Species Report for the Anchialine pool shrimp (*Procaris hawaiana*)
Version 1.0

Cover. Anchialine pool shrimp (*Procaris hawaiana*). Photo provided by Troy Sakihara.

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EXECUTIVE SUMMARY

This Species Report for the anchialine pool shrimp *Procaris hawaiana*, was completed to assess the species' biology, threats and conservation actions, and current status. The U.S. Fish and Wildlife Service identified the species' ecological requirements for survival and reproduction at the individual, population, and species levels, and identified the factors influencing the species current condition. We used the conservation biology principles of resiliency, redundancy, and representation to assess the overall viability for *P. hawaiana*.

Procaris hawaiana is a member of the family Procarididae and is endemic to the Hawaiian archipelago. Ranging between 0.39 and 1.18 inches (10 and 30 millimeters) in length, this crustacean is known from anchialine pool habitats along the coast of Maui and the island of Hawai'i. Although very little is known about the biology of these shrimp, salinity is likely a strong driver of its distribution; *P. hawaiana* has not been found in pools with salinities below 10 parts per thousand, despite the accessibility of fresher waters at their habitat sites. The lower and upper limits of salinity tolerance is unknown for all life stages of *P. hawaiana*.

Hawai'i is the only state in the United States with anchialine pools. With over 700 recorded pools in Hawai'i, *Procaris hawaiana* has only been documented in 28 pools. Primary threats to *P. hawaiana* are: (1) habitat degradation and destruction due to urban and groundwater development and other associated anthropogenic activities and (2) predation, competition, and habitat degradation by nonnative fish, plants, and invertebrates. The principal means of conserving the species is through protecting and restoring the anchialine pool habitat. This habitat must be free of both direct and indirect human disturbance as well as nonnative flora and fauna.

For the purpose of this Species Report, viability is the ability of *Procaris hawaiana* to persist over time and avoid extirpation. A species is considered viable when there are a sufficient number of self-sustaining populations (resiliency) distributed over a large enough area across the range of the species (redundancy) and occupying a range of habitats to maintain environmental and genetic diversity (representation) to allow the species to adapt and persist indefinitely when faced with annual environmental stochasticity and infrequent catastrophic events. The species is currently known from five population units: two on Maui and three on the island of Hawai'i.

Resiliency of *Procaris hawaiana* is considered low to moderate because of limited population units, low observed abundance, historical habitat destruction, and high risk of extirpation from nonnative predators. Since this species is only present on two islands with all population units located on western facing coastal areas (increased chances of extirpation from a single catastrophic event) with likely little connectivity between populations, *P. hawaiana* is considered to have low to moderate redundancy. Likewise, representation is also considered low to moderate for this species since very few individuals have been observed and there is likely little, if any, genetic exchange between populations. Therefore, the current viability of *P. hawaiana* is low to moderate.

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Introduction

The anchialine pool shrimp, *Procaris hawaiana*, is a member of the family Procarididae that is endemic to the Hawaiian Islands. These shrimp primarily inhabit anchialine pools, which are land-locked bodies of water that occur coastally but are not openly connected to the ocean. *Procaris hawaiana* can be found at five sites across Maui and the island of Hawaiʻi. Habitat degradation and loss, and predation and competition by invasive fish and invertebrates are just a couple of the major threats that have limited the population of *P. hawaiana*.

This biological report summarizes the biology and current status of *Procaris hawaiana* and was conducted by Pacific Islands Fish and Wildlife Office. The biological report provides an in-depth review of the species' biology, factors influencing viability (threats and conservation actions), and an evaluation of its current status and viability.

The intent is for the Species Report to be easily updated as new information becomes available, and to support the functions of the Service's Endangered Species Program. As such, the Species Report will be a living document upon which other documents such as recovery plans and 5-year reviews will be based.

Regulatory History

Procaris hawaiana was listed as endangered under the Endangered Species Act of 1973 (16 U.S.C. 1531 *et seq*.), as amended on September 30, 2016 (USFWS 2016 (81 FR 67786)). All federal regulatory information can be found at the following link: https://ecos.fws.gov/ecp0/profile/speciesProfile?sId=6944.

No critical habitat or recovery outlines are available for *Procaris hawaiana*.

Methodology

We used the best scientific and commercial data available to us, including peer-reviewed literature, grey literature (government, academic, business, and industry reports), and expert elicitation.

Where little information was available for *Procaris hawaiana*, we used information collected from other anchialine shrimp species in Hawaiʻi to fill in these data gaps.

To assess the current status and viability of *Procaris hawaiana*, we identified population units. These units were necessary in order to avoid confusion over any assumptions regarding the health of a group of individuals simply by calling it a population. The classic definition of a population is a self-reproducing group of conspecific individuals that occupies a definite area over a span of evolutionary time, possesses an assemblage of genes (the gene pool) of its own and has its own ecological niche. However, due to information gaps, we could not assess the viability of *P.* hawaiana using this definition. Instead, after consulting with anchialine pool experts and considering the known biology of *P. hawaiana*, population units of *P. hawaiana* were determined by geographic region, distance (including if suitable habitat was unoccupied between two occupied pools), and other geographic and marine barriers such as open ocean.

Like other anchialine pool shrimp species, *Procaris hawaiana* inhabits an extensive network of water-filled interstitial spaces (cracks and crevices) leading to and from the actual pool, a trait which has precluded researchers from ascertaining accurate population size estimates without draining the entire pool (Holthuis 1973, p. 36; Maciolek 1983, pp. 613–616; Iwai et al. 2009, entire). Often, surveys for many rare species of anchialine pool shrimp, including *P. hawaiana* involve a present or absent survey approach in their respective habitat (often with the aid of baiting) (Iwai et al. 2009, entire; Wada 2016 in litt., entire). Absence, and presumably extirpation, of shrimp species from a suitable habitat is likely the best or only measure of a species' decline, as population sizes are not easily determined (Holthuis 1973, pp. 7–12; Maciolek 1983, pp. 613–616; Iwai et al. 2009, entire). Therefore, the definition for population unit used herein in this report is primarily based on presence/absence observations of *P. hawaiana* in the epigeal (above-ground) part of their habitat.

Based on this working definition, maps were created to display population units. In an effort to protect the sensitivity of species data, we created maps with symbol markers rather than displaying species points or polygons. We created the symbols in steps. First, we added a 1,640-foot (ft) (500-meter [m]) buffer around each individual species point and polygon to include all points representing the same population. We then dissolved all buffer areas intersecting each other into a single shape. Finally, we created a centroid (i.e., point representing the center of a polygon) within each dissolved buffer area. The symbol marker represents the centroid. All points and polygons were used in this process, regardless of observation date or current status (historical, current, extant, or extirpated), to represent the known range of the species.

This Species Report assesses the ability of *Procaris hawaiana* to maintain viability over time. Viability is the ability or likelihood of the species to maintain populations over time (i.e., likelihood of avoiding extinction). To assess the viability of *P. hawaiana*, we used the three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs" (Figure 1; USFWS 2016, entire). We will evaluate the viability of a species by describing what the species needs to be resilient, redundant, and represented, and compare that to the status of the species based on the most recent information available to us.

