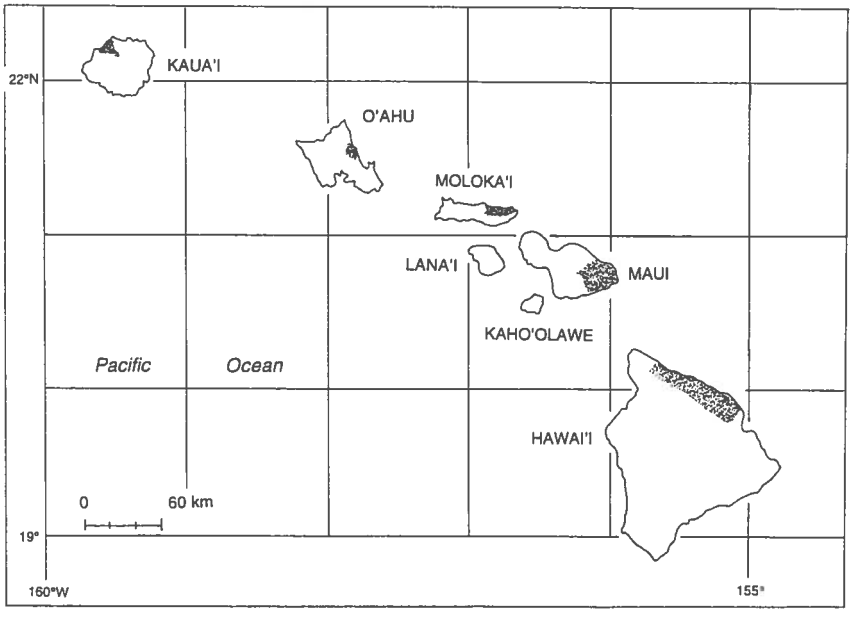

Figure 1. Main Hawaiian Islands. Stippled areas represent the highest concentrations of perennial streams

Nishimoto 1991). The entire compliment of Hawaiian stream fishes consists of only five species, four gobies and one eleotrid (Table 1). In all streams, adults have a distinct instream distribution (Nishimoto & Kuamo'o 1991). *Eleotris sandwicensis* and *Stenogobius hawaiiensis* are common near sea level and are usually absent immediately upstream from the smallest waterfall with a precipitous gradient. The remaining three species, *Awaous guamensis, Sicyopterus stimpsoni* and *Lentipes concolor* occur in this order and extend far into the rainforest to elevations as high as 3,000 ft. (*L. concolor*). All Hawaiian freshwater fishes have a diadromous life cycle (Tate 1995). Juvenile and adult stages are spent in streams, where courtship and egg-laying occurs. Attached eggs hatch within 24 to 70 hours (Kido & Heacock 1991, Lindstrom & Brown 1994), and the larvae are swept out to sea where they undergo development. After several months, these fishes recruit

Table 1. Native stream fishes inhabiting Hawaiian streams.

Family	Species	Hawaiian name
Gobiidae	*Awaous guamensis*	*'o'opu nākea*
Gobiidae	*Lentipes concolor*	*'o'opu hi'ukole* (m)
		'o'opu alamo'o (f)
Gobiidae	*Sicyopterus stimpsoni*	*'o'opu nōpili*
Gobiidae	*Stenogobius hawaiiensis*	*'o'opu naniha*
Eleotridae	*Eleotris sandwicensis*	*'o'opu 'ōkuhe*
		'o'opu 'akupa

back into streams, usually *en masse,* as postlarvae. The marine phase of *S. hawaiiensis* lasts 119–150 days and that of *A. guamensis* lasts 151–164 days (Radtke et al. 1988). A subsistence fishery for goby post larvae, collectively known by the native Hawaiians, as *hinana* or *ahina,* depending on size, was a favorite seasonal activity, especially on the island of Kaua'i. This practice is now illegal.

This report describes patterns of recruitment for the five species of native Hawaiian stream gobies into a pristine perennial stream along the Hamakua Coast of the island of Hawai'i.

Study Site

The study area was located at the mouth of Hakalau Stream, located about 15 miles north of Hilo just off of Highway 11. This stream originates in the rain forest on the northeastern flank of Mauna Kea and flows eastward for about 17 miles through native forest and agricultural lands and ends with an estuary where the ocean meets the stream. Because of the interactions between the tidal periods and the constant stream flow, a sand berm usually forms at the mouth of the stream. When the sand berm is present, the estuary's water level is higher than the ocean during low tides. A passive larval trap, designed and constructed by the second author (Kuamo'o, unpubl.) was positioned along the stream edge at the exit of the estuary into the ocean. Recruiting goby postlarvae prefer the stream bank when recruiting inland and more often on the side with the fastest outflow current (C. Akuna, personal communication).

