Partulina variabilis
(Lānaʻi tree snail)

5-Year Review
Summary and Evaluation

U.S. Fish and Wildlife Service
Pacific Islands Fish and Wildlife Office
Honolulu, Hawaiʻi

5-YEAR REVIEW

Species reviewed: *Partulina variabilis* (Lānaʻi tree snail)

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1.0 GENERAL INFORMATION

1.1 Reviewers:

Diane Sether, Ph.D., Invertebrate and Wildlife Biologist, Pacific Islands Fish and Wildlife Office (PIFWO)
John Vetter, Animal Recovery Coordinator, PIFWO
Megan Laut, Conservation and Restoration Team Manager, PIFWO

Lead Regional Office:
Interior Region 12, Portland Regional Office

Lead Field Office:

Cooperating Field Office(s):
N/A

Cooperating Regional Office(s):
N/A

1.2 Methodology used to complete the review:

This review was conducted by staff of the Pacific Islands Fish and Wildlife Office of the U.S. Fish and Wildlife Service (Service), beginning in October 2019. The review was based on the final rule listing this species; the final critical habitat designation; peer reviewed scientific publications; unpublished field observations by the Service, State of Hawaiʻi, and other experienced biologists; unpublished survey reports; notes and communications from other qualified biologists; as well as a review of current, available information. The evaluation completed by Diane Sether, Ph.D., Invertebrate and Wildlife Biologist, was reviewed by John Vetter, Animal Recovery Coordinator, and Megan Laut, Conservation and Restoration Team Manager.

1.3 Background:

1.3.1 FR Notice citation announcing initiation of this review:

[USFWS] U.S. Fish and Wildlife Service. 2018. Endangered and threatened wildlife and plants; initiation of 5-year status reviews for 156 species in Oregon, Washington, Hawaii, Palau, Guam, and the Northern Mariana Islands. Federal Register 88(83): 20088–20092, May 7, 2018.

1.3.2 Listing history:

Original Listing
FR notice: [USFWS] U.S. Fish and Wildlife Service. 2013. Endangered and threatened wildlife and plants; determination of endangered status for 38 species

on Molokai, Lanai, and Maui; final rule. Department of the Interior, Federal Register 78: 32014-32065, May 28, 2013.

Date listed: May 28, 2013
Entity listed: *Partulina variabilis*
Classification: Endangered

Revised Listing, if applicable
FR notice: N/A
Date listed: N/A
Entity listed: N/A
Classification: N/A

1.3.3 Associated rulemakings:

FR notice: [USFWS] U.S. Fish and Wildlife Service. 2016. Endangered and threatened wildlife and plants; designation and nondesignation of critical habitat on Molokai, Lanai, Maui, and Kahoolawe for 135 species; Final Rule. Federal Register 81: 17790-18110.

Critical habitat for the species was considered on Lānaʻi in the historical lowland wet forest, montane wet forest and wet cliff habitats, but was not designated as a consequence of exclusions under section 4(b)(2) of the Endangered Species Act (USFWS 2016). The decision to exclude Lānaʻi from critical habitat designation was based on landowner cooperation to conserve the species. Ownership of Lānaʻi is about 98 percent private and 2 percent by the State of Hawaiʻi. As a result of the critical habitat exclusion, a Memorandum of Understanding was signed in 2015 between the Service, Pūlama Lānaʻi (Lānaʻi Resorts, LLC) and Castle & Cooke Properties, Inc. to work together to contribute to the conservation, protection and management of endangered plant species and Lānaʻi tree snail species on the island. Conservation of the Lānaʻi tree snails requires control of threats from nonnative plant and animal species, fire prevention, proactive construction of predator-proof enclosures, and translocation of species into their historical range where they no longer occur. Pūlama Lānaʻi cooperates with the Service, the State of Hawaiʻi, and other organizations to implement voluntary conservation activities on their lands that result in conservation benefits to the tree snail species and its habitat.

1.3.4 Review History:

This is the first 5-year review for *Partulina variabilis*.

1.3.5 Species' Recovery Priority Number at start of this 5-year review:

5

1.3.6 Current Recovery Plan or Outline:

Name of plan or outline: Recovery Outline for the Islands of Maui, Molokaʻi, Kahoʻolawe, and Lānaʻi (Maui Nui).

Date issued: October 31, 2019
Dates of previous revisions, if applicable: N/A

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate?
____Yes
__X_ No

2.1.2 Is the species under review listed as a DPS?
____Yes
____No

2.1.3 Was the DPS listed prior to 1996?
____Yes
____No

2.1.3.1 Prior to this 5-year review, was the DPS classification reviewed to ensure it meets the 1996 policy standards?
____Yes
____No

2.1.3.2 Does the DPS listing meet the discreteness and significance elements of the 1996 DPS policy?
____Yes
____No

2.1.4 Is there relevant new information for this species regarding the application of the DPS policy?
____Yes
____No

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?
____Yes
__X_ No

2.2.2 Adequacy of recovery criteria.

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

____Yes
____No

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery?

