Species Status Assessment Report

for

Lepanthes eltoroensis

Version 1.1

October 2019

U.S. Fish and Wildlife Service

Region 4

Atlanta, GA

<u>Summary of Version Updates</u>

The changes from version 1.0 (August 2018) and 1.1 (October 2019) are minor and do not change the SSA analysis for *Lepanthes eltoroensis*. The changes were:

1) Page numbers were added to each reference citation.
2) Additional reference citations were added to support information throughout the report.
3) Clarifying information was provided for precipitation, drought, temperature, and life zones in section 6.2.
4) An additional time step (2040) was added to section 6.3 to describe the 3Rs at an intermediate time step compared to the 2100 time step.

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Chapter 1: INTRODUCTION

Lepanthes eltoroensis is a small epiphytic orchid endemic to the El Yunque National Forest (EYNF) in Puerto Rico. It has been listed as an endangered species under the Endangered Species Act of 1973, as amended, since 1991 due to its rarity, restricted distribution, specialized dwarf forest habitat, and vulnerability to habitat destruction or modification. Over the last 27 years, the Service has worked closely with partners to make significant progress toward recovery of the species. The latest 5-year review, completed in August 2015, did not recommend a change from its status as an endangered species. However, information since 2015 indicates that the main threats to the species may be reduced or eliminated. Additionally, recent population estimates indicate there are significantly more individuals that at the time of listing. Therefore, the Service is initiating this Species Status Assessment (SSA) to aid in determining the appropriateness of reclassifying the species.

The SSA framework (USFWS 2016, entire) summarizes the information compiled and reviewed by the U.S. Fish and Wildlife Service (Service), incorporating the best available scientific and commercial data, to conduct an in-depth review of the species' biology and threats, evaluate its biological status, and assess the resources and conditions needed to maintain long-term viability. The intent is for the SSA to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Listing to Consultations to Recovery.

Importantly, the SSA does not result in a decision by the Service on whether this species should be proposed for reclassification under the Act. Instead, this SSA provides a review of the available information strictly related to the biological status of the *Lepanthes eltoroensis*. The reclassification decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies. The results of a proposed decision will be announced in the *Federal Register,* with appropriate opportunities for public input. In the event that the SSA does not support reclassification, the SSA would be used to inform the development of an updated Recovery Plan.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in its natural systems over time. Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire).

- **Resiliency** describes the ability of a species to withstand stochastic disturbance and is positively related to population size and growth rate and may be influenced by connectivity among populations.

- **Redundancy** describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.
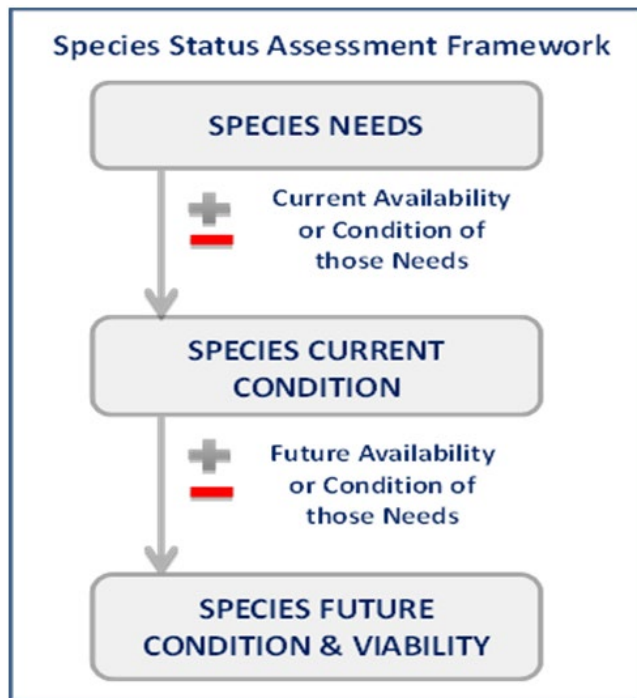
Figure 1.1. Species Status Assessment Framework

To evaluate the biological status of *Lepanthes eltoroensis*, both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA provides a thorough assessment of biology and natural history, and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA includes: (1) Species Biology (2) Species Needs (3) Current Conditions (4) Influences on Viability and (5) Future Conditions. This document is a compilation of the best available scientific and commercial information, and a description of past, present, and likely future risk factors to the *Lepanthes eltoroensis*.

Chapter 2: SPECIES BIOLOGY

2.1 Taxonomy and Species Description

Lepanthes eltoroensis is a member of the genus *Lepanthes,* a large genus of orchids including more than 800 species distributed in the Antilles and from Mexico through Bolivia; approximately 118 species in this genus are from the Caribbean and all but one are single-island endemics (Stimson 1969, p. 332; Barre and Feldmann 1991, p. 11; Tremblay and Ackerman 1993, p. 339; Luer 2014, p. 260). *L. eltoroensis* is closely related to *L. selenitepala* and *L. caritensis*; however, it is distinguished by several morphological features described below.

L. eltoroensis is a small, epiphytic orchid about 1.57 inches (4 centimeters) tall which is distinguished from other members of the genus by its obovate to oblanceolate leaves, ciliate sepals, and the length of the inflorescence (Vivaldi et al. 1981, p. 26; Luer 2014, p. 260). The inflorescence is a long, peduncled raceme (flower cluster with flowers on separate short stalks) with reddish flowers (Figure 2.1). No more than 2 flowers are produced at the same time, and the flowers are open on the inflorescence for about 10 days (Meléndez-Ackerman and Tremblay 2017, p. 1).

Figure 2.1. Image of *L. eltoroensis* on host tree.

2.2 Distribution and Status

L. eltoroensis was listed as an endangered species due to its rarity, restricted distribution, specialized dwarf forest habitat, and vulnerability to habitat destruction or modification (56 FR 60933). *L. eltoroensis* is restricted in distribution to one general area within the sierra palm, palo colorado, and dwarf forests of the El Toro and Trade Winds Trails in EYNF, Puerto Rico (Figure 2.2: USFWS 2015, p. 5), at elevations above 2,461 feet (750 meters) (USFWS 1996, p. 2). The distribution of *L. eltoroensis* has not changed (remains endemic to El Yunque). It grows low on moss covered tree trunks and is locally common but geographically quite restricted (Luer 2014, p. 260).

Figure 2.2. Distribution map of *Lepanthes eltoroensis*.

2.3 Life History

Mortality and Survival

Lifespan is an important life cycle component that should be considered to understand the probability of survival of any species. Tremblay (2000, entire) investigated plant longevity in four species of orchids, including *L. eltoroensis*. Because distribution of the species is within a protected national forest, survivorship is more likely influenced by access to phorophytes, migration ability, reproductive success, and lifespan, rather than other potential human induced threats. The mean lifespan of the species was determined to be 5.2 years, with an average percent mortality of 10% per year, however, this varies greatly among lifestages. Variance in life span of *Lepanthes* varies by stage, where survival increases as they reach later stages (Tremblay 2000, p. 265; Rosa-Fuentes and Tremblay 2007, p. 207); thus, adult stages are more likely to have a longer life span than smaller individuals.

Reproduction and Development

The species is a sympodial (i.e. specialized lateral growth pattern in which the apical meristem is terminated and growth is continued by one or more lateral meristems), caespitose (i.e. growing in clusters or tufts), herbaceous plant that does not reproduce vegetatively (Tremblay and Ackerman 2001, p. 48). Plants are obligate cross-pollinated and protandrous (i.e. male reproductive organs come to maturity before the female) (Tremblay et al. 2006, pp. 76-77; Tremblay and Velazquez-Castro 2009, p. 212). In the case of *L. eltoroensis*, sexual reproduction occurs throughout the year, rather than being confined to a particular season (Tremblay and Hutchings 2002, p. 172).

