THESIS

ADVANCING THE SCIENCE AND PRACTICE OF CONSERVING HIHIWAI: USING ECOLOGY AND TRADITIONAL ECOLOGICAL KNOWLEDGE TO IDENTIFY AND OVERCOME THREATS TO AN ENDEMIC HAWAIIAN GASTROPOD

Submitted by

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ABSTRACT

ADVANCING THE SCIENCE AND PRACTICE OF CONSERVING HIHIWAI: USING ECOLOGY AND TRADITIONAL ECOLOGICAL KNOWLEDGE TO IDENTIFY AND OVERCOME THREATS TO AN ENDEMIC HAWAIIAN GASTROPOD

Aquatic gastropods are valuable indicators of stream health in tropical ecosystems globally. Sustaining gastropods on islands is particularly important because these species provide numerous ecosystem services such as water purification, nutrient cycling, mediating the transfer of carbon through food webs, and providing sustenance for people. Hihiwai (*Neritina granosa*) is an amphidromous snail that was used as a subsistence food source in ancient times by Native Hawaiians and is still harvested today. Yet, this species is of conservation concern and both the ecological factors associated with its density and distribution as well as the socio-cultural knowledge associated with this species are largely unknown. Bridging Traditional Ecological Knowledge (TEK) and western science, which requires valuing indigenous knowledge and leadership and incorporating these ways of knowing into conservation science and practice, is an effective strategy to address this paucity of information in local and Indigenous communities. TEK is particularly important on islands where indigenous communities steward their often imperiled cultural and natural heritage. Evaluating the factors contributing to hihiwai loss and recovery using a combination of western science and TEK could serve as a model for Indigenous and local communities at the marine/freshwater interface globally.

To address these knowledge gaps, I surveyed four streams on the Hawaiian Islands of Molokai and Maui to 1) determine which characteristics of stream systems are associated with

Hihiwai population density across age classes, and 2) evaluate the size distribution of adult hihiwai as a function of stream characteristics. Specifically, I used stratified random quadrat sampling to assess hihiwai densities along an elevational gradient in streams with (n = 2) and without (n = 2) diversions. I collected data on stream characteristics such as width, depth, velocity, discharge, temperature, shading, and substrate. I found that hihiwai recruits, juveniles and adults were more abundant in diverted streams, all size classes and adult length were positively associated with stream depth, adult hihiwai were more likely to occur at higher elevations, and there was an inverse relationship between adult size and density, with larger hihiwai more likely to occur where adults were least abundant.

In parallel with the stream surveys, I conducted semi-structured interviews with 20 local community members on Molokai to examine how traditional ecological knowledge and local experience can be used to better understand the ecology and cultural value of hihiwai, and to engage local communities in the conservation of this species and its habitat. Three major takeaways were identified as relevant for understanding the drivers, impacts, and next steps for hihiwai conservation: 1) community members believe that hihiwai populations are decreasing due to a combination of direct (overharvesting, water diversions) and indirect (higher stream temperatures, invasive plants) anthropogenic effects; 2) The perceived decrease in hihiwai abundance on Molokai has resulted in fewer opportunities for local people to connect with each other and spend quality time (eating and picking hihiwai), a loss of historic knowledge of hihiwai and cultural identity, and has disrupted the transmission of cultural and ecological knowledge to the next generation; and (3) Community members emphasized the need for informed local conservation leaders who represent the interests of the local Molokai people to guide and enforce hihiwai and Hawaiian stream management. Although community perceptions of whether bottom-up or top-down management strategies would be more effective were mixed, there is a general consensus that a change in values toward hihiwai harvest and possible harvest limits are needed to ensure healthy hihiwai populations in the future. My findings from this cross disciplinary study highlight the overlap, as well as the novel information that can emerge from integrating ecological and social research. Bridging the gap between western ecological science and TEK through local community collaboration will be critical for developing effective management plans that ensure ecological and cultural sustainability of hihiwai in Hawaii.

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TABLE OF CONTENTS

CHAPTER ONE

THE EFFECT OF ABIOTIC FACTORS ON THE DENSITY AND DISTRIBUTION OF A CULTURALLY IMPORTANT HAWAIIAN GASTROPOD

SUMMARY

Aquatic gastropods are valuable indicators of stream health in tropical ecosystems globally. Sustaining gastropods on islands is particularly important because these species provide numerous ecosystem services such as water purification, nutrient cycling, mediating the transfer of carbon through food webs, and providing sustenance for people. Hihiwai (*Neritina granosa*) is an amphidromous snail that was used as a subsistence food source in ancient times by Native Hawaiians and is still harvested today. Yet, this species is of conservation concern and the factors associated with its density and distribution are largely unknown. Major threats to this species may include instream diversions, which are expected to impede hihiwai recruitment and movement across all age classes. To address this knowledge gap, I surveyed four streams on the Hawaiian Islands of Molokai and Maui to 1) determine which characteristics of stream systems are associated with hihiwai population density across age classes, and 2) evaluate the size distribution of adult hihiwai as a function of stream characteristics. Specifically, I used stratified random quadrat sampling to assess hihiwai densities along an elevational gradient in streams with (n = 2) and without (n = 2) diversions. I collected data on stream characteristics such as width, depth, velocity, discharge, temperature, shading, and substrate. I found that hihiwai recruits, juveniles and adults were more abundant in diverted streams, all size classes and adult

length were positively associated with stream depth, adult hihiwai were more likely to occur at higher elevations, and there was an inverse relationship between adult size and density, with larger hihiwai more likely to occur where adults were least abundant. To achieve healthy hihiwai populations across Hawaii, future research and conservation efforts should more explicitly consider the role of diverted as well as free-flowing streams, manage stream discharge to ensure a diversity of stream depths, which promote optimum hihiwai growth across all age classes, and explore the possibility of raising hihiwai in controlled environments as a potential avenue for alleviating human harvest pressure on declining wild populations. Such strategies could help sustain and recover this unique endemic gastropod and its' valuable contributions to ecological function and cultural practice.

INTRODUCTION

Aquatic macroinvertebrates make important contributions to global biodiversity, fill ecological roles that have cascading effects across ecosystems, and are key indicators of healthy ecosystems (Collier et al., 2016; Johnson et al., 2013). Macroinvertebrates are crucial to stream biodiversity, as the extinction of one species within a food web can result in secondary extinctions due to bottom-up effects (Calizza et al., 2015). Macroinvertebrates are also commonly used in environmental monitoring because they are often sensitive to anthropogenic disturbance and thus serve as effective indicators of ecological integrity (Calizza et al., 2015; Johnson et al., 2013). For example, long-term monitoring of aquatic macroinvertebrates has been shown to correlate with habitat loss not detected by traditional water quality assessments (Forio et al., 2017).

Despite their ecological importance, aquatic invertebrates are grossly underrepresented in assessments of conservation status and often neglected in aquatic conservation efforts (Sor et al., 2020). In a global assessment of 7,857 freshwater invertebrates and 2,864 marine invertebrates, 30-34% of the total species assessed were considered data deficient (Collier et al., 2016). Of those invertebrate groups that have been assessed, species with poor dispersal abilities and high local endemism, such as many gastropods, crayfish, and mussels, are most threatened (Johnson et al., 2013). Within those groups, freshwater snails are particularly imperiled (61% of all U.S. species; Wilcove & Master, 2005). The disparity between the number of freshwater snails in the US that have been sufficiently studied and the proportion of US freshwater snails that are imperiled has resulted in a crucial knowledge gap in the field of freshwater science and conservation (Collier et al., 2016; Johnson et al., 2013).

Dams and diversions, pollution, and invasive species are the main threats to freshwater ecosystems worldwide (Carlisle et al., 2011; McManamay & Frimpong, 2015; Poff et al., 2007; Poff & Zimmerman, 2010). In addition to biophysical threats to aquatic invertebrates, there are also major social impediments to aquatic invertebrate conservation. These include limited knowledge of habitat requirements and basic life history, population status and trends, the need for broad scale actions to account for connectivity within and across ecosystems, lack of political will and investment, and the prospect that conditions may get worse before they improve, possibly not in time to protect already highly imperiled invertebrate species from extinction (Collier et al., 2016; Johnson et al., 2013).

Island ecosystems provide ideal conditions to investigate both the ecological and social dimensions of conserving gastropods in freshwater streams (Brasher et al., 2006; Gutiérrez-Fonseca & Ramírez, 2016; Hodges & Allendorf, 1998; Jenkins et al., 2010; Wheeler et al., 2018). Many islands are experiencing multiple and often interacting threats to aquatic systems, including invasive species, land use change, and exploitation of limited freshwater for municipal and agricultural use to support high densities of residents and tourists. Isolation from continental systems has led to native stream fauna characterized by high endemism and unusual life history traits on islands (Smith et al., 2003). One of these unusual traits is that freshwater fauna on tropical islands is dominated by amphidromous stream species that migrate across a broad range of habitats throughout their life cycle, compared to a higher proportion of freshwater residents on continents (Brasher et al., 2006; Jenkins et al., 2010). High endemism, limited geographic range, and susceptibility to generalist invasive species heighten the need for proactive and integrated management of these unique aquatic communities (Brasher et al., 2006; Wheeler et al., 2018).

Sustaining island gastropods is particularly important because these species provide numerous ecosystem services such as water purification, nutrient cycling, transferring carbon through food webs, and providing sustenance for people (Collier et al., 2016). Native gastropods hold significant value within local communities in the tropics, as many local people harvest stream snails as a food source, both for subsistence and as a delicacy (Collier et al., 2016). Gastropods in the family Neritidae in particular are widely used as a source of food in rural tropical communities. For example, Poutiers (1998) identified 11 neritid species known to be used for food within the Western Central Pacific. Many of these gastropods are collected by local fishermen for personal consumption or sold as food at local markets before the empty shells are resold to collectors or to the shell craft industry.

Hihiwai (*Neritina granosa*) is an amphidromous snail that was used for subsistence in ancient times by Native Hawaiians (Hodges & Allendorf, 1998) and is still harvested today. In ancient Hawai'i, hihiwai was also referred to as "wī", which means famine in the Hawaiian language, suggesting this species was an important food source for Native Hawaiians during times of food shortage (Hodges & Allendorf 1998). Today, hihiwai continues to be valued by Native Hawaiians and Hawaii's rural residents as both a source of subsistence food and recreation (Hodges & Allendorf 1998). Hihiwai is known to persist in relatively undisturbed streams on the Hawaiian Islands of Kaua'i, Molokai, Maui, and Hawai'i Island (Hodges & Allendorf 1998). According to the IUCN Red List, hihiwai populations are decreasing and this species is currently listed as vulnerable (Johnson et al., 2013).

Hihiwai habitat on Molokai and Maui includes four perennial valley streams, two of which are free flowing, and two that are heavily diverted (Hodges & Allendorf 1998). Instream diversions likely impede hihiwai recruitment and movement across all age classes as individuals may not have the means to traverse these manmade barriers. Dams and diversions also disrupt hihiwai larvae hatched and released from egg cases upstream of diversions by redirecting larvae from their anticipated destination of nearshore marine habitat to manmade water storage sites for agricultural use, resulting in larvae unable to complete their development. Instream diversions may also be expected to increase stream temperature and alter both natural stream flow regimes and substrate composition (Carlisle et al., 2011; McManamay & Frimpong, 2015; Poff et al., 2007; Poff & Zimmerman, 2010).

The local communities on Molokai and Maui have a strong cultural connection to this species as hihiwai are collected both for household consumption and for large celebratory events (Hodges & Allendorf 1998). According to local resource users and fishermen on the island of Molokai, hihiwai harvest is limited to medium to larger adult hihiwai. This selective harvest strategy is expected to have a direct influence on adult hihwai through active removal from Hawaiian stream systems, and a longer-term indirect influence on hihiwai eggs, recruits, and juveniles as a result of these harvested adults. Because this species is of conservation concern and has long been valued by the local community, evaluating the factors that affect hihiwai density and distribution could contribute to socio-ecological approaches to conserving ecosystems at the marine/freshwater interface around the world.

The objectives of this study were to 1) determine which abiotic characteristics of stream systems are associated with hihiwai populations across age classes within and among streams, and 2) evaluate the size distribution of adult hihiwai as a function of stream characteristics. Based on previous studies in similar systems (Brasher, 1997; Carlisle et al., 2011; McManamay & Frimpong, 2015; Poff et al., 2007; Poff & Zimmerman, 2010; Smith et al., 2003), I hypothesize that hihiwai density will be greater in streams with higher discharge and fewer diversions, and positively associated with cooler water temperatures, less sedimentation, and smaller streambed substrate size. I predict that hihiwai in larger size classes will occur in higher densities in natural flow streams, and in streams with less human harvest pressure.

METHODS

Study Area

The study area includes four streams, three of which are located on the island of Molokai, and one on the adjacent island of Maui (Hawaii, United States) (Figure 1.1). The three study sites on Molokai are perennial streams located on the Northeastern coastline of the island, in remote, undeveloped valleys readily accessible only by boat, plane or on foot. The fourth study site is located in East Maui in a valley that is also rural but adjacent to Maui's road network, and thus more accessible to visitors. The study streams will not be named in this thesis to respect and protect the integrity and anonymity of these areas, which are highly valued by the local community for subsistence and cultural use. Two of the three streams on the North Shore of Molokai, hereafter referred to as “Natural Flow 1” and “Natural Flow 2”, are natural flow streams without any artificial water diversion structures. The remaining stream on Molokai and the stream on Maui both contain at least one structure that diverts water for agricultural use, and are hereafter referred to as “Diverted 1” and Diverted 2”. Each stream ranges in elevation from 0 m where they meet the ocean to a maximum elevation of 430 m in the main channel. All four valleys are characterized by similar native and non-native plant communities and these habitats support large populations of non-native ungulates, including axis deer (*Axis axis)*, feral pigs (*Sus scrofa*), and wild goats (*Capra ibex*), that contribute to increased erosion.

“Natural Flow 1” is visited regularly by local community members who camp and harvest food, including hihiwai, in this area. “Natural Flow 2” is more difficult to access and likely subject to less hihiwai harvest pressure. “Diverted 1” is more remote and difficult to visit, as agency regulations within this valley and strict enforcement are present, but despite these stringent guidelines, this valley still experiences some harvest pressure. “Diverted 2” is easily accessible due to maintained trails, but hihiwai harvest is uncommon in this valley. Based on knowledge gathered from local resource users on north shore Molokai and East Maui harvest pressure levels, I consider “Natural Flow 1” as having high harvest pressure, “Natural Flow 2” as moderate harvest pressure, and “Diverted 1” and “Diverted 2” both experiencing low harvest pressure (Table 1.1).