____Yes
____No

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information:
The draft recovery plan that includes *Partulina variabilis* is currently under review and is expected to be finalized in 2020.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history:
Partulina variabilis, a member of the family Achatinellidae and the endemic Hawaiian subfamily Achatinellinae, is known only from Lānaʻi (Pilsbry and Cooke 1912–1914b, p. 86). The oblong to ovate shells of adult *Partulina variabilis* are 0.5 to 0.6 inches (in) (14 to 16 millimeters [mm]) long, have 5 to 7 whorls, and have white, yellow, black, or other shades as a base color with a variable number of spiral bands of varying width or with no banding (Pilsbry and Cooke 1912-1914b, 83-86). The shell may coil to the right (dextral) or the left (sinistral), and both types of shells can be found in a single population. Only snails with the same coil type can mate. *Partulina* tree snails reach adult size in 4 to 7 years. Upon reaching adult size, the snails stop growing and form a thickened edge or lip along the opening of the shell. A tree snail may attain an age that exceeds 15 years.

Lānaʻi tree snails are simultaneous hermaphrodites, meaning they have both male and female reproductive organs, which are functional at the same time. Hermaphroditism is a form of sexual reproduction in which the snail can act as the female or male during mating. The species is not known to self-fertilize. After mating, the Hawaiian tree snails can store sperm and may produce live young for a year or more without breeding (Sischo 2019 in litt., entire). In the case of the closely related *Partulina redfieldi*, production of offspring by an isolated adult snail in captivity continued for 4 years (Kobayashi and Hadfield 1996, pp. 346, 351); birth rate and birth size remained constant and comparable with those estimated for field populations of this species (Hadfield 1986, pp. 330-332). Reproductive maturity for Lānaʻi tree snail is believed to be 4 to 7 years of age based on other *Partulina* species (Hadfield and Miller 1989, p. 10).

Partulina variabilis gives birth to live young about 0.18 in (4.5 mm) in size. Reproductive output is low with an adult snail giving birth to four to six live young per year (Hadfield and Miller 1989, pp. 5-7). *Partulina* spp. obtain adult size in 4 to 7 years (Hadfield *et al*. 1993, p. 620). The longevity of the Lānaʻi tree snail, based on other *Partulina* species, may be greater than 15 years (Hadfield and Miller 1989 p. 12).

The habitat of *Partulina variabilis* includes the wet montane forest of the Mount Lānaʻihale summit, the surrounding wet cliffs, and the lowland wet forest that extends below Lānaʻihale. The montane wet ecosystem, where populations of *P. variabilis* occur, is found at elevations ranging from 3,300 feet (ft) (1,000 meters [m]) up to the summit of Mount Lānaʻihale at 3,660 ft (1,116 m), in areas where annual precipitation is greater than 75 in (190 centimeters [cm]). The wet cliff ecosystem is generally composed of shrublands on near vertical slopes (greater than 65 degrees). The wet cliffs provide suitable habitat for *Partulina variabilis*, though surveys have not been conducted on the cliffs because of the access constraints of the terrain. The lowland wet ecosystem is generally found below 3,300 ft (1,000 m) elevation (Gagne and Cuddihy 1999, p. 85). This lowland habitat includes a variety of wet grasslands, shrublands, and forests that receive greater than 75 in (190 cm) annual precipitation. On Lānaʻi, this ecosystem is best developed in wet valleys and on slopes.

Distribution of *Partulina variabilis* is correlated with habitat quality (Thacker & Hadfield 1998, p. 9). Cool, shaded forest habitat with high humidity and low air movement that prevents excessive water loss are critical factors. Adults can estivate to survive temporary drier periods but juveniles are vulnerable to desiccation because of the greater shell-surface to air ratio. *Partulina variabilis* is found on the following native host plants: *Metrosideros polymorpha (*ʻōhiʻa)*, Broussaisia argute* (kanawao) *Psychotria* spp. (kōpiko), *Coprosma* spp. (pilo), *Melicope* spp. (ʻalani), and dead *Cibotium glaucum* (hapuʻu fern). Occasionally, *P. variabilis* is found on nonnative plants such as *Psidium guajava* (guava) and *Cordyline australis* (New Zealand ti) (Hadfield 1994b, p. 2).