Reproductive success in this orchid, as in most orchids is pollinator-limited (Tremblay et al. 2005, p. 6). Fruits take up to 6 weeks to develop prior to opening (Meléndez-Ackerman and Tremblay 2017, p. 1). Fruit set is very low, but not atypical of orchids that employ deception to attract pollinators (Zimmerman and Aide 1989, p. 68). In one study, most individuals (83%) never had a fruit during the survey period of 16 consecutive months ending in January 1996; out of 148 adult plants total which were followed, only 17 had one or more fruits (Tremblay 1996, pp. 78, 104, 107). Fruits have about ±2000 seeds per fruit (Meléndez-Ackerman and Tremblay 2017, p. 1) and require a mycorrhizal association for germination and survival until plants start photosynthesis. Seeds are wind dispersed (Tremblay and Ackerman 2001, p. 55).

It is nearly universally acknowledged that orchids are dependent on mycorrhizal fungi, which they parasitize during germination and early developmental stages (Bayman et al. 2002, p. 1002). Although mycorrhizas are less commonly associated with epiphytic orchids compared to terrestrial, temperate orchids, they appear to be important (Bayman et al. 1997, p. 143). Frequency of mycorrhizas in adult plants of epiphytic, tropical orchids varies from very low to very high (Benzing 1982, pp. 608-609; Lesica and Antibus 1990, p. 252), suggesting many species may not be as dependent upon them as adults (Bayman et al. 2002, p. 1002). It is not clear from the literature if the frequency of mycorrhizal infection is determined by the orchid species, the availability of compatible fungi, or environmental factors.

The species has a deceptive pollination system which is typically characterized by very few reproductive events (~ less than 20% chance; Tremblay et al. 2005, p. 12). Although we do not know the pollinator for *L. eltoroensis*, elsewhere *Lepanthes* orchids are visited by fungus gnats (Blanco and Barboza 2005, p. 765) and pollinated by pseudocopulation (i.e. attempted copulation by a male insect with a flower (especially an orchid) that resembles the female in some combination of odor, color, shape, and size, carrying pollen to it in the process). Fragrances of Puerto Rican species of *Lepanthes* have the biochemical signature of insect sex pheromones (Cuevas and Ackerman, unpublished). Fungus gnats do not likely travel far—perhaps tens of meters or even a few hundred (Ackerman 2018, pers. comm.)—limiting pollen dispersal for *L. eltoroensis*. Many epiphytic orchids, including *L. eltoroensis*, have skewed distributions of reproductive success (with considerably low averages) mediated in part by pollinator limitation and short life spans (Calvo and Horvitz 1990, p. 499; Calvo 1993, p. 1033; Tremblay 2000, p. 257; Tremblay et al. 2005, entire).

2.4 Habitat

L. eltoroensis is found growing on moss-covered trunks of upper elevation forests in the Sierra Palm, Palo Colorado, and dwarf forest associations of the EYNF (Figure 2.3; Ewel and Whitmore 1973, pp. 41-49). The Palo Colorado forest type is, in essence, an upland wetland of short-statured trees with shallow root systems. This forest type is found at elevations between 600-1,000 feet, on gentle slopes and valleys, contains approximately 65 tree species, and covers 7,726 acres of the EYNF. In the Sierra Palm forest type, flora does not normally attain great height or large trunk diameters, but it occurs in dense patches within the elevation ranges of both the Palo Colorado and Tabonuco Forest types. This forest type is found on steep slopes, unstable soils and streambeds above 1,500 feet (450 meters) and covers 4,673 acres of the ENYF. The Dwarf Forest types, also known as "elfin woodlands", are found at the upper edges of the Palo Colorado and Sierra Palm Forest Types, near the ridge tops. In this area tree types become shorter, blending into a zone of stunted vegetation. This forest type exists in a zone of water-saturated soils deficient in oxygen. Most mineral inputs for plants become dissolved in the rain and fog. This forest type covers 640 acres on the EYNF.

Relative humidity in all of these forest types ranges from 90 to 100 percent, and cloud cover is continuous during the evening hours and the majority of the day (55 FR 41248), forming at approximately 600 m elevation. Most of the rainfall in the EYNF is orographic (associated with mountains) in nature. Moisture-laden air is carried by wind and forced to ascend over the mountains. The rise in elevation cools the air, causing condensation in the form of rain.

Figure 2.3. *L. eltoroensis* habitat and host tree depicted during recent surveys in EYNF.

Trade winds that originate off the African coast and sweep across the Atlantic Ocean bring the EYNF most of the rain that falls between the months of May and November. Depending on their intensity and speed, these winds can produce a few clouds to several days of cloudy and rainy weather, and occasionally hurricanes. Most of the rain falls as the wind rises over and along the east-west mountain axis. More rain falls on the Luquillo mountains (where the EYNF is located) in the eastern part of the island than the western part, because the moisture-laden trade winds first ascends the eastern slopes. The northern slopes of the mountains also receive more rainfall

than the southern slopes, because their gradual rise to the peaks serves as a natural catchment area, creating a rain shadow on the southern slopes.

Important habitat components seem to be adequate temperature and moisture regimes, open/semi-open gaps in the canopy, and presence of bryophytes, as discussed below. Studies show that higher temperatures and lower moisture availability are negatively correlated with growth, reproduction, and recruitment in certain orchids (Zotz and Schmidt 2006, p. 82; Olaya-Arenas et al. 2011, p. 2044). Tremblay and Salguero-Faría (2001, p. 40) documented increased mortality in an epiphytic orchid population exposed to warmer and drier conditions within its natural habitat. Survivorship may be negatively associated with decreasing rainfall in *L. eltoroensis* (Tremblay 2000, p. 257), and actual correlations for this have been shown in *L. caritensis* (Crain and Tremblay 2017, p. 508) a closely related species.

The amount of light that a plant receives is directly related to canopy cover, and is a factor that will affect a plant's mode of development, growth and reproduction (Ruiz-Canino et al. 2007, p. 357). Indirect evidence suggests gaps in the canopy may be an important habitat factor for *Lepanthes eltoroensis*, and long term abundance trends suggest higher plant counts have been noted after canopies have been opened by events such as hurricanes, situations which may have produced more suitable light qualities (Ackerman 2018, pers. comm.). However, it is important to note that all surveys have taken place along trails where canopy gaps are common, and under natural conditions, such gaps in the canopy are not common, rather the dominant structure in which the species evolved is a dwarf forest with a relatively closed canopy.

Lepanthes spp. are correlated with high levels of moss cover; often there is substantially more moss cover at locations where *Lepanthes* occur than at locations where they do not occur. (Crain 2012, pp. 15-16). Accordingly, bryophytes appear to form a commensalism with this diverse group of orchids, and moss cover seems to be important for orchid growth and survival. Population abundance is positively associated with moss presence in some species of *Lepanthes* (Crain and Tremblay 2012, pp. 89-9; Garcia-Cancel et al. 2013, p. 6), but has not been explored for *L. eltoroensis*. The species has been observed using the moss-covered trunks of several tree

species, and it appears to face the non-windy side of the tree (Tremblay and Velazquez-Castro 2009, p. 215; Tremblay 2008, p. 84).

