

Solanum nelsonii
(pōpolo)

5-Year Review
Summary and Evaluation

U.S. Fish and Wildlife Service
Pacific Islands Fish and Wildlife Office
Honolulu, Hawai‘i

5-YEAR REVIEW
Species reviewed: *Solanum nelsonii* (pōpolo)

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5-YEAR REVIEW

***Solanum nelsonii* (pōpolo)**

1.0 GENERAL INFORMATION

1.1 Reviewers:

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Lauren Weisenberger, Plant Recovery Coordinator, PIFWO
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Lead Regional Office:

Interior Region 12, Portland Regional Office

Lead Field Office:

Pacific Islands Fish and Wildlife 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 2020. The review was based on the final rule listing this species; peer reviewed scientific publications; unpublished field observations and species status report by the Service, State of Hawai‘i, and other experienced biologists; unpublished survey reports; notes and communications from other qualified biologists; as well as a review of current, available information.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 by Cheryl Phillipson, Biologist, was reviewed by Lauren Weisenberger, Plant 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. 2019a. Endangered and threatened wildlife and plants; initiation of 5-year status reviews for 91 species in Oregon, Washington, Hawaii, and American Samoa. Federal Register 84 (112): 27152–27154, June 11, 2019.

1.3.2 Listing history:

Original Listing

FR notice: [USFWS] U.S. Fish and Wildlife Service. 2016. Endangered and Threatened Wildlife and Plants; endangered status for 49 species from the

Hawaiian Islands; final rule. Department of the Interior, Federal Register 81 (190): 67786–67860, Friday, September 30, 2016.

Date listed: September 30, 2016

Entity listed: *Solanum nelsonii*

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:

N/A

1.3.4 Review History:

This is the first 5-year review for *Solanum nelsonii*.

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 Multi-Island Species

Date issued: August 2020

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

☒ 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
☒ 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:

A synthesis of the threats (Listing Factors A, B, C, D, and E) affecting this species is presented in section 2.3.2 and Table 2.

The recovery plan is currently being drafted. However, the Hawai'i and Pacific Plants Recovery Coordinating Committee (HPPRCC) has outlined the actions and goals for stages leading towards recovery (2011). These stages are described below.

Current information is lacking for many Hawaiian plant species on the status of the species and their habitats, breeding systems, genetics, and propagule storage options. The following downlisting and delisting criteria for plants have therefore been adopted from the revised recovery objective guidelines developed by the HPPRCC (2011). Many of the Hawaiian plant species are at very low numbers, so the Service also developed criteria for avoiding imminent extinction and an interim stage before downlisting, based on the recommendations of the HPPRCC, to assist in tracking progress toward the ultimate goal of recovery. These criteria are assessed on a species-by-species basis, especially as additional information becomes available.

In general, long-lived perennials are those taxa either known or believed to have life spans greater than 10 years; short-lived perennials are those known or believed to have life spans greater than one year but less than 10 years; and annuals are those known or believed to have life spans less than or equal to one year. When it is unknown whether a species is long- or short-lived, the Service has erred on the side of caution and considered the species short-lived. This will be revised as more is learned about the life histories of these species. Narrow extant range and broad contiguous range are recognized as not needing different numbers of individuals or populations, but that the populations will be distributed more narrowly or more broadly, respectively, across the landscape. Obligate outcrossers are those species that either have male and female flowers on separate plants or otherwise require cross-pollination to fertilize seeds, and therefore require equal numbers of individuals contributing to reproduction as males and females, doubling the number of mature individuals. Species that reproduce vegetatively may reproduce sexually only on occasion, resulting in the majority of the genetic variation being between populations, therefore requiring additional populations. Species that have a tendency to fluctuate in number from year to year require a larger number of mature individuals on average to allow for decline in years of extreme habitat conditions and recuperation in numbers in years of more normal conditions.

Preventing Extinction

Stabilizing (interim), downlisting, and delisting objectives have been updated according to the draft revised recovery objective guidelines developed by the HPPRCC (2011). The HPPRCC identifies an additional initial objective, the Preventing Extinction Stage, in addition to the Interim Stabilization, Delisting, and Downlisting objectives. Furthermore, life history traits such as breeding system, population size fluctuation or decline, and reproduction type (sexual or vegetative), have been included in the calculation of goals for the number of populations and reproducing individuals for each stage. The goals for each stage remain grouped by life span defined as annual, short-lived perennial (fewer than 10 years), or long-lived perennial.

Solanum nelsonii is a short-lived perennial sprawling or trailing shrub. To prevent extinction, which is the first milestone in recovering the species, the taxon must

be managed to control threats (e.g., fenced) and have 50 individuals (or the total number of individuals if fewer than 50 exist) from each of three populations represented in *ex situ* (secured off-site, such as a nursery or seed bank) collections that are well managed. In addition, a minimum of three populations total should be documented throughout the species' range where they now occur or occurred historically. Each of these populations must be naturally reproducing (i.e., viable seeds, seedlings) with a minimum of 50 mature individuals per population.

This recovery objective has not been met (see Table 1).

Interim Stage

To meet the interim stage of recovery of *Solanum nelsonii*, 300 mature individuals are needed in each of three populations and all major threats must be controlled around the populations designated for recovery at this stage. Multi-island species should be represented by at least one population on each of the islands from which they were known historically as long as suitable habitat exists. There should also be demonstrated regeneration of seedlings and documented replacement regeneration within each of the target populations. The populations must be adequately represented in an *ex situ* collection as defined in the Center for Plant Conservation's guidelines (Guerrant et al. 2004, entire) that is secure and well managed. Adequate monitoring must be in place and conducted to assess individual plant survival, population trends, trends of major limiting factors, and response of major limiting factors to management.

This recovery objective has not been met (see Table 1).

