5-YEAR REVIEW

Short Form Summary

Genus Reviewed: *Achatinella*

41 Species Reviewed: *Achatinella bellula, A. buddii, A. caesia, A. casta, A. cestus, A. curta, A. decora, A. dimorpha, A. elegens, A. judii, A. juncea, A. lehuiensis, A. leucorraphe, A. lorata, A. papyracea, A. phaeozona, A. pulcherrima, A. rosea, A. spaldingi, A. stewartii, A. swifti, A. taeniolata, A. thaanumi, A. turgida, A. valida, A. viridans, A. vittata, A. vulpina, A. abbreviata, A. apexfulva, A. bulimoides, A. byronii/decipiens, A. concavospira, A. fulgens, A. fuscobasis, A. lila, A. livida, A. mustelina, A. pupukanioe, A. sowerbyana*

Current Classification: Endangered

Federal Register Notice announcing initiation of this review:

[USFWS] U.S. Fish and Wildlife Service. 2017. Endangered and threatened wildlife and plants; initiation of 5-year status reviews of 138 Species in Hawai‘i, Oregon, Washington, Montana, and Idaho. Federal Register 82 (75): 18665-18668.

Lead Region/Field Office:

Region 1/Pacific Islands Fish and Wildlife Office (PIFWO), Honolulu, Hawai‘i

Name of Reviewer(s):

Joy Hiromasa Browning, Fish and Wildlife Biologist, PIFWO

Megan Laut, Conservation and Restoration Team Manager, PIFWO

Methodology used to complete this 5-year review:

This review was conducted by staff of the Pacific Islands Fish and Wildlife Office (PIFWO) of the U.S. Fish and Wildlife Service (USFWS), beginning on June 20, 2017. The review was based on a review of current, available information since the publication of the 5-year review for *Achatinella* spp. (Table 1 and 2) (USFWS 2011a-oo) and Amendment to the Recovery Plan for the O‘ahu Tree Snails in the Genus *Achatinella* (USFWS 2019). The document was prepared by Joy Hiromasa Browning, PIFWO Fish and Wildlife Biologist, and was reviewed for PIFWO approval by the Conservation and Restoration Team Manager.

Background:

For information regarding the species listing history and other facts, please refer to the USFWS Environmental Conservation On-line System (ECOS) database for threatened and endangered species (*http://ecos.fws.gov/tess_public*).

Review Analysis:

For a complete review of the species’ status, threats, and management efforts, refer to:

- Amendment to the Recovery Plan for the O‘ahu Tree Snails in the Genus *Achatinella* signed on August 7, 2019 (USFWS 2019), available at https://ecos.fws.gov/docs/recovery_plan/Achatinella_Final_Recovery_Plan_Amendment_20190807.pdf,
- 41 5-year Reviews for the Genus *Achatinella* signed on August 2, 2011 (USFWS 2011a-oo), available at https://ecos.fws.gov/docs/five_year_review/doc3903.pdf, and

- The Recovery Plan for the O‘ahu Tree Snails of the Genus *Achatinella* (Recovery Plan) published on June 20, 1992 (USFWS 1992), available at https://ecos.fws.gov/docs/recovery_plan/920630.pdf).

New status information:
Despite ongoing surveys by the Snail Extinction Prevention Program (SEPP), in the last 20 years, 28 of the 41 listed species have not been observed within their historical range in the wild (Table 1). SEPP continues to survey for those species when they are within their historical ranges (D. Sischo 2019, pers. comm.). At this time, there is no new biological, life history, demographic, or geneitc information pertaining to the species in Table 1 because these species have not been observed in the wild.

New information is available for extant species (Table 2). Research since the last 5-year review (USFWS 2011a-oo) has looked into evaluating food preference, slime trail analysis, and genetic diversity.

Biology and Life History
The listing of the genus *Achatinella* as endangered includes 41 species (Table 1 and 2) from the Wai‘anae and Ko‘olau Mountain Ranges on O‘ahu. All species share common characteristics such as being arboreal, nocturnal, and grazing on fungus from the surface of leaves (USFWS 1992, p. 17). Young are live born, ranging from 3 to 4 millimeters (mm), growing 16.7 to 20.4 mm in length, and live around 11 years (Severns 1981 *in* USFWS 1992, p. 17). One to four young are born to a hermaphroditic adult each year, with reproductive maturity ranging from five to seven years old.

The genus *Achatinella* is a conservation-reliant genus, meaning that the genus will require active management in perpetuity (Scott *et al.* 2005, pp. 383−389; Scott *et al.* 2010, pp. 92−93: Goble *et al.* 2012, pp. 869−872). Protecting forest habitat from alteration, degradation, and destruction from invasive species and ungulates and conducting predator control are identified for the recovery of this species.

Achatinella mustelina (found in the Wai‘anae Mountain Range) is a generalist microbial grazer, whose feeding, movement, and defecation activities may play a role in their microbial environment (Lindow and Brandi 2003; Yadav *et al.* 2005; Iguchi *et al*. 1982, 1985; and Kubota *et al.* 1985 *in* O’Rorke *et al.* 2014, p.8). In contrast, sister species *A. sowerbyana* and *A. lila* (found in the Ko‘olau Mountain Range) showed preference to native host-tree *Metrosideros polymorhpa*, or ‘ōhi‘a, the dominant tree in the forest, and ten other native plants (Price *et al.* 2016, p. 4; Sato et al. 2018, p. 328). Both Price *et al.* (2016) and O’Rorke *et al.* (2014) were not able to complete a gut analysis for *A. mustelina*, *A. sowerbyana*, and *A. lila* due to their endangered status and low numbers of individuals. O’Rorke *et al.* (2014, pp. 2-3) conducted a gut analysis on *Auriculella ambusta*, which is in the same family as *A. mustelina* and showed similar microbes in the gut, leaf, and feces samples while not identifying any microbe only associated with the gut, leaf, or feces. Price *et al.* (2016, p. 6) speculate the microbial differences they found in the feces and leaf samples could be a result of selective ingestion or random ingestion and selective digestion.

