Nā Wai ʻEkolu: Stream Biodiversity, Watershed Health, and Citizen Science in the Ala Wai Watershed

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INTRODUCTION

Hawaiian Stream Animals

In Hawaiʻi, the freshwater macrobiota of relatively natural streams is dominated by native amphidromous species that have a marine larval phase but spend the juvenile and adult phases in freshwater. These migratory species include five endemic gobioid fishes, two decapod crustaceans, and two neritid mollusks (Table 1).

TABLE 1. Native amphidromous macrobiota in Hawaiian Streams

Species	Hawaiian / Common Name	Origin
Awaous guamensis	(ʻOʻopu nākea, Pacific river goby)	Endemic
Sicyopterus stimpsoni	(ʻOʻopu nōpili, Stimpson's goby)	Endemic
Lentipes concolor	(ʻOʻopu ʻalamoʻo or ʻOʻopu hiʻu kole)	Endemic
Stenogobius hawaiiensis	(ʻOʻopu naniha, Naniha goby)	Endemic
Eleotris sandwicensis	(ʻOʻopu ʻakupa, Hawaiian Sleeper)	Endemic
Atyoida bisulcata	(ʻŌpae kalaʻole, Hawaiian freshwater shrimp)	Endemic
Macrobrachium grandimanus	(ʻŌpae ʻOehaʻa, Hawaiian river prawn)	Endemic
Neritina granosa	(Hīhīwai, Hawaiian freshwater snail)	Endemic
Neritina vespertina	(Hapawai, Hawaiian freshwater snail)	Endemic

Habitat Loss and Threats

Anthropogenic influences have drastically altered the environment of Hawaiian streams where native amphidromous freshwater stream species occur. Factors associated with habitat alteration include the introduction of nonnative flora and fauna, riparian zone alteration, water diversions, stream channel modification and water quality degradation. Reductions in stream velocity and depth caused by water diversions may result in higher water temperatures and concomitant decreases in dissolved oxygen levels. Most human activity in Hawaiʻi is concentrated in the lowlands and the changes in Hawaiian streams tend to be greatest in these areas. While the upper reaches of streams may remain pristine, the lower reaches are often made nearly uninhabitable to the native fishes and invertebrates by habitat alterations. Additionally, vital access to the sea is lost to seaward moving larvae and returning juveniles of native amphidromous fauna because of habitat alterations listed above. Stream flow alterations can also negatively impact competition, predation, behavioral changes, changes in life history characteristics and alterations of food chains. The combined effects of all these impacts on Hawaiian streams means that the management of these intensely modified ecosystems requires detailed knowledge of how cumulative stresses may affect native species. And the successful maintenance of natural streambeds and adequate water quality of Hawaiian streams may be necessary to insure the retention of populations of Hawaiʻi's endemic aquatic fauna, including the native fishes.

Although long-term habitat restoration efforts in highly urbanized landscapes are not realistic, we believe it is still possible to remove invasive species from waterways with considerable intensive effort. Most freshwater alien introductions come from the aquarium

trade, where unwanted fish and macro-invertebrates are discarded in streams and other water bodies around the state. The largest populations and diversity of these aquarium-introduced species often correlates to human disturbance (Figure 1), and even locations where animals can be conveniently introduced to streams, i.e. road crossings in residential areas. A major concern continues to be the introduction and spread of alien freshwater species like loricariid catfishes, particularly *Hypostomus sp.* and *Ancistrus sp*., as well as Japanese *Neocaridina denticulata sinensis* (Japanese Swamp Shrimp), which have similar food preferences as native stream animals. Predatory freshwater game fishes have also been intentionally introduced to similar areas, to stimulate the recreational fishing industry, including *Micropterus dolomieu* (Smallmouth Bass) and *M. salmoides* (Largemouth Bass), *Cichla ocellaris* (Peacock Bass) and *Oncorynchus mykiss* (Rainbow Trout).