Epiphytic orchids often exhibit specificity in microhabitat associations (Johansson 1974, p. 100; Pupulin et al. 1995, pp. 49-51; Zotz 2007, p. 128; Adhikari et al. 2012, p. 332; Crain 2012, p. 16), and evidence shows that the distribution of *L. eltoroensis* individuals on a host tree is not random (Meléndez-Ackerman and Tremblay 2017, p. 1). Individual plants are not distributed randomly around the bole of trees; they prefer the northwestern side of the bole (Figure 2.4: Tremblay and Velazquez-Castro 2009, p. 214). This may be linked to the presence of moss cover, as with other local *Lepanthes,* the presence of moss has been shown to be an important factor influencing orchid presence (Tremblay et al. 1998, p. 297) and abundance (Garcia-Cancel et al. 2013, p. 6). There is likely an interaction between the northeastern trade winds and associated rain shadow that creates localized microhabitat differences in temperature and relative humidity leading to optimal and suboptimal habitats within a tree bole. Micro-environmental differences across the bole of the tree hosts (North = wetter and cloudier, South = dryer and more light exposure) may develop as the result of processes related to wind direction. In turn, these microhabitat variations may lead to differential moss cover and perhaps variation in *Lepanthes* orchid densities across the tree trunks as well (Meléndez-Ackerman and Tremblay 2017, p. 1).
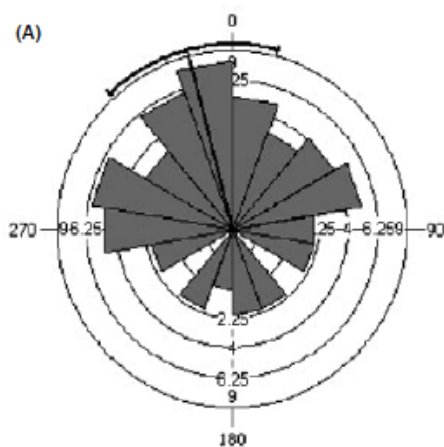

Figure 2.4. Graphical representation of the concentration of orchids on the bole of trees along the Trade Winds Trail and the El Toro trail of 58 trees where orchids were observed. The zero degree represents the magnetic north (*From: Tremblay and Velazquez-Castro 2009, p. 214*).

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2.5 Genetics

Tremblay (1997a, p. 91) found large morphological variance among populations of *L. eltoroensis*, *L. rubripetala*, and *L. rubipestris*, even though populations that share a common gene pool and similar environment are expected to share similar phenotypes and be more similar to each other than populations separated by large distances. It was suggested that, if the morphological variance among populations of these species is not dominated by phenotypic plasticity, then genetic drift and founder effects may be responsible for much of the variance in morphological characters among populations because of the low gene flow and small population size (Tremblay 1997a, p. 92). Recent data strongly suggests that conditions are present for genetic drift in *L. eltoroensis* that may enhance population differentiation (Tremblay and Ackerman 2001, p. 56).

Populations of *Lepanthes* exhibit few adults per population (Tremblay 1997a, p. 95), high variance in reproductive potential, high variance in mean reproductive lifespan (Tremblay 2000, pp. 264-265*),* and low gene flow among populations, resulting in small effective population sizes. Population size is a fundamental parameter in determining the importance of natural selection and genetic drift for population differentiation, where continuous large populations are expected to have larger effective population sizes (Ne) than fragmented small populations, assuming gene flow patterns to be equal. Because the distribution of individual *L. eltoroensis* is not random and given that reproductive effort is highly variable among individuals, it is expected that the effective population size (Ne) will be much smaller than the standing population size (N). Using three different methods for evaluating Ne for three *L. eltoroensis* populations, Tremblay and Ackerman (2001, p. 54) found that Ne spans from 9% to 3% of the standing population. Effective population size is influenced by the lifespan of individuals, and *L. eltoroensis* demographic lifespan ranges in the order of 30 to 50 years (Tremblay 1996, pp. 88-89, 114). Thus, individuals that reach adulthood tend to survive many years, and have an opportunity to contribute offspring to the next generation. Because the effective population size is extremely small, gene flow and selection must be large for genetic drift to be unimportant in the evolution of these species. Thus, rapid genetic differentiation of these orchids with similar

dispersion patterns and reproductive variance is expected (Tremblay and Ackerman 2001, pp. 57-58).

In terms of gene flow, plants that occur on the same phorophyte are more likely to be closely related than those that occur between phorophytes. Using two different estimates of gene flow, both estimates suggest there is less than two effective migrants per generation (the effective generation of the orchid) namely Nm =1.54 (Slatkins method) and Nm (Wrigth) = 0.89 (Tremblay and Ackerman 2001, p. 54). Thus most mating may be among individuals within a host tree, potentially resulting in high inbreeding, which in turn could lead to low genetic variability and inbreeding depression if the pattern is consistent among generations. However, the species is likely an obligate cross pollinated species (Tremblay et al. 2006, p. 78), which is a mechanism to reduce inbreeding, but the breeding system of *L. eltoroensis* needs to be corroborated to determine potential vulnerabilities at the pollination stage.

2.6 Management: Relocation

Researchers conducted a study to evaluate the effect of relocation of *L. eltoroensis* as a management strategy to improve and maximize survival, and reproductive success of this species after hurricane events (Benítez and Tremblay 2003, pp. 67-69). A study conducted in June 2000 consisted of evaluating the populations along the Trade Winds trail and the El Toro trail two years after Hurricane Georges struck the Island. Benítez and Tremblay (2003, pp. 67-69) monitored plants on the fallen trees and plants that where transplanted from fallen trees into standing trees for a period of two years. Their results suggested that plants left on fallen trees had lower survival probability than transplanted individuals. Therefore, the authors recommended relocation or transplanting as a viable strategy for the conservation of this species (Benítez and Tremblay 2003, pp. 67-69).

Chapter 3: SPECIES NEEDS FOR VIABILITY

For the purpose of this report, we define viability as the ability of the species to sustain populations in the wild over time. Species with greater numbers (redundancy) of healthy populations (resiliency), encompassing a broad array of ecological and genetic diversity in a spatial arrangement that maintains adequate gene flow (representation), are more likely to be viable. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation.

3.1 Delineating Populations

There is no agreed upon way to delineate demographic populations of L. *eltoroensis.* Tremblay and Hutchings (2002, p. 166) defined a population as the set of individuals growing on a single host tree, however, as noted by Tremblay (1997a, p. 85), many orchids are distributed in small, hyperdispersed populations, and a metapopulation concept may best apply to this species.