In general, tree snails subsist entirely by grazing throughout the night on microbes that live on the leaf and trunk surfaces of plants (Pilsbry and Cooke 1912–1914a, p. 103; O'Rorke et al. 2016, p. 177). This microbial ecosystem on the plant surfaces above the ground is called the phyllosphere and is comprised of a variety of microorganisms including fungi, algae, bacteria, protists, etc. The tree snails feed by scraping the surface they are on with their specialized radula. This does not appear to damage the plant host.

2.3.1.2 Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family

size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:
Historic populations of *Partulina variabilis* were restricted to the wet and mesic ʻōhiʻa forests on Lānaʻi (Pilsbry and Cooke 1912–1914a, p. 103; Pilsbry and Cooke 1912–1914b, pp. 83-86). Snails were reported on the windward ridges above Waiʻapaʻa, behind Kōʻele, and Lānaʻihale. In 1994, field surveys were conducted throughout the remaining native habitat in the historic range from 2,690-3,339 ft (820-1,018 m) in elevation (Hadfield 1994b, entire). The few remaining individuals observed were restricted to 16 small isolated populations with 175 individuals (28 adult, 111 juvenile, and 36 newborn snails) (Hadfield 1994b, entire). These populations were found on ʻōhiʻa, kanawao, kōpiko, pilo, ʻalani, hapuʻu fern, guava, and New Zealand ti (Hadfield 1994b, entire).

In 2005, Hadfield resurveyed the 16 original sites and a newly discovered site not previously recognized as tree snail habitat of Lānaʻihale. Ten sites, which included nine of the sites from the 1994 survey and one newly discovered site, only supported *Partulina variabilis* and two sites supported *P. variabilis* and *Partulina semicarinata* (Hadfield 2005). Tree snails at four of the sites surveyed in 1994 appeared to be extirpated. A total of 90 *P. variabilis* were observed in 12 out of the 16 sites surveyed (**Table 1**; Hadfield 2005). The number of snails observed does not represent a census of the population because of the cryptic nature of the snails.

From 2017-2019, surveys for *Partulina variabilis* on Lānaʻihale identified 10 isolated populations in previously known wet forest habitats (**Table 1**; Sischo 2019 in litt., entire). The number of known wild populations is declining. A population census has not been conducted for any of the 10 populations, but all are thought to be small and are isolated from each other. A predator-proof snail enclosure was completed in 2018, and a second in 2019 by Pūlama Lānaʻi. One enclosure was constructed around one of the existing *P. variabilis* populations identified in the surveys in 2017. The population in the tree snail enclosure has representatives of all life stages and appears to have positive growth.

A second enclosure has been constructed around a population of the closely related *Partulina semicarinata*, which may serve as a translocation site for *P. variabilis*. The nine known wild populations that are not within the enclosure may benefit from ongoing rat control efforts across Lānaʻihale, but continue to be at high risk of predation from rats, *Euglandina* spp., Jackson's chameleons (*Chamaeleo jacksonii*), habitat-related threats, and catastrophic and stochastic events. The population within the enclosure is also at risk should the barriers fail or catastrophic or stochastic events damage the enclosure or habitat inside.

Although surveys in suitable habitat have been conducted in recent years, it is possible that other populations persist on Lānaʻihale, especially in habitats, such as steep cliffs, where surveys have not been conducted and where the terrain would have provided some protection from threats. As rat trapping and habitat management, including fencing and removal of ungulates to protect endangered plants and seabirds, occurs on the mountain, it is possible that the unknown tree snail populations will benefit from these activities.

Captive rearing is also used as a form of rescue to prevent extirpation of wild tree snail populations and to preserve genetic representation. Captive rearing is conducted with the intent of translocation back to the natural habitat where predatory threats have been abated. A population of *Partulina variabilis* is currently in the State of Hawaiʻi, Division of Forestry and Wildlife, Snail Extinction Prevention Program captive rearing program (Snail Extinction Prevention Program 2019, entire).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):
No genetic analysis has been conducted on the 10 populations known and it is unclear how closely these populations mimic the historic genetic diversity of Lānaʻi tree snail. The distance between the populations suggests the populations may represent distinct geographic population units that do not presently interbreed.

2.3.1.4 Taxonomic classification or changes in nomenclature:
Pilsbry and Cooke's 1912-1914 taxonomic description of *Partulina variabilis* is the most recent and accepted taxonomy for this species (Pilsbry and Cooke 1912-1914b, pp. 83-86).

2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):
See section 2.3.1.2 above for historic and current spatial distribution of the species. Only ten *Partulina variabilis* populations are known to remain in the wet forests of Lānaʻihale, though individuals or small populations may exist in unsurveyed areas. The species has drastically declined throughout its historical lowland wet forest range due to loss of habitat, fragmentation, and introduction of nonnative species that have either resulted in direct tree snail mortality or have altered the habitat, making it unsuitable for the tree snail. See section 2.3.2 for habitat altering threats.