The Ala Wai Watershed

Mānoa, Pālolo, and Makiki Valleys comprise the highly urbanized "Ala Wai Watershed." The Ala Wai Watershed is one of the most densely populated areas in the state with ~ 200,000 residents in a total land area of only 16.3 sq. miles. Natural stream flows to the ocean from these valleys in the Koʻolau Mountain Range are today interrupted by the Ala Wai Canal. Roughly one-third of the upper / headwater region are in forested watershed, while the majority remainder is moderate to heavily urbanized, supporting residencies, condominiums, hotels, businesses, and educational institutions. The middle to lower reaches of Mānoa Stream were found to be significantly modified for flood control with its channel widened and banks earthen-shaped or hardened with concrete walls. Of the three streams, Mānoa is the least modified, whereas Pālolo and Makiki have a more infrastructure for flood control. With this kind of intense urbanization and public use, it is not surprising that the Ala Wai Watershed has amongst the lowest populations of native stream animals, and the highest densities and diversity of invasive species in the State of Hawaiʻi.

The Hawaiian Stream Index of Biological Integrity

The concept of "integrity" is a holistic one and incorporates the idea that comparisons are made using the "functions and components of whole natural systems" as examples of robust ecological health. The Hawaiian Stream Index of Biological Integrity (HS-IBI) incorporates 11 metrics covering five ecological categories, and has shown to effectively differentiate relative environmental/habitat quality in streams on all Hawaiian Islands across gradients of human influence, from near-pristine to severely impaired (Table 2, Figure 1). To determine biological integrity scores for a given site, counts and measurements of fishes and macro-invertebrates are obtained by either underwater visual census or electrofishing techniques. The sites with the highest native species densities are designated as reference sites and obtain the maximum of 55 points (up to 5 points per metric). Any deviation in native species abundance and distribution, or presence of non-native species will result in lower HS-IBI scores, and presumably lower ecosystem health (Table 2, Figure 1).

TABLE 2. Metrics / scoring criteria for the Hawaiian Stream Index of Biological Integrity

Category	Metric	Scoring criteria		
		5 (best)	3	1 (worst)
Taxonomic richness	1a. Number native species (non-estuary)	4–3	2–1	0
	1b. Number native species (estuary reach)	6–5	4–2	1–0
	2. % native taxa	100–75 %	74–50 %	≤49 %
	3. Number alien taxa	0–1	2–3	>3
Sensitive "sentinel"	4. % sensitive native fish[a]	≥50 %	49–20 %	≤19 %
Species	5. Sensitive native fish density (fish m^{-2})[b]	≥0.46	0.45–0.20	≤0.19
Reproductive capacity	6. Sensitive native fish size (%≥6.0 cm TL)[c]	≥50 %	49–25 %	≤24 %
	7. *Awaous guamensis* size (%≥8.0 cm TL)[c]	≥50 %	49–25 %	≤24 %
Trophic/habitat	8. Total native fish density (fish m^{-2})	≥0.75	0.74–0.36	≤0.35
Capacity	9. Community weighted average (CWA)	1.0–4.0	4.1–9.0	9.1–10
Tolerance capacity	10. % Tolerant alien species	0 %	1–4 %	≥5 %
	11. % Diseased or parasitized fish	≤1 %	2–10 %	≥11 %

[a]Sensitive species are *L. concolor* and *S. stimpsoni*, [b]*L. concolor* or *S. stimpsoni* (whichever is in higher density), and [c]Excluding post-larval size classes (≤ 3.0 cm TL).