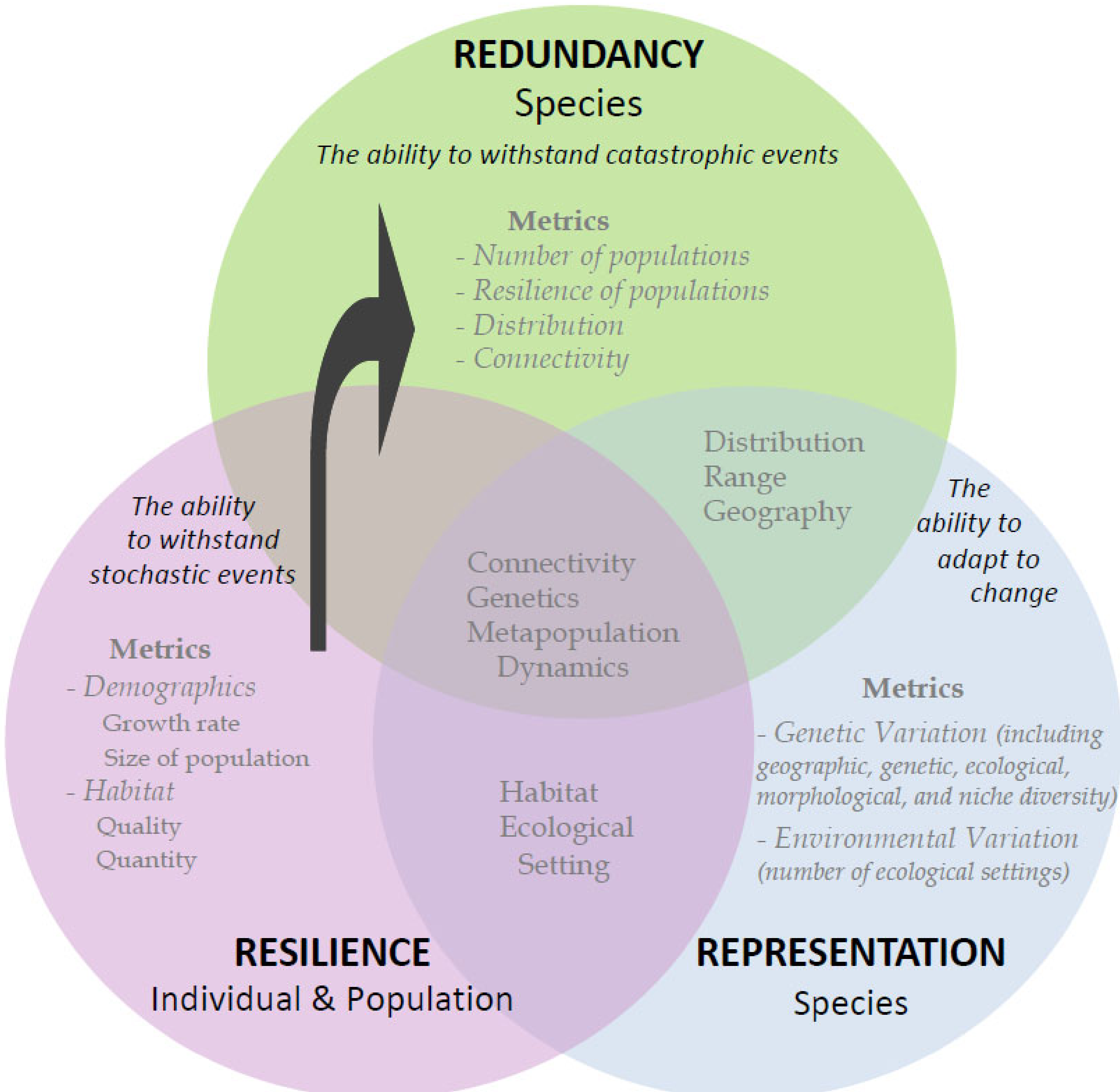

Figure 1. The three conservation biology principles of resiliency, redundancy, and representation (3Rs) used to assess species viability.

Definitions

Resiliency

Resiliency is the capacity of a population or a species to withstand the extreme limits of normal year-to-year variation in environmental conditions such as temperature and rainfall extremes, and unpredictable but seasonally frequent perturbations such as fire, flooding, and storms (i.e., environmental stochasticity). Quantitative information on the resiliency of a population or species is often unavailable. However, a population or species found within a known area over an extended period of time (e.g., seasons or years) is likely to be resilient to current environmental stochasticity. If quantitative information is available, a resilient population or species will show enough reproduction and recruitment to maintain or increase the numbers of individuals in the population or species, and possibly expand the range of occupancy. Thus, resiliency is positively related to population size and growth rate, and may be influenced by the connectivity among populations.

Redundancy

Redundancy is having more than one resilient population distributed across the landscape, thereby minimizing the risk of extinction of the species. To be effective at achieving redundancy, the distribution of redundant populations across the geographic range should exceed the area of impact of a catastrophic event that would otherwise overwhelm the resilient capacity of the populations of a species. In the report, catastrophic events are distinguished from environmental stochasticity in that they are relatively unpredictable and infrequent events that exceed the more extreme limits of normal year-to-year variation in environmental conditions (i.e., environmental stochasticity), and thus expose populations or species to an elevated extinction risk within the area of impact of the catastrophic event. Species redundancy is conferred when the geographic range of the species exceeds the impact area of a catastrophic event. In general, a wider range of habitat types, a greater geographic distribution, and connectivity across the geographic range will increase the redundancy of a species and its ability to survive a catastrophic event.

Representation

Representation is having more than one population of a species occupying the full range of habitat types used by the species. Alternatively, representation can be maintaining the breadth of genetic diversity within and among populations, in order to allow the species to adapt to changing environmental conditions over time. The diversity of habitat types, or the breadth of the genetic diversity of a species, is strongly influenced by the current and historic biogeographical range of the species. Conserving this range should take into account historic latitudinal and longitudinal ranges, elevation gradients, climatic gradients, soil types, habitat types, seasonal condition, etc. Connectivity among populations and habitats is also an important consideration in evaluating representation.

Species Viability

Species viability is derived from the combined effects of the 3Rs. A species is considered viable when there are a sufficient number of self-sustaining populations (resiliency) distributed over a large enough area across the range of the species (redundancy) and occupying a range of habitats to maintain environmental and genetic diversity (representation) to allow the species to persist indefinitely when faced with annual environmental stochasticity and infrequent catastrophic events. The 3Rs share ecological factors such as connectivity among habitats across the range of the species. Connectivity sustains dispersal of individuals, which in turn greatly affects genetic diversity within and among populations. Connectivity also provides access to the full range of habitats normally used by the species and is essential for re-establishing occupancy of habitats following severe environmental stochasticity or catastrophic events (see Figure 1 for more examples of overlap among the 3Rs). Another way the three principles are inter-related is through the foundation of population resiliency. Resiliency is assessed at the individual and population level; redundancy and representation are assessed at the species level. Resilient populations are the necessary foundation needed to attain sustained or increasing representation and redundancy within the species. For example, a species cannot have high redundancy if the populations have low resiliency. The assessment of viability is not binary, in which a species is either viable or not, but rather on a continual scale of degrees of viability, from low to high. The health, number, and distribution of populations were analyzed to determine the 3Rs and viability. In broad terms, the more resilient, represented, and redundant a species is, the more viable the species is. The current understanding of factors, including threats and conservation actions, will influence how the 3Rs and viability are interpreted for *Procaris hawaiana.*

SPECIES ECOLOGY

Species Description

Procaris hawaiana (Holthuis 1973, pp. 12–19) is an anchialine pool shrimp that is endemic to the Hawaiian Islands. These shrimp are a part of the Procarididae family, which was once thought to be a superfamily within the infraorder Caridea, and only includes one other genus, *Vetericaris* (Kensley and Williams 1986, p. 428; Fransen et al. 2013, p. 625). The genus *Procaris* has a global distribution and includes at least five known species, including *P. hawaiana* (Bruse and Davie 2006, pp. 23–24).

The currently accepted taxonomy for this species is (ITIS 2020):
Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca
Order: Decapoda
Family: Procarididae
Genus: *Procaris*
Species: *hawaiana*

The size of *Procaris hawaiana* ranges between about 0.39 and 1.18 inches (in) (10 and 30 millimeters [mm]) in length (USFWS 2008, entire). This shrimp has a pink to light red pigmentation with a dark midline and white to yellow upper body (USFWS 2008). *Procaris hawaiana* is characterized as a hypogeal species, which means that these shrimp occur not just in the illuminated parts of the anchialine pool but also in the interconnected water table below (Brock and Kam 1997, pp. 5–6). These hypogeal parts or interstices of the anchialine pools are where shrimp like *P. hawaiana* are able to move between pools (The Nature Conservancy 1987). This species is found just above the substrate to mid-water and can move through the water column using swimmerets (pareopods and uropods) (Holthuis 1973, pp. 12–19). With the exception of observations on two dates from a single pool at the Kaloko-Honokōhau National Historical Park in September 2016, *P. hawaiana* has not been found in open, brightly illuminated waters (Maciolek 1983, p.612; Beavers 2016, entire). Maciolek (1983, p. 612) suggested that they do not have 'direct vision' (i.e., no response to approach, nearby movement, or localized shadowing) but rather have reduced eyes in order to better detect illumination across a very broad range.

Habitat

The habitat conditions (e.g., salinity, temperature) for all life stages of *Procaris hawaiana* are unknown. *Procaris hawaiana* occupies anchialine pools, which are defined as a body of water with mixed salinity within a geological formation (coastal lava flows or limestone exposures) that exposes the underlying water table (Hiromasa-Browning et al. 2019, p. 4). These include typical small bodies of water such as water in lava fields, tubes, cracks, and under rock overhangs, and open wells, and may occur singly or in groups (Maciolek and Brock 1974, entire). Pools display tidal dampening with some pools only having water at high tide. These pools have subterranean connections to the groundwater and ocean but have no regular surface connection to the sea (Holthuis 1973, p. 3; Sakihara 2012, pp. 83–84). Water chemistry is highly variable with salinities ranging from zero to 41 parts per thousand (ppt) and surface temperatures ranging from 62 to 97 degrees Fahrenheit (17 to 36 degrees Celsius) (Yamamoto et al. 2015, entire; Hiromasa-Browning 2019, p. 4).

Hawaiʻi is the only state in the United States with anchialine pools and the Hawaiian name for an anchialine pool is Wai ʻopāe - wai means water and ʻopāe means shrimp. Anchialine pools have been recorded on Oʻahu, Molokaʻi, and Kahoʻolawe but the majority are located on the islands of Maui and Hawaiʻi (Hiromasa-Browning et al. 2019, p. 9). Over 650 of the 700 known pools are located on the island of Hawaiʻi (Brock 2004, p. i). Of these 700 known anchialine pools in the State of Hawaiʻi, *Procaris hawaiana* has only been documented in two pools at ʻĀhihi-Kinaʻu Natural Area Reserve (NAR) (formerly referred to as Cape Kinau) on Maui island (Holthuis 1973, entire; Maciolek 1983, entire; USFWS 1998, 2003, entire) and in 26 pools on the island of Hawaiʻi (1 at Lua O Palahemo, 24 at Manukā, and 1 at Kaloko-Honokōhau National Historical Park on the island of Hawaiʻi) (Maciolek and Brock 1974, entire; Chan 1995, entire; Brock 2004, p. 28; Sakihara 2009, entire, Beavers 2016, entire). This small population representation limits the species' ability to adapt to environmental change.