Table 1. Twenty-eight species not observed in the last 20 years (< 1999) (USFWS 1992, 2011c, d, g, h, i, k, m, n, o, r, s, t, u, x, z, aa, bb, dd, ff, gg, hh, ii, jj, kk, ll, mm, nn, oo; D. Sischo 2019, pers. comm.; N. Yeung 2019, pers. comm.).

GENUS	SPECIES	YEAR LAST SEEN
Achatinella	*bellula*	1981
Achatinella	*buddii*	Uncommon by 1900
Achatinella	*caesia*	~1990
Achatinella	*casta*	No current info
Achatinella	*cestus*	1966
Achatinella	*curta*	1989
Achatinella	*decora*	Uncommon by 1900
Achatinella	*dimorpha*	1967
Achatinella	*elegens*	1952
Achatinella	*juddii*	1958
Achatinella	*juncea*	No current info
Achatinella	*lehuiensis*	1922
Achatinella	*leucorraphe*	1989
Achatinella	*lorata*	1979
Achatinella	*papyracea*	1945
Achatinella	*phaeozona*	1974
Achatinella	*pulcherrima*	1993
Achatinella	*rosea*	1949
Achatinella	*spaldingi*	1938
Achatinella	*stewartii*	1963
Achatinella	*swiftii*	1970
Achatinella	*taeniolata*	1966
Achatinella	*thaanumi*	Rare since 1900
Achatinella	*turgida*	1974
Achatinella	*valida*	1951
Achatinella	*viridans*	1979
Achatinella	*vittata*	1953
Achatinella	*vulpina*	1965

Slime trail or mucus from mollusks can perform functions such as directional communication, reproduction, and locomotion (Denny 1980, 1989; Viney *et al.* 1993; and Ng *et al.* 2013 *in* Holland *et al.* 2018, p. 1). In rain/cloud forests on O‘ahu, reproduction may be limited due to the number of adult snails present in a tree rather than in a population (Holland *et al.* 2018, p. 1). Adult *Achatinella* spp. have been shown to follow conspecific adult slime trails, while adults will not follow juvenile trails (Holland *et al.* 2018, pp. 6-7). Decreasing the likelihood of finding a mate, Holland *et al.* (2018, pp. 7-8) suggest the chemical strength of slime trails significantly decrease around 24 hours. In addition, increases in precipitation levels wash away slime trails.

Table 2. Species observed in the wild, are present in predator-proof exclosures or in captive propagation (DOFAW 2019, p. 8; U.S. Army 2018, p. 118; D. Sischo 2019, pers. comm.).

GENUS	SPECIES	YEAR LAST SEEN IN THE WILD	Individuals present in:		
			Wild	Captivity	Enclosure
Achatinella	*abbreviata*	2008	Yes	No	No
Achatinella	*apexfulva*[1]	2005	No	No	No
Achatinella	*bulimoides*	2019	Unknown[2]	Yes	No
Achatinella	*byronii/decipiens*[3]	2019	Yes	Yes	No
Achatinella	*concavospira*	2019	Unknown[2]	Yes	Yes
Achatinella	*fulgens*	2019	Unknown[2]	Yes	No
Achatinella	*fuscobasis*	2016	Yes	Yes	No
Achatinella	*lila*	2019	Unknown[2]	Yes	Yes
Achatinella	*livida*	2019	Unknown[2]	Yes	No
Achatinella	*mustelina*	2019	Yes	Yes	Yes
Achatinella	*pupukanioe*	2014	Unknown	No	No
Achatinella	*sowerbyana*	2019	Unknown[2]	Yes	Yes

[1] Last known individuals died in captivity on January1, 2019.

[2] All known wild individuals were collected from the wild and brought into captivity due to extremely low numbers of less than 20 individuals in a population (DOFAW 2017, p. 20) in past 4 years.

[3] Genetic analysis and morphological data show no distinction between the two species. They are managed and reported as one species (DOFAW 2017).

Demographic Trends

Surveys and monitoring of snail populations found in the wild, in predator-proof exclosures, and in captive rearing within the last 20 years (Table 2) are being conducted by SEPP, U.S. Army Natural Resources Program – O‘ahu (OANRP), and other researchers and conservationists (D. Sischo 2019, pers. comm.; U.S. Army 2018, pp. 116-159). Although monitoring of all extant species and efforts to find new populations of those species are occurring, significant declines of some species have occurred in recent years (Hawai‘i Division of Forestry and Wildlife (DOFAW) 2017, pp. 6-7; USFWS 2019, p. 2).

Of the 12 species observed in the last 20 years, *A. apexfulva, A. fuscobasis,* and *A. pupukanioe* were last seen 14, 3, and 4 years ago, respectively (Table 2 and 3). Due to extreme predation pressure, all located individuals of *A. bulimoides*, *A. concavospira, A. fulgens*, *A. lila, A. livida*, and *A. sowerbyana* have been evacuated from the wild between 2017 and 2019 and brought to the SEPP captive rearing facility for eventual reintroduction to the wild (Tables 2, 3, and 4). Due to low detection probability it is likely that individuals remain in the wild at very low abundance. SEPP continues to conduct surveys at the last known sites for these species.

In 2014, seven *Achatinella pupukanioe* were discovered in the wild in the central Ko‘olau Mountains for the first time since the 1980’s. They were still observed in 2015, but when efforts to evacuate the small population for captive propagation in 2016 were conducted, no individuals were found.

Table 3. Snails in the wild and in snail exclosures (U.S. Army 2018, p. 117-152); D. Sischo 2019, pers. comm.). This data should not be interpreted as census records as they were collected as part of monitoring procedures, and at best, could be interpreted as a minimum number of snails present.

GENUS	SPECIES	Number of snails in:	
		Wild No. of Population (No. of Individuals) Year	Snail Exclosures No. of Enclosures (No. of Individuals) Year
Achatinella	*abbreviata*	0	0
Achatinella	*apexfulva*	0	0
Achatinella	*bulimoides*	Unknown[1]	0
Achatinella	*Byronii/decipiens*	4 (243) 2016	0
Achatinella	*concavospira*	Unknown[1]	100
Achatinella	*fulgens*	Unknown[1]	0
Achatinella	*fuscobasis*	0	0
Achatinella	*lila*	Unknown[1]	200
Achatinella	*livida*	Unknown[1]	0
Achatinella	*mustelina*	Approx. 92 (3,608) 2018	4 (1,183) 2018
Achatinella	*pupukanioe*	0	0
Achatinella	*sowerbyana*	1 (5) 2019	50

[1] Although known individuals were removed from the wild and brought into captive rearing, there is still a high likelihood that individuals may still be present in low numbers in the wild.

