

Macrofauna Survey Results for Mohihi, Waiakoali, Kauaikinanā, and Kōke‘e Streams at 3,400ft in Waimea, Kaua‘i

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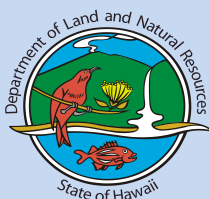
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State of Hawai‘i

Department of Land and Natural Resources

Commission on Water Resource Management



Macrofauna Survey Results for Mohihi, Waiakoali, Kauaikinanā, and Kōke‘e Streams at 3,400ft in Waimea, Kaua‘i

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Background

The Waimea Surface Water Hydrologic Unit is located on the southwest flank of the island of Kaua‘i (Figure 1). The Waimea River is composed of tributary streams with headwaters at or near the Alaka‘i Marsh: Kōke‘e, Kauaikinanā, Kawaikoi, Waiakoali, and Mohihi. In 1925, the Kōke‘e Ditch was built to divert water from these streams to irrigate state lands leased for sugarcane production. The ditch was constructed at approximately 3500 ft above sea level (asl) along the contour to gravity feed Pu‘u Lua Reservoir. The confluence of Waiakoali and Kawaikoi streams is located at approximately 3200 ft asl and the confluence of these streams with Kauaikinanā is at approximately 2700 ft asl. There is a series of steep waterfalls on this stream at about 2300 ft in elevation, upstream of their confluence with Mohihi Stream (Figure 1). The Mohihi Stream flows downstream over a steep waterfall, also at about 2300 ft in elevation, and then to the confluence with the previously mentioned streams at approximately 1900 ft in elevation, to form the Po‘omau tributary. The Kōke‘e Stream flows down Waipo‘o Falls at about 2900 ft asl to the confluence with Helemanu Stream at 1700 ft asl to form the Waiahulu Stream.

In the 1970s, due to the high maintenance costs and relative inaccessibility, the Mohihi Stream diversion was abandoned and the hydrological regime for this stream was returned to natural flow conditions. The diversions on Waiakoali, Kawaikoi, Kauaikinanā, and Kōke‘e streams continue to be active, with varying degrees of withdrawal: Waiakoali and Kawaikoi are completely diverted except for seepage around and under the low-head dam structure and when high flows overtop the dam; Kauaikinanā is partially diverted, with some flow remaining in the stream and excess ditch flow from Waiakoali and Kawaikoi discharging downstream; Kōke‘e is partially diverted with the stream conveying the ditch flows from the left bank to the right bank and excess flows diverted from the previous streams remaining in Kōke‘e Stream. In 2017, the Commission on Water Resource Management (Commission) established minimum instream flow standards for these streams to be met by modifications to the low-head dams that divert streamflow into Kōke‘e Ditch.

Goal

Recent discussions among stakeholders, managers, and regulators regarding modifications to stream diversions that divert water to the Kōke‘e Ditch identified the need for sufficient fish passage over the diversion structures, regardless of the restored quantity of flow, to facilitate the connectivity of upstream habitat for migratory species. However, based on historic literature and available information, Commission staff did not believe that connectivity was important, as habitat at this elevation (~3300 ft asl) was not utilized by amphidromous species due to its distance from the stream mouth and natural downstream barriers (e.g., high waterfalls). The lower gradient Po‘omau and Waiahulu tributaries, below these waterfalls, support amphidromous biota including *Lentipes concolor*, *Awaous stamineus* and *Sicyopterus stimpsoni*, namely gobies (i.e., ‘o‘opu), and *Atyoida bisulcata* (i.e., ‘opae). To test the hypothesis that endemic

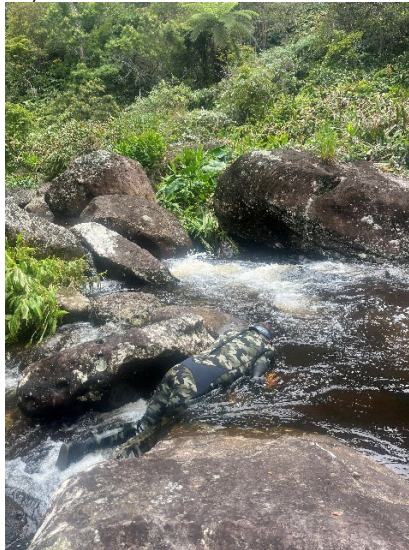
amphidromous macrofauna did not occupy stream reaches above these high waterfalls, staff conducted visual surveys at elevations ranging from 3,300 to 3,500 ft in elevation in each of four streams with varying degrees of withdrawal: Mohihi (undiverted); Kauaikinanā (restored-augmented); Waiakoali (diverted- minimally restored); and Kōke‘e (restored-augmented). Survey locations were over 11 miles inland from the sea and above high waterfalls, we hypothesized that few native biota would be seen in these high elevation reaches.