Downlisting Criteria

In addition to achieving 5 to 10 populations with 500 mature individuals per population and all of the goals of the interim stage, all target populations must be stable, secure, and naturally reproducing for a minimum of 10 years. Multi-island species should be represented by at least three populations on each of the islands from which they were known historically as long as suitable habitat exists. Species-specific management actions are not ruled out. Downlisting should not be considered until an adequate population viability analysis (PVA) has been conducted to assess needed numbers more accurately based on current management and monitoring data collected at regular intervals determined by demographic parameters of the species, although they should only be one of the factors used in making a decision to downlist. Information necessary for the PVA that should be available through monitoring (ideally annually) includes major limiting factors, breeding system, population structure and density, and proven management methods for major threats.

This recovery objective has not been met (see Table 1).

Delisting Criteria

In addition to achieving 5 to 10 populations with 500 mature individuals per population and all of the goals of the interim and downlisting stages, all target populations must be stable, secure, naturally reproducing, and within secure and viable habitats for a minimum of 20 years. Multi-island species should be represented by at least three populations on each of the islands from which they were known historically as long as suitable habitat exists. Species-specific management actions must no longer be necessary, but ecosystem-wide management actions are not ruled out if there are long-term agreements in place to continue management. These numbers are initial targets, but may be revised upward as additional information is available, including adequate PVAs for individual species based on current management and monitoring data collected at regular intervals determined by demographic parameters of the species, although they should only be one of the factors used in making a decision to delist. Genetic analyses should be conducted to ensure that adequate genetic representation is present within and among populations compared to the initial variation assessed in the interim stage. Numbers need to be considered on a species-by-species basis.

This recovery objective has not been met (see Table 1).

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:

Solanum nelsonii (pōpolo [‘ākia on Ni‘ihau]) is a sprawling or trailing shrub in the Solanaceae (nightshade) family up to 1-meter (m) (3.2-feet [ft]) tall, forming clumps up to 1.5 m (4.9 ft) in diameter, with young stems and leaves densely pubescent with stellate (star-shaped) hairs. Leaves are grayish green, alternate, broadly ovate to orbicular, often 3 to 4 centimeters (cm) (1.2 to 1.6 inches [in]) long, 2.5 to 3 cm (1 to 1.2 in) wide, margins entire, occasionally with shallow rounded lobes, apex rounded or acute, base rounded to cordate, often oblique, and petioles (leaf stems) 0.5 to 1.2 cm (0.2 to 0.5 in) long. Flowers perfect (male and female), symmetrical, in racemose cymes (unbranched, with terminal flower blooming first). The corolla is white, tinged with lavender to pale purple, stellate, lobes 12 mm (0.5 in) long, stamens (pollen-producing structure) inserted on corolla tube; filaments 1.5 mm (0.06 in) long, flattened below; anthers purple or yellow, flushed purple. Berries are 1 to 4 in clusters, usually black when mature (red on some plants from Nihoa), globose, 1 cm (0.4 in) in diameter. Seeds are numerous, flattened, kidney-shaped, 3 to 4 mm (0.1 to 0.2 in) long and minutely reticulate (veined) (Symon 1999, p. 1273; Rounds et al. 2020, p. 14).

One of the most abundant plant species on Nihoa, *Solanum nelsonii* displays a large range of characteristics with variance in leaf-shapes and

color of mature fruit. Some plants produce dark purple mature fruits and some plants produce red fruits. While some plants exhibited sparse, fuzzy, silver-green foliage, other plants had large leaves (up to 10 cm), with a waxy appearance. This variation may be reflective of the substrate in which the plant grows (Rounds et al. 2020, p. 14). *Solanum nelsonii* is unusual in the genus with its sigmoid (S-shaped) purple anthers which suggest different pollinators than solitary bees (Symon 1999, p. 1273).

Plants have been observed flowering and fruiting in August in 1899, 1977 and 2020 (Schauinsland 1899, p. 43; Clapp et al. 1977, p. 37; Rounds et al. 2020, p. 14).

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:

The historical distribution *Solanum nelsonii* was known from twenty-one populations: east of Ka Lae (South Point, Kamā‘oa Pu‘u‘eo) and Kaulanamauna (Manukā) on the island of Hawai‘i; south of the mouth of Waihe‘e Stream and on the isthmus of Maui; at Kaiehu Point, southeast of Kalani, south of Kawa‘aloha Bay within Mo‘omomi, and at ‘Īlio Point on Moloka‘i; at Ka‘ena on the island of O‘ahu; at an undetermined location on the island of Kaua‘i; at Kawa‘ewa‘e, Lē‘ahi, and on a cliff at the south end of Ni‘ihau; throughout the island of Nihoa; on Kamole (Laysan); on Seal-Kittery Island, Grass Island, North Island, and Southeast Island within Manawai (Pearl & Hermes Atoll); on Eastern Island, Spit Island, and Sand Island within Kuaihelani (Midway Atoll); and on Green Island within Hōlanikū (Kure Atoll) (Hawai‘i Biodiversity and Mapping Program (HBMP) 2010).

Currently, on the island of Hawai‘i, there is one individual at Kamā‘oa Pu‘u‘eo and five individuals were last observed at Kaulanamauna in 2011 (PEPP 2009, 2011; HBMP 2010). There has been some effort to reintroduce *S. nelsonii* within this area in 2010 to 2016; however, the status is currently unknown.

The only known individual on Maui was reported to have disappeared in the mid-1990s after cattle had been allowed to graze in its last known habitat (HBMP 2010; Duvall 2015, in litt.).