In 2016, a single live individual of *Achatinella fuscobasis* was observed along a hiking trail in the Southern Koʻolau Mountains. Efforts continue by SEPP to locate snails; however, no live snails have been observed at the site.

Captive rearing continues to play an important role in the preservation of individual species within the genus *Achatinella.* Although a few species remain under 100 individuals, other species, such as *A. lila,* are flourishing at the captive rearing facility (Table 4). The conservation goal is to continue utilizing captive rearing as a tool to propagate species in a predator free environment for the eventual release into a predator-proof enclosure within the historical range of the species.

On January 1, 2019, the last known *A. apexfulva* died in captivity at the approximate age of 14 years old. A small snippet of living tissue was collected in 2017 and was deposited in a deep freezer container at San Diego's Frozen Zoo for future replication and cloning (Hawaiʻi Department of Land and Natural Resources (DLNR) 2019, p. 2).

Throughout the Waiʻanae Mountains, *A. mustelina* is represented in nine Evolutionary Significant Units (ESU). With the exception of two ESU, all ESUs have over 300 individuals in the wild populations (US Army 2018, p. 118). In addition, three ESUs have four exclosures that

have 33, 174, 229 and greater than 700 individuals (US Army 2018, p. 118). Representatives of these ESUs are also in the captive rearing facility (Table 4).

Four species of *Achatinella (A. mustelina, A.concavospira, A lila,* and *A. sowerbyana*) have been translocated from the wild with no predator control into areas with a predator control system (rat grid, temporary enclosure, or permanent enclosure) or from the captive rearing facility into the wild with a permanent predator-proof enclosure (Tables 3 and 4). SEPP and OANRP maintain and monitor exclosures on State and Federal lands. Populations within the predator-proof exclosures have remained stable or are increasing, with all size classes being observed (D. Sischo 2019, pers. comm.).

Table 4. SEPP Captive Rearing Facility – Number of snails in captive propagation and translocations into a secure enclosure (DOFAW 2019, p. 8).

GENUS	SPECIES	In captivity	Total in Captive Propagation	Total Translocated between 2011-2019 (Facility to Enclosure)
Achatinella	*apexfulva*	No (1994-2019)	0	0
Achatinella	*bulimoides*	Yes (2005-present)	47	0
Achatinella	*byronii/decipiens*	Yes (1990 - present)	107	0
Achatinella	*concavospira*	Yes (2018 – present)	271	0
Achatinella	*fulgens*	No (2006 – present)	42	0
Achatinella	*fuscobasis*	Yes (1991 - present)	352	0
Achatinella	*lila*	Yes (1997 - present)	305	200
Achatinella	*livida*	Yes (1997 - present)	19	0
Achatinella	*mustelina*[1]	Yes (1989 - present)	253	52
Achatinella	*sowerbyana*	Yes (1993 - present)	249	0

[1] Several snail enclosure projects included bringing snails at the construction site into the lab prior to construction of the snail exclosures then being released into the enclosure upon completion of the construction, predator eradication, and habitat restoration (USFWS 2012)

Genetics

The genetic viability of some species in the genus *Achatinella* may be at risk due to inbreeding and population bottlenecks. Studies have shown that wild and captive reared populations of some *Achatinella* species have low levels of genetic diversity with evidence of inbreeding depression (Erickson and Hadfield 2014, p. 1209; Price and Hadfield 2014, pp. 11-16). A recent study on the captive population of *A. fuscobasis* lead to the discovery that a bottleneck likely occurred in the wild prior to the founding of the *ex situ* population (Sischo *et al.* 2016, p. 133). The continued population declines observed across extant *Achatinella* species could decrease genetic diversity, jeopardizing their adaptive potential. (DOFAW 2017, p. 31). Currently, the complete mitochondrial genome for *A. mustelina*, *A. fulgens,* and *A. sowerbyana* has been sequenced (Price *et al.* 2016, pp. 1-2; Price *et al*. 2018, pp. 1-2).

New threats:
Research and observations since the last 5-year review (USFWS 2011a-oo) have provided new information to currently known or potential threats, changing the extent or scope of those threats to extant *Achatinella* spp.

Factor A. The present or threatened destruction, modification or curtailment of its habitat or range
Ungulates and non-native plant species continue to be a threat to the wet and mesic forests. habitat of the *Achatinella* species. The 5-year review by USFWS (2011) gives detailed information on these threats.

Rapid ʻŌhiʻa Death (ROD) is a new threat to *A. sowerbyana*, *A. lila*, and other species that utilize *M. polymorpha* or ʻōhiʻa trees. ʻŌhiʻa is the dominant tree in the Koʻolau forests and the preferred host-tree of these two species. Currently, two fungal pathogens (*Ceratocystis huliohia* (ROD Canker disease) and *C. lukuohia* (ROD wilt disease) occur in Hawaiʻi and ultimately lead to the mortality of *M. polymorpha* (USFWS 2019, p.1). First observed on the island of Hawaiʻi in 2014, both pathogens are now present on Kauaʻi (2018), with confirmed infections of *C. huliohia* found on Maui and Oʻahu (University of Hawaii Center College of Tropical Agriculture and Human Resources (UH CTAHR) 2019a). Wounds caused by cutting, pruning, sawing, breakage, strong winds, root abrasion, weed-whacking, lawn-mowing, rubbing by ungulates, and root trampling create openings for the pathogens to enter the tree (UH CTAHR 2019c). Researchers from the University of Hawaiʻi, U.S. Department of Agriculture Research Station (USDA), and the U.S. Forest Service (USFS) are studying these pathogens (UH CTAHR 2019b.) and providing the latest information at <https://cms.ctahr.hawaii.edu/rod/>.