Lua O Palahemo is located in the Kaʻu District on the island of Hawaiʻi. The single anchialine pool, formed from a collapsed lava bubble, has an opening 32.8 ft (10 m) in diameter and is directly exposed to sunlight (Kensley and Williams 1986, p. 418). This pool, which is connected to a submerged lava tube that is directly connected to the ocean, has previously been explored to a depth of 98.4 ft (30 m) and along a length of 1000.7 ft (305 m) (Kensley and Williams 1986, p. 418). The anchialine pools in the Manukā NAR have a large physical diversity including shallow pools, wet depressions, shallow fissures, and caves (Sakihara 2015, p. 31). Unlike the sunken lava tube at Lua O Palahemo, Manukā pools tend to be small, less than 328 ft^2 (100 m^2) and shallow (<3.3 ft (1m) depth) (Chan 1995, p. 15). Located on the western side of the island of Hawaiʻi, there are more than 200 anchialine pools within the 1,200-acre (ac) (486-hectare [ha]) Kaloko-Honokōhau National Historical Park. Over half of the pools at Kaloko-Honokōhau are characterized as being small (with surface areas less than 32 ft^2 (10m^2) and shallow (less than 1.6 ft (0.5m) in depth) (Marrack and Beavers 2011, p. 21). On Maui, *Procaris hawaiana* can be found in anchialine pools within the ʻĀhihi-Kinaʻu NAR on the southwest side of the island. Most pools, which vary in surface area from <3.3 to 4,265 ft^2 (<1 up to 1,300 m^2), are generally shallow (1.6 ft (<0.5m)) except for one pool which is >16.4 ft (>5 m) deep (Maciolek 1986, p. 121).

Diet
Based on limited field studies and observations of captive individuals, *Procaris hawaiana* is known to be a filter feeder, using setae covered appendages to trap plankton and other food particles as they swim through the water column (USFWS 2008, entire; Yamamoto et al. 2015, p. 35). While extensive studies on the feeding behavior of *P. hawaiana* are lacking, the endemic *P. hawaiana* has also been observed feeding on moribund shrimp in a laboratory setting (Holthuis 1973, pp. 12–19; Maciolek 1983, p. 612). Although the closely related *Procaris ascensionis*, found in anchialine pools on Ascension Island in the South Atlantic Ocean, has been observed feeding on amphipods and other small shrimp (Abele and Felgenhauer 1985, pp. 20–24), *Procaris hawaiana* lacks conspicuous claws or chelipeds and has poorly developed eyes, which supports the idea that these shrimp are not specialized hunters but rather opportunistic predators. Still, it is likely that the Halocaridina shrimp, ʻōpaeʻula (*Halocaridina rubra*), as well as amphipods, still may serve as a significant food source to *P. hawaiana* (Chan 1995, p. 11). If *P. hawaiana* does rely on *H. rubra* as a consistent food source, the depletion of *H. rubra* populations due to over-harvesting as part of the aquarium trade may have cascading trophic consequences on *P. hawaiana*.

Reproduction
Little is known of either the reproductive biology or ontogeny of the genus *Procaris* and even less is known about *Procaris hawaiana*. Maciolek (1983, p. 613) suggested that based on the absence of egg bearing females in the epigeal portion of the anchialine pool, *P. hawaiana* likely restricts their reproduction to the interstices of the water table. However, nothing is known about the larval stages. Females of the closely related *Procaris ascensionis* have been documented carrying up to 60 large bright orange eggs (Felgenhauer et al. 1988, p. 334). While the large eggs suggest the existence of a larval stage (usually meant for planktonic dispersal) (Felgenhauer et al. 1988, p. 334), no studies on *Procaris* spp. dispersal have been done.

Individual Needs
Hypogeal shrimp are usually found in waters with salinities between 2 and 30 ppt and temperatures between 71 to 86 degrees Fahrenheit (22 and 30 degrees Celsius) (Wiegner et al. 2006, p. 29). Of the hypogeal shrimp, only one is reported exclusively from waters with salinities above 35 ppt (Maciolek 1983, p. 612). *Procaris hawaiana* was not recorded by Maciolek (1983, pp. 611–612) in pools with salinities below 10 ppt, despite the accessibility of fresher waters at their habitat sites. Salinity is likely a driver of *P. hawaiana'*s distribution and may be central to their occurrences in particular pools and/or geographic areas (Maciolek 1983, pp. 611–612; Brock 2004, pp. 6, 31–32). However, the lower and upper limits of salinity tolerance is unknown for all life stages for *P. hawaiana*. Pool volume also appears to be linked with *P. hawaiana* distribution. For example, at Manukā the distribution of *P. hawaiana* was negatively correlated with pool volume. Sakihara (2012, pp. 89–90) suggested that this might be attributable to *P. hawaiana's* elusive behavior and constant movement throughout the interstitial habitat.

Population Needs
We define population units of *Procaris hawaiana* by geographic region, distance (including if suitable habitat was unoccupied between two occupied pools), and other geographic and marine barriers such as open ocean. Since the hypogeal (subterranean habitat) portion of the habitat remains unmapped, the definition for population unit is based primarily on knowledge and occurrences of *P. hawaiana* in the epigeal (above-ground) part of their habitat.

Resiliency is the capacity of an individual or population to withstand stochastic disturbance events. The survival rate of *Procaris hawaiana* offspring, population demographics, and growth rate needed to sustain a population in the presence of threats are unknown. Additionally, as noted above, accurate population estimates are difficult to determine. Thus, we base resiliency of *P. hawaiana* on the little we can determine of population size based on epigeal population index surveys and habitat quality and quantity. A key habitat quality that supports the reproduction and population growth of *P. hawaiana* is the availability of suitable anchialine pools free or reduced of threats. Threats to habitat quality include invasive species, habitat degradation and habitat destruction. Invasive fish have a voracious appetite, can reproduce rapidly, and thus, can swiftly devastate entire populations of anchialine shrimp and significantly alter pool function and water quality. In addition, it is estimated that over 90% of anchialine pools in Hawaiʻi have been destroyed by the introduction of invasive fish (Brock 2004, p. i). Thus, even though the destruction of anchialine pool habitat has slowed significantly over the past several decades, as urban and suburban development continue to grow in Hawaiʻi, the threat remains. Accordingly, a resilient population of *P. hawaiana* has abundant individuals, stable to increasing populations in the wild, and access to quality habitat without threats.

Species Needs
Redundancy is the ability of *Procaris hawaiana* to withstand catastrophic events and it is measured by the number of populations (redundancy/duplication), distribution of the populations across the landscape, and connectivity among population units. In order to achieve redundancy, the distribution of *P. hawaiana* populations across the geographic range should exceed the area of impact of a catastrophic event that would otherwise overwhelm the resilience of the populations. Essentially, the greater the number of populations of *P. hawaiana* and the broader the distribution of those populations, the more redundancy the species will exhibit thereby increasing its ability to survive a catastrophic event. Captive populations of a species would provide a source of individuals that could supplement redundancy; however, there are no known *P. hawaiana* currently in captivity. For *P. hawaiana*, redundancy requires the presence of multiple, stable to increasing populations distributed across its coastal anchialine pool ranges on Maui and the island of Hawaiʻi.

Representation is the ability of *Procaris hawaiana* to adapt to changing environmental conditions over time and can be measured by having one or more populations of a species occupying the full range of suitable habitat used by the species. Alternatively, representation can be viewed as maintaining the breadth of genetic diversity, within and among, populations. This allows the species to adapt to changing environmental conditions over time. However, there are no known population estimates collected before the 1970s and no genetic studies have been conducted on this particular species. While genetic studies on the distribution and connectivity of the ʻōpaeʻula anchialine shrimp (i.e., Santos 2006, entire) may give us a clue on potential geographic and marine barriers to dispersal, because so little is known about the behavior and development of *P. hawaiana* we cannot use these studies as a definitive mapping tool to distinguish genetically distinct populations of *P. hawaiana*. From the 1970s until now, *P. hawaiana* has been reported only on Maui and the island of Hawaiʻi. Brock (2004, p. 24) estimated that more than 90% of all anchialine pools in Hawaiʻi have been destroyed by invasive fish. Therefore, representation for *P. hawaiana* is determined by abundant individuals in stable to increasing populations dispersed throughout the full coastal anchialine pool range on Maui and the island of Hawaiʻi.

FACTORS INFLUENCING VIABILITY

Threats

General

There are currently an estimated 700 or so anchialine pools found throughout the archipelago, although they are most abundant on the islands of Maui and Hawaiʻi (Hiromasa-Browning et al. 2019, p. 9). However, anchialine pools throughout the State of Hawaiʻi have steadily become susceptible to degradation from a number of both natural and anthropogenic threats. These pools have become ecologically degraded and their native biota drastically altered from its pristine conditions (Hiromasa-Browning et al. 2019, p. 10). Hawaiʻi's anchialine habitats have been historically and contemporarily lost or degraded by anthropogenic activities like coastal development and the spread of invasive fish (Brock 2004, pp. 14, 24). It is estimated that >90% has become biologically degraded by the introduction of invasive fish (Brock 2004, p. 24). Of 300 pools on the island of Hawaiʻi surveyed by Acly in 2002, 43% no longer contain visible shrimp populations of any species (Wiegner et al. 2006, p. 30).

