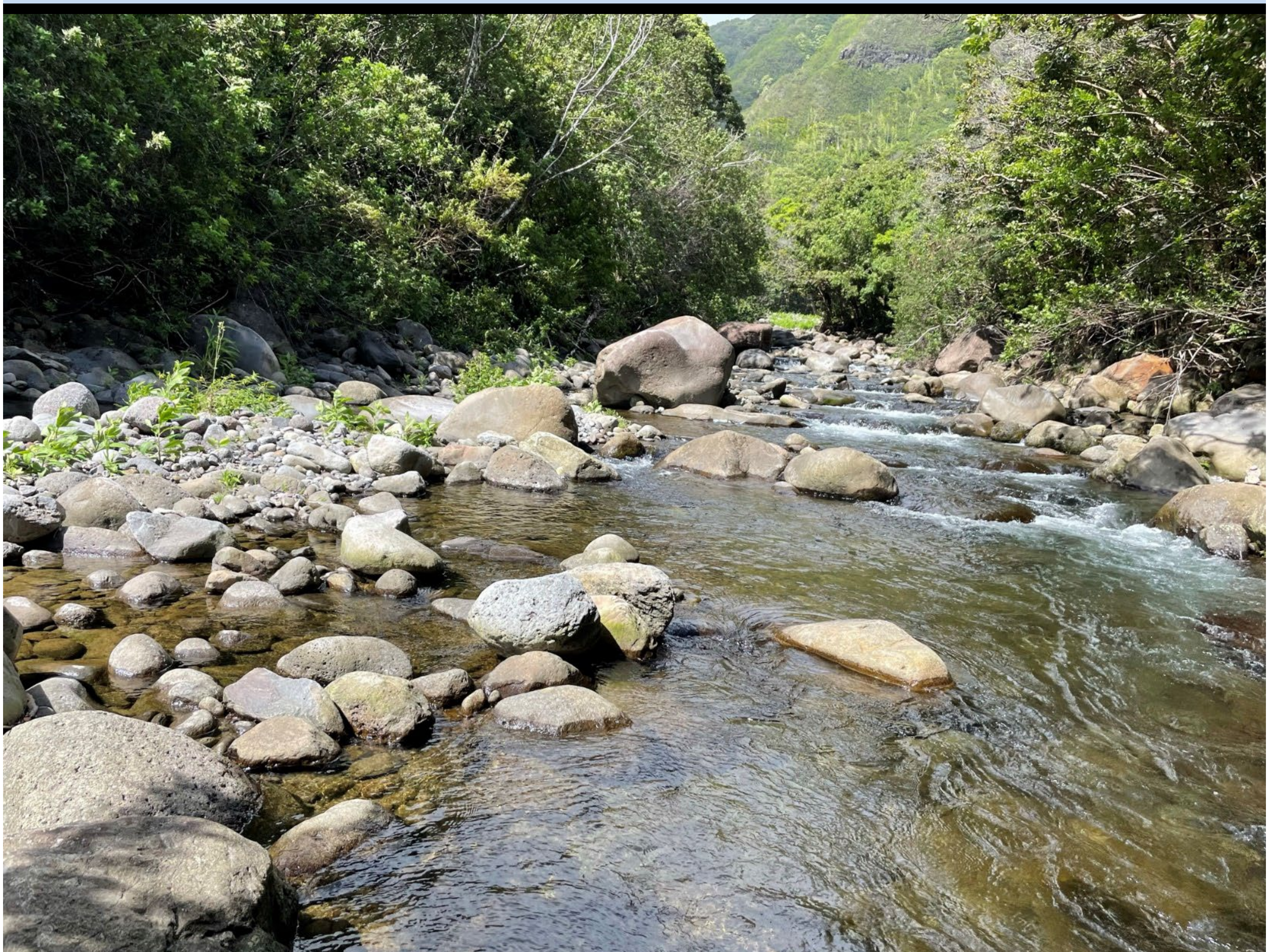
Hydrological and Biological Assessment of Nā Wai ʻEhā Streams Following Streamflow Restoration, Maui

August 2025 **PR-2025-01**



State of Hawaiʻi
Department of Land and Natural Resources
Commission on Water Resource Management

Acknowledgements

The authors are grateful for the tireless assistance in the field from Doug Kagawa, Malie Beach-Smith, Alexa Dieike, ‘Iwalani Kaaa, and Alyssandra Rousseve from the Commission on Water Resource Management and Jody Kimmel, Skippy Hau, and Haruko Mauro-Koike from the Division of Aquatic Resources. We are forever indebted to Kathy Yoda for all her work behind the scenes. Dean Uyeno provided guidance, support, and helpful comments for this fieldwork. Malie Beach-Smith assisted with database management. Additionally, stream access was provided by Avery Chumbley at Wailuku Water Company, Mark Vaught at Mahi Pono, and the ‘ohana of Preston Kepano. The authors thank YinPhan Tsang for helpful comments in the development of this report.

Cover photo: Waihe‘e River at 330ft (Credit: Ayron M. Strauch)

Citation: Strauch, A.M. and C.L. Chacon, 2025. Hydrological and Biological Assessment of Nā Wai ‘Ehā Streams Following Streamflow Restoration, Maui. Commission on Water Resource Management, Public Report PR-2025-01.

Executive Summary
In 2024, the State of Hawaiʻi Supreme Court (Court) issued a ruling (SCOT-21-0000581) with regards to contested case hearing (CCH) CCH-MA-15-01 addressing the issuance of surface water use permits and amendments to interim Instream Flow Standard (interim IFS) for streams in the Nā Wai ʻEhā region of Central Maui. Of the multiple issues needing to be addressed in the remand was the incorporation of additional data the Commission on Water Resource Management (Commission) gathered with regards to attainment of interim IFS and ecological conditions following streamflow restoration. The Court ruled that while streamflow was restored to each of the four streams in July 2014, no follow-up surveys were conducted to justify the maintenance of instream flow standards issued in the Commission's 2021 Decision & Order (2021 D&O).

Commission staff, in cooperation with the US Geological Survey, have operated continuous record gaging stations monitoring regulated flow conditions on each of the four streams since 2014, in addition to natural flow monitoring. Further, Commission staff, in cooperation with the State of Hawaiʻi Division of Aquatic Resources, have conducted multiple biological surveys at varying elevations in Nā Wai ʻEhā since 2021. These datasets were not part of the evidentiary portion of the CCH, which was closed in 2015. This report is a summary of the hydrological and biological data gathered since 2014.

Due to long-term reductions in rainfall and groundwater contributions to streamflow, overall surface water availability in Nā Wai ʻEhā has declined approximately 10% in the 2004-2023 period compared to the 1984-2007 period used in CCH-MA-15-01. Biological survey results from 2021-2024 suggest that, with the exception of Waikapū Stream, which does not have natural connectivity with the ocean, fish populations are healthy at the middle and upper elevation reaches in Nā Wai ʻEhā. *Sicyopterus stimpsoni* (ʻoʻopu nōpili) and *Lentipes concolor* (ʻoʻopu ʻalamoʻo) densities were particularly high in Waiheʻe River, equivalent to naturally flowing Maui streams at multiple elevations. The size distribution suggests that there is consistent recruitment of *Awaous stamineus*, *L. concolor*, and *S. stimpsoni* to Wailuku and Waiheʻe Rivers. We found that existing flow standards in these streams maintains a healthy aquatic community, supporting reproductive adults and connectivity for the continual recruitment of juveniles. As habitat availability, population size, and ecosystem structure already meet standards established by reference streams representing more natural hydrological systems, increasing downstream flows will unlikely produce a quantifiable improvement in ecological function outside of the natural variability associated with stream communities.

Table of Contents

Hydrological and Biological Assessment of Nā Wai ʻEhā Streams Following Streamflow Restoration, Maui

By Ayron M. Strauch and Cody L. Chacon

1. Background

The region of Central Maui known as Nā Wai ʻEhā, includes the four ahupuaʻa that incorporate Waiheʻe, Waiehu, Wailuku, and Waikapū streams in the Moku of Wailuku (Figure 1). This region once fed the largest contiguous loʻi kalo growing region in Hawaiʻi (Handy and Handy, 1972). These streams, sourced from Mauna Kahalawai, supported a vast Hawaiian population, endemic stream life, nearshore fisheries and fishponds, and immense estuary and marine environments.

Starting in the 1860s, sugar plantations began to withdrawal large quantities of water from each of these streams, sometimes at multiple elevations (Wilcox, 1997). This frequently left certain stream reaches dry for considerable periods of time. In 1987, the Hawaiʻi Legislature adopted Chapter 174C, Hawaiʻi Revised Statutes (HRS; State Water Code), establishing the State of Hawaiʻi Commission on Water Resource Management (Commission) to manage water as a public trust resource. In subsequent years, the interim instream flow standard (interim IFS) adopted was the "status quo" (Hawaiʻi Administrative Rules (HAR) 13-169-44 to 13-169-49.1). This essentially grandfathered in all existing withdrawals of water from streams. In 2003, Hui o Nā Wai ʻEhā petitioned to amend the instream flow standards for Waiheʻe, Waiehu, Wailuku, and Waikapū streams as part of a request to designate the ʻĪao Aquifer as a groundwater management area. Following the designation of the region as a surface water management area in 2008, the Commission established interim instream flow standards for Waiheʻe and Waiehu streams in 2010. This decision was appealed to the Supreme Court, which remanded the case back to the Commission to address the lack of streamflow standards in Wailuku and Waikapū streams (Nā Wai ʻEhā I). In 2014, prior to reopening the Contested Case proceedings, the parties agreed to a mediated settlement establishing interim instream flow standards in all four streams. Water use permits were applied for in 2009, with provisional recognition of appurtenant rights and quantification of appurtenant rights conducted in separate hearings in 2014 and 2016, respectively.

Per the State Water Code, the Commission has a mandate to amend instream flow standards (i.e., minimum environmental flows) that protect instream values, while balancing public trust uses and reasonable and beneficial uses of water. One of the four public trust uses of water is water in its natural state, i.e., the maintenance of water in sufficient quantities in the stream channel to support a healthy aquatic ecosystem. However, there are two fundamental issues with this presumption: 1) that a single quantitative value is sufficient to provide for a healthy aquatic ecosystem (Mims and Olden, 2012); and 2) that a healthy aquatic ecosystem is solely dependent on the flow of water (McManamay, 2013).

When the State Water Code was passed (i.e., 1987), there was very little understanding of flow-ecology relationships (Lake et al., 2007; Bruckerhoff et al., 2018). This research was in its infancy into the 1990s, with increased acknowledgement of the role environmental stability, variability, and seasonality plays in the suitability of habitat (Poff et al. 2010; Mims and Olden, 2012). Natural systems experience cycles of growth, disturbance, and reorganization at multiple spatial and temporal scales (Sundstrom and Allen, 2019), with flow regimes providing natural disturbances driving ecological processes (Stanley et al. 2010). This is particularly important in the tropics where low-frequency, high magnitude rainfall events drive runoff characteristics (Strauch et al., 2014). Understanding how amphidromous species that migrate between freshwater and marine environments fit into current models of ecosystem health is challenging (McDowall, 2007). Initial work to establish basic habitat preferences and behavior of endemic aquatic fauna in Hawaiʻi has focused on generalizing from more natural stream systems (Kinzie, 1988; Way et al., 1998; Kido, 2008) and little work has focused on the effects of varying flow conditions (but see Kinzie et al., 2006). In Nā Wai ʻEhā, Oki et al. (2010) modeled available habitat units under varying flow conditions for endemic aquatic species, although no subsequent fieldwork was conducted by U.S. Geological Survey (USGS) following restoration.

Problem

In 2024, the State of Hawaiʻi Supreme Court (Court) issued a ruling (SCOT-21-0000581) with regards to contested case hearing (CCH) CCH-MA-15-01 addressing the issuance of surface water use permits and amendments to interim IFS for streams in Nā Wai ʻEhā (Nā Wai ʻEhā II). Of the multiple issues needing to be addressed in the remand is the incorporation of additional data the Commission has been gathering with regards to instream uses and ecological conditions following streamflow restoration. The Court ruled that while streamflow was restored to each of the four streams in July 2014, no follow-up surveys were conducted to justify the maintenance of instream flow standards issued in the Commission's 2021 Decision & Order (2021 D&O). The court stated:

> "It has been well over ten years since the 2010 amendments, and almost ten years since the most recent 2014 amendments to the IIFS [interim instream flow standard]; thus, the finding actually suggests the IIFS should now increase. Second, that finding suggested such time was necessary in order to properly study the effects of stream flow restoration, but the Commission has not sought out the information it needs through additional scientific studies or otherwise; further, Waiāhole I suggested a lack of proper studies and adequate information weighs in favor of higher stream flows."
>
> p. 61

While the Commission staff have closely monitored the interim IFS in the region by maintaining continuous record gaging stations, no additional data were included in the 2021 D&O since the evidentiary portion of the CCH was concluded in 2015. This left little time (between July 2014 and 2015) for Commission staff to have conducted additional fieldwork for the data to be available for the contested case proceedings. Further, the Commission did not have the budget to afford follow up fieldwork by a third-party, as the Commission had already contracted the USGS for the Southeast Kauaʻi Low-Flow Study (USGS SIR 2020-5128), the USGS Statewide Low-Flow study (USGS SIR 2016-5103), and the statewide monitoring needs assessment (USGS SIR 2020-5115) between 2014 and 2020.

However, following the 2014 flow restoration, both USGS and Commission staff have gathered more data regarding the hydrological and ecological conditions of the streams in Nā Wai ʻEhā. This report will summarize these data.

Goal

This report provides a summary and analysis of the available hydrological and ecological data collected to date in Nā Wai ʻEhā. We then discuss these data in the context of two nearby stream systems in West Maui as well as two streams on Kauaʻi with similar hydrological and topographic conditions.

2. Hydrological Data Collection

Rainfall

Rainfall data were summarized for three stations in the region: Waiheʻe Valley (station 482; elevation 300ft); ʻĪao Valley (station 387.1; elevation 720ft); Waikapū Reservoir #1 (station 390.1; elevation 1100ft) (Figure 1). Monthly rainfall was analyzed by wet (November to April) and dry (May to October) seasons and annually by water years (October to September). To verify that rainfall patterns did not vary significantly with time, trends were tested using the Mann-Kendall Test (S statistic) and Sen's Slope test (Z statistic) with significant two-tailed effects using an $\alpha = 0.05$.

Continuous Record Streamflow Stations

The USGS, in cooperation with the Commission, State Department of Transportation (DOT), and Mahi Pono, currently (2024) cost-share stream gaging in all four streams of Nā Wai ʻEhā. Two stations, USGS 16614000 on Waiheʻe River and USGS 16604500 on Wailuku River, have collected continuous-record natural flow discharge data since 1983 (Figure 1). Flow duration statistics at these locations for varying periods of record are presented here as reported in previous publications, as well as the most recent 20-year period of record ending in water year 2023 for USGS 16614000 (Table 1) and USGS 16604500 (Table 2) stations. Since 2022, USGS 16605500 on Wailuku River and USGS 16611500 on South Waiehu Stream have monitored regulated flow thanks to cost-sharing with Mahi Pono. USGS 16647900 on Waikapū Stream above the South Waikapū Ditch intake began to monitor natural flow at the 1,145 ft elevation in 2022, but discharge data are not yet available.

Partial-Record Streamflow Stations

In support of Oki et al. (2010; USGS SIR 2010-5011), USGS established partial record gaging stations on North Waiehu, South Waiehu, and Waikapū streams from 2006-2008 to develop low-flow characteristics in relation to nearby long-term index stations. Data from these stations were summarized in Oki et al. (2010) for the water years 1984-2007. While the 1984-2007 hydrological period was largely similar to the longer-term period from 1920-2007 (Oki et al., 2010), recent (post-1978) trends in rainfall identified in Frazier and Giambelluca (2017) and Frazier et al. (2018), have highlighted a shift in climate patterns resulting in decreased recharge and baseflow to streams. For example, Bassiouni and Oki (2013) and Clilverd et al. (2019) calculated downward trends in selected flow duration statistics across the state, including significant declines in low-flow and baseflow in streams on Maui.

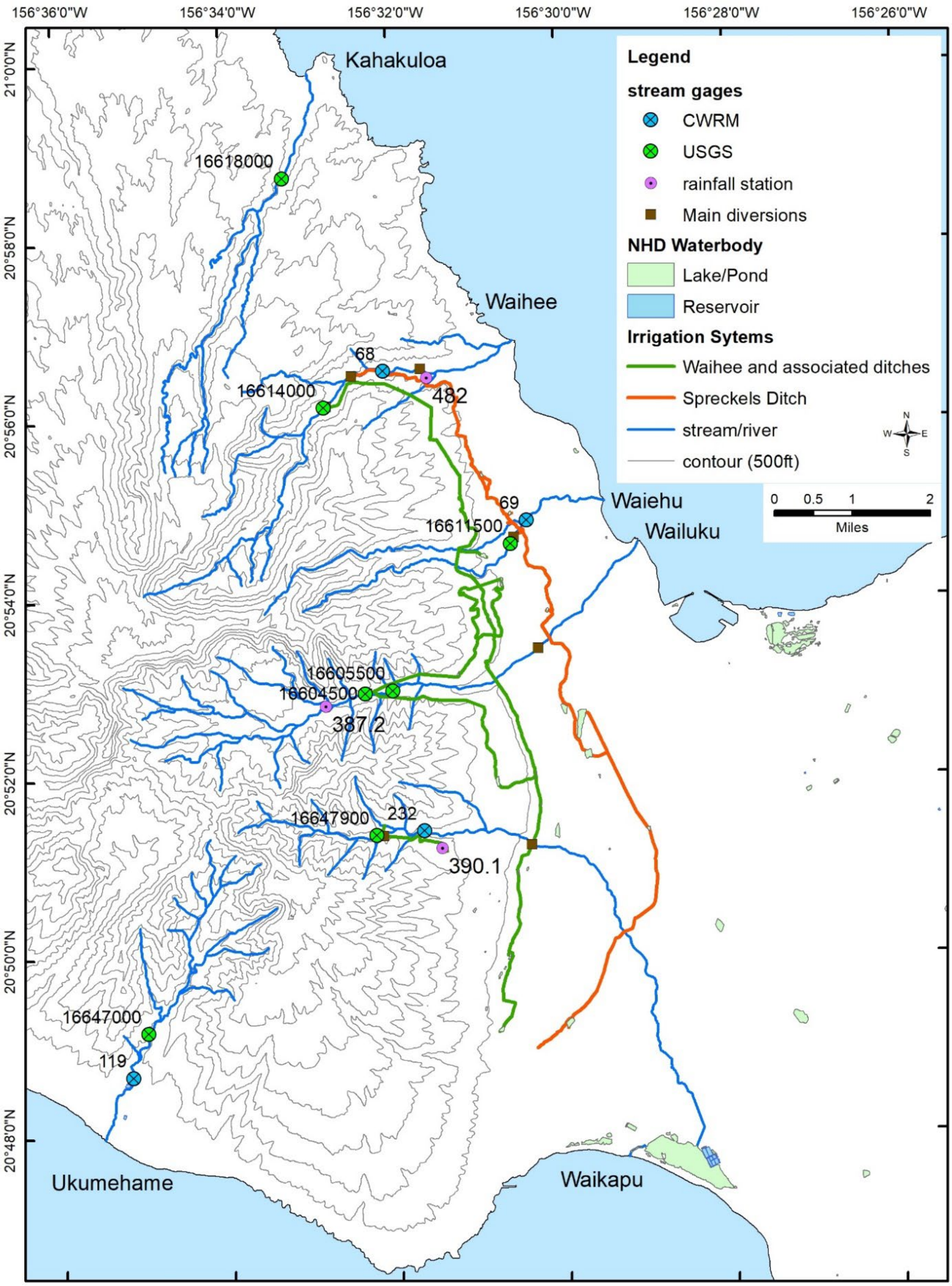


Figure 1. Kahakuloa, Waihe'e, Waiehu, Wailuku, Waikapū, and Ukumehame streams in Nā Wai 'Ehā with active US Geological Survey (USGS) and Commission on Water Resource Management (CWRM) gaging stations, rainfall stations, and main stream diversions.

Further, Cheng (2016, USGS SIR 2016-5103) updated estimates of low-flow characteristics at both continuous and partial record stations for the 1983-2013 climate period, which also highlighted declines in the magnitude of low-flow for streams in Nā Wai ʻEhā.

In support of an update to the statewide low-flow streamflow statistics, USGS operated additional partial-record stations on South Waiehu (Table 3), North Waiehu (Table 4), and Waikapū (Table 5) streams at varying elevations in the 2018-2021 period. These data are readily available for use from the National Water Information System[1] (NWIS). Using the Maintenance of Variance 1 (MOVE.1) record-extension technique (Hirsch, 1982), we developed natural, low-flow statistics at Waikapū Stream at 915ft, South Waiehu stream at 620ft, and North Waiehu stream at 610ft elevations for this study. We estimated statistics for the 2004-2023 period and compared them to low-flow statistics available from Oki et al. (2010) for the 1984-2007 period or Cheng (2016) for the 1984-2013 period.

Record-extension techniques using measurements from 2018-2021 relied on mean daily flow from USGS 16604500 (for Waikapū Stream at 915ft) or USGS 16614000 (for South Waiehu and North Waiehu streams) as index stations for the 2004-2023 period of record. These stations represent natural flow conditions at their respective elevations. Comparisons are made to previous estimates of low-flow statistics, although other estimates were developed at differing elevations, which contributes to some of the observed disparity.

The updated partial-record station data for Waikapū Stream maintained by Commission staff includes measurements made at the 915ft elevation, upstream of the partial-record station at 880ft elevation previously used by Oki et al. (2010), with concurrent diverted flow values in the South Waikapū Ditch. These measurements are provided in Supplemental Table S1.

Data Analysis at Partial-Record Streamflow Stations

We used three statistics to evaluate the strength of the relationship between the measured value and the modeled discharge based on the MOVE.1 record-extension: the correlation coefficient (r), the root mean square error (RMSE), and a modified Nash-Sutcliff coefficient of efficiency (NSE). The correlation coefficient (Vogel and Stedinger, 1985) measures the strength of the linear relation between concurrent discharges at the index station and the partial-record site. The root mean square error (or standard deviation) is the square root of the variance, and it aggregates the differences (or residuals) between individual estimated and measured discharges at the partial-record sites into a single predictive measure. The modified Nash-Sutcliff coefficient of efficiency (Legates and McCabe, 1999), with values ranging from negative infinity to 1, determines the accuracy to which the statistical relation predicts low-flow duration discharges at the partial-record sites from the low-flow duration discharges at the index station. For the three partial-record stations, the "goodness-of-fit" statistics to evaluate model competency are provided in Supplemental Table S2.

USGS Seepage Measurements

Numerous seepage measurements were made in support of Oki et al. (2010; USGS SIR 2010-5011). The results of these seepage measurements quantify seepage gains and losses between elevations within stream channels. From 2018 to 2021, USGS staff conducted additional

[1] https://maps.waterdata.usgs.gov/mapper/index.html

seepage measurements on Waikapū Stream to better characterize the seepage gains and losses. These measurements are provided in Supplemental Table S3. Commission staff have made additional measurements on Wailuku River near Waiehu Beach Road (elevation 20ft) to improve the estimate of seepage loss between USGS 16605500 and the mouth (Table 6). Additionally, measurements were made on Waiehu Stream below the confluence (at CWRM 6-68) and at the mouth (Table 7). One seepage measurement was made on Waiheʻe River below the Spreckels Ditch at 330ft and at 50ft in elevation, but this did not account for any flow diverted at an intervening elevation at the Field 1 Intake (North Waiheʻe Auwai).

Monitoring of Diverted Streamflow

Monthly (from 2004-2016) and daily (2016-2023) measurements of diverted flow converted into mean monthly flow were submitted by Wailuku Water Company for the Waiheʻe Ditch below the Waiheʻe River intake and the Spreckels Ditch below the Waiheʻe River intake, the ʻĪao-Maniania Ditch and ʻĪao-Waikapū Ditch below the Wailuku River intake, and the South Waikapū Ditch below the South Waikapū Stream intake (Figure 3). These data were analyzed to provide context with regard to water withdrawn from surface water sources over time (Table 8).

Regulated Flow Conditions (Instream Flow Standard Monitoring)

Commission staff have monitored Waiheʻe River below Spreckels Ditch, Waiehu Stream below the confluence of North and South Waiehu, Wailuku River below Kepaniwai Park at ʻĪao Valley Rd, and Waikapū Stream at 915ft since 2014. The continuous records for these stations have been interrupted by flooding that altered the stream channel, caused extensive damage to the station, or resulted in the complete loss of a station multiple times over the years. For example, the September 13, 2016 Wailuku River flood eliminated the CWRM monitoring station below Kepaniwai Park. Streamflow monitoring was re-established in 2019 using a newly installed USGS gaging station (16605500). On February 18, 2018, a flood in Waiheʻe and Waiehu valleys eliminated the CWRM monitoring stations on both streams. These stations were re-established in July 2018, and March 2018, respectively. Table 9 provides flow statistics for each of these locations for the data available.