Sampling Method

Recruiting goby postlarvae were sampled hourly over a 24-hour period for nineteen consecutive months from December 1993 to June 1995. Monthly sampling was scheduled on the third quarter lunar phase, the period when *hinana/ahina* recruitment is heaviest (C. Akuna, personal communication, and 1996 Ancient Hawaiian Moon Calendar Related to Fishing and Farming). Sampling started at about sunrise and ended the following morning.

Fishes in each hourly sample were euthanized immediately in ice water, identified to species, and measured with a dissection microscope and calipers. The specimens were then preserved in 5% buffered formalin. The samples are catalogued at the Museum of Natural Sciences, Louisiana State University.

Water depth at the trap entrance was measured with a ruler, and the tidal heights were extrapolated from the tide chart published by a local fishing tackle shop. Since there are no stream gauges on Hakalau Stream, flow was proximated from daily rainfall data printed in the local newspaper.

Species Identification

The identification of the five freshwater gobies were based on the structure of the pelvic fin, occurrence of notches in the upper lips, and arrangement of

melanophores in larvae and postlarvae (Tate et al. 1992, present study) (Fig. 2). Because freshly collected specimens were used to identify the species during the course of the sampling period, the distinct ventral melanophore pattern for each species of postlarva was the most useful characteristic. For *E. sandwicensis,* a single mid-ventral row of melanophore extends from the isthmus through the pelvic fin base to the anal opening, and then continues posteriorly as two rows on each side of the anal fin. *Stenogobius hawaiiensis* has a single mid-ventral row of melanophores that extend from the isthmus just past the attachment of the pelvic disk and then continues posteriorly as a double row across the abdomen and on either side of the anal fin. *Awaous guamensis* has a single mid-ventral row of melanophores from the isthmus to the middle of the pelvic disc attachment and then continues posteriorly as a double row. It also has a c-shaped "beard" formed by pigment spots below its chin, which helps to distinguish this species from *S. hawaiiensis. Sicyopterus stimpsoni* is the largest of the postlarvae to enter the streams; these fish have a single mid-ventral row of melanophores reaching from the attachment of the pelvic disk to the bottom edge of the disk and two rows originating at the attachment and extending just past the edge of the disk. Finally, *Lentipes concolor* has a conspicuous spot on the tip of its chin formed by a single large melanophore. These small fish also have a single mid-ventral row of melanophores that extends from the base of the pectoral fins posteriorly to the end of the pelvic disk.

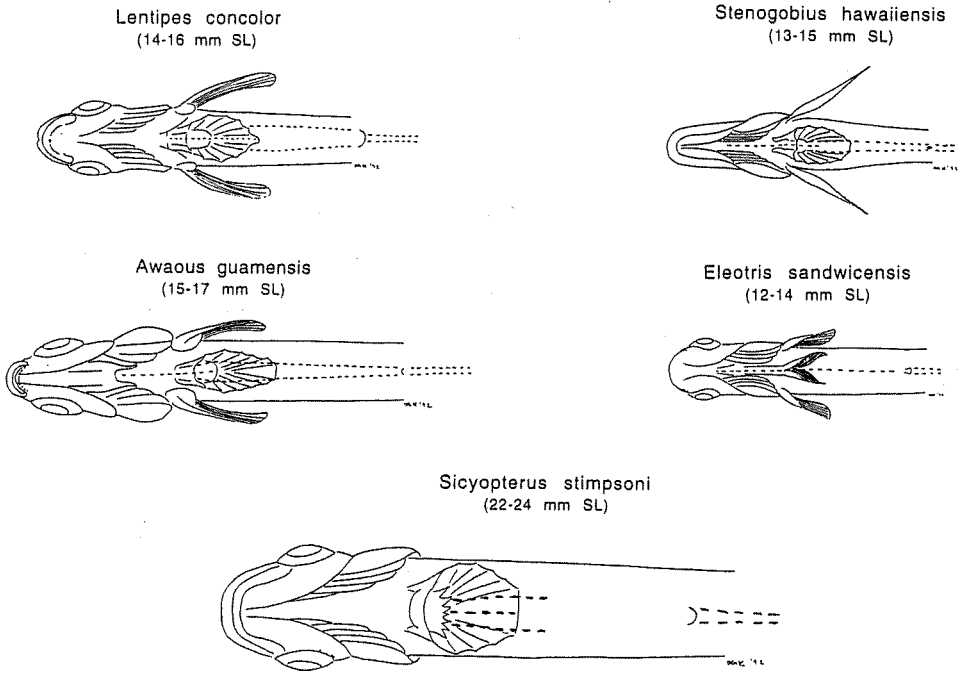

Figure 2. Antero-lateral view of newly recruited stream goby postlarvae. Dashes represent melanophore patterns.