Development

Coastal development is likely to negatively affect *Procaris hawaiana* through direct destruction of their anchialine pool habitat, increase in nutrients, and reduction in water quality. Water extraction (e.g., withdrawal of subsurface fresh water for development and human use) from underground fresh water sources increases salinity levels of anchialine pools and negatively affect the *P. hawaiana* which relies on the delicate balance of mixohaline (brackish water) habitats (Conry 2012 in litt., entire). On the island of Hawaiʻi, much development has occurred in the major areas for anchialine pools between Kawaiahae and Kailua-Kona which resulted in the infilling of many anchialine pools (Mitchell et al. 2005, pp. 40, 44, 465). For example, during the construction of the Waikoloa Resort in 1985, at least 130 pools were destroyed (Brock et al. 1987, p. 201). While similar destruction is extremely unlikely to be allowed by present day regulatory agencies, given the scarcity of the anchialine pools, habitat destruction remains a potential threat (Brock and Kam 1997, p. 11). While hypogeal shrimp such as *P. hawaiana* may be able to survive in the water table below the filled pools, it is likely at a lower population density (Brock and Kam 1997, p. 12).

Besides the direct destruction of anchialine pools during development, more indirect but persistent effects can occur including nutrient loading and reduction in water quality. The addition of fertilizers, pesticides, and other runoff from resort, urban, and commercial development may leach into the groundwater and into anchialine pools. For example, anchialine pools at both Waikoloa and Hokuli'a had nutrient concentrations that were >70% higher than concentrations reported for anchialine pools in undeveloped locations (Wiegner et al. 2006, p. 4).

Moreover, it is estimated that nutrient concentrations have more than doubled since the resort's development (Cox et al. 1969, p. 2, Bienfang 1977, entire). The runoff that may leach into the groundwater may directly introduce effluents that can directly harm *Procaris hawaiana* or it can also alter the chemical properties of the anchialine pool thereby affecting productivity and all the flora and fauna that depend on that environment. In addition to pesticides and nutrients, freshwater runoff from landscaping is also potentially harmful. During a survey in 1972 and 1985, salinity recordings showed an approximately 25% reduction (Wiegner et al. 2006, p. 30). While this may not be a problem for some anchialine shrimp species, *P. hawaiana* is thought to be intolerant of low salinities below 10 ppt (Maciolek 1983, pp. 611–612).

Of the four locations where *Procaris hawaiana* has been documented, two are NARs (ʻĀhihi-Kinaʻu and Manukā), one is a National Park unit (Kaloko-Honokōhau National Historical Park) and the fourth (Lua O Palahemo) is unlikely to be developed anytime soon due to its remote location. Therefore, while coastal development may have initially destroyed much potential habitat for *P. hawaiana*, there is a reduced likelihood of future adverse impacts of infilling from coastal development in areas where *P. hawaiana* currently occur.

Aquarium trade

In the past several years, one species of anchialine shrimp, the ʻōpaeʻula, has been increasingly prized by aquarists and companies in the pet trade industry worldwide (Yamamoto 2015, p. 83). These anchialine shrimp are sought after because of their ability to live in hermetically sealed containers (Yamamoto 2015, p. 83) and as live feed for seahorses (Yamamoto 2015, p. 83). While the shrimp that are being harvested are primarily ʻōpaeʻula, which is not endangered, as the popularity of this business increases, there is also an increasing chance that endangered species such as *Procaris hawaiana* may either intentionally or accidentally become part of the aquarium trade. Because these shrimp are so rare, a single person with a hand-net could do irreparable damage to a population of *P. hawaiana* (Yamamoto 2015 in litt., entire). The collection of the anchialine pool shrimp is considered an ongoing threat because despite the prohibition on collecting within the NAR and the permitting process for collection elsewhere, collection can occur at any time owing to insufficient patrolling or other monitoring or enforcement at the pools where *P. hawaiana* occurs.

Human use

Given their close proximity to the beach and their fresh water content, anchialine pools have been used by humans as baths, latrines, and dumps. Ziemann (1985, entire) documented evidence of shampoo containers in and around one anchialine pool adjacent to a popular swimming beach but could not attribute any direct degradation to the activity. However, effects of potential contaminants like soap, shampoo, and sunscreen on the life cycle of shrimp have not been studied. Fecal coliform bacteria were also recovered from three pools, which have the potential to introduce disease and other pathogens into the system (Chan 1995, p. 14). Trampling damage from using the anchialine pools for swimming and bathing has also been documented (Brock 2004, pp. 13–17). The use of anchialine pools as a dumpsite has been documented at all locations (some before they were protected). While Brock (undated personal observation cited in 2004, pp. 13–17) noted that trash items such as bottles and cans appear to have a minimal impact on anchialine pool shrimp, the dumping of used oil and grease, as was done to a pool adjacent to Honokōhau Harbor on the island of Hawaiʻi, can cause the total disappearance of the shrimp. In addition, the dumping of trash can lead to accelerated sedimentation in the pool, exacerbating conditions leading to its senescence (Brock 2004, pp. 13–17).

Invasive species

Invasive plants and animals are some of the greatest threats to anchialine pool health and the survival of *Procaris hawaiana*. It is estimated that more than 95% of anchialine pools in West Hawaiʻi have been contaminated by invasive fish and that this spread has only occurred over the past 20–30 years (Havird et al. 2013, pp. 189–190). Invasive fish are especially problematic for the anchialine pool habitat where their waste products plug up water flow, preventing proper functioning which results in the loss of the pool as a habitat (Wada 2018 in litt., entire). In addition to effects on the habitat, the effects of invasive fish on the anchialine shrimp are also wide ranging, from direct competition and predation to indirect (e.g., the introduction and transmission of parasites and disease) (Maciolek 1984, entire). Some alien species include members of the Poeciliidae (e.g., mosquito fish [*Gamubusia affinis*], shortfin or Atlantic molly [*Poecilia mexicana*], guppy [*Poecilia reticulata*]) and the tilapia (*Tilapia mossambica*). Tilapia (family Cichlidae) were brought to Hawaiʻi for aquaculture. The mosquito fish was introduced as a biological control agent in 1905 and has since spread throughout Hawaiʻi (Dudley et al. 2017, p. 2). The presence of invasive fish has been directly linked to the decline in anchialine pool shrimp at Kaloko-Honokōhau on the south shore of the island of Hawaiʻi (Brock and Kam 1997, p. 56); a survey of pools in 1972 documented 75% of the 41 pools included in the study within the future park boundaries contained ʻōpaeʻula but in a re-survey of the same area in 1997, only 33% of the 64 pools surveyed had ʻōpaeʻula (Brock and Kam 1997, p. 56). It was also documented that there was an increase in the prevalence of invasive fish at Kaloko-Honokōhau, especially noticeable in pools that no longer contained ʻōpaeʻula (Brock and Kam 1997, p. 56). These fish prey on and exclude native anchialine pool shrimp that are usually the dominant fauna in these pools (Bailey-Brock and Brock 1993, p. 354). While none of these effects have been documented specifically with *P. hawaiana*, most impacts to other anchialine pool shrimp such as ʻōpaeʻula are likely to be similar to *P. hawaiana*. Gut content analysis of poecilid fishes found in anchialine pools in Kona show ʻōpaeʻula appendages (Chai 1993, p. 59). Furthermore, through predation upon detrital feeders (amphipods and isopods) and primary consumers such as ʻōpaeʻula, invasive fish can initiate a change in the ecological succession of pools (Brock 2004, p. i). Other effects, such as changes in behavior can be more indirect. For example, in pools where invasive fish have been introduced, ʻōpaeʻula exhibited strong diel activity patterns not seen in fishless pools (Capps et al. 2009, pp. 31–35). While invasive fishes remain the main threat, other fishes commonly found offshore such as āholehole (*Kuhilia* spp.) or ulua/pāpio (*Caranx* spp.) can also wipe out anchialine pools of shrimp if introduced into the system (Kinzie 2010 in litt., entire; Wada 2013 in litt., entire).

Another invasive predator of anchialine pool shrimp is the Tahitian prawn (*Macrobrachium lar*). The omnivorous prawn was introduced to Hawaiʻi in 1956 for aquaculture purposes and, through several intentional introductions into streams and anchialine pools, by the mid-1960s it had spread throughout the islands (Brock 1960, entire; Yamamoto and Tagawa 2000, entire; Staples and Cowie 2001, entire). Chai et al. (1989, p. 6) documented direct predation of Tahitian prawn on the shrimp ʻōpaeʻula in pools where the species co-occur. Furthermore, as a primarily nocturnal species, the Tahitian prawn has also been shown to influence the activity and presence of ʻōpaeʻula at night, causing reverse diel patterns compared to the effects of invasive fish (Carey et al. 2011, pp. 38–40). Although Sakihara (2017, p. 13) found that the effects of Tahitian prawn on shrimp diel activity was habitat dependent (i.e., ʻōpaeʻula was not affected in pools that were dark and deep), the presence of Tahitian prawn in conjunction with invasive fish could severely restrict the overall activity of anchialine pool shrimp. While no studies have been done on the impact of Tahitian prawn on *Procaris hawaiana*, the Tahitian prawn has been documented in at least one known habitat of *P. hawaiana* (Manukā) and it is likely to affect the endangered *P. hawaiana* in at least two ways. First, if the Tahitian prawn predates on ʻōpaeʻula it is likely to also predate on *P. hawaiana* since they are similar in size. Second, since *P. hawaiana* is known to use ʻōpaeʻula as a food source, if the Tahitian prawn is also feeding on ʻōpaeʻula, the prawn could exhaust *P. hawaiana*'s primary food source or at least make it more difficult to obtain by increasing its scarcity.