Methods

In April and May 2024, Commission staff conducted point-quadrat visual surveys in Mohihi, Waiakoali, Kauaikinanā and Kōke‘e streams at the 3,300-3,500 feet asl to determine if endemic amphidromous biota occupy these headwater reaches (Figure 1). Commission staff conducted visual surveys in streams using a modified point quadrat snorkel method as described by Higashi and Nishimoto (2007). At each location, twenty surveys were conducted at 10 m intervals starting from the most downstream location and moving upstream. The quadrat was randomly (left bank, middle, right bank) assigned at each transect and the number and estimated size of each species was counted for 120 seconds. Biota sizes were estimated to the nearest 0.5 inch, and then converted to cm. After each survey, the perimeter of the quadrat (top, right, bottom, left) was measured to calculate the area surveyed and the maximum depth of the quadrat was measured. Habitat type (run, pool, riffle) was determined, and the quadrat’s substrate type and proportions were estimated to the nearest 5% (Table 1).

Table 1. Example habitats of riffle, run, and pool from Kauaikinanā Stream

A.) riffle



B.) run



C.) pool



Habitat types and substrate categories were assigned following Higashi and Nishimoto (2007), with the addition of bedrock to encompass large boulders (>1 m diameter intermediate axis) and large, flat, basalt formations following Kinzie et al. (1984). Leaf litter and coarse woody debris decomposing in the stream bed were recorded as organic substrates. Velocity was measured at 60% of the depth in the center of the quadrat using a FlowTracker2 (SonTek, San Diego, California). The wetted width and active channel width were measured at each transect following the visual survey. Immediately after the survey, streamflow was measured using standard US Geological Survey (USGS) techniques (Turnipseed and Sauer 2010). Canopy cover

(%) was measured at every-other transect (10x) per survey using CanopyApp (version 1.0.3, University of New Hampshire) and averaged for the survey reach. General characteristics of each surveyed reach are provided in Table 2. Significant differences among streams were determined with a one-way Analysis of Variance (ANOVA). Due to violations with normality, velocity measurements were cube-root transformed and canopy measurements were log transformed.

Table 2. Characteristics of stream reaches surveyed (reach slope based on Tingley et al. (2019))

Characteristic	Mohihi	Waiakoali	Kauaikananā	Kōke‘e
Order	3	2	2	2
Survey elevation (m)	1036.32	1036.32	1066.80	1005.84
Distance inland (km)	26.05	26.26	26.32	23.26
Catchment area (km ²)	5.99	5.29	3.76	4.38
Slope (%)	13.24	13.76	10.99	6.62
Temperature (°C)	16.79	19.23	16.78	17.04
Flow (ft ³ s ⁻¹)	7.29	0.12	10.66	7.45

Across all four streams, only four species were found: *Procambarus clarkia* (Red Swamp Crayfish), *Misgurnus anguillicaudatus* (Dojo Loach), *Oncorhynchus mykiss* (Rainbow Trout), and fishes in the *Poeciliidae* family (including *Poecilia reticulata* and *Xiphophorus hellerii*). In total, 60 *P. clarkia*, 68 poeciliids, three *M. anguillicaudatus*, and two *O. mykiss* were seen (Table 4). Waiakoali stream was the only stream with *Poeciliid spp.* and Kōke‘e stream was the only stream with *O. mykiss*. We observed *P. clarkia* in all streams (Table 4), but densities were greatest in Waiakoali and Mohihi Streams.