In 1986, approximately 32 mature plants occurred near the crest of a dune on the southern area of Kawa‘aloha Bay on Moloka‘i (HBMP 2010). In 1987, seven mature plants were observed in a compact area southwest of the same bay (HBMP 2010). Several other plants (approximately three to five) occurred on the dune at the back of the beach between the bay and the Kaluako‘i-Pālā‘au boundary in 1986 (HBMP 2010). Over 230 mature

plants were observed in 1990 (HBMP 2010). In 1999, 18 plants were observed at Kaiehu Point, in the Mo‘omomi Preserve. In 2014, the Plant Extinction Prevention Program (PEPP) surveys documented only 18 *Solanum nelsonii* in flower or fruit and 8 seedlings within Mo‘omomi (PEPP 2019). In 2019, outplanting efforts by PEPP occurred within this population (PEPP 2019). Approximately 100 plants were counted in a quarter-mile stretch at ‘Īlio Point in 1985 (HBMP 2010). By 2012, this population declined to 47 plants, with the large majority mature. In 2016, the population size further declined to only 12 mature plants (6 vegetative and 6 in flower, with some recruitment) (PEPP 2019).

On the island of O‘ahu, *Solanum nelsonii* was observed at an unknown location in the 1860s (HBMP 2010). In 2019, 48 plants were reintroduced at Kapapa Islet from founders in the Nihoa population (PEPP 2019). From 2016 to 2019, an additional 361 plants were reintroduced to Kalaeloa using the same founders (USFWS 2020). In 2008, plants were also reintroduced at Ka‘ena with stock from the same founders, but none of those plants survived.

Solanum nelsonii was last collected on Ni‘ihau in 1949 (HBMP 2010).

In Manawai (Pearl & Hermes Atoll), in 1980, plants were common in nearly pure stands on Seal-Kittery Island (in 2018, 18 to 20 individuals), common on Grass Island (in 2018, 15 to 20 individuals), and scattered throughout the central portions of both the east and west halves of Southeast Island (in 2018, no plants remained) (HBMP 2010). In 1983, *Solanum nelsonii* was common in almost pure stands, either as single plants or large clumps, growing throughout the central plain and extended to the beach on North Island (in 2018, 15 to 20 individuals) (HBMP 2010). In 1980, at Kuaihelani (Midway), on Eastern Island, plants were either observed singly, a few plants together, or abundant on the southeast corner, northwest shore, and in the interior of the island (in 2018, 11 individuals) (HBMP 2010). In 2018, there were 762 plants counted on Spit Island, and 10 plants (with augmentation) on Sand Island. At Hōlanikū (Kure Atoll), *S. nelsonii* was documented on the central open plain, in the west-central area, at the edge of the runway, and throughout Green Island in 1979 (in 2019, 131 individuals) (HBMP 2010). In 1896, *S. nelsonii* was already uncommon on Kamole (Laysan) (only about 12 individuals) and it was reported only on the northern side of the island on sand dunes near the beach (Schauinsland 1899, p. 43). The last known wild individuals occurred on small sand dunes in a few places near the north beach of Kamole in 1903 (HBMP 2010). In the 1960’s, seeds from Nihoa and Hōlanikū were propagated and plants reintroduced on the island, but no individuals were observed in 1999 (Starr and Starr 2013, p. 52). Thousands of seeds from Nihoa and Manawai were used to reintroduce plants in the early 2000’s (Starr and Starr 2013, p. 52). There were

approximately 490 individuals in 2006 (Rehkemper 2006, in litt.). Surveys conducted in 2013 found only dead plants (Starr and Starr 2013, p. 13). On the island of Nihoa, observations in 1977 and 1983 noted *S. nelsonii* as an abundant and widespread, representing approximately 22 percent of vegetative cover on the island (Clapp et al. 1977, p. 36; HMBP 2010). At that time fruits were much less abundant than flowers, suggesting that pollinators may have been low in number or ineffective (HMBP 2010). In 2017, Plentovich et al. (2018, pp. 7–9) established 30 randomly selected permanent vegetation plots to document long-term changes on the island. All *S. nelsonii* individuals were counted if they were rooted within a 2.5 m (8 ft) radius plot. Plot counts were then extrapolated to estimate the total number of individuals on the island, resulting in 168,000 and 278,000 individuals (Plentovich 2018, p. 10). Plentovich et al. (2018, p. 11) noted that the end of the grasshopper (*Schistocerca nitens*) outbreak resulted in successful plant recruitment in 2018, and thus the increase in the number of *S. nelsonii* individuals.

In summary, *Solanum nelsonii* occurs on the main Hawaiian islands of Hawai‘i and Moloka‘i, and on Nihoa, Manawai, Kuaihelani, and Hōlanikū in Papahānaumokuākea (the Northwestern Hawaiian Islands (NWHI)). There are currently eleven wild populations containing thousands of wild individuals; however, over 99 percent are isolated in the single population on Nihoa. This species has declined dramatically in range and in numbers of populations overall (Starr et al. 2006, pp. 67–68).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

The somatic (diploid) chromosome number was determined as $2n = 24$ (Symon 1999, p. 1273); however, no other genetic studies have been conducted for this species. Morphological diversity has been documented in leaf shape, flower color, and fruit color, and we assume that there may be unique traits in each region that the species occurs because of the geographic separation that historically and currently exists.