In Hawaiʻi, many native plant assemblages have been replaced by *Prosopis pallida* (kiawe), mainly as the result of years of pressure from historical cattle grazing (D'Antonio and Vitousek 1992 p. 65; Wagner et al. 1999, pp. 45, 55, 58–62; Dudley et al. 2014, pp. 511–512). While the impact of invasive plants is not as direct as invasive fish and invertebrates, some plants such as kiawe may threaten the health of anchialine pools through the introduction of leaf litter. Kiawe have been identified as potential causal agents of 'nutrient loading' (Brock et al. 1987 p. 205; Street et al. 2008, p. 370). As a nitrogen-fixing plant, kiawe can add large quantities of nitrogen to the soils, which has the ability to alter nutrient availability and productivity in anchialine pools through direct additions of nitrogen rich litter (Dudley et al. 2014, p. 511). Furthermore, leaf litter that is deposited and trapped in the anchialine pool can lead to infilling and accelerate the natural senescence of the anchialine pool habitat (Brock 2004, p. 34).

Natural senescence of pools

Anchialine pool habitats can gradually disappear when wind-blown materials accumulate through a process known as senescence (Brock 2004, p. 11). According to Brock (2004, p. 11), senescence can begin in as little as 100 years. Conditions promoting rapid senescence include an increased amount of sediment deposition, good exposure to light, shallowness, and a weak connection with the water table, resulting in sediment and detritus accumulating within the pool instead of being flushed away with tidal exchanges and ground water flow (Brock 2004, p. 16). Leaf litter also can speed up the senescence process where pools may become marshes within 100 to 150 years (Brock 2004, p. 34).

Biological Limitations

As a result of extremely low known numbers, *Procaris hawaiana* may experience the following: reduced reproductive success due to inbreeding depression, reduced levels of genetic variability leading to diminished capacity to respond and adapt to environmental changes, and increased vulnerability to localized catastrophes such as hurricanes, tsunami, and drought. Together these may result in population extirpation and extinction of this species.

The persistence of *Procaris hawaiana* is threatened by having only five known populations: two sites on Maui and three sites on the island of Hawaiʻi. This limited number leaves the species vulnerable to extinction from natural and anthropogenic caused factors. The demographic structure needed to support *P. hawaiana* is unknown. While the interconnectedness of the hypogeal environment has not been mapped, because of their dependence upon these interstices of the water table, small isolated populations may be particularly vulnerable to reduced mating encounters and decreased reproductive success caused by inbreeding depression. These populations may suffer a loss of genetic diversity over time due to random genetic drift, resulting in a decreased evolutionary potential and lessened ability to cope with environmental change (Lande 1988, p. 1455).

Environmental Factors
Both stochastic disturbance and catastrophic events such as hurricanes, earthquakes, and tsunamis can result in the direct loss of *Procaris hawaiana*. The coastal area where anchialine pools are found can be directly exposed to storm surge and flooding associated with severe storms. Indirect effects may include flooding of the anchialine pools with fresh water that lowers the salinity of the pools; because species, such as *P. hawaiana*, are thought to be limited to salinities ≥ 10 ppt, flooding the pools with fresh water could result in high rates of mortality. Obliteration of the habitat may also occur through infilling by storm surf (carrying sand and rubble) (Brock 2004, p. 12). In addition, storm surge could also result in the introduction of predators such as fish into the anchialine pools. Because there are so few pools occupied by *P. hawaiana*, fish introduced into a single pool may have a dire effect on the entire population. Other catastrophic events such as earthquakes or volcanic lava flows have the ability to directly alter or destroy the habitat. Since *P. hawaiana* depends upon the hypogeal environment for connectivity, any alteration to this environment could have devastating consequences for reproductive success and the maintenance of genetic diversity. Small populations are demographically vulnerable to extinction caused by random fluctuations in population size and sex ratio. Thus, both catastrophic events and stochastic disturbance may extirpate a species from an island with a single population (Lande 1988, p. 1455).

Climate change associated sea level rise may also adversely affect *Procaris hawaiana*. With a projected rise between 2.5 and 6.2 ft (0.75 and 1.9 m) by 2100 (Vermeer and Rahmstorf 2009, pp. 21528, 21530; Parris et al. 2012, entire), coastal ecosystem distribution and community structure are expected to change significantly due to flooding, erosion, salt-water intrusion, or a combination thereof (Nicholls and Cazenave 2010, pp. 1517–1519; Church et al. 2013; Williams 2013, pp. 184–196). While current geospatial models show new pools are likely to form inland due to sea level rise and that the high subsurface hydrologic connectivity can allow for these new habitats to be populated by anchialine shrimp (Oki 1999, pp. 1–70; Kano and Kase 2004, pp. 423–424; Craft et al. 2008, pp. 676–677), higher water levels and more frequent storm surges may allow introduced fishes to disperse into new areas (Marrack 2015, entire).

Site Specific Threats
Lua O Palahemo
Lua O Palahemo is on Department of Hawaiian Homeland's property and is accessible to the public. As of 2010, no nonnative fishes were observed at Lua O Palahemo. Guppies were observed sometime in the 1980s but were removed (Brock 2012 pers. comm.). However, dumping has been documented (Brock 2004, pp. 15–16; Bozanic 2004, entire) and observations made in 2005 indicate that erosion and associated sedimentation have increased since the 1980s (Brock 2012 pers. comm.). Likewise, a 2010 survey by the U.S. Fish and Wildlife Service (Servie) (Wada 2010 in litt., entire), noted that visibility within Lua O Palahemo was extremely poor (<5 in (127 mm) which indicates even further increases in sedimentation, likely due to

water passages being blocked and reduced flow. Service staff also observed copious amounts of both organic and inorganic debris throughout the pool (Wada 2010 in litt., entire). These conditions also indicate that Lua O Palahemo is currently undergoing senescence and will likely become unavailable as habitat for any anchialine pool shrimp (Wada 2010 in litt., entire). This increase in sedimentation, whether from natural senescence, dumped materials or a combination of both, is likely associated with the lower number of shrimp species present in the pool.

Manukā

Despite being part of a NAR (est. 1983), the anchialine pools at Manukā have become critically threatened by alien species, trash, human waste, and development. In a 2016 trip to Manukā Shizuma et al. (2016, p. 33) removed more than 225 pounds (102 kilograms) of marine debris and camp litter from the area. In some of the Manukā anchialine pools, there was evidence of degradation including the presence of two exotic predators in several pools (a poeciliid fish species and Tahitian prawn) and use of at least one pool as a latrine (Sakihara 2009, pp. 4–5).

Kaloko-Honokōhau

Dissolved nutrient concentrations in pools of Kaloko-Honokōhau downslope of developments have increased (Raikow 2016, entire). There have also been significant problems with invasive fish found in some anchialine pools such as the Mozambique tilapia. The Mozambique tilapia is flourishing in ʻAimakapā Fishpond, which is a 30 ac (12 ha) brackish-water wetland complex within the Kaloko-Honokōhau National Historical Park. A 1997 survey of 64 pools by Brock and Kam (1997, pp. 44–45) noted that a number of pools were found to also include guppies and numerous anchialine pools in Kaloko-Honokōhau which were once free of invasive fish (surveyed previously in 1974 (Maciolek and Brock, entire)) now were full of them.

ʻĀhihi-Kinaʻu

The two Maui pools that are known to contain *Procaris hawaiana*, were once modified for use as fishponds by early Hawaiian and later inhabitants of the area (USFWS 2013 in litt., entire), but now they are protected by state regulations as part of a NAR. In 2004, Brock (entire) surveyed the anchialine pools and noted that they were the most biologically intact anchialine resources in the nation. However, despite the isolation and lack of development, the pools were still experiencing degradation as evidenced by footprints in the pool sediment, presence of human waste, and the suspected harvesting of shrimp for the aquarium trade (Brock 2004, pp. 13–17; NARS 2012, pp. 44–54).

Conservation Actions

General

In addition to federal regulations, all terrestrial and aquatic invertebrates (including anchialine pool shrimp) are protected under (1) the State of Hawaiʻi Revised Statues (1993) chapter 195D-4-f license; and (2) Department of Land and Natural Resources (DLNR) chapter 124: Indigenous Wildlife, Endangered and Threatened Wildlife, and Introduced Wild Birds. Two anchialine pools on Maui and 12 anchialine pools on the island of Hawaiʻi are located within State NARs. State NARs were created to preserve and protect samples of Hawaiʻi's ecosystems and geological formations. Designation as a State NAR prohibits the removal of any native organism and the disturbance of pools (HAR 13-209-4). While signs are posted at NARs to notify the public that anchialine pools are off-limits to bathers, off-road vehicle use around the pools, and other activities, the enforcement at remote locations like Manukā and ʻĀhihi-Kinaʻu is difficult. In addition, no State regulatory protection of these shrimp exists at Lua O Palahemo and the five anchialine pools adjacent to the Manukā NAR.

Lua O Palahemo

Unlike ʻĀhihi-Kinaʻu and Manukā, Lua O Palahemo is not part of a NAR. Instead it is on land controlled by the Hawaiʻi State Department of Hawaiian Home Lands. At Lua O Palahemo there is a sign stating site disturbance is subject to a fine per HRS 6E and 16 USC 3701. However, signs do not provide an active deterrent. For example, in 1985, at the Waikoloa Anchialine Pond Preserve in North Kona, Hawaiʻi a sign warned people from entering the preserve but in December 2003 it was discovered that someone released tilapia and mosquito fish into the system; within six months following the introduction, nonnative fish invaded two thirds of the system and almost all anchialine shrimp disappeared (Brock 2004, pp. 13–17). Other than the sign, there are currently no conservation actions that have been documented at this location specific to the protection of the anchialine pool or its inhabiting fauna.