Table 1.1. Environmental characteristics of study streams located on Molokai and Maui, Hawaii

Stream	**Island**	**Harvest Pressure**	**Elevation Range (m)**	**Length of Stream Surveyed (m)**
Natural Flow 1	Molokai	High	0 - 183	5,107
Natural Flow 2	Molokai	Moderate	0 - 224	3,878
Diverted 1	Molokai	Low	0 - 369	4,320
Diverted 2	Maui	Low	0 – 14	1,035

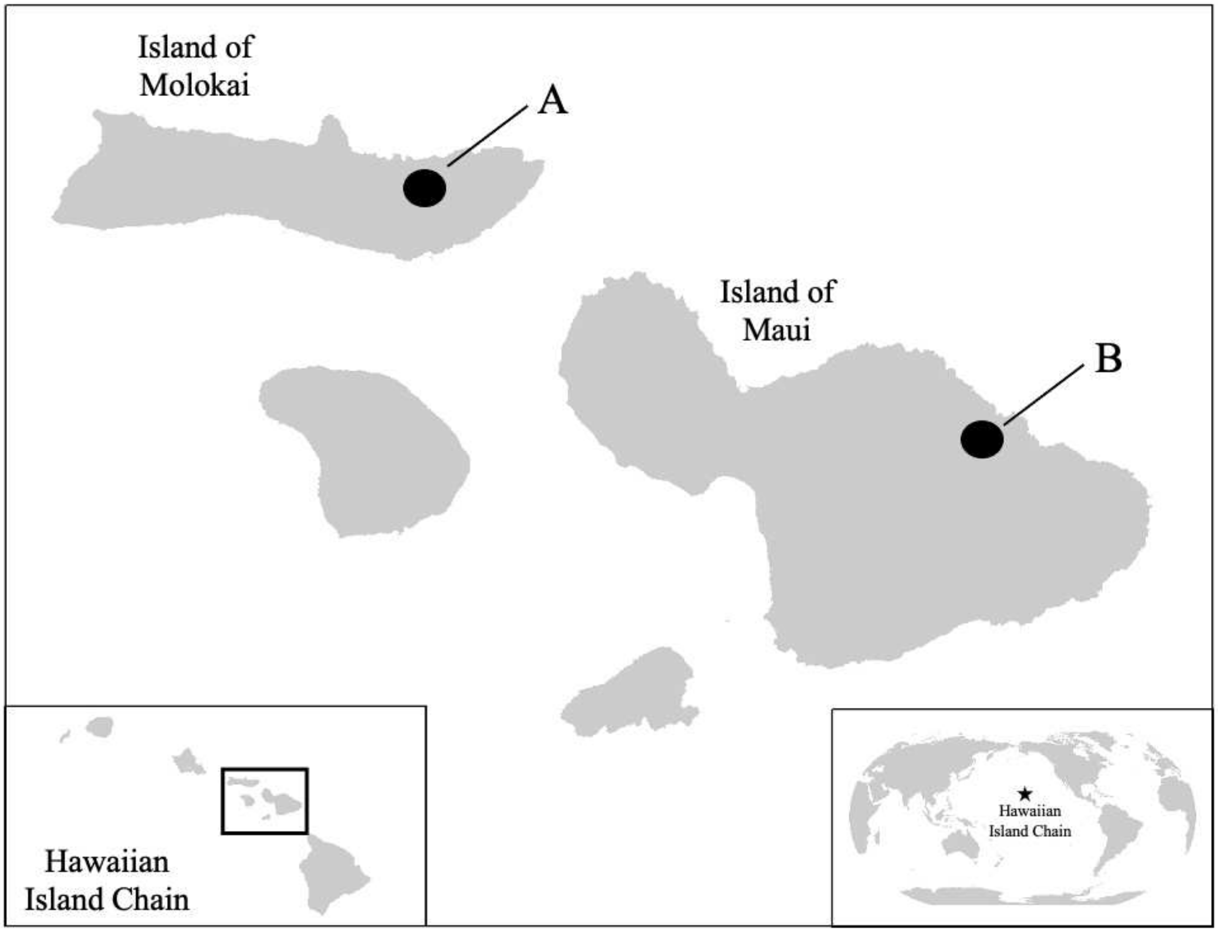

Figure 1.1. Hihiwai were surveyed in 3 streams on the north shore of Molokai (A), and in one stream in northeastern Maui (B). The general locations of study regions are indicated, but streams are not delineated or named to protect this culturally important resource. The left inset map shows the location of Molokai and Maui within the Hawaiian archipelago, and the right inset illustrates the location of these islands globally.

Study Design

Within each stream, the total stream length from the mouth to the last prominent tributary in the main stem was measured in Google Earth and divided by ten to establish sampling sections. Upstream tributaries beyond the last prominent main stem site were not sampled due to limited accessibility. To determine sampling sites within each of the ten stream sections, a random number generator from 0 to 600 was used to determine the distance (m) from the bottom of the sampling section to the center of the sampling site. If the random number exceeded the stream section length, then a new number was generated. To include intra- and inter-annual variation, all sites were sampled twice between June and August in both 2019 and 2020. Sites were sampled at least 30 days apart within the same season.

Abiotic Characteristics

At each sampling site, I quantified geomorphological, hydrologic, temperature, and chemical characteristics either in the field or using available satellite imagery and geospatial datasets. These included: presence or absence of water flow, average stream depth across the width of stream (cm), ambient surface water velocities (m/s), discharge (m^3/s), microhabitat type (run, riffle, pool, and cascade), shading within each quadrat (%), presence/absence of stream diversions, stream temperature (°C), and sediment type. Sediment was categorized using the Wolman Pebble Count Procedure into four size classes: sand (<2mm), gravel (<64 mm), cobble (<256 mm), and boulder (<4096 mm). Stream discharge, current velocities, and stream temperature were measured using a Vernier Lab Quest 2 interface. Percent shading was collected using a handheld densiometer directly over the center of each sample quadrat surveyed. Elevation was taken at each sampled stream reach using a handheld GPS. For data analysis, elevation data were pooled into for categories: Category 1 (0-50 m), Category 2 (51-100 m), Category 3 (101-150 m), and Category 4 (>150 m).

Hihiwai Surveys

To assess densities of hihiwai, I conducted stratified random quadrat sampling. This methodology is a standardized visual survey technique involving snorkeling and is well suited for the physical and ecological characteristics of Hawaii’s streams (Higashi and Nishimoto 2007). An instream section of 10 m upstream and downstream from each sampling site was delineated as the hihiwai sampling area. I conducted visual surveys at 6 randomly selected points within each sampling area, determined using the Cartesian coordinate system (Legleiter & Kyriakidis, 2006). A 1 m^2 PVC quadrat was used for instream hihiwai sampling. Small holes were drilled into the PVC pipes to allow the sampling quadrat to be quickly submerged in the fast-moving streams being sampled. Prior to each hihiwai survey, data on environmental variables that may influence visual detection, including precipitation, gusts and wind using the Beaufort scale, and % cloud were recorded.

Every hihiwai observed within each quadrat was counted, with total numbers of recruits, juveniles, and adults recorded separately. For hihiwai found straddling the quadrat edge, only individuals on two of the four sides of the quadrat were counted. To determine age class, a visual assessment was used to label each hihiwai as either a new recruit (<5 mm), juvenile (6-9 mm), or adult (>9 mm). Freshly laid egg capsules were also tallied, indicating active reproduction within the sample quadrat within the last three weeks. Fresh egg capsules were identified based on their bright white coloration. Older, discolored, beige or dark brown egg capsules were ignored as the age of these older egg capsules are extremely difficult to age properly, and could provide inaccurate reproduction data. Hihiwai predation was not recorded because bird-predated shells are commonly found assembled in piles on boulders above the stream, and prawn predated shells are usually washed into side channels or pools, making it difficult to identify the stream location where predation occurred.

Hihiwai Adult Length

To assess adult body condition as an index of fitness, I utilized a handheld dial caliper to measure shell length (SL = greatest anterior-posterior dimension) of all adults within each quadrat. Adults (>9 mm) found within sample quadrats were manually removed from their rock surface to be measured. After manual removal, adult hihiwai were carefully replaced under a rock in the stream, allowing them time to reattach safely outside of the sample quadrat and decrease the chance of predation by Tahitian prawns and native birds. I also minimized handling stress during measurements by ensuring fresh river water and an aerator was present in storage buckets where adult hihiwai were being kept while sampling within a quadrat. I processed all individuals as quickly as possible to minimize time outside of the stream.

Statistical Analyses

I tested for differences in the density of eggs, recruits, juveniles, and adults and adult size among valleys, elevation categories (< 50 m, 51-100 m, 101-150 m, and > 150 m), and microhabitats using general linear models (PROC GLM, SAS version 9.4). An additional GLM analysis was run and included year as a categorical variable. In regard to variation across years, there was an unusually high spike in the number of recruits recorded in "Diverted 2" during the second year of sampling. However, across all valleys GLM models did not show any other significant variation between years, and thus data from both years were grouped for modeling and analysis. To determine if hihiwai abundance in each age/size category was associated with continuous stream variables, data were log-transformed (ln [x+1]) to satisfy assumptions of normality and homogeneity of variance. Using a stepwise selection procedure based on AIC (GLM SELECT), I developed models to predict the influence of all variables on hihiwai recruits, juveniles, and adult density as well as adult size. The 3 categorical variables (valley, elevation, and microhabitat) described above were included in the AIC selection process along with the continuous environmental variables measured at each station (stream width, depth, current velocity, discharge, stream temperature, percent boulder, percent cobble, percent gravel, and percent shade). Finally, I examined the influence of water temperature and adult density on adult size using linear regression (PROC REG).

RESULTS

Stream characteristics

Abiotic characteristics varied among diverted and free-flowing streams. Natural flow streams had higher mean temperatures, discharge and velocities relative to streams with diversions, but shading and percent boulder did not differ significantly between diverted and natural flow streams (Figure S1.1, Figure S1.2). Depth varied significantly between natural flow and diverted streams, with “Diverted 1” significantly deeper than natural flow streams and “Diverted 2” significantly shallower than natural flow streams (Figure S1.3). Elevation was often but not always associated with stream characteristics. Stream temperature decreased while depth increased with increased elevation (Figure S1.1, Figure S1.3). Middle elevation reaches yielded higher stream velocity, discharge, and lower percent shading compared to the lowest and highest stream reaches, but percent boulder, cobble, or gravel did not produce significant variation across elevation. Stream velocity was also significantly higher in cascade microhabitats (0.64 m/s) and lowest in pools (0.27 m/s) (Figure S1.4), but did not differ between riffles and runs. Percent shading followed the same pattern across microhabitats, ranging from 25.31% in pools, to 38.35% in cascades (Figure S1.4).

Hihiwai distribution and abundance

Hihiwai of all age classes (eggs, recruits, juveniles, and adults) were found in each of the four study valleys (Table 1.2). Across all sampled quadrats, a total of 6,957 hihiwai eggs, 47,189 hihiwai recruits, 2,342 hihiwai, and 10,090 hihiwai adults were recorded (Table 1.2). The large spike in hihiwai recruits in 2020 was limited to a single stream (Diverted 2), where samples were collected during the peak of hihiwai recruitment, explaining the wide range of individuals per quadrat and low percent occupancy (Table 1.2).

Table 1.2. Total and average hihiwai counts across sample years 2019 and 2020 and averages and ranges of individuals per quadrat.

	2019	2020	Average per quadrat	Range of Individuals per Quadrat	% Quadrats Occupied
Eggs	4,449	2,508	7.25	0 - 116	40%
Recruits	3,523	43,666	49.16	0 – 15,726	25%
Juveniles	1,428	914	97	0 - 97	24%
Adults	4,394	5,696	10.51	0 - 144	48%

Effects of diversions, elevation, and microhabitat on hihiwai abundance and size

Hihiwai abundance and adult size was most strongly associated with valley (Table S1.1, Table S1.2). Valleys with diversions were associated with significantly higher densities of hihiwai recruits, juveniles, and adults, while recruits, juveniles, and adults were virtually absent in the two natural flow streams (Figure 1.2, Table S1.3). All four streams had moderate numbers of hihiwai eggs. In contrast to these abundance patterns, natural flow streams were associated with significantly larger hihiwai shell lengths (Figure 1.2).

Hihiwai adult size and the abundance of all age classes except for eggs was also associated with elevation (Table S1.1, Table S1.2). Higher densities of hihiwai recruits and juveniles were found at the lowest elevations, resulting in a strong inverse relationship between elevation and abundance for these life stages (Figure 1.3, Table S1.3). Egg and adult abundance both did not follow this pattern, showing no significant differences among elevation categories (Figure 1.3).

Abundance of eggs was significantly influenced by microhabitat type (Table S1.1), with runs, pools and cascades having higher densities of eggs (Figure S1.5). Recruits and juveniles were virtually absent in cascades, while they were fairly evenly distributed across the other microhabitats (riffle, run, and pool). Adult shell length was significantly greater in cascades than in other microhabitats (Figure S1.5).

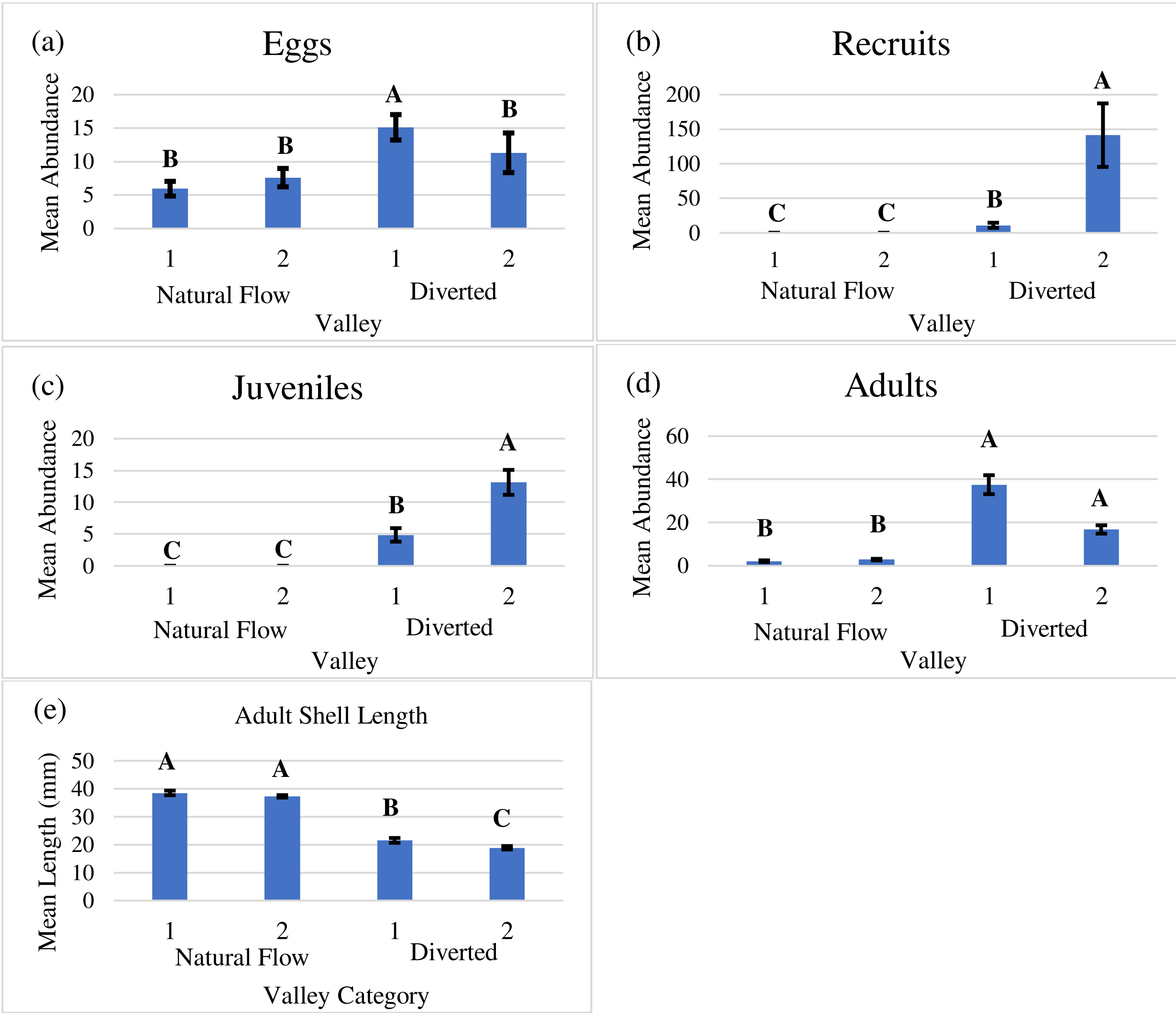

Figure 1.2. Mean hihiwai abundance of eggs (a), recruits (b), juveniles (c), adults (d), and mean shell lengths (e) across natural flow and diverted streams.