2.3.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Predation, habitat loss, and habitat degradation have contributed significantly to the decimation of the once abundant snail populations on Lāna‘ihale. The remaining wild populations face imminent threats from rats, nonnative predatory snails (*Euglandina* spp.) and Jackson’s chameleon present or encroaching on their habitat.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range (Factor A):

Habitat loss and degradation have contributed significantly to population declines of the Lāna‘i tree snail. Land use conversion to non-lowland wet forest, invasive nonnative species, fire, and climate change all contribute towards habitat loss and degradation. Habitat loss for *Partulina variabilis* began when humans first settled Lāna‘i and wet lowland forests were cleared to make way for agriculture and development.

In addition to direct habitat destruction by humans, ungulates were introduced for hunting and consumption. Forests not cleared for agriculture were invaded by feral cattle (*Bos taurus*), mouflon sheep (*Ovis gmelini musimon*), horses (*Equus ferus caballus*), goats (*Capra hircus*), axis deer (*Axis axis*) and pigs (*Sus scrofa*) (Cuddihy and Stone 1990, pp. 63-67). The browsing, grazing, and trampling by these mammals degraded native forests and facilitated the invasion of exotic plants by spreading their seeds and creating disturbed areas where seeds could germinate (Hobdy 1993, pp. 205-208). Specific threats to the *Partulina variabilis* habitat posed by introduced ungulates, particularly axis deer and goats include trampling and grazing of the host plants used by Lāna‘i tree snails for food, shelter, and reproduction. Ungulate paths increase soil disturbance and cause mechanical damage of host plant roots leading to erosion and possible entry points for plant disease organisms. Ungulates also create openings and disturbed areas, which facilitate weedy plant invasion and disperse fruits and seeds resulting in the conversion of a native community to one dominated by nonnative vegetation.

Nonnative plants represent a serious and ongoing threat to the Lāna‘i tree snail because they adversely affect microhabitat by modifying the availability of light, alter soil-water regimes, modify nutrient cycling processes, alter fire characteristics of native plant habitat; and outcompete, and possibly directly inhibit the growth, of native plant species. Each of these threats can convert native-dominated plant communities to nonnative plant communities (Cuddihy and Stone 1990, p. 74; Vitousek 1992, pp. 33–35). This conversion has negative effects on the host plants that the Lāna‘i tree snail feeds upon. Changes of the plant community can destroy continuity of the phyllosphere created by overlapping canopies. While

Lānaʻi tree snails have been observed on invasive species such as guava, this invasive plant changes the hydrology, canopy structure, and microclimate needed for the habitat of the tree snail. Changes to the native plant communities effect the availability of the tree snail's alternate native plant hosts via environmental changes in water, canopy and shading structure.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes (Factor B):
Achatinellidae tree snails were extensively collected for scientific as well as recreational purposes in the 18th to early 20th centuries (Hadfield 1986, p. 320-321). These impacts may have been especially severe to some species and populations within the genera of *Achatinella* and *Partulina* (Hadfield 1994a, pp. 320, 322). Lee et al. (2007, pp. 2,908–2,910) found evidence that *Partula hyalina* had been traded as far away as the southern Cook Islands by early Polynesians. During the 1800s, collectors observed 500 to 2,000 snails per tree, and sometimes collected over 4,000 snails in just several hours (Hadfield 1986, p. 322). Repeated collections of hundreds to thousands of individuals by early collectors certainly resulted in decreases in population sizes and reductions in reproduction potential. Collection, possession, and sale of the tree snail shells is legally prohibited.

2.3.2.3 Disease or predation (Factor C):
Predation by nonnative species is a well-documented threat to tree snails throughout Hawaiʻi and the Pacific islands (Cowie 1992, entire; Hadfield and Mountain 1980, p.355; Hadfield 1986, p. 327; Hadfield and Saufler 2009, entire). Predation by rats has been linked with the dramatic declines of populations of native tree snails (Hobdy 1993, p. 208; Hadfield and Saufler 2009, p. 1; Meyer and Shields 2009, p. 344). Rats decimated a large population of a closely related species, *Partulina splendida*, on Maui (Thacker and Hadfield 1998). Rats appear to selectively prey on large snails rather than juveniles. Rat predation poses one of the most serious threats to populations of *Partulina variabilis.* Three rat species (black rat [*Rattus rattus*], Norway rat [*R. norvegicus*], and Polynesian rat [*R. exulans*]) are present on Lānaʻi, but the black rat appears to be the most important threat to the Lānaʻi tree snails (Hobdy 1993, p. 208; Hadfield 1994a, entire; Hadfield 1994b, p. 5; Thacker and Hadfield 1998, entire; Hadfield 2007, entire). Rat damage has been observed on the empty shells of *Partulina variabilis*, indicating rats likely caused their mortality (Hadfield 1994b, p. 5).