Preliminary climate change analysis indicates a severe reduction in habitat for the genus *Achatinella* in the future (2050 and 2100) and is related to a decrease in precipitation (USFWS 2019, pp. 2-3; A. Vorsino 2019, pers. comm.). Further analysis is needed to provide more precision on the impacts to the habitat for this genus.

Factor B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes
No new information exists since the most recent 5-year review (USFWS 2011a-oo). See synthesis below.

Factor C. Disease or Predation
All threats identified in this section apply to the listed genus *Achatinella* (Tables 1 and 2).

Predation - Rats (*Rattus exulans*, *Rattus rattus*, and *Rattus norvegicus*)
Rats continue to threaten *Achatinella* sp. populations. Rat control is being conducted by SEPP and OANRP. No new information on this threat exists since the most recent 5-year review (USFWS 2011a-oo).

Predation – Rosy wolf snail (*Euglandina rosea*)
Predation from the rosy wolf snail (*Euglandina rosea)* continue to threaten the genus *Achatinella*, (USFWS 1992; Hadfield *et al*. 1993; Hadfield and Saufler 2009). SEPP noticed

"catastrophic declines in wild tree-snail populations across the island, associated with *E. rosea* presence." (DOFAW 2019, p. 4). *E. rosea* has been shown to prefer endemic snails over non-native snails and slugs (Meyer and Cowie 2010, p. 140; Holland, *et al.* 2012, p. 155) and consume prey up to three times their size (Sugiura, *et al*. 2011, p. 101). Meyer and Cowie (2010, pp. 141-142) state that consumption rate of prey is related to the size of the predator. This increases the vulnerability of smaller *Achatinella* spp. since adult *E. rosea* prefer small snails, consuming it whole and increasing the number of prey it consumes (Meyer and Cowie 2010, p. 141-142). All newly hatched juveniles of *Achatinella* are at risk of being preyed upon by *E. rosea* (Meyer and Cowie 2010, p. 141; Cook 2013, p. 10) which will bite exposed soft parts then insert its head into the prey's shell (Sugiura, *et al.* 2011, p. 101), leaving the shell clean and undamaged (USFWS 2011a-oo).

Meyer and Cowie (2011, p. 325) observed that *E. rosea* can be found climbing trees, although they prefer cool, moist leaf litter habitat over open, fern/shrub or woody surfaces. This increases the vulnerability of arboreal *Achatinella* species since slime trails are easier to track on vegetation than on leaf litter. Consumption rates decreases as leaf litter increases (Gerlach 1999 *in* Meyer and Cowie 2011, p. 331). *E. rosea* can also follow prey slime trails with directionality (Davis-Berg 2011, p. 7). Cool, moist leaf litter habitat serve as corridors between warmer, drier mountain ridges or plains (Meyer and Cowie 2011, p. 329).

Meyer *et al.* (2017, pp. 1300-1405) conducted genetic and morphometric analyses which discovered that two *E. rosea* species are present in Hawai'i and possibly other areas in the Pacific. More than 600 individuals were bred by the Hawai'i Department of Agriculture for a biocontrol effort on *Lissachatina fulica* and released on O'ahu between 1955-1956 (Davis and Butler 1964 *in* Meyer *et al.* 2017, p. 1400). *Euglandina* individuals were later collected from O'ahu for release in other biocontrol efforts throughout the tropical region (Davis and Butler 1964; Gerlach 1999; Bieler and Slapcinsky 2000; Auffenburg and Stange 2001 *in* Meyer *et al.* 2017, p. 1400). In the initial 1950's collections made in Leesburg, Florida may have overlooked morphometric differences, attributing them to intraspecific variations (Pillsbury 1946 *in* Meyer *et al.* 2017, p. 1403). What has historically known as *E. rosea* may actually be ten distinct lineages with two being present in Hawai'i (Meyer *et al.* 2017, p. 1402). Biological differences between the two clades may pose impacts to *Achatinella* as one species may be more voracious, have a larger range, or breed quicker. Preliminary studies suggests one species may be more adept at overcoming predator barriers on snail exclosures (N. Yeung 2019a, pers. comm.).

Predation – Jackson's chameleon
Jackson's chameleons (*Trioceros jacksonii xantholophus*) are known to inhabit humid and wet montane (about 900 meters (m) to 2,800 m elevation) habitats in Kenya and Tanzania, with temperatures ranging between 5° to 30° C (Eason *et al* 1998; and Nečas 1999 *in* Kraus *et al.* 2012, p. 579; Chiaverano and Holland 2014, pp. 115 – 116). Nečas (1999 *in* Kraus *et al.* 2012, pp. 579-580) found that brood gestation period is six to seven months with live births of seven to fifty one young per brood. Females are ready to mate 20 days after giving birth and can be sexually mature at nine months.

Jackson's chameleons arrived in Hawai'i in the early 1970's and established populations throughout the state by the mid 1990's with the possible exception of Kaua'i (McKeown 1996 *in*

Kraus *et al.* 2012, p. 580; Holland *et al.* 2010, p. 1437; Chiaverano and Holland 2014, p. 116). Populations are found in residential areas, alien lowland forests, and native dry, mesic, and wet forests (Kraus *et al.* 2012, p. 584). Suitable habitat in Hawai‘i for populations of Jackson’s chameleons include continuous forest habitat, with relatively high floral composition, canopy cover, and precipitation (Rödder *et al.* 2011 *in* Chiaverano *et al.* 2014, p. 472).

Intraspecific species competition and availability of resources in the habitat may influence habitat partitioning and the distance and time Jackson’s chameleons spend foraging (Chiaverano *et al* 2014, p. 476; Van Kleek *et al.* 2018, p. 2). In suitable habitats, adult Jackson’s chameleons have home ranges between 400-450 meter² (m) and primarily occupied the canopy 4 to 4.5 m off the ground in silk oak (*Grevillea robustas*) and other tall tree species (Van Kleek *et al.* 2018, p. 9). In comparison, juveniles have home ranges of around 250 m² and are found closer to the ground at about 2.5 m on different plants including guinea grass (*Megathyrsus maximus*), koa haole (*Leucaena leucocephala*), and strawberry guava (*Psidium* sp.) (Van Kleek *et al.* 2018, p. 9).