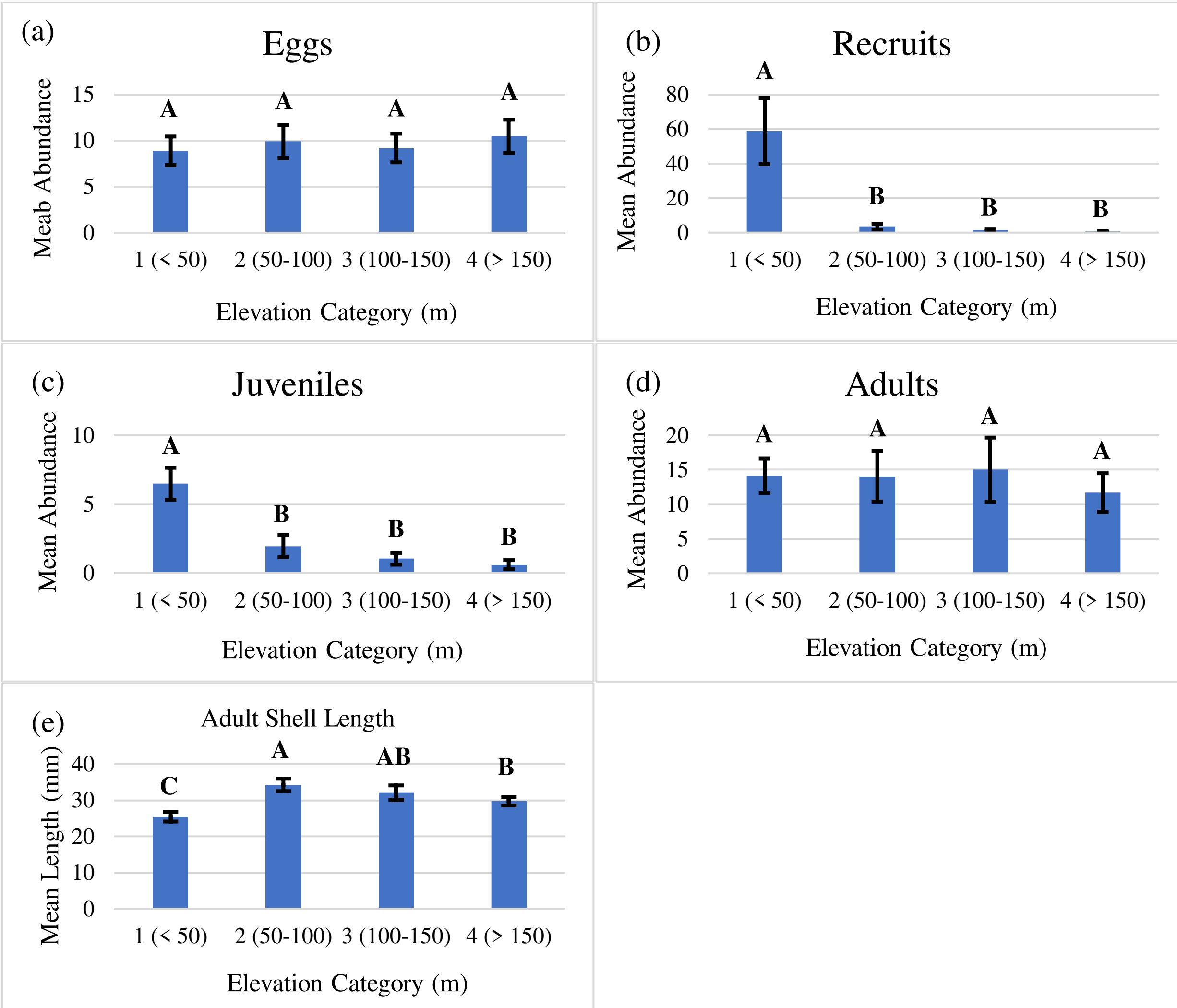

Figure 1.3. Mean hihiwai abundance of eggs (a), recruits (b), juveniles (c), adults (d), and mean shell lengths (e) across elevation categories.

The influence of abiotic variables on hihiwai abundance and size

General linear models (GLMs) developed to explain adult size and abundance of hihiwai life stages based on the environmental variables described above were highly significant, accounting for 37-87% of the total variation (Table S1.2). Several of these abiotic variables were associated with hihiwai density, but their relative importance differed among life classes. Stream depth was an important predictor for all hihiwai life stages as well as adult length, positively associated with egg density and adult length, but negatively associated with recruit, juvenile, and adult density (Table S1.2). Substrate composition was also consistently included in the models to explain abundance and adult size. Percent gravel was negatively associated with egg and juvenile density, but was not important for recruits, adults, or adult length. In contrast, percent boulder was negatively associated with recruit density and positively associated with adult length, but not important for eggs, juveniles, or adults (Table S1.2). Stream velocity was negatively associated with juvenile density and positively associated with adult length, but not important for egg, recruit, or adult density (Table S1.2).

Percent shading, stream temperature, stream width, and discharge did not emerge as important predictors for hihiwai densities across all age classes and hihiwai adult length. These included percent shade (negatively associated with juvenile density), stream temperature (negatively associated with adult density), stream width (positively associated with adult length), and stream discharge (negatively associated with adult length).

Relationships among life stages

Adult density was selected as an important predictor for the density of eggs, recruits, and juveniles, all of which were positively associated with adult density (Table S1.2). In contrast, adult shell length was inversely related to adult abundance ($r^2 = 0.60$; Figure 1.4). The GLM model for length also highlighted this relationship, showing a negative relationship with adult density ($t = -4.42$, Table S1.2). This inverse relationship resulted in a pattern where natural flow streams with low hihiwai adult abundance contained the largest individuals (Figure 1.2).

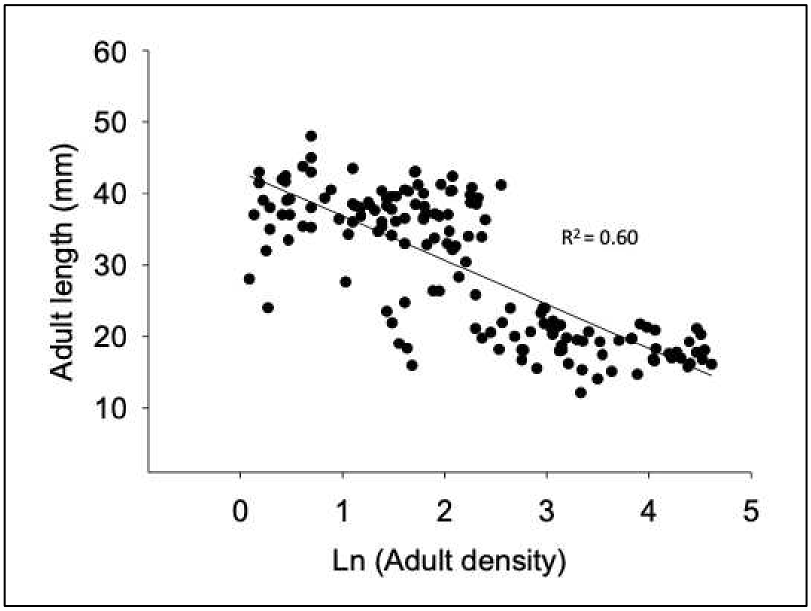

Figure 1.4. Adult hihiwai density is negatively associated with adult length across four streams on Molokai and Maui.

DISCUSSION

Understanding how characteristics of Hawaiian stream systems influence hihiwai population density, distribution, and size is important to inform socio-ecological approaches to conserving ecosystems at the marine-freshwater interface around the world. In the first systematic survey of hihiwai in Molokai and Maui streams, recruits, juveniles and adult hihiwai were all more abundant in diverted streams, contrary to my predictions. Furthermore, hihiwai eggs and adult length were positively associated with stream depth while recruits, juveniles and adults were negatively associated with depth. Higher densities of hihiwai recruits and juveniles occurred at low elevations, and adults were more likely to occur at high elevations. Finally, I observed an unexpected negative relationship between adult size and density, with larger hihiwai found where adults were least abundant.

Preference for Diverted Streams

Observing higher hihiwai densities in diverted streams for most size categories was a surprising outcome of this study. Based on previous studies of the effects of instream diversions on stream systems, instream diversions were expected to impede hihiwai recruitment and movement across all age classes (Carlisle et al., 2011; McManamay & Frimpong, 2015; Poff et al., 2007; Poff & Zimmerman, 2010). Yet, hihiwai eggs and small adult hihiwai (10-14mm) were observed in stream reaches above the first of two prominent in-stream diversions, suggesting that hihiwai recruiting upstream can traverse these diversions.

Considering variations in abiotic characteristics across streams could help explain these unexpected findings. Stream temperatures were markedly lower in diverted streams compared to natural flow streams, while stream discharge and stream velocity were higher in diverted streams. Generally, instream diversions were expected to increase stream temperature and alter both natural stream flow regimes and substrate composition (Carlisle et al., 2011; McManamay & Frimpong, 2015; Poff et al., 2007; Poff & Zimmerman, 2010). My findings contradicted these expectations and showed the opposite patterns, perhaps because diverted study streams were narrower than the natural flow streams, had more tributaries feeding into the streams from pristine natural area reserves at the tops of the watershed, and because free flowing valleys were wider and more exposed to the sun. These unexpected characteristics of diverted streams highlight how considering such abiotic and hydromorphological factors may be more important than simply the presence or absence of diversions.

Stream Depth

Stream depth was associated with higher densities of hihiwai eggs and larger individuals, while shallower depths supported higher densities of recruits, juveniles, and adults (Figure S1.3).

Similar to many aquatic species, larger adults produce both larger and higher quality eggs and larvae, while smaller adults at the early stages of their reproductive age produce much smaller and lower quality eggs and larvae (Appeldoorn, 2020; Norton et al., 2018). Deeper stream reaches with large adults could thus lead to higher hihiwai egg density. In regard to shallow depths supporting higher densities of hihiwai recruits and juveniles, this supports the hypothesis that lower stream reaches near the river mouth connecting to the ocean are where highest densities of these life stages will be located, as they are recruiting up from the ocean. As these young hihiwai move upstream, they are experiencing rapid body growth. Most juvenile hihiwai transition from juveniles to adults (>10 mm) during their migration upstream, resulting in a greater density of recruits and juveniles in lower stream reaches. The average adult hihiwai sampled was 10.5 mm which is on the lower end of the size range of adult hihiwai (10-52mm). This could suggest that the majority of adults observed had only recently transitioned from the juvenile stage and just started reproducing. This transition from juvenile to adult happens in low to medium elevation stream reaches where overall depth is much lower than in higher elevation reaches, which support the patterns observed in this study. Patterns observed across stream depths could also be explained by deeper sections of streams having less available biofilm and periphyton for grazing hihiwai than shallower reaches that receive more sunlight (Kazemi-Dinan et al., 2014; Köhler et al., 2010; Ryder, 2004; Wang et al., 2018).

Inverse Relationship Between Adult Abundance and Adult Size

This study also revealed a strong inverse relationship between adult abundance and adult size, where larger hihiwai were found where adults were least abundant. Understanding the different environmental factors important to each of these hihiwai age classes are crucial to understanding this relationship. Differences in age class distribution and abundances seem to indicate a shift in environmental and habitat characteristics that are favored as hihiwai transition from eggs to recruits, juveniles, and finally adults. Due to the amphidromous nature of hihiwai, recruits re-enter the stream from the ocean and migrate upstream as they grow and develop. As a result, most hihiwai recruits and juveniles are found at lower elevations which are characterized by wider, shallower, warmer, and slower flowing water dominated by riffle and run microhabitats, with limited cascades. Recruits and juveniles thrive in this environment and seem more tolerant to warmer water temperatures and microhabitats with more biofilm and periphyton. Hihiwai adults are found across all elevations and are represented well in every microhabitat, but the largest hihiwai are disproportionately present in cascades, while average hihiwai size is much lower in pool, riffle, and run microhabitats. These differences suggest a shift in habitat requirements for different life stages. These patterns may also indicate that recruits and juveniles may be experiencing a series of bottleneck events, which is reducing the number of juveniles that are surviving to adulthood and peak mature size. Possible bottleneck events at the recruit and juvenile life stages may include competition for resources such as space or available periphyton. Compared to other life stages, the distribution of hihiwai eggs did not vary with elevation. This means that distribution of other life stages was probably not limited by the inability of adults to reach all elevations, and due more directly to the environmental factors highlighted above.

To reach the largest mature adult size, adult hihiwai seem to prefer cascade microhabitats, where stream velocity is high, stream temperature is low, and shading is higher. Possible explanations for low abundance but large sizes in these habitats could include natural disturbance events. Hawaiian streams are characterized by high flood periods occurring over relatively short time periods, where streamflow is greatly increased during winter. These flooding events could cause such high stream flow that adult hihiwai are unable to remain attached to boulders and substrate in cascade microhabitats.

Finally, selective human harvest may also explain variation of hihiwai across certain microhabitats. Evidence of hihiwai harvest is provided through traditional ecological knowledge (TEK) in local Hawaiian communities on the island of Molokai. TEK is defined as a ‘system of experiential knowledge gained by continual observation and transmitted among members of a community’, also acknowledging its intergenerational character (Huntington 1998, Berkes, 1999, Fernandez-Gimenez). TEK consists of biophysical observations, skills, and technologies, as well as social and cultural values, norms, and institutions that guide human-environment interactions (Berkes 1999; Fernandez-Gimenez, 2000; Fernandez-Gimenez). According to TEK from community members and resource users on Molokai, cascades are optimal microhabitats for large adult hihiwai, and thus are disproportionately targeted by human harvesters. Selective human harvest may also explain the inverse relationship between density and adult size, where fishermen concentrate harvest in areas where hihiwai densities are known to be greatest. Although beyond the scope of this study, collecting data through community harvest polls or questionnaires and including which microhabitats or stream reach types are preferred or were targeted during hihiwai harvest visits may inform this hypothesis.

Research Limitations and Future Priorities

To investigate the strong inverse relationship between hihiwai adult density and shell size and understand its connection to microhabitat selection, quantifying algal production should be a research priority. Patterns in hihiwai abundance across elevational categories and microhabitats raise questions as to what may be causing variation in dispersal and abundance among age classes. Quantifying algal biomass and production across study streams and microhabitats and hihiwai algal consumption through a mixture of in-field and controlled experiments and collection could elucidate the mechanisms responsible for these relationships. Future research could also investigate temperature thresholds of hihiwai, and determine if these thresholds differ across age classes. This could provide crucial information to inform the development of Hawaii stream management plans and establish management thresholds imperative for the health of Hawaiian stream species, due to the sensitivity of gastropods to these fine-scale changes in streams. As anadromous species, hihiwai must traverse both freshwater and marine habitats over the course of their life. As a result, only a small portion of larval spat that hatch in streams survive to mature adulthood. Although beyond the scope of this study, quantifying the number of larvae entering the ocean would be help inform a relatively unstudied component of this species' life cycle and life history.

Although considered a key factor in change of hihiwai abundance by local community members, quantifying human harvest pressure across study valleys proved challenging in this study. Harvest of traditional foods is an extremely sensitive and private subject and information is usually kept within the family group. In addition, due to lack of requirements to report hihiwai harvest or harvest limits set, there is no established system to accurately track harvest in the state of Hawaii. Yet, the fact that human harvest varied across the study region, specifically that it was higher in natural flow streams, suggests that harvest could help explain the unexpected relationship between hihiwai adult size and density in these streams, as well as higher abundance in diverted streams, which face lower harvest pressure. According to TEK shared by local Molokai residents who have an intimate relationship with this species as a resource for food and cultural identity, harvest plays a significant role in changing hihiwai populations, affecting adults directly, and other age classes indirectly. Investigating the role of human harvest on hihiwai populations is a key next step for informing the development of effective management and policy that benefits and is led by resource users who depend on this species for sustenance and cultural preservation.

Conservation Implications

Aquatic gastropods are widely recognized as effective indicators of ecological integrity, and declining populations can signal habitat loss and ecosystem degradation (Calizza et al. 2015, Johnson et al. 2013, Forio et al. 2017). Such losses can also disrupt cultural connections to natural resources where gastropods are a source of subsistence. Local communities in the Hawaiian Islands have a strong connection to hihiwai, which are collected both for household consumption and for large celebratory events (Hodges & Allendorf 1998). My findings can be used to develop science-based management plans with local resource users to ensure healthy and sustainable populations of this valued species, both for cultural and consumptive use. Key management recommendations include recognizing the value of both natural flow and diverted streams for sustaining hihiwai populations and ensuring diversity in stream depth to support different hihiwai age classes. Specifically, managers should increase the number of deep stream reaches to promote adult hihiwai growth in the upper portion of the watershed, while maintaining sufficient shallow reaches for recruit and juvenile development downstream. Research priorities should also include a better understanding of harvest pressure on adult densities and shell size, as well as exploring the possibility of raising hihiwai in controlled environments to alleviate pressure on wild populations in Hawaii's few remaining perennial streams. Finally, bridging the gap between western ecological science and TEK through local community collaboration will be critical for developing effective management plans that ensure ecological and cultural sustainability of hihiwai in Hawaii.