Manukā

Part of the Manukā watershed was designated as a NAR in 1983 and consequently much of Manukā's anchialine habitats have seen very little change over the past few decades (Chan 1995 pp. 15–16; Brock 2004, pp. 28–33; Sakihara 2012, pp. 83–84). The Manukā NAR is currently the largest of 19 reserves established by the State of Hawaiʻi, covering 25,550 ac (10,340 ha) from sea level to 5,524 ft (1,684 m) elevation (Sakihara 2012, pp. 83–84). The anchialine habitats within Manukā are considered exceptionally unique from other Hawaiian anchialine communities for several reasons: 1) the lack of development within the watershed considerably reduced anthropogenic effects on groundwater intrusion, 2) the remoteness and difficulty of access limits the amount of people in the area, 3) the barren landscape presents little to no encroaching vegetation, and 4) the high salinity levels of the pools within this area provide preferable conditions to rare shrimp species such as *Procaris hawaiana* (Brock 2004, p. 6, 31–32). Despite its isolation and designation as a NAR, the increasing frequency of campers at Manukā threaten the anchialine pool habitat by introducing alien species, trash, and human waste (Sakihara 2012, p. 84). There are currently 24 anchialine pools within the Manukā watershed that are known to host *P. hawaiana*. While 19 of those pools fall within the NAR boundary, the other five pools are located on unencumbered State land that is adjacent to the NAR, which means that they are not subject to the same protections from potentially harmful activity as the pools that are within the NAR (Conry 2012 in litt., entire).

Kaloko-Honokōhau

Established on November 10, 1978, Kaloko-Honokōhau National Historical Park is a unit of the national park system (PL 95-625) and encompasses approximately 650 ac (263 ha) of land and 500 ac (202 ha) of marine waters. The anchialine pools within Kaloko-Honokōhau are consistently monitored by park staff since 1994 and a quantitative occupancy analysis is currently being conducted to allow for more robust estimate of shrimp (not only *Procaris hawaiana*) abundances (Carlson 2016, entire; Peck 2016, entire). There have been concerted efforts, especially with children and school groups, to educate the public about the importance of anchialine pools in Hawaiʻi (USFWS 2019 in litt., entire). There are also active efforts to eradicate the invasive Mozambique tilapia from the anchialine pools (USFWS 2019 in litt., entire). Among the options being assessed is rotenone, a natural piscicide that is commonly used in fish management (Nico et al. 2015, p. 84). While no testing was done directly on *P. hawaiana*, initial laboratory tests found that rotenone was effective at killing juvenile and adult tilapia and had little to no effect on invertebrates, including other anchialine pool shrimp (Nico et al. 2015, pp. 91–101). Other methods of invasive fish removal including hand removal and pumping carbon dioxide (CO_2) anchialine pools has been used successfully in two small pools at Kaloko-Honokōhau and other locations around the island of Hawaiʻi (Sedar et al. 2020 in litt., entire). The hand removal and CO_2 methods only seem to be successful in smaller sized pools (Sedar et al. 2020 in litt., entire)

ʻĀhihi-Kinaʻu

ʻĀhihi-Kinaʻu is a NAR that was established in 1973 for the protection of Native Hawaiian ecosystems and geological features in as unmodified a manner as possible (NARS 2012, p. 1). Since that establishment, the anchialine pools within the reserve have been completely fenced off from public access. There have also been a number of other conservation actions taken to ensure the longevity of the entire reserve including the anchialine pools. For example, in the early 2000s, DLNR the state's managing agency took several management actions designed to reduce the impact of visitors: 1) hired-two full time Reserve Rangers; 2) provided support to the Hawaiʻi Wildlife Fund (HWF) for a half-time education station, naturalists, and human use surveys; 3) installed portable toilets at Keoneʻoʻio and Kanahena, trash receptacles and information signage; 4) prepared a draft Environmental Assessment of potential boundary buoys; and 5) contracted an archeological survey management plan for high use areas (NARS 2012, pp. 58–78).

CURRENT CONDITION

Historic Condition

Pre-human Habitat and Species Distribution

There is very little information on the pre-human distribution of anchialine pools in Hawaiʻi. However, since anchialine pools are dependent on underground movement and flow of water and thus require porous volcanic or limestone substrates, it is possible that anchialine pools were present wherever this type of rock formation occurred in close proximity to the ocean. In Hawaiʻi, the volcanic basalt parent material and derived minerals are extremely porous, and ancient limestone coral uplifts or karst material are full of cracks and crevices allowing water to drain to a water table, deep below the surface (Maciolek 1969, entire). It is also possible that *Procaris hawaiana* occupied any of the anchialine pools that had suitable environmental conditions and that they moved between these pools that maintained subterranean connections. While we do not know much about the development, and thus the dispersal capability of the larvae of *P. hawaiana*, it is likely that there was limited if any genetic exchange between islands. Given the unique habitat where *P. hawaiana* is found it is unlikely that *P. hawaiana* would produce larvae meant for long-term ocean dispersal; rather, any genetic exchange would take place within the interconnected water tables of each island. In addition, threats that once destroyed almost their entire habitat such as urban development and the introduction of nonnative predators were not present until after human contact. Thus, *P. hawaiana* was probably more widespread in much higher abundance than present.

Historical trends
Lua O Palahemo
Procaris hawaiana was first discovered at Lua O Palahemo during a survey by Maciolek and Brock in 1974. No population size was recorded during that survey, but a follow-up survey in 1985 by Kensley and Williams (1986, p. 418) estimated that there were more than 1,000 individuals of *P. hawaiana* within the pool. However, because of the pool's large size, no accurate population estimate was conducted (Kensley and Williams 1986, p. 418).

Manukā Watershed
Initially discovered at Manukā during a 1989-1992 survey, Chan (1995, p. 3) found three individuals. The area was not surveyed again until 2004 during which time the species was observed but no population size was recorded (Brock 2004, p. 28). Eventually through more widespread surveys, *Procaris hawaiana* was documented within 24 anchialine pools within the Manukā watershed, which is located in south Kona on the island of Hawaiʻi. Nineteen of these pools are located within the Manukā NAR, which encompasses an area of 25,500 ac (10,319 ha). The remaining five pools are located on unencumbered state land that is adjacent to the NAR boundary (Conry 2012 in litt., entire).

Kaloko-Honokōhau
Procaris hawaiana was observed twice within a single pool at Kaloko-Honokōhau, once on 9/12/2016 and again on 9/27/2016 (Beavers 2016, entire; USFWS 2019 in litt., entire).

ʻĀhihi-Kinaʻu
ʻĀhihi-Kinaʻu is the location where *Procaris hawaiana* was initially discovered during a 1973 survey by Holthuis (1973, pp. 12–19). During that survey, at least two individuals were found (Holthuis 1973, pp. 12–19). A survey of the area from 1979–1980 only mentions that they observed *P. hawaiana* but did not specify abundance (Maciolek 1980, p. 124). However, Maciolek (1983, pp. 607–614) mentioned that out of the four documented species of anchialine shrimp found at ʻĀhihi-Kinaʻu, *P. hawaiana* was the least common. Finally, a re-survey of the area in 1986, again did not specify abundance but did identify the pools in which *P. hawaiana* was found. Maciolek (1986, p. 121) found two pool groups occupied by *P. hawaiana* which were less than 0.62 mile (mi)(1 kilometer [km]) apart; however, because there were at least seven pools or groups of pools between these that were unoccupied by *P. hawaiana*, this suggests two separate populations of *P. hawaiana* at ʻĀhihi-Kinaʻu.

Current Condition
Of the 700 known anchialine pools in the State of Hawaiʻi, *Procaris hawaiana* has only been documented in 2 pools at ʻĀhihi-Kinaʻu NAR (formerly referred to as Cape Kinau) on Maui island (Holthuis 1973, entire; Maciolek 1983, entire; USFWS 1998, 2003, entire) and in 26 pools on the island of Hawaiʻi (1 at Lua O Palahemo, 24 at Manukā, and 1 at Kaloko-Honokōhau National Historical Park on the island of Hawaiʻi) (Maciolek and Brock 1974, entire; Chan 1995, entire; Brock 2004, p. 28; Sakihara 2009, entire).

Lua O Palahemo
The most recent surveys at Lua O Palahemo for *Procaris hawaiana* was from 2012 where seven individuals were observed (Wada 2012 in litt., entire). Similarly, in 2009–2010, eight individuals

were observed (Wada 2010 in litt., entire) (Figure 2, Population Unit A). No numbers like the >1,000 recorded by Kensley and Williams (1986, p. 418) have been documented since their survey. This pool has been recorded as undergoing natural senescence (Wada 2010 in litt., entire; Brock 2012 pers. comm.). Additionally, while Lua O Palahemo is only 9.3 mi (15 km) away from Manukā (Chan 1995, p. 11), the Manukā watershed is not directly connected to Lua O Palahemo (Fransen et al. 2013, p. 630).

Manukā Watershed

Since 2004, the anchialine pools at Manukā have been formally surveyed twice more, once from 2008–2009 and another from 2009–2010 (Figure 2, Population Unit B). During the 2008–2009 survey, no population size was recorded but *Procaris hawaiana* was observed in four different pools (Sakihara 2009, p. 4). Then during the 2009–2010 survey by Conry (2012 in litt., entire), again no specific population size was recorded, but 19 pools within the NAR were found to contain *P. hawaiana* and 5 pools located on unencumbered State land adjacent to the coastal NAR boundary was also found to contain *P. hawaiana.* In 2016, *P. hawaiana* was observed but no numbers were recorded (Shizuma et al. 2016, p. 33).