In suitable habitats, adults are territorial, moving farther, and have larger home ranges than juveniles, which they defend, potentially playing a role in juvenile movement to the edges of the population range or perch closer to the ground to avoid negative interactions with adults (Van Kleek *et al.* 2018, pp. 9, 12). In unsuitable habitats, regardless of sex, adults are less territorial and have overlapping or shared territories, possibly due to the lack of resources (Chiaverano *et al.* 2014, p. 477). Once home ranges are established Jackson’s chameleons are not found to change the size or location of their home range (Chiaverano *et al.* 2014, p. 477).

Habitat partitioning of adults in the canopy and younger chameleons on perches near the ground may be a result of younger chameleons learning and developing their tongue strike behavior on prey (Van Kleek *et al.* 2018, pp. 9, 13). Gut content analysis by Van Kleek *et al.* (2018, p. 13) found insects associated with the canopy such as flies (Diptera) in adults, and insects associated with leaf litter or on the trunks of trees such as moth larvae (Lepidoptera) and millipedes (Diplopoda) in juveniles. Jackson’s chameleons primarily consume active prey but have been shown to consume inactive mollusk prey (Holland *et al.* 2010, pp. 1437-1443; Kraus *et al.* 2012, p. 590).

On O‘ahu, Jackson’s chameleons are in the Wai‘anae and Ko‘olau Mountain Ranges (Holland, *et al.* 2010, pp.1437-1441; USFWS 2011a-oo; Van Kleek *et al.* 2018, p. 2) and found in pristine native and non-native forests (Kraus *et al.* 2012, pp. 579-593). The first documented predation of a species in the genus *Achatinella* was by Holland *et al.* (2010, p. 1438). They examined the gut contents of wild caught Jackson’s chameleons from O‘ahu and found intact shell remains of *Achatinella mustelina*, *Auriculella* sp., *Lamellidea* sp., and *Philonesia* sp. Based on a study by Chiaverano and Holland (2014, p. 121), the shells Holland *et al.* (2010) found could have been consumed one to three days prior to examination. They have also concluded that well feed Jackson’s chameleons can pass (defecate) fairly intact shells through their digestive system in about five days, while individuals in areas lacking in food resources may completely digest shells in approximately eight days.

At Pu‘u Hapapa on O‘ahu where *A. mustelina* is present, Chiaverano and Holland (2014, p. 121) estimate one chameleon per every 44 m² or 45 chameleons per 2000 m². They assume 45 Jackson’s chameleons are consuming about eight snails every three to four days. Further extrapolation of the previous scenario, in one year, consumption of 730 to 974 snails is expected. Consumption rate can vary depending on snail density as one Jackson’s chameleon in Chiaverano and Holland’s (2014, p. 121) study had five snails in various stages of digestion, ingesting *A. mustelina* in three consecutive days.

As the population continues to grow, Jackson’s chameleons’ range will expand into unoccupied areas, with the exception of areas that are too cold or too wet (Kraus *et al.* 2012, p. 589). Human-mediated transport and release will also assist in range expansion as well (Chiaverano *et al.* 2014, p. 477). Aside from manual removal from the wild, there are currently no other available control methods (Chiaverano *et al.* 2014, p. 477).

Predation – Platydemus manokwari
Predation on all *Achatinella* spp. by *Platydemus manokwari* has not been observed. However, *P. manokwari* has been confirmed at low elevations on O‘ahu, Maui, and the island of Hawai‘i (N. Yeung 2019b, pers. comm.).

Predation – Oxychilus alliarius
Predation from *Oxychilus alliarius* (garlic snail) continues to be a potential threat to *Achatinella* spp. (Curry and Yeung 2013, p. 3166). *O. alliarius* is abundant and widespread in Hawai‘i, living in the leaf litter and has been observed climbing vegetation nearly two meters off the ground (Barker 1999 *in* Curry and Yeung 2013, p. 3166; Curry and Yeung 2013, p. 3168). In a study by Meyer and Cowie (2010, p. 141) *O. alliarius* did not consume snails with a shell length of more than 3 mm. However, Curry and Yeung (2013, p. 3168) observed *O. alliarius* killing a *Pleuropoma* cf. s*andwichiensis* (4 mm shell diameter) and *Kaala subrutila* (10 mm shell diameter). Currently *O. alliarius* is found throughout the Wai‘anae and Ko‘olau Mountain Ranges in areas with *Achatinella* spp. (Curry and Yeung 2013, p. 3168; D. Sischo 2019, pers. comm.).

Predation - Gonaxis kibwexiensis and *Geoplana septemlineata.*
Although no observations of terrestrial flatworms and the terrestrial snail, *Geoplana septemlineata,* have been reported in areas with *Achatinella* spp. they continue to be a possible potential threat to this genus.

Disease – Unknown Cause
In the fall of 2018, eighty-nine *A. mustelina* of all age classes died in their captive rearing cages (DOFAW 2019, pp. 3-4). Necropsies conducted on two specimens by U.S. Geological Survey’s (USGS) Wildlife Pathology Lab in Honolulu, Hawai‘i, were inconclusive, but hint at viral pathogen or poisoning (DOFAW 2019, p. 3). The captive rearing facility implemented their quarantine protocol, actions prior to the mortality event were reviewed to identify potential causes, and the mortality ceased after several months. The exact cause of mortality is still unknown however, the cause is linked to a bag of vegetation that was brought as part of the husbandry program. Little is known regarding the impacts of pathogens and parasites on

populations of *Achatinella*. However, they may pose a serious threat to both wild and captive populations. (DOFAW 2019, pp. 3-4).