CHAPTER TWO

"HIHIWAI IS OUR KULEANA"; TRADTIONAL ECOLOGICAL KNOWLEDGE AND CULTURAL IMPACTS OF A DECLINING HAWAIIAN GASTROPOD

SUMMARY

Bridging Traditional Ecological Knowledge (TEK) and western science requires valuing indigenous knowledge and leadership and incorporating these ways of knowing into conservation science and practice. TEK is particularly important on islands where indigenous communities steward their often imperiled cultural and natural heritage. Hihiwai (*Neritina granosa)* is an amphidromous snail that was used for subsistence in ancient times by Native Hawaiians and is still harvested today. Because this species is of conservation concern, evaluating the factors contributing to hihiwai loss and recovery using traditional ecological knowledge could serve as a model for indigenous and local communities at the marine/freshwater interface globally. The objective of this study was to identify how traditional ecological knowledge and local experience can be used to better understand the ecology and conservation of hihiwai, impacts of hihiwai population change to local community members on Molokai Island (Hawaii, U.S.A.), and to engage local communities in the conservation of this species and its habitat. I used semi-structured interviews with local community members to address the following research questions: 1) According to traditional ecological knowledge, do local Molokai community members perceive current populations of hihiwai on Molokai to be changing relative to historical numbers?, 2) What factors do local Molokai residents perceive to be causing the proposed hihiwai population change?, 3) What is the value of hihiwai to the

Molokai community, and how does hihiwai shape social activities and interactions?, 4) What are the impacts of these perceived changes to hihiwai populations on the individuals, families, and community as a whole on the island of Molokai, and 5), What paths forward do local Molokai community members envision for hihiwai conservation and conservation leadership? Three major takeaways were identified as relevant for understanding the change, drivers, values, impacts, and next steps for conservation of hihiwai populations: 1) community members believe that hihiwai populations are decreasing due to a combination of direct (overharvesting, water diversions) and indirect (higher stream temperatures, invasive plants) anthropogenic effects; 2) The perceived decrease in hihiwai abundance on Molokai has resulted in a reduction in opportunities for local people to connect with each other and spend quality time (eating and picking hihiwai), a loss of historic knowledge of hihiwai and cultural identity, as well as the prevention of future transmission of cultural and ecological knowledge to the next generation; and (3) community members emphasize the need for informed local conservation leaders who represents the interests of the local Molokai people to guide and enforce hihiwai and Hawaiian stream management. Although community perceptions of whether bottom-up or top-down management strategies would be more effective were mixed, there is a general consensus that a change in community values toward hihiwai harvest and possible harvest limits are needed to ensure healthy hihiwai populations in the future. This study revealed rich and community-informed insights about hihiwai decline and recovery, providing additional evidence that TEK should play a primary role in driving conservation decision-making.

INTRODUCTION

Integrating Traditional Ecological Knowledge (TEK) and western science can advance ecological understanding and empower decision-making on the part of indigenous peoples (Krupnik and Carleton Ray, 2007). TEK fills knowledge gaps, fosters community engagement and co-management, and integrates indigenous relationships with nature into conservation practice (Aswani & Hamilton, 2004; Aswani & Lauer, 2006; Fassnacht et al., 2018; Fernandez-Gimenez et al., 2006; Kurashima et al., 2018; Pert et al., 2015; Thornton & Scheer, 2012). TEK also benefits science and society by contributing knowledge to conservation issues that are important to native people's way of life (Krupnik & Carleton Ray, 2007). Local and indigenous members of the community should be the prime guiding roles in collecting TEK and building TEK into management programs (Kurashima et al., 2018; Moller et al., 2009; Thornton & Scheer, 2012). These community members are able to filter out unreliable knowledge and are more prone to follow management recommendations if their own socially accepted knowledge systems predict the need for change. Acknowledging the validity, value of indigenous knowledge bases as well as the leadership of indigenous scholars and community members and showing willingness to actively incorporate this knowledge into the research process are critical steps to bridging TEK and western science.

Most environmental studies involving indigenous communities are extractive (David-Chavez & Gavin, 2018). Extractive research is characterized as a lack of community access to findings, relevance, credit, ethical considerations, or benefit to indigenous communities. This results in an imbalanced exchange between academic researchers and indigenous knowledge holders, including a deficiency in long term accountability and reciprocity. Studies that engaged indigenous community members from the beginning of the research process (e.g. those initiated by community members) consistently reported higher proportions of indicators for responsible community engagement, and were more successful in integrating TEK into management practices (David-Chavez & Gavin, 2018; Fernandez-Gimenez et al., 2006). Using indigenous knowledge to make indigenous-led conservation decisions is particularly important in hotspots of biocultural diversity such as island ecosystems.

TEK is rarely incorporated into decision making on islands (Blaich Vaughan & Caldwell, 2015; Kurashima et al., 2018), despite the prevalence of traditional cultural practices and gathering rights related to native species among local communities in island ecosystems such as the Hawaiian Islands. Collecting food from rivers and the ocean is an active Hawaiian practice in rural Hawaiian communities and Hawaiians and local residents in these communities are continually building upon and maintaining local TEK (Poepoe et al., 2007). For example, it is a traditional practice for Hawaiians to 'consult nature' so that the methods, times and places of fishing are compatible with local marine resource rhythms and biological renewal processes. Hawaiian communities care deeply about what becomes of their subsistence resources, not only as a source of food for themselves and future generations, but also because their way of life and identity are at stake (Poepoe, 2007). Hawaii's biodiversity is also at risk due to land use and climate change and invasive species. Integrating TEK and western science to address these challenges and sustain Hawaii's linked natural and cultural heritage is critical (Blaich Vaughan & Caldwell, 2015; Kurashima et al., 2018; Poepoe et al., 2007).

Such an approach is ideal for the conservation and recovery of hihiwai (*Neritina granosa* Sowerby 1825) on the Hawaiian island of Molokai. Hihiwai is an amphidromous snail in the family Neritidae that was used for subsistence in ancient times by Native Hawaiians (Hodges & Allendorf 1998) and is still harvested today. In ancient Hawai'i, hihiwai was also referred to as "wī", which means famine in the Hawaiian language. This suggests that this species was an important food source for Native Hawaiians during times of food shortage (Hodges & Allendorf, 1998). Hihiwai is known to persist in relatively undisturbed streams on the Hawaiian Islands of Kaua'i, Molokai, Maui, and Hawai'i Island (Hodges & Allendorf, 1998). According to the IUCN Red List, hihiwai populations are decreasing across the state of Hawai'i and this species is currently listed as Vulnerable (Johnson et al., 2013). Hihiwai habitat on Molokai includes three perennial valley streams, two of which are free flowing, and one that is heavily diverted (Hodges & Allendorf, 1998). Today, this coveted species continues to be valued by Native Hawaiians and rural residents of Molokai who have had an innate connection with hihiwai for generations. The local communities on Molokai and Maui have a strong cultural connection to this species as hihiwai are collected for household consumption, in large quantities for celebratory events such as weddings, graduation parties, and baby showers, and as a form of supplemental income to support families. Because this species is of conservation concern and has long been valued by the local community, evaluating the anthropogenic effects on hihiwai using both biological and traditional ecological knowledge, and exploring the ways that declines in this species affect culture and communities, could serve as a model for using socio-ecological approaches to conserve ecosystems and people at the marine/freshwater interface around the world.

The primary objective of this research is to identify how traditional ecological knowledge and local experience can be used to better understand the ecology and conservation of hihiwai, impacts of hihiwai population change to local Molokai community members, and to engage local communities in the conservation of this species and its habitat. I used semi-structured interviews with local community members to address the following research questions: 1) According to traditional ecological knowledge, do local Molokai community members perceive current populations of hihiwai on Molokai to be changing relative to historical numbers?, 2) What factors do local Molokai residents perceive to be causing the proposed hihiwai population change?, 3) What is the value of hihiwai to the Molokai community, and how does hihiwai shape social activities and interactions?, 4) What are the impacts of these perceived changes to hihiwai populations on the individuals, families, and community as a whole on the island of Molokai, and 5), What paths forward do local Molokai community members envision for hihiwai conservation and conservation leadership?

METHODS

Study Area and Focal Species

The Island of Molokai is one of five main Hawaiian Islands, with a population of 7,400. Molokai is characterized by a predominantly Native Hawaiian community with direct connections to subsistence farming, fishing, and hunting, strong cultural ties, pride in Hawaiian ancestry, and strong family units. This island is 773km^2 with an elevation range of 0-1510m. Molokai's climate is diverse, including dry forest and scrub dominating by non-native kiawe (*Prosopis pallida*) in the east, and lush wet forests in the west which receive more than 7600mm of rain annually. Vegetation here is dominated by native trees such as *ʻōhiʻa lehua* (*Metrosideros polymorpha*) and a diverse endemic flora and fauna in the understory at higher elevations, and non-native, invasive flora and fauna at lower elevations. This island serves as a perfect study location for investigating human relationships and perceptions of hihiwai and their habitat, as this species is an important part of this community's cultural and natural heritage – past, present and future.

Hihiwai are almost exclusively found within perennial streams along the northeastern section of Molokai, within the Wailau, Pelekunu, and Waikolu watersheds. The northern coastline of Molokai suffered a collapse about 1.5 million years ago, lying as debris scattered northward across the bottom of the Pacific Ocean. This resulted in the creation of the highest sea cliffs in the world. The primary freshwater habitat for hihiwai is nestled in remote valleys along this northeastern coast. Hihiwai also utilize and occupy nearshore marine habitat during their larval development stage, first as free-floating larvae in the water column, then settling on the bottom of the sea floor as hihiwai recruits before returning to freshwater to complete their life cycle. Local Molokai residents frequent these north shore valleys during the summer and early fall, from April to September, for camping, fishing, recreation, and limited tourism via local boat charter. Molokai locals have harvested hihiwai in these valleys for generations for subsistence living, selling them for supplementing income, and as a delicacy for large celebrations and parties.

Interviews

I conducted semi-structured in-person interviews aimed to stimulate discussion around participants' experience with, relationship to, and knowledge of hihiwai, its habitat, as well as past, current, and future conservation management. Each individual that agreed to participate in the interview was asked a series of open-ended questions pertaining to their knowledge of hihiwai and their perceptions of this species in terms of management and status. The interview included questions about how hihiwai abundance has impacted social behavior, what habitats are of greatest conservation concern and how to manage those habitats, what policies or practices could be beneficial, how the respondent interacted with hihiwai as a child/adolescent, and how they would like to be engaged in hihiwai conservation in the future (see Appendix for interview questions). Before conducting these interviews, I held a focus group of experts on hihiwai management, conservation, and cultural connection from the island of Molokai to review the interview questions and provide input and suggestions.

My interview population was selected to include individuals that represent a diversity of demographic metrics and experience with hihiwai. I interviewed residents of Molokai from June 2019 to May 2020 ranging in age from 24 years to greater than 60 years old. Having prior knowledge of, and interaction with community members, I first identified 10 individuals that represented a diversity of demographic, occupational, and cultural backgrounds I knew to have had interactions or experience with hihiwai throughout their life. Snowball sampling was employed to identify further participants, where each of the first 10 participants selected were asked to suggest one Molokai community member they thought would share similar perceptions and ideas as them, and one community member who they believed to hold different values, perceptions, or ideas about hihiwai population change, impacts, and conservation. I employed an interview until saturation method, where new participants were interviewed until reaching the stage when repetition of thoughts or ideas is observed in the participants with limited new responses (Given, 2016; Saldaña, 2013, Urquhart, 2013). Once reaching a saturation point from a certain demographic group, I stopped interviewing that subject group.

All RICRO IRB requirements were met and approved before starting the interview process (Protocol#: 19-9451H). Informed consent was obtained by each participant by signing a pre-approved IRB form outlining the purpose of the research study, interview procedures, study benefits, risks and discomforts associated with the study, and confidentiality assurance. Each interview was recorded using an EVISTR handheld recorder, and interview lengths varied from

20 minutes to 70 minutes. A total of 20 individual interviews were conducted, including 16 in person and four over the phone.

Data Analysis

I transcribed recorded interviews verbatim and coded them using the qualitative software NVIVO10 (QSR International, http://www. qsrinternational.com/products_nvivo.aspx). Due to varied audio quality and the use of pidgin and Hawaiian words and phrases, each NVIVO transcription was screened and edited. I started with In Vivo codes that captured participants' exact words. I then conducted thematic analysis to group these codes into subthemes based on the five research questions (population change, drivers, values, impacts, and next steps), but also remained open to emerging themes and patterns. I developed codes through an iterative process. I coded in a hierarchical structure, developing 293 In Vivo codes that were grouped into four parent themes. An example of a parent theme was impacts of hihiwai declines to local community members; two subthemes within impacts were preservation and transmission of ecological knowledge and losing components of cultural identity. Additional branching subthemes were developed from subthemes as additional fine-scale responses and details were identified from the data. Each file was then assigned case classifications, including demographic and identification data. Demographic data recorded included age, gender, location of home in Hawaii, whether or not the interviewee has Hawaiian ancestry, their individual level of subsistence fishing and hunting, occupation, and whether or not they were born on Molokai.

I organized the coding and results by the five research questions. Within each of these themes, numerous individual codes and subcodes were established if they were found to address some aspect of the research question. To assign codes to the transcription files, any subset of the interview quote that captured an idea or topic associated with a particular research question was highlighted and assigned to a specific code. A single quote or section of transcription could also be assigned to multiple different codes spanning multiple themes. After all of the files were coded, codes with 5 or more mentions by different people were considered relevant, and those codes were included in the results section. For each of the four themes, three illustrative quotes are included in the results section (See appendix for full list of codes and quotes).

RESULTS

Respondent demographics

I interviewed 20 individuals, 15 of which are men and 5 are women. Among the participants, 18 individuals identify as Native Hawaiian, 1 as Asian American, and 1 as white. 17 individuals were born and raised on Molokai, 2 were born and raised on other islands but have spent more than the last 20 years of their life as Molokai residents, and 1 who was born and raised and currently lives on a neighboring island of Maui. Although not a resident of Molokai, the latter individual was interviewed because they offered robust ecological and social information about hihiwai from the perspective of a Native Hawaiian conservation professional raised in Hawaii with expertise on freshwater species. The interviewees ranged in age from 28 to 80, with an average age of 59 years old. 40% are in professional roles related to natural resource management, conservation, education or outreach. The findings reported below are organized by the three main research questions: perceptions of drivers to hihiwai population change, impacts of these perceived changes to local community members, and next steps for hihiwai conservation and leadership.

Research Question 1 and 2: Extent and drivers of hihiwai population change

Drivers were mentioned by all 20 interviewees. There was a total of 106 mentions across all interviews, with an average of 5.3 mentions per interviewee (Table 2.2). To advance understanding of drivers, each respondent was asked if they believed hihiwai populations have increased, decreased, or remained the same over the course of their life. Nearly all respondents (95%) indicated that hihiwai populations are decreasing. For instance, a Native Hawaiian respondent shared that "as a child, we could pick every day and would always have hihiwai. But nowadays…you don't see any. Even early in the summer when you know nobody has harvested yet." On a similar theme, a Native Hawaiian woman shared that "as an older adult, I really see less and less even at parties…which is a good thing. But then I'm wondering, is it intentional that it's not at the party or is it because there just aren't any more hihiwai?"