Metapopulations are defined as a set of subpopulations with asynchronous (independent) local dynamics occupying discrete patches (Hanski 1999, entire; Hanski and Gaggiotti 2004, pp. 3-22), so that simultaneous extinction of all subpopulations is unlikely. Persistence requires equilibrium between extinction of populations in occupied patches and colonization of suitable unoccupied patches across the landscape (Johnson 2000, p. 67)). A number of characteristics suggest that a metapopulation approach may be appropriate to understand epiphytic species (Snall et al. 2003, p. 567; 2004, p. 758; 2005, pp. 209-210), like *L. eltoroensis*, and orchid population dynamics. For example, epiphytic orchid species are predisposed to a discrete or patchy distribution (Ackerman 1995, entire; Tremblay 1997a, p. 85) and inhabit ephemeral habitats (Catling et al. 1986, pp. 194-202). Many orchid species also exist as genetically subdivided populations regardless of their habitat (Tremblay and Ackerman 2003, pp. 87-92; and references therein). In addition, a number of studies have shown that patches of orchids may be prone to extinction (Tamm 1991, entire; Vanhecke 1991, entire; Wells and Cox 1989, entire) because of small population size, skewed life span and stochastic reproductive success (Tremblay 1997c, p. 160; Willems 2002 pp. 23-32; Tremblay and Hutchings 2002, entire). For

these reasons, the metapopulation concept seems most appropriate for predicting population dynamics and persistence, and thus viability for *L. eltoroensis.*

One of the most difficult tasks in assessing metapopulation dynamics is being able to define suitable patches (Ouborg and Eriksson 2004, entire). No direct dispersal or genetic data is available to indicate what constitutes a suitable "patch", however individual trees where the species are present do seem to somewhat aggregate in space (Figure 3.1). It is unlikely that there is random interbreeding at the level of these tree aggregates given the species has a deceptive pollination system characterized by very few reproductive events (Tremblay et al. 2005, p. 6). Also, while seeds are wind dispersed, there is high genetic differentiation among host tree patches, with a reported mean tree distance among patches of 38.6 m (Tremblay 1997a, pp. 94-95; Tremblay and Ackerman 2001, p. 48), although new data suggests mean distances among hosts and levels of aggregation should be recalculated (Meléndez Ackerman 2018a, pers. comm.).
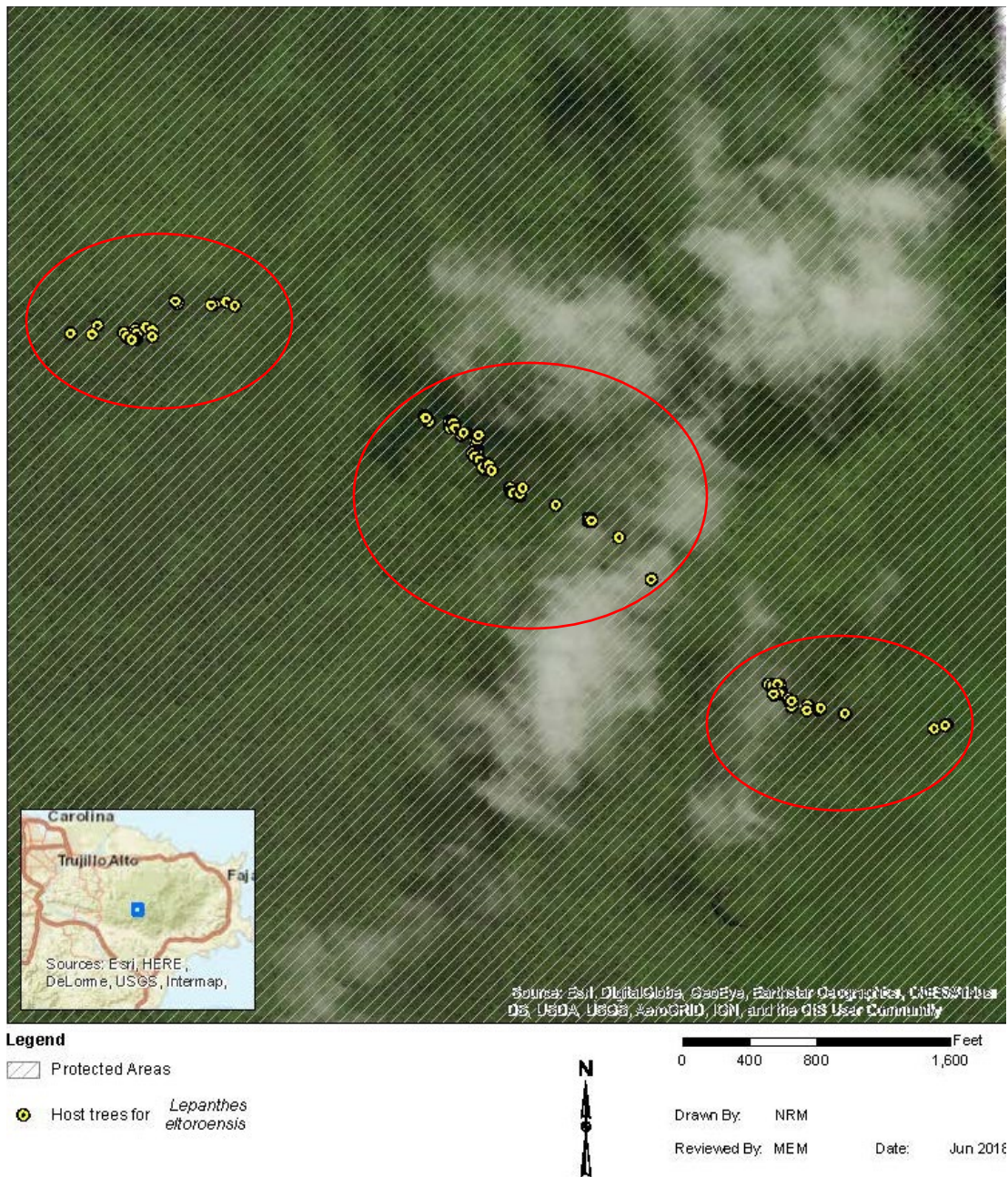
Figure 3.1. *Lepanthes eltoroensis* distribution along the El Toro Trail. Individual host trees where the species is present are patchily distributed.

We assess resilience at the metapopulation level for the purposes of this SSA. The species is one metapopulation consisting of two important aggregate lower levels of clustering: individual trees (subpopulation hereafter) and tree aggregates (patch hereafter). When data is available, we

report resilience metrics at all of these levels, although due to metapopulation dynamics, our ultimate unit of resilience is at the species level.

3.2 Metapopulation Resiliency

For *L. eltoroensis* to maintain viability, the metapopulation and associated subpopulations must be resilient. Other factors that influence the resiliency of *L.* eltoroensis include abundance of individuals and their associated growth trend within host trees, and habitat factors such as elevation, slope, aspect, precipitation, temperature, canopy cover, and presence of moss, mycorrhizal fungi, and pollinators. Influencing those factors are elements of *L. eltoroensis* ecology that determine whether populations can grow to maximize habitat occupancy, thereby increasing resiliency. Stochastic factors that have the potential to affect *L. eltoroensis* include impacts to its habitat from hurricanes and climate change (i.e. changes in temperature and precipitation regimes). Also, urbanization of lands surrounding El Yunque National Forest increases light pollution, generates heat, and subsequently raises the temperature and dew point, reducing cloud cover in upper elevations of the forest (expanded on later in Influences on Viability). These factors and habitat elements are discussed below (Figure 3.2).
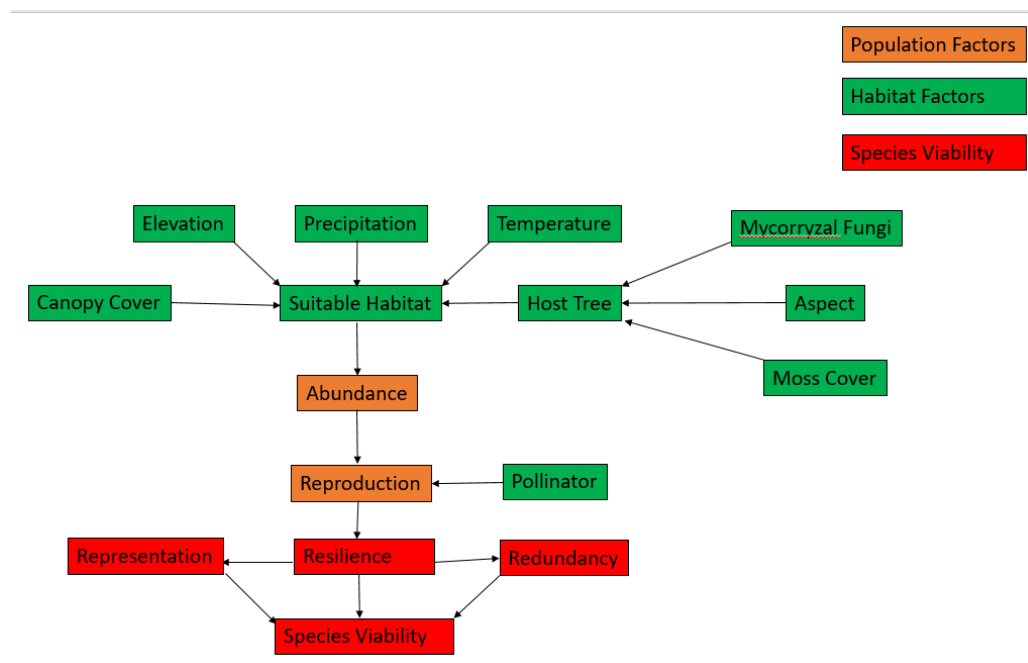