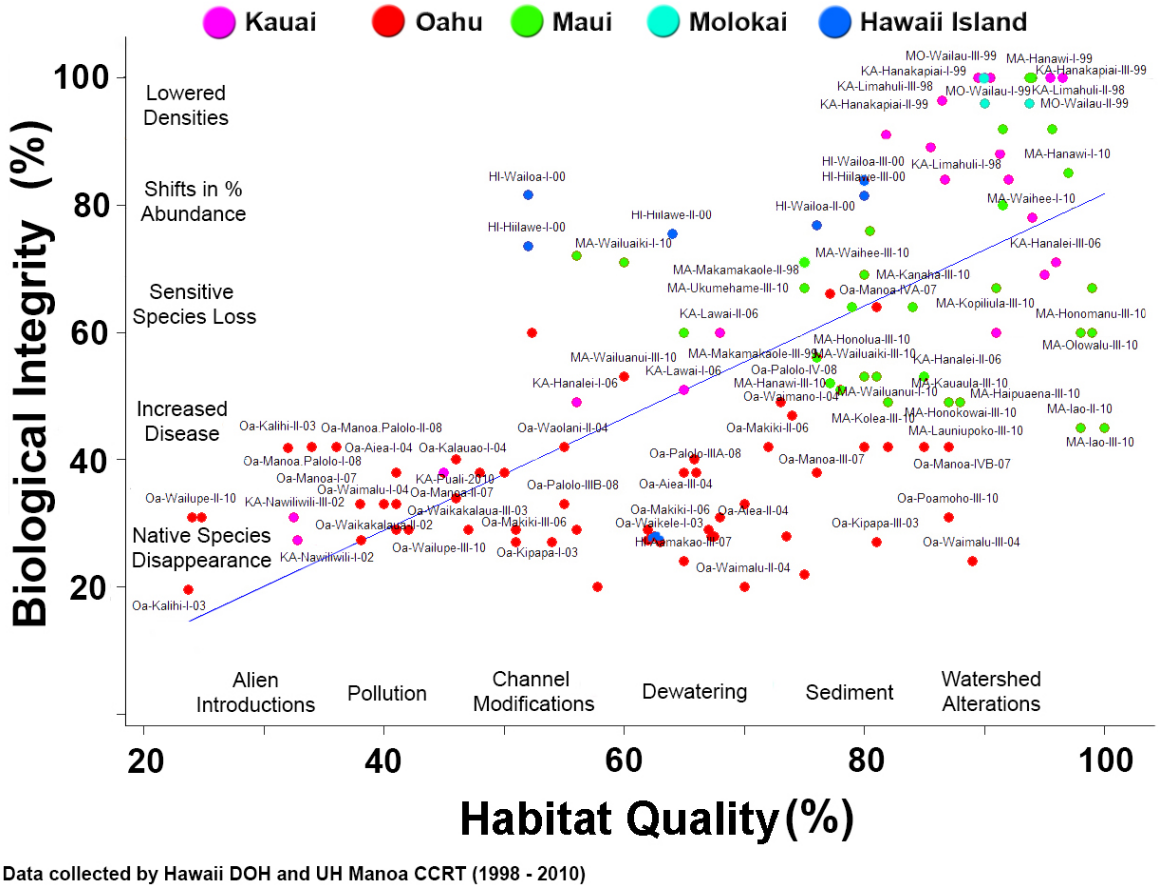

Figure 1. Significant relationship between biological integrity and habitat quality in Hawaiian Streams. Scores displayed as % for each of the five islands samples.

Nā Wai 'Ekolu: Community Outreach and Stream Restoration

As a stream outreach and restoration project, to educate the public about Hawai'i's unique native freshwater species and the effect of anthropogenic influence on their populations, a collaborative effort was established between the University of Hawai'i at Mānoa Center

for Conservation Research and Training (UH-CCRT) and ʻIolani School. Together, classroom curricula and field protocols were developed for use in K-12 public, private, and charter schools in the Ala Wai Watershed, emphasizing biological integrity (or the health of an system as indicated by species diversity / abundance) through three sequential freshwater stream and watershed health lessons (Figure 2).