When asked about factors impacting hihiwai population change, respondents indicated both direct and indirect anthropogenic drivers, often emphasizing that they "think it was human impact" responsible for the major decrease in hihiwai along the North Shore of Molokai. Overharvesting as a driver of hihiwai population decline was mentioned most frequently (n=13). Manmade water diversions were also highlighted as a major anthropogenic driver (n=6). Respondents frequently discussed how natural flow streams facilitate the most ideal instream habitat for native stream species such as hihiwai, as a key component to a healthy and high functioning stream system. One Native Hawaiian male participant reflected on how:

> *…everything is the way God created things. You know, it's supposed to be a natural flow. Any time you take water away, when you divert, that would create a big impact on the reproduction of all the resources. And the resources from the mountain to the ocean are connected together. Yeah. All that the mountain gives to the ocean, the ocean gives back*

by the reproduction of the 'o'opu, the 'opoha, the hihiwai. So that's where they reproduce. The hinana (baby fish). The hinana all come from the ocean. The baby 'o'opu and hihiwai as well.

Another Hawaiian woman in her seventies expressed related sentiments on the impact manmade diversions have had on instream temperatures and stream discharge, based on her memories of natural flow streams from her childhood. Her description highlights the apparent change manmade diversions have had not only on hihiwai habitat, but the local Hawaiian experience in these altered streams:

Before. Healthy. Healthy. And when the water comes, it's full blast. The stream was healthy, but now because of diversion, the stream is decreasing and shrinking. When we used to go in there, the river was ice cold. Then after that you like go on top the rock to heat up, warm up. But that's the difference. See, the hihiwai likes cold water. When we were growing up, the stream was open, wide, flat. You can see far, not too many trees. And that's why the hihiwai, there use to be big buggers. Because the water was ice cold. Not anymore. Because the weather is all changed now. Warm. Too warm."

Other respondents described degraded watersheds as contributing to hihiwai population decline. Invasive plant assemblages were frequently mentioned as having a substantial negative impact on native watersheds and stream systems, where "invasive plants absorb more water, providing less water feeding the stream", and as a result, "the whole water system has been disrupted". A lifelong resident working for a conservation agency on Molokai further elaborated on the importance of an intact Native Hawaiian plant assemblage and the impacts of invasive plants:

> *"We have the ʻōhia and then we have ʻõlapa, uluhe, mosses. The Hawaiian forest system is a kind of slow draining process. The plants take more water in. But when you get just clidemia, strawberry guava, you no more that. You just get the strawberry guava trees, under that is clidemia bushes, and that's it. And then you get dirt and leaves. But the water just runs straight past the soil. The invasive plants are not really capturing the water, it's just running off. The water goes straight to the ground and runs off. But what I think is these plants too, they use more water than native plants. Look at the land. The land gets really dry, they are sucking everything out of the land. The root system, too, must be different. But it seems like they just suck the water out of the ground. But they no give water for the natives yeah, the natives get hard time growing."*

Landslides and erosion were also described as a driver of hihiwai population decrease because they "are causing stream scouring that cause hihiwai to have less algae to feed on." A lifelong Molokai resident who works for a conservation agency shared her observations:

> *We also have been seeing a lot of landslides. After we had a major event where the landslides just wiped out the stream, the stream didn't recover after that.*

Community members discussed numerous ecological challenges as a result of increased stream temperatures, and cumulatively agreed that hihiwai require cold stream temperatures to survive, reproduce, and reach mature adult size. For example, one respondent shared that "there used to be big buggers, because the water was ice cold." In regard to ecological implications, a respondent suggested that "the rocks in streams are catching all the heat, and the stream will increase to a certain temperature… maybe affecting the hihiwai from growing, the water getting warmer." A Hawaiian raised professional working for a conservation agency discussed his understanding of the impact of channelized streams on instream temperatures and other environmental dynamics:

> *In channelized streams, there is no canopy or natural shading that would kind of keep the stream cooler. Although people have talked about putting vegetation or artificially putting in vegetation, that's not going to be the same as a natural tree canopy, which would kind of cool down the stream in certain location. Under the existing situation for 'Iao stream or Wailuku stream, what happens is the concrete channel actually heats up the water. The water temperature, I think has a higher water temperature. And it should be optimally, like I said, when I'm working in the streams. I'd like to see in Fahrenheit, maybe under 70 degrees Fahrenheit. The cooler the water, would also contain, well, higher saturation level for oxygen. The cooler the water, there would be more oxygen and more for the animals living in the water."*

Intermittent flow and lack of stream connectivity to nearshore marine habitats was also reported as a key driver of hihiwai population decrease, creating lasting "impacts on the reproduction of all the (instream) resources." Respondents related this issue of lack of connectivity to the disruption of the Hawaiian principle of ahupua'a, which is an ancient

Hawaiian political and ecological unit of land, designed to meet the food, material, and cultural needs of the human community living within it.

Research Question 3: Value of hihiwai to Molokai community

The value of hihiwai to local community members were mentioned by all 20 interviewees. There was a total of 30 mentions across all interviews, with an average of 1.5 mentions per interviewee (Table 2.3). Respondents provided rich information about the value of hihiwai in cultural, social, and environmental contexts. Hihiwai was identified as a "resource that feeds" and was closely tied to the importance of resource management and care for resources. Interviewees discussed how hihiwai is a resource that provides the opportunity for locals of all ages to understand and learn values, like where "their food comes from", resource conservation, and how to appropriately engage or fellowship with the land and resources Hawaiians so innately depend on. Respondents highlighted that upholding these environmental and cultural values ensures an end goal of generational sustainability, and a loss of hihiwai compromises the Molokai community's ability to ensure generation sustainability. A lifelong Molokai resident shared teaching she received from her grandfather that:

> *... the mountain is the meat, under our feet is our bread, and the ocean is our freezer. The mindset of a Hawaiian. And that the significance of the hihiwai in our culture is that it feeds us, it takes care of us. It's our kuleana (responsibility) to take care of it as a food source-- not for us, but for everything that comes after us. And that's with everything-- that's with all our gathering rights; the limu, the fish, the opihi, all of it is to malama, to take care of it, to take care of us, to feed us now and healthy living, as well as take care of the ones that's with us, the ones that will be born in the future. So as far as our culture,*

it is who we are. Our dependence on the ‘aina is that as long as we take care of it, it takes care of us.”

Respondents frequently mentioned the importance of a functioning ahupua’a system. One lifelong resident of Molokai shared that:

…if you look at ahupua'a, the one thing that connects the entire ahupua'a is the stream. And the stream is life giving, its water. And looking at our word for value, "waiwai". Right? The stream is the most important thing. And then the stream besides giving us water to drink, water to make the kapa, water to do the lo'i. It gives us food. If you think of our culture as an ancient culture when the people first came here, they didn’t have four legged animals, they never eat that much meat. The animals that they brought with them was pig, dog, chicken. And they didn't raise that much meat. A lot of their food came from the ocean or from the stream. And if you know, the life cycle of the ocean, it's not every time you can go in the water (ocean), go fish, go gather. And so, where are you going to do that? You're going to do that in the stream you're going to eat 'o'opu, you're going to eat hihiwai, pipiwai, hapawai, 'opae. So, not just the hihiwai, but all of those stream animals, they’re life giving, you know. That's survival. That's their ice box. I see the hihiwai as just another life-giving resource for our Hawaiian people. And then you're not going, you're not gonna make your icebox any kind, right? Because you want to eat all the time. They're going to learn the cycles and they're gonna learn how to malama, and they're going to have that respect and observe the kapu for all those animals.”

In addition to the importance of understanding the importance of a functioning stream system, hihiwai allows the opportunity to not only learn about where your food comes from, but also the value in appreciating the process of harvesting, preparing, and enjoying food that comes from the land. One respondent shared that teaching young Hawaiians and local kids about hihiwai is a direct opportunity to preserve culture through practice. One Molokai resident shared her hopes for her grandchild:

> *I want her to understand where her food comes from, that it doesn't come from Foodland and Safeway and Misaki or Friendly Market. That it's the land and the ocean, that's where life comes from, you know. And so, if you don't take care of the land, then the land not going take care of you. Well, if you don't take care of the ocean, the ocean cannot take care of you. And so, I want her to understand that from the beginning, from early on, so that as she grows into adulthood and starts making decisions and making choices, that those choices and decision will reflect the knowledge and education that we gave her early on."*

Respondents frequently shared that instilling values of treasuring and appreciating natural resources leads to a connection and "respect to our kupuna (elders and past generations) who have come before." A lifelong resident also highlights the importance of learning to prepare food from the land as a way to appreciate the value of a resource and reconnect oneself to your kupuna. She shared a story about how food preparation has changed for Hawaiians on Molokai:

Nowadays. Instead of going lay net, or malama the fishponds, and going through all that hana, we just buy crab by the case, already clean white crab from China, or whatever. You don't even have to do all the work of cleaning and scrubbing and whatever, you just defrost it, throw your inamona and chilli pepper water, you know, kimchi sauce, gone, pau. We don't have the same appreciation of the hana, the preparation. Before, it took so much to go gather, to process, it was like "you better eat everything on your plate. You better honor your kupuna and not disrespect them. They went give their life for you." I remember being told these things when I was younger. Like don't you dare disrespect the kupuna. You better eat all your food. And that's why I feel that our kupuna was like, whenever they saw hihiwai, they were like "woah, we know what it took to go all the way to the backside, go in the cold water, for go get em, for grow em." When you look at kalo or you look at things that you know are a little bit on the high maintenance side. Just our connection to food in general, like if you go store, give your dollar, package, you know. No more aloha and mana in that. I feel like our younger generations are disconnected from their food. But maybe in the last, I don't know, 5-10 years. There seems to be a swinging back of consciousness that people are starting to go, "wait, where does our food come from?" and wanting to get more involved."

Respondents frequently mentioned hihiwai as a delicacy, being referenced by one respondent as "like having caviar" or "top-of-the-line champagne." Respondents shared that when a family hosted a large party and brought out hihiwai, "they were considered somebody". Hihiwai was considered a status symbol, representing the ability to provide a special delicacy for everyone to enjoy. Another lifelong resident reflected back on memories of seeing hihiwai at large community parties:

> *Thinking back when I go to parties that was serving hihiwai, it gives you a sense of status, like, "wow, these guys get this". You know, it's just like, you know, you are serving up lobster at your party. Hihiwai is kind of like that, that same element.*

Hihiwai was highlighted as a means for survival and provide for the family. One respondent emphasized the importance of considering and valuing the "human side" to the issue of hihiwai conservation. When asked about successful conservation strategies for managing hihiwai populations on Molokai, one Native Hawaiian respondent who grew up on the north shore shared that:

> *…there is a human side to this. I mean we can look at all the other sides, but some people went inside the valley because they had to survive. But at the same time, they malama (cared for) the land and they took care of the land. I remember where guys used to come inside the valley, and they used to make rubbish and Papa used to go over there and scold them. "No don't do that."*

Local Molokai community members displayed a range and diversity of both ecological and social values they hold in regard to hihiwai. For many respondents, hihiwai was intertwined with values and cultural practices dependent on ecosystems, like harvesting and resulted in an innate connection between people and place to maintain these values. Respondents discussed values as affected by and formed through social interactions, which are in turn affected by and related to those cultural practices.

Research Question 4: Impacts of change in hihiwai abundance to Molokai culture and people

Impacts were mentioned by all 20 interviewees. There was a total of 42 mentions across all interviews, with an average of 2.1 mentions per interviewee (Table 2.3). Respondents were asked to identify how their perceptions of hihiwai population change has impacted how they interact with other community members, the activities and cultural practices they participate in, or any other impacts on their lives. Due to the overwhelming consensus among respondents that hihiwai populations are decreasing, the following impacts are attributed to this perceived decline in hihiwai. Respondents reported that the loss of hihiwai has led to diminished opportunities for the preservation and transmission of TEK. One respondent shared how the decrease in hihiwai has disrupted her ability pass on the knowledge she has about harvesting, preparing, and enjoying hihiwai to her grandchild. She shared that she:

> *…just became a grandmother. My first mo'opuna (grandchild). And I thought, you know, one day I'd like to teach her all the things that I taught my children and go take her camping Halawa and try some hihiwai and learn how to use it for whistle. But that's pau. I gotta show her pictures now, maybe, and tell stories about that. Yeah, but it's not going to be a reality for her. Probably not.*

Another Hawaiian woman in her fifties expressed related thoughts on a societal level. She highlights that Native Hawaiians have an innate relationship with hihiwai that spans far beyond a resource-harvester relationship:

…when you look at the way we treat food, if we look at all these plants and animals as our kupuna, whether you believe in evolution or in creation, the plants and animals came before kanaka. They are older than us. They been here first. Our relationship to them tends to be one of rank and genealogy. You either put yourself above or you put yourself below. And for me, I put myself below.

She posits that as hihiwai populations decrease, Hawaiian community members need to reevaluate their relationship with hihiwai and may need to make changes to their practices that were not required by previous generations. For example, she has made an intentional decision to shift her relationship from one of direct consumption to one of respect and admiration so as to preserve this valued resource. She shared that:

…going behind the island and seeing the decline of hihiwai and everybody else's attitude, my aloha 'aina has been to stop my own personal consumption. When I made the conscious decision whether or not to eat hihiwai, it's a bittersweet one because I know that honoring them is to partake of them, like allowing them to bless me with that energy and that mana, that nutrition, so that I can go on and do the good things that people want me to do, that only I, one kanaka can do. And yet, like you get this whole other dynamic to that philosophy where people are just taking them with no consideration of that relationship and how it affects us as a community. It's one hukihuki (tug-of-war), because to ensure our kupuna's survival and presence means to deny our own relationship with them. And that is probably the most (I like cry) because we really have to think on that

level in this generation. And you know, our kupuna never really need to really think like that because everybody knew their place, everybody remembered their place.

Another respondent added:

…the idea that you can harvest as much hihiwai as you wanted was okay during an- era where Molokai was momona (bountiful), and you could harvest, and we didn't even make one dent. Now, hihiwai population declines dictates a shift in thinking about how resource users partake in the resource…

Respondents indicate that a distancing between hihiwai as a resource and the user due to declines in this species is causing a disconnect with the natural resource, a foreign concept to Hawaiian culture and ideology. A lifelong Molokai resident shared that she "cannot remember the last time she ate hihiwai, maybe 10 years already." Another lifelong resident recalls that "hihiwai was good. I forget what the thing looks like now, or even how it tastes."

Respondents also mentioned functional use of hihiwai beyond consumption. One Native Hawaiian female respondent shared that she and her family would "take the (hihiwai) shells and teach the kids how to make a whistle. And it was just a part of us growing up. That part of growing up no longer exists." Hihiwai shells were also mentioned to be used to make necklaces. Respondents agreed that decreases in hihiwai populations have limited the ability and opportunity to create crafts and jewelry.

The loss of Hawaiian cultural identity as a result of hihiwai declines was frequently mentioned by respondents. Picking, cooking, and eating hihiwai with the family was "like the highlight of our camp. Because we used to camp on the North side (of the island) from April to September. And that's what we used to eat all the time. That was like the highlight of our trip whenever we could get." Picking and eating hihiwai was consistently mentioned by respondents as a medium in which families and individuals could spend time. The practice of harvesting hihiwai was "something everybody in your family can do…even babies. We used to take the 1-year-olds. So, without this, it's kind of like the breaking down of the family structure. Having everybody together and doing stuff. Because like now, if you throw net, maybe take one or two people. Or if you go on the rocks to pick hihiwai, you can only take maybe three or four people. But the river environment allows the whole family to go. Everybody is able to go no matter how old or young. This participant continues by emphasizing the rapid degradation of knowledge transmission to future generations in relation to hihiwai. She shares that:

> *…that's our culture, you know what I mean? It's part of the culture, it's in the history. But as they (hihiwai) are disappearing, that part of the culture is disappearing. Which is really sad. And we're seeing this in our lifetime, which is even more sad. Yeah. It shouldn't be that fast. Our great grandchildren, like the next generation down, might not even see hihiwai.*

A male respondent in his forties added his thoughts on how loss of hihiwai has led to the loss of Hawaiian cultural identity in relation to the significance of historical Hawaiian place names.:

Pelekunu…and Pu'upilo, its associated wind, is actually an 'aina momona reference, a reference to the abundance of resources on the land, or in the stream, or…ocean. Food sources particularly. Harriet Ne talks about Pelekunu Valley and the hihiwai. And them coming upstream and them being on these rocks and all they needed to do to get back and into the water was to release. But if they got stuck on the sunny side of that rock…They get stuck in these "pu'u pilo" (stink piles). And so they would die in these smelly heaps. And with the wind moving through the valley, it would create this general malodorous quality to the valley…And actually, each of the North Shore valleys are talking about the abundance of the stream and the streams and the water sources that are found there. But in general, I'm pretty sure it's not how it used to be. Right. These things that would be readily apparent, you know, where there are all of these 'olelo no'eau.