Figure 3.2. Influence diagram depicting the habitat and population factors influencing resiliency for *Lepanthes eltoroensis*.

Abundance

The influence of stochastic variation in demographic (e.g. reproductive and mortality) rates is much higher for small populations than large ones. Stochastic variation in demographic rates causes small populations to fluctuate randomly in size. In general, the smaller the population, the greater the probability that fluctuations will lead to extinction. There are also genetic concerns with small populations, including reduced availability of compatible mates, loss of genetic and morphological variability and potentially inbreeding depression. Small subpopulations of *L. eltoroensis* with insufficient rates of migration and colonization are particularly vulnerable to stochastic events, and thus would be expected to have low resilience. In *L. rupestris,* it has been shown that larger population sizes increase probability of persistence (Tremblay et al. 2006, p. 78), and are correlated with a higher number of reproductive individuals (Gomez-Rivera et al. 2006, p. 115).

At the time of listing in 1991, approximately 140 individuals were known within the metapopulation of *L. eltoroensis*. Additional subpopulations and individuals have been found since the species was listed. Furthermore, the currently known subpopulations appear to be healthy (USFWS 2015, p. 5). Although the recovery plan reported a population of approximately 360 individuals of *L. eltoroensis*, in 1996, Meléndez Ackerman (2007, pers. comm.) indicated that the meta-population appeared stable at about 1,000 individuals during his visit near El Toro trail in July 2007. More recent estimates indicate that the total number of *L. eltoroensis* to be in the range of 3,000 individuals (Tremblay 2008, p. 90; USFWS 2015, p.5). However, this estimate is based on surveys along the existing Trade Winds Trail, and based on Tremblay's opinion that further populations may occur within suitable habitat outside this trail, which is not surveyed due to the inaccessibility and steepness of the terrain. Surveys including habitat outside traditional population sites may result in additional undetected individuals.

A rapid assessment was conducted by Service biologists in 2014 in conjunction with Dr. Raymond L Tremblay on one of the currently known patches of *L. eltoroensis* (Valentin and Labiosa 2014, entire). They found 198 healthy individuals, including seedlings, juveniles, and adults of *L. eltoroensis;* flowers and fruits were also observed. The assessment did not represent an entire survey of the patch because only a short segment of the trail was assessed.

Growth Rates

Individual, demographic, and environmental variation, and the interactions between these sources of variation, can all affect population growth rate. Environmental variation can be further broken down into temporal, spatial and catastrophic variation. For plants, stage-based matrix projection models are more appropriate for analyzing plant population dynamics than age-based models because life history stage (for example, seed, seedling, juvenile, adult, senescent) and size are more important than age in determining demographic parameters (Tremblay and Hutchins 2002 p. 165). For example, in *Lepanthes* spp., survivorship (Tremblay and Ackerman 2001, p. 57) and reproductive effort are more highly correlated with plant stage than with age (Tremblay and Hutchings 2002, p. 165), while in the bromeliad *Tillandsia brachycaulus*, size categories are an effective method for categorizing the life cycle (Mondragón et al. 1999, p. 250; Tremblay and Hutchings 2002, p. 165).

Demographic analyses of *L. eltoroensis* have been conducted using stage-based models, and simulations of demographic stochasticity suggest that these populations are highly sensitive to temporal variation in reproductive success (Tremblay and Hutchings 2002, entire). These analyses assume a more important role for local dynamics relative to regional dynamics, yet the large spatial and temporal variability in demographic parameters in *L. eltoroensis* (Tremblay and Hutchings 2002, p. 179) is similar to that found for *L. rupestris* in this study. Although this early demographic work suggests a generally declining population based on a mean value of k that is less than one (Tremblay and Hutchings 2002, pp. 180-181), it was based on 16 months of census data, which may be insufficient to catch significant declines or increases. Also, the species has never been fully surveyed given studies have only occurred along 2 trails, and it is likely that a large portion of its habitat remains unsurveyed. Finally, long-term work still needs to be done to assess trends and is blind to the impact of stochastic events such as hurricanes. Hurricanes vary in strength and their impact on *L. eltoroensis* dynamics, recruitment, survivorship, and persistence should not be perceived as uniform.

Habitat Factors

Although there are no habitat models for the species, there are a number of habitat factors that are known to be important to subpopulation and meta-population persistence. These factors include canopy cover, presence of mycorrhizal fungi and moss cover, elevation, aspect, temperature, precipitation, and presence of pollinators. Below is a brief description of the importance of each of these factors as they relate to resiliency.

In terms of canopy cover, there are numerous studies on the effects of light environment on plant growth in orchids (Soontornchainaksaeng et al. 2001, entire; Stancato et al. 2002, entire). The amount of light that a plant receives is a factor that will affect its mode of development, growth and reproduction independent of plant density. Life history traits may evolve when light requirements are a limiting factor in the survival of plant populations. For *L. eltoroensis*, there is some indirect evidence that light variability is important habitat factor affecting population size and growth (Ruiz-Canino et al. 2007, p. 357; Fernandez et al. 2003, p. 76). Maximum growth rate has been shown to occur within a narrow range of light (as measured by photon flux density) in *L rupestris* (Ruiz-Canino et al. 2007, p. 359; Fernandez et al. 2003, p. 76). Although we do not know the optimal light environment for *L. eltoroensis,* anecdotal evidence (i.e. presence of plants along trail openings, increased numbers after canopy opening post-hurricane) suggests this species prefers canopy gaps (Ackerman 2018, pers. comm.).

Elevation, aspect, temperature, and precipitation are all habitat factors associated with the cloud forests of EYNF in which the species resides. EYNF has a tropical climate in which there is no wet or dry season; rainfall is constant year round. Due to its location in Northeast Puerto Rico, the incoming trade winds lead to an average annual rainfall of 152 inches of rain per year which increases with elevation, and constant cloud cover through a process called orographic lift. The species is found within the upper elevation forests in the sierra palm, Palo Colorado, and dwarf forest associations, where humidity ranges from 90-100 percent, and cloud cover is continuous (USFWS 2015, p. 5). Figure 3.3 shows the species affinity for two specific vegetation types: Elfin wet and Palo Colorado wet vegetation types. Aspect seems to be important at the scale of the host tree. For example, individual plants are not distributed randomly around the bole of the tree; they show a strong preference for the northwestern side of the bole (Tremblay and

Velazquez-Castro 2009, p. 214), and this seems to be due to an interaction between the northeastern trade winds and associated rain shadows, which create very localized microhabitat differences in temperature and relative humidity leading to optimal and suboptimal habitats within a bole.