METHODS

Figure 2. Three sequential lessons offered to K-12 public and private schools from UH-CCRT / ʻIolani partnership

Lesson 1 begins with a classroom lecture that introduces participants to native / non – native stream animals and how they are indicators of stream health. Participants are then able to view live native and non-native animals that are from their watershed, as well as engage in hands-on activities. Lessons range between 30 to 60 minutes, and depends on the age of participants or the length of time allotted for a class period (Figure 2). For Lesson 2, students learn how to work together to capture stream fishes and macro-invertebrates in a standardized method. Since professional procedures are neither safe nor practical for K-12 students to perform, a modified "paʻēpaʻē" procedure was adapted for student groups. After being assigned to specific teams, where various seines, A-framed nets (ʻŌpae nets), and PVC pipes are used to herd and trap animals in a predetermined length of a modeled stream (Figure 2). Participants familiarize themselves with the appropriate field equipment for their team, as well as the roles of other teams, in preparation for field application. The lesson requires ≥ 30 minutes per class, but may require more time if entire grade levels participate. After rehearsing their field methods, participants are taken to a nearby stream site for field application, as Lesson 3. The paʻēpaʻē stream bioassessment survey requires 45 per replicate, but performing the survey twice is strongly encouraged if time permits. Once captured, animals are identified to species, counted and measured. If the animal is non-native, it is removed from the site; if they are native they are temporarily held in aerated buckets of stream water and after

Figure 3. Stream animal identification, counts, and removal of invasive species for composting

being recorded (Figures 2 and 3). Data from the activity is then used to score the stream site using the HS-IBI, and then stored in an online database maintained by UH-CCRT (https://www.nawaiekolu.org/stream-biodiversity-database-google-sheet. The field activity concludes with a summary about what animals are found and what they tell us about the health of the stream / habitat. After the activity, invasive species are euthanized with ice, and taken to Hoʻoulu ʻĀina (a nearby forest restoration, sustainability, and cultural education center, http://www.hoouluaina.com) to be used for composting (Figure 3 and 4). Native species are then released back to their capture locations once participants are no longer in the stream site. In the classroom, educators are given the option to use Lesson 4, science curriculum that have been designed to fit the next generation science standards in four modules (https://www.nawaiekolu.org/n-wai-ekolu-curriculum) and to be used in tandem with an ArcGIS story map (https://iolaniresearch.maps.arcgis.com/apps/Cascade/index.html?appid=8447f3fe684e40f78a0c3ccb9330a2d0):

K-2: What's In a Number? Students explore and visualize numbers, deepening their number sense, more fully understanding their impact on stream health via invasive species removal.

3-5 Exploring the Possible! Long-term effects of invasive species removal and their contribution to the health of the watershed.

6-8 Find Your Soapbox! Analyze, interpret, and use data to support an argument.

9-12 Calculating a Biodiversity Index to Assess Stream Health.

RESULTS and DISCUSSION

From November 2015 to December 2018, we have worked with 11353 students and 1508 educators from ~ 39 educational and professional institutions around the island of O‘ahu (Appendix). During this period, Lessons 1, 2, and 3 were performed 258, 180, and 180 times, respectively (Appendix). Total number of fishes and macroinvertebrates captured during field lessons was ~ 28,515, of which only 522 were native species (Table 3). All invasive animals were removed from the stream, totaling 1324 pounds, and converted into compost or adopted as household pets from students, parents, and teachers. Native species were always released back to their capture location following the field activity.