Newly recruited goby postlarvae are essentially clear-bodied (except for the large eyes, internal organs and blood sinuses) when first entering the estuary. The tail is essentially forked but becomes progressively truncated and the body completely pigmented, as it metamorphoses from being part of the plankton community to becoming essentially a bottom dweller in its adult habitat, a freshwater stream. Other morphological changes, such as the enlargement of the head in *S. stimpsoni,* will be described in detail by other authors in this volume.

Results and Discussion

The postlarvae of all five species were present (Table 2). Except for *S. hawaiiensis,* all of the other species were collected in at least 15 of the 18 monthly samples. *Stenogobius* was the least common numerically and collected in only 11 of the 18 monthly samples.

The migration of the native goby postlarvae into Hakalau Stream seems to be size dependent (Fig. 3). The indigenous people of Hawai'i recognized two distinct size groups and differentiated them as: *hinana* which is *S. stimpsoni* and *ahina* which comprises the other four species. It was thought that the *ahina* were the runts and that the season for collecting postlarvae was over (C. Akuna, personal communication) when these sized larvae were collected in their nets.

The *hinana, S. stimpsoni,* was significantly larger than the other species (Table 2, Fig. 3). The four species of *ahina* were similar in size but *A. guamensis* was consistently the largest and *E. sandwicensis* was always the smallest.

The time of recruitment varied by species. *Lentipes concolor* and *S. stimpsoni* recruited heaviest immediately after sunrise (Fig. 4), *A. guamensis* continuing throughout the day and night (Fig. 5) and *S. hawaiiensis* and *E. sandwicensis* almost always recruited into the stream at night (Fig. 6). Upon entering the estuary, they rapidly change from opaque to pigmented and with a corresponding decrease in length. There may be as much as a 0.5 mm decrease in length between the clear and pigmented individuals. The hourly samples frequently had individuals from the same species ranging from clear to opaque to pigmented.

The three upper-elevation gobies, *L. concolor, S. stimpsoni* and *A. guamensis,* actively seek fresh water once at the stream mouth. When the *Lentipes* catch was separated by pigmentation, the pigmented animals showed up earliest followed by the opaque individuals during the afternoon, and the clear specimens during the

Table 2. Recruiting native stream Goby postlarvae trap-collected monthly at the entrance to Hakalau Stream, Hawai'i Island, December 1993 to June 1995.

Species	Total number	Total frequency	Mean size (SL, mm)	Standard deviation
Lentipes concolor	1,645	43.6%	14.43	0.39
Awaous guamensis	1,167	30.9%	15.95	0.34
Eleotris sandwicensis	783	20.8%	13.46	0.38
Sicyopterus stimpsoni	117	3.1%	23.61	0.63
Stenogobius hawaiiensis	62	1.6%	14.09	0.52