Mean (standard deviation, SD) of *P. clarkia* size was 6.7 cm (3.1) across all streams, with a mean (SD) size of 6.8 cm (2.8) in Mohihi, 5.28 cm (2.8) in Waiakoali, 10.16 cm (0.0) in Kauaikananā, and 9.44 (2.31) in Kōke‘e streams (Table 5). *P. clarkia* sizes ranged from 2.5-12.7 cm, with the most common individuals in the 2.5-5.1 cm range. Mean (SD) size of *Poeciliid spp.* was 3.51 cm (1.19). *Poeciliid spp.* sizes ranged from 2.5-5.1 cm, with 2.5 cm being the most common size (Table 5). Mean (SD) of *M. anguillicaudatus* size was 9.3 cm (1.5), with a mean (SD) size of 8.9 cm (1.8) in Waiakoali stream, and Kauaikananā stream with the largest observed size 10.2 cm. *M. anguillicaudatus* size ranged from 7.6-10.2 cm with 10.2 cm being the most common size (Table 5). Mean (SD) size of *O. mykiss* was 8.89 cm (1.8) in Kōke‘e stream with only two sizes seen: 7.62 cm and 10.16 cm.

Table 3. Mean (\pm standard deviation) Stream channel characteristics of Mohihi, Waiakoali, Kōke‘e, and Kauaikananā streams in Waimea, Kaua‘i. One-way ANOVA among reaches provided [WW=wetted width, ACW=active channel width/bankfull width]

Characteristic	Mohihi	Waiakoali	Kauaikananā	Kōke‘e	ANOVA
Canopy %	14.9 (\pm 10.9)	13.2 (\pm 9.6)	9.5 (\pm 7.1)	41.1 (\pm 30.7)	F _{3,36} = 6.98***
Depth (cm)	60 (\pm 26)	48 (\pm 29)	60 (\pm 23)	51 (\pm 15.9)	F _{3,76} = 1.295
Velocity (m/s)	0.48 (\pm 0.52)	0.09 (\pm 0.14)	0.91 (\pm 0.62)	0.36 (\pm 0.79)	F _{3,76} = 14.4***
WW (m)	8.5 (\pm 7.0)	5.8 (\pm 7.6)	7.3 (\pm 7.5)	4.6 (\pm 3.8)	F _{3,76} = 13.8***
ACW (m)	11.2 (\pm 9.8)	9.3 (\pm 4.6)	12.2 (\pm 8.9)	6.7 (\pm 3.7)	F _{3,76} = 24.3***

*** p < 0.001

Table 4. Total abundance and density by species for visual surveys in Mohihi, Waiakoali, Kauaikinanā, and Kōke'e streams in Waimea, Kaua'i. *Poecilid* spp. category consists of fishes from the family *Poeciliidae*.

Total Abundance				
Stream	<i>P. clarkii</i>	<i>Poecilid</i> spp.	<i>M. anguillicaudatus</i>	<i>O. mykiss</i>
Mohihi	22	0	0	0
Waiakoali	26	68	2	0
Kauaikinanā	1	0	1	0
Kōke'e	11	0	0	2
Total	60	68	3	2

Density (count m ⁻²)				
Stream	<i>P. clarkii</i>	<i>Poecilid</i> spp.	<i>M. anguillicaudatus</i>	<i>O. mykiss</i>
Mohihi	1.07	0.00	0.00	0.00
Waiakoali	1.40	3.71	0.11	0.00
Kauaikinanā	0.06	0.00	0.14	0.00
Kōke'e	0.55	0.00	0.00	0.09

Table 5. Number and mean (\pm standard deviation) size estimates by species for visual surveys in Mohihi, Waiakoali, and Kauaikinanā streams in Waimea, Kaua'i. *Poecilid* spp. category consists of fishes from the family *Poeciliidae*. Sizes were estimated to the nearest 0.5 in, and then converted to cm for analysis.