3. Hydrological Results

Trends in Monthly Rainfall

Total monthly rainfall for water years 2004-2023 for three rainfall stations in Nā Wai ʻEhā is provided in Figure 2. At the Waiheʻe Valley station, there was no significant trend in total dry season (Z = -0.35, Q = -2.268), wet season (Z = 1.12; Q = 9.121) or total annual rainfall (Z = 0.98, Q = 14.376). At the ʻĪao Valley station, there was no significant trend in total dry season rainfall (Z = 0.63, Q = 5.687), but there was a significant positive trend in total wet season (Z = 1.68; Q = 15.292) and total annual rainfall (Z =1.82, Q = 34.036), although this was primarily driven by the extreme rainfall events in 2016 and 2018. At the Waikapū Reservoir #1 station, there was no significant trend in dry season (Z = 0.49, Q = 2.997), wet season (Z = 1.12; Q = 16.211) or total annual rainfall (Z = 1.54, Q = 23.58).

Shifts in Low-Flow Statistics at Continuous-Record Stations Over Time

Continuous natural-flow monitoring stations in operation on Waiheʻe River and Wailuku River have demonstrated the continual decline in the magnitude of low-flows for West Maui (Tables 1 and 2). For the 2004-2023 period compared to the 1984-2007 period, there has been a 9.6%

decline in the magnitude of the median (Q_{50}) flow, 11.4% decline in the magnitude of the Q_{70} flow, and an 8.8% decline in the magnitude of the Q_{95} flow for Waihe‘e River.

For Wailuku River, there was a 12.8% decline in the magnitude of the median (Q_{50}) flow, a 11.1% decline in the magnitude of the Q_{70} flow, and a 11.8% decline in the magnitude of the Q_{95} flow in the 2004-2023 period compared to the 1984-2007 period.

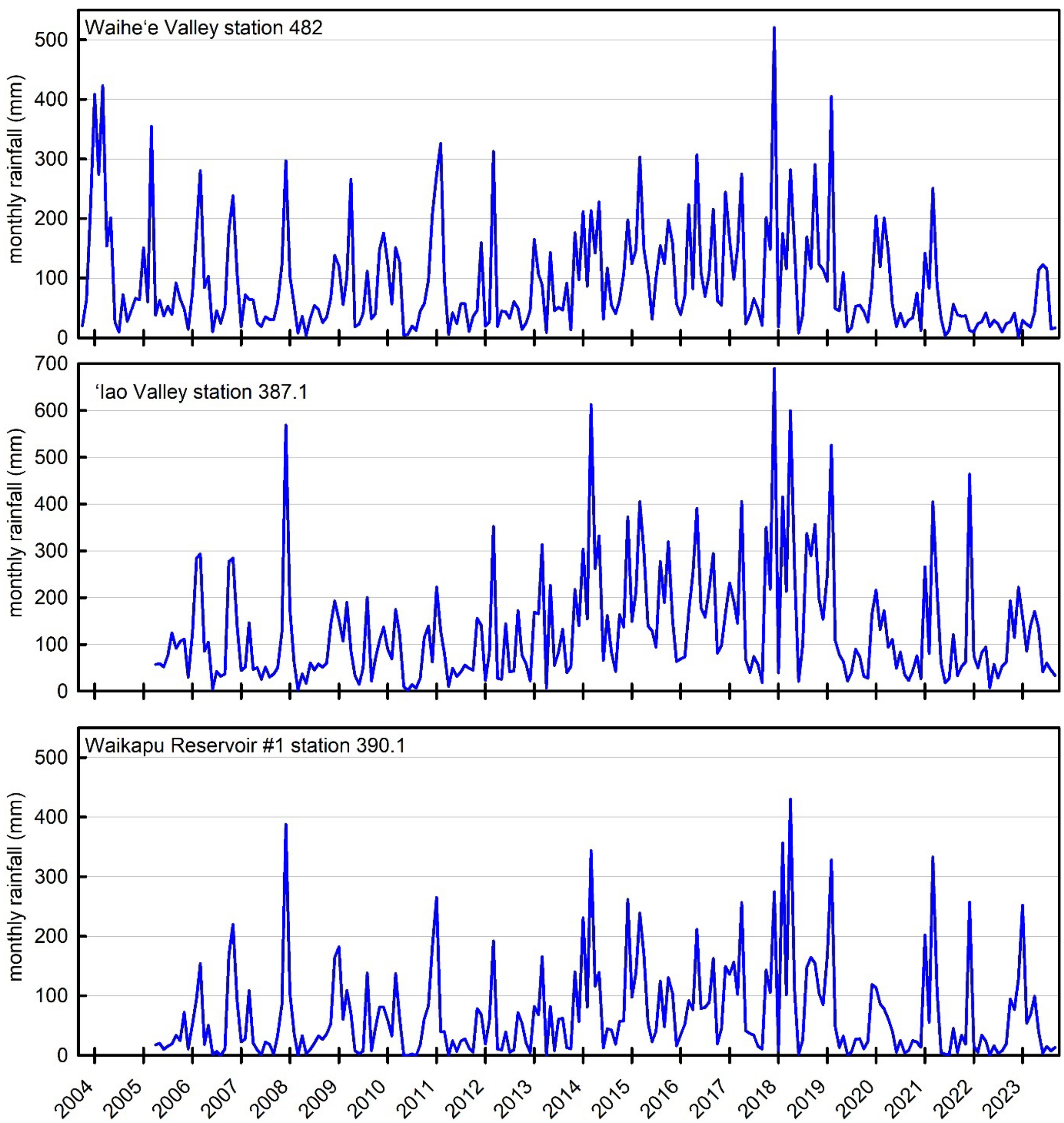


Figure 2. Monthly total rainfall (mm) for three stations in Nā Wai ‘Ehā, Maui.

Table 1. Low-flow characteristics in cubic feet per second (million gallons per day) in Waihe‘e River at USGS 16614000 at 610ft for varying periods of record.

Period of Record	Q_{50}	Q_{55}	Q_{60}	Q_{65}	Q_{70}	Q_{75}	Q_{80}	Q_{85}	Q_{90}	Q_{95}	Q_{99}
1984-2007[1]	52 (34)	50 (32)	48 (31)	46 (30)	44 (28)	43 (28)	41 (27)	39 (25)	37 (24)	34 (22)	28 (18)
1984-2013[2]	50 (32)	48 (31)	46 (30)	44 (28)	42 (27)	40 (26)	39 (25)	37 (24)	35 (23)	32 (21)	
2004-2023	47 (30)	44 (29)	42 (27)	40 (26)	39 (25)	37 (24)	36 (23)	35 (22)	33 (21)	31 (20)	29 (19)

[1]Oki et al., 2010 USGS SIR 2010-5011
[2]Cheng, 2016 USGS SIR 2016-5103

Table 2. Low-flow characteristics in cubic feet per second (million gallons per day) in Wailuku River at USGS 16604500 at 780ft for varying periods of record.

Period of Record	Q_{50}	Q_{55}	Q_{60}	Q_{65}	Q_{70}	Q_{75}	Q_{80}	Q_{85}	Q_{90}	Q_{95}	Q_{99}
1984-2007[1]	39 (25)	35 (23)	32 (21)	30 (19)	27 (17)	25 (16)	23 (15)	21 (14)	19 (12)	17 (11)	13 (8.4)
1984-2013[2]	36 (23)	33 (21)	30 (19)	28 (18)	26 (17)	24 (16)	22 (14)	20 (13)	18 (12)	16 (10)	
2004-2023	34 (22)	31 (20)	28 (18)	26 (17)	24 (15)	22 (14)	20 (13)	19 (12)	17 (11)	15 (10)	12 (7.7)

[1]Oki et al., 2010 USGS SIR 2010-5011
[2]Cheng, 2016 USGS SIR 2016-5103

Table 3. Low-flow characteristics in cubic feet per second (million gallons per day) in South Waiehu Stream at USGS 205426156313601 near 670ft (partial-record station) for varying periods of record and USGS 205427156312901 near 620ft (partial-record station) for the 2004-2023 period of record.

Period of Record	Q_{50}	Q_{55}	Q_{60}	Q_{65}	Q_{70}	Q_{75}	Q_{80}	Q_{85}	Q_{90}	Q_{95}	Q_{99}
1984-2007[1]	5.0 (3.2)	4.7 (3.0)	4.2 (2.7)	3.8 (2.5)	3.5 (2.3)	3.2 (2.1)	2.8 (1.8)	2.5 (1.6)	2.2 (1.4)	1.9 (1.2)	1.3 (0.84)
1984-2013[2]	2.5 (1.62)	2.5 (1.62)	2.5 (1.62)	2.5 (1.62)	2.4 (1.55)	2.4 (1.55)	2.4 (1.55)	2.3 (1.49)	2.1 (1.36)	2.0 (1.29)	
2004-2023[3]	4.3 (2.8)	4.0 (2.6)	3.8 (2.4)	3.5 (2.3)	3.4 (2.2)	3.2 (2.1)	3.0 (2.0)	2.9 (1.8)	2.7 (1.7)	2.5 (1.6)	2.2 (1.5)

[1]Oki et al., 2010 USGS SIR 2010-5011 at 670ft
[2]Cheng, 2016 USGS SIR 2016-5103 at 670ft
[3]partial-record station at 620ft operated from 2018-2021

Table 4. Low-flow characteristics in cubic feet per second (million gallons per day) in North Waiehu Stream at partial-record USGS stations (Oki et al., 2010) for varying periods of record.

Period of Record	Q_{50}	Q_{55}	Q_{60}	Q_{65}	Q_{70}	Q_{75}	Q_{80}	Q_{85}	Q_{90}	Q_{95}	Q_{99}
1984-2007[1]	4.9 (3.2)	4.6 (3.0)	4.3 (2.8)	4.1 (2.7)	3.8 (2.5)	3.5 (2.3)	3.2 (2.1)	3.0 (1.9)	2.6 (1.7)	2.3 (1.5)	1.5 (0.97)
2004-2023[2]	5.1 (3.3)	4.8 (3.1)	4.5 (2.9)	4.2 (2.7)	4.0 (2.6)	3.7 (2.4)	3.5 (2.3)	3.3 (2.1)	3.1 (2.0)	2.9 (1.9)	2.6 (1.7)

[1]Oki et al., 2010 USGS SIR 2010-5011 at 880ft
[2]partial-record station at 660ft operated from 2018-2021

Table 5. Low-flow characteristics in cubic feet per second (million gallons per day) in Waikapū Stream at 880ft (1984-2007) or 915ft (2004-2023) for varying periods of record.

Period of Record	Q_{50}	Q_{55}	Q_{60}	Q_{65}	Q_{70}	Q_{75}	Q_{80}	Q_{85}	Q_{90}	Q_{95}	Q_{99}
1984-2007[1]	8.6 (5.6)	8.2 (5.3)	7.7 (5.0)	7.3 (4.7)	7.0 (4.5)	6.7 (4.3)	6.3 (4.1)	6.0 (3.9)	5.6 (3.6)	5.1 (3.3)	4.1 (2.7)
2004-2023[2]	5.6 (3.6)	5.3 (3.4)	5.1 (3.3)	4.9 (3.2)	4.7 (3.1)	4.5 (2.9)	4.4 (2.9)	4.3 (2.8)	4.0 (2.6)	3.4 (2.2)	2.5 (1.6)

[1]Oki et al., 2010 USGS SIR 2010-5011 at 880ft
[2]partial-record station at 915ft operated from 2018-2023

Updated Low-Flow Statistics at Partial-Record Stations

The goodness-of-fit statistics for the partial-record stations are provided in Supplemental Table S2. For South Waiehu, the 2004-2023 estimated median (Q_{50}), baseflow (Q_{70}), and low (Q_{95}) flow was 0.7 cfs less, 0.1 cfs less, and 0.6 cfs more in flow, respectively, compared to the 1984-2007 period, representing a decline of 14.0%, a decline of 2.8%, and an increase of 32%, respectively. Differences in flows might represent changes in groundwater-surface water interactions or slight differences in catchment area represented by the lower elevation of the measurement site.

For North Waiehu, the 2004-2023 estimated median flow (Q_{50}), baseflow (Q_{70}), and low-flow (Q_{95}) were 0.2 cfs, 0.2 cfs, and 0.6 cfs greater compared to the 1984-2007 period, respectively. Oki et al. (2010) measured flow at the 880ft, above the North Waiehu Ditch intake. The more recent flow measurements were made by USGS at the 660ft elevation due to the abandonment of the North Waiehu Ditch intake. Thus, the increase in streamflow may be reflective of groundwater gains between the two elevations, greater catchment area contributing to flow, or both.

For Waikapū Stream, measurements were made at a location upstream of the one Oki et al. (2010) used (915ft vs 880ft) for the 2004-2023 period compared to the 1984-2007 period. Flow measurements made at both elevations represent regulated flow below the South Waikapū Ditch. Measurements presented here include simultaneous measurements of diverted flow in the South Waikapū Ditch. The magnitude of the estimated median flow (Q_{50}), baseflow (Q_{70}), and low-flow (Q_{95}) decreased by 3.0 cfs, 2.3 cfs, and 1.7 cfs, respectively. Because USGS did not explicitly account for flow diverted by the South Waikapū Ditch at the 1100ft elevation in their estimates, it is difficult to determine if the decline in flow is a result of declining rainfall in the area.

Seepage Change Calculations

Oki et al. (2010) estimated a total seepage loss on Wailuku River of approximately 8.7 cfs (5.6 mgd) between Kepaniwai Park and Waiehu Beach Rd. Based on more recent measurements, we estimate the seepage loss to be closer to 4.7 cfs (3 mgd). For Waiehu Stream between 190ft and the mouth, we measured a small gain in flow on two dates and a small loss in flow on the third date. It is possible that the small gain in flow is a result of the hoʻi (i.e., a traditional ʻauwai return flow) discharging water from Spreckels Ditch currently used by some permit holders for kalo cultivation. Oki et al. (2010) estimated a mean seepage loss of 2.26 cfs in Waiheʻe River between the 310ft elevation and the 45ft elevation. Commission staff measured 27.2 cfs on September 9, 2024 at 45ft and 34.5 cfs at 330ft in elevation, resulting in a seepage loss of approximately 7.3 cfs (4.7 mgd), although this does not account for any flow potentially diverted at the North Waiheʻe Auwai.

Table 6. Streamflow measurements in cubic feet per second (million gallons per day) on Wailuku River at Waiehu Beach Road following flow restoration below the ʻĪao-Waikapū Ditch diversion and concurrent streamflow on Wailuku River at USGS 16605500 at ʻĪao Valley Road.

Date	Wailuku River at ʻĪao Valley Road at USGS 16605500	Wailuku River at Waiehu Beach Road	Seepage Change
03/09/2022	6.8 (4.39)	3.9 (2.53)	-2.9 (1.86)
10/24/2023	6.7 (4.33)	2.3 (1.49)	-4.4 (-2.82)
02/22/2024	10.9 (7.04)	6.0 (3.88)	-4.9 (-3.17)
06/10/2025	9.4 (6.07)	4.1 (2.65)	-5.3 (-3.42)

Table 7. Streamflow measurements in cubic feet per second (million gallons per day) on Waiehu Stream near mouth and at 190ft elevation.

Date	Waiehu Stream at 190ft	Waiehu Stream near Mouth	Seepage Change
01/04/2021	6.1 (3.94)	6.9 (4.46)	+0.8 (+0.52)
08/08/2023	7.7 (4.98)	8.4 (5.43)	+0.7 (+0.45)
08/06/2024	5.7 (3.68)	5.4 (3.49)	-0.3 (-0.19)
06/04/2025	4.2 (2.72)	3.5 (2.24)	-0.7 (-0.48)

Diverted Flow and Current System Operations

From October 2004 to June 2014, daily diverted flow averaged approximately 29 mgd from Waiheʻe River, 28 mgd from Wailuku River, and 2 mgd from Waikapū Stream (Figure 4). Following the mediated agreement in 2014, which amended the interim IFS to Wailuku River and Waikapū Stream, in addition to the Waiheʻe and Waiehu interim IFS established in 2010, daily diverted flow declined to approximately 20 mgd (-27%) and 1.4 mgd (-28%), from Wailuku and Waikapū Streams, respectively (Table 8). With the cessation of irrigation water demand for sugarcane in June 2016, daily diverted flow declined to 19 mgd from Waiheʻe River, 6 mgd from Wailuku River, and 1 mgd from Waikapū Stream, with no water being diverted from Waiehu Stream into either Waiheʻe Ditch or Spreckels Ditch. At the same time, the use of Spreckels Ditch between Waiehu and the Hopoi Chute was discontinued. Expanded use of ditch water for diversified agriculture, including kalo cultivation, occurred during this period.

Between July 2016 and June 2021, when the 2021 D&O was released, mean diverted flow from the Waiheʻe River declined by 34% compared to the 2004-2014 period. Following the 2021 D&O, mean diverted flow in Waiheʻe River declined by 82.3% compared to the 2004-2014 period (Table 8). For Wailuku River, between July 2016 and June 2021, mean diverted flow declined by 79% compared to the 2004-2014 period, and after June 2021, mean diverted flow declined by 82%, compared to the 2004-2014 period.

The 2016 flood event in ʻĪao Valley carved a new channel around the ʻĪao-Maniania/ʻĪao-Waikapū ditch intake above Kepaniwai Park and filled the intake with gravel. While some of the intake capacity has been restored, there continues to be substantial mauka to makai flow past this intake to meet the interim IFS.

Following a flood event in Waiheʻe River in 2018, the two Waiheʻe Ditch intakes on Waiheʻe River at the 600ft elevation filled in with gravel. Subsequently, only the South Intake has been cleaned out, reducing the overall capacity of the Waiheʻe Ditch intake. Further, the flood waters carved a new channel in Waiheʻe River above the Spreckels Ditch intake, reducing the availability of water for off-stream use at this intake. As such, rarely does water have to be released from the Waiheʻe Ditch or the Spreckels Ditch to meet the downstream interim IFS, as sufficient water bypasses these two diversions.

The agricultural plan put forth by Mahi Pono will ramp up planting of diversified agriculture, resulting in a gradual increase in off-stream demand for irrigation water. Currently (2024), the irrigation needs of Mahi Pono's Maalaea fields can be met with water from Waiheʻe River via the Hopoi Chute from Waiheʻe Ditch, without the use of Spreckels Ditch. Only water distributed to the South Waiheʻe ʻAuwai and other permittees via Reservoir 40 is currently being served via the Spreckels Ditch, and any excess ditch water is discharged into South Waiehu Stream.

Only six other reservoirs are currently in use: Reservoir 1 from the South Waikapū Ditch; Reservoir 9 from the Waiheʻe Ditch; Reservoir 45 from the ʻĪao-Maniania Ditch; Reservoir 25 from the Spreckels Ditch, and Reservoirs 90 and 97 from the Waiheʻe Ditch. This has resulted in a reduction in seepage and evaporative loss from the system, but has also restricted the ability to store higher flow events for future use during low-flows.

Table 8. Total mean (standard deviation) daily flow diverted from Waiheʻe River via Waiheʻe Ditch and Spreckels Ditch, from Wailuku River via "Īao-Maniania Ditch, "Īao-Waikapū Ditch, and Spreckels Ditch, and from Waikapū Stream via South Waikapū Ditch for varying periods of time. [values provided in cubic feet per second (cfs) and in million gallons per day (mgd)]

period of record	Waiheʻe River Diverted Flow		Wailuku River Diverted Flow		Waikapū Stream Diverted Flow	
	cfs	mgd	cfs	mgd	cfs	mgd
10/2004-06/2014	44.7 (12.4)	28.89 (8.04)	42.7 (8.5)	27.59 (5.50)	2.9 (0.9)	1.89 (0.55)
07/2014-06/2016	45.4 (10.5)	29.32 (6.79)	31.2 (8.3)	20.19 (5.34)	2.1 (0.2)	1.39 (0.12)
07/2016-06/2021	29.3 (1.0)	18.95 (7.08)	8.9 (2.4)	5.78 (1.55)	1.4 (0.4)	0.88 (0.28)
07/2021-10/2023	7.9 (5.5)	5.09 (3.57)	7.7 (0.7)	4.98 (0.42)	0.5 (0.2)	0.35 (0.11)

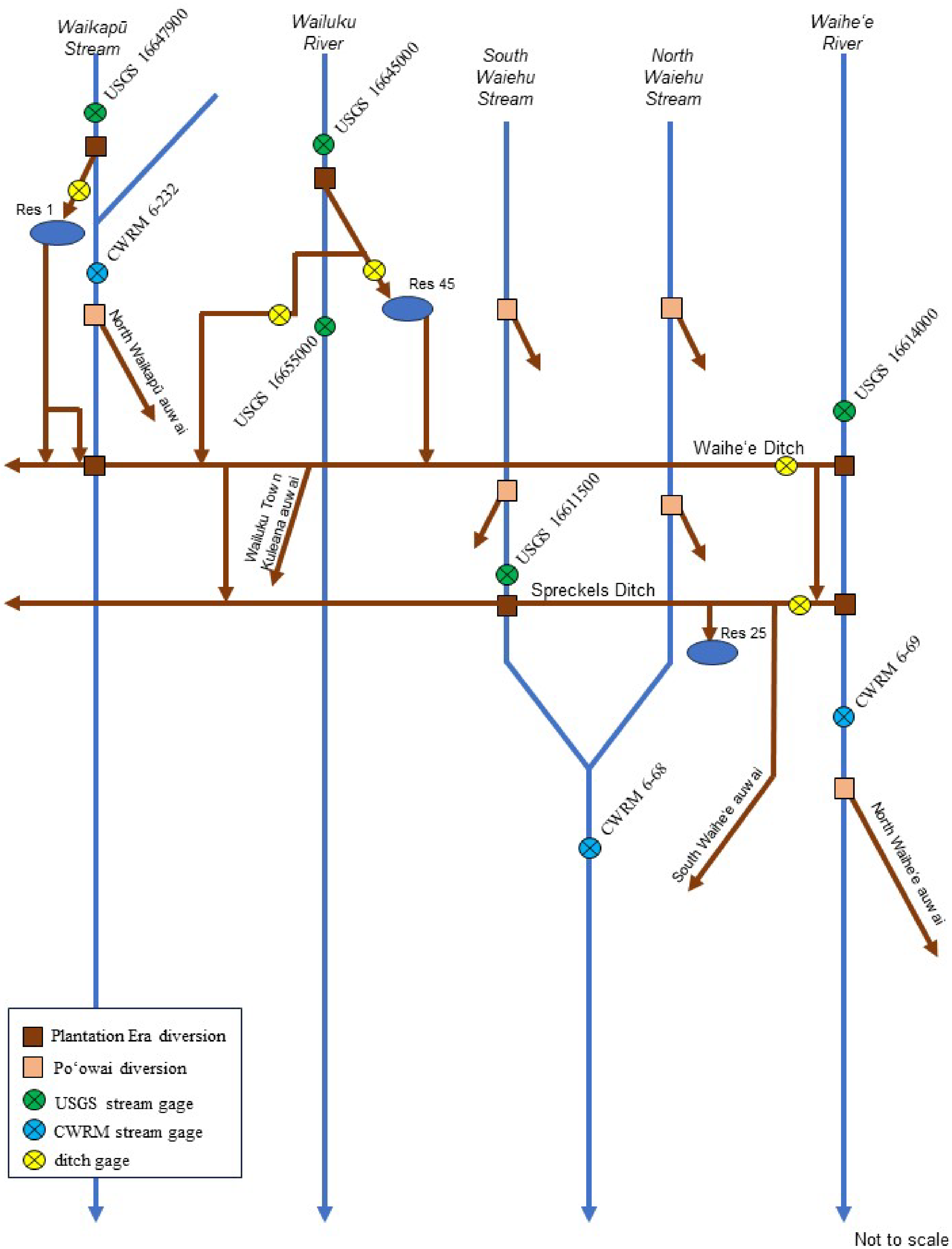


Figure 3. Schematic diagram of Nā Wai ʻEhā streams, plantation era and existing poʻowai diversions, ditches, and stream gages.