This respondent continues by questioning whether a place name indicating an 'aina momona reference (an old Hawaiian phrase used to make reference to an abundantly plentiful resource available) should remain or be renamed if the resource responsible for the name is no longer abundant:

I think it's very important actually to preserve the place names so that you know where that origin point was. You have this declining reference point of what the resource looks like, and the folks of the generation passed are talking about like "momona", an exceedingly unknown amount of this resource. And so, I think I find it valuable to look back at that and say, you know, this is how the generation before lived, is that, you know, how can we preserve and so on? I think preserving the place names is very important. In *terms of changing them, I think as long as it's not to the forgetfulness of what was before, you know? I mean, I think other names can be valuable as they point out other things. Maintaining that source and that connection to how things were is critical, especially if you're trying to embark on restoration, because it shows that area's ability and capacity to hold that number of species. It shows, "Okay. We have, or it's feasible to then have this amount of hihiwai or whatever it is back in this area because it historically was shown to do so."*

Research Question 5: Next steps for hihiwai conservation and conservation leadership

Next steps were mentioned by all 20 interviewees. There was a total of 115 mentions across all interviews, with an average of 5.75 mentions per interviewee (Table 2.4). Participants provided their ideal vision of successful conservation leadership for sustaining and recovering Hawaiian streams and species such as hihiwai. Respondents frequently mentioned that conservation leaders must be familiar with Hawaiian culture, species, and the places where they work. Locally grown leaders that have an innate connection to where their food comes from was a common priority identified by respondents. A Native Hawaiian participant shared that "being a Native Hawaiian, one percent, you know, or ninety nine percent, it doesn't matter. But you know that that's one little plus too to have." Another common subtheme mentioned when identifying successful conservation leaders familiar with Hawaiian culture, species, and the places they work was the idea that these ideal candidates possessed knowledge that extended beyond books and was grounded in firsthand traditional ecological knowledge and teachings. A female Hawaiian respondent expressed how:

You have to pick the right person for the right job, especially if you're dealing with conservation. You know, you get people that only know through the books, but you have to have somebody who lived and walked it and know it firsthand. That's the kind of people I feel that should be the ones that's in there and can teach all the newcomers. Practitioners. And then they can follow in the footsteps. And they have to love and have passion for the land."

A Native Hawaiian male respondent expressed similar sentiments:

You need a leader with the knowledge. It's not so much the one that goes to college and gets all the degrees, but they have to be one that is born in that area that has the 'ike (insight/knowledge) and was handed down to that individual from his or her kupuna (elders). Yeah. So that knowledge supersedes the knowledge of you going to the classroom and look through the books. You know, book learning, that's only waha (lip service). You only hear. You have to experience. You have to be part of the resource.

Respondents (n=9) also emphasized someone who represents the interests of the local Molokai people as an important conservation leadership quality. A key component of this theme was the value of honor and integrity. A Native Hawaiian respondent shared that:

Today, this generation has the idea that you need money to protect something. No, that's not true. The most important is that the community is pa'a (solid) and they live by their word, their word of honor. Other ahupua'a (land divisions) are going to follow. And *that's how we all, the whole island will come together and we're going to try malama (preserve) all those very important resources that was created here for us in Hawaii to sustain us…Molokai has a lot of potential*

Seven respondents explicitly mentioned the need for a conservation leader that is informed of the current natural resources prevalent across the state of Hawaii. A Native Hawaiian female respondent recalled one instance of this issue in an interaction she had with a Hawaiian political figure responsible for conservation decision making. She shared that:

It's important to me that the leaders are connected to what's going on in their environment, in their communities. You need money for Hawaii conservation. And so, when you go to your council and ask for appropriation of funding to threats in the watershed, how is this guy that's running for office going to make that kind of valuable decision when he doesn't even know what the main threats are? You know, so that connection to place and your understanding and a sense of what's going on and knowing the importance of these things, you know. So that on your level, when you're appropriating moneys and making law and stuff, you're appropriating enough moneys or making the right laws, you know.

Participants were also asked to identify ideal Hawaiian stream management strategies that could be adopted to help reestablish healthy hihiwai and other stream species populations. The top mentioned response was community buy-in to conservation efforts and bottom-up community-led management. Many local respondents viewed this method of management most effective after sharing how they feel that “management in the state or federal sense doesn't work. The Department of Land and Natural Resources (DLNR) doesn't work.” One Native Hawaiian respondent shared his reservations about federal and state agency follow through in conservation implementation, specifically enforcement of agency mandates regarding hihiwai and other species harvest, both freshwater and marine. He shares that:

> *…even if…you ban it, who is going to enforce it? You cannot depend on the government to take care of your resources. The best way to do it, is that those within that ahupua'a (land division), those community people, that's their kuleana (responsibility) because what they get preserved is going to be for generation after generation. But it has to be a community effort, not just one group of individuals within a community. You know, where should all the rules and regulations come from? Totally a community effort. And you've got to get love. You've got to get love in your heart for one another, because what you're doing, what you're trying to preserve is for their prosperity and what we all work together for all our prosperity. And the best education is not someone from outside who don't gather those resources. They have no idea.*

Another Hawaiian woman in her forties expressed related sentiments in regard to the efficacy of community driven natural resources conservation. When asked about successful conservation of hihiwai, she explained a successful hierarchical community led system for informing, deliberating, and disseminating community conservation efforts where ‘aha (or committees) are established within each land division on Molokai to deliberate conservation needs and solutions internally, without the need for agency influence or intervention. She outlined a potential framework for intra-community management of natural resource species like hihiwai where:

> *(community-led) decisions were so instantaneous. Never take major policies and years to come up with a plan. It was very reactive to the now. It was easy to implement because the way the structure was in place, everybody agreed already. Yeah. But at least we had a place for the conversation to happen, they call the council. Boom. Assemble. This is the scoop; this is what's happening. What do we need? Whatever the ʻaha decided, the community members stuck to it. Right. You know, they weren't like "ah, I still going do what I going do. I don't agree." But your kupuna already, the chain of command went up, and this is what was decided. So, when it came back to the community, they say, okay gang, this is what we are doing this year. The integrity of the system was effective. And you followed the instructions to the T. Whether you disagreed on not. Because you know what? If you do it this year, guess what? Next year gonna be better. And I really believe that that's how, that's the best "management system" Molokai could come up with if we ever could get our act together. They were almost there. They came up with the "Aha Moku", but they did it wrong, and they did it where we had a nomination and a ballot or whatever. That process, haole, not Hawaiian.*

In relation to community buy-in and bottom-up community-led management, respondents highlighted the importance of value changes toward hihiwai harvest.

In an ideal world, people would self-regulate. You know, you go back there for eat and maybe not parties. I mean, maybe that's a general attitude that we have to change, because the numbers of hihiwai are changing.

Perspectives about whether hihiwai conservation management should be top-down regulated or bottom-up regulated varied. One respondent shared his involvement in the process undertaken in tandem with the federal government to ban the commercialization of hihiwai in Hawaii. He highlighted the speed and efficacy of this strategy, in which he:

…went to Akaka. One of Akaka's aides, Mike Kitamura, so he helped me with banning of the commercialization of hihiwai. That took only a few months. That's who you have to deal with when you want to have something done. You know, they can do it right then. They you don't need to hold a public hearing or anything like the state. So that's one thing good that the federal government did, was to ban commercial hihiwai harvest."

Another Hawaiian woman in her forties who works for a Hawaiian conservation agency shared related sentiments regarding the efficacy and assurance of agency regulation of key natural resources species like hihiwai. She shared her:

hope that eventually there will be (agency regulation) because, you know, more people know about them (hihiwai). So, more awareness. All the way to the top into the government where they can be protected, legally.

In addition to proposing different hierarchical regulation strategies for managing hihiwai, 5 respondents explicitly mentioned making hihiwai harvest off limits for a period of time as a potential conservation strategy. One male Native Hawaiian respondent suggested that this enforced rest period would allow the needed time for hihiwai populations to recharge and reestablish in streams along the north shore of Molokai. He posited that:

> *…they should shut down hihiwai harvest. They should shut it down for maybe three to five years. We should shut 'em down. Just make it illegal to harvest it. They should stop the harvest from three to five years. Just let 'em come back again. I always wanted that done for like a long time.*

As an alternative strategy, a lifelong male Molokai resident suggested employing hihiwai translocation within and across north shore streams, emphasizing the need for community agreement for successful implementation of this strategy. This respondent shares that:

> *"Hihiwai translocation works. But then nobody can pick them. Everybody comes inside during the summer. Being that it's summer. For some reason, that's the only time people come to pick, because during the winter, rough the water, nobody goes to pick. But if we can have the people to agree. Whether they disagree, that a river section is kapu. That would be ideal."*

DISCUSSION

Understanding traditional ecological knowledge and the insights of local and indigenous resource users is critical for informing the conservation of at-risk species that are important for subsistence and cultural practice. This study provides insights into the drivers, impacts and next steps for the conservation of hihiwai, an aquatic gastropod, on the island of Molokai. Interviews with local residents and cultural practitioners demonstrated widespread agreement that (1) hihiwai populations are decreasing due to a combination of anthropogenic and indirect effects resulting in poor watershed conditions; (2) that these declines are leading to reductions in cultural identity, opportunities for people to connect, and transmission of ecological knowledge (both past and present); and (3) that there is a need for local conservation leaders to promote and carry out conservation management decisions aimed at intra-community value change and community led management of this species.

I found that community members believed that hihiwai population declines were due to human overharvesting and a suite of factors contributing to habitat quality degradation, including invasive plant assemblages, lack of connectivity, landslides and erosion, water diversions and overuse, decreased stream discharge, intermittent stream flow, and warm stream temperatures. Of these factors identified by the community, some were similar, and some proved different from what prior ecological studies had identified as key drivers of hihiwai population change (Figure 2.1). My findings thus provide novel information and insight not highlighted in prior ecological studies, which is consistent with the increasingly widespread view that TEK yields information that sometimes contradicts findings from conventional ecological science approaches, offering new knowledge that can be used to provide novel insights and approaches from which scientists and managers might learn (Gaspare et al., 2015; Rist et al., 2010). For example, Marin et al.

(2017) discovered that Cree fishers described a richer diversity of sympatric lake trout forms than did scientific research that was conducted simultaneously. TEK also provided descriptions of lake trout seasonal movements, spawning locations, and reproductive timing that were not captured by scientific research and highlighted several concerns or temporal changes of import to future management initiatives (Marin et al., 2017). My study and others thus suggest that TEK has untapped potential to be used in tandem with ecological science, acting as a source of baseline information to fill knowledge gaps or confirm findings associated with the ecology and conservation of at-risk and harvested species (Celentano et al., 2014; Gaspare et al., 2015; Marin et al., 2017; Peacock et al., 2020; Rist et al., 2010; Serra et al., 2018). Furthermore, TEK offers the opportunity to draw on observations made over multiple generations to evaluate changes in abundance and drivers of change, which is complementary to ecological data collected through shorter term research studies (Fraser et al., 2006; Rist et al., 2010).

Importantly, Molokai community members highlighted that declining hihiwai is leading to reductions in cultural identity, opportunities for people to connect, and transmission of ecological knowledge. The erosion of TEK observed on Molokai has also been documented in many other communities. The apparent loss in younger generations' abilities to identify key local plant and bird species may be due to a combination of lifestyle change, particularly in terms of food habit, or due to individual differences in life histories (Si, 2020). This challenge was highlighted by Molokai community members that explained that TEK transmission across generations is valued but currently at risk due at least in part to the decline in culturally important resources. TEK associated with hihiwai life history and associated values were transmitted through oral history and teachings provided through family as a primary source, a traditional and vertically transmitted knowledge base used in conveying ecological knowledge in indigenous cultures around the world (Mattalia et al., 2020). TEK, cultural identity, and their relationships to environmental stewardship are also viewed as the basis for social resilience in Hawaii (McMillen et al., 2017). Some strategies used to cope with social–ecological change have decreased (e.g., forecasting, storage, and mobility), while others have maintained but adapted (e.g., livelihood diversification, knowledge transmission and storage, communal pooling, and cultural identity), underscoring the importance of considering multiple strategies together to promote community resilience (McMillen et al., 2017). TEK has also been used to inform local perceptions of species such as hihiwai that are valued not only as a source of protein, but as species with rich roles in ancestral stories, myths, and legends, resulting in the support of conservation measures by local villagers and resource users (Rasalato et al., 2010).

Community member perceptions of next steps highlights the need for local leaders to co-develop and implement management decisions to achieve intra-community value change and community led recovery of hihiwai. Another TEK study in Hawaii focused on natural resource co-management between governmental agency members and resource users highlighted similar factors for consideration in early phases of co-management, including: 1) the role of bridging organizations in capacity building, 2) cross-generational leadership development, and 3) connection of the co-management rule-making process to the target geography (Blaich Vaughan & Caldwell, 2015). Returning ownership of process and findings to indigenous communities is critical to achieving cultural and ecological objectives (Blaich Vaughan & Caldwell, 2015; Diver, 2017; Turner & Spalding, 2013). Molokai community members also emphasized the need for self-initiated value change toward natural resources. In past studies using TEK, successful models for ecosystem and species restoration included ecological, cultural, and socioeconomic values of resource users to meet both environmental and social goals (Celentano et al., 2014;

Pitcher, 2001). In addition to highlighting value shifts in communities toward species of interest to meet conservation goals, TEK research has highlighted that respect and recognition of kinship with other species can remind us of the importance of conserving and protecting these species to sustain humanity (Turner & Spalding, 2013). TEK has also been used to underscore aboriginal concerns related to human pressures on harvested species, not revealed by evolutionary biology knowledge, to encourage restoration of traditional fishing practices (Fraser et al., 2006).

Although the number of respondents was not atypical for an interview-based study (Saldaña, 2013), the prevalence of perceptions about drivers of hihiwai decline, consequences to community and culture, and priorities for next steps, could vary with a larger and more diverse sample population. The respondents I interviewed were predominantly Native Hawaiian and over 60 years old ("kupuna"). Future studies should investigate how viewpoints pertaining to hihiwai and its management varies across demographic groups. Investigating how responses pertaining to impacts, drivers, values, and next steps for hihiwai populations and conservation may vary across generations (ʻopio, makua, kupuna) could inform how best to engage, educate, and communicate knowledge and implement conservation plans. Understanding how perceptions about hihiwai may differ between Native Hawaiian and non-Hawaiian respondents may be critical to informing conservation policy and practice. Many policy and management decisions in Hawaii are made by non-Hawaiians, often limiting Native Hawaiian recommendations and insights to the consultative stages. Understanding the disparities in perceptions and priorities between Hawaiian and non-Hawaiians could lead to conservation decisions that better align with the community and are more likely to succeed. Participatory mapping could also add rich information to the data collected through verbal interviews. Participatory mapping transforms cognitive spatial knowledge into map and descriptive forms. This tool can provide an efficient and effective means of obtaining information where considerable knowledge is held by community members and resource users (Levine & Loftus Feinholz, 2015), and it can empower local and indigenous people that rely on natural resources for subsistence living and as a way of life (Bauer, 2009; Pert et al., 2015; Sharma et al., 2015).