Legend

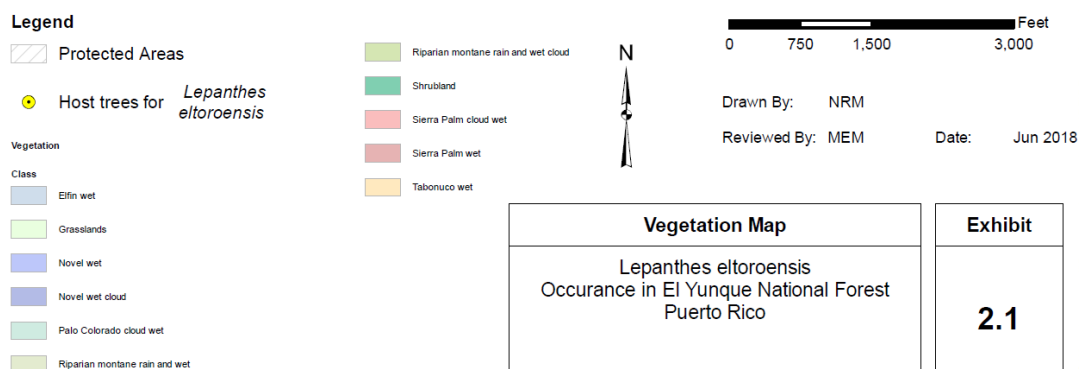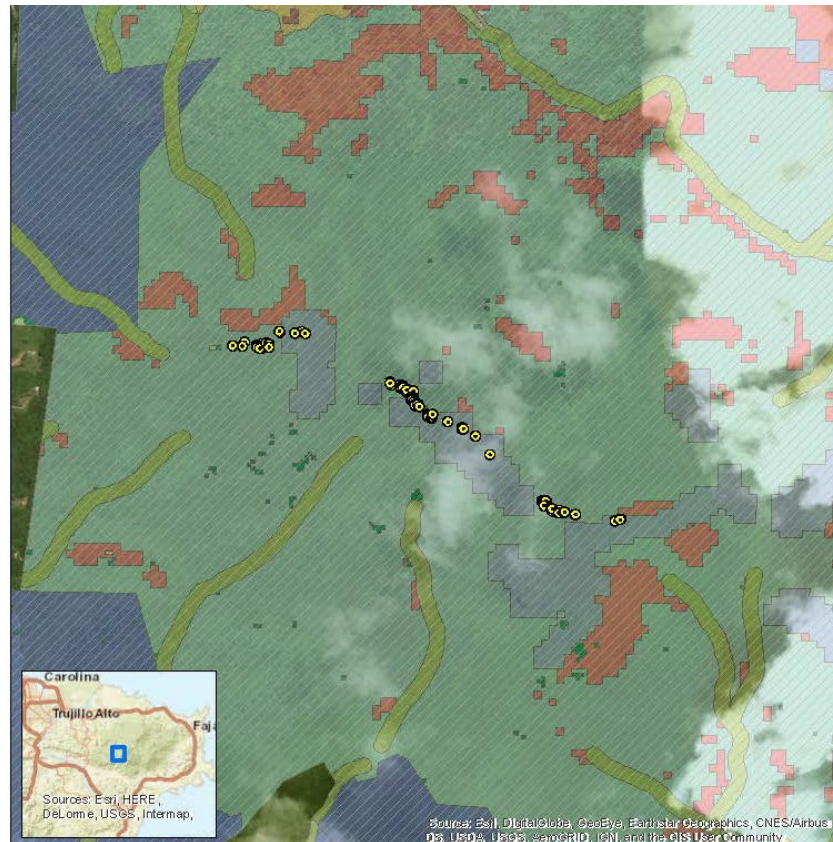|		Vegetation Map	Exhibit
		Lepanthes eltoroensis Occurance in El Yunque National Forest Puerto Rico	**2.1**

Figure 3.3. Distribution of *L. eltoroensis* within various vegetation types in the EYNF. The species shows a strong affinity for the Palo Colorado and Elfin wet forest types.

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As with most epiphytic orchid species, the presence of moss cover seems to be an important habitat factor affecting resilience. Population abundance is positively associated with moss presence in some species of *Lepanthes* (Crain and Tremblay 2012, pp. 89-94; Garcia-Cancel et al. 2013, p. 6), however this needs to be explored for *L. eltoroensis*. Also, these orchids are dependent on mycorrhizal fungi, which they parasitize during germination and early developmental stages. The importance of these mycorrhizal fungi are not well understood throughout all life stages, but they are critically important at seed germination stage and likely for seedlings as well, and not as important to adults (Bayman et al. 2002, p. 1002).

3.3 Species Representation

Representation describes the ability of a species to adapt to changing environmental conditions. We lack genetic and ecological diversity data to characterize representation for *L. eltoroensis*. In the absence of species-specific genetic and ecological diversity information, we typically evaluate representation based on the extent and variability of habitat characteristics across the geographical range. Presumably there is high genetic differentiation across short distances (driven by genetic drift) but variation in ecophysiological traits across landscape features has not been explored. Because the species does not appear to have much physiological flexibility, given that it has a rather restricted distribution (cloud forests on ridges), and after consulting with experts, we decided delineating representative units was not appropriate for this species.

3.4 Species Redundancy

Redundancy describes the ability of a species to withstand catastrophic events by spreading risk among multiple populations to minimize the potential loss of the species. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations). Because of metapopulation dynamics, redundancy for *L. eltoroensis* can be thought of as the total number and resilience of subpopulations and their distribution across the species range. Another way of looking at redundancy is that the species is very restricted in range, and thus is quite vulnerable to catastrophic events, and thus has inherently low redundancy.

Chapter 4: INFLUENCES ON VIABILITY

Aspects of the biological and ecological factors of *L. eltoroensis*, such as narrow tolerance to changes in humidity, light, and temperature, infrequent reproduction, low effective population size, low gene flow and low genetic diversity, and restricted distribution, represent potential negative influences to the viability of the species. These factors are exacerbated by the effects of hurricanes, which can decimate the number of *L. eltoroensis* individuals by killing their host trees or through habitat modification (vegetation openings) that increase light penetration and temperatures that affect the species and its microhabitat. Although low effective population size may be naturally low for *L. eltoroensis*, viability of the species can also be influenced by the low number of adult individuals that contribute offspring to the next generation, and low genetic exchange among individuals from different host trees, particularly when habitat is affected by external factors such as hurricanes. Positive influences to viability relate to laws and regulations that provide protection for the species and its habitat, as well as the ability to relocate individuals to higher quality habitat, particularly as a post-hurricane management response. These influences are described in detail below.

4.1 Forest Management Practices

At the time of listing (1991), forest management practices such as establishment and maintenance of plantations, selective cutting, trail maintenance, and shelter construction were considered threats to *L. eltoroensis* (56 FR 60933). The Recovery Plan further indicated that destruction and modification of habitat might be the most significant factors affecting the number of individuals and distribution of the species (USFWS 1996, p. 5). However, neither document explicitly indicates how destruction or modification of this species' habitat had impacted *L. eltoroensis*, or what activities would modify its habitat. Scientists who have conducted research on this species do not consider destruction, curtailment or modification of this species' habitat to be a factor currently threatening this species (Ackerman 2007, pers. comm.). Both El Toro and Trade Winds trails, where the species is known to occur, receive few visitors and their maintenance is minimal. The implementation of management practices in the forest has improved, no selective cutting is conducted, and the USFS coordinates with the Service to avoid impacts to listed species as part of their management practices. Furthermore, in

2005, the area where *L. eltoroensis* is found was congressionally designated as El Toro Wilderness Area. This area is characterized by undeveloped Federal lands that is managed to retain primitive character without any permanent improvements or human habitation, and managed to preserve its natural conditions (USFS 2016, pp. 1-35). Currently, trails across *L. eltoroensis* habitat are used mostly by researchers and forest personnel, few human encounters are expected on these trails (USFS 2016, pp. 1-35). No evidence is available suggesting forest management practices are negatively impacting the species.

