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A note on cascade climbing of migrating goby and shrimp postlarvae in two Maui streams

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Abstract—In this study, we documented cascade climbing rates of 133 and 230 postlarvae of *Lentipes concolor* (O‘opu alamo‘o) and *Atyoida bisulcata* (Opae kahaole), respectively, from two streams on the island of Maui, Hawaii. Climbing measurements and observations were made of postlarvae at the water-substrate interface in cascade habitats of constricted water flow. Both species were observed to move in short bursts of forward progression within or above the pulsing water-substrate interface. Goby postlarval climbing rates ranged from 0.04 – 1.50 cm s⁻¹ and were slower than shrimp rates which ranged from 0.30 – 3.06 cm s⁻¹. The high variability is attributed to the bursting movement behaviors exhibited by both species. During one night of monitoring, a mean of 9.4 shrimp min⁻¹ were observed to climb along ~ 0.4 m stretch of the water-substrate interface, resulting in conservative recruitment estimate of 564 shrimp h⁻¹. Potential applications to stream management are discussed.

Introduction

The Hawaiian Islands are faced with large scale stream degradation where most streams are either partially or fully diverted, dammed, or channelized. The

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native, amphidromous fauna are particularly sensitive to stream degradation (Timbol & Maciolek 1978). Amphidromy, a form of diadromy (see McDowall 1996), involves a life cycle with breeding adults in the upper stream reaches. Eggs are laid on the benthic substrate and, upon hatching, larvae are swept to the ocean to spend from three months to over a year (Radtke et al. 1988) developing before recruitment, as postlarvae (*hinana*), back into the freshwater streams. Stream degradation can: (1) destroy adult breeding habitat (e.g., channelization), (2) prevent complete larval drift to the ocean (e.g., diversions), and (3) obstruct postlarval recruitment back into breeding stream habitat (e.g., weirs and dams).

There are five amphidromous fish species native to Hawaii with four endemic (Gobiidae: *Lentipes concolor*, *Sicyopterus stimpsoni*, *Stenogobius hawaiiensis*; Eleotridae: *Eleotris sandwicensis*) and one indigenous (Gobiidae: *Awaous guamensis*) to the Indo-Pacific. In addition, the native stream shrimp (*Atyoida bisulcata*), prawn (*Macrobrachium grandimanus*), and snail (*Neritina granosa*), as well as an introduced prawn (*Macrobrachium lar*), are amphidromous. As postlarvae, these species migrate back into the streams from the ocean and may encounter cascades and waterfalls that inhibit upstream movement of most non-amphidromous species. The larger cascades and waterfalls inhibit upstream progression of *E. sandwicensis* and *S. hawaiiensis*. Also, in most Hawaiian streams there are areas of constricted, high velocity flows between rocks and boulders that can make up portions of cascades and the lips of waterfalls. These habitats can impede upstream swimming, making it necessary for postlarvae to climb out of the water near the water-substrate interface, through a shallow (a few mm) splashing fringe layer of water, until reaching lower velocity areas above the flow constriction. The goby species that successfully climb these habitats as postlarvae (i.e., *A. guamensis*, *L. concolor* and *S. stimpsoni*) are thought to use their fused pelvic fins (forming a ventral sucker) to hold, or "suction" to vertical or high gradient substrates (e.g., under the lips of waterfalls), and their pectoral fins to provide the necessary forward thrust. Migrating shrimp and prawn postlarvae are thought to use their tarsal claws for both functions.

As part of another study addressing the seasonal and diurnal recruitment patterns of the amphidromous species, we had the opportunity to make observations and quantitative measurements of goby (*L. concolor*) and shrimp (*A. bisulcata*) postlarvae climbing in several areas of constricted, high velocity flows in Makamaka'ole Stream and Hanaw'i Stream during several months of 1999, 2000 and 2001. The objectives of this paper are to introduce these observations and measured climbing rates, information which has not been previously published, and that provides important information for developing additional hypotheses and experimental protocols associated with understanding migration and climbing rates of the native Hawaiian amphidromous fauna. In addition, data on postlarval migration and climbing can be important in assessing appropriate minimum stream flow requirements necessary for mitigation and restoration plans.