Factor D. The Inadequacy of Existing Regulatory Mechanism

Jackson's chameleon (*Trioceros jacksonii xantholophus*) was legally imported into the state of Hawai'i in the early 1970's, when it was not considered a threat to native Hawaiian ecosystems. Established populations could be found on all islands by the 1990's with the possible exception of Kaua'i (McKeown 1996 *in* Kraus *et al.* 2012, p. 580; Holland *et al.* 2010, p. 1437; Chiaverano and Holland 2014, p. 116). The spread of this species is partly due to pet hobbyists finding it challenging to keep this species in captivity and releasing them in the wild (Chiaverano and Holland 2014, p. 122). In addition, there was reported attempt to establish a naturalized population in Hawai'i to export in the pet trade (Kraus *et al.* 2012, p. 580; Chiaverano and Holland 2014, p. 116). Legal importation of Jackson's chameleons was prohibited in 1973 by the Hawai'i Board of Agriculture when it was removed from the list of organisms approved for importation into Hawai'i (Kraus *et al.* 2012, p. 580). Between 1991 and 1998, Hawai'i Administrative Rules (HAR) Chapter 4-71 (September 19, 1991) and its amendments (February 21, 1992 and March 2, 1998 (HAR Chapters 13-124)) placed Jackson's chameleons on a the List of Restricted Animals prohibiting the import and export and transporting between the islands but allowing for possession and sale of locally obtained animals (Kraus *et al,* 2012, pp. 580-581; Chiaverano and Holland 2014, p. 116). Legally, Jackson's chameleons continue to be sold in pet stores (Holland *et al.* 2010, p. 1439) but without prosecution due to the lack of enforcement, they are being illegally released into the wild when care for the animal becomes overwhelming (Kraus *et al.* 2012, p. 580; Chiaverano and Holland 2014, p. 116). Chiaverano *et al.* (2014, p. 477) suggests that establishment of patchy populations of Jackson's chameleons in the Wai'anae and Ko'olau Mountain Ranges are due to human-mediated transport and release.

Factor E. Other Natural or Manmade Factors Affecting Their Continued Existence

Tropical cyclone intensity and frequency

Early theoretical and numerical models support an increase in tropical cyclone frequency and intensity in a warmer world, including the central Pacific (after 2040) (Murakami *et al.* 2013, p. 749; Kossin *et al.* 2013, Bindoff *et al.* 2013, Camargo 2013, Christensen *et al.* 2013, Knutson *et al.* 2015, Walsh *et al.* 2015, *in* Kossin *et al.* 2017, p. 258). Since these models are primarily based on uncertain sea surface temperature patterns, Murakami *et* al. (2013) suggests cyclones originating in the southeast of the Hawaiian islands track more in a northwestward direction towards the Hawaiian Islands. They also suggest an increase in the frequency of tropical cyclones originating near the Hawaiian Islands. Impacts from a tropical cyclone can degrade, damage, and destroy *Achtinella* spp. habitat and the SEPP captive rearing facility (DOFAW 2019, p. 3; Murakami *et al*. 2013, p. 749).

Resiliency and redundancy to stochastic events

The collective and individual effects of all threats to the genus *Achatinella*, including negative impacts from predators and potential impacts to habitat, can affect the resilience and redundancy of this species within the foreseeable future. In long-lived, late maturing species with low fecundity like the *Achatinella* spp. (Price and Hadfield 2014, p. 2) effects of low reproductive success may not be immediately evident, as aging populations can remain apparently stable for

many years (Holmes and York 2003, p. 1795; Miles *et al.* 2015, p. 1). Additional pressure from predators can significantly decrease the resilience and redundancy of this genus.

New management:
Ongoing and planned management actions will benefit the genus *Achatinella* by mitigating predation. These include:

Snail Extinction Prevention Program (SEPP)
This program was created in 2012 by the Hawai‘i Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) and PIFWO. The mission of SEPP is to:

> "Prevent the extinction of rare land snail species in all families and preserve the ecosystems in which these species and their local assemblages depend on throughout the Hawaiian Islands."

This will be accomplished by following these objectives:
- Preventing the imminent extinction and local extirpation of imperiled land snail species
- Integrate *ex situ* captive rearing and *in situ* management
- Sync rare snail conservation objectives and management techniques across entities and islands.

In 2014, SEPP's strategic plan for 2015-2019 was a guide, not only for their actions but to communicate their ideas and timelines with other conservation partners, and to encourage discussion and combine funds and staffing to accomplish their mission. SEPP conducts surveys and monitors known snail populations, conducts predator control, assists in the design and upgrades of temporary and permanent predator-proof snail exclosures, and runs the captive propagation lab, which is a primary tool in preventing the extinction of many of the species listed in Table 4. In addition, SEPP provides technical assistance to managers of private lands and businesses and other State and Federal agencies.

Snail Exclosures
Predator-proof exclosures are currently the most effective conservation tool to protect snail populations in the wild. There are currently eight exclosures, six in the Wai‘iane and two (one under construction) in the Ko‘olau Mountain Ranges. One exclosure in the Waiane Mountain Range has been rebuilt, expanding the original footprint and incorporating the newer predator barriers that the old exclosure did not have. OANRP and SEPP have plans to construct additional exclosures in both the Wai‘iane and Ko‘olau Mountain Ranges. The goal is to have at least one representative population of all extant *Achatinella* sp. protected inside an exclosure (DOFAW 2017, p. 25).

New and ongoing research:
- Assisting SEPP with genetic and morphologic identification of *Achatinella* species currently in captive propagation (N. Yueng 2019c, pers. comm.).
- Assessing the systematics of Achatinellidae and relationships within all Hawaiian subfamilies including the Achatinellidae (N. Yueng 2019c, pers. comm.).
- Surveying and monitoring of *E. rosea* distribution (N. Yueng 2019c, pers. comm.).

- Designing predator exclusionary devices that will keep out all *E. rosea* sp.

Synthesis:
Downlisting criteria set forth in a recovery plan are intended to serve as objective, measurable guidelines to assist us in determining when an endangered species has recovered to the point that it is appropriately classified as threatened. However, the actual downlisting process is not solely dependent on achieving the downlisting criteria; it is achieved through the formal rulemaking process based upon a five-factor analysis (per section 4(a)(1) of the Endangered Species Act [Act]) in conjunction with an analysis of the recovery criteria, that results in a determination that the threats to the listed entity have been sufficiently controlled or eliminated such that downlisting is warranted.

The downlisting criteria in the amended recovery plan (USFWS 2019) represents our best assessment, at the time the plan was prepared, of the conditions that would most likely result in a determination that the genus *Achatinella* should be listed under the Act as threatened rather than endangered. As summarized in Table 5, the downlisting criteria have not yet been met.

Below we evaluate the current and anticipated threats to the species under the five listing factors.