4.2 Overutilization

Collection for commercial or recreational purposes was identified as the cause of the elimination of one population of *L. eltoroensis* (56 FR 60933). Ackerman (2007, pers. comm.,) believes that, although collection of *L. eltoroensis* next to El Toro Trail is a possibility (given that he has observed evidence of collection of other orchid species in the area), the small size (less than 2 inches tall) and inconspicuousness of this species reduces the likelihood of collection. Tremblay (2007, pers. comm.) concurs that the threat of collection is low, because few people venture into El Toro Trail and the species is easily overlooked. Currently, we are not aware of overutilization of this species for commercial or recreational purposes and the species is not considered desirable by collectors (USFWS 2015, p. 8). Additionally, Federal regulations 36 CFR 261.9 (FSM 2673.1) from the USFS prohibit collection of listed plant species in wilderness areas. Thus, we conclude that there is no evidence that overutilization for commercial, recreational, scientific, or educational purposes is currently impacting *L. eltoroensis*.

4.3 Low Subpopulation Size and Reproduction

In general, the smaller the population, the greater the probability that fluctuations in population size from stochastic variation (e.g. reproduction and mortality) will lead to extinction. There are also genetic concerns with small populations, including reduced availability of compatible mates, genetic drift, and inbreeding depression. Small subpopulations of *L. eltoroensis* are particularly vulnerable to stochastic events, thus contributing to lower resilience of the meta-population, and ultimately species viability.

It is possible that *L. eltoroensis* may experience declining growth related to the distribution of individuals among host trees and demographic processes (e.g. reproductive success, survival) which may be negatively influenced by environmental and catastrophic risks. For example, opportunities for establishment may be limited by the fact that fruit production is limited. Less than 20% of individuals reproduce and most subpopulations (60% of host trees) have very few individuals (<15). Also, the distribution of number of individuals (seedling, juvenile and adults) vary enormously among trees and skewed towards few individuals per tree (Tremblay and Velazquez-Castro 2009, p. 214; Figure 4.1).
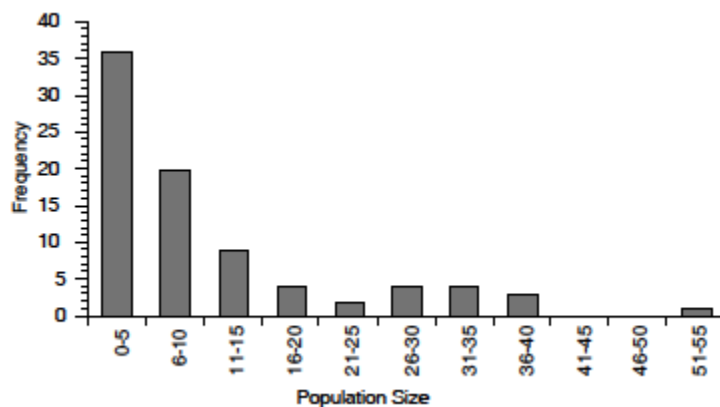
Figure 4.1. Frequency distribution of host trees as a function of the number of orchids they carry (ie. population size)

4.4 Climate Change

Climate projections (from 1960-2099) indicate a 4.6 to 9 °C (20.3 to 48.2 ºF) temperature increase for Puerto Rico (Khalyani et al. 2016, p. 275). Although climate models vary in the degree of warming, it is known that the average temperatures at EYNF have increased over the past 30 years (Jennings et al. 2014, p. 4; Khalyani et al. 2016, p. 277). Also, precipitation is projected to decrease, influenced by warming, and it will tend to accelerate the hydrological cycles resulting in wet and dry extremes (Jennings et al. 2014, p. 4; Cashman et al. 2010, pp. 52-54). In fact, precipitation is projected to decrease faster in wetter regions like the Luquillo mountains, where EYNF is located, and the central mountains of Puerto Rico (Khalyani et al. 2016, p. 274)

Likely, the most important potential risk to the species is the projected shift of the life zones of Puerto Rico from humid to drier. This includes changes in relative area and distribution pattern of the life zones, and the disappearance of humid life zones (Khalyani et al. 2016, p. 275). The areas projected to shift from moist to drier forest will not likely have sufficient climatic support for moist forests regardless of the local conditions, resulting in loss of large areas of rain and moist forests (Khalyani et al. 2016, p. 279). Decreased rainfall in northeastern Puerto Rico (i.e., EYNF) can cause migration, distribution changes, and potential extirpation of many species that depend on the unique environmental conditions of the rain forest (Weaver and Gould 2013, p. 62).

The above projections will have direct implications for *L. eltoroensis* because the acreage of the lower montane wet forest life zone it occupies would decrease, resulting in less habitat available for the species. Also, epiphytes like *L. eltoroensis* will experience moisture stress due to higher temperatures and less cloud cover with a rising cloud base, affecting their growth and flowering (Nadkarni and Solano 2002, p. 584). Due to its specialized ecological requirements and restricted distributions within the dwarf forest, *L. eltoroensis* could be more adversely impacted by climate change than other species with wider distribution (e.g., lower elevation species) and plasticity, thus, reducing its viability.

Local experts hypothesize that predicted changes in climate may have direct or at least indirect effects on *L. eltoroensis* based on its biology or the biology of closely related species. Data from *L. rupestris,* a closely related species, indicate a negative correlation between the average number of seedlings and number of dry days (Figure 4.2), average number of fruits and minimum average temperature, and average number of adults and the maximum temperature. These results were gathered from biannual demographic censuses of 218 sites with values of maxima, minima and averages of climatic variables expressed as biannual values based on the 6-month period prior to each census. Observed lag responses mean that temperature effects on response variables are seen later in time with the magnitude of time determined by the magnitude of the lag. Given that life history stages are similar to *L. eltoroensis* and the species are closely related it is not unreasonable to assume that similar relationships may be found in *L. eltoroensis*, nor to assume that relationships may be even stronger in the later given its restricted distribution

to very wet environments. We know that leaf area is positively correlated with the number of flowers in a related species, *L. caritensis* (previously *L. sanguinea*: Agosto-Pedroza and Tremblay 2003, p. 65, Figure 4.3), so the relationship between climatic variables and reproduction may result from factors that influence growth rate.
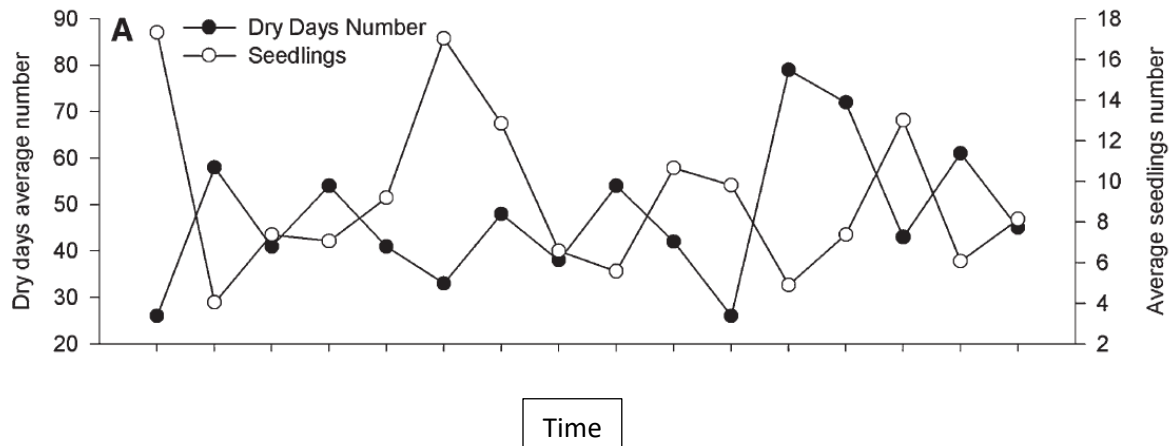