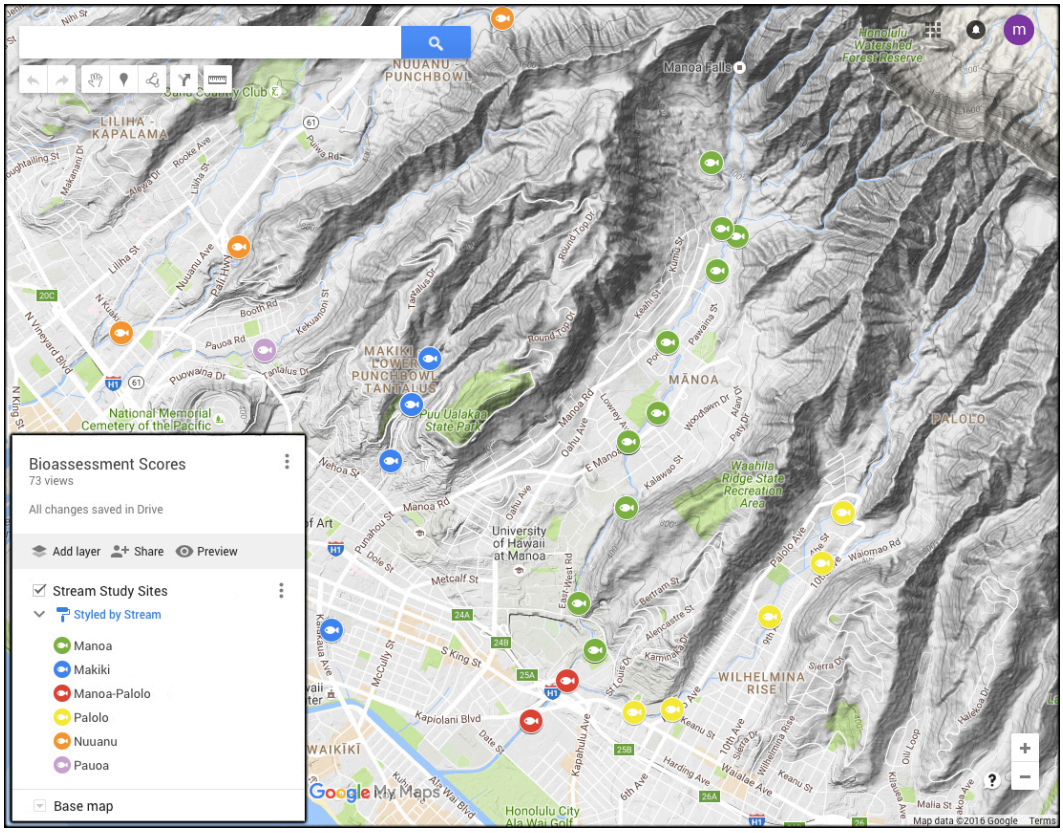

Figure 4. Current and near-future stream sites in Nu‘uanu, Makiki, Mānoa, and Pālolo Valleys

Table 3. Preliminary results of students participating in Lesson 3 surveys (Jan 2016 to Dec 2018)

	Year 1	Year 2	Year 3	All Years
Site Visits	**24**	**47**	**49**	**120**
Total Captured	4536	14278	9701	28515
Total Natives	26	183	313	522
% Natives	0.6	1.3	3.2	
Total Invasives	4510	14095	9388	27993
% Invasives	99.4	98.7	96.8	
HSIBI	**30.3**	**30.2**	**32.7**	**31.3**
Weight (lbs)	**176.8**	**709.8**	**414.6**	**1301.3**