Methods

Makamaka'ole Stream is part of the West Maui Mountains (Mauna Kahalawai) and located on the northern windward shore of Maui. The watershed drains an area of 5.69 km², and is one of the few remaining free flowing streams of the island, except for a few negligible taro diversions. Land use in the area is mainly cattle ranching and is increasing in suburban housing development. Data were collected and observations made approximately 150 m upstream of the mouth at two small cascades. Hanaw'i Stream is a larger stream located along the northern coast of East Maui (Mauna Haleakala) draining an area of 14.36 km². Stream flow is disrupted by several diversions upstream of a large freshwater spring. All data were collected and observations made below this spring (~ 80 m upstream of the ocean) at two small cascades.

Climbing data were collected on a total of 133 *L. concolor* postlarvae between 0915 and 1530 on 3 May 2000 in Makamaka'ole Stream (N = 99) and 28 May 2001 in Hanaw'i Stream (N = 34). This time period covers *L. concolor* and *S. stimpsoni* postlarval peak migration from about 1100 – 1500 (Nishimoto & Kuamo'o 1997; M.E. Benbow, unpublished data). Because the shrimp are nocturnal, peak migration is usually continuous after dusk but peaks from 2100 to 0300 (M.E. Benbow, unpublished data). Shrimp data were only collected in Makamaka'ole Stream from 2130 – 0254 on 29 July 1999 (N = 150) and 23 June 2000 (N = 80). In addition to climbing data, the total number of shrimp passing a marked spot on the substrate for two 10 min periods was recorded on 23 June 2000.

Observations and climbing rate measurements for fish and shrimp postlarvae were made in areas directly adjacent to high velocity water in shallow splash zones at the water-substrate interface. Climbing distances (from 5 – 20 cm) were measured and marked onto flat rock surfaces at the water-substrate interface using a centimeter ruler. Climbing rates were made by timing an individual over a measured distance. Distances for individuals that were swept from the substrate during erratic pulses of water were estimated to the nearest 0.5 cm. A stopwatch was used to record climbing speed to the nearest 0.1 s. All data were converted to rates expressed as cm s⁻¹.

In order to synthesize data, nonparametric Wilcoxon/Kruskal-Wallis Rank Sums tests were run between dates for each species. Testing for the effect of sampling date (and stream for the goby data) on climbing rates would allow us to pool data between dates or streams (i.e., for the goby postlarvae) if there was not a significant difference.

Results and Discussion

The Wilcoxon/Kruskal-Wallis Rank Sums tests found no significant differences in postlarval climbing rate between streams (goby: $\chi^2 = 2.586$, d.f. = 1, p = 0.108) or dates (shrimp: $\chi^2 = 2.617$, d.f. = 1, p = 0.106). Therefore, we pooled all the respective goby (N = 133) or shrimp (N = 230) data over all dates of study. Mean (SD) goby and shrimp climbing was 0.26 (0.26) and 1.13 (0.51) cm s⁻¹,

respectively (Figure 1). There was high variability in climbing rates with ranges from $1.50 - 0.04 \text{ cm s}^{-1}$ and $3.06 - 0.30 \text{ cm s}^{-1}$ for the goby and shrimp, respectively. The large variability may be because the postlarvae climb in a stop-and-go fashion within the erratic splash zones of high velocity waters. This movement pattern probably reduces the probability of being swept from the substrate while climbing. Observer influence was minimal. Qualitative observations of the gobies were made from several meters away that agreed with observations made during measurements. This was further supported by infrared video of climbing postlarval shrimp taken $\sim 2 \text{ m}$ away without lights.

Flow in climbing habitats is not constant, and is characterized by fluctuating depth and velocity in unpredictable pulses. The slightest change in these conditions probably alters the flow microhabitat for the postlarvae. These flow fluctuations occur at a scale that may be critical at body lengths between of 17.0 and 5.0 mm for the goby and shrimp postlarvae, respectively. Additional observations found that some individual postlarvae were swept off substrates by large and quick pulses of water; while other postlarvae would change their path after a short burst of flow. We propose that this erratic flow pattern induces cues for the postlarvae to "jump" in small bursts.