Kaloko-Honokōhau

The sighting at Kaloko-Honokōhau is one of the most recent documented observations of *Procaris hawaiana* (Figure 3, Population Unit C). However, after *P. hawaiana* was sighted in September 2016, the species has not been observed since then despite quarterly water quality monitoring (USFWS 2019 in litt., entire).

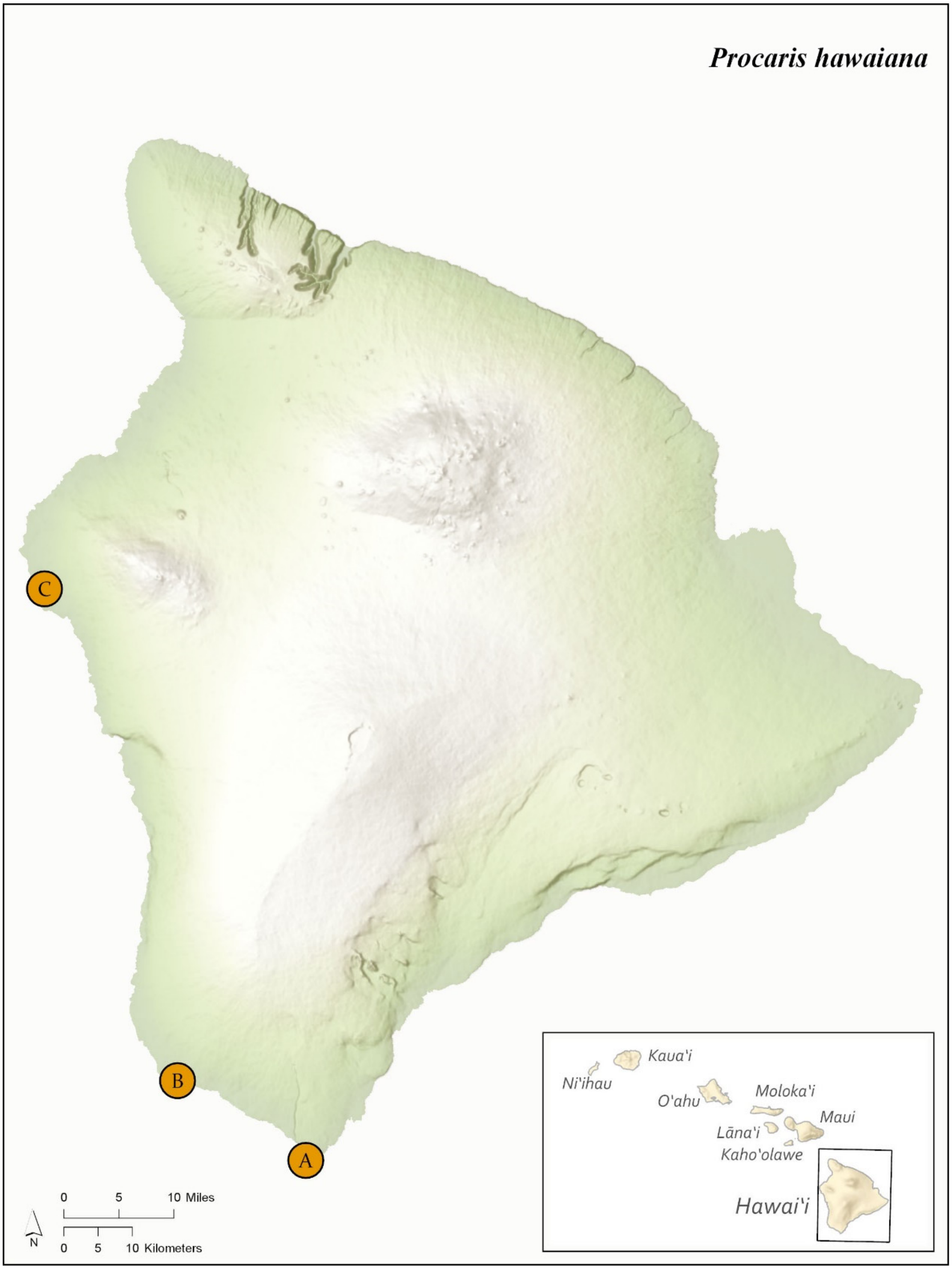

Figure 2. Population units of the anchialine shrimp, *Procaris hawaiana*, on the island of Hawai'i.

ʻĀhihi-Kinaʻu

Since the last survey by Maciolek in 1986, ʻĀhihi-Kinaʻu was surveyed three more times, once by Brock (2004, p. 19) and twice more by the Service in 2007 and 2010 (USFWS 2013 in litt., entire). During the 2004 survey by Brock (pp. 30–57), *Procaris hawaiana* was again found at the same pools or pool groups identified by Maciolek (1986, p. 121), but no abundance was recorded. Thus, despite the two pools/groups being less than 0.62 mi (1 km) apart, based on the last two surveys (Maciolek 1986, p. 121 and Brock 2004, pp. 30–57), and the large number of pools that were occupied by other anchialine shrimp but not *P. hawaiana*, we conclude that there are two separate population units (D) and (E) at ʻĀhihi-Kinaʻu (Figure 3). In the 2007 survey by the Service and State of Hawaiʻi NAR and DLNR Division of Aquatic Resources personnel, *P. hawaiana* was found in one of the pool groups in which it was previously known to occur (USFWS 2013 in litt., entire). And in the most recent 2010 survey, *P. hawaiana* was again found in one of the two pool groups where it was previously known to occur (USFWS 2013 in litt., entire).

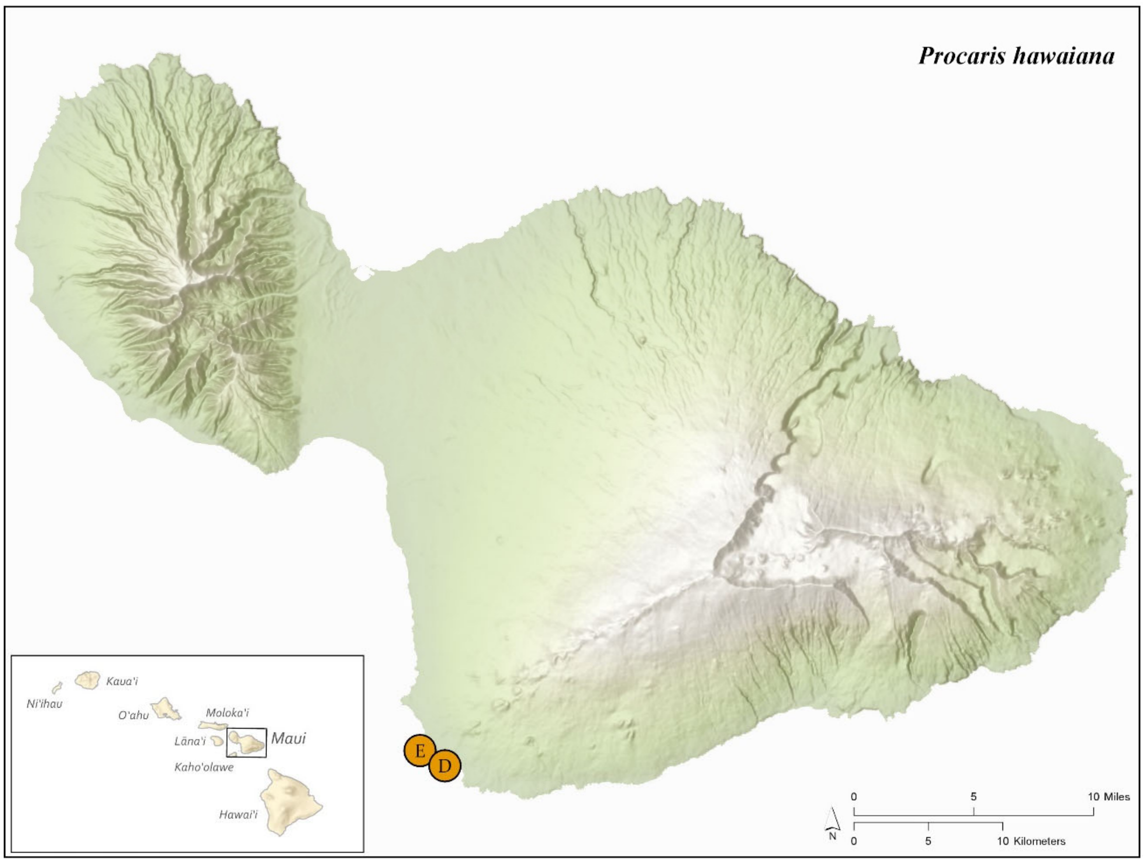

Figure 3. Population units of the anchialine shrimp, *Procaris hawaiana*, on Maui.

SPECIES VIABILITY SUMMARY

Resiliency

Resiliency is the capacity of an individual or population to withstand stochastic disturbance events. We define resiliency for *Procaris hawaiana* based on population size, population growth rate, and habitat quality. As noted previously, accurate population estimates for anchialine pool inhabitants are difficult to determine because of their hypogeal (below ground) lifestyle. Thus, we base population size and growth rate on observed occurrences of *P. hawaiana* in the epigeal (above ground) portion of the habitat.