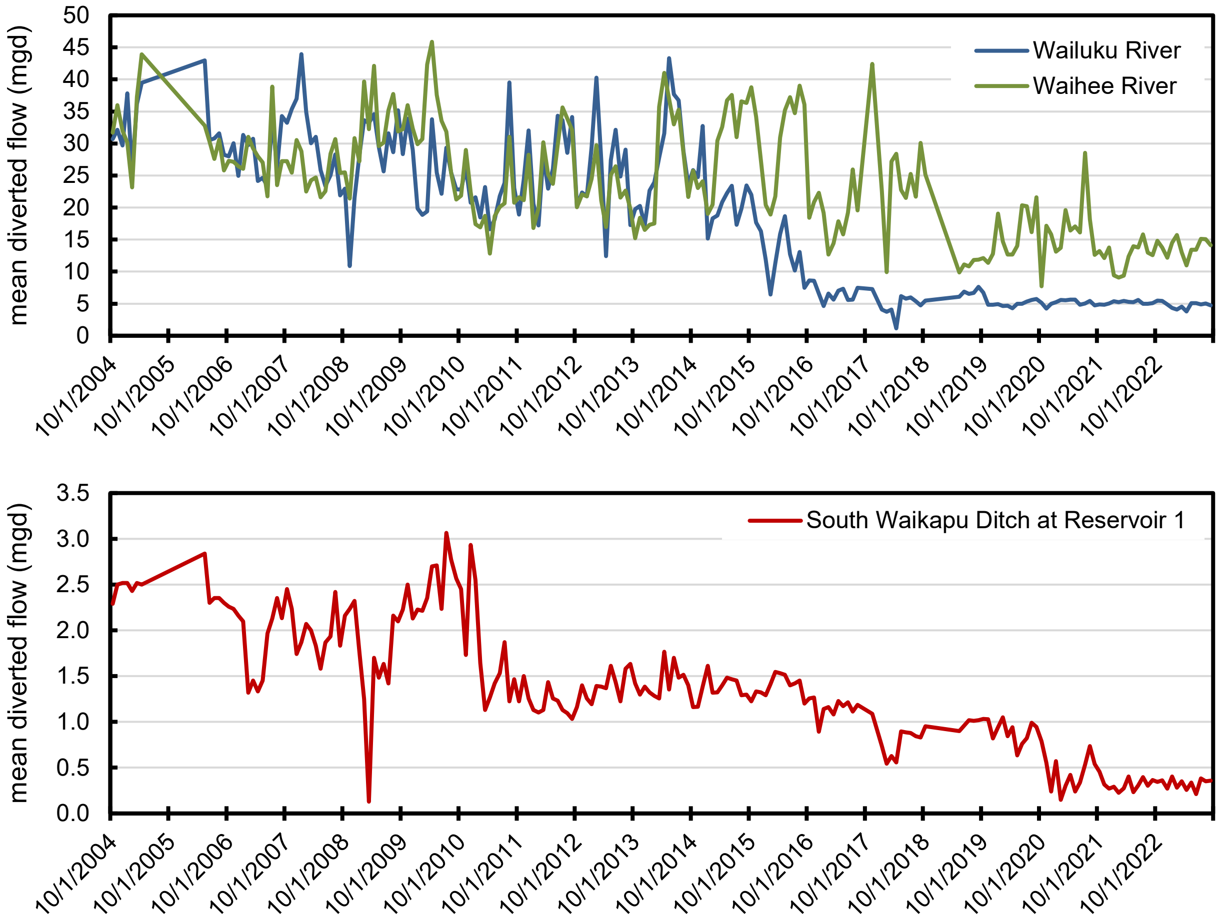


Figure 4. Total average daily diverted flow (in million gallons per day) from Wailuku River (total of ʻĪao-Maniania Ditch, ʻĪao-Waikapū ditches, and Spreckels Ditch) and Waiheʻe Rivers (total of Waiheʻe Ditch and Spreckels Ditch) (top) and South Waikapū Ditch at Reservoir 1 (bottom) by month for water years 2004 to 2023.

Implementation of Interim Instream Flow Standards

In 2009, the USGS located appropriate reaches in Waiheʻe and Waiehu streams downstream of the Spreckels Ditch intakes to cite continuous monitoring stations. Commission staff have operated continuous monitoring stations at approximately these locations since 2011, although records were interrupted by station malfunction or equipment damage due to flooding events numerous times. Flow duration statistics for various periods of time from these locations are provided in Table 9.

Table 9. Regulated flow conditions in Waiheʻe River at 300ft, Waiehu Stream at 190ft, and Wailuku River at 600ft for varying periods of time in cubic feet per second (million gallons per day)

Waiheʻe River blw Spreckels Ditch (at 330ft)									
Period of Record	**Q_{50}**	**Q_{60}**	**Q_{70}**	**Q_{75}**	**Q_{80}**	**Q_{85}**	**Q_{90}**	**Q_{95}**	**Q_{99}**
03/21/2011 – 03/24/2014	16.3 (10.5)	15.7 (10.2)	15.2 (9.8)	14.9 (9.6)	14.4 (9.3)	13.8 (8.9)	13.1 (8.4)	11.9 (7.7)	6.2 (4.0)
12/01/2014 – 12/11/2017	26.0 (16.8)	22.3 (14.4)	20.1 (13.0)	19.0 (12.3)	17.8 (11.5)	16.9 (10.9)	15.4 (10.0)	14.7 (9.5)	13.1 (8.4)
07/01/2018 – 09/30/2023	27.7 (17.9)	22.5 (15.5)	18.7 (12.1)	17.1 (11.0)	15.4 (10.0)	14.3 (9.3)	13.0 (8.4)	11.3 (7.3)	8.2 (5.3)
Waiehu Stream blw Confluence (at 190ft)									
Period of Record	**Q_{50}**	**Q_{60}**	**Q_{70}**	**Q_{75}**	**Q_{80}**	**Q_{85}**	**Q_{90}**	**Q_{95}**	**Q_{99}**
03/22/2011 – 06/30/2014	2.4 (1.5)	1.9 (1.2)	1.4 (0.91)	1.3 (0.82)	1.1 (0.71)	0.6 (0.40)	0.4 (0.28)	0.3 (0.17)	0.2 (0.12)
07/01/2014 – 12/06/2017	12.3 (7.9)	9.8 (6.3)	7.6 (4.9)	6.6 (4.3)	6.1 (3.9)	5.1 (3.3)	4.0 (2.6)	3.0 (1.9)	1.3 (0.81)
04/23/2018 – 09/30/2023	10.6 (6.9)	8.9 (5.8)	6.8 (4.4)	6.1 (3.9)	5.2 (3.4)	3.9 (2.5)	3.0 (2.0)	2.1 (1.3)	1.5 (1.0)
Wailuku River at ʻĪao Valley Rd (at 600ft)									
Period of Record	**Q_{50}**	**Q_{60}**	**Q_{70}**	**Q_{75}**	**Q_{80}**	**Q_{85}**	**Q_{90}**	**Q_{95}**	**Q_{99}**
11/20/2014 – 09/07/2016	45.7 (29.5)	35.0 (22.7)	26.0 (16.8)	21.2 (13.7)	18.3 (11.8)	16.2 (10.5)	14.4 (9.3)	13.1 (8.5)	6.0 (3.9)
10/01/2019 – 09/30/2023	20.8 (13.4)	17.4 (11.3)	15.0 (9.7)	13.7 (8.9)	12.5 (8.1)	11.1 (7.2)	9.5 (6.1)	7.9 (5.1)	5.2 (3.4)

5. Biological Data Collection

Background

While there is longitudinal zonation (i.e., elevational difference) within Hawaiian stream systems of the three most common stream species (i.e., *Sicyopterus stimpsoni*, *Lentipes concolor*, *Awaous stamineus*), it is not uncommon to find two or more species occupying the same habitat (Kinzie, 1988; Kido, 2013). This is not surprising since there is a narrow range of physical and biological resources available within Hawaiian stream systems and juveniles of all three species, and the adults of two species, are omnivores. Thus, there is potential for biotic interactions to structure stream communities independent of physical resource constraints mediated by streamflow restoration (Holitzki et al. 2013). Additionally, recruitment constraints for these species are limited to high waterfalls not found in Nā Wai ʻEhā, although poor habitat conditions driven by land use and non-native riparian species may lead to resource limitations.

Goal

Commission staff, in cooperation with the State of Hawaiʻi Division of Aquatic Resources (DAR), quantified habitat availability, population size and density, reproductive capacity, and various measures of community composition, to assess macrofauna under existing (2021-2024) restored flow conditions. In addition to the four streams in Nā Wai ʻEhā, identical surveys were conducted on Kahakuloa (to the north of Nā Wai ʻEhā) and Ukumehame (to the south of Nā Wai ʻEhā) as reference streams on Maui due to their similar hydrogeology, landcover, and flow regimes. Additionally, these streams are not currently affected by legacy plantation diversions and hydrological conditions are largely natural. Results are also anecdotally compared to two streams on the north shore of Kauaʻi with similar streamflow characteristics: Hanakāpiʻai Stream, which has a slightly greater gradient stream but undiverted; and Waioli Stream, which has a slightly lower gradient stream and is partially diverted.

Methods

Study Sites

Staff utilized a systematic method for quantifying habitat and populations of aquatic species targeting stream reaches at three specific starting elevations for comparison: 5-40ft, 200-330ft, and 600-660ft (Figure 4). Elevation ranges targeted stream reaches that were representative of habitat utilized by a wide range of endemic stream macrofauna: *Eleotris hawaiiensis*, *Stenogobius hawaiiensis*, *Kuhlia* spp. (*K. xenura* and *K. sandvicensis*) and *A. stamineus* regularly inhabit lower elevation reaches (<60 ft); while *S. stimpsoni*, *L. concolor*, and *A. stamineus* are usually found at higher (>200 ft) elevations.

Biological surveys were conducted from August to October in 2024 on Kahakuloa (at 5ft, 200ft, 600ft elevations), Waiheʻe River (at 40ft, 330ft, 600ft elevations), Waiehu Stream (at 5ft, 200ft, 600ft elevations), Wailuku River (at 20ft, 200ft, 660ft elevations), Waikapū Stream (at 20ft, 200ft, 600ft elevations) and Ukumehame Stream (at 5ft, 200ft, 600ft elevations). The 600ft-700ft elevation reaches were either at or upstream of plantation diversions on Waiheʻe, Waiehu, and Wailuku Rivers. Hanakāpīʻai and Waioli stream reaches were surveyed in July and November 2024 at 20ft, 200ft, and 400ft in elevation (Supplemental Figure S6).

Identical biological surveys were conducted in 2021 in Waiheʻe River (at 330ft, 600ft elevations), Waiehu Stream (at 5ft, 200ft elevations), and Wailuku River (at 20ft, 660ft elevations). Additionally, Waiehu Stream was surveyed in 2023 at 5ft and 200ft elevations. Hydrological characteristics of each surveyed reach for the 2021 and 2023 surveys are provided in Table 10.

Table 10. Characteristics of stream reaches surveyed in 2021 and 2023.
[Note: Ukumehame upper elevation survey conducted at 400ft in 2021 and 2023]

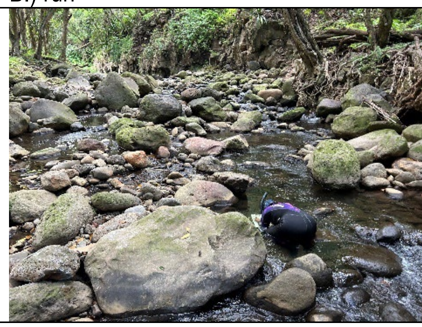
	Upper Reach		Middle Reach		Lower Reach	
2021	**Flow (ft^3s^{-1})**	**Temperature (°C)**	**Flow (ft^3s^{-1})**	**Temperature (°C)**	**Flow (ft^3s^{-1})**	**Temperature (°C)**
Waiheʻe	56.7	19.9	25.8	21.1		
Waiehu			6.1	21.0	6.9	20.2
Wailuku	35.4	19.9			3.9	19.6
Ukumehame	9.7	18.5	11.3	18.4	3.4	20.2
2023	**Flow (ft^3s^{-1})**	**Temperature (°C)**	**Flow (ft^3s^{-1})**	**Temperature (°C)**	**Flow (ft^3s^{-1})**	**Temperature (°C)**
Waiehu			7.7	23.8	8.5	23.5
Ukumehame	3.0	20.5	2.3	21.3	1.2	23.7

Visual Surveys

To quantify macrofauna population density, community composition, and habitat, we used the point-quadrat visual snorkel survey method as described by Higashi and Nishimoto (2007). Each survey utilized a stratified-random approach of approximately 200 m of stream channel. The stream channel was delineated at 10 m intervals by 20 perpendicular transects starting from the most downstream location and moving upstream. One point-quadrat survey was conducted on each transect at a randomly assigned location (left bank, middle channel, right bank). For 120 seconds, the number and estimated size of each species was counted. Both endemic amphidromous macrofauna (e.g., fish, crustaceans, mollusks) and non-native macrofauna were identified to the species and size estimates were made to the nearest half-inch (approximately one centimeter) and then converted to centimeters. Exceptions were made for non-native species due to time limitations, with species in the Poeciliidae Family identified to family as many introduced species within this family hybridize (Devick, 1991; Yamamoto and Tagawa, 2000). Also, two endemic species of the *Kuhlia* genus (*K. xenura* and *K. sandvicensis*) exist that are difficult to distinguish in situ and were classified together as *Kuhlia* spp.

After each survey, the perimeter of the quadrat was measured to calculate the area surveyed and the maximum depth of the quadrat was measured. The dominant habitat type (run, side pool, pool, riffle, cascade) was assigned to the quadrat (Table 11), and the quadrat's substrate type (e.g., bedrock, boulder, cobble, gravel, sand, silt, organic) and their proportions were estimated to the nearest 5%. 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, fruit deposition, and coarse woody debris 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 to the nearest 0.5 foot. Immediately after the entire survey was conducted, streamflow was measured using standard USGS techniques at an appropriate nearby location (Turnipseed and Sauer, 2010). Canopy cover (%) was estimated at every-other transect (10x) per survey using CanopyApp (version 1.0.3, University of New Hampshire) and averaged for the survey reach.

Table 11. Example habitats of riffle, run, and pool from Kahakuloa Stream.

A.) riffle	B.) run	C.) pool
		

Data Analysis

Habitat Characteristics

Due to the limited number of quadrats classified as side pool or cascade, these were reclassified for statistical analysis as pool or riffle, respectively. Statistical analyses in habitat were conducted among Maui stream reaches only due to their similar geology. Survey elevations were grouped into categories (lower, middle, upper) for subsequent analyses. Significant differences in the proportion of reaches classified as percent (%) riffle, % run, and % pool were determined using a chi-squared (X^2) test with expected proportions based on the arithmetic mean of all surveys within elevations. Similarly, statistical differences in substrate were tested using a X^2 test within elevations. Statistically significant differences in velocity and depth across elevations and streams were tested using a two-way analysis of variance (ANOVA) on square-root transformed data to pass the equal variances assumption and to reduce positive skewness in the distribution. Percent (%) canopy cover was compared to wetted width (WW) and active channel width (ACW) measured at the individual transect using a non-parametric Spearman rho (ρ) correlation analysis.

Habitat Suitability and Weighted Usable Area

Quadrat habitat suitability was determined based on suitability curves developed by Oki et al. (2010) and Gingerich and Wolff (2005) specifically on Maui streams for three species: *A. stamineus, S. stimpsoni,* and *L. concolor*. Calculations of quadrat suitability (S_q) for each species were based on the Froude (F) suitability, substrate (B) suitability, and depth (D) suitability (Supplemental Table S5). The Froude (F) value of a quadrat is a dimensionless ratio used to describe the bulk flow characteristics of water based on the relationship between depth and velocity as calculated by Gingerich and Wolff (2005). Quadrat suitability was thus calculated as:

$$S_q = F_q \times B_q \times D_q$$

and then averaged by reach (S_{reach}) for all (n = 20) quadrats:

$$S_{reach} = \frac{1}{n}\sum_{q=1}^{n} S_q$$

Total weighted usable area (WUA) per 100 m was calculated as the product of each species' reach suitability and the mean reach wetted width. The relationship between WUA and species density was calculated using a general linear model for log(x+1)-transformed density.

Species Density and Abundance

Species density was calculated by reach based on total surveyed area and total number of individuals per species. Because no native species were observed in Waikapū Stream, subsequent statistical analyses omitted this stream. Significant differences in density were tested across streams and reach elevations (as a categorical value) using a two-way ANOVA on log(x+1)-transformed values for each species. Density was transformed to address the large number of zero values and positive skewness. Estimated total abundance by species per 100 m of stream channel was then calculated based on mean reach wetted width (Figures 5 and 6). The densities of *Atyioda bisulcata* were not analyzed as the preferred habitat of this species is usually much steeper gradient, and higher elevation reaches than the maximum elevations studied here. For example, in East Maui, *A. bisulcata* are regularly found at elevations >1200ft (Strauch et al., 2022).

We also calculated a derivation of the Bray-Curtis community dissimilarity index for fish species called the normalized Canberra Distance (NCD) to compare each pair of streams (Ricotta and Podani, 2017). This index is not as sensitive to large abundances of rare species by using species-specific weight differences and species-wise differences are not exaggerated by squaring. The normalization occurs by dividing by the total number of fish species (e.g., 6) observed across all streams resulting in a range from 0 (identical) to 1 (completely dissimilar).

Assessment of Community Trophic Capacity

Trophic capacity is the ability of one stream to support multiple trophic levels, from producers to primary consumers to secondary consumers, and is constrained by population dynamics (Primm and Lawton, 1977). Shifts in the environment that affect the structure and availability of food and habitat will alter the community composition and proportionate species assemblage. We calculated the community-weighted average (CWA) trophic capacity as the proportionate numerical abundance of individual taxa in the sampled population multiplied by their respective weighting value as described in Kido (2013). Trophic value assigned to each species is provided in Supplemental Table S6. A lower value represents more specialized consumers, and a community dominated by *L. concolor* or *S. stimpsoni*, while a higher value represents more generalist species. These species are regularly used as indicators of healthy streams in Hawaiʻi (Kido, 2015). Finally, we calculated the combined relative abundance of *L. concolor* or *S. stimpsoni* as the total cumulative abundance of both species relative to the total observed number of macrofauna. Differences across streams were qualitatively described.

Table 12. Characteristics of stream reaches surveyed in 2024 (reach slope based on Tingley et al. (2019)
[note: Waioli and Hanakāpīʻai, Kauaʻi upper elevation surveyed at approximately 400ft]

Upper Reach	Order	Elevation (m)	Distance inland (km)	Catchment area (km²)	Slope (%)	Temp. (°C)	Flow (ft³s⁻¹)
Kahakuloa	2	180.1	3.41	7.14	13.5	22.4	1.9
Waiheʻe	2	184.4	4.70	11.0	5.2	20.9	38.0
North Waiehu	1	189.0	4.34	2.3	7.6	22.0	3.0
South Waiehu	1	182.9	4.84	2.7	5.4	20.9	1.9
Wailuku	3	201.2	7.10	15.9	6.1		23.5
Waikapū	2	182.9	12.9	8.6	8.0	20.6	12.0
Ukumehame	3	181.0	3.51	7.7	5.7	20.2	7.9
Hanakāpīʻai	3	118.3	1.43	7.2	7.0	19.3	14.7
Waioli	3	124.7	4.86	5.2	8.8	19.4	15.4
Middle Reach	**Order**	**Elevation (m)**	**Distance inland (km)**	**Catchment area (km²)**	**Slope (%)**	**Temp. (°C)**	**Flow (ft³s⁻¹)**
Kahakuloa	2	61.0	1.0	9.3	5.4	22.7	4.6
Waiheʻe	2	97.5	3.1	14.4	3.7	22.5	23.7
Waiehu	2	67.1	2.2	9.0	5.4	22.6	5.7
Wailuku	3	61.0	1.5	21.2	3.5	27.1	9.3
Waikapū	2	61.0	7.6	9.2	3.0	24.1	4.6
Ukumehame	3	54.9	1.5	10.3	4.4	21.5	3.5
Hanakāpīʻai	3	50.3	0.77	8.8	7.2	20.4	12.6
Waioli	3	51.8	3.52	7.6	5.1	22.0	26.1
Lower Reach	**Order**	**Elevation (m)**	**Distance inland (km)**	**Catchment area (km²)**	**Slope (%)**	**Temp. (°C)**	**Flow (ft³s⁻¹)**
Kahakuloa	2	1.5	0.01	10.6	4.1	23.1	2.78
Waiheʻe	2	9.1	0.20	18.0	4.2	23.4	27.2
Waiehu	3	1.5	0.02	12.1	2.4	22.3	5.4
Wailuku	3	6.1	0.80	28.0	1.6	28.4	12.8
Waikapū	2	6.1	1.83	18.0	1.1	22.4	4.0
Ukumehame	3	1.5	0.01	11.1	4.8	23.1	2.4
Hanakāpīʻai	3	7.9	0.03	9.6	5.5	19.3	7.2
Waioli	3	6.0	1.98	12.7	2.6	22.0	14.7

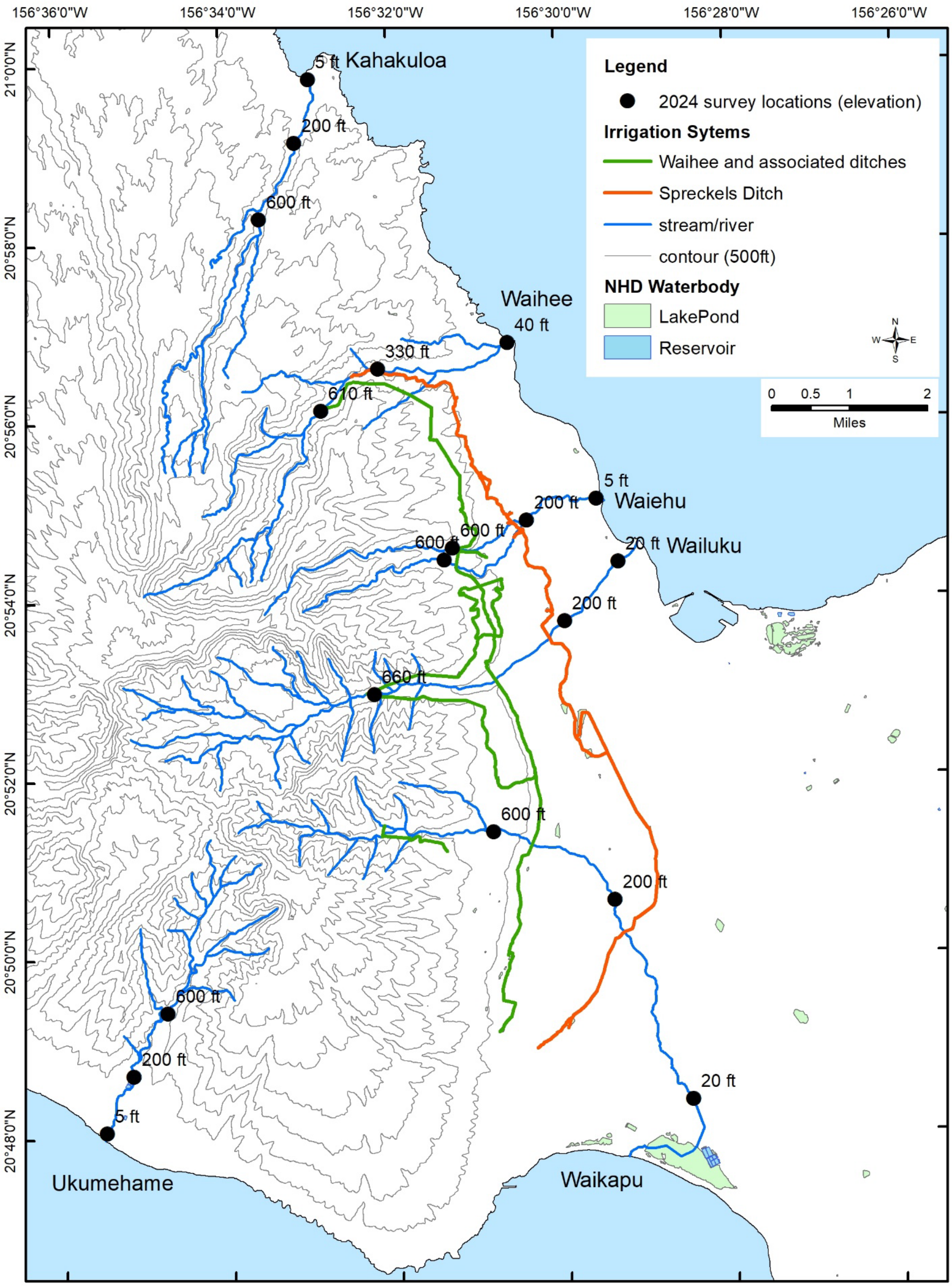


Figure 4. Kahakuloa, Waihe'e, Waiehu, Wailuku, Waikapū, and Ukumehame streams in West Maui with locations of biota surveys (starting elevation).

Reproductive Capacity

Reproductive capacity of a population is the theoretical maximum fecundity (i.e., number of offspring) produced in a given year. As a surrogate indicator, the proportion of reproductive adults (based on observed sizes) relative to the total number of individuals observed was used to estimate reproductive capacity. Individual species sizes were classified into post-larvae (<3 cm), juveniles (3 to 6 cm for *L. concolor* and *S. stimpsoni*; 3 to 8 cm for *A. stamineus*) and adults (> 6 cm for *L. concolor* and *S. stimpsoni;* > 8 cm for *A. stamineus*) based on Kido (2013), Kinzie (1988), and Gingerich and Wolff (2005). The entire stream was considered the population, and the proportion of adults was calculated relative to the total number of juveniles and adults (i.e., eliminating post-larvae individuals) observed across all surveys. We used a chi-squared (X^2) test to determine significant differences in reproductive capacity.