An imminent threat to *Partulina variabilis* is predation by the nonnative *Euglandina* spp. These predatory snail species were purposefully introduced to the main islands of Hawaiʻi in a failed attempt to control the giant African snail, *Achatina fulica* (Davis and Butler 1964, entire; Cowie

2001b, pp. 66-67). Not only did *Euglandina* spp. fail to reduce giant African snail populations, the species decimated endemic tree snails and are a major cause of the decline and extinction of native tree and terrestrial snails throughout Hawai‘i, Moorea (French Polynesia) and other tropical and subtropical regions (Cowie 2001a, entire; Cowie 2001b, pp. 66-67; Hadfield 1986, p. 327; Hadfield et al. 1993, entire). The introduced predatory snails, initially identified as *Euglandina rosea* in Hawai‘i, were recently shown to be a mixture of *Euglandina* species (Meyer III et al. 2017 pp. 1402-1404). These predatory snail species actively hunt by following the slime trails of their prey (Clifford et al. 2003, entire; Holland et al. 2018, entire). The predatory snails will climb the host tree to find its tree snail prey and can decimate a tree snail population (Hadfield 1986, p. 327). *Euglandina* spp. are known from Lāna‘i (Hadfield 2005; Sprague 2020 in litt. entire).

The nonnative terrestrial garlic snail, *Oxychilus alliarius*, present on Lāna‘i, poses a threat to smaller Lāna‘i tree snails (Hadfield 2007, p. 8).

Jackson’s chameleon is known to prey on native insects and tree snails. Currently, there are established Jackson’s chameleon populations on all of the main Hawaiian Islands, with the greatest number of individuals on the islands of Hawai‘i, Maui, and O‘ahu (Holland et al. 2010, entire). Several dozen Jackson’s chameleons, native to Kenya and Tanzania, were introduced to Hawai‘i in the early 1970s through the pet trade (Holland et al. 2010, p. 1,438). Inter-island transport of Jackson’s chameleons for the pet trade was unrestricted until 1997, when they were classified as ‘‘injurious wildlife,’’ and export, as well as inter-island transport, was prohibited (State of Hawai‘i 1996, Hawai‘i Administrative Rule 13–124–3; Holland et al. 2010, entire). The occurrence of *Partulina variabilis* at high elevations on Lāna‘i may reduce the predation risk by Jackson’s chameleon because the chameleon has only been observed in Lāna‘i City. It is possible that the chameleon also occurs in the wild on Lāna‘i at higher elevations, and as its populations grow, it is expected that it will eventually inhabit the upper elevations where the tree snails occur.

Terrestrial flatworms (*Geoplana septemlineata* and *Platydemis manokwari* have been reported to feed on terrestrial and tree snails (Hadfield 2007, entire; Sugiura 2010, entire). The flatworm is able to climb wet trees and locate arboreal snails via scent (Sugiura and Yamaura 2009, p. 740-741). *Platydemus manokwari* decimated populations of native tree snails on Guam (Hopper and Smith 1992, entire). Although *P. manokwari* has been found on the islands of O‘ahu and Hawai‘i and is likely on all of the main islands, the flatworm has not been documented in the wet forest habitats of the Lāna‘i tree snail.

Disease is a potential threat to the *Partulina variabilis,* and to tree snails in

general (Hadfield 1994, pp. 328-329). Wild and captive-reared Lānaʻi tree snails have not been subjected to testing for disease pathogens. However, an unknown disease has been observed in the tree snail captive rearing program and anecdotal evidence suggests it was introduced via leaf material used for the captive population (Sischo 2019 in litt., entire). Protocols are now in place to avoid or minimize introduction of disease organisms to the captive populations.

The plant disease, rapid ʻōhiʻa death (ROD), is an ongoing threat to *Metrosideros polymorpha*, an important host for *Partulina variabilis*. This lethal disease of ʻōhiʻa is caused by two fungal pathogens, *Ceratocystis lukuohia and Ceratocystis huliohia* (Barnes et al., 2018, entire). *Ceratocystis lukuohia* is highly aggressive and has been identified on the islands of Hawaiʻi and Kauaʻi (Friday et al. 2020, entire; Heller et al. 2019, entire). The impacts of ROD on Lānaʻi tree snail will depend on the movement of the fungi, distribution of the disease, and ability of the snails living on a dying tree to find a new food source. The multiple plant hosts used by this tree snail may reduce the effects of ROD on the wild populations.