2.3.1.4 Taxonomic classification or changes in nomenclature:

Symon (1999, p. 1273) described the degree of differentiation within *Solanum nelsonii* as consisting of four intergrading variants that can be recognized. The type material from Moloka‘i, as well as the collections from Moloka‘i, Maui, and Hawai‘i described *S. nelsonii* as plants with thick, rounded leaves, often with cordate bases, and white to purple flowers with purple anthers (Symon 1999, p. 1273). A second variant included plants with leaves larger and thinner in texture, sometimes repand (shallowly sinuate or slightly wavy margin) to shallowly angled, base oblique, white flowers with purple anthers, and the only record of red fruit (though black fruit has also been observed), from Nihoa, Ni‘ihau, and Kaua‘i (Symon 1999, p. 1273). *Solanum nelsonii* var. *acuminatum* (Caum

68, BISH) and *S. nelsonii* var. *caumii* (Caum 84, Bryan 3, Judd 6, 7, and 8, BISH) refer to the Nihoa collections, and a Nuttall collection with shallowly lobed leaves from Kaua‘i (historically published as *S. nelsonii* var. *thomasiaefolium*) make up this second variant (Symon 1999, p. 1273). A third variant recognized as *S. nelsonii* var. *intermedium* includes plants with larger leaves, rounded bases, and no lobing; longer and more slender, perhaps more divided inflorescences (few records of flowers), from Hōlanikū and Kuaihelani (Caum 12, 29, BISH) (Symon 1999, pp. 1273–1274). The fourth variant includes plants with usually rounded leaves, no distinct lobing, simple inflorescences, usually violet flowers, from Kuaihelani, Manawai, and Kamole. Recently, McClelland et al. (2020, pp. 11–15) revised the status and combination of the Nihoa population to *S. caumii* based on herbarium specimens of *S. nelsonii* var. *caumii* and *S. nelsonii* var. *acuminatum* from the island. It is unclear whether *S. nelsonii* also occurs on Nihoa. If this revised taxonomy is accepted, the taxonomic changes will be published in the *Federal Register*; and all variants will remain protected as endangered as under current listing.

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 and 2.3.1.4 above for spatial distribution of the species.

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

Solanum nelsonii occurs in coral rubble or sand in coastal sites up to an elevation of 490 feet (ft) (150 meters [m]) (Clapp et al. 1977, p. 36; Symon 1999, p. 1273; HBMP 2010). Associated native species include *Achyranthes splendens* (‘Ewa hinahina), *Boerhavia repens* (alena), *Chenopodium oahuense* (‘āheahea, ‘āweoweo), *Cressa truxillensis* (makihi), *Eragrostis variabilis* (kāwelu), *Euphorbia celastroides* (‘akoko), *E. degeneri* (‘akoko), *Fimbristylis cymosa* (mau‘u ‘aki‘aki), *Heliotropium anomalum* var. *argenteum* (hinahina), *H. curassavicum* (kīpūkai), *Ipomoea indica* (koali ‘awa), *I. pes-caprae* ssp. *brasiliensis* (pōhuehue), *Jacquemontia sandwicensis* (pā‘ū o hi‘iaka), *Lepidium bidentatum* var. *owaihiense* (‘ānaunau), *Lepturus repens*, *Lipochaeta integrifolia* (nehe), *Lycium sandwicense* (‘ōhelo kai), *Portulaca lutea* (‘ihi), *Pseudognaphalium sandwicense* (‘ena‘ena), *Rumex albescens* (hu‘ahu‘akō), *Scaevola sericea* (naupaka kahakai), *Sesbania tomentosa* (‘ōhai), *Sicyos maximowiczii* (‘ānunu), *S. pachycarpus* (kūpala), *Sida fallax* (‘ilima), *Sporobolus virginicus* (‘aki‘aki), *Tetramolopium rockii*, *Tribulus cistoides* (nohu), *Vigna marina* (mohihihi), and *Vitex rotundifolia* (pōhinahina) (Lamoureux 1963, pp. 10–13; Gagné and Cuddihy 1999, pp. 57–58; 60–61; HBMP 2010).

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):

Ungulate destruction and degradation of habitat—Axis deer (*Axis axis*) and cattle (*Bos taurus*), and evidence of their activities, are observed at occurrences and in habitat of *Solanum nelsonii* on Moloka‘i and Maui (PEPP 2012, 2013, 2014; Duvall 2015, in litt.; HBMP 2010). Feral ungulates modify and degrade habitat by disturbing and destroying vegetative cover, trampling plants and seedlings, reducing or eliminating plant regeneration by damaging seeds and seedlings, and by increasing erosion by creating large areas of bare soil (Loope 1998, pp. 747–774; van Riper and van Riper 1982, pp. 34–35).

Established ecosystem-altering invasive plant modification and degradation of habitat—Invasive nonnative plants modify habitat occupied by native plant species by changing the availability of light, altering soil-water regimes, modifying nutrient cycling, and changing the fire characteristics of the native plant community (Smith 1985, pp. 180–250; Cuddihy and Stone 1990, p. 74). Nonnative plants including *Lantana camara* (lantana), *Leucaena leucocephala* (koa haole), *Pennisetum ciliare* (fountain grass), *Prosopis pallida* (kiawe), and *Setaria verticillata* (bristly foxtail), modify and destroy the native habitat of *Solanum nelsonii* on the main islands of Hawai‘i and *Cenchrus echinatus* (sandbur), *Eleusine indica* (wiregrass), and *Tetragonia tetragonioides* (New Zealand spinach) impact *S. nelsonii* on the islands and atolls of Papahānaumokuākea (Rounds et al. 2020, pp. 3–8, 14–15; HBMP 2010).

Fire destruction and degradation of habitat—Fire is a threat to the coastal habitat and to individuals of *Solanum nelsonii* on Moloka‘i (HBMP 2010; PEPP 2009, 2012, 2014). Increasing episodes of drought, expansion of invasive nonnative grass cover, and temperature increases, have led to an increase in the number of wildfires (Trauernicht et al. 2015, pp. 439–440). Fire can destroy dormant seeds as well as plants themselves, even in steep or inaccessible areas. Successive fires that burn farther and farther into native habitat destroy native plants and remove habitat for native species by altering microclimate conditions to one more favorable to nonnative invasive plants. Nonnative plants convert native plant communities to nonnative dominated plant communities, contributing to continuation of the fire cycle (D’Antonio and Vitousek 1992, pp. 77–78; Tunison et al. 2002, p. 126).