Historical Data

Staff from DAR conducted point-quadrant surveys spanning a variety of elevations in this region at previous periods of time (1995-2007). However, surveys were generally conducted across a wide range of dates, with few overlapping periods across streams, and efforts were not designed to be representative of a particular reach or elevation. For comparative purposes, Commission staff have used historic DAR data where possible, organized by reach elevation, with a minimum sample size of 10. The methods used by DAR to collect species abundance data are assumed to be the same as they followed the same survey protocol (Higashi and Nishimoto, 2007), however, the assumptions regarding the stratified-random approach may not have been followed. Due to differing sample sizes (from 13 to 38), the relatively small sample size in some years, and the potential difference in sampling method, we tested for statistical differences in density across years using a Kruskal-Wallis non-parametric ANOVA and a Dunn's post-hoc test for individual differences.

6. Biological Survey Results

Differences in Habitat Across Streams and Elevations

Table 13 and Table 14 provide general characteristics of each surveyed reach for the 2024 surveys. Both North and South Waiehu streams were surveyed in 2024, but only North Waiehu survey results were included in graphs and statistical analyses to maintain a balanced design. Mean wetted width was greatest in Waiheʻe and Wailuku Rivers and did not vary significantly with elevation for any stream (Table 13). Mean active channel width was also greatest in Waiheʻe and Wailuku Rivers followed by Kahakuloa, ranging across similar values.

Mean quadrat depth ranged from 19 cm to 48 cm across all locations. There was a significant effect of reach elevation ($F = 3.458$, $df = 2{,}342$, $p = 0.03$) and stream ($F = 13.383$, $df = 5{,}342$, $p < 0.001$) on quadrat depth, along with a significant interaction effect ($F = 3.142$, $df = 10{,}342$, $p < 0.001$) (Supplemental Table S4). Waiheʻe River had a significantly deeper mean depth compared to Waiehu ($p < 0.001$), Waikapū ($p < 0.001$), and Kahakuloa ($p = 0.022$). Overall, depths were greater in the lower and upper elevations of all streams compared to the middle elevations.

Mean quadrat velocity ranged from 0.12 to 0.45 m s^{-1}. There was a significant effect of elevation ($F = 4.715$, $df = 2{,}342$, $p < 0.01$), and stream ($F = 4.484$, $df = 5{,}342$, $p < 0.001$), and a significant interaction effect ($F = 2.272$, $df = 10{,}342$, $p = 0.013$) on velocity (Supplemental Table S4). The elevation effect was driven by a significant difference in mean velocities between upper and lower elevation sites ($p = 0.002$). Velocity increased at lower elevations in Kahakuloa, Waiheʻe, Waiehu, and Wailuku streams compared to upper elevations. The river effect was driven by a significant difference in mean velocity between Wailuku River and Kahakuloa Stream ($p < 0.001$).

The overall mean reach % canopy was 50.7%, although it ranged from 0.0% to 3.3% in Wailuku River and 78.6% to 91.1% in Ukumehame Stream (Table 13). Canopy cover was lowest in Wailuku River at all elevations as well as Waiheʻe River at middle and upper elevations. Percent canopy cover was inversely related to wetted width ($\rho = -0.498$, n = 180, $p < 0.001$) and active channel width ($\rho = -0.488$, n = 180, $p < 0.001$), although it also reflected the dominance of large, non-native riparian species in some reaches that produced a closed canopy, while the extent of urbanization produced an open canopy in other watersheds.

As is typical for young volcanic streams, boulder and cobble were the dominant substrate categories for all streams (Table 14). There was substantially more silt and organic debris in the lower Waikapū Stream compared to other streams, but this was not statistically significant ($X^2 = 4.00$, $df = 30$, $p > 0.05$). At middle elevations, Waiheʻe (40%), Wailuku (45%), and Kahakuloa (47%) had somewhat greater proportions of boulder compared to the other streams, but overall, this was not statistically significant ($X^2 = 1.46$, $df = 30$, $p > 0.05$). At the upper elevations, Ukumehame had the greatest proportion of cobble (74%) but, this was also not statistically significant ($X^2 = 1.65$, $df = 35$, $p > 0.05$). Similarly, there was no significant difference in habitat composition across streams at the lower elevations ($X^2 = 3.29$ $df = 10$, $p > 0.10$), middle elevations ($X^2 = 0.64$ $df = 10$, $p > 0.10$), or upper elevations ($X^2 = 0.69$ $df = 12$, $p > 0.10$). There were almost equivalent proportions of riffle and run across all streams and elevations, with a mean percent riffle habitat of 42.5%, 45.8%, and 41.4% at the lower, middle, and upper elevations, respectively (Table 14). Mean percent pool was 8.3% at the lower elevations, 4.2% at the middle elevations, and 15.3% at the upper elevations. Wailuku River at the lower elevation had a slightly greater proportion of riffle (75%), while Waikapū at the lower elevation had less riffle (25%).

Table 13. Mean (± standard deviation) stream channel characteristics (n = 20) of Kahakuloa, Waiheʻe, Waiehu, Wailuku, Waikapū, and Ukumehame streams on Maui and Hanakāpīʻai and Waioli streams on Kauaʻi at varying elevations in 2024, Hawaiʻi. [canopy = percent canopy cover; depth = maximum quadrat survey depth; velocity = quadrat water column velocity; WW = wetted width; ACW = active channel width]

Upper Reach	Canopy (%)	Depth (cm)	Velocity (m s^{-1})	WW (m)	ACW (m)
Kahakuloa	27.9 (±17.4)	36 (±26)	0.12 (±0.13)	6.7 (±2.2)	16.3 (±5.0)
Waiheʻe	6.1 (±11.9)	48 (±23)	0.17 (±0.15)	14.0 (±4.1)	20.3 (±5.3)
North Waiehu	68.9 (±19.8)	29 (±12)	0.19 (±0.19)	4.3 (±1.2)	8.4 (±2.4)
South Waiehu	80.8 (±12.1)	29 (±12)	0.26 (±0.24)	5.0 (±1.6)	11.0 (±2.1)
Wailuku	3.3 (±5.5)	39 (±20)	0.31 (±0.27)	12.6 (±4.2)	19.9 (±4.9)
Waikapū	68.6 (±15.1)	30 (±14)	0.26 (±0.19)	4.2 (±0.9)	9.2 (±2.0)
Ukumehame	82.1 (±9.2)	30 (±13)	0.36 (±0.24)	4.3 (±0.1)	9.4 (±0.3)
Hanakāpīʻai	14.7 (±12.7)	46 (±14)	0.28 (±0.21)	10.6 (±3.8)	17.3 (±4.0)
Waioli	37.7 (±12.7)	47 (±20)	0.36 (±0.27)	11.5 (±2.7)	16.8 (±1.9)
Middle Reach	**Canopy (%)**	**Depth (cm)**	**Velocity (m s^{-1})**	**WW (m)**	**ACW (m)**
Kahakuloa	47.6 (±13.8)	37 (±17)	0.18 (±0.14)	5.8 (±1.6)	13.3 (±3.1)
Waiheʻe	17.4 (±20.3)	35 (±12)	0.29 (±0.43)	11.8 (±2.2)	18.7 (±2.4)
Waiehu	62.0 (±25.1)	25 (±10)	0.29 (±0.31)	5.6 (±1.7)	9.4 (±1.7)
Wailuku	0	43 (±14)	0.29 (±0.28)	7.7 (±2.9)	14.5 (±3.6)
Waikapū	65.4 (±12.9)	24 (±8)	0.43 (±0.27)	4.3 (±0.9)	6.7 (±1.3)
Ukumehame	91.1 (±3.3)	25 (±10)	0.30 (±0.20)	3.8 (±1.2)	8.4 (±1.4)
Hanakāpīʻai	15.8 (±13.1)	44 (±13)	0.33 (±0.27)	9.2 (±2.4)	13.5 (±2.1)
Waioli	24.5 (±10.9)	42 (±22)	0.29 (±0.23)	14.6 (±4.7)	20.7 (±3.3)
Lower Reach	**Canopy (%)**	**Depth (cm)**	**Velocity (m s^{-1})**	**WW (m)**	**ACW (m)**
Kahakuloa	36.4 (±29.8)	29 (±12)	0.23 (±0.21)	6.8 (±2.0)	13.2 (±2.9)
Waiheʻe	66.8 (±26.0)	48 (±19)	0.37 (±0.42)	12.8 (±3.9)	23.8 (±4.4)
Waiehu	36.3 (±31.1)	27 (±11)	0.35 (±0.27)	4.3 (±1.2)	7.1 (±1.6)
Wailuku	0	26 (±12)	0.45 (±0.23)	8.2 (±2.1)	17.1 (±3.5)
Waikapū	67.8 (±24.1)	33 (±18)	0.22 (±0.15)	3.7 (±0.9)	5.6 (±1.6)
Ukumehame	78.6 (±15.1)	19 (±6)	0.25 (±0.16)	3.7 (±0.6)	7.5 (±1.3)
Hanakāpīʻai	10.6 (±9.1)	42 (±19)	0.15 (±0.18)	8.4 (±2.0)	15.1 (±1.7)
Waioli	25.6 (±19.1)	40 (±15)	0.33 (±0.29)	10.1 (±3.6)	13.8 (±2.8)

Table 14. Percent (%) reach classified as run, riffle, or pool habitat and percent reach substrate classification (n = 20) for Kahakuloa, Waiheʻe, Waiehu, Wailuku, Waikapū, and Ukumehame streams on Maui and Hanakāpīʻai and Waioli streams on Kauaʻi at varying elevations in 2024, Hawaiʻi. [note: substrate values do not add up to 100% due to the omission of other categories (i.e., bedrock, sand, silt)]

	Habitat			Substrate			
Upper Reach	**Run (%)**	**Riffle (%)**	**Pool (%)**	**Boulder (%)**	**Cobble (%)**	**Gravel (%)**	**Organic (%)**
Kahakuloa	50%	30%	20%	54.0%	32.5%	12.3%	0.0%
Waiheʻe	30%	50%	20%	38.3%	39.5%	21.3%	0.0%
North Waiehu	50%	30%	20%	33.0%	40.3%	26.0%	2.0%
South Waiehu	50%	45%	5%	21.0%	50.3%	28.3%	0.5%
Wailuku	30%	60%	10%	35.5%	45.8%	13.0%	0.0%
Waikapū	50%	30%	20%	28.5%	45.5%	14.0%	6.0%
Ukumehame	30%	65%	5%	10.3%	74.3%	10.5%	1.0%
Hanakāpīʻai	60%	35%	10%	58.0%	23.8%	8.8%	0.0%
Waioli	25%	70%	5%	56.8%	28.3%	7.3%	0.0%
Middle Reach	**Run (%)**	**Riffle (%)**	**Pool (%)**	**Boulder (%)**	**Cobble (%)**	**Gravel (%)**	**Organic (%)**
Kahakuloa	50%	40%	10%	47.0%	33.3%	10.5%	0.3%
Waiheʻe	35%	50%	15%	39.8%	46.3%	14.0%	0.0%
Waiehu	45%	55%	0%	9.3%	46.3%	19.8%	0.3%
Wailuku	55%	45%	0%	45.3%	47.3%	5.0%	0.0%
Waikapū	50%	50%	0%	6.5%	70.5%	12.5%	0.3%
Ukumehame	40%	60%	0%	21.8%	48.8%	23.3%	0.5%
Hanakāpīʻai	35%	55%	10%	53.3%	31.0%	7.3%	0.8%
Waioli	60%	25%	15%	41.0%	47.5%	7.3%	4.3%
Lower Reach	**Run (%)**	**Riffle (%)**	**Pool (%)**	**Boulder (%)**	**Cobble (%)**	**Gravel (%)**	**Organic (%)**
Kahakuloa	35%	55%	10%	42.5%	38.3%	18.8%	0.0%
Waiheʻe	50%	35%	15%	57.3%	29.3%	12.3%	0.3%
Waiehu	45%	55%	0%	9.3%	49.3%	31.0%	0.3%
Wailuku	25%	75%	0%	21.0%	61.8%	15.3%	0.0%
Waikapū	50%	25%	25%	28.5%	45.5%	14.0%	8.0%
Ukumehame	50%	50%	0%	5.5%	62.5%	23.0%	3.8%
Hanakāpīʻai	45%	15%	40%	36.0%	53.8%	4.8%	2.8%
Waioli	25%	70%	5%	38.0%	45.3%	13.8%	2.3%

Weighted Usable Area

In the 2024 surveys, Waiheʻe River had the greatest amount of suitable habitat per 100 m for each of the three species modeled at all elevations (Table 15). The stream with the second most suitable habitat was Wailuku River, with about 25% less suitable habitat than Waiheʻe River at the 600ft elevation reach, about 30% less habitat at the 200ft elevation reach, and about 50% less habitat at the lower elevation reach. At all elevations, more habitat was suitable for *A. stamineus*, followed by *S. stimpsoni*, and then *L. concolor*. Wailuku River compared favorably in terms of habitat area supported relative to either Hanakāpīʻai or Waioli for *A. stamineus*, *S. stimpsoni*, and *L. concolor* at all three elevations. Overall, there was a significant positive relationship between available habitat and species density for *A. stamineus* ($F = 249$, $df = 1,24$, $p < 0.001$) and for *L. concolor* ($F = 5.899$, $df = 1,24$, $p < 0.05$), but not for *S. stimpsoni* ($F = 0.671$, $df = 1,24$, $p > 0.05$). *Sicyopterus stimpsoni* may be more sensitive to canopy cover and substrate composition due to their reliance on algae grown on large boulders as a food resource (Kido, 1996) .

Differences in Species Density Across Streams and Elevations

Eleotris sandwicensis (ʻoʻopu ʻakupa) were only observed in low-elevation reaches of Wailuku, Waiehu, and Waiheʻe streams, with 2024 densities of 0.28 m^{-2}, 0.15 m^{-2}, and 0.09 m^{-2}, respectively. *Stenogobius hawaiiensis* (ʻoʻopu naniha) were not observed in any stream in 2024. Across all six streams, the following species were used for subsequent analyses: *A. stamineus* (ʻoʻopu nākea), *S. stimpsoni* (ʻoʻopu nōpili), *L. concolor* (ʻoʻopu alamoʻo), *N. granosa* (hīhīwai), and *M. lar* (Tahitian Prawn).

Overall, *A. stamineus* and *S. stimpsoni,* had the greatest densities in the middle elevation reaches, while *L. concolor* and *N. granosa* had the greatest densities at upper elevation reaches, and *M. lar* had the greatest densities at lower elevation reaches (Table 16). *Macrobrachium lar* was the only species observed in all streams. Waikapū was the only stream with no native species observed and *M. lar* was only observed in Waikapū Stream at the lower elevation survey. Statistical results for the 2-way ANOVA by species are provided in Supplemental Table S7. Estimates of total species abundance per 100 m of stream channel are provided in Figure 5 for *A. stamineus*, *S. stimpsoni*, and *L. concolor*, while estimated total species abundance per 100 m of stream channel for *N. granosa* and *M. lar* are provided in Figure 6.

Awaous stamineus density varied significantly across streams and elevations, but statistically significant differences were limited to the middle elevation reaches (Supplemental Table S7): Wailuku River had a significantly ($p < 0.01$) greater density compared to all other locations at the middle elevation reach. Densities of *A. stamineus* in Waioli and Hanakāpīʻai streams were similar to Maui streams at all comparable elevations (Table 16).

Sicyopterus stimpsoni density varied significantly across streams and elevations, with significant ($p < 0.001$) differences across streams at each elevation (Supplemental Table S7). Density was greatest in Waiheʻe River at both middle and upper elevation reaches, followed by Kahakuloa, Wailuku, and Ukumehame (Table 16). At the lower elevation reaches of Kahakuloa, Waiheʻe, Wailuku, and Ukumehame, density of *S. stimpsoni* was also high, reflecting the abundance of new recruits to the streams (i.e., juveniles were more common). Compared to Maui streams, densities were greater in Hanakāpī‘ai Stream at middle and lower elevations, while densities in Waioli Stream were less.

Lentipes concolor density varied significantly with stream and elevation, although significant differences across streams was limited to upper elevation reaches (Supplemental Table S7). Density was greatest in upper elevation reaches in the Waihe‘e River, followed by Wailuku River, Kahakuloa Stream, and Waiehu Stream (Table 16). The densities of *L. concolor* in Hanakāpī‘ai and Waioli streams on Kaua‘i were similar to those on Maui in the upper elevation reaches, but Hanakāpī‘ai Stream had slightly greater densities in the middle and lower elevation reaches.

Neritina granosa was largely absent from most locations. The greatest density of *N. granosa* was observed at the upper elevation reach of Kahakuloa Stream, followed by North Waiehu Stream, and Ukumehame Stream (Table 16). Densities of *N. granosa* varied significantly across stream and elevation, although differences in the density of *N. granosa* were only statistically significant for upper elevation reaches (Supplemental Table S7). Hanakāpī‘ai and Waioli streams had similarly variable densities of *N. granosa* at all elevations.

Macrobrachium lar density was greatest in the lower reaches of all streams and declined in the middle and upper elevation reaches, with the exception of greater densities in Waiehu and Wailuku streams at the middle elevation reaches (Table 16). Hanakāpī‘ai and Waioli streams had densities similar to the Maui streams at all elevations.

The fish community in Waihe‘e River was most similar (i.e., had the lowest NCD) compared to Kahakuloa (0.34) and Hanakāpī‘ai (0.37). Wailuku River was most similar to Waihe‘e (0.59) and Waiehu (0.60) streams. Other stream pairs with low NCD were Ukumehame and Kahakuloa (0.47), Ukumehame and Hanakāpī‘ai (0.56), Hanakāpī‘ai and Kahakuloa (0.33), Waiehu and Waioli (0.51).

Table 15. Total weighted usable area (m^2) based on mean habitat suitability and mean wetted width per 100 m of reach for *A. stamineus*, *S. stimpsoni*, and *L. concolor* in Kahakuloa, Waiheʻe, Waiehu, Wailuku, Waikapū and Ukumehame streams on Maui and Hanakāpīʻai and Waioli streams on Kauaʻi at varying elevations in 2024.

Upper Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***
Kahakuloa	373.9	229.9	72.6
Waiheʻe	1077.2	656.0	410.1
North Waiehu	306.1	204.2	66.1
Wailuku	800.2	509.8	301.0
Waikapū	218.3	161.7	40.3
Ukumehame	61.1	25.5	2.4
Hanakāpīʻai	680.5	524.8	120.9
Waioli	609.4	370.7	87.0
Middle Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***
Kahakuloa	432.1	306.0	129.5
Waiheʻe	832.2	705.1	214.4
Waiehu	258.6	193.4	21.3
Wailuku	598.7	439.7	176.1
Waikapū	211.0	139.0	9.8
Ukumehame	192.2	147.8	30.9
Hanakāpīʻai	472.4	363.2	69.2
Waioli	849.3	558.9	103.2
Lower Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***
Kahakuloa	432.1	215.6	116.5
Waiheʻe	845.9	573.4	328.3
Waiehu	232.3	164.4	12.1
Wailuku	410.7	276.7	44.5
Waikapū	115.9	79.9	12.3
Ukumehame	171.5	102.0	11.1
Hanakāpīʻai	411.1	216.6	44.7
Waioli	480.5	291.3	59.1

Table 16. Mean density (± standard deviation) by species for visual surveys (n = 20) in Kahakuloa, Waiheʻe, Waiehu, Wailuku, Waikapū and Ukumehame streams in Maui and Hanakāpīʻai and Waioli streams on Kauaʻi at varying elevations in 2024, Hawaiʻi. For species that had significantly different densities across Maui streams within elevation groups, statistical results are provided with superscripts representing streams that are significantly different from each other based on Tukey post-hoc analysis after a 2-way ANOVA on log-transformed values. [note: Waikapū and South Waiehu were not included in statistical analyses; Waioli and Hanakāpīʻai upper elevation reaches surveyed at approximately 400ft]

Upper Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***	***N. granosa***	***M. lar***
Kahakuloa	0.40 (±1.04)	3.27 (±4.10)^{ab}	1.34 (±1.54)^{b}	0.98 (±1.78)^{a}	0.78 (±1.38)
Waiheʻe	0.64 (±0.23)	5.93 (±1.27)^{a}	2.99 (±0.71)^{a}	0.00^{b}	0.13 (±0.09)
North Waiehu	0.40 (±0.22)	0.00^{b}	0.33 (±0.17)^{c}	0.81 (±0.57)^{a}	0.53 (±0.26)
South Waiehu	0.32 (±0.21)	0.23 (±0.17)	1.50 (±0.44)	0.00	0.41 (±0.29)
Wailuku	1.20 (±0.38)	0.00^{b}	1.78 (±1.49)^{bc}	0.00^{b}	0.09 (±0.09)
Waikapū	0.00	0.00	0.00	0.00	0.00
Ukumehame	0.20 (±0.11)	2.17 (±0.80)^{b}	0.19 (±0.16)^{c}	0.14 (±0.11)^{b}	0.08 (±0.08)
Hanakāpīʻai	0.50 (±0.77)	7.45 (±5.16)	2.26 (±2.01)	0.11 (±0.50)	0.20 (±0.50)
Waioli	2.18 (±2.24)	0.97 (±1.07)	0.46 (±0.81)	0.00	0.18 (±0.56)
Middle Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***	***N. granosa***	***M. lar***
Kahakuloa	0.92 (±0.66)^{b}	6.68 (±1.26)^{a}	0.37 (±0.21)	0.10 (±0.10)	1.61 (±0.54)^{a}
Waiheʻe	0.45 (±0.18)^{b}	7.73 (±1.49)^{a}	0.38 (±0.26)	0.00	0.26 (±0.12)^{b}
Waiehu	1.08 (±0.45)^{b}	0.66 (±0.45)^{b}	0.00	0.00	1.97 (±0.88)^{a}
Wailuku	3.87 (±0.98)^{a}	0.85 (±0.57)^{b}	0.00	0.00	2.41 (±0.60)^{a}
Waikapū	0.00	0.00	0.00	0.00	0.08 (±0.08)
Ukumehame	0.06 (±0.06)^{b}	1.31 (±0.55)^{b}	0.00	0.00	1.44 (±0.65)^{a}
Hanakāpīʻai	0.54 (±1.08)	14.3 (±12.3)	1.03 (±1.29)	1.80 (±3.31)	1.82 (±2.35)
Waioli	5.81 (±3.96)	2.01 (±3.64)	0.00	0.00	0.88 (±1.80)
Lower Reach	***A. stamineus***	***S. stimpsoni***	***L. concolor***	***N. granosa***	***M. lar***
Kahakuloa	0.19 (±0.59)	5.66 (±6.27)^{a}	0.00	0.00	3.55 (±4.30)^{a}
Waiheʻe	0.25 (±0.12)	1.28 (±0.39)^{b}	0.00	0.00	1.27 (±0.42)^{ab}
Waiehu	0.15 (±0.15)	0.00^{b}	0.00	0.00	0.80 (±0.49)^{b}
Wailuku	0.78 (±0.29)	0.31 (±0.17)^{b}	0.00	0.14 (±0.14)	0.79 (±0.37)^{b}
Waikapū	0.00	0.00	0.00	0.00	0.00
Ukumehame	0.31 (±0.31)	0.81 (±0.47)^{b}	0.00	0.33 (±0.26)	2.10 (±0.52)^{ab}
Hanakāpīʻai	0.91 (±1.63)	21.6 (±19.7)	0.12 (±0.53)	0.00	1.09 (±1.60)
Waioli	0.43 (±0.70)	0.97 (±2.64)	0.00	0.00	0.59 (±1.20)

Community Trophic Capacity and Reproductive Capacity Across Streams

Non-native species composed the entirety of the aquatic macrofauna community in Waikapū Stream and were the dominate species in Waiehu Stream, especially at the lower and middle elevations. *Macrobrachium lar* were present in all streams at all elevations except Wailuku River at the upper reach. The relative abundance of *M. lar* was lowest in the upper elevation reaches, and in the Waihe‘e and Wailuku Rivers at all elevations (Figure 7).

Trophic capacity ranged widely across streams due to the differing abundances of native and non-native species. The sites with the best trophic capacity were Waihe‘e River at the upper (1.36) and middle elevations (1.47) followed by Wailuku River at the upper elevation (2.28) and South Waiehu Stream at the upper elevation (2.96) (Table 17). The four locations with the poorest measures of trophic capacity were Waikapū Stream at all elevations followed by Waiehu Stream at the middle elevation (7.11). Combining all surveys within a stream, the mean trophic capacity was best for Waihe‘e River (2.35) and then Kahakuloa (3.15), with similar values for Waiehu (4.32), Wailuku (4.49), and Ukumehame (4.53), followed by Waikapū (10.0). The Hanakāpī‘ai Stream trophic capacity was similar to Waihe‘e River. Non-native species were more common in Waioli Stream compared to Hanakāpī‘ai, resulting in a trophic capacity similar to Wailuku River.