2.3.2.4 Inadequacy of existing regulatory mechanisms:
Existing State and Federal regulatory mechanisms are not effectively preventing the introduction and spread of nonnative species from outside the State of Hawaiʻi or within the State between islands and watersheds. Predation by nonnative species such as predatory snails, rats, Jackson's chameleon, flatworms, and habitat-altering, nonnative plant species and ungulates pose major ongoing threats to the Lānaʻi tree snail. The State's current management of nonnative game mammals is inadequate to prevent the degradation and destruction of habitat of the tree snail.

2.3.2.5 Other natural or manmade factors affecting its continued existence (Factor E):
Drought is a significant threat to juvenile Lānaʻi tree snails (Kobayashi and Hadfield 1996; Sischo 2019 in litt., entire; Snail Extinction Prevention Program 2019, entire). Adults can create a seal between the opening of their shell and the plant surface to minimize moisture loss during times of drought or high temperatures. However, juveniles have a shell-surface area to body mass ratio that makes them far less tolerant to drought. In addition, drought can cause habitat degradation and loss of host tree(s) as well as an increase in forest and brush fires. Because of the limited dispersal capability of the tree snail, drought conditions are lethal to juveniles and can be lethal to adults in wild population if the drought is prolonged. Neither juveniles nor adults can survive a fire.

High winds and intense rains from hurricanes can dislodge snails from host plants and deposit them on the forest floor where they may be

crushed by falling vegetation or exposed to predation by rats and predatory snails (Hadfield et al. 1993, p. 620). Damage by future hurricanes could further decrease the remaining native plant-dominated habitat that supports *Partulina variabilis*. Lānaʻi tree snails require a shaded, high humidity habitat. Hurricanes adversely impact Lānaʻi tree snail habitat by destroying native vegetation, opening the canopy and thus modifying the availability of light, and creating disturbed areas conducive to invasion by nonnative species (Asner and Goldstein 1997, p. 148; Harrington et al. 1997, pp. 539-540). Wind storms can disperse tree snails, but it can also result in isolation of individuals. Adults require several years to reach sexual maturity, have low reproductive rates and limited dispersal, with most individuals remaining in the bush, tree, or tree complex on which they were born. All of these traits and the few populations remaining make these snails very sensitive to any stochastic or catastrophic event that could lead to a reduction or loss of reproductive individuals and an imbalance in demographic distribution (Lande 1988).

Climate change has the potential to adversely affect *Partulina variabilis*. Lānaʻi tree snails occupy the highest elevation on the island. The remaining wet forests on which the snail depends may be affected by changes in temperature, humidity, precipitation and the frequency and severity of storms. These stressors may change the forest habitat rendering it unsuitable, as described in Clark et al. 2019.

The threat to *Partulina variabilis* from limited numbers of populations and number of individuals is ongoing and is expected to increase into the future. As a result, the species may experience reduced reproductive vigor due to inbreeding depression, reduced levels of genetic variability leading to diminished capacity to adapt and respond to environmental changes, and increased vulnerability to a catastrophic event (e.g., hurricane, drought) (Hadfield 1986, entire; Hadfield and Miller 1989, pp. 7-15; Hadfield et al. 1993, entire; Hadfield 1994a, entire; Hadfield 2005, entire; Kobayashi and Hadfield 1996, entire). Together these may result in population extirpation and potentially to the extinction of this species

Persistence of populations is hampered by the small number of known wild populations (10) and shrinking geographic range of the species. These circumstances make this species vulnerable to extinction due to a variety of natural and anthropogenic caused factors. Though the tree snails are hermaphrodites and can store sperm for a limited time, small or limited populations are particularly vulnerable to reduced mating encounter, reproductive vigor caused by inbreeding depression, and they may suffer a loss of genetic variability over time due to random genetic drift, resulting in decreased evolutionary potential and ability to cope with environmental change (Lande 1988).

Conservation Actions
The wet forest at the summit of Mount Lānaʻihale, surrounding cliffs, and what remains of the wet lowland forest, benefits from the dedicated conservation efforts of the Pūlama Lānaʻi (**Table 2**). Lānaʻi tree snails occur solely on lands managed by Pūlama Lānaʻi. Additional, unknown populations of *Partulina variabilis* may persist on the cliffs. These populations may be afforded limited protection from rat control, fencing, removal of ungulates, and habitat management to protect endangered plants and endangered seabirds that also occur on the mountain. Because staff that conduct these management actions are trained in tree snail identification, these management actions may lead to the locating previously undocumented *P. variabilis* populations.