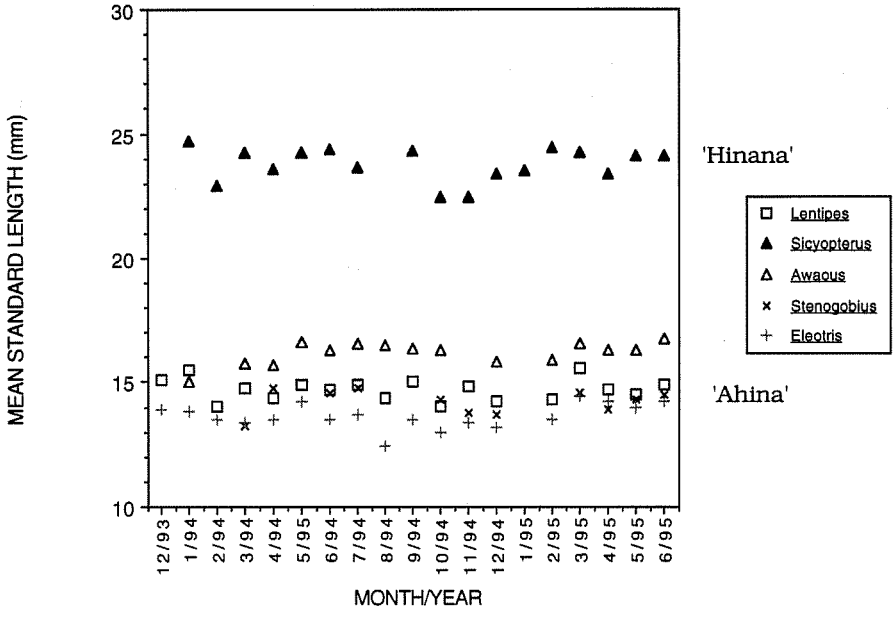

Figure 3. Mean standard lengths of goby postlarvae trap-collected at Hakalau stream, December 1993 to June 1995.

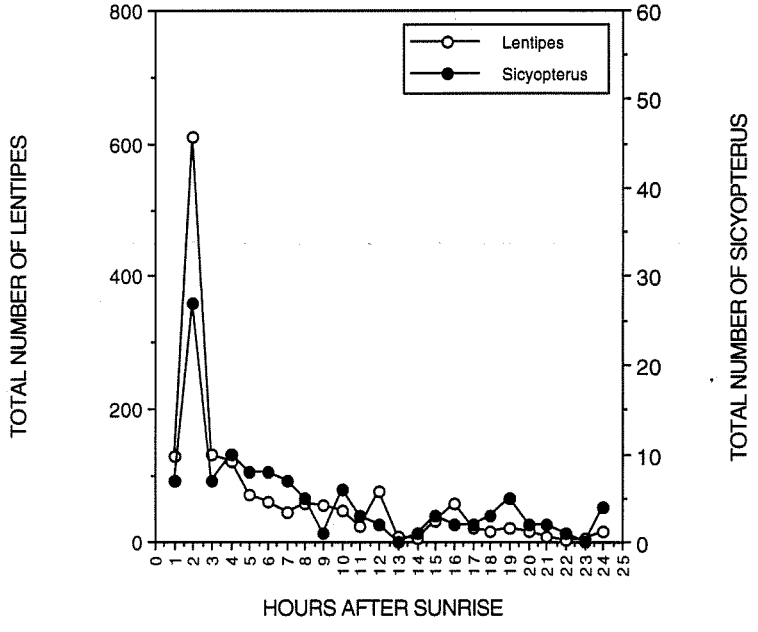

Figure 4. Diel occurrence of *Lentipes* and *Sicyopterus* postlarvae trap-collected at Hakalau stream, December 1993 to June 1995.

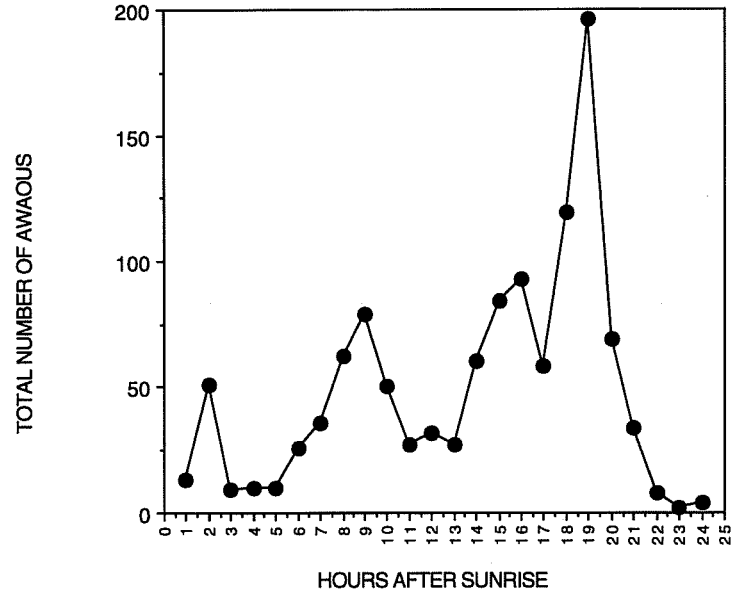

Figure 5. Diel occurrence of *Awaous* postlarvae trap-collected at Hakalau stream, December 1993 to June 1995.