<i>P. clarkii</i>									
Stream	2.5 cm	3.8 cm	5.1 cm	7.6 cm	8.9 cm	10.2 cm	11.4	12.7 cm	Mean (SD)
Mohihi	1	0	11	7	0	0	0	3	6.8 (2.8)
Waiakoali	10	0	7	7	0	1	0	1	5.3 (2.8)
Kauaikinanā	0	0	0	0	0	1	0	0	--
Kōke'e	0	1	0	1	2	5	2	0	9.4 (2.3)

<i>Poecilid</i> spp.									
	2.5 cm	3.8 cm	5.1 cm	7.6 cm	8.9 cm	10.2 cm	11.4	12.7 cm	Mean (SD)
Mohihi	0	0	0	0	0	0	0	0	--
Waiakoali	39	5	24	0	0	0	0	0	3.5 (1.2)
Kauaikinanā	0	0	0	0	0	0	0	0	--
Kōke'e	0	0	0	0	0	0	0	0	--

<i>M. anguillicaudatus</i>									
	2.5 cm	3.8 cm	5.1 cm	7.6 cm	8.9 cm	10.2 cm	11.4	12.7 cm	Mean (SD)
Mohihi	0	0	0	0	0	0	0	0	--
Waiakoali	0	0	0	1	0	1	0	0	8.9 (1.8)
Kauaikinanā	0	0	0	0	0	1	0	0	--
Kōke'e	0	0	0	0	0	0	0	0	--

<i>O. mykiss</i>									
	2.5 cm	3.8 cm	5.1 cm	7.6 cm	8.9 cm	10.2 cm	11.4	12.7 cm	Mean (SD)
Mohihi	0	0	0	0	0	0	0	0	--
Waiakoali	0	0	0	0	0	0	0	0	--
Kauaikinanā	0	0	0	0	0	0	0	0	--
Kōke'e	0	0	0	1	0	1	0	0	8.9 (1.8)

Figure 1. Kōke'e, Kauaikinānā, Waiakoali, and Mohihi streams in the Waimea watershed (see insert) with locations of biota surveys, active and inactive USGS gaging stations, and downstream waterfalls identified.