Controlling the principal threats of rats and *Euglandina* spp. in *Partulina variabilis* natural habitat is difficult, if not impossible. Predator-proof tree snail enclosures have proven successful for protecting other tree snail species (Rohrer et al. 2016) in Hawaiʻi. A tree snail enclosure is constructed around tree snail habitat and when completed, excludes *Euglandina* spp., rats, and Jackson's chameleons. Enclosures are sited based on the tree snails' habitat requirements, known occupancy, and construction constraints of the terrain. Habitat within the snail enclosures must be suitable to support the tree snails for the foreseeable future, including being free of all tree snail predators. Enclosures can provide a protected habitat for tree snail translocation when a nearby wild population is in eminent danger of being extirpated. Enclosures are vulnerable to the same environmental risks as is the surrounding habitat including storms and vegetation senescence, and require targeted, iterative management and maintenance inside and outside of the fence in perpetuity to ensure they continue to provide effective barriers against *Euglandina* spp., rats, and chameleons.

One such predator-proof snail enclosure, completed by Pūlama Lānaʻi in 2018, is supporting *Partulina variabilis* in a natural, but protected, environment (**Table 2**). The enclosure may serve as a destination for translocation of tree snail populations that are in immediate peril in the wild and meet translocation criteria. The enclosure is maintained by Pūlama Lānaʻi with guidance from the USFWS and the Snail Extinction Prevention Program. Changes in threats and tree snail population inside the enclosure are monitored by Pūlama Lānaʻi and the Snail Extinction Prevention Program and reported to the USFWS. A second enclosure has been constructed around a population of the closely related *Partulina semicarinata*, and may serve as a future translocation site for *Partulina variabilis*.

Recent efforts to captive rear *Partulina variabilis* have been successful by the Snail Extinction Prevention Program (Snail Extinction Prevention

Program 2019, entire). Lānaʻi tree snails representing one of the populations in the wild are showing population stability, consistent production, and juvenile survival in captive rearing (**Table 2**; Sischo 2019, entire). The captive rearing program is designed with safeguards to prevent introduction of disease and parasites (Snail Extinction Prevention Program 2019, entire). The captive-reared *P. variabilis* may be used for translocation efforts once the tree snails produced meet the size and translocation standards. The long-term management plan of the Lānaʻi tree snail captive rearing program is to translocate the captive-reared tree snails to snail enclosures.

Table 1 – Known populations of *Partulina variabilis* from listing to this 5-year review.

Date	Populations	Individuals	Recovery Criteria
2013 listing	12	<100	N/A
2020 5-year review	10	>100	N/A

Table 2 – Status of threats to *Partulina variabilis* from listing through the current 5-year review.

Threat	**Listing Factor**	**Current Status**	**Conservation/Management Efforts**
Agriculture and urban development	A	Ongoing	Partial—land management has reduced the threat of development
Ungulates	A	Ongoing	Partial— some strategic fencing is in place and maintained; some ungulate removal has occurred
Invasive nonnative plants	A	Ongoing	Partial—land management and invasive plant removal by Pūlama Lānaʻi
Fire	A	Ongoing	Partial— general fire management plans developed by Pūlama Lānaʻi are in place
Stochastic events (drought, hurricane)	A	Ongoing	None
Disease	C	Ongoing	Partial—Snail Extinction Prevention Program has implemented safeguards against introduction of disease and parasites to captive-reared tree snails
Predation by rats	C	Ongoing	Partial—two predator-proof snail enclosures are built by Pūlama Lānaʻi and one is occupied by *Partulina variabilis*; the Snail Extinction Prevention Program has one population of *P. variabilis* in captivity; tree snail populations may be afforded limited protection from rat control to protect endangered plants and endangered seabirds that also occur on Lānaʻihale.
Predation by Jackson's chameleon	C	Ongoing	Partial—predator-proof snail enclosure built on private land in the tree snails habitat; one population of *P. variabilis* is in captivity

Threat	Listing Factor	Current Status	Conservation/Management Efforts
Predation by predatory snails	C	Ongoing	Partial—predator-proof snail enclosure built on private land in the tree snails habitat; one population of *P. variabilis* is in captivity
Predation by flatworms	C	Ongoing	Partial— the Snail Extinction Prevention Program has one population of *Partulina variabilis* in captivity
Inadequate existing regulatory mechanisms	D	Ongoing	Partial—restrictions on transport of invasive species to the island and inspections at the dock and airport are conducted
Loss of plant hosts	E	Ongoing	Partial—some landscape-scale plant and pathogen management
Limited numbers	E	Ongoing	Partial— Snail Extinction Prevention Program has one population in captivity
Treefall	E	Ongoing	None
Climate change	E	Ongoing	None

2.4 Synthesis

Partulina variabilis is an endangered tree snail endemic only to the wet forests of Lānaʻihale, on Lānaʻi, in areas where annual precipitation is greater than 75 in (190 cm). Lānaʻi tree snail feeds on microbes living on the leaf, branch and trunk surfaces of its plant hosts that include ʻōhiʻa), kanawao, kōpiko, pilo, ʻalani, guava, New Zealand ti, and dead hapuʻu fern. The species exhibits the late maturity and low reproductive rate characteristic of other Hawaiian tree snails belonging to the family Achatinellidae.