Table 17. Community weighted average trophic capacity by stream and elevation. [note: North Waiehu / South Waiehu Upper Reach]

Stream	Lower Reach	Middle Reach	Upper Reach	Mean
Kahakuloa	3.65	3.10	2.70	3.15
Waihe‘e	4.21	1.47	1.36	2.35
Waiehu	3.10	7.11	4.13 / 2.96	4.32
Wailuku	5.55	5.65	2.28	4.49
Waikapū	10.0	9.99	10.0	10.0
Ukumehame	6.44	4.95	2.21	4.53
Hanakāpī‘ai	1.56	2.01	1.33	1.63
Waioli	5.26	4.03	3.14	4.14

The total observed percentage of adults ranged widely by species and stream (Table 18). The reproductive capacity, based on percentage of adults, of *A. stamineus* was greatest for Waiehu, Waihe‘e, Hanakāpī‘ai, and Ukumehame. For *S. stimpsoni*, the reproductive capacity was greatest for Waihe‘e, Ukumehame, and Kahakuloa. For *L. concolor*, the reproductive capacity was greatest for Waihe‘e, Waiehu, and Waioli streams. The combined relative abundance of *S. stimpsoni* and *L. concolor* was greatest in the Waihe‘e River at the upper (90.2%) and middle (89.7%) elevation reaches, followed by the upper elevation reach for South Waiehu Stream (68.0%), Wailuku River (60.4%), and Kahakuloa Stream (59.6%). Hanakāpī‘ai Stream had similarly high relative abundances of *S. stimpsoni* and *L. concolor* at all elevations (91.7% at upper elevation, 76.3% at middle elevation, 88.2% at lower elevation), while Waioli Stream had lower abundances (33.8% at upper elevation, 22.0% at middle elevation, 28.6% at lower elevation).

Table 18. Total number of juveniles and adults by species and proportion of the population as adults for each stream based on three surveys at varying elevations.

	A. stamineus			*S. stimpsoni*			*L. concolor*		
	juvenile	**adult**	**%adult**	**juvenile**	**adult**	**%adult**	**juvenile**	**adult**	**%adult**
Kahakuloa	10	1	9.1%	83	38	31.4%	13	4	23.5%
Waiheʻe	10	10	50.0%	103	81	44.0%	9	35	79.6%
Waiehu	2	7	77.8%	2	0	0.0%	3	12	80.0%
Wailuku	40	15	27.3%	8	3	27.3%	24	5	17.2%
Waikapū	0	0	0	0	0	0	0	0	0
Ukumehame	1	6	77.8%	17	11	39.3%	1	0	0
Hanakāpīʻai	9	13	59.1%	209	43	17.1%	26	17	39.5%
Waioli	60	44	42.3%	7	3	30.0%	4	5	55.6%

Comparison of Species Density Over Time

Waiheʻe River

In 1995, DAR conducted 34 point-quadrat surveys in Waiheʻe River in the 600-700ft elevation range with mean (± SD) densities of *S. stimpsoni* 0.38 (± 1.15) # m^{-2}, *A. stamineus* 1.39 (± 1.57) # m^{-2}, and *L. concolor* 5.45 (± 10.2) # m^{-2} (Supplemental Table S8). By comparison, in 2021 and 2024, we observed a mean (± SE) density of *L. concolor* of 1.59 (± 0.39) # m^{-2} and 2.99 (± 0.71) # m^{-2}, respectively, while *S. stimpsoni* density was 0.62 (± 0.25) # m^{-2} and 5.93 (± 1.27) # m^{-2}, respectively, and *A. stamineus* density was 0.30 (± 0.18) # m^{-2} and 0.64 (± 0.23) # m^{-2}, respectively (Figure 7). Across sampling years, there was a significant difference in density at the 600-700ft elevation for *A. stamineus* (K-W ANOVA $H = 17.395$, $df = 3$, $p < 0.001$), *S. stimpsoni* (K-W ANOVA $H = 40.985$, $df = 3$, $p < 0.001$), and *L. concolor* (K-W ANOVA $H = 8.533$, $df = 3$, $p = 0.036$).

In the 300-400ft elevation range on Waiheʻe River, DAR conducted 13 surveys in 1995 with a mean ± SD) density of *S. stimpsoni* of 3.44 (± 2.11) # m^{-2}, *A. stamineus* of 0.67 (± 0.97) # m^{-2}, and *L. concolor* 1.25 (± 1.31) # m^{-2} (Supplemental Table S8). By comparison, in 2021 and 2024, we observed a mean (± SD) density of *S. stimpsoni* of 7.89 (± 6.52) # m^{-2} and 7.73 (± 1.49) # m^{-2}, of *A. stamineus* of 0.11 (± 0.35) # m^{-2} and 0.45 (± 0.18) # m^{-2}, and of *L. concolor* of 0.35 (± 0.65) # m^{-2} and 0.38 (± 0.26) # m^{-2}, respectively (Figure 7). Across sampling years, there was a significant difference in density at the 300-400ft elevation for *A. stamineus* (K-W ANOVA $H = 13.674$, $df = 2$, $p = 0.001$) and *S. stimpsoni* (K-W ANOVA $H = 6.424$, $df = 3$, $p = 0.04$), but not for *L. concolor* (K-W ANOVA $H = 2.722$, $df = 2$, $p = 0.256$).

Waiehu Stream

In Waiehu Stream at the 200ft elevation, there was no flow in the stream until restoration in 2010, and therefore no prior surveys were conducted at this elevation. From 2021 to 2024, there was no significant difference in *A. stamineus* (K-W ANOVA $H = 0.55$, $df = 2$, $p > 0.05$) or *S. stimpsoni* (K-W ANOVA $H = 0.70$, $df = 2$, $p > 0.05$) density among years.

From 2021 to 2024 in the lower elevation (5ft) reach of Waiehu, we observed no change in *S. stimpsoni* (K-W ANOVA $H = 0.09$, $df = 3$, $p > 0.05$), *S. hawaiiensis* (too few to compare), or *A. stamineus* (K-W ANOVA $H = 0.52$, $df = 3$, $p > 0.05$), but a steady increase in *Kuhlia* spp. (K-W ANOVA $H = 9.05$, $df = 3$, $p < 0.05$),. In 2005, DAR conducted 25 surveys in Waiehu Stream above the stream mouth in the lower reach up to an elevation of 40 ft. In these surveys, *Poeciliidae* spp. were the most abundant (mean ± SD) (38.38 ± 71.37 # m^{-2}) followed by *Kuhlia* spp. (9.91 ± 26.06 # m^{-2}), and *A. stamineus* (8.52 ± 21.56 # m^{-2}), *S. stimpsoni* (7.15 ± 19.21 # m^{-2}) and *S. hawaiiensis* (1.57 ± 3.73 # m^{-2}) (Supplemental Table S8). Following flow restoration, *Poeciliidae* spp. abundance declined to 0.26 (± 0.80) # m^{-2} in 2021, 0.08 (± 0.08) # m^{-2} in 2023, and 0.30 (± 1.01) # m^{-2} in 2024, although this was not statistically significant (K-W ANOVA H = 2.26, df = 3, $p > 0.05$). There was no statistically significant change in *A. stamineus* (K-W ANOVA H = 0.519, df = 3, $p > 0.05$), and *S. hawaiiensis*, although the former may have moved further upstream with increased streamflow and the latter has consistently low densities (Figure 8). However, the abundance of *Kuhlia* spp. did vary significantly (K-W ANOVA H = 9.045, df = 3, $p < 0.05$) over time. Pre-restoration densities may be greater than expected due to the limited availability of habitat, restricting new recruits to small areas of flowing water.

Wailuku River

DAR conducted surveys in 2005 (n = 46) at approximately the same 600-700ft elevation on Wailuku River. In 2005, the Wailuku River upper reach (mean ± SD) was dominated by non-native Physid snails (5.24 ± 17.97 # m^{-2}) and Poeciliidae sp. (18.20 ± 33.67 # m^{-2}), whereas endemic *S. stimpsoni* (0.36 ± 1.28 # m^{-2}), *A. stamineus* (0.35 ± 1.40 # m^{-2}), and *L. concolor* (0.17 ± 0.99 # m^{-2}) were relatively rare (Supplemental Table S8). By contrast, following flow restoration in 2014, densities of *L. concolor* increased 3x in 2021 and 10x in 2024 relative to 2005, and *A. stamineus* increased 2x in 2021 and 4x in 2024, compared to 2005 (Figure 9). This resulted in a significant difference in density at the upper elevation reach for *A. stamineus* (K-W ANOVA H = 7.04, df = 2, $p < 0.05$) and but not for *L. concolor* (K-W ANOVA H = 2.65, df = 2, $p > 0.05$). More interestingly, Poeciliidae sp. density (K-W ANOVA H = 9.72, df = 2, $p < 0.01$) and Physid snail populations (K-W ANOVA H = 1.08, df = 2, $p > 0.05$) substantially declined in Wailuku River at the upper elevation reach following flow restoration.

In 2005, DAR conducted 29 surveys at approximately the 200-300ft elevation. While no endemic species were observed, the mean (± SD) density of Poeciliidae sp. was 15.04 (± 44.63) # m^{-2} compared to 0.18 (± 0.54) # m^{-2} observed in 2024, although this was not statistically significant (K-W ANOVA H = 0.57, df = 1, $p > 0.05$).

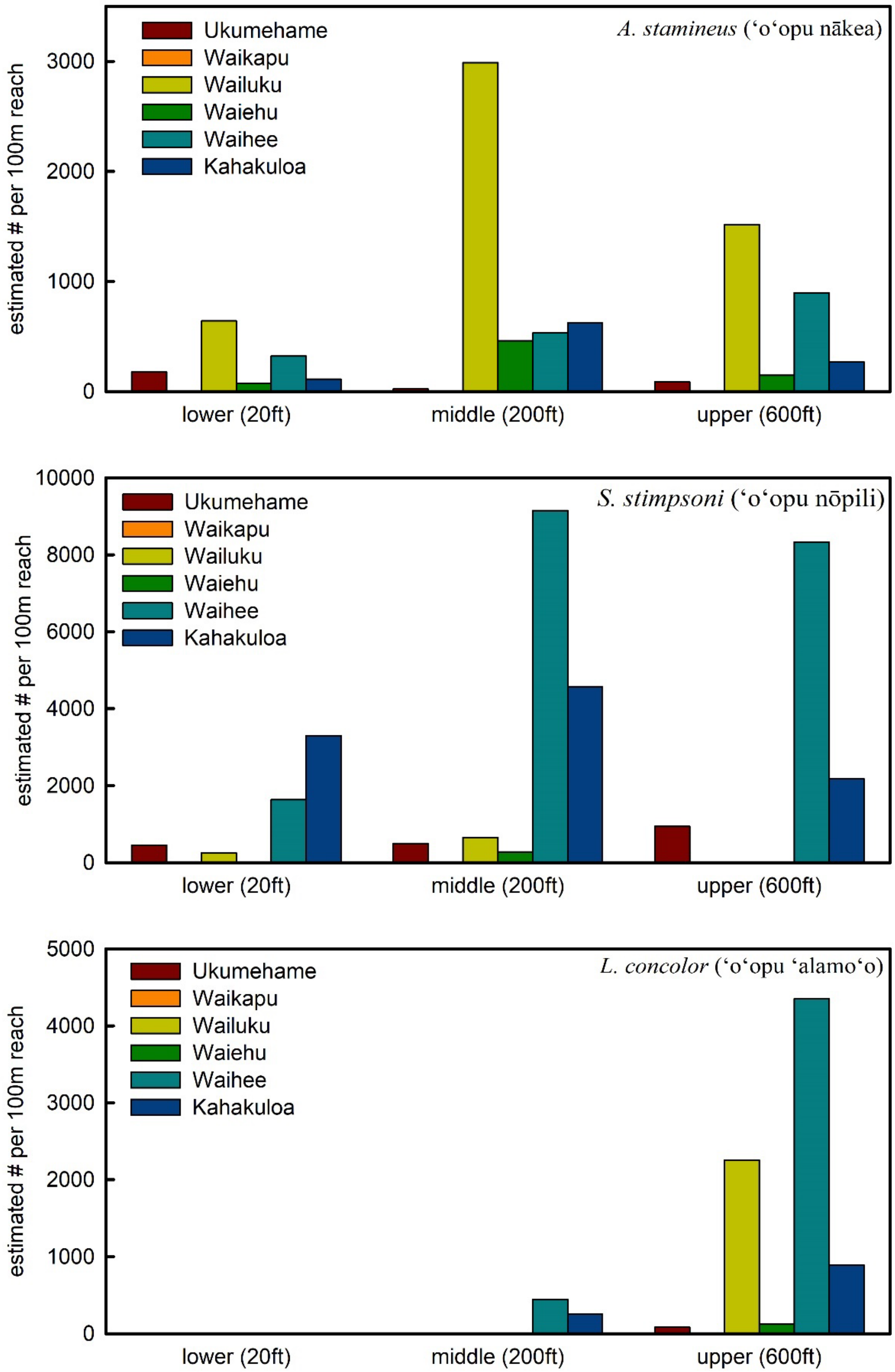


Figure 5. Estimated 2024 abundance supported per 100 m of stream channel for the three most common endemic fish species at lower (20ft), middle (200ft), and upper elevation (600ft) reaches. [note: only North Waiehu results graphed for upper elevation site for Waiehu Stream]

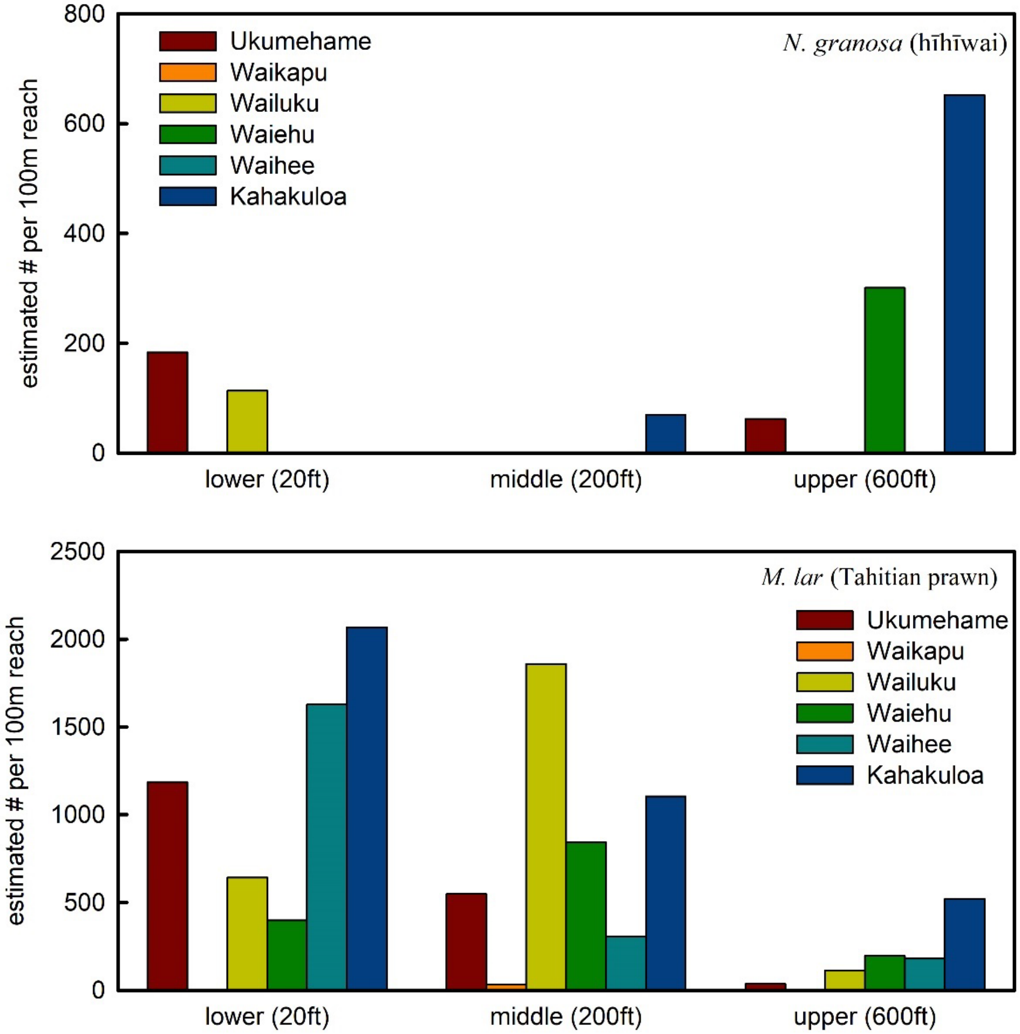


Figure 6. Estimated abundance of common invertebrates supported per 100 m of linear stream channel based on visual surveys and channel dimensions for surveys conducted in 2024 at lower elevation (20ft), middle elevation (200ft), and upper elevation (600ft) reaches. [note: only North Waiehu results graphed for upper elevation site for Waiehu Stream]

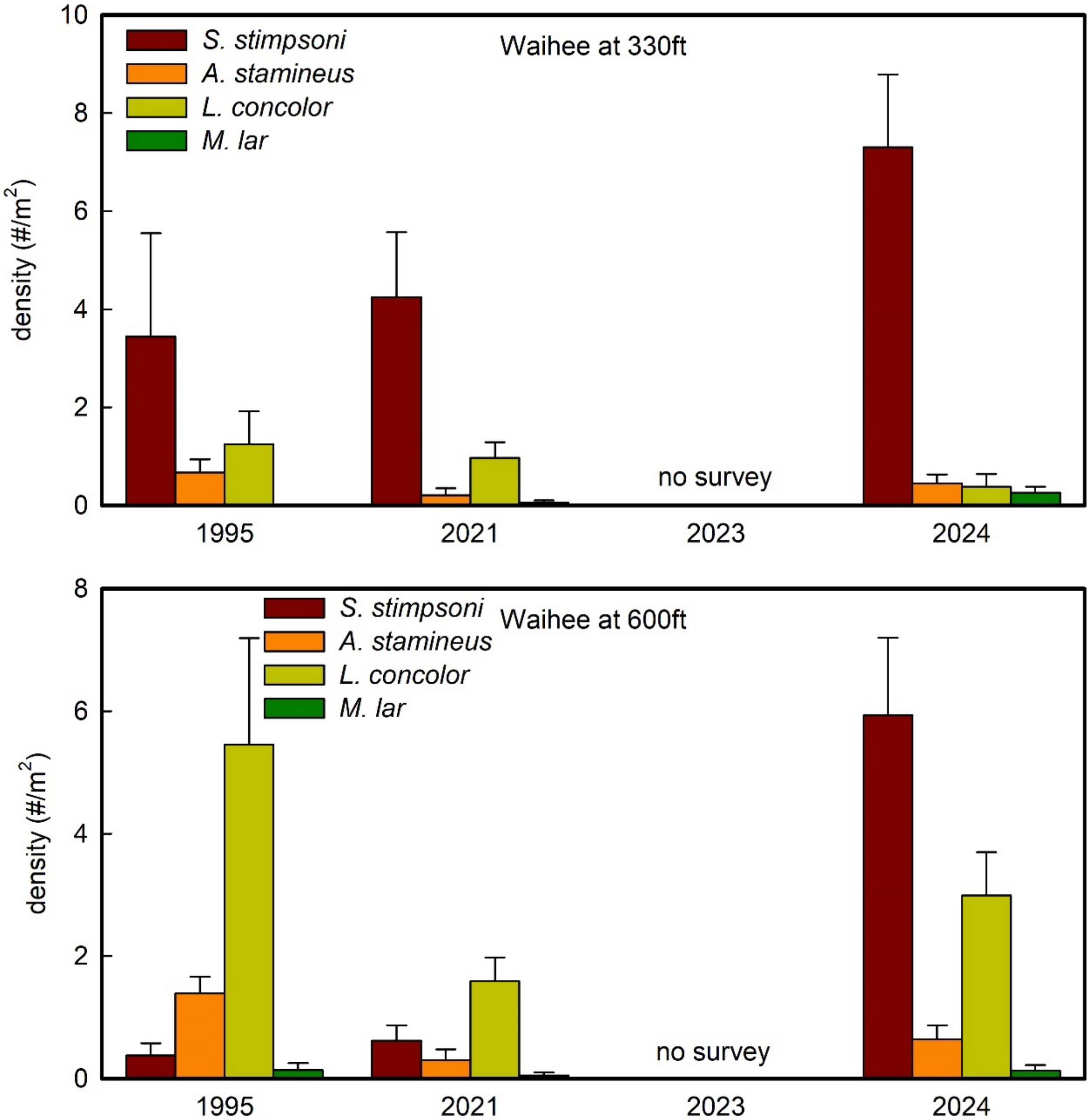


Figure 7. Mean (± standard error) density by species based on visual surveys in Waihe‘e Stream at two different elevations. [note: n = 20 for 2021 and 2024; n = 34 for 1995 at 600ft; n = 13 for 1995 at 330ft]

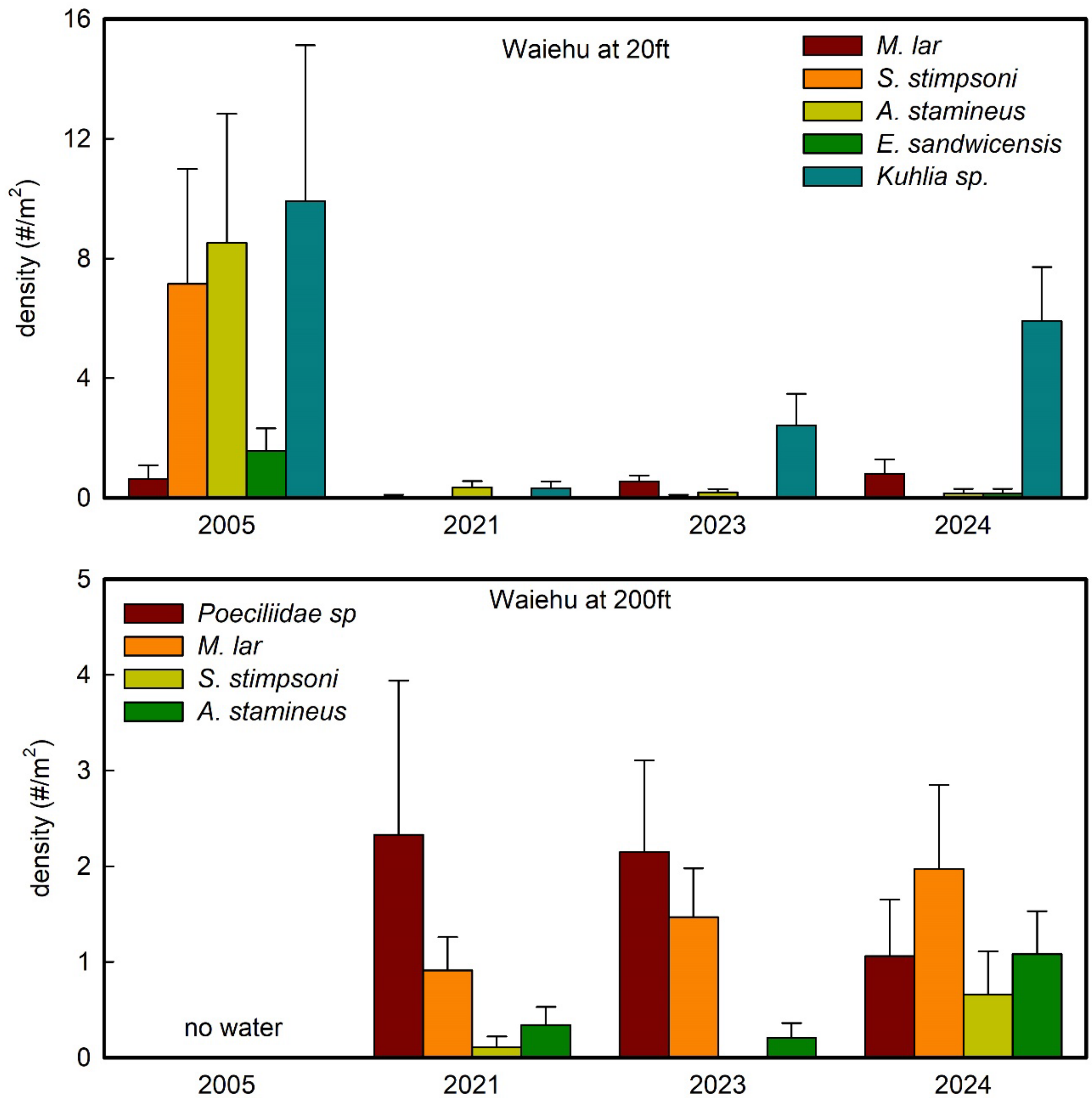


Figure 8. Mean (± standard error) density by species based on visual surveys in Waiehu Stream at two different elevations. [note: n = 20 for 2021, 2023, and 2024; n = 24 for 2005 at 20ft]