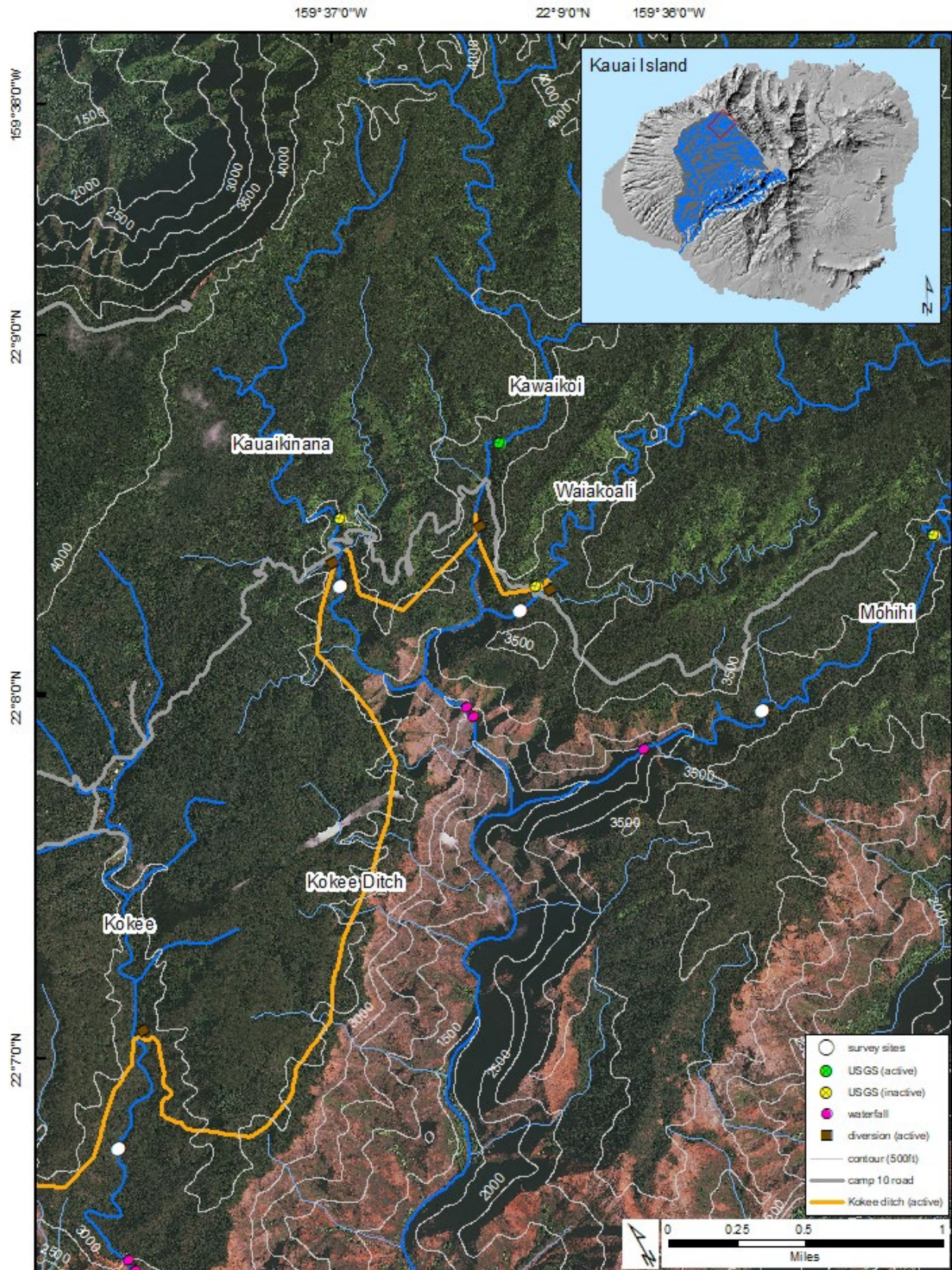


Figure 2. Habitat types and substrate categories for biota surveys conducted in Kōke'e, Kauaikinā, Waiakoali, and Mohihi streams in the Waimea watershed, Kaua'i, Hawai'i. Pie charts were created using the ggplot2 package in R (Wickham 2016).



DISCUSSION

Lack of endemic species

Surveys of high-elevation, headwater stream reaches in Waimea, Kaua'i were devoid of amphidromous macrofauna, and community assemblages were composed solely of introduced species. The absence of endemic amphidromous species in these reaches is not surprising given the distance from the stream mouth (>23 km) and the high waterfall barriers located downstream.

Endemic macrofauna of Hawaiian streams consists of species with amphidromous life-histories and necessitate an ocean-dependent life cycle with dual migrations: larvae drift downstream to the ocean and juveniles recruit upstream. Although an ocean-dependent life cycle increases the likelihood that a single reproductive adult will pass their genes to progeny that colonize other streams, migrations increase the likelihood of predation both to and from the ocean in lower elevation reaches. In estuary and low-elevation stream habitat, numerous freshwater, and estuarine species prey upon migrating juveniles as they move upstream. By moving inland away from the estuary, these species reduce predation pressure imposed by estuarine species that lack climbing abilities (Kinzie, 1998). Juvenile upstream migrations are aided by morphological adaptations that enable them to scale wetted surfaces (e.g., riffles, cascades, waterfalls). The ability to climb waterfalls can increase fitness by reducing competition with non-climbing species, without increasing the distance from the stream mouth (Kinzie, 1988; Fitzsimons and Nishimoto, 1995). The most successful climbers (*Lentipes concolor*, *Sicyopterus stimpsoni*, *Awaous stamineus*, *Atyoida bisulcata*) are primarily filter-feeding or foragers (although *A. stamineus* will regularly prey upon invertebrates) and do not regularly prey on each other.

Juveniles ascend waterfalls either through a “power burst” motion of axial undulation (*L. concolor* and *A. stamineus*) or by an “inching” mechanism using alternating attachments between oral and pelvic suckers to the substrate (Schoenfuss and Blob, 2003). However, it is disadvantageous to migrate too far from the ocean mouth, since newly hatched larvae cannot survive for more than a few days in freshwater and lack the morphology to allow them to stay in freshwater streams during extreme rainfall events (Iida et al., 2010; Lindstrom, 1998; Lindstrom, 1999).