Rats and habitat degradation have decimated the once abundant snail. Remaining wild populations face imminent threats from rats, nonnative predatory snails (*Euglandina* spp.), and Jackson's chameleons present or encroaching on Lānaʻihale. There are 10 small, Lānaʻi tree snail populations known in the wild, all of which are located on Lānaʻihale. Additional, unknown populations may persist on the cliffs where terrain prohibits discovery.

Conservation measures that benefit *Partulina variabilis* focus on protecting the species from predation by rats and *Euglandina* spp., trampling by ungulates, and destruction and loss of host plants. The wild populations may be afforded limited protection from rat control, fencing, removal of ungulates, and habitat management to protect endangered plants and endangered seabirds that also occur on the mountain. Because staff that conduct these management actions are trained in tree snail identification, these management actions may lead to observations of previously undocumented *Partulina variabilis* populations. One Lānaʻi tree snail population is protected by a predator-proof snail enclosure constructed in 2018 by Pūlama Lānaʻi. A second enclosure was constructed in 2019 around an existing

population of *Partulina semicarinata* and may be used for a future translocation site for *P. variabilis*. The remaining populations in the wild continue to be at risk of predation from rats, *Euglandina* spp., Jackson's chameleons, habitat-related threats, and catastrophic and stochastic events. The population within the enclosure is also at risk should the barriers fail or catastrophic or stochastic events damage the enclosure or habitat inside. Representatives from one wild population are also maintained in captive rearing and that population shows positive growth.

With only 10 small populations of *Partulina variabilis* known, a low number of individuals, and most threats still unmanaged across the landscape, this species continues to meet the definition of endangered.

3.0 RESULTS

3.1 Recommended Classification:

____Downlist to Threatened
____Uplist to Endangered
____Delist
____*Extinction*
____*Recovery*
____*Original data for classification in error*
__X__**No change is needed**

3.2 New Recovery Priority Number:

Brief Rationale:

3.3 Listing and Reclassification Priority Number:

Reclassification (from Threatened to Endangered) Priority Number:____
Reclassification (from Endangered to Threatened) Priority Number:____
Delisting (regardless of current classification) Priority Number:____

Brief Rationale:

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

- Finalize the recovery plan with measureable downlisting and delisting criteria for the recovery of *Partulina variabilis*.
- Conduct surveys for extant populations throughout the range of *Partulina variabilis.*
- Monitor and assess abundance of individuals and growth trend of populations.
- Protect existing populations in the wild from threats.

- Expand the capacity of the captive rearing program and increase the number of captive-reared individuals and populations.
- Identify and prepare suitable habitats for translocation of captive-reared Lānaʻi tree snail.
- Construct and maintain tree snail predator-proof enclosures to protect extant populations or to protect translocated Lānaʻi tree snails.
- Increase numbers of populations and individuals in suitable habitat through translocation to build resilient populations with redundancy and representation.
- Control invasive, nonnative plant species that degrade the wet forest habitat of *Partulina variabilis*.
- Implement effective control methods for nonnative *Euglandina* spp. at all *Partulina variabilis* populations in habitats.
- Expand and continue to implement effective control methods for rats in all *Partulina variabilis* populations.
- Implement effective control methods for Jackson's chameleon at all *Partulina variabilis* populations.
- Control any new threats to *Partulina variabilis* before they become widespread.
- Develop fine-scale climate models to identify future suitable habitat based on existing and historical distributions and determine potential future climate conditions.
- Identify, develop, and support alliances and partnerships to plan and implement *Partulina variabilis* habitat restoration, protection from predators, and management to benefit and recover the species.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of *Partulina variabilis*
(Lānaʻi tree snail)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review:

____Downlist to Threatened
____Uplist to Endangered
____Delist
_X__No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: _____

Review Conducted By:
Diane Sether, Ph.D., Invertebrate and Wildlife Biologist, PIFWO
John Vetter, Animal Recovery Coordinator, PIFWO
Megan Laut, Conservation and Restoration Team Manager, PIFWO

FIELD OFFICE APPROVAL:

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for _____
Field Supervisor, Pacific Islands Fish and Wildlife Office