This study informs and advances conservation by including indigenous voices which are usually misrepresented, underrepresented, or completely excluded in decision-making. Although natural resource agencies in Hawaii often do not prioritize Native Hawaiian voices, natural resource co-management and collaborative rulemaking between Hawaiian resource users or community groups and government agencies has proved to be effective for the management and enforcement of nearshore marine resource management (Blaich Vaughan & Caldwell, 2015; McMillen et al., 2017). To build lasting collaborative capacity in fledgling co-management efforts in local communities, important factors to consider include the role of bridging organizations in capacity building, cross-generational leadership development, and connection of the co-management rule-making process to the target geography. The outcomes of this study are consistent with these recommendations and could be used to inform the development of a fledgling joint management plan between Native communities and the agencies that oversee hihiwai and its habitat. TEK shared by Molokai community members highlights the power of drawing on multiple knowledge streams to identify threats to nature and culture (Figure 2.1), and sheds new light on pathways for recovery that are more likely to be successful because they are embraced and led by local knowledge-holders. TEK should be the basis for developing management plans that integrate and perpetuate generational learning and recover ecologically and culturally valuable species in Molokai and other island communities.

TABLES & FIGURES

Table 2.1. Themes addressed by at least 5 interview respondents (including responses to specific questions) Rows in italics are themes that were not specifically prompted in interviews.

Theme Name	# Interviews	# Mentions	Theme Description
Drivers	20	106	Biotic or abiotic factors perceived to be influencing changes (positive or negative) to hihiwai populations in Hawaii
Impacts	20	42	Impacts or changes to local community members, their values, activities, and livelihoods related to hihiwai population change
Values	20	30	Values of hihiwai to local Molokai community members – an overarching description of value that does not fit three main research goals
Next Steps	20	115	Next steps identified for conservation leadership and Hawaiian stream management with respect to hihiwai

Table 2.2. Drivers subcodes. A division of the 106 references to drivers into subthemes, with an example provided for each subtheme.

Theme Name	People	Mentions	Theme Description	*Example*
Drivers Biotic or abiotic factors perceived to be influencing changes (positive or negative) to hihiwai populations in Hawaii				
Hihiwai Declining	16	34	Hihiwai populations declining (over course of participant's lifetime or on shorter time scale)	"…I think that the population physically, the hihiwai population is diminishing."
Anthropogenic Drivers				
Overharvesting	15	18	Humans harvesting hihiwai mentioned	"What do I think is causing a decrease in the hihiwai? I think it's several things. The first thing, of course, is overharvesting."
Water Diversions	7	9	Water diversions mentioned	"Well, one of the big concerns I have about whether hihiwai lives and everything that lives in the river with the hihiwai is the diversion (of water)"
Indirect Anthropogenic Drivers				
Poor Watersheds			Any mention of biotic or abiotic factors that are contributing to poor watersheds and stream habitat for native stream species	"I think there is a combination of environmental and human causes. I think one of the one of the things that I think are impacting hihiwai is poor watersheds."
Invasive Plant/Animal Assemblages	8	11	Invasive plant or animal species mentioned as a detriment to healthy stream systems	"We also get invasive plants. And weeds. Don't forget cattle in the watershed and pigs affecting how much soil is entering the stream. As well as that. And so even the pigs that probably are stirring up the watershed. So it's not stable like they used to be."
Landslides/Erosion	8	17	Mention of landslides or erosion as a	"I think one of the things that I think is going on is increased erosion and landslides, more

			detriment to healthy stream systems	events that are causing stream scouring that cause the hihiwai to have less to feed on.”
Warm Water Temperature	7	8	Warm stream temperatures mentioned as a detriment to healthy hihiwai habitat	“And the streams now are very narrow and very shallow, and the water is warm. Water is very warm now in that I can sit in the water now for a long periods of time and not be cold.”
Intermittent Flow	6	9	Intermittent flow mentioned as a detriment to healthy hihiwai habitat	“It would be lack of water, you know, with the droughts and then intermittent flow in the stream.”

Table 2.3. Impacts and values subcodes. A division of the 72 references to impacts and associated values into subthemes, with an example provided for each subtheme.

Theme Name	**People**	**Mentions**	**Theme Description**	Example
Impacts Impacts or changes to local community members, their values, activities, and livelihoods related to hihiwai population change				
Preservation & Transmission of TEK	12	16	Changes in hihiwai causing loss of ability to remember and pass on past knowledge related to hihiwai and ecological relationship	"I just became a grandmother. My first mo'opuna. And I thought, you know, one day I'd like to teach her all the things that I taught my children and go take her camping Halawa, and try some hihiwai and learn how to use it for whistle. But that's pau. I gotta show her pictures now, maybe, and tell stories about that. Yeah, but it's not going to be a reality for her. Probably not."
Losing Cultural Identity	8	9	Decrease in hihiwai populations leading to loss in cultural identity (i.e., place names associated with hihiwai abundance now no longer applicable)	"I think I find it valuable to look back at that and say, you know, this is how the generation before lived, is that, you know, how can we preserve and so on? So I think preserving the place names is very important. In terms of changing them, I think as long as it's not to the forgetfulness of what was before, you know?"
Connection & Quality Time	11	17	Hihiwai a means for spending quality time and making connections with family and friends (i.e., eating, harvesting, and camping together)	"Yeah, I remember that too. When we would go (harvest hihiwai). We would have aunties, uncles, the little kids. Yeah. It was good fun! And then everybody would pick, you know, where in the river you like. Okay. "The right side is my side". No, that was really good. But you don't ever see that anymore. Which is really sad."
Values Values of hihiwai to local Molokai community members – an overarching description of value that does not fit three main research themes (values inform "impacts" theme)				

Means for Survival	5	9	Hihiwai mentioned as a means for survival	“The hihiwai we picked up was because we needed to make a living. (We) sold hihiwai for $20 an onion bag.”
A Resource That Feeds	9	13	Hihiwai mentioned as an important food source	“What is the importance? It's part of the Hawaiian way of life. It's part of the, I mean, just the name, hihiwai. Yeah, it's a Hawaiian name. The Hawaiians obviously named it. It was an esteemed food source.”
Delicacy	7	8	Hihiwai mentioned as a delicacy	“Hihiwai is like having the caviar or whatever. Top of the line champagne. You bust out hihiwai, then you are somebody.”

Table 2.4. Next steps subcodes. A division of the 115 references to next steps into subthemes, with an example provided for each subtheme.

Theme Name	**People**	**Mentions**	**Theme Description**	*Example*
Next Steps Next steps identified for conservation leadership and Hawaiian stream management with respect to hihiwai				
Successful Leadership Mentions of leaderships types important for successful hihiwai conservation and implementation of management strategies				
Familiar w/ Hawaiian Culture	11	14	Mentions of conservation leaders needing to be familiar with Hawaiian culture.	"You gotta look for people who lived in that valley, people that were experienced in that valley. They need to sit down with them. And say, "what do we need?" You know, what do we need to keep this thing going?"
Local Raised Leaders	13	13	Mentions of conservation leaders needing to be raised in Hawaii	One plus is, you know, just being born from Molokai, you know, born and raised, you know grew up, that's one plus, you know, even being one Native Hawaiian, one percent, you know, ninety-nine. doesn't matter.
Innate Connection to Food	13	13	Importance of conservation leaders to have an innate connection to where their food comes from	"I think definitely, for me, the ideal thing would be the leaders would all come from here and that would have a connection to the 'aina and the ocean or an investment in it or realize the importance of the land and the ocean to the people. That they have that connectivity. That you don't think of your food coming from Safeway. You know, or Foodland. You know where your food comes from."
Represent Community Interests	11	11	Importance of conservation leaders to have a desire to represent the interests of the local community	"You have to pick the right person for the right job, especially if you're dealing with conservation. You know, you get people that only know through the books, but you gotta have somebody who lived and walked

				it and know it firsthand. That's the kind of people I feel that should be the ones that's in there and can teach all the newcomers. Practitioners.”
Informed of Conservation Issues	9	9	Importance of conservation leaders to be informed of pertinent conservation issues in Hawaii	“So it's important to me that the leaders are connected to what's going on in their environment, in their communities…”
Ideal Conservation Strategies Potentially successful conservation strategies in regard to establishing healthy hihiwai populations				
Community Buy-In	9	14	Community buy-in and involvement and integration into conservation implementation highlighted as important	“But if you going look at money, so today, the generation has the idea that you need money to protect something. No, that's not true. Yeah. The most important is that the community is pa'a and they live by their word, their word of honor. Yeah. Other ahupua'a are going to follow. And that's how we all, the whole island. Not only the one ahupua'a, but the whole island will come together and we're going to try malama all those very important resources that was created here for us in Hawaii to sustain us.”
Change Value of Harvesting	9	13	Changes in values needed to be established in community about hihiwai harvest and interaction with hihiwai	“You gotta have a change in attitude. You have to change a generation or two or three, pretty much. So I guess that falls down to education and management.”
Government Protection	7	8	Government protection or agency regulation mentioned as a successful conservation strategy	“Gotta get enforcement. I mean, if somehow, like we had an idea one time when we first got Pelekunu, we are going to hire somebody. He will live in the valley mouth. He can be like the ranger watching the river.”

Bottom-Up Regulation	10	14	Community based and led conservation mentioned as a successful management strategy	"And so they're managing their resource like that. And it's all self-led and respected because of that. And it's people that are respected in the community. So, the same thing could happen here."
Set Hihiwai Harvest Limits	6	6	Hihiwai harvest limits mentioned as a successful management strategy	"I think they should shut down dakine. They should shut it down for I would say maybe three, maybe three to five years. Just make it illegal to harvest it. They should stop the harvest from three to five years. Just let em come back again."

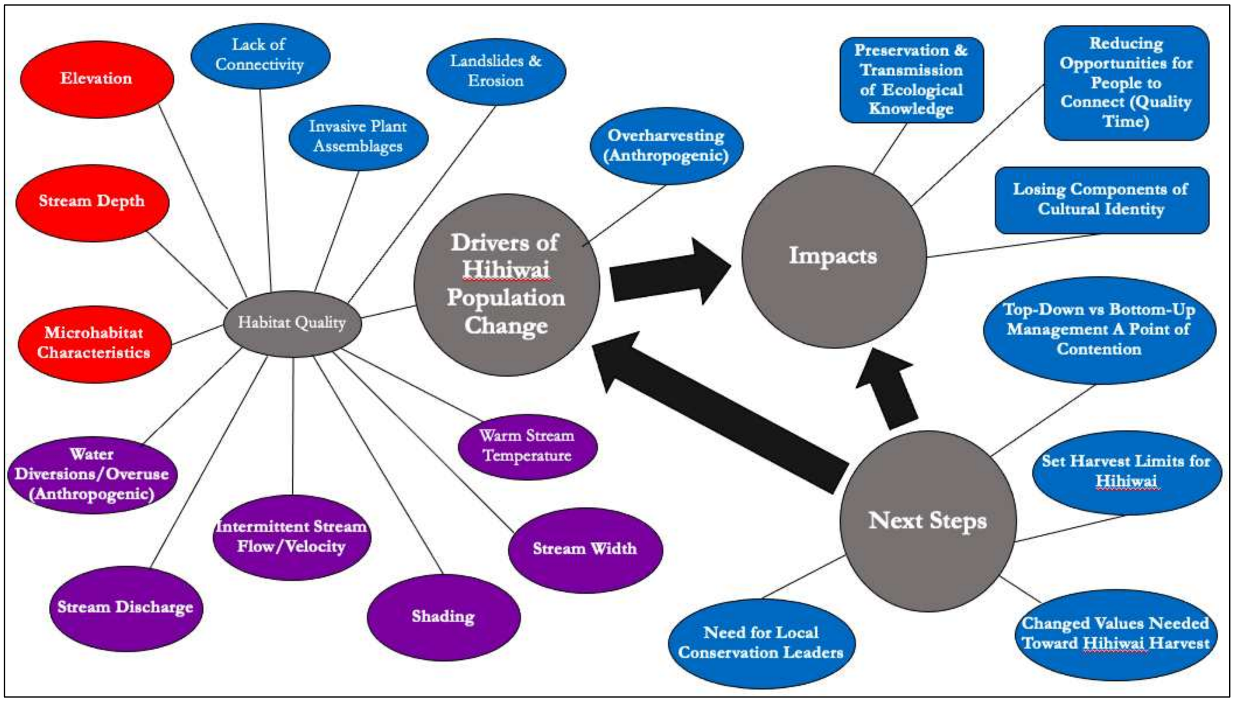

Figure 2.1. Drivers and impacts of hihiwai population declines, and next steps for recovering the species on Molokai. Blue boxes indicate novel topics raised only by interview respondents, purple boxes denote topics raised by respondents and reported in ecological literature, and red boxes indicate topics only in ecological literature.

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APPENDIX

Supplemental Tables

Table S1.1. Results of Generalized Linear Model evaluating the associations between hihiwai abundance in each age class, and adult length, with valley, elevation, and microhabitat.

Source	F Value	Pr > F	R-Square
Eggs			
Model	4.87	0.0001	0.19
Valley	10.56	0.0001	
Elevation Category	1.29	0.2794	
Microhabitat	2.97	0.0331	
Recruits			
Model	37.26	0.0001	0.64
Valley	77.42	0.0001	
Elevation Category	7.09	0.0002	
Microhabitat	0.06	0.9829	
Juveniles			
Model	40.28	0.0001	0.65
Valley	91.29	0.0001	
Elevation Category	8.14	0.0001	
Microhabitat	0.2	0.8932	
Adults			
Model	23.93	0.0001	0.53
Valley	69.5	0.0001	
Elevation Category	6.34	0.0004	
Microhabitat	1.76	0.1563	
Length			
Model	65.81	0.0001	0.80
Valley	153.47	0.0001	
Elevation Category	4.53	0.0045	
Microhabitat	0.98	0.4048	

Table S1.2. Results of Generalized Linear Model evaluating associations between hihiwai egg density and stream characteristics. Direction of effect assigned to continuous variables with (+) for positive effect and (-) for negative effect.

	List of Significant Variables	**F-Value**	DF	Overall R-Square
EGGS	VALLEY ADULTS (+) DEPTH (+) GRAVEL (-)	16.37	Model: 6 Error: 148 Corrected Total: 154	0.3745
RECRUIT	VALLEY ADULTS (+) DEPTH (-) BOULDER (-)	86.51	Model: 6 Error: 148 Corrected Total: 154	0.7691
JUVS	VALLEY ADULTS (+) DEPTH (-) VELOCITY (-) GRAVEL (-) SHADE (-)	52.99	Model: 8 Error: 146 Corrected Total: 154	0.7298
ADULTS	VALLEY ELEVCAT DEPTH (-) TEMP (-)	46.38	Model: 8 Error: 146 Corrected Total: 154	0.7021
LENGTH	VALLEY ELEVCAT ADULTS (-) WIDTH (+) DEPTH (+) VELOCITY (+) DISC (-) BOULDER (+)	91.14	Model: 8 Error: 146 Corrected Total: 154	0.8851

Table S1.3. Means and associated standard error values for four hihiwai age classes and adult hihiwai length across microhabitat, stream, and elevation categories.