Figure 4.2. Example of negative correlation between the average number of seedlings and number of dry days and associated lag response for *L. rupestris* (from Olaya-Areanas et al. 2009)
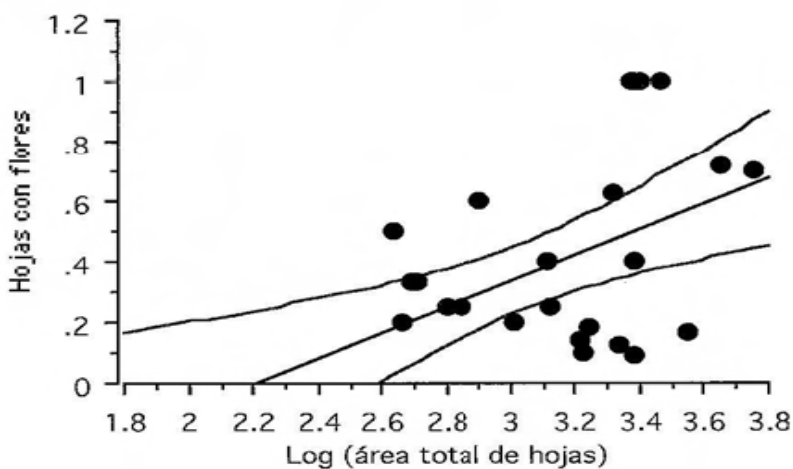

Figure 4.3: The relationship between total leaf area and flower production in *L. caritensis* (previously *L. sanguinea*).

Evidence for indirect effects of climate change include changes in bryophyte cover and composition that may have important implications to *L. eltoroensis*. Data from *L. rupestris* showed that orchid density was positively associated with bryophyte species richness (Garcia-Cancel et al. 2013, p. 6). Other studies also suggest that bryophyte cover can be important for growth and establishment in *Lepanthes* (Crain 2012, pp. 15-16). Therefore, a change in forest temperature and humidity could affect the establishment and distribution of bryophytes and, therefore, *Lepanthes*.

Urban heat islands exist in Puerto Rico where temperatures are higher in developed areas than in rural, vegetated areas (PRCCC 2013, p. 4). For instance, San Juan's observed temperature trend is higher than the rest of the island at 0.022°C/yr (0.04° F/yr) since 1900 (PRCCC 2013, p. 4). If this trend continues, San Juan's average annual temperature will have increased to 27°C (80.6° F) in 2050 (as compared to 25.5°C/77.9° F in 1950) (PRCCC 2013, p. 4). Although development has stalled for now, future urbanization around EYNF, may lead to urban heat island effects and influence cloud formation and cover around the cloud forest.

In a warming climate, the distributions of plant species inhabiting mountain slopes tend to move uphill. However, species abundance may also change, leading to altered dynamics in the plant communities. Rumpf et al. (2018, entire), in a study of nearly 200 mountain species in the European Alps, recorded trends toward increased local abundance in the majority of species. In particular, plants from lower elevations tended to increase in abundance as their upper range limits shifted uphill, whereas those from higher elevations showed the opposite trend. Thus, higher-elevation species are more likely to lose out through the combined effects of climate change and competition. Thus, because *L. eltoroensis* already occurs at higher elevations, climate change combined with potential competition from species at lower elevations would likely result in overall negative impacts to the species.

4.5 Genetic Risks

The main genetic risk factor for the species is low genetic variability. Tremblay and Ackerman (2001, entire) evaluated the effective population size (*Ne*; number of individuals in a population who contribute offspring to the next generation) for three *L. eltoroensis* populations and found

that *Ne* ranges from 9% to 3% of the standing population (*N*; number of individuals in a population). In other words, for every 100 adults, only 9 transfer genes to the next generation. Thus, for the 148 adult *L. eltoroensis* evaluated during their study, the effective population size would be about 13 adult individuals. Following these results, assuming that the approximately 3,000 individuals of *L. eltoroensis* currently estimated are all adults, and that no other processes are affecting the species, about 270 of those would contribute genes to the next generation. Also, although *L. eltoroensis* is estimated to survive for up to 50 years, most seedlings and juveniles die (Tremblay 2000, p. 264). Therefore, very few individuals are responsible for the majority of seeds production, decreasing the likelihood of genetic diversity as a whole in the population (Meléndez-Ackerman and Tremblay 2017, pp. 5-6).

There is evidence for low gene flow in the species. Tremblay and Ackerman (2001, p. 54) estimated gene flow in *L. eltoroensis* using two different methods, and found both estimates were below 2 (Slatkins method: Nm = 1.54 and Wright method: Nm = 0.89). These numbers suggest there are less than two effective migrants per generation (the effective generation of the orchid) (Tremblay and Ackerman 2001, p. 54). These results imply that most mating is among individuals within a host tree, potentially resulting in high inbreeding, low genetic variability, and inbreeding depression (Tremblay and Ackerman 2001, pp. 55-58). Low genetic diversity may be reflected in reduced genetic and environmental plasticity, and thus, low ability to adapt to environmental changes. If there are high rates of inbreeding, and this could lead to inbreeding depression, there could be profound long term negative impacts to the viability of the species.

4.6 Hurricanes

Disturbances such as hurricanes and tropical storms frequently affect the islands of the Caribbean (Figure 4.4; NOAA 2018, unpaginated). *Lepanthes eltoroensis* has an extremely narrow distribution, which makes this species vulnerable to large scale disturbances. As previously mentioned, known occurrences are limited to El Toro and the Trade Winds trails at EYNF. Due to its geographic location, hurricanes are more frequent in the northeastern quadrant of Puerto Rico, where EYNF is located (White et al. 2014, p. 30). The heavy rains and winds associated with tropical storms and hurricanes cause tree defoliation, habitat modification due to falling of trees, and landslides (Lugo 2008, p. 368). Projected changes in hurricane frequencies

(and associated habitat changes: e.g., increased light exposure, reduction in relative humidity) may negatively affect the growth rate of *L. eltoroensis* populations (Tremblay 2008, pp. 89-90). For example, in natural experiments at EYNF after Hurricane Georges, non-transplanted populations of *L. eltoroensis* had negative growth rates while groups of plants that were transplanted to better habitats within the forest had positive growth rates (Benitez and Tremblay 2003, pp. 67-69). In fact, data from *L. rupestris* (a related species) at EYNF showed that an excess of light resulted in reduced growth rates for the species (Figure 4.5; Fernandez et al. 2003, p. 76). Thus, it is expected that growth rates in *L. eltoroensis* may also be affected by an increase in light penetration due to habitat modification (e.g., defoliation) caused by hurricanes.