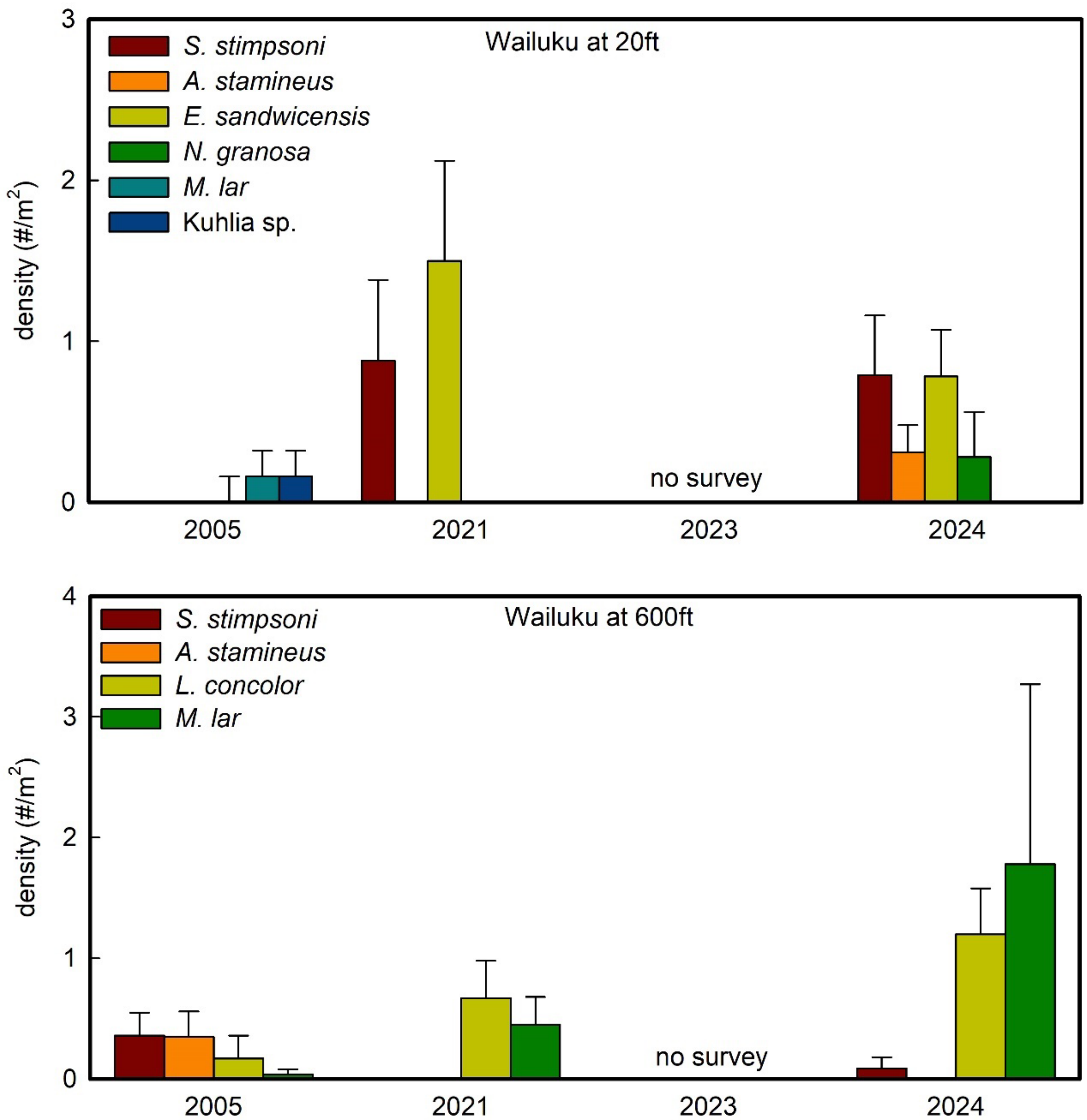


Figure 9. Mean (± standard error) density by species based on visual surveys in Wailuku River at two different elevations. [note: n = 20 for 2021 and 2024; n = 46 for 2005 at 600ft, n = 38 for 2005 at 20ft]

7. Discussion

Overview

Long-term shifts in the magnitude and distribution of rainfall across Maui have resulted in reductions in baseflow and an increase in the frequency of low-flow conditions. This is evident in declines in the median and low-flows observed at continuous-record gaging stations in Nā Wai ʻEhā and has consequences for water availability to meet public trust uses, including habitat for aquatic species, water for domestic use, and traditional loʻi kalo production dependent on the delivery of water through irrigation systems. The first part of this report details the most updated summary of hydrological conditions for streams in Nā Wai ʻEhā, as well as shifts in the rate of water withdrawal from streams following amendments to instream flow standards.

The second part of this report examines recent and historic biological surveys documenting shifts in the composition of macrofauna in Nā Wai ʻEhā following streamflow restoration and comparing them to four reference streams: two nearby on Maui and two similar streams on Kauaʻi. Results suggest that, with the exception of Waikapū Stream, populations of endemic fish are healthy at the middle and upper elevation reaches of streams in Nā Wai ʻEhā. The size distribution suggests that there is consistent recruitment of *A. stamineus*, *L. concolor*, and *S. stimpsoni* to Wailuku and Waiheʻe Rivers. Interestingly, *N. granosa* and *A. bisulcata* were sparsely populated across all streams and elevations, with the greatest densities in Kahakuloa. It is possible that these species are harvested more heavily in streams closer to urban development or that the surveys did not target their preferred elevation range. *Kuhlia* spp. abundance was particularly high in Waiehu Stream near the mouth. Compared to historic surveys, we observed large increases in *L. concolor* and *S. stimpsoni* populations across middle and upper elevation reaches, particularly in Wailuku and Waiheʻe Rivers, at or eclipsing reference streams. The abundant proportion of adults relative to juveniles in these streams indicates that populations are reproductively healthy following flow restoration. Overall, non-native generalist species have declined in many reaches over time, improving community trophic capacity.

Declines in availability of surface water under low-flow conditions

Recent trends in rainfall identified in Frazier and Giambelluca (2017) and Frazier et al. (2018) have highlighted a shift in climate patterns resulting in decreased recharge and baseflow to streams (Bassiouni and Oki, 2013). Shifts in the magnitude and duration of rainfall events can have substantial consequences for watershed hydrology, particularly in compact, steep-gradient stream systems (Strauch et al., 2014). Declines in mean annual rainfall have led to declines in groundwater recharge and baseflow to streams (Strauch et al., 2017). Further, current climate trends suggest that drier conditions are accompanied by less frequent, but more intense storm events, resulting in shifts in the magnitude of peak flow events or a shift in the timing of peak events (Huang et al., 2021).

In the Commission's 2021 D&O, low-flow statistics were provided by Oki et al. (2010) based on data up to water year 2007. For the 20-year period of record from water years 2004 to 2023, the magnitude of natural low flows has declined substantially at USGS continuous record stations on Waiheʻe and Wailuku Rivers compared to the period of record used by Oki et al. (2010). For example, median flow (Q_{50}), baseflow (Q_{70}), and low-flow (Q_{95}) at USGS 16614000 on Waiheʻe River declined by 5 cfs (9.6%), 5 cfs (11.4%), and 3 cfs (8.8%), respectively. Similarly, median flow (Q_{50}), baseflow (Q_{70}), and low-flow (Q_{95}) at USGS 16604500 on Wailuku River declined by 5 cfs (12.8%), 3 cfs (11.1%), and 2 cfs (11.7%), respectively.

Variability in species density across space and time

As expected, the density and abundance of endemic species varied across elevations and streams. Following the 2014 restoration of streamflow, endemic species at upper elevations responded positively, with increases in *S. stimpsoni* and *L. concolor* abundances in both Waiheʻe and Wailuku Rivers. Compared to reference streams on Maui at middle elevation reaches, Wailuku River had a greater density of *A. stamineus*, while Waiheʻe River had a greater density of *S. stimpsoni*.

Between 2021 and 2024, *S. stimpsoni*, *A. stamineus*, and *L. concolor* all had either stable or growing populations in Waiheʻe River at both middle and upper elevation reaches. Wailuku River had stable or growing populations of *A. stamineus* and *L. concolor* at the upper reach, while at the lower reach, *A. stamineus* was the dominant species despite non-native species introductions. *Awaous stamineus* is more tolerant of poor habitat conditions driven by urbanization (Brasher, 2003), which are found in Wailuku River and Waiehu Stream at the middle and lower reaches. By contrast, *L. concolor*, *N. granosa*, and *S. stimpsoni* are sensitive to habitat degradation (Brasher, 2003; Kido, 2013).

In the development of a Hawaiʻi Stream Index of Biological Integrity, Kido (2013) used a threshold density of 0.45 # m^{-2} to identify streams with the best scores of sentinel native fish (e.g., *S. stimpsoni* and *L. concolor*). Using this threshold, Waiheʻe and Wailuku rivers were rated well for sentinel species density.

Community Composition Across Streams

In terms of reproductive capacity, Waiheʻe River had the greatest percentage of adult *L. concolor* and *S. stimpsoni*, while Waiehu Stream and Waiheʻe River had the greatest percentage of adult *A. stamineus*. A larger percentage of adults increases the reproductive output of the population. Wailuku and Waiheʻe Rivers were rated best for community trophic capacity, followed by Kahakuloa. These streams had larger populations of endemic species and smaller populations of non-native species. Waiehu, Ukumehame, and Waiheʻe streams were similar to Hanakāpīʻai in terms of overall reproductive capacity, community weighted trophic capacity, and the relative abundances of *L. concolor* and *S. stimpsoni*, while the values for Wailuku River were similar to Waioli Stream on Kauaʻi. Waioli Stream is similarly degraded by poor stream channel (i.e., invasive vegetation/urbanization) management in the lower reaches, resulting in reduced recruitment.

Habitat and use by endemic species

The fishes, crustaceans, and mollusks constituting Hawaiʻi's endemic stream-dwelling macrofauna originated from marine ancestors and have preserved a pelagic marine larval stage (Radtke and Kinzie, 1996). Further, endemic stream species exhibit an amphidromous life cycle, where adults spawn in freshwater, larvae drift towards oceanic feeding sites (Radtke et al. 1988), and post-larvae migrate back into freshwater to metamorphose into juveniles (Nishimoto and Kuamoo, 1997). After migrating from the ocean to the stream, endemic fish in Hawaiʻi have general habitat preferences and exhibit a longitudinal separation along the stream gradient

(Brasher, 1997; Kinzie, 1988; Nishimoto and Kuamoo, 1991) although there is considerable overlap in habitat preferences (Kinzie, 1988). Species distribution is dependent on many factors, including competition with other species, predation, quality of habitat, and barriers to upstream movement. The structure of freshwater communities is thus determined by random larval recruitment, each species' unique capacity to migrate upstream, and the persistence of species through unpredictable events (Nishimoto and Kuamoo, 1997; Kinzie, 1988).

Awaous stamineus is the most common freshwater goby in Hawaiʻi is regularly found in lower and middle stream reaches (Ford and Yuen, 1988). *Awaous stamineus* is omnivorous, exhibiting both herbivorous and predatory behaviors (Ego, 1956; Maciolek, 1981). This species is a strong climber and can be found in fast flowing waters, although Kinzie (1988) also established that they are regularly found in deeper pools. In 2024, *A. stamineus* had the highest densities at lower elevations, aligning with findings in previous studies (Ego 1956; Kinzie 1988; Brasher 1997; Yamamoto and Tagawa 2000). Interestingly, almost 60% of *A. stamineus* observed in this study were found in run habitat, which was also observed by McRae (2013) in the lower reach of Wailoa River, Hawaiʻi Island. We also observed substantial populations of *A. stamineus* at the upper elevations of Waiheʻe and Wailuku Rivers, highlighting a lack of barriers to its upstream movement and their successful colonization.

Sicytopterus stimpsoni typically occurs in middle to upper reaches, overlapping with *A. stamineus* in the middle reaches and *L. concolor* in the upper reaches and utilizes more rapid stream velocities (Fitzsimons et al., 1993, Kinzie 1988). Post-metamorphic transition at the stream mouth, the ventral position of the mouth facilitates both their ability to climb vertical substrates and their preference for feeding on benthic surfaces. This species is herbivorous and feeds exclusively on the benthic diatom community and algae grown on large cobble and boulders, where sunlight drives primary production (Tomihama, 1972). Novel algal growth is maintained by regular grazing of adults, continuously initiating succession through disturbance (Fitzsimons et al., 2003). Males aggressively defend territories (Yuen, 1987), regularly attacking smaller conspecifics where densities are high, especially in prime feeding areas (pers. obs). The density of *S. stimpsoni* varied inversely with canopy cover, suggesting they are resource limited where riparian vegetation covers the stream.

Lentipes concolor is an excellent climber and is found in the middle to upper reaches of streams, although it may occur near the stream mouth in streams that end in terminal waterfalls due to reduced competition (Maciolek, 1977, Nishimoto and Kuamoo, 1991). In our study, *L. concolor* had the greatest densities in upper elevation reaches, with large populations in Waiheʻe and Wailuku Rivers. *Lentipes concolor* spend more time in mid-water pools than other species, though they can also have a strong affinity for fast riffles (Kinzie and Ford, 1982, Timbol et al., 1980). About 53% of the *L. concolor* observed in this study were in run habitat types, with 35% in riffle habitat types. This species feeds on particulates and organisms floating in the water column, with juveniles more omnivorous and adults more carnivorous (Lau, 1973).

We found highly varied populations of *N. granosa*, with some streams supporting *N. granosa* in lower to middle elevation reaches and others in the upper elevation reaches, as described by Brasher (1997). *Neritina granosa* prefer rocks with algae as a food source and require clear, cool, well-oxygenated streams (Ford 1979, Kinzie 1990), similar to *S. stimpsoni*. About 53% of

N. granosa observed in this study were found in riffle habitat types. Although we did not continuously monitor for stream temperature and oxygen, temperature at the time of survey varied consistently with elevation, as expected.

Interspecific Interactions

The extent of inland movement by species may be affected by competition or predation with endemic or introduced species (Connell, 1980). As suggested for stream gobies in other areas of Micronesia (Nelson et al., 1997), the presence of predators such as *E. sandwicensis* and *Kuhlia* spp. in estuaries and lower stream elevations may promote upstream dispersal and species segregation. This gauntlet is expected to affect fitness of species (Hain et al., 2019). In three repeated surveys in Waiehu Stream over a four-year period, we observed that as *Kuhlia* spp. density increased in the lower elevation reach, the densities of *A. stamineus* and *S. stimpsoni* decreased, while conversely, the densities of these two species increased at the middle elevation reach, where no *Kuhlia* spp. exist. Hawaiian streams are generally considered unproductive, with low species diversity (Archer, 1983), thus movement upstream to reduce competition is expected to be advantageous by increasing resource availability. For example, large densities of *S. stimpsoni* compete for space with *L. concolor*, especially at mid-elevations, and *L. concolor* are expected to move upstream under these conditions. Adult male *S. stimpsoni* defend breeding and feeding territories which reduces their congregation within single survey points (Fitzsimons and Nishimoto, 1990). Further, the restoration of flow has resulted in a decline in non-native species, which compete for resources, introduce parasites, alter community structure, and prey upon endemic species (Devick, 1991; Font and Tate, 1994; Holitzki et al., 2013).

Amphidromy and Streamflow Restoration

Amphidromy is a migratory behavior that is widely present in the life histories of freshwater fauna of islands, especially in the tropics and subtropics (McDowall, 2007). The endemic freshwater species (e.g., excluding estuarine or transiently freshwater) in Hawaiʻi exhibit an amphidromous life-history, with stream-dwelling reproductive adults producing viable eggs and embryos that hatch and get carried downstream to the ocean, grow into post-larval forms that migrate back to the stream mouths and metamorphose into juveniles, which subsequently migrate back upstream to viable habitat (McDowall, 2007; Fitzsimons et al., 1997). Recruitment of larvae to stream mouths may be driven by oceanic currents, estuary conditions, or marine and nearshore population dynamics (Nishimoto and Kuamoo, 1997; Nishimoto and Fitzsimons, 2007). The timing of post-larval return to streams was reportedly observed after heavy rainfall events resulting in freshet conditions (Fitzsimons and Nishimoto, 1995; Fitzsimons et al., 2003). For example, Diamond et al. (2024) observed *Sicyopterus stimpsoni* juveniles migrating in pulses over several days immediately following flash floods. Previous studies documented juveniles recruiting back to streams from February to May during the late wet season (Kinzie and Ford, 1982).

Results described here provide substantial evidence that there is adequate upstream to downstream connectivity for distribution of larvae and recruitment of post-larvae. By increasing downstream flows and reducing entrainment at stream diversions, restoring streamflow and habitat connectivity past stream diversions improved the reproductive potential of the population inhabiting stream reaches. Flow restoration in Waiheʻe and Wailuku Rivers resulted in habitat availability for endemic species at levels equivalent to reference streams on Maui and Kauaʻi.

This has resulted in the continual recruitment of juveniles to middle and upper elevation stream reaches, leading to a diverse distribution of size/age classes with numerous reproductive adults.

Factors that Affect the Structure of Stream Ecosystems

There are three primary factors that are driving the structure of stream ecosystems: the availability of resources; competition and predation, often from introduced species; and disturbance-mediated habitat alterations (anthropogenic or natural). The availability of resources is dependent on multiple factors acting at large (watershed) and small (reach) scales which can alter reproduction, recruitment, and interspecies interactions. This includes habitat quality driven by streamflow, riparian vegetation, and instream modification (e.g., channelization, culverts, etc). The highest levels of disturbance, in the form of urban development and agriculture, often result in negative outcomes for ecosystem structure and function (Lake, 2000; Brasher et al., 2003). Lower and middle elevation reaches of almost all streams experience some form of landscape disturbance (Tingley et al., 2019), with the greatest disturbance in Nā Wai ʻEhā occurring in Wailuku, Waiehu, and Waikapū. The dominance of non-native vegetation along the stream channel can alter nitrogen and carbon inputs to stream environments (Larned et al., 2001; MacKenzie et al., 2013; Roberts et al., 2016). Invasive riparian vegetation, including African tulip (*Spathodea campanulate*), Java plum (*Syzygium cumini*), Albizia (*Albizia julibrissin*), guava (*Psidium guajava*), strawberry guava (*Psidium cattleianum*), hau bush (*Hibiscus tilaceus*), inkberry (*Ilex glabra*), and bamboo (*Bambusa vulgaris*) can choke out the stream, limiting primary productivity, depositing large quantities of leaf litter that reduce habitat suitability, and altering flow paths by clogging the stream channel (Stephens et al., 2012).

Further, non-native aquatic species in Hawai'i have been shown to alter resource use, affect food webs, introduce novel competition and influence species distributions (Yamamoto and Tagawa, 2000; Brasher, 2003; Holitzki et al., 2013). In some areas, endemic species are nearly absent in highly invaded and disturbed streams (Layhee et al., 2014). Two introductions that have had lasting consequences for endemic species are *M. lar* and *Poeciliidae* spp. *Macrobrachium lar* were introduced to Hawaiʻi in 1956 and eventually spread to streams throughout the state (Devick, 1991; Yamamoto and Tagawa, 2000). The amphidromous life history facilitated *M. lar*'s colonization of new streams, akin to the colonization patterns of endemic species (Englund et al., 2000). *Macrobrachium lar* are considered omnivores (Maciolek, 1972, Nelson and Kropp, 1985), directly prey on native fish and mollusks (Englund et al., 2000), and territorial, chasing away endemic fauna. Tomihama (1972) observed a large *M. lar* capturing a *S. stimpsoni* in the field, while Yuen (1987) concluded that *M. lar* competes with *S. stimpsoni* for space and appears to disrupt courtship and mating behaviors. Kinzie and Ford (1982) observed *M. lar* lunge towards an adult *L. concolor*, seeming to part a cost to their social behavior (e.g., reduce breeding opportunities) or fitness (e.g., increased stress, reduced time foraging). *Macrobrachium lar* exhibits climbing abilities, enabling it to overlap with native species across a broader range of habitats compared to other introduced species (Yamamoto & Tagawa 2000). On many occasions, we observed *M. lar* chasing *S. stimpsoni* and *A. stamineus* from ideal feeding habitats on Maui. Additionally, previous studies found that *Poeciliidae* spp. compete for food (MacKenzie & Bruland, 2012), harbor parasites known to infect endemic fish (Font & Tate, 1994), and alter nutrient cycling in Hawaiian streams (Holitzki et al., 2013).

Ecosystems with larger proportions of native species have increased trophic niche space, trophic diversity, and often less niche redundancy (Kido, 2013). Habitat suitability for native species is affected by the number of invasive species, the intensity of interactions among species, and the resilience of the native species pool.

Finally, disturbances to streams can elicit nonlinear responses in habitat availability or food resources (Tingley et al., 2024). Flood events result in the widespread redistribution of sediment, riparian vegetation, and consequently, aquatic habitat and food webs. For example, the 2016 flood event in Wailuku River and the 2018 flood event in Waiheʻe River, drastically reduced food availability for grazers by eliminating algae (preferred food by *S. stimpsoni*) and moss (preferred habitat by *A. bisulcata*) and even reduced or eliminated species temporarily from these rivers. Hawaiian streams are typically nutrient- and light-limited (Larned and Santos, 2000; Holitzki et al., 2013). However, the widening of stream channels and reduction of instream vegetation following floods is likely to benefit algal growth in subsequent years by reducing canopy cover, resulting in observed increases in *S. stimpsoni*. Benthic algal community succession depends on cycles of disturbance from freshets (i.e., peak runoff events) that remove organic debris and sediments, resetting surfaces of substrates and promoting early stages of community succession, such as the growth of filamentous algal species (Hoagland et al., 1982; Fitzsimons et al., 2003).

There is a common assumption that reductions in streamflow are drivers of negative ecological outcomes (Brasher, 2003; Brasher et al., 2003; March et al., 2003). This originated from the widespread dewatering of lotic ecosystems during the sugar plantation era and subsequent environmental enlightenment in the last 50 years. However, precise, minimum flow standards do not account for the importance of flow variability as a part of the functioning of the watershed (Grossman et al., 1985). Floods and droughts help shape habitat heterogeneity important for maintaining biological diversity (Lake, 2000). While amphidromous species have specific adaptations for utilizing habitats within stream systems, disturbances drive heterogeneity important for stream productivity (Fitzsimons et al., 1997). Even streams with partially restored flow can support recruitment to high-elevation reaches (Strauch et al., 2022) and streamflow alone may not be sufficient to restore functioning aquatic ecosystems: urbanization, riparian species management, water quality, invasive aquatic species, and stream mouth closure all play a role (Brasher, 2003).

8. Conclusions

In Nā Wai ʻEhā II, the Court concluded that "the Commission made insufficient findings and conclusions on the value of restoring additional stream flow versus authorizing additional offstream uses…and the Commission's failure to seek out further information does not justify it not restoring additional stream flows." Further, the Commission shall establish interim standards "based on the best information presently available." (94 Hawaiʻi at 156, 9 p. 3d at 468) and is to confront any scientific uncertainty "as systematically and judiciously as possible — considering every offstream use in view of the cumulative potential harm to instream uses and values and the need for meaningful studies of stream flow requirements." The "Commission should incorporate any allowances for scientific uncertainty into its initial determination of the minimum" IIFS, and a lack of adequate scientific information weighs toward incorporating more water into the IIFS." (94 Hawaiʻi at 156, 9 p. 3d at 468).

Here we present a comprehensive assessment of existing hydrological and ecological conditions for Nā Wai ʻEhā streams and compare them to four perennially flowing streams that are unregulated by large plantation-era water withdrawals. With the exception of Waikapū, which does not support natural connectivity at the mouth, we found that existing flow restoration in these streams maintains a healthy aquatic community, supporting reproductive adults and connectivity for the continual recruitment of juveniles. As habitat availability, population size, and ecosystem structure already meet standards established by reference hydrological systems, increasing downstream flows will unlikely produce a quantifiable improvement in ecological function outside of the natural variability associated with stream communities.

We found that available habitat under existing flow conditions in Waiheʻe and Wailuku Rivers provides adequate habitat and connectivity to upstream reaches and meaningful protections to downstream habitats. Poor conditions in Waiehu and Waikapu Streams associated with land use, riparian species management, and invasive aquatic species are not going to change with additional flow restoration. We demonstrate that the Waiheʻe and Wailuku Rivers support densities and abundances of key indicator species at or greater than reference streams. Hawaiian freshwater communities exhibit stochastic shifts in recruitment, reproduction, and survival, dependent on natural fluctuations in climate and hydrological conditions. Species are adapted to surviving in extreme drought and floods and repopulate streams following local extirpation. Management of the entire watershed to promote healthy aquatic ecosystems (e.g., limiting introduced aquatic ecosystems, limiting stream channelization and urban runoff, and controlling the spread of non-native riparian vegetation) is also needed to promote recruitment and successful reproduction of aquatic species.

9. Literature Cited

Archer, K.M. 1983. Leaf litter in Hawaiian streams. M.S. Thesis, University of Hawaii. Honolulu, 52 pp.

Bassiouni, M., Oki, D.S. 2013. Trends and shifts in streamflow in Hawaiʻi, 1913-2008. *Hydrological Processes*, 27: 1484-1500.

Brasher, A.M. 1997. Habitat use by fish (ʻoʻopu), snails (hihwai), shrimp (ʻōpae), and prawns in two streams on the island of Molokaʻi. Honolulu: Cooperative National Park Resources Studies Unit. Technical Report 116.

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

Brasher, A.M., Wolff, R.H., Luton, C.D. 2003. Associations among land use, habitat characteristics, and invertebrate community structure in nine streams on the island of Oahu, Hawaii. 1999-2001. U.S. Geological Survey Water-Resources Investigations Report 03-456.

Bruckerhoff, L.A., Leasure, D.R., Magoulick, D.D. 2018. Flow-ecology relationships are spatially structured and differ among flow regimes. *Journal of Applied Ecology*, 56: 398-412.