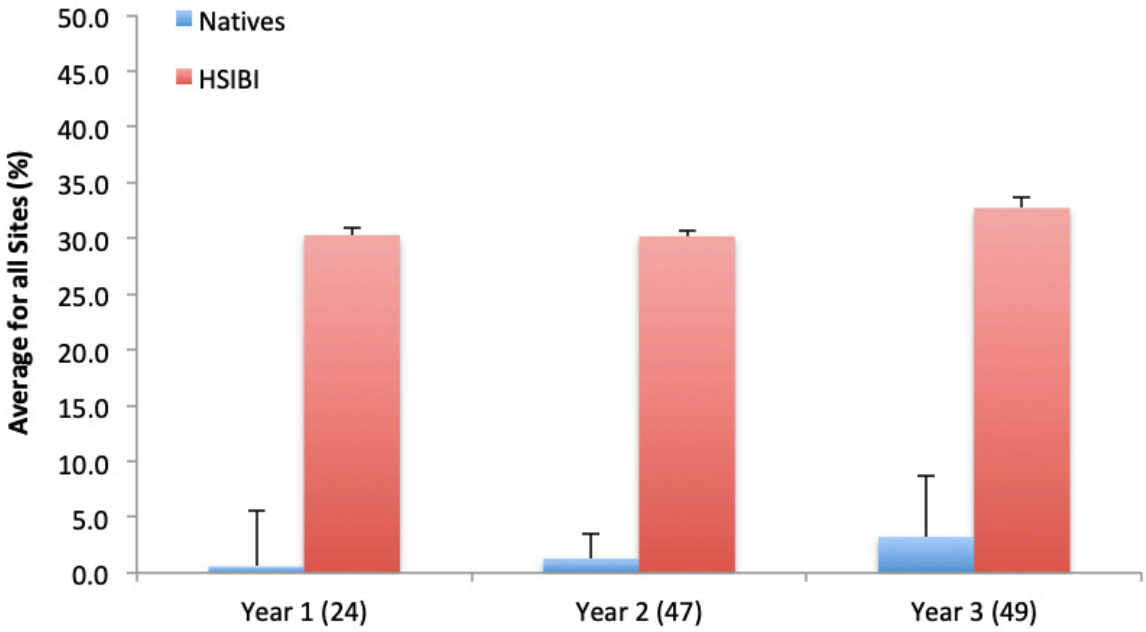

Figure 5. Annual percent native and Hawaiian Stream Index of Biological Integrity (HSIBI) scores during project period. (surveys per year)

Preliminary annual native species and biological integrity scores indicate a small increase in Year 3 when averaged across all study sites (Table 3, Figure 5). Sustaining our efforts in Year 4 will be critical to validate our findings, as we only received 50% of the participants in Year 1 compared to Year 2 and 3. Although early in this study, we hope that a positive trend will be observed in subsequent years. As our study sites decrease in invasive species density, we expect our activities will provide important refuges for native recruiting or migrating animals, as they are likely to be areas of decreased competition / areas of predation with / from invasive species. There are at least small populations that persist in all three streams in these degraded environments, we expect proportions of native to non-native stream animals to increase as our efforts continue.

CONCLUSIONS

Despite having received high community support for this activity in a relatively short time, improvements in stream biological integrity and/or health of Hawaiian Streams will require more participation from more educational and professional institutions. By engaging in more environmental education workshops and symposia, we also hope to stimulate more community interest and maintain intensive efforts to improve stream health in Hawai‘i’s watersheds that need it most.

APPENDIX

Stream Outreach Activity Statistics (Nov 2015 - Dec 2018)

Number Reached	Lessons Given: (618)	Animals Captured (28515):
Grades (K - 12+)	Lesson 1 (258)	Invasive Species (27993)
Students (11353)	Lesson 2 (180)	Native Species (522)
Educators (1508)	Lesson 3 (180)	Biomass Removed (1324 lbs)

Educational institutions involved (* multi-grade): 39

Kaahumanu Elem*
Aliiolani Elem
Hokulani Elem*
Kamehameha Elem*
Hauula Elem*
Blanche Pope Elem
Pauoa Elem
Jefferson Elem
Haleiwa Elem
Noelani Elem
Manoa Elem
Palolo Elem
Waikiki Elem

Anuenue School*
Stevenson
Washington Middle
Kailua Intermediate
Jarrett Middle
Myron B. Thompson*
Halau Ku Mana
SEEQS*
Voyager Academy
Hanahauoli School
University Laboratory*
Ka‘i Program
Home School Students*

Radford High
Roosevelt High
Waialua High*
Kaimuki High
Mililani High
Mid Pacific Institute*
Punahou School*
Iolani School*
Hawaii Baptist Academy
Pacific Buddhist Acad.
Chaminade University
University of Hawaii*
Hawaii Nature Center*
Queen Liliuokalani CC*