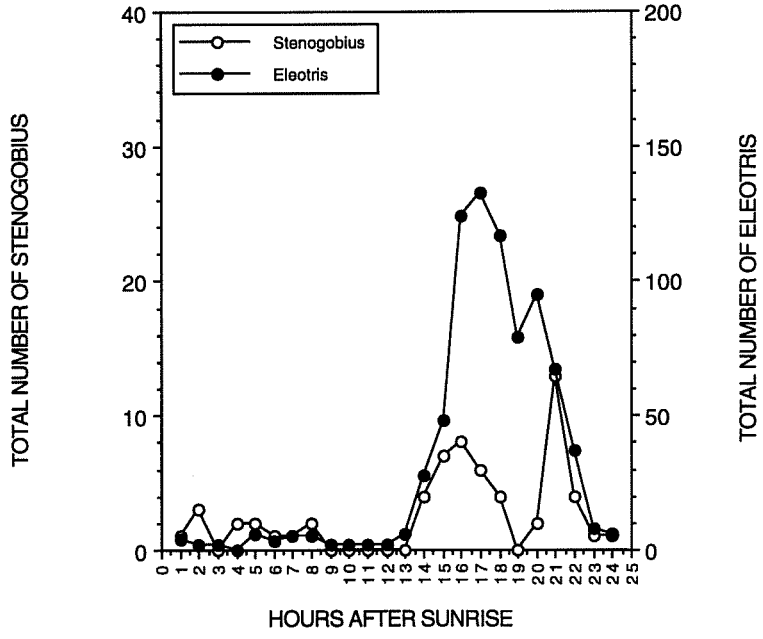

Figure 6. Diel occurrence of *Stenogobius* and *Eleotris* postlarvae trap-collected at Hakalau stream, December 1993 to June 1995.

highest diel tide. The pigmented and opaque individuals were the earlier settlers to the bottom and were at an advanced developmental stage and first to enter the estuary. The bulk were the clear recruits, which were probably less developed and transported into the estuary with the highest diel tide. The other two species of gobies, *S. stimpsoni* and *A. guamensis,* show a similar trend.

The two lower elevation species, *S. hawaiiensis* and *E. sandwicensis,* are the weakest swimmers. Unlike the other gobies, recruitment for these two species into the estuary only occurs during the nocturnal high tide or during high storm surf conditions, regardless of their developmental stage.

Goby recruitment into streams occurs year-round but is heaviest immediately after freshet flows and associated with periods of heavy rainfall (Fig. 7). Natural stream flows are a strong attraction to the inland migration of native Hawaiian stream fishes. Even intermittent streams on the leeward side of the island, which flow only after major storms, will immediately attract recruiting goby post larvae. The movement of these young fishes from the ocean into streams is the quintessential link in completing the amphidromous life cycles for fishes and also for the major species of macroinvertebrates in Hawaiian streams. The migratory events described here for fishes from Hakalau stream are mirrored in streams throughout the high islands of the archipelago. This and similar studies underscore the singular significance of the connection between stream flow and amphidromy as the key to resource sustainability in freshwater ecosystems in the Hawaiian Islands.

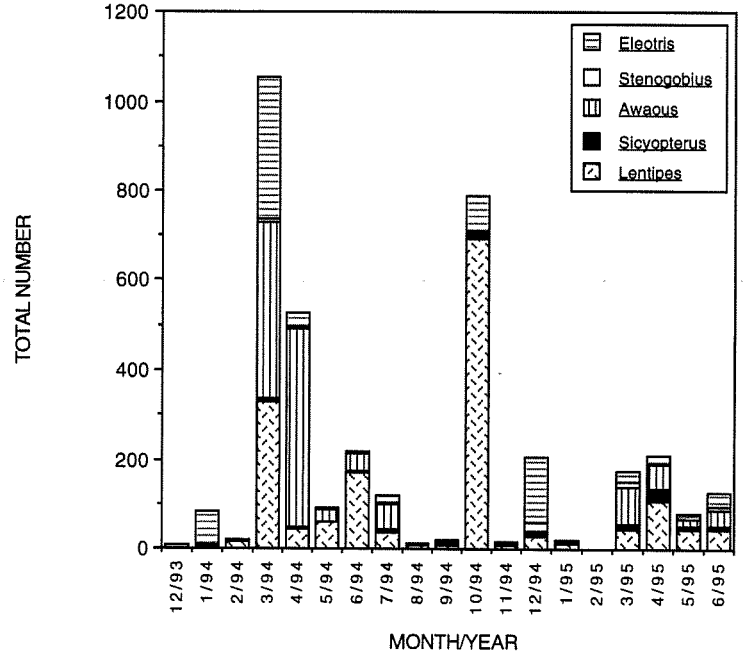

Figure 7. Monthly distribution of goby postlarvae by species trap-collected at Hakalau stream, December 1993 to June 1995.

Acknowledgment

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