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes (Factor B):

Not a threat.

2.3.2.3 Disease or predation (Factor C):

Herbivory and predation by feral ungulates—Axis deer and cattle, and evidence of their activities, are observed at the Mo‘omomi and ‘Īlio Point occurrences of *Solanum nelsonii* on Moloka‘i (HBMP 2010; PEPP 2009, 2013, 2014). These animals damage and destroy plants by direct herbivory, bark stripping, and trampling (Cuddy and Stone 1990, p. 64; van Riper and van Riper 1982, pp. 34–35; Tomich 1986, pp. 153–156).

Herbivory and predation by rats—Seed predation by rats, especially in areas of reintroductions on the islands of O‘ahu, Moloka‘i, Maui, and Hawai‘i, is a threat to *Solanum nelsonii* (PEPP 2012, 2014). Although rats do not currently occur within Papahānaumokuākea, if they become accidentally introduced, then plants will also be impacted there. Rats eat virtually every part of plants and at every stage: fleshy fruits, seeds, flowers, stems, leaves, shoot, seedlings, and roots (Russell 1980, pp. 269–272; Cuddihy and Stone 1990, pp. 34, 67). The effects on plants range from reduced vigor and decreased reproduction to mortality of individuals and complete lack of recruitment.

Herbivory and predation by nonnative invertebrates—Herbivory and predation by nonnative invertebrates, such as ants (family Formicidae), mealybugs (family Pseudococcidae), and the gray bird grasshopper (*Schistocerca nitens*) are threat to *Solanum nelsonii*. On Kuaihelani, the longhorn crazy ant (*Paratrechina longicornis*) “farming” mealy bugs was reported to have resulted in the death of five large, established reintroduced plants in less than four weeks (Duhr-Schultz 2016, p. 9). On Nihoa, herbivory by the gray bird grasshopper is a threat to the population. The grasshopper was first recorded on Nihoa in 1977 (Latchininsky 2008, p. 348). Population explosions are apparently triggered by warm, dry conditions. First in 2002, and then again in 2004, a large increase in numbers of the grasshopper led to denuded vegetation on Nihoa (Wegmann et al. 2002 and Culliney 2004 as cited in Latchininsky 2008, pp. 4; 7, 11). During the infestation in 2004, an estimated six million grasshoppers ingested vegetation at the rate of about 1,200 pounds per day, removing practically all green foliage (Miller 2006, in litt.). A scientific team visiting in October 2006 found the island was fairly wet, the vegetation recovering, and only a moderate grasshopper population (TenBruggencate 2006, in litt.; USFWS 2009).

2.3.2.4 Inadequacy of existing regulatory mechanisms (Factor D):

Lack of adequate hunting regulations—Nonnative feral ungulates are a threat to *Solanum nelsonii* through destruction and degradation of the

species' habitat, and directly by predation and herbivory, but regulatory mechanisms are inadequate to address this threat. The State of Hawai'i provides game mammal hunting opportunities in State-designated public hunting areas (DLNR 2010). However, the State's management objectives for game animals range from maximizing public hunting opportunities (i.e., "sustained yield") in some areas to removal by State staff, or their designees (State of Hawai'i, H.A.R. 13-123). The only known occurrences of *S. nelsonii* on Moloka'i are within or adjacent to public hunting areas. Public hunting areas are not fenced, and game mammals have unrestricted access for most areas across the landscape, regardless of underlying land use designation; therefore, any unfenced populations of *S. nelsonii* are at risk (DLNR 2010).

Lack of adequate biosecurity legislation—Introduction of nonnative plants and insects—Currently, four agencies are responsible for inspection of goods arriving in Hawai'i (CGAPS 2009). The Hawai'i Department of Agriculture (HDOA) inspects domestic cargo and vessels and focuses on pests of concern to Hawai'i, especially insects or plant diseases. The U.S. Department of Homeland Security-Customs and Border Protection (CBP) is responsible for inspecting commercial, private, and military vessels and aircraft and related cargo and passengers arriving from foreign locations, focusing on non-propagative plant materials, and internationally regulated commercial species under the Convention in International Trade in Endangered Species (CITES). Also included are federally listed noxious seeds and plants, soil, and pests of concern for forests and agriculture. The U.S. Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (USDA-APHIS-PPQ) inspects propagative plant material, provides identification services for arriving plants and pests, and conducts pest risk assessments among other activities (HDOA 2009). The Service inspects arriving wildlife products, enforces the injurious wildlife provisions of the Lacey Act (18 U.S.C. 42; 16 U.S.C. 3371 et seq.) and prosecutes CITES violations. The State of Hawai'i allows the importation of most plant taxa, with limited exceptions. Many invasive plants established in Hawai'i have expanding ranges. Resources available to reduce the spread of these species and counter their negative ecological effects are limited. Control of established nonnative invasive plants is largely focused on a few invasive species that cause significant economic or environmental damage to public and private lands, and comprehensive control of an array of invasive plants remains limited in scope. The introduction of new invasive plant species to the State of Hawai'i is a significant risk to federally listed species including any remaining wild or outplanted individuals of *Solanum nelsonii*.

2.3.2.5 Other natural or manmade factors affecting its continued existence (Factor E):

Reduced viability due to low numbers—Small, isolated populations often exhibit reduced levels of genetic variability, which diminishes the species' capacity to adapt and respond to environmental changes, thereby lessening the probability of long-term persistence (Barrett and Kohn 1991, pp. 3,7; Newman and Pilson 1997, pp. 354–355). The problems associated with small population size and vulnerability to random demographic fluctuations or natural catastrophes are further magnified by synergistic interactions with other threats, such as anthropogenic impacts like habitat loss from human development or predation by nonnative species. Very small plant populations may experience reduced reproductive vigor due to ineffective pollination or inbreeding depression. There is only one large population of *Solanum nelsonii*, on Nihoa (estimated at 168,000 to 278,000 individuals), and two other isolated populations of more than 100 individuals each at Kuaihelani and Hōlanikū; all other occurrences are very small (fewer than 20 wild individuals each) and widely scattered on islands and atolls.