The threats identified in the recovery plan (USFWS 1992), most recent 5-year review (USFWS 2011a-oo), and amended recovery plan (USFWS 2019) are ongoing and increasing (Table 7). The main threats to the genus *Achatinella* continue to be the loss and degradation of habitat, including invasion of non-native plants and a changing climate (Factor A: the present or threatened destruction, modification, or curtailment of habitat or range) and predation by a variety of introduced mammalian and invertebrate species (Factor C: Disease or Predation). Other threats that continue to impact the genus *Achatinella* are enforcement and prosecution of regulations (Factor D: The inadequacy of existing regulatory mechanisms) and the predicted increase in tropical cyclone intensity and frequency (Factor E: Other natural or manmade factors affecting their continued existence).

A new threat to habitat loss and degradation is from ROD, which causes drastic altering of native forests dominated by ʻōhiʻa trees. First found on the island of Hawaiʻi in 2014, this tree killer was confirmed on Oʻahu in 2019 (UH CTAHR 2019a; D. Sischo 2019, pers. comm.). Continued presence of ungulates in the wet forests on Oʻahu increases the potential for this disease to spread through the wet forests on Oʻahu. ʻŌhiʻa is the preferred-host-tree for *A. sowerbyana* and *lila.* Currently, *A. sowerbyana* has declined significantly in the wild to almost undetectable levels at all populations in the wild, an estimated 50 individuals are currently in an enclosure and 249 in captivity (Table 3 and 4). *A. lila* may persist in low numbers in the wild. Sharp declines in the number of populations resulted in SEPP collecting all individuals of *A. lila* in the wild and rearing them in captivity (Table 3). Currently, there are 305 *A. lila* individuals in captivity and 200 individuals released into an enclosure with ʻōhiʻa trees (Table 4). Presently, ROD has not altered the species composition or structure of the native rain/cloud forests on Oʻahu, but the confirmed presence of ROD on Oʻahu is a significant threat to the habitat of *Achatinella* spp.

Habitat loss and degradation due to the changing climate is currently unknown, but preliminary research suggest significant range reductions are possible for some species of *Achatinella*.

However, a dryer and hotter environment with an increase in tropical cyclones is anticipated (Kossin *et al.* 2013, Bindoff *et al.* 2013, Camargo 2013, Christensen *et al.* 2013, Knutson *et al.* 2015, Walsh *et al.* 2015, *in* Kossin *et al.* 2017, p. 258; USFWS 2019, pp. 2-3).

New research on the genetics, morphology, biology, and niche requirements of *E. rosea* and Jackson's chameleons identified characteristics of both species that significantly increases the understanding of their efficiency and range as a predator (Meyer and Cowie 2010, p. 140; Holland *et al*. 2012, p. 155; Davis-Berg 2011, p. 7; Holland *et al*. 2010, pp. 1437-1443; Kraus *et al.* 2012, p. 590; Van Kleek *et al*. 2018, pp. 9, 12). Predation pressure also continues from rats, with control measures being implemented in and around known snail populations in the wild. Although predation by terrestrial flatworms and other carnivorous snails on *Achatinella* sp. in Hawai‘i has not been observed, but they continue to pose a constant threat (D. Sischo 2019, pers. comm.; N. Yeung 2019b, pers. comm.).

Disease plays an unknown level of threat to the genus *Achatinella.* It is a constant concern for populations in captivity especially because those populations can represent the last remaining individuals of a species. SEPP's captive rearing facility quarantine protocols and partnership with USGS' Wildlife Pathology Lab are measures currently in place to minimize the impact of disease and attempt to identify the cause of mortality.

Range expansion of Jackson's chameleons is partially due to human transport (Chiaverano *et al.* 2014, p. 477). In 2010, Jackson's chameleons could legally be purchased from pet stores on O‘ahu (Holland *et al.* 2010, p. 1439). However, care for this species can be difficult and without enforcement of current regulations, illegal releases into the wild continue to occur (Kraus *et al*. 2012, p. 580; Chiaverano and Holland 2014, p. 116).

In addition to predator control, management of remaining individuals and populations of species in the genus *Achatinella* focuses on diet analysis and managing small populations. Successful captive rearing requires knowledge on diet preference and genetic mixing. Diet analysis of *A. mustelina*, *A. sowerbyana*, and *A. lila* highlights the microbial differences between species in the genus *Achatinella* (O'Rorke *et al.* 2014; Price *et al.* 2016). Accurate cultivation of microbial preferences by species, allows for manufacturing of food while eliminating potential disease or poisons being introduced when providing fresh foliage (DOFAW 2017, p. 32; DOFAW 2019, pp. 3-4).

Inbreeding and genetic bottlenecks occurred in some wild *Achatinella* spp. populations prior to collecting founders for the *ex situ* population (Sischo *et al.* 2016, p. 133). As the number of individuals and populations in a species significantly decline, reevaluation of keeping populations separate to maintain genetic diversity is warranted. Even with small numbers of individuals and populations, SEPP is attempting to create redundancies by having snails in exclosures and in the wild (Tables 3 and 4). However, both captive rearing and the exclosures are still susceptible to damage during stochastic events (DOFAW 2019, p.3).

The genus continues to be vulnerable to loss and degradation of habitat, predation, and is not resilient nor are there redundancies in the face of stochastic events. Thus, the genus *Acatinella* continues to meet the definition of endangered.

Recommendations for Future Actions:
The recovery strategy for the genus *Achatinella* centers on habitat protection and management, predator control, and studying the impacts from climate change on all the main Hawaiian islands.