Waterfalls are natural barriers to upstream migration by placing external physical forces on animals as they ascend (Polhemus et al. 1992). Small juvenile fishes can easily ascend waterfalls as high as 450 m in Hawai‘i within a few kilometers from the coastline (Englund and Filbert, 1997). However, as juveniles migrate upstream, they are feeding and growing, rapidly accumulating mass and length. As gobies increase in size, their climbing performance declines for several reasons. First, because mass-specific power production tends to decrease with body size (Irschick et al., 2003). A lack of positively allometric growth among climbing-related structures like the fused pelvic sucker fin and associated musculature that support body weight against gravity (Blob et al., 2007), size-related limits to power production might restrict the maximum body size at which ‘powerbursting’ is a viable climbing mechanism on vertical faced waterfalls (Blob et al., 2006). This limits the climbing ability in adult *A. stamineus* and *L. concolor*. Power demands might not limit climbing by *S. stimpsoni* because of the slow cycle frequencies of inching allowing *S. stimpsoni* to rest and regain strength (Schoenfuss and Blob, 2003). Second, the pelvic sucking disk of gobies grows isometrically with body length (i.e., scales $\propto BL^2$) and thus, does not grow proportionally with increases in the mass of the body ($\propto BL^3$). This is crucial as the fused pelvic fin apparatus must keep the fish attached to the substrate (Maie et al., 2007). As a result, even inching climbers like *S. stimpsoni* might show reduced climbing performance as they grow larger. For juveniles using ‘powerbursts’ to climb waterfalls, Blob *et al.* (2007) found that adult performance and kinematics showed marked changes compared to juveniles: adult *A. stamineus* failed to climb, and adult *L. concolor* used multiple pectoral fin adductions to crutch up surfaces at slower speeds, rather than rapid power bursts. Post-metamorphosed *S. stimpsoni* have greatly depleted energy reserves prior to climbing (Schoenfuss et al., 1997) following their energy intensive metamorphosis, aerobic “inching-up” might be the only energetically feasible mode of climbing to overcome in-stream obstacles like waterfalls while stopping to feed (Schoenfuss and Blob, 2003). The evolution of this distinctive juvenile climbing style in *Sicyopterus spp.* may have been correlated with the increased energetic cost associated with moving against falling water in juveniles with a greater body mass than that of other species who migrate earlier or at smaller life-stages (Fukui 1979). Such feeding requirements and physical abilities to exclude Hawaiian gobies from populating otherwise high quality habitats which either lack a food resource (e.g., particular species of algae or floating food resources) or habitat resource (e.g., sand and gravel substrates) (Schoenfuss and Blob, 2007).

Natural landscape variables such as stream channel slope, catchment area, and rainfall, are associated with differences in taxa distributions in Hawai‘i (Tingley et al., 2019). Further, elevation is commonly associated with differences in species assemblage on tropical islands across the Pacific (Polhemus et al., 1992) and is regularly used to differentiate potential habitat among reaches within stream systems (Parham and Lapp, 2006; Parham et al., 2008). In a classification of stream community composition based on statewide historical presence/absence data, Tingley et al. (2019) classified streams identified in this study as headwater streams, which were expected to lack amphidromous species.

Presence of introduced species

Aquatic macrofauna was dominated by non-native species. The dojo or pond loach (*Misgurnus anguillicaudatus*) has an eel-like body, brown with greenish grey-brown marble markings that may also appear pale silver ventrally. Native to Eastern Asia, *M. anguillicaudatus* can grow to 28 cm in length, but averages 10-20 cm (Kottelat and Freyhof 2007). This species was likely introduced to Hawai‘i by Asian immigrants during the late 1800s, probably for food (Maciolek 1984; Devick 1991). Brock (1960) stated that *M. anguillicaudatus*'s use as a bait fish was instrumental in its spread in Hawai‘i, while Maciolek (1984) categorized it as having an intermediate impact on Hawaiian streams based on their preferred habitat, diet, and overall abundance. Their diet consists primarily of small aquatic insects and their larvae are classified as dietary generalists (Tabor et al. 2001, Schmidt and Schmidt 2014, Urquhart and Koetsier 2014). Generally found in shallow, slow-moving habitat with woody debris or vegetative cover (McNair et al. 2023), dojo are highly tolerant of poor water quality due to their ability to breathe air through their gills, skin, and posterior intestine (McMahon and Burggren 1987). Potential threats to native stream species include competition for resources, as the females are extremely fertile, (individuals in Idaho have been reported to produce up to 40,000 eggs in a single spawning season (Urquhart 2013), and they are known to carry at least four parasites and one virus (Lintermans et al. 1990, Reyda et al. 2020).