Climate change loss or degradation of habitat, including drought, flooding and sea level rise—Fortini et al. (2013) conducted a landscape-based assessment of climate change vulnerability for native plants of Hawai'i using high resolution climate change projections. Climate change vulnerability is defined as the relative inability of a species to display the possible responses necessary for persistence under climate change. The assessment concluded that *Solanum nelsonii* is extremely vulnerable to the impacts of climate change with a vulnerability score of 0.966 (on a scale of 0 being not vulnerable to 1 being extremely vulnerable to climate change). In addition, the assessment classified *S. nelsonii* as a “wink-out” species. “Wink-out” species are those with no future climate envelope. No projected suitable climate areas exist for the species to persist into the future. This means that this species must persist within suitable microrefugia or move to newly available climate-compatible areas to avoid extinction. Therefore, additional management actions are needed to conserve this taxon into the future, such as identifying suitable microsites where climate change is anticipated to occur more slowly and considering suitable habitat in areas outside of its known range.

Sea-level rise destruction and degradation of habitat—The effects of climate change resulting in sea-level rise will alter environmental conditions and the ecosystem that support this species, especially as impacts of climate change, such as increase in storm severity and frequency, as well as sea level rise, could continue to degrade the habitat and lead to catastrophic events, both of which can contribute to population extirpations. Although we cannot predict the timing, extent, or magnitude of specific impacts, we do expect the effects of climate change and

associated sea-level rise to exacerbate the threats to *Solanum nelsonii*, especially to populations and individuals on low-lying islands and atolls.

Drought destruction and degradation of habitat—Over the last 100 years, the islands of Hawai‘i have experienced an annual decline in precipitation of over 9 percent, increasing to as much as 15 percent within the last 20 years (US-NSTC 2008, p. 61; Chu and Chen 2005, pp. 4812–4813; Diaz et al. 2005, 4 pp.). Drought affects plants directly by desiccation and limiting the resources needed for survival. The increase in drought frequency and intensity leads to a self-perpetuating cycle of increase in cover of nonnative plants, increase in the number of fires, and an increase of erosion (US-GCRP 2009, pp. 18, 24; Warren 2011). On the main islands of Hawai‘i, episodes of drought have also driven deer farther into urban and forested areas in search of food, increasing their negative impacts to native vegetation from herbivory and trampling (Waring 1996, in litt; Nishibayashi 2001, in litt.).

Flooding destruction and degradation of habitat—In the open sea near Hawai‘i, rainfall averages 25 to 30 in (635 to 762 mm) per year, yet the islands may receive up to 15 times this amount in some places, caused by orographic features (physical geography of mountains) (Wagner *et al.* 1999; adapted from Price (1983) and Carlquist (1980)), pp. 38–39). During storms, rain may fall at 3 in (76 mm) per hour or more, and sometimes may reach nearly 40 in (1,000 mm) in 24 hours, causing destructive flash-flooding in streams and narrow gulches (Wagner *et al.* 1999; adapted from Price (1983) and Carlquist (1980)), pp. 38–39). Erosion and disturbance caused by introduced ungulates exacerbate the potential for flooding, which in turn is a threat to native plants. For those species that occur in small numbers in highly restricted geographic areas, such events have the potential to eradicate all individuals of a population, or even all populations of a species, resulting in extinction.

Tsunami destruction and degradation of habitat—Tsunamis can destroy and modify habitat for species in Papahānaumokuākea and in low-lying coastal areas of the main islands of Hawai‘i. Major tsunamis occur worldwide about once every 10 years, on average, and almost 60 percent of those occur in the Pacific Ocean (Pacific Tsunami Warning Center 2016). In 2011, a tsunami swept over Kuaihelani’s Eastern Island and Hōlanikū’s Green Island, inundating *Solanum nelsonii* plants, spreading plastic debris, and destroying seabird nesting areas, reaching about 150 m (500 ft) inland (Division of Forestry and Wildlife (DOFAW) 2011, in litt.; Starr 2011, in litt.; USFWS 2011, in litt.). This threat could occur at any time and negatively affect occurrences and habitat of *S. nelsonii* at low elevations.

Current Management Actions:

- Surveys and monitoring—
 - Starr et al. (2006) conducted surveys of Spit Island, Sand Island, and Eastern Island in 2006. Plants were found only on Spit Island.
 - The Nature Conservancy Hawai‘i (TNCH) surveys for and provides restoration for rare plant populations and communities within the Mo‘omomi Preserve (TNCH 2011, p. 18–19).
 - DOFAW regularly monitors Kapapa Islet as a State Seabird Sanctuary, with vegetation and outplant monitoring (Misaki 2020, pers. comm.).
 - The Service’s Refuge Biology Program conducts surveys and restoration activities at Midway Atoll National Wildlife Refuge (Duhr-Schultz 2016, p. 1).
 - PEPP monitored wild and reintroduced plants at Mo‘omomi and ‘Īlio Point on Moloka‘i, and at Kaulana on the island of Hawai‘i (PEPP 2009, 2011, 2012, 2013, 2014).
- Ungulate control—
 - TNC has fenced Mo‘omomi Preserve; however, axis deer remain within the area and are difficult to eradicate (Dunbar-Co 2021, in litt.).
- Invasive nonnative plant management—
 - The Service conducts nonnative plant control on Nihoa (Rounds et al. 2020, pp. 4–8, 14–15).
 - DOFAW manages Kapapa Islet and controls nonnative invasive plants (Misaki 2020, pers. comm.).
- Fire management—TNC formed a Task Force for fire management at Mo‘omomi that is administered by the Moloka‘i-Lāna‘i Soil and Water Conservation District as part of the national Coral Reef Task Force Program (TNC 2011, pp. 21–22).
- Control of predation and herbivory by rats—DOFAW monitors Kapapa Islet and currently there are no observation of rodents (Misaki 2020, pers. comm.).
- Captive propagation for genetic storage and reintroduction—
 - The Service’s Refuge Biology Program reported collection of 185 seeds and propagation of 397 plants at the Midway native plant nursery in 2016 (Duhr-Schultz 2016, pp. 2, 4). Seeds and cuttings are collected from the wild population on Manawai, and seeds are collected from populations at Kuaihelani and Nihoa (USFWS 2018a, p. 21).
 - PEPP collected fruit and cuttings from plants at Kaulana Bay (South Point, island of Hawai‘i) and from Mo‘omomi for storage or propagation at VRPF (PEPP 2009, 2014).
 - The Lyon Arboretum Seed Conservation Laboratory reported collection and propagation of seeds of *Solanum nelsonii* (Kroessig 2017, p. 19). Seeds in storage as of 2020 include:

236 seeds representing one founder from Nihoa; 17,190 seeds from six collections from Ni‘ihau (an unknown number of founders); 542 seeds representing one founder from Midway; 2,482 seeds representing one founder from Pearl & Hermes; 16,915 seeds representing at least two founders from Kure Atoll; 73 seeds representing an unknown founder from Moloka‘i; 959 seeds representing five founders from ‘Īlio Point, Moloka‘i; 2,723 seeds representing six founders from Mo‘omomi, Moloka‘i; and 2,334 seeds representing unknown-sourced cultivated stock for research purposes) (Lyon Arboretum 2020).

- Between 2010 and 2019, the Volcano Rare Plant Facility (VRPF) reported propagation and storage of 66 plants representing 18 founders from Kaulana, South Point, island of Hawai‘i (VRPF 2020).
- Maui Nui Botanical Garden (MNBG) collected and stored 500 seeds from 10 reintroductions at Kanahā (sourced from Mo‘omomi) and propagated four plants (MNBG 2019).
- Moloka‘i Land Trust (MLT) reported collection of 100 seeds from plants at Mo‘omomi (MLT 2019).
- From 1990 to 2020, the National Tropical Botanical Garden (NTBG) collected and stored more than 18,000 seeds from plants at Mo‘omomi, and from plants in their living collections on Kaua‘i representing populations at Nihoa and Midway. NTBG also propagated at least 11 plants for their living collections (NTBG 2020).
- The Olinda Rare Plant Facility (ORPF) reported collection of seeds representing two founders from Mo‘omomi (ORPF 2020).
- Waimea Arboretum reported propagation of two plants representing one founder from Midway in 2013, and collection of 22 seeds between 2015 and 2018 representing as many as three founders from Midway (Waimea Arboretum 2013, 2014, 2015, 2017, 2018).
- Reintroduction and translocation—
 - DOFAW manages reintroductions of *Solanum nelsonii* on Kapapa Islet (Ching 2020, in litt.). Plants were reintroduced at the Manukā Natural Area Reserve (NAR); however, their current status is unknown.
 - PEPP reintroduced *Solanum nelsonii* to Kapapa Islet in 2019, using seeds collected and propagated from Nihoa plants (PEPP 2019).
 - Molokai Land Trust reported reintroduction of 45 plants to ‘Īlio Point (MLT 2019).
 - Between 2009 and 2019, VRPF reported reintroduction of 86 plants to Manukā NAR (VRPF 2020).

- The Service’s Refuge Biology Program reported reintroduction of four plants each at Sand and Eastern Island that are now established and are used as a resource to support large-scale propagation from cuttings (Duhr-Schultz 2016, p. 3; USFWS 2018b, entire). The Service, with staff of DOFAW, propagated seeds from Nihoa stock and reintroduced plants at the Kalaeloa Unit of the Pearl Harbor National Wildlife Refuge in 2017 (156 plants), 2018 (172 plants), and 2019 (33 plants) (USFWS 2020). Regeneration from these reintroduced plants has been documented (USFWS 2019b).
- Population biology research—Seed viability testing indicates a 30 to 40 percent germination rate after 12 weeks of storage, suggesting *S. nelsonii* exhibits seed dormancy (Kroessig 2017, p. 19).

Table 1. Status and trends of *Solanum nelsonii* from listing through 5-year review.

Date	No. wild individuals	No. outplanted	Preventing Extinction Criteria identified by HPPRCC	Preventing Extinction Criteria Completed?
2016 (listing)	ca 50 (islands of Hawai‘i and Moloka‘i) 8,290-15,360 (NWHI)	<50 (Hawai‘i) ca 1,000s (NWHI) none survive	All threats managed in all 3 populations	Partially, exclosure on Moloka‘i; but deer difficult to control; some nonnative plant control in NWHI and at reintroduction sites
			Complete genetic storage	Partially
			3 populations with 50 mature individuals each	Yes, in the NWHI
2021 (5-year review)	<10 (island of Hawai‘i) <25 (Moloka‘i) <60 (Manawai) 783 (Kuaihelani) ca 130 (Hōlanikū) 168,00–278,000 (Nihoa)	ca 45 (Moloka‘i) ca 400 (O‘ahu) <10 (NWHI)	All threats managed in all 3 populations	Partially, exclosure on Moloka‘i but deer difficult to control; some nonnative plant control in the NWHI and at reintroduction sites
			Complete genetic storage	Partially, most founders from small populations on atolls of the NWHI represented in collections; ca 13 founders from Moloka‘i, 18 founders from the island of Hawai‘i
			3 populations with 50 mature individuals each	Yes, but only in the NWHI
			Each population naturally reproducing	Partially

Table 2. Threats to *Solanum nelsonii* and ongoing conservation efforts.