- Assessing the systematics of Achatinellidae and relationships within all Hawaiian subfamilies include the Achatinellinae.
- Research on snail diseases as this can have a large impact in captive rearing (D. Sischo 2019, pers. comm.).
- Rosy wolf snail
    - Survey and monitor distribution of rosy wolf snail.
    - Identify biology, life history, ecology of the rosy wolf snail.
    - Identify control and exclusion techniques.
    - Gene drive research
- Jackson's chameleon
    - Identifying the fundamental-niche requirements to predict areas that are susceptible to colonization by natural migration or if limitations are overcome by human-facilitated releases (Soberón and Peterson 2005 *in* Kraus *et al.* 2012, p. 586).
    - Identifying intraspecific interactions as Jackson's chameleon niche expands (Van Kleek *et al.* 2018, p. 14).
    - Identify the geographic distribution and population density of Jackson's chameleons in the Waiʻanae and Koʻolau Mountain Ranges with particular interest in areas where there are wild populations of *Achatinella* or within habitats similar to where snails are known from (Kraus *et al.* 2012, p. 590; Chiaverano and Holland 2014, p. 121).
    - Quantify the predation pressure Jackson's chameleons exert (Kraus *et al.* 2012, p. 590) on *Achatinella* spp.
- Diet
    - Research and manufacture an appropriate diet for captive rearing to expand breeding options (D. Sischo 2019, pers. comm.)
    - Study the effects of abrupt diet changes on the immediate health and long-term fitness (O'Rorke *et al.* 2016, p. 8) of all extant *Achatinella* spp.
    - Study the role of snails in structuring their microbial environment (O'Rorke *et al.* 2016, p. 8).
    - Study microbial habitats specific to *Achatinella* spp. where snails are still present in the wild.
    - Identify the need to incorporate microbial habitat manipulation into *Achatinella* spp. release plans.
- Climate Change
    - Identify locations in both the Waiʻanae and Koʻolau Mountain Ranges that may sustain populations of *Achatinella* spp. within their historical ranges as weather patterns change.
    - Design and construct predator-proof enclosures to protect habitat and snails from habitat degradation and predation as the climate changes.

Table 5. Status and trends of genus *Achatinella* from listing through current 5-year review.

Date	No. wild individuals	Downlisting Criteria	Downlisting Criteria Completed?
1981 (listing)		None established yet	N/A
1992 (recovery plan)	See Table 6.	No downlisting goal established but downlisting may be considered once all remaining populations have been located and stabilized.	No
2011 (5-year review)	See Table 6.	No downlisting goal established but downlisting may be considered once all remaining populations have been located and stabilized.	No change from 1992
2019 (recovery plan amendment)	See Table 3 & 4.	At least 6 to 10 stable populations (possibly actively managed) are distributed across the known historical range of the species. Also, each ESU of the species (or each GU if ESUs have not been identified) must be represented by one or more stable populations; thus any species for which more than six GUs or ESUs are identified will require more than six stable populations to represent every GU or ESU.	No
		To be considered stable, a population must number at least 300 individuals distributed across all size classes combined, and must have a population growth curve that is stable or positive for at least 4 of 5 sequential years.	No

Date	No. wild individuals	Downlisting Criteria	Downlisting Criteria Completed?
2019 (5-year review)	See Table 3 & 4.	At least 6 to 10 stable populations (possibly actively managed) are distributed across the known historical range of the species. Also, each ESU of the species (or each GU if ESUs have not been identified) must be represented by one or more stable populations; thus any species for which more than six GUs or ESUs are identified will require more than six stable populations to represent every GU or ESU.	No
		To be considered stable, a population much number at least 300 individuals distributed across all size classes combined, and must have a population growth curve that is stable or positive for at least 4 of 5 sequential years.	No

Table 6. Number of wild individuals from 1992-2011 (Hadfield 2011, p. 6; U.S. Army 2011).

		1981	1992	2011 Individuals present in:		
GENUS	SPECIES	No. Wild individuals	No. Wild individuals	Wild	Captivity	Enclosure
Achatinella	*abbreviata*	unknown	unknown	0	2	0
Achatinella	*apexfulva*	unknown	unknown	0	0	0
Achatinella	*bulimoides*	unknown	unknown	2	27	0
Achatinella	*byronii*[1]	unknown	unknown	3	--	0
Achatinella	*concavospira*	unknown	unknown	47	0	0
Achatinella	*decipiens*[1]	unknown	unknown	7	4	0
Achatinella	*fulgens*	unknown	unknown	14	12	0
Achatinella	*fuscobasis*	unknown	unknown	2	203	0
Achatinella	*lila*	unknown	unknown	22	504	0
Achatinella	*livida*	unknown	unknown	103	53	0
Achatinella	*mustelina*	unknown	unknown	2,752	326	50
Achatinella	*pupukanioe*	unknown	unknown	0	0	0
Achatinella	*sowerbyana*	unknown	unknown	21	13	0

Table 7. Status of threats to the genus *Achatinella* from listing through current 5-year review.

Threat	Listing factor	Current Status	Conservation/ Management Efforts
Habitat degradation, alteration, and destruction	A	Ongoing	ESA section 7 consultations and Partners programs assist to decrease loss and degradation of *Achatinella* forest habitat.
Collection	B	Still remains a threat	
Predators	C	Increasing	Installation of predator-proof fences, improving predator control programs, survey and monitoring, and research.
Disease	C	Ongoing	Monitoring and implementing avian disease response plans when available.
Tropical cyclone intensity and frequency	E	Increasing	Research
Temperature and precipitation changes	E	Increasing	Research
Resiliency and redundancy to stochastic events	E	Ongoing	Captive rearing

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PERSONAL COMMUNICATIONS

Sischo, D. 2019. Telephone communication regarding SEPP Activities, Management and

Vorsino, A, 2019 Email communications regarding climate change modeling in relation *Achatinella*.

Yeung, N. 2019a. Email communication regarding *Euglandina rosea* species complex

Yeung, N. 2019b. Email communication regarding Occurrence of *Platydemus manokwari* on O‘ahu or in Hawai‘i.

Yeung, N. 2019b. Email communication regarding Research pertaining to *Achatinella* (Biological, life history, predations, diet, genetics, etc.)

U.S. FISH AND WILDLIFE SERVICE
SIGNATURE PAGE for 5-YEAR REVIEW of the Genus *Achatinella*

Pre-1992 DPS listing still considered a listable entity? __N/A_____

Recommendation resulting from the 5-year review:

___Delisting
__Reclassify from Endangered to Threatened status
___Reclassify from Threatened to Endangered status
_x_No Change in listing status

PACIFIC ISLANDS FISH AND WILDLIFE OFFICE APPROVAL:

for MEGAN LAUT Digitally signed by MEGAN LAUT Date: 2019.09.27 15:26:53 -10'00' Date _____

Field Supervisor