During two, 10 min time intervals on 23 June 2000 in Makamaka'ole Stream, the total number of passing shrimp postlarvae were counted. In the first and second 10 min intervals 107 and 81 shrimp postlarvae climbed up a path of $\sim 0.4 \text{ m}$ along the splash zone of a boulder with tightly constricted flow. If these data are

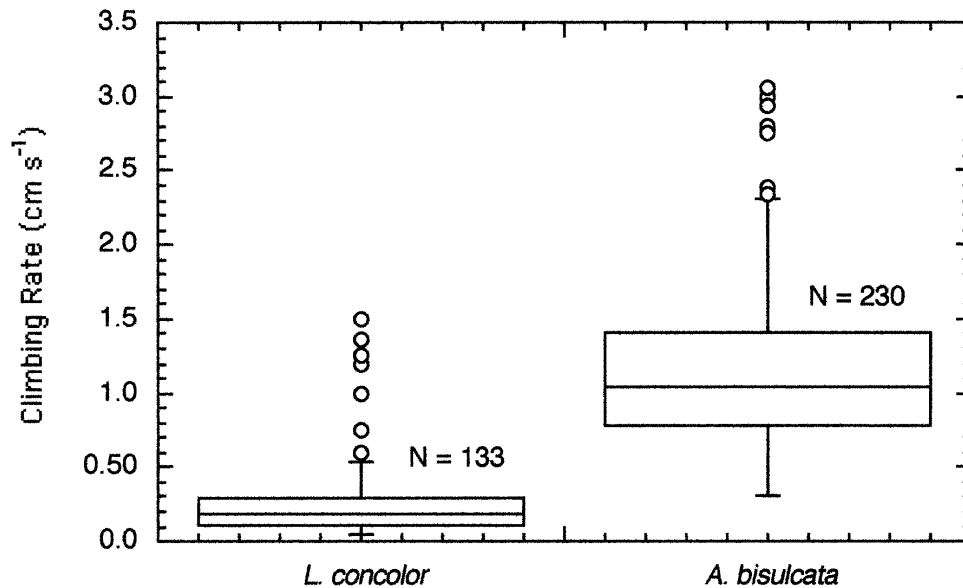


Figure 1: Box plots of amphidromous goby (*Lentipes concolor*) and shrimp (*Atyoida bisulcata*) postlarval climbing rates in Makamaka'ole Stream and Hanaw'i Stream (data pooled for each stream). The horizontal line within each box represents the median within the inter-quartile range (50% of the data). The open circles represent outliers.

converted to numbers passed per minute, a mean of 9.4 shrimp min^{-1} , or 564 shrimp h^{-1} , is obtained. Considering that we undoubtedly missed additional post-larvae moving in interstitial spaces and on the other side of the constricted water area, this mean recruitment is certainly conservative. However, if this estimate is extrapolated for the hours of peak migration time (2100 – 0300) for one night, the estimated shrimp recruitment that night was 3,384 shrimp d^{-1} . Obviously additional data are needed to corroborate these findings; however, these data provide an initial estimate of shrimp recruitment potential into Makamaka'ole Stream.

We have documented short term climbing rates and behavior of two species of endemic Hawaiian amphidromous species. Because these two species are known to be the highest (i.e., elevation) amphidromous climbers with populations found above the highest waterfalls in the Hawaiian Islands (Englund 1997), estimates can be made regarding climbing time requirements for these energetically costly habitats. There must be certain body size restrictions for climbing vertical substrates, which is probably dependent upon allometric scaling of body mass, length or volume to sucker volume and pectoral fin area, or tarsal claw morphology for the shrimp. Postlarval body size differences may play a role in explaining the adult fish longitudinal species occurrence patterns of Hawaiian streams (Kinzie et al. 1986).

Postlarval migration is probably slowest in areas of constricted flow that requires most individuals to climb out of the water at the water-substrate interface. Thus, with an understanding of climbing rate ranges in these habitats, better estimations can be made on time and flow requirements necessary for successful migration to particular locations within a stream. These estimations would be particularly useful when addressing flow mitigation strategies that may entertain the release of water from diversions for limited periods of time, with the goal to facilitate amphidromous faunal recruitment into diverted streams. Along with seasonal recruitment data, climbing rates may be helpful in answering such questions as, "How much and how long must water be released into the ocean in order to achieve postlarval recruitment above a certain elevation?" Additional studies are needed to determine species-specific spatial and temporal variation in cascade and waterfall climbing rates of Hawaii's amphidromous fauna.

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