Cheng, C.L. 2016. Low-Flow Characteristics for Streams on the Islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi, State of Hawaiʻi. U.S. Geological Survey Scientific Investigations Report 2016-5103.

Clilverd, H., Tsang, Y.-P., Infante, D.M., Strauch, A.M. 2019. Long-term Streamflow Trends in Hawaii and Implications for Native Stream Fauna. *Hydrological Processes*, 33(5): 699-719.

Connell, J.H. 1980. Diversity and coevolution of competitors, the ghost of competition past. *Oikos*, 35: 131-138.

Diamond, K.M., Nishiura, L., Sakihara, T., Schoenfuss, H.L., Blob, R.W. 2024. When to go against the flow: Examining patterns of performance over multiday migration events in the Hawaiian stream fish, ʻoʻopu nōpili (*Sicyopterus stimpsoni*). *Integrative and Comparative Biology*, 64(2): 496-505.

Devick, W.S. 1991. Patterns of introductions of aquatic organisms to Hawaiʻi freshwater habitats. In: New directions in research, management and conservation of Hawaiian freshwater stream ecosystems. Proceedings of 1990 symposium on freshwater stream biology and fisheries management, Hawaiʻi Department of Land and Natural Resources ,Division of Aquatic Resources, Honolulu, HI. pp. 190-213.

Ego, K. 1956. Life history of freshwater gobies. Project No F-4-R. Freshwater game fish management research. Department of Land and Natural Resources. Territory of Hawaiʻi, Honolulu.

Englund, R.A., Arakaki, K., Preston, D.J., Coles, S.L., Eldredge, L.G. 2000. Nonindigenous freshwater and estuarine species introductions and their potential to affect sportfishing in the lower stream and estuarine regions of the south and west shores of Oʻahu, Hawaiʻi: final report prepared for the Hawaiʻi Department of Land and Natural Resources, Division of Aquatic Resources (No. 17). Bishop Museum Press.

Fitzsimons, J.M., Nishimoto, R.T., Yuen, A.R. 1993. Courtship and territorial behavior in the native Hawaiian stream goby, *Sicyoptertus stimpsoni*. *Ichthyological Exploration of Freshwaters*, 4:1-10.

Fitzsimons, J.M., Nishimoto, R.T. 1990. Territories and site tenacity in males of the Hawaiian stream goby *Lentipes concolor* (Pisces: Gobiidae). *Icthyology Exploration of Freshwater*, 1: 185-198.

Fitzsimons, J.M., Nishimoto, R.T. 1995. Use of fish behavior in assessing the effects of Hurrican Iniki on the Hawaiian island of Kauaʻi. *Environmental Biology of Fishes*, 43: 39-50.

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

Fitzsimons, J.M., McRae, M.G., Schoenfuss, H.L., Nishimoto, R.T. 2003. Gardening behavior in the amphidromous Hawaiian fish *Sicyopterus stimpsoni* (Osteichthyes: Gobiidae). Ichthyological Exploration of Freshwaters, 14: 185-191.

Frazier, A.G., Timm, O.E., Giambelluca, T.W., Diaz, H.F. 2018. The influence of ENSO, PDO, and PNA on secular rainfall variations in Hawaiʻi. *Climate Dynamics*, 51: 2127-2140.

Fitzsimons, J.M., McRae, M.G., Nishimoto, R.T. 2007. Behavioral Ecology of Indigenous Stream Fishes in Hawaii, In N.L., Evenhuis & J.M. Fitzsimons, Biology of Hawaiian Streams and Estuaries. *Bishop Museum Bulletin in Cultural and Environmental Studies*, 3: 11-21.

Font, W.F., Tate, D.C. 1994. Helminth parasites of native Hawaiian freshwater fishes: An example of extreme ecological isolation. *Journal of Parasitology*, 80: 682-688.

Ford, J.I. 1979. Biology of a Hawaiian fluvial gastropod *Neritina granosa* Soverby (Prosobrachia: Neritidae). M.S. Thesis. University of Hawaiʻi at Mānoa. 94 pp.

Ford, J.I., Yuen, A. 1988. Natural history of Pelekunu Stream and its tributaries, island of Molokaʻi, Hawaiʻi, Part 1: Summary report. Nature Conservancy of Hawaiʻi, Honolulu.

Frazier, A. Giambelluca, T.W. 2017. Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. *Journal of Climatology*, 37(6): 2522-2531.

Gingerich, S.B., Wolff, R.H. 2005. Effects of Surface-Water Diversions on Habitat Availability for Native Macrofauna, Northeast Maui, Hawaii. U.S. Geological Survey Scientific Investigations Report 2005-5213.

Grossman, G.D., Freeman, M.C., Moyle, P.B., Whitaker, J.O., Jr. 1985. Stochasticity and assemblage organization in an Indiana stream fish assemblage. *American Naturalist*, 126: 275-285.

Hain, E.,F., Moody, K.N., Lamphere, B.A., Nelson, S.A.C., McIntyre, P.B., Gilliam, J.F., Blume, M.J. 2019. Migratory gauntlets on oceanic islands: Watershed disturbance increases the cost of amphidromy. *Ecology of Freshwater Fish*, 28(3): 446-458.

Handy, E.S.C, and Handy, E.G. 1972. Native Planters In Old Hawaiʻi: their Life, Lore, and Environment. Bernice P. Bishop Museum Bulletin 233, Honolulu, Hawaiʻi.

Hoagland, K.D., Roemer, S.C., Rosowski, J.R. 1982. Colonization and community structure of two periphyton assemblages, with emphasis on the diatoms (Bacillariaphyceae). *American Journal of Botany*, 69: 188-213.

Holitzki, T.M., MacKenzie, R.A., Wiegner, T.N., McDermid, K.J. 2013. Differences in ecological structure, function, and native species abundance between native and invaded Hawaiian streams. *Ecological Applications*, 6: 1367-1383.

Hughes, R.M., Infante, D.M., Wang, L., Chen, K., Terra, B. (editors). 2019. Advances in Understanding Landscape Influences on Freshwater Habitats and Biological Assemblages. American Fisheries Society, issue 90. Bethesda, Maryland.

Kido, M.H. 1996. Diet and food selection in the endemic Hawaiian amphidromous goby, *Sicyopterus stimpsoni* (Pisces: Gobiidae). *Environmental Biology of Fishes*, 45: 199-209.

Kido, M.H. 2008. A persistent species assemblage structure along Hawaiian stream from catchment-to-sea. Environmental Biology of Fishes, 82: 223-235.

Kido, M.H. 2013. A native species-based index of biological integrity for Hawaiian stream environments. *Environmental Monitoring and Assessment*, 185: 4063-4075.

Kinzie, R.A. III. 1988. Habitat utilization by Hawaiian stream fishes with reference to community structure in oceanic stream islands. *Environmental Biology of Fishes*, 22:179-192.

Kinzie, R.A. III. 1990. Species profiles: life histories and environmental requirements of coastal invertebrates, Pacific Ocean region. Report 3. Amphidromous Macrofauna of Island Streams. Technical Report EL-89-10, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 28 pp.

Kinzie, R.A. III, Ford, J.I. 1982. Population biology in small Hawaiian streams. Technical Report No. 147. Water Resources Center, University of Hawaiʻi at Mānoa. Honolulu, Hawaiʻi. 60 pp.

Kinzie, R.A., Ford, J.I., Yuen, A.R., Chow, S.J. 1984. Habitat utilization curves for native Hawaiian stream fish. Water Resources Research Center Special Report No. 6: 20:84, University of Hawaii, Manoa, HI.

Kinzie, R.A. III, Chong, C., Devrell, J., Lindstrom, D., Wolff, R. 2006. Effects of water removal on a Hawaiian stream ecosystem. *Pacific Science*, 60(1): 1-47.

Huang, Y-F., Tsang, Y. Strauch, A.M., Clilverd, H.M. 2021. Shifting magnitude and timing of streamflow extremes and the relationship with rainfall across the Hawaiian islands. *Journal of Hydrology*, 600: 126424.

Lau, E.T.K. 1973. Dimorphism and speciation in the Hawaiian freshwater goby genus Lentipes. M.S. Thesis, Department of Zoology, University of Hawaii. Honolulu. 83 pp.

Lake, P.S. 2000. Disturbance, patchiness, and diversity in streams. *Journal of the North American Benthological Society*, 19: 573–592.

Lake, P.S.. Bond, N., Reich, P. 2007. Linking ecological theory with stream restoration. *Freshwater Biology*, 52: 597-615.

Larned, S.T., Santos, S.R. 2000. Light- and nutrient-limited periphyton in low order streams of Oahu, Hawaii. *Hydrobiologia*, 432: 101-111.

Larned, S.T., Chong, C.T., Punewai, Noelani. 2001. Detrital Fruit Processing in a Hawaiian Stream Ecosystem. *Biotropica*, 33(2): 241-248.

Layhee, M., Marchetti, M.P.., Chandra, S., Engstrom, T., Pickard, D. 2014. Impacts of aquatic invasive species and land use on stream food webs in Kaui, Hawaii. *Pacific Conservation Biology*, 20(3): 252-271.

Legates, D.R., McCabe, G.J., Jr. 1999. Evaluation the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation: *Water Resources Research*, 35(1): 233-241.

Maciolek, J.A. 1972. *Macrobrachium lar* as a culture prawn in the tropical insular Pacific. In: Western Association of State Game and Fish Commissioners. Proceedings of the 52nd Annual Conference of Western Association of State Game and Fish Commissioners, Portland, Oregon.

Maciolek, J.A. 1977. Taxonomic status, biology, and distribution of Hawaiian *Lentipes*, a diadromous goby. *Pacific Science*, 31:355-362.

Maciolek, J.A. 1981. Consumer trophic relations in a tropical insular estuary. *Bulletin of Marine Science*, 31: 702-711.

MacKenzie, R.A., Bruland, G.L. 2012. Nekton Communities in Hawaiian Coastal Wetlands: The Distribution and Abundance of Introduced Fish Species. *Estuaries and Coasts*, 35: 212-226.

MacKenzie, R.A., Wiegner, T.N., Kinslow, F., Cormier, N., Strauch, A.M. 2013. Leaf-litter inputs from an invasive nitrogen-fixing tree influence organic-matter dynamics and nitrogen inputs in a Hawaiian river. *Freshwater Science*, 32(3): 1036-1052.

March, J.G., Benstead, J.P., Pringle, C.M., Scatena, F.N. 2003. Damming Tropical Island Streams: Problems, Solutions, and Alternatives. BioScience, 53(11): 1069-1078.

McDowall, R.M. 2007. On amphidromy, a distinct form of diadromy in aquatic organisms. *Fish and Fisheries*, 8(1): 1-13.

McRae, M.G., McRae, L.B., Fitzsimons, J.M. 2013. Microhabitat use in an Assemblage of Native and Introduced Fishes in a Hawaiian Stream. *Pacific Science*, 67: 205-217.

McManamay, R.A., Orth, D.J., Kauffman, J., Davis, M.M. 2013. Application of the ELOHA (Ecological Limits of Hydrologic Alteration) framework to the Cheoah River: a regulated system in the Little Tennessee River Basin. *Environmental Management*, 51: 1210-1235.

Mims, M.C. and Olden, J.D. 2012. Life history theory predicts fish assemblage response to hydrologic regimes. *Ecology*, 93: 35-45.

Nelson, S.G., Kropp, R.K. 1985. Ammonia excretion and nitrogen assimilation by the tropical freshwater prawn Macrobrachium lar (Crustacea, Palaemonidae). *Comparative Biochemistry and Physiology Part A: Physiology*, 81(3): 699-704.

Nelson, S.G., Parham, J.E., Tibbatts, R.B., Camacho, F.A., Leberer, T., Smith, B.D. 1997. Distributions and microhabitats of the amphidromous gobies of Micronesia. *Micronesica*, 30: 83-91.

Nishimoto, R.T., and Kuamoo, D.G.K. 1991. Occurrence and distribution of the native goby (*Lentipes concolor*) in Hawaii Island streams with notes on the distribution of species, p. 77-95. In: W. Devick (ed.), New directions in research, management and conservation of Hawaiian freshwater stream ecosystems: Proceedings of the 1990 symposium on stream biology and fisheries management. State of Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu.

Nishimoto, R.T., and Kuamoo, D.G.K. 1997. Recruitment of goby postlarvae into Hakalau stream, Hawaiʻi Island. *Micronesica*, 30, 41-49.

Nishimoto, R.T., Fitzsimons, J.M. 2007. Status of Native Hawaiian Stream Fishes, A Unique Amphidromous Biota. *American Fisheries Society Symposium*, 53: 59-65.

Oki, D.S., Wolff, R.H., Perreault, J.A. 2010. Effects of Surface-Water Diversion on Streamflow, Recharge, Physical Habitat, and Temperature, Nā Wai ʻEhā, Maui, Hawaiʻi. U.S. Geological Survey Scientific Investigations Report 2010-5011.

Poff, N.L, Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., Warner, A. 2010. The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshwater Biology*, 55: 147-170.

Primm, S.L., J.H. Lawton. 1977. Number of trophic levels in ecological communities. *Nature*, 268: 329-331.

Radtke, R.L., Kinzie III, R.A., and S.D. Folson. 1988. Age at recruitment of Hawaiian freshwater gobies. *Environmental Biology of Fishes*, 23:205-213.

Radtke, R.L., Kinzie III, R.A. 1996. Evidence of a marine larval stage in endemic Hawaiian stream gobies from isolated high-elevation locations. *Transactions of the American Fisheries Society*, 125(4):613-621.

Ricotta, C., Podani, J. 2017. On some properties of the Bray-Curtis dissimilarity and their ecological meaning. *Ecological Complexity*, 31:201-205.

Roberts, M., Strauch, A.M., Wiegner, T., MacKenzie, R.A. 2016. Leaf Litter Breakdown of Native and Exotic Tree Species in Two Hawaiian Streams that Differ in Flow. *Pacific Science*, 70(2): 209-222.

Stanley, E.H., Powers, S.M., Lottig, N.R. 2010. The evolving legacy of disturbance in stream ecology: concepts, contributions, and coming challenges. *Journal of the North American Benthological Society*, 29(1): 67-83.

Stephens, S.H., Brasher, A.M.D., Smith, C.M. 2012. Response of an algal assemblage to nutrient enrichment and shading in a Hawaiian stream. *Hydrobiologia*, 683: 135-150.

Strauch, A.M., MacKenzie, R.A., Giardina, C.P., Bruland, G.L. 2014. Climate driven changes to rainfall and streamflow patterns in a model tropical island hydrological system. *Journal of Hydrology*, 523: 160-169.

Strauch, A.M., Giardina, C.P., MacKenzie, R.A., Heider, C., Giambelluca, T.W., Salminen, E., Gruland, G.L. 2017. Modeled Effects of Climate Change and Plant Invasion on Watershed Function Across a Steep Tropical Rainfall Gradient. *Ecosystems*, 20: 583-600.

Strauch, A.M., Tingley III, R.W., Hsiao, J., Foulk, P.B., Frauendorf, T.C., MacKenzie, R.A., Infante, D.M. 2022. Population response to connectivity restoration of high elevation tropical stream reaches in Hawaii. *Conservation Science and Practice*, 4(12): e12836.

Sundstrom, S.M., Allen, C.R. 2019. The adaptive cycle: More than a metaphor. *Ecological Complexity*, 39: 100767.

Timbol, A.S., Sutter, A.J., Parrish, J.D. 1980. Distribution, relative abundance, and stream environment of Lentipes concolor (Gill 1860), and associated fauna in Hawaiian streams. Water Resources Research Center Cooperative Report No. 5. University of Hawaiʻi at Mānoa. Honolulu, Hawaiʻi.

Tingley, R.A., Infante, D.M., MacKenzie, R.A., Cooper, A.R., and Tsang, Y.P. 2019. Identifying natural catchment landscape influences on tropical stream organisms: classifying stream reaches of the Hawaiian Islands. *Hydrobiologia*, 826:67-83.

Tingley III, R.T., Infante, D.M., MacKenzie, R.A., Strauch, A.M., Foulk, P.B., Roth, B. 2024. Climate-driven differences in flow regimes alter tropical freshwater ecosystems with consequences for an endemic shrimp. Frontiers in Ecology and Evolution, 12: 1182021.

Tomihama, M.T. 1972. The biology of *Sicydium stimpsoni*: freshwater goby endemic to Hawaiʻi. B.S. Honors Thesis. Biology Department, University of Hawaiʻi at Mānoa. Honolulu, Hawaiʻi. 123 pp.

Turnipseed, D.P., Sauer, V.B. 2010. Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 97 p.

Vogel, R.M. Stedinger, J.R. 1985. Minimum variance streamflow record augmentation procedures. *Water Resources Research*, 21(5): 715-723.

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

Wilcox, C. 1997 Sugar Water: Hawaii’s Plantation Ditches. University of Hawaii Press. 191 pp.

Yamamoto, M.N., and Tagawa, A.W. 2000. Hawai‘i’s native and exotic freshwater animals. Mutual Publishing, Honolulu, Hawai‘i.

Yuen, A.R. 1987. Social and territorial behavior of the endemic freshwater goby *Sicyopterus stimpsoni*. M.S. Thesis. Zoology Department, University of Hawai‘i at Mānoa. Honolulu, Hawai‘i. 51 pp.

10. Supplemental Data

Table S1. Streamflow measurement (in cubic feet per second) on Waikapū Stream at 915ft with concurrent flow in South Waikapū Ditch in cubic feet per second and total flow

Date	Waikapū Stream at 915ft	South Waikapu Ditch	total natural flow at 915ft
6/6/2018	16.77	1.39	18.16
7/9/2018	9.70	1.39	11.09
8/14/2018	11.40	0.31	11.71
10/8/2018	10.07	1.47	11.54
10/15/2018	16.37	1.32	17.69
11/21/2018	11.37	1.55	12.92
12/18/2018	9.92	1.24	11.16
1/18/2019	7.37	2.32	9.69
3/7/2019	22.99	1.55	24.54
6/4/2019	10.55	1.32	11.86
9/19/2019	5.37	1.55	6.91
12/16/2019	8.12	1.32	9.44
1/10/2020	18.00	1.86	19.86
2/10/2020	7.90	1.86	9.76
6/22/2020	3.45	1.86	5.31
7/13/2020	3.39	1.55	4.94
8/3/2020	5.07	1.24	6.31
8/10/2020	9.04	0.15	9.19
10/23/2020	3.12	1.01	4.13
10/27/2020	3.32	0.62	3.94
10/30/2020	3.11	0.62	3.73
12/4/2020	4.69	0.54	5.23
1/4/2021	5.60	0.31	5.91
2/22/2021	5.17	0.54	5.71
3/19/2021	17.09	0.00	17.09
5/7/2021	6.64	0.70	7.34
6/18/2021	4.68	0.46	5.14
9/28/2021	4.46	0.77	5.23
11/15/2021	3.65	0.62	4.27
3/4/2022	3.91	0.46	4.37
3/29/2022	4.64	0.31	4.95
4/21/2022	12.4	0.77	13.17
4/26/2022	22.40	0.54	22.94
5/12/2022	17.90	0.31	18.21
7/12/2022	4.77	0.62	5.39
9/22/2022	3.63	0.46	4.09
10/7/2022	5.24	0.62	5.86
2/24/2023	5.23	0.46	5.69
3/2/2023	20.90	0.60	21.50
5/31/2023	4.70	0.46	5.16
7/7/2023	7.34	0.70	8.04
7/12/2023	3.8	0.54	4.34
8/8/2023	3.61	0.46	4.07
10/4/2023	3.14	0.54	3.68
2/8/2024	7.63	0.46	8.09
3/14/2024	6.17	0.46	6.63

Table S2. Goodness-of-fit statistical measures from updated partial-record gaging stations: coefficient of variation (R^2), root mean square error (RMSE), and Nash-Sutcliffe Efficiency Index (NSE) statistical results for the MOVE.1 model compared to observed low-flow measurements for Waikapū Stream at 915ft, South Waiehu Stream at 620ft, and North Waiehu at 660ft.

Date	R^2	RMSE	NSE
Waikapū Stream at 915ft	0.83	1.096	0.89
South Waiehu Stream at 620ft	0.80	0.65	0.81
North Waiehu Stream at 660ft	0.79	0.82	0.81

Table S3. Seepage run measurements on Waikapū Stream from Oki et al. (2010) and recent USGS fieldwork. Seepage measurements conducted on 10/16/2018 were made under unstable flow conditions.

Location Description	Elevation (ft)	10/28/2004	11/15/2007	10/16/2018
Waikapū Stream 120ft US South Waikapū Ditch	1,160	3.57	2.76	12.1
South Waikapū Ditch withdrawal	1,130	2.79	2.43	2.48
South Waikapū Ditch leakage return flow	1,070	0.07	0.10	0.068
Waikapū Stream US Kalena confluence	1,060	0.62	0.51	11.4
seepage change		-0.23	+0.08	
Waikapū Stream US Kalena confluence	1,060	0.62	0.61	11.4
Kalena Stream US Waikapū confluence	1,057	2.27	1.53	4.02
Waikapū Stream	1,020		2.19	
Waikapū Stream	950		1.68	
seepage change			-0.51	
Waikapū DS Kalena confluence		2.87	2.19	15.42
South Waikapū ditch return flow	925		0.10	0.94
Waikapū Stream blw ditch return flow	922	3.11	1.68	16.3
seepage change				-0.06
Waikapū Stream	880	3.11	1.68	16.3
Waikapū Stream abv Poʻowai to North Waikapū	560	2.92		15.5
seepage change		-0.19		-0.80
Waikapū Stream abv Poʻowai to North Waikapū	560	2.92		15.5
North Waikapū ʻAuwai withdrawal	550	1.02		1.68
North Waikapū ʻAuwai Overflow Return Flow	540	0.46		0.0006
North Waikapū ʻAuwai Return Flow 1	530	0.19		
North Waikapū ʻAuwai Return Flow 2	530			0.19
North Waikapū ʻAuwai Return Flow 3	516			0.08
North Waikapū ʻAuwai Return Flow 4	479			0.68
South Waikapū ʻAuwai Return Flow	480	0.20		0.21
net change in flow from all ʻauwai flows		-0.17		-0.94
Waikapū Stream US of Waiheʻe Ditch	446	2.77		16.1
seepage change		+0.02		+0.34
Waikapū Stream US of Waiheʻe Ditch	446	2.77		16.1
Waikapū Stream DS of Waiheʻe Ditch	440	0.60		15.5
Waiheʻe Ditch Return	440	0.50		11.1
Waikapū Stream ds of Waiheʻe Ditch Return	421	1.10		25.6
Waikapū Stream at Route 380	200			28.9
Waikapū Stream near Kihei	35			22.5
seepage change				-6.4

Table S4. Two-Way (reach elevation, stream, elevation x stream interaction) Analysis of Variance results on square-root transformed depth and square-root transformed velocity values.

depth	SS	MS	df	F-statistic	p-value
elevation	10.71	5.35	2	3.458	0.032
stream	103.6	20.7	5	13.38	<0.001
elevation x stream	48.67	4.87	10	3.143	<0.001

velocity	SS	MS	df	F-statistic	p-value
elevation	0.456	0.228	2	4.715	<0.01
stream	1.085	0.217	5	4.484	<0.001
elevation x stream	1.099	0.110	10	2.272	0.013

Table S5. Substrate, Froude, and depth suitability for *Awaous stamineus*, *Sicyopterus stimpsoni*, and *Lentipes concolor* based on Gingerich and Wolff (2005).

substrate	bedrock	boulder	cobble	gravel	sand	silt
A. stamineus	0.2	1.0	1.0	0.5	0.2	0.2
S. stimpsoni	0.2	1.0	1.0	0.2	0.2	0.2
L. concolor	0.2	1.0	0.2	0.2	0.0	0.0
Froude	**F < 0.20**	**0.2 ≤ F < 0.4**	**0.4 ≤ F < 0.8**	**0.8 ≤ F**		
A. stamineus	1.0	0.5	0.2	0.2		
S. stimpsoni	1.0	0.5	0.2	0.1		
Froude	**F < 0.10**	**0.1 ≤ F < 0.15**	**0.15 ≤ F < 0.2**	**0.2 ≤ F < 0.6**	**0.6 ≤ F**	
L. concolor	1.0	0.5	0.2	0.1	0.05	
Depth (ft)	**D < 0.6**	**0.6 ≤ D < 1.8**	**1.8 ≤ F < 2.3**	**2.3 ≤ F < 5.0**	**0.8 ≤ F**	
A. stamineus	0.5	1.0	1.0	0.2	0.2	
Depth (ft)	**D < 0.4**	**0.4 ≤ D < 0.8**	**0.8 ≤ F < 1.5**	**1.5 ≤ F < 1.8**	**1.5 ≤ F < 2.4**	**2.4 ≤ F < 5.0**
S. stimpsoni	0.2	0.5	1.0	0.5	0.2	0.1
Depth (ft)	**D < 0.4**	**0.4 ≤ D < 0.8**	**0.8 ≤ F < 1.4**	**1.4 ≤ F < 4.0**	**4.0 ≤ F < 6.0**	**6.0 ≤ F**
L. concolor	0.1	0.2	0.5	1.0	0.5	0.05

Table S6. Weighting value scoring relative species sensitivities to habitat-trophic disturbance in streams for calculation of community-weighted average trophic capacity from Kido (2013).