Threat	Listing Factor	Current Status	Conservation/Management Efforts
Destruction and degradation of habitat by feral ungulates	A	Ongoing	Partial, an ungulate enclosure on Moloka‘i (no ungulates present in NWHI)
Destruction and degradation of habitat by established ecosystem-altering invasive plants	A	Ongoing	Partial, nonnative plant control at reintroduction sites, on Nihoa, and some of the NWHI
Destruction and degradation of habitat by fire	A	Ongoing	Partial, fire management plan for Mo‘omomi
Predation and herbivory by feral ungulates	C	Ongoing	Partial, an ungulate enclosure on Moloka‘i
Predation and herbivory by rats	C	Ongoing	None (no rats present on NWHI)
Predation and herbivory by nonnative invertebrates	C	Ongoing	None
Inadequacy of regulatory mechanisms	D	Ongoing	None
Low numbers	E	Ongoing	Partial, collection, propagation, and reintroduction
Climate change degradation or loss of habitat	E	Ongoing	Partial, collection, propagation, and reintroduction

2.4 Synthesis

There are approximately 168,00–278,000 wild individuals of *Solanum nelsonii* on the island of Nihoa, with only two other populations in the NWHI larger than 100 individuals (at Manawai and Kuaihelani), and fewer than 35 on the main Hawaiian islands of Hawai‘i and Moloka‘i. A landscape-based assessment of climate change vulnerability for native plants of Hawai‘i using high resolution climate change projections was made by Fortini et al. (2013) and their analysis showed that *S. nelsonii* is extremely vulnerable to the effects of climate change. A fire management plan is implemented for the wild population on Moloka‘i. An ungulate enclosure and control is provided at Mo‘omomi (Moloka‘i); however, deer are within the enclosure and are difficult to control. There is some nonnative plant management within the enclosure and on the NWHI. Seed collection, propagation, and reintroduction efforts are ongoing.

Preventing extinction, interim stabilization, downlisting, and delisting objectives are provided in HPPRCC’s Revised Recovery Objective Guidelines (2011). To prevent extinction, which is the first step in recovering the species, the taxon must

be managed to control threats (e.g., fenced) and have 50 individuals (or the total number of individuals if fewer than 50 exist) from each of three populations represented in an ex situ (at other than the plant's natural location, such as a nursery or arboretum) collection. In addition, a minimum of three populations total should be documented on the islands where they now occur or occurred historically and each of these populations must be naturally reproducing (i.e., viable seeds, seedlings) with a minimum of 50 mature, reproducing individuals per population.

The preventing extinction goals for this species have not been met. Although there are large numbers of individuals in the NWHI, 99 percent of the individuals occur on only one island (Nihoa). There are no populations totaling 50 mature, reproductive individuals on the main Hawaiian Islands. Populations on the smaller islands and atolls of the NWHI are at risk of the effects of climate change and sea level rise. Stochastic events such as tsunamis are a threat to low-lying populations. Seed collections, and propagation are ongoing, with some reintroductions; however, many are unsuccessful and little to no natural recruitment has been reported (Table 1). Not all threats are being sufficiently managed throughout the range of the species (Table 2). Therefore, *Solanum nelsonii* meets the definition of endangered as it remains in danger of extinction throughout its range.

3.0 RESULTS

3.1 Recommended Classification:

☐ Downlist to Threatened

☐ Uplist to Endangered

☐ Delist

☐ *Extinction*

☐ *Recovery*

☐ *Original data for classification in error*

☒ 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

- Surveys and inventories—Continue to conduct surveys for *Solanum nelsonii* in current and potentially suitable habitat, especially in historic and suitable habitat on the main Hawaiian Islands.
- Ungulate monitoring and control—Continue to construct and maintain fenced enclosures to protect individuals from the negative impacts of feral ungulates.
- Nonnative invasive plant management—Continue to implement nonnative plant control. Conduct post-removal treatment with monitoring to determine if recruitment improves.
- Fire management—Continue to develop and implement fire management plans for all populations.
- Predation and herbivory control—Continue to construct and maintain fenced enclosures to protect individuals from the negative impacts of feral ungulates. Develop and implement control methods for rats and nonnative invertebrates. Continue to prevent rats and ungulates from arriving to the NWHI.
- Captive propagation for genetic storage and reintroduction—Continue collection and propagation efforts for maintenance of genetic stock.
- Reintroduction and translocation—Continue to reintroduce individuals to managed suitable habitat to increase numbers of populations and individuals in suitable habitat to build resiliency and redundancy and reduce the impacts of habitat destruction, nonnative plant competition, predation, low numbers, climate change, and stochastic events.
- Population biology research—Continue research regarding failure of reintroductions. Conduct genetic analysis of individuals exhibiting morphological differences.
- Climate change adaptation strategy—Research suitability of habitat in the future due to the impacts of climate change, especially in regards to loss of low elevation habitat in the NWHI.
- Alliance and partnership development—Continue to contribute to planning and implementation of ecosystem-level restoration and management to benefit this taxon.

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U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of *Solanum nelsonii*
(pōpolo)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review:

☐ Downlist to Threatened
☐ Uplist to Endangered
☐ Delist
☒ No change needed

Appropriate Listing/Reclassification Priority Number, if applicable: _____

Review Conducted By:

Cheryl Phillipson, Fish and Wildlife Biologist, PIFWO
Lauren Weisenberger, Plant Recovery Coordinator, PIFWO
Megan Laut, Conservation and Restoration Team Manager, PIFWO

FIELD OFFICE APPROVAL:

for

Field Supervisor, Pacific Islands Fish and Wildlife Office