	STREAM	Mean	STDERR	ELEVATION	Mean	STDERR	MICROHAB	Mean	STDERR
EGGS	Diverted 2	11.32	2.96	1 (< 50)	8.92	1.56	Cascade	7.93	1.91
	Natural Flow 2	7.60	1.37	2 (50-100)	9.91	1.82	Pool	11.69	1.86
	Diverted 1	15.12	1.90	3 (100-150)	9.21	1.56	Riffle	6.98	1.63
	Natural Flow 1	5.95	1.10	4 (> 150)	10.49	1.80	Run	10.20	1.44
RECRUIT	Diverted 2	141.40	45.94	1 (< 50)	58.98	19.20	Cascade	0.41	0.39
	Natural Flow 2	0.00	0.00	2 (50-100)	3.49	1.68	Pool	24.48	18.54
	Diverted 1	10.99	3.70	3 (100-150)	1.54	0.55	Riffle	26.88	10.37
	Natural Flow 1	0.06	0.06	4 (> 150)	0.58	0.27	Run	25.56	11.96
JUVS	Diverted 2	13.14	1.96	1 (< 50)	6.48	1.16	Cascade	0.30	0.28
	Natural Flow 2	0.00	0.00	2 (50-100)	1.96	0.80	Pool	2.12	0.62
	Diverted 1	4.88	1.06	3 (100-150)	1.04	0.43	Riffle	4.75	1.36
	Natural Flow 1	0.01	0.01	4 (> 150)	0.61	0.33	Run	3.70	0.92
ADULTS	Diverted 2	16.84	1.93	1 (< 50)	14.12	2.49	Cascade	5.16	1.18
	Natural Flow 2	2.88	0.36	2 (50-100)	14.05	3.66	Pool	12.44	2.52
	Diverted 1	37.55	4.38	3 (100-150)	15.01	4.65	Riffle	14.31	3.44
	Natural Flow 1	2.15	0.40	4 (> 150)	11.68	2.80	Run	16.79	3.10
LENGTH	Diverted 2	18.88	0.61	1 (< 50)	25.40	1.30	Cascade	34.79	1.52
	Natural Flow 2	37.28	0.44	2 (50-100)	34.21	1.73	Pool	30.48	1.41
	Diverted 1	21.54	0.86	3 (100-150)	32.08	2.01	Riffle	24.79	1.97
	Natural Flow 1	38.53	0.82	4 (> 150)	29.68	1.13	Run	29.22	1.23

Table S1.4. Environmental characteristics of study streams located on Molokai and Maui, Hawaii

Stream	**Island**	**Harvest Pressure**	**Avg. Temp. (°C)**	**Avg. Discharge (m^3/s)**	**Avg. Quadrat Velocity (m/s)**	**Avg. Depth (m)**	**Avg. Percent Shading**
Natural Flow 1	Molokai	High	23.78 (+/- 0.19)	2.18 (+/- 0.17)	0.52 (+/- 0.03)	0.49 (+/- 0.02)	26.25 (+/- 3.83)
Natural Flow 2	Molokai	Moderate	23.49 (+/- 0.22)	0.96 (+/- 0.07)	0.50 (+/- 0.03)	0.48 (+/- 0.03)	22.08 (+/- 3.48)
Diverted 1	Molokai	Low	20.29 (+/- 0.17)	0.67 (+/- 0.10)	0.25 (+/- 0.03)	0.72 (+/- 0.05)	40.90 (+/- 3.90)
Diverted 2	Maui	Low	22.18 (+/- 0.31)	0.18 (+/- 0.06)	0.09 (+/- 0.05)	0.12 (+/- 0.01)	23.8955 (+/- 5.70)

Abiotic Stream Characteristics

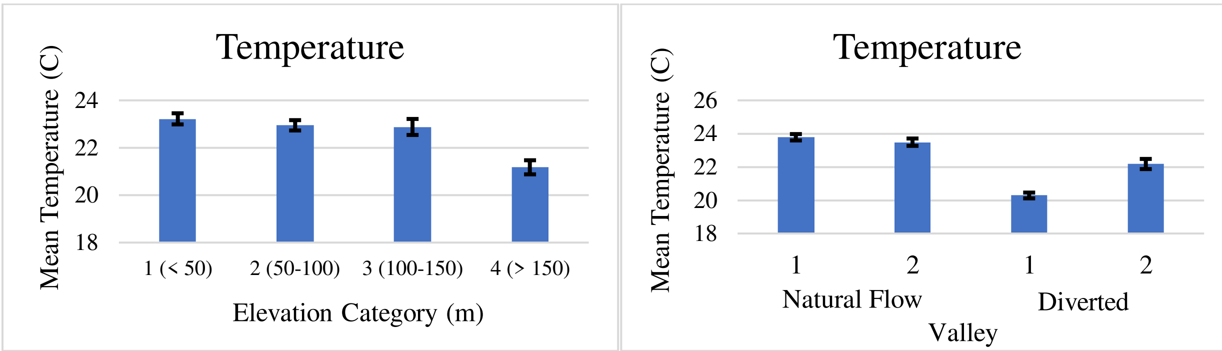

Figure S1.1. Mean stream temperatures across valleys and elevation categories.

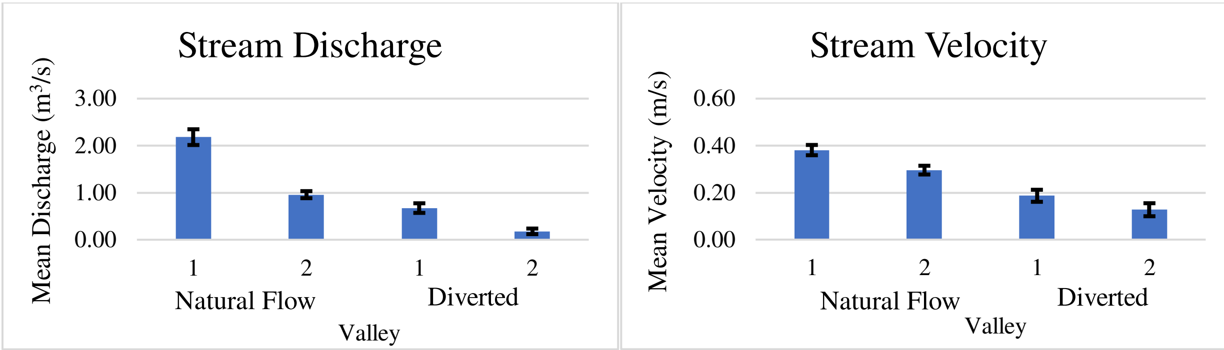

Figure S1.2. Mean stream discharge and velocity across valleys.

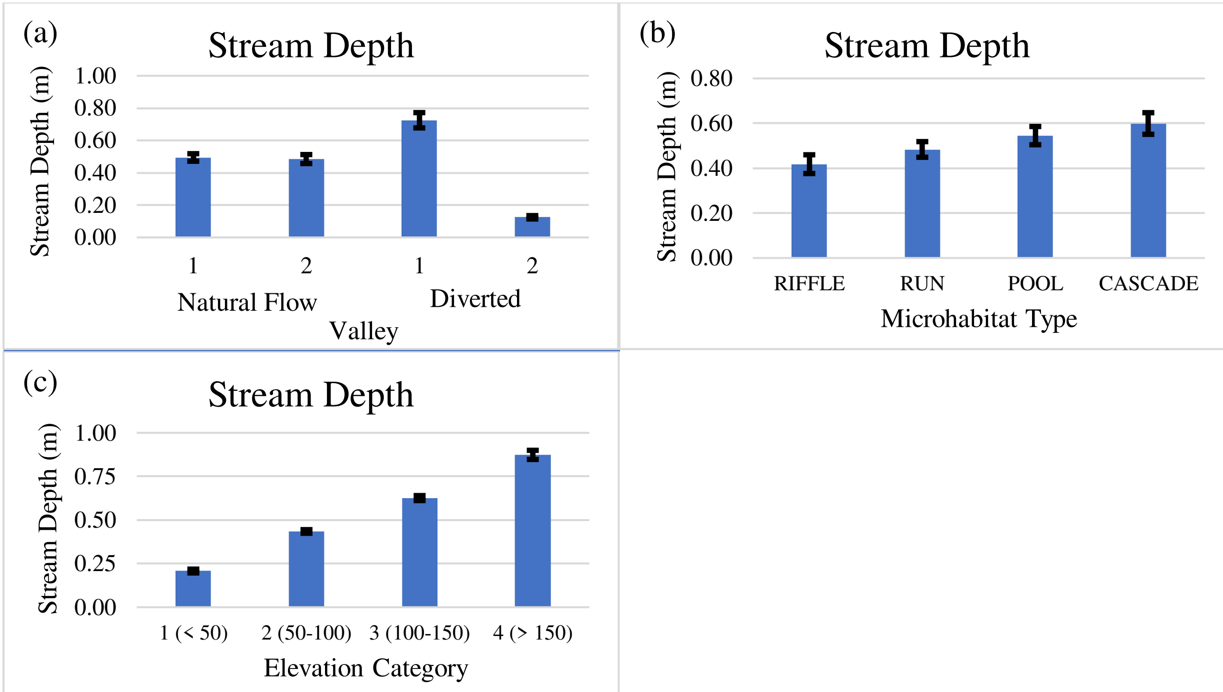

Figure S1.3. Mean stream depths across study streams (a), microhabitat type (b), and elevation category (c).

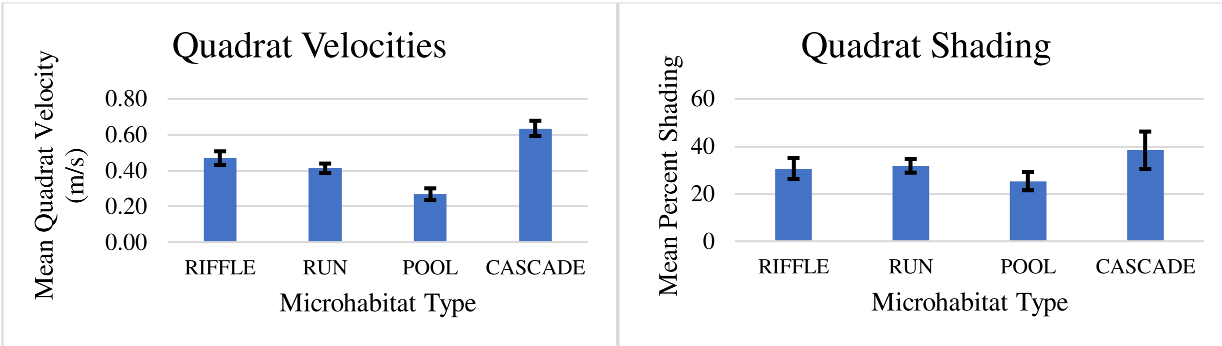

Figure S1.4. Mean quadrat shading and velocities across microhabitats.

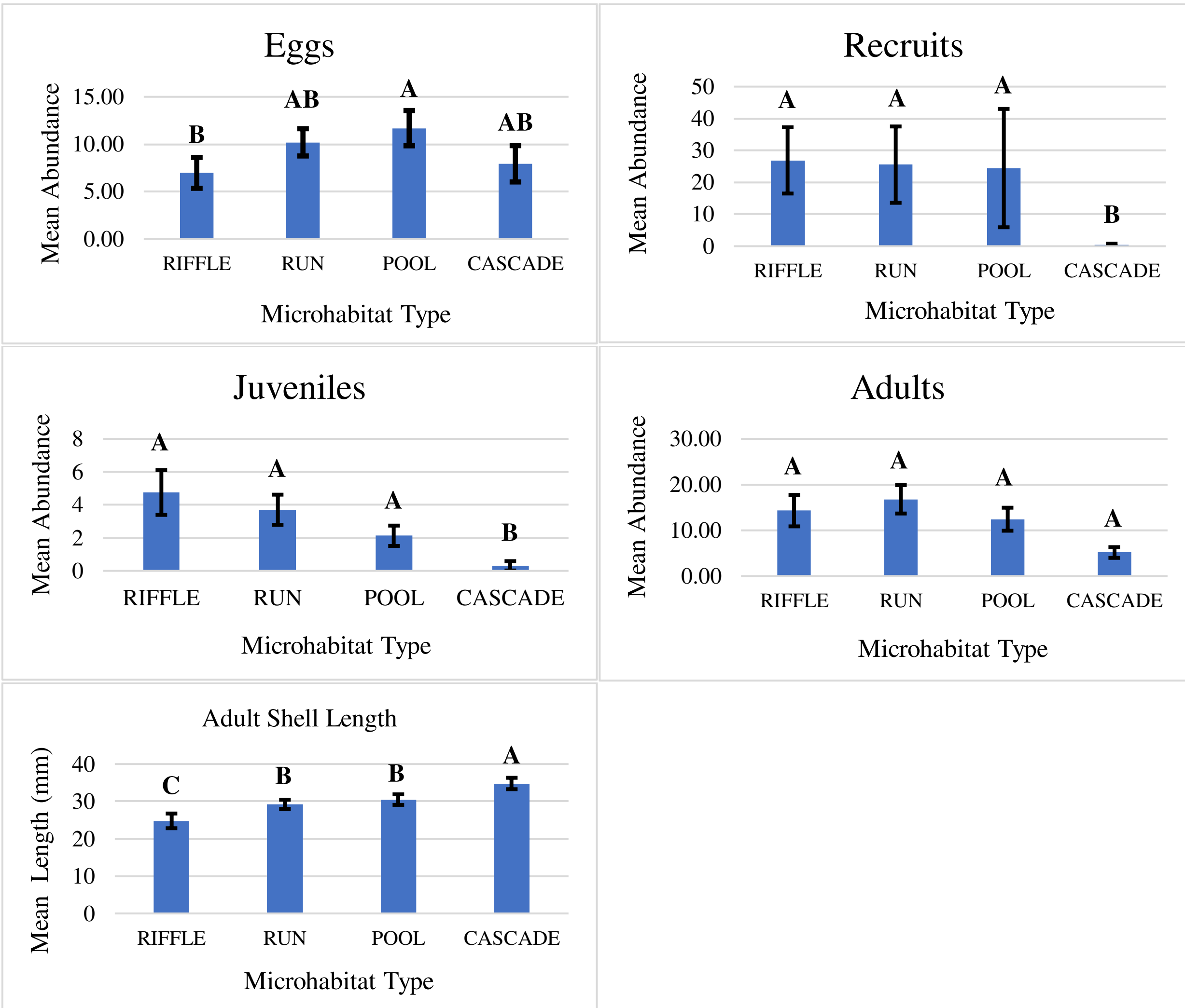

Figure S1.5. Mean hihiwai abundance of eggs (a), recruits (b), juveniles (c), adults (d), and mean shell lengths (e) across microhabitat categories.

Research Questions for Community Interviews – IRB ID: 19-9451H

The objective of this study was to identify how traditional ecological knowledge and local experience can be used to better understand the ecology and conservation of this species, and to engage local communities in conservation of this species and its habitat through mixed methods qualitative inquiry.

Central Questions

The four following central questions were addressed through a suite of questions disseminated through face-to-face interviews.

Question 1: Do individuals from the Molokai community believe the population of hihiwai on Molokai is changing in relation to historical numbers? If so, do they perceive a population increase or decrease, and why?

Question 2: If individuals from the Molokai community believe there is a population change of hihiwai, what do they believe is causing the proposed population change, and how do these perspectives vary based on the interviewees' professional, cultural, geographic, and demographic backgrounds?

Question 3: What is the perceived value of hihiwai to the Molokai community? How does hihiwai shape activities and social interactions in the Molokai community?

Question 4: What does the Molokai community want to see for the future of hihiwai conservation and conservation leadership, in terms of who they think should be leading hihiwai conservation efforts and what future efforts should be taken?

Interview Questions:

1. What change, if any, have you observed in the number of hihiwai in Molokai streams since you were a child? Increased, decreased, remained the same?

2. If you think hihiwai are increasing or decreasing in Hawaii, what do you think is causing the change?

3. Are the same factors that are affecting hihiwai also affecting local practices you participate in (i.e., fishing, local food preparation, camping, etc.)? If yes, how?

4. Tell me a bit about how any changes in hihiwai abundance have affected you or others in the community. Have these changes influenced the things you or your family do and the people you engage with?

5. What makes for good or bad stream habitat for hihiwai?

6. Tell me about how you learned about and engaged with hihiwai as a child/adolescent (e.g., eating hihiwai, harvesting hihiwai, learning about hihiwai in school, etc...)

7. What is the importance or significance of hihiwai to the Hawaiian culture and indigenous identity?

8. How do you think Hawaiian streams should be managed to ensure healthy hihiwai populations in the future?

9. How do you envision successful conservation leadership taking place in the future? Specifically, what types of leaders are needed to develop and enforce successful conservation management for species like hihiwai on Molokai?

10. How often do you teach/talk about hihiwai to others? Can you give a specific example of these interactions?

11. How do you plan or wish to be involved/engaged with hihiwai conservation in the future?

List of demographics deemed important to capture/include within sample population:

* At the end of the interview, subjects were asked the following demographic questions:

How old are you? Please select one of the following age categories (18-21, 28-60, 61 or older)

Were you born and raised on Molokai? If not, where are you from originally?

What part of the island have you lived in for most of your time on Molokai?

Do you identify as a Native Hawaiian?

Do you practice subsistence or commercial hunting or fishing? If so, what kind?