Species	Weighting Value
Lentipes concolor	1
Sicyopterus stimpsoni	1
Neritina granosa	2
Atyoida bisulcata	3
Macrobrachium grandimanus	3
Stenogobius hawaiiensis	3
Awaous stamineus	4
Eleotris sandwicensis	4
Alien species (*Tilapia* spp., *Poeciliidae* spp., etc)	10
Macrobrachium lar	9

Table S7. Two-way Analysis of Variance sum of squares (SS), mean square (MS), degrees of freedom (df), F-statistic, and p-value on log(x+1)-transformed species density values with elevation and stream/river and their interaction as effects.

S. stimpsoni	**SS**	**MS**	**df**	**F-statistic**	**p-value**
stream	18.575	4.644	4	46.858	<0.001
elevation	1.532	0.766	2	7.731	<0.001
elevation x stream	3.080	0.385	8	3.855	<0.001

A. stamineus	**SS**	**MS**	**df**	**F-statistic**	**p-value**
stream	2.663	0.666	4	12.671	<0.001
elevation	0.714	0.357	2	6.791	<0.001
elevation x stream	1.031	0.129	8	2.454	<0.001

L. concolor	**SS**	**MS**	**df**	**F-statistic**	**p-value**
stream	1.334	0.334	4	11.256	<0.001
elevation	2.602	1.301	2	43.901	<0.001
elevation x stream	1.581	0.198	8	6.669	<0.001

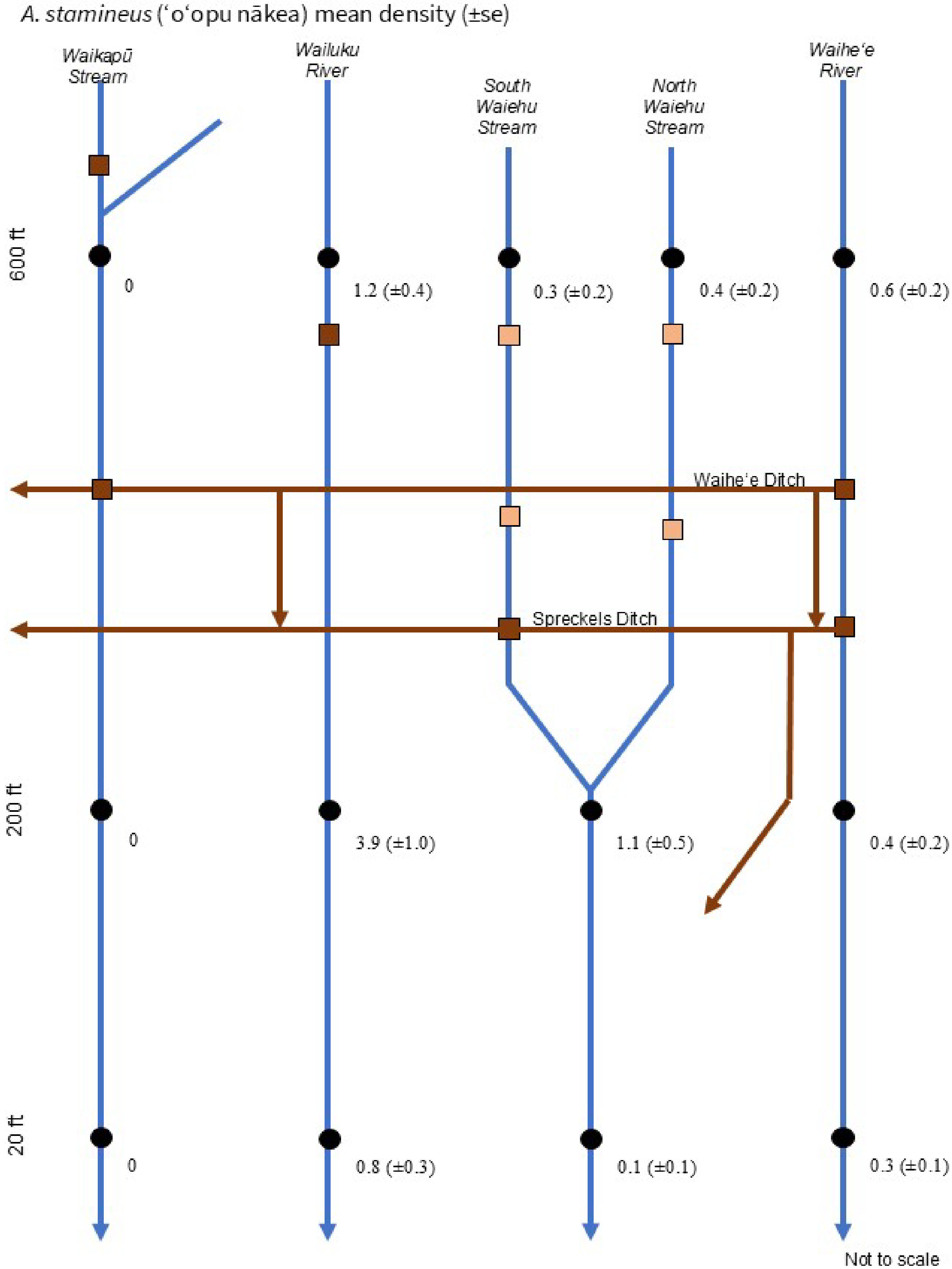
N. granosa	**SS**	**MS**	**df**	**F-statistic**	**p-value**
stream	0.167	0.042	4	2.511	<0.001
elevation	0.201	0.101	2	6.067	<0.001
elevation x stream	1.581	0.048	8	2.871	<0.001

M. lar	**SS**	**MS**	**df**	**F-statistic**	**p-value**
stream	1.074	0.268	4	3.135	0.0015
elevation	2.324	1.162	2	13.572	<0.001
elevation x stream	2.210	0.276	8	3.227	0.002

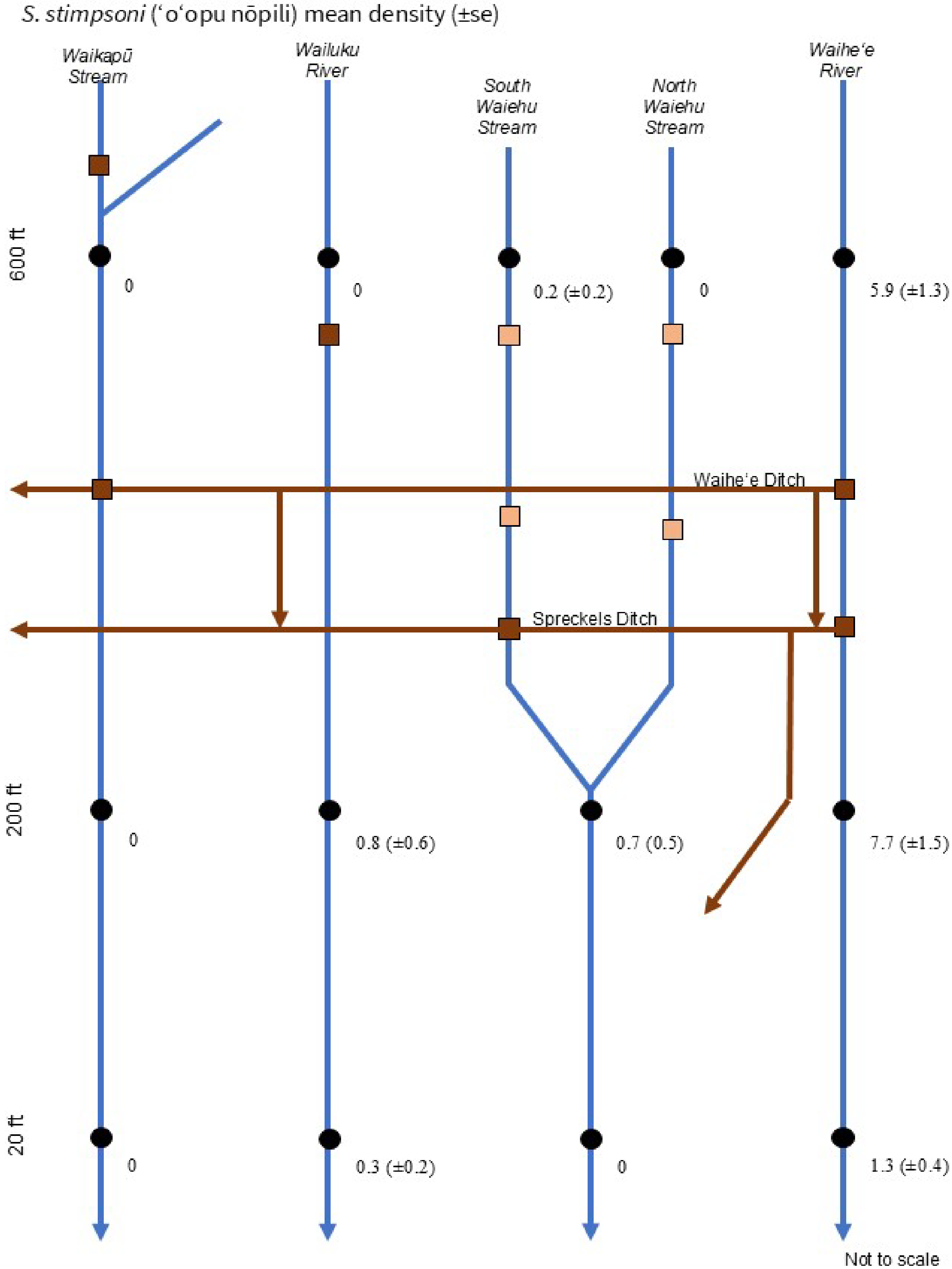
Table S8. Mean (±standard deviation) density by species, sample size, and reach elevation range used to compare historic point-quadrat visual surveys conducted by the State of Hawai'i Division of Aquatic Resources to present day survey efforts.

Upper Reach	year	n	*A. stamineus*	*S. stimpsoni*	*L. concolor*	*N. granosa*	*M. lar*	*Kuhlia spp.*
Waihe'e	1995	34	1.39 (±1.57)	0.38 (±1.15)	5.45 (±10.2)	0.00 (±0.00)	0.14 (±0.62)	0.00 (±0.00)
Waihe'e	2021	20	0.30 (±0.80)	0.62 (±1.13)	1.59 (±1.75)	0.00 (±0.00)	0.05 (±0.22)	0.00 (±0.00)
Wailuku	2005	46	0.35 (±1.40)	0.36 (±1.28)	0.17 (±0.99)	0.00 (±0.00)	0.04 (±0.28)	0.00 (±0.00)
Wailuku	2021	20	0.67 (±1.40)	0.00 (±0.00)	0.45 (±1.01)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Waikapū	2008	10	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.10 (±0.30)	0.00 (±0.00)
Middle Reach	**year**	**n**	***A. stamineus***	***S. stimpsoni***	***L. concolor***	***N. granosa***	***M. lar***	***Kuhlia spp***
Waihe'e	1995	13	0.67 (±0.97)	3.44 (±2.11)	1.25 (±1.31)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Wailuku	2005	29	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Wailuku	2007	15	0.46 (±1.79)	0.00 (±0.00)	0.46 (±1.79)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)
Waihe'e	2021	20	0.11 (±0.35)	7.89 (±6.52)	0.35 (±0.65)	0.00 (±0.00)	0.05 (±0.22)	0.00 (±0.00)
Waiehu	2021	20	0.34 (±0.83)	0.11 (±0.50)	0.00 (±0.00)	0.00 (±0.00)	0.91 (±1.57)	0.00 (±0.00)
Waiehu	2023	20	0.21 (±0.69)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	1.47 (±2.28)	0.00 (±0.00)
Lower Reach	**year**	**n**	***A. stamineus***	***S. stimpsoni***	***L. concolor***	***N. granosa***	***M. lar***	***Kuhlia spp***
Waiehu	2005	24	8.52 (±21.6)	7.15 (±19.2)	0.00 (±0.00)	0.00 (±0.00)	0.63 (±2.29)	9.91 (±26.1)
Wailuku	2005	38	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.16 (±0.97)
Wailuku	2021	20	1.50 (±2.79)	0.00 (±0.00)	0.00 (±0.00)	0.14 (±0.62)	0.88 (±2.25)	0.00 (±0.00)
Waiehu	2021	20	0.35 (±0.92)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.05 (±0.24)	0.32 (±1.04)
Waiehu	2023	20	0.18 (±0.46)	0.05 (±0.23)	0.00 (±0.00)	0.00 (±0.00)	0.55 (±0.92)	2.42 (±4.72)

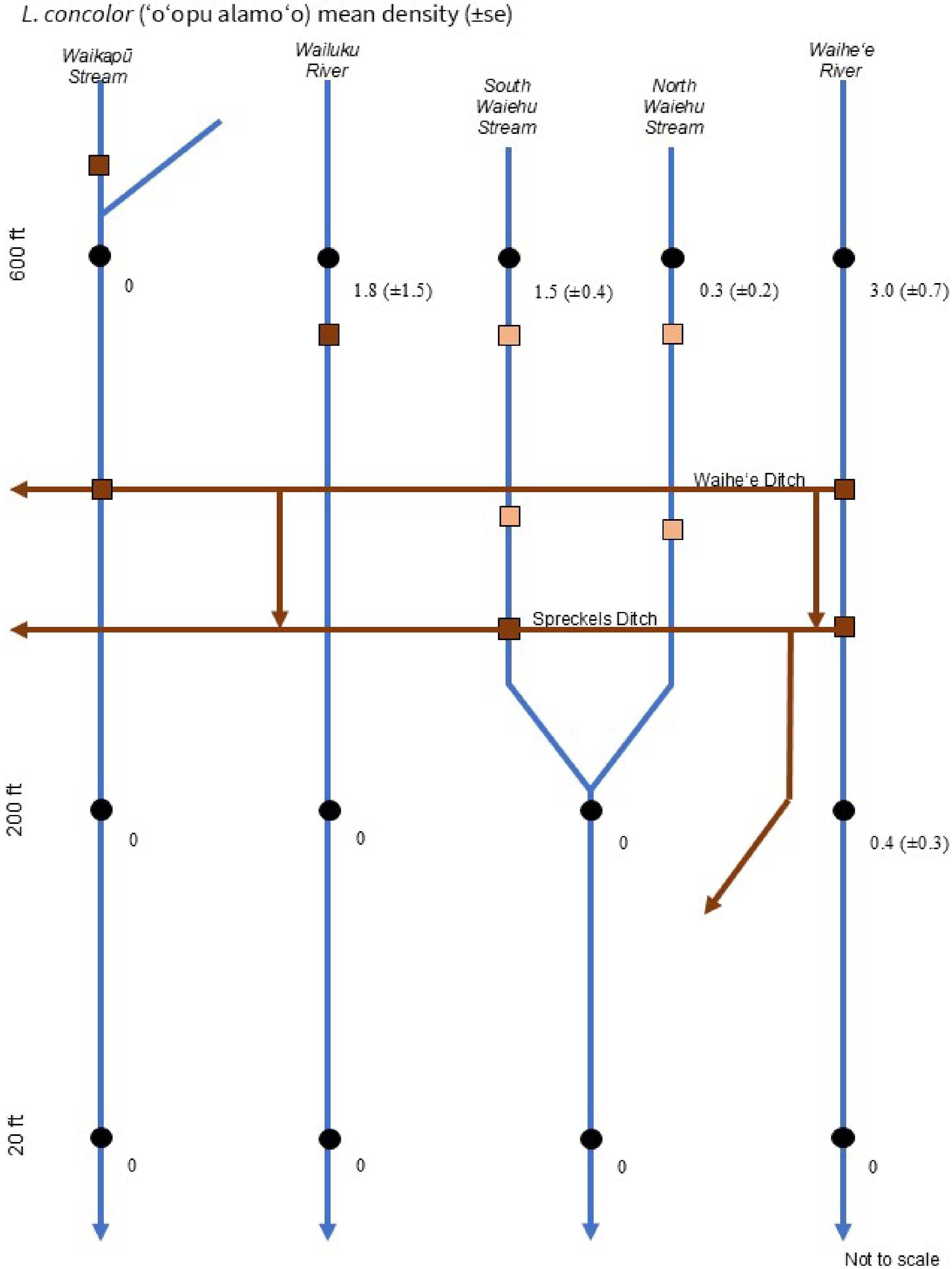
Supplemental Figure S1. Schematic diagram of Nā Wai ʻEhā streams with mean (±se) reach density of *Awaous stamineus* (ʻoʻopu nākea) from 2024 biological surveys



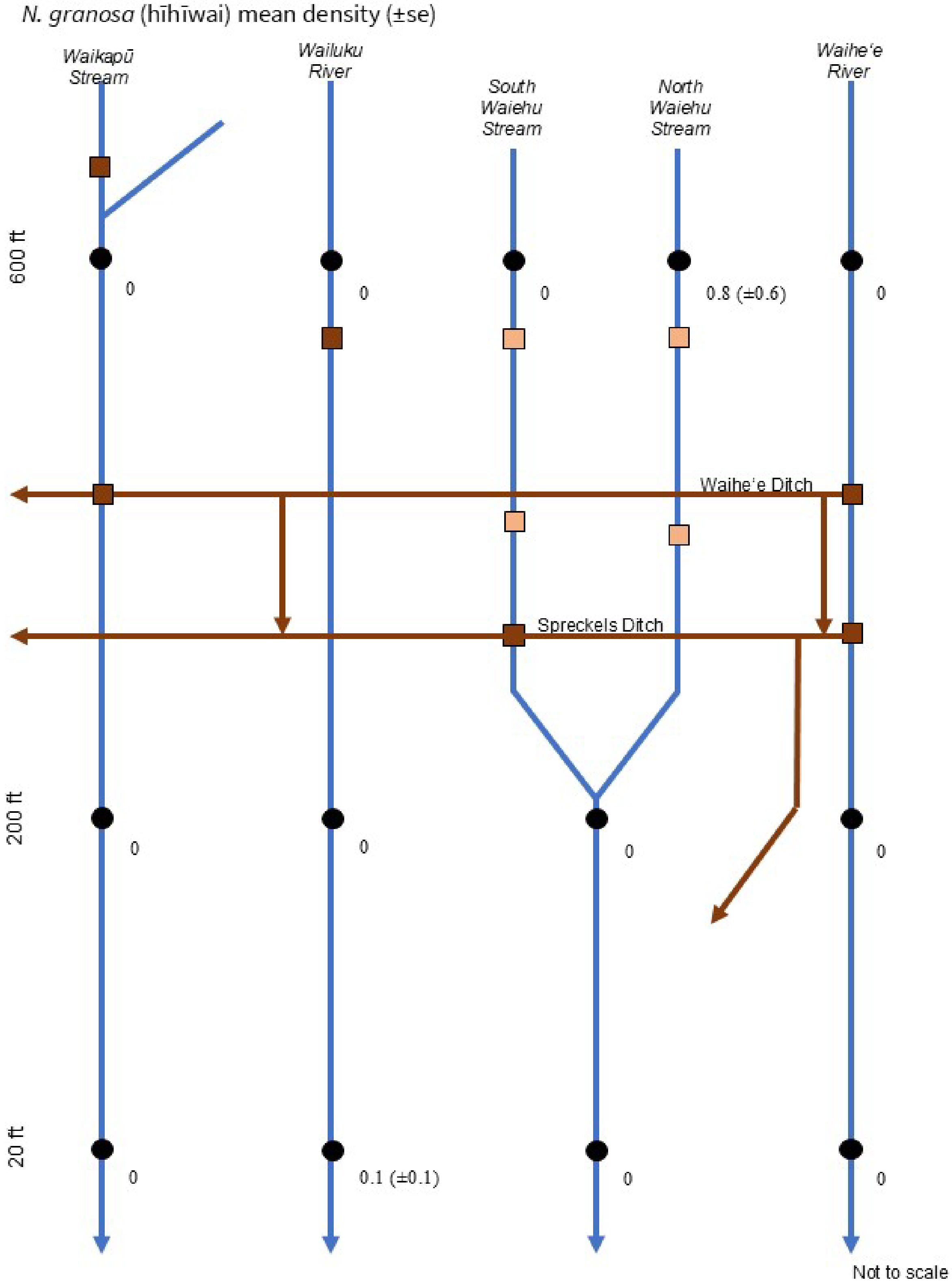
Supplemental Figure S2. Schematic diagram of Nā Wai ʻEhā streams with mean (±se) reach density of *Sicyopterus stimponsi* (ʻoʻopu nōpili) from 2024 biological surveys.



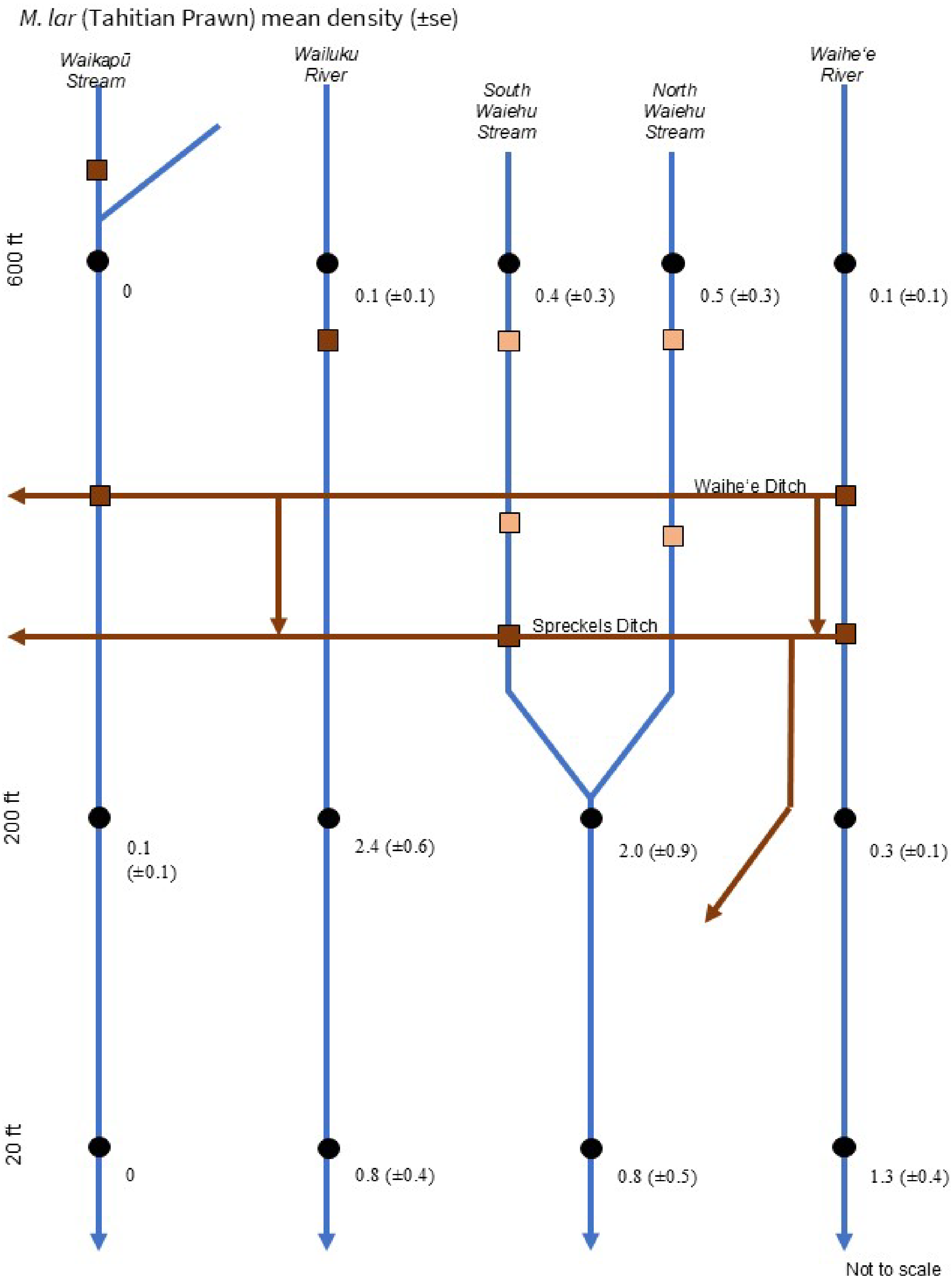
Supplemental Figure S3. Schematic diagram of Nā Wai ʻEhā streams with mean (±se) reach density of *Lentipes concolor* (ʻoʻopu alamoʻo) from 2024 biological surveys.



Supplemental Figure S4. Schematic diagram of Nā Wai ʻEhā streams with mean (±se) reach density of *Neritina granosa* (hīhīwai) from 2024 biological surveys.



Supplemental Figure S5. Schematic diagram of Nā Wai ʻEhā streams with mean (±se) reach density of *Macrobrachium lar* (Tahitian prawn) from 2024 biological surveys.



Supplemental Figure S6. Location of 2024 surveys conducted on the north shore of Kaua'i.