The red swamp crayfish (*Procambarus clarkii*) was introduced from California to O‘ahu in the 1920s and from there to the other islands. Crayfish have the potential to be good freshwater invaders due to their ability to integrate into the food web at many levels and survive on energy reserves from a detrital pool (Moyle and Light 1996). *Procambarus clarkia* have been documented to consume taro, prey on insects and snails, and create burrows that affect stream banks or lo‘i (Klose and Cooper, 2013). Across its range, this species lives in a variety of habitats, but entirely in freshwater, including ponds, streams, canals, seasonally flooded swamps, and ditches with mud or sandy bottoms and plenty of organic debris (Huner and Barr 1991). Like most crayfish, *P. clarkia* is an opportunistic omnivore, consuming plant material, animals, detritus, and sediment (Alcorlo et al. 2004; Correia 2003; Gherardi and Barbaresi 2007; Gutiérrez-Yurrita et al. 1998; Smart et al. 2002). It appears that *P. clarkii* may exhibit selectivity for particular plants but not among animal prey (Gherardi and Barbaresi 2007). The animal constituents of the *P. clarkii* diet tend to be dominated by insects (particularly chironomids), other crayfish, mollusks (snails), and fish (Ilheu and Bernardo 1993, Pérez-Bote 2004). Introduced crayfish in Hawai‘i have been known to reduce leaf litter, filamentous algae, and benthic invertebrate biomass (Klose and Cooper 2013). They also have the potential to cause environmental stress and induce shifts in species diversity (Hobbs et al. 1989).

Poeciliids spp. were introduced to the Hawaiian Islands in the 1900s for mosquito control (Van Dine 1907; Englund 1999) or unwanted aquarium stock (Myers 1940, Brock 1952). *Poeciliids spp.* are known as generalist species that can live in a broad array of habitats. This is due to being excellent colonizers (i.e., a single gravid female can give rise to a new populations) and for having high thermal and salinity tolerances (Meffe and Snelson 1989). Potential impacts to native stream biota in the tropics include feeding directly on larvae of endemic fish, shrimp, or mollusks and aquatic insects (Englund 1999), as well as competing with native species for the same food resources (Pyke 2005). The introduction of *Poeciliids spp.* in Hawai‘i has also led to the introduction and spread of non-native parasites to four of the five native freshwater gobies (Font 2003, Gagne et al. 2018).

Oncorhynchus mykiss (Rainbow trout) is native to the Pacific drainages of western North America and have been introduced to Africa, Asia, Australia, Europe, and South America

(MacCrimmon 1971). *O. mykiss* was introduced to Waimea River, Kaua'i starting in 1920 (Needham & Welsh 1953). Stocking of *O. mykiss* continued annually after World War II (Needham & Welsh 1953) but was discontinued in 1992 due to concerns regarding negative impacts to the endemic *Megalagrion* damselflies which had a few species listed under the U.S. Endangered Species Act. *O. mykiss* are considered opportunistic predators (Tilzey 1977) and are functioning primarily as opportunistic drifter feeders in these freshwater systems (Englund & Polhemus 2001). Englund & Polhemus 2001 examined 80 *O. mykiss* stomachs between 1997-1999 and found no evidence that this introduced species significantly impact *Megalagrion* damselflies, Federally Endangered aquatic species such as Newcomb's Snail or any other endemic aquatic species. It appears that on Kaua'i, *O. mykiss* only persist in streams with the proper hydrological and geomorphological conditions, and that stocked trout did not tend to survive in most of the upper elevation headwater reaches of the Waimea watershed representing a minimal threat to native biota (Englund & Polhemus 2001).

Conclusions

To determine if endemic amphidromous species were inhabiting high-elevation headwater stream reaches (>2300 ft elevation) far from the stream mouth (>23 km), we conducted visual surveys in four streams of varying flow regimes. No endemic species were observed, although introduced fish and crustaceans were observed at low densities. Flow regime did not appear to affect species composition as no endemic macrofauna were observed in Kōke'e Stream despite continual augmented flow regime for at least 20 years, or in Mohihi Stream despite over 40 years of natural flow regime. Waiakoali Stream had similar densities of *P. clarikii* as Mohihi despite substantially reduced streamflow. Based on this, we conclude that amphidromous macrofauna do not migrate to reaches greater than 3400 ft in elevation this far from the stream mouth. Results suggest that downstream waterfalls impede the upstream movement of amphidromous species in Hawai'i, forming a natural barrier to endemic species movement.

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