Procaris hawaiana is most recently known from five sites. The population units consist of three sites on the island of Hawaiʻi and two sites on Maui. The presence of populations on two islands presents a low to moderate level of resiliency. Four out of the five populations do occur on land set aside for conservation purposes: ʻĀhihi-Kinaʻu NAR (State; two populations), Manukā NAR (State), and Kaloko-Honokōhau National Historical Park (Federal) which suggests a medium to high level of resiliency. In addition, because anchialine pools are generally located in the middle of barren lava fields and do not depend on any particular vegetation, threats from environmental stochasticity is relatively low. Potential flooding of the anchialine pools with freshwater may lower the salinity enough to make the pool temporarily uninhabitable but seawater intrusion from tidal fluctuations will likely balance that out quickly. Storm surges may occasionally flood the anchialine pools, inadvertently introducing predatory fish and other predators that may quickly consume *P. hawaiana* (with the exception of Lua O Palahemo because elevation precludes storm surge as a threat). Invasive fish and invertebrate predators have also been documented in at least two out of the five population units and have been demonstrated to not only consume anchialine shrimp but also alter their behavior (Capps et al. 2009, pp. 31–35; Carey et al. 2011, pp. 38–40). Therefore, while the threat from flooding is low, because of the devastating effects that a single predator could do to a single pool either from human or natural introduction, the threat from environmental stochasticity suggests a moderate level of resiliency.

In contrast, the observed population sizes of each site suggests an extremely low level of resiliency; only a few individuals at each site have been observed and all five populations are either stable or declining. Small populations are extremely vulnerable to reduced reproductive success caused by inbreeding depression and loss of genetic variation over time due to random genetic drift, which results in a decreased evolutionary potential and ability to cope with environmental change (Lande 1988, p. 1455). Small populations like these are also demographically vulnerable to extinction caused by random fluctuations in population size and sex ratio (Lande 1988, p. 1455). Thus far, the populations at Manukā on the island of Hawaiʻi and ʻĀhihi-Kinaʻu on Maui appear to be stable but less than 20 individuals have been observed. While *Procaris hawaiana* has been observed as recently as 2016 at Kaloko-Honokōhau, since that time, it has not been spotted again. Thus, this population is at the best stable and at the worst, declining. At Lua O Palahemo, more than 1,000 individuals were once observed by Kensley and Williams (1986, p. 418), but since then only a handful of individuals have been recorded (Wada 2010 in litt., entire; Conry 2012 in litt., entire). The comparatively low observation numbers in recent surveys suggest a declining population. Additionally, Lua O Palahemo is undergoing natural senescence, which means that over time it will be completely unavailable as habitat for any anchialine pool shrimp (Wada 2010 in litt., entire; Brock 2012 pers. comm.). Lua O Palahemo may also not be the only anchialine pool undergoing natural senescence. According to Brock (2004, p. 11), anchialine pools can begin natural senescence as early as 100 years old, after which, these pools typically convert to marsh habitat with sedges and grasses. While the exact ages of the current anchialine pools are not known, given the ages of the most recent lava flows in those areas (ʻĀhihi-Kinaʻu, 1790, Oostdam 1965, p. 393; Lua O Palahemo, 1868, USGS 2002a; Manukā, 1907, USGS 2002b; Kaloko-Honokōhau, 1801, Moore et al. 1987, p. 576) these anchialine pools are estimated to be at least 100 years old. However, radiocarbon dating of the pool itself dates Lua O Palahemo at a minimum age of 11,780 years old (Kelly et al. 1979, p. 314). Based on the age of the most recent lava flows, many of these anchialine pool habitats may already be in varying degrees of senescence and likely lost as suitable habitat for anchialine shrimp in the future. However, based on projections of sea level rise within the next 100 years, more anchialine pool habitat may be created thus expanding the amount of suitable habitat for *P. hawaiana*. In addition, Brock (2004, p. 12) noted that anchialine species appear to be capable of rapidly colonizing new habitats and that the ephemeral nature of the habitat dictates that anchialine species be opportunistic colonizers of habitats that are suboptimal or otherwise unavailable to most other aquatic species.

Based on these findings, we determine that resiliency of *Procaris hawaiana* is <u>low to moderate</u> for the following reasons:

(+) for increased resiliency, (-) for reduced resiliency

1) Only five populations are known (-) but four out of the five populations occur on conservation land (either State or Federal) (+).
2) The populations occur on two different islands (+).
3) Observed occurrences of individuals in each population extremely limited which lead to biological limitations with small population size (-).
4) Each population may be potentially isolated by varying degrees from other sites (-).
5) All populations demonstrate a low risk of extirpation by environmental stochasticity (+).
6) All populations are at risk of extirpation from nonnative species (-).
7) Much of the historically documented habitat has been destroyed (-) and most are likely to undergo natural senescence (-) but sea level rise is likely to create new anchialine pool habitat (+).
8) Anchialine species are often opportunistic colonizers (+).

Procaris hawaiana has <u>low to moderate</u> resiliency.

Redundancy

Redundancy is the ability of *Procaris hawaiana* to withstand catastrophic events and is measured by the presence of multiple, stable to increasing populations distributed across its coastal anchialine pool range on Maui and the island of Hawaiʻi. Each known occupied site is considered a population because of habitat isolation and distance between sites. Some redundancy is provided by the existence of populations on the two islands: two populations on Maui and three populations on the island of Hawaiʻi. However, all populations are located along coastal zones, which are highly vulnerable to a number of threats including the threat of complete extirpation on a single island by a catastrophic event such as a hurricane, tsunami, or volcanic flow. Additionally, all five populations are along the western shores of Maui and the island of Hawaiʻi, which means that a single tsunami or hurricane could devastate the species. Because most anchialine pools are connected to complex network of subterranean corridors, it is possible and highly likely that *P. hawaiana* would be able to retreat to these areas during a catastrophic event. However, it is unknown how long they are able survive and reproduce in that environment without a surface connection. This subterranean network also may provide connectivity between sites and even populations, but these have not been mapped and are therefore unknown. However, even if the populations are connected, the low number of individuals observed and the distance between populations even on a single island suggest that there would be limited encounter rates and therefore limited reproductive success.

Based on these findings, we determine that redundancy of *Procaris hawaiana* is <u>low to moderate</u> for the following reasons:

(+) for increased redundancy, (-) for reduced redundancy

1) There are five populations on two islands (+).
2) They are all on westward facing shores (-).
3) There is likely very little connectivity between populations, especially between Maui and the island of Hawaiʻi (-)

Procaris hawaiana has <u>low to moderate</u> redundancy.

Representation

Representation is the ability of *Procaris hawaiana* to persist and adapt to changing environmental conditions over time. Based on the locations of current population units, good representation would require more than one stable to growing population on both Maui and Hawaiʻi islands in anchialine pools that are well connected, have a salinity of at least 10 ppt, and are free of threats such as development and nonnative plants and animals. However, as previously stated, out of 700 known anchialine pools across the state of Hawaiʻi, *P. hawaiana* is only found in 28 pools with little connectivity between population units. In addition, all five populations on both islands are either stable or potentially declining and it is already estimated that approximately 90% of all anchialine pool habitat has been destroyed (Brock 2004, p. i). While conservation measures are being taken at Kaloko-Honokōhau, Manukā, and ʻĀhihi-Kinaʻu, consistent monitoring and enforcement can be difficult in these remote locations. Thus, population stability and habitat availability suggest low representation. Although genetic diversity also contributes to a species ability to adapt to changing environments, we do not have any genetic information on *P. hawaiana* and therefore cannot make any conclusions on genetic variation. However, genetic exchange between populations is likely limited. Based on the low number of individuals observed at each site and the distance between populations, there is likely limited connectivity between population and therefore little gene flow. Representation of *P. hawaiana* is determined by stable to increasing populations, which embodies the full existing genetic diversity throughout its full coastal anchialine pool range on Maui and the island of Hawaiʻi.

The lack of information on the genetics, development, and reproductive behavior of *Procaris hawaiana* makes this determination difficult. However, based on these findings, we determine that redundancy of *P. hawaiana* is <u>low to moderate</u> for the following reasons:

(+) for increased representation, (-) for reduced representation

1) Populations are at best stable (+) but there is evidence the some populations are on the decline (i.e., Lua O Palahemo) (-). However, as previously stated, it is extremely difficult to estimate population size of anchialine pool shrimp because of their complex habitat.
2) Likely limited genetic exchange due to poor connectivity between the five extant populations, especially between Maui and the island of Hawaiʻi. (-)

Procaris hawaiana representation is <u>low to moderate</u>.

Summary
Procaris hawaiana is currently known from five populations located on two Hawaiian Islands. The populations consist of two sites on Maui and three sites on the island of Hawaiʻi. Resiliency of the populations is considered low to moderate because of limited populations, low observed abundance, historical habitat destruction, and high risk of extirpation from nonnative predators. Likewise, redundancy is considered low to moderate because of the limited number of populations on two islands, low connectivity, and vulnerability of catastrophic events. The representation for this species is also considered low to moderate because despite having five populations on two island, the number of observed individuals has been extremely low and there is likely little, if any, genetic exchange between populations. Therefore, the current viability of *Procaris hawaiana* is low to moderate (Table).

Table. Viability summary of *Procaris hawaiana*, under current conditions.

Species	Resiliency	Redundancy	Representation	Viability
Procaris hawaiana	Low to moderate	Low to moderate	Low to moderate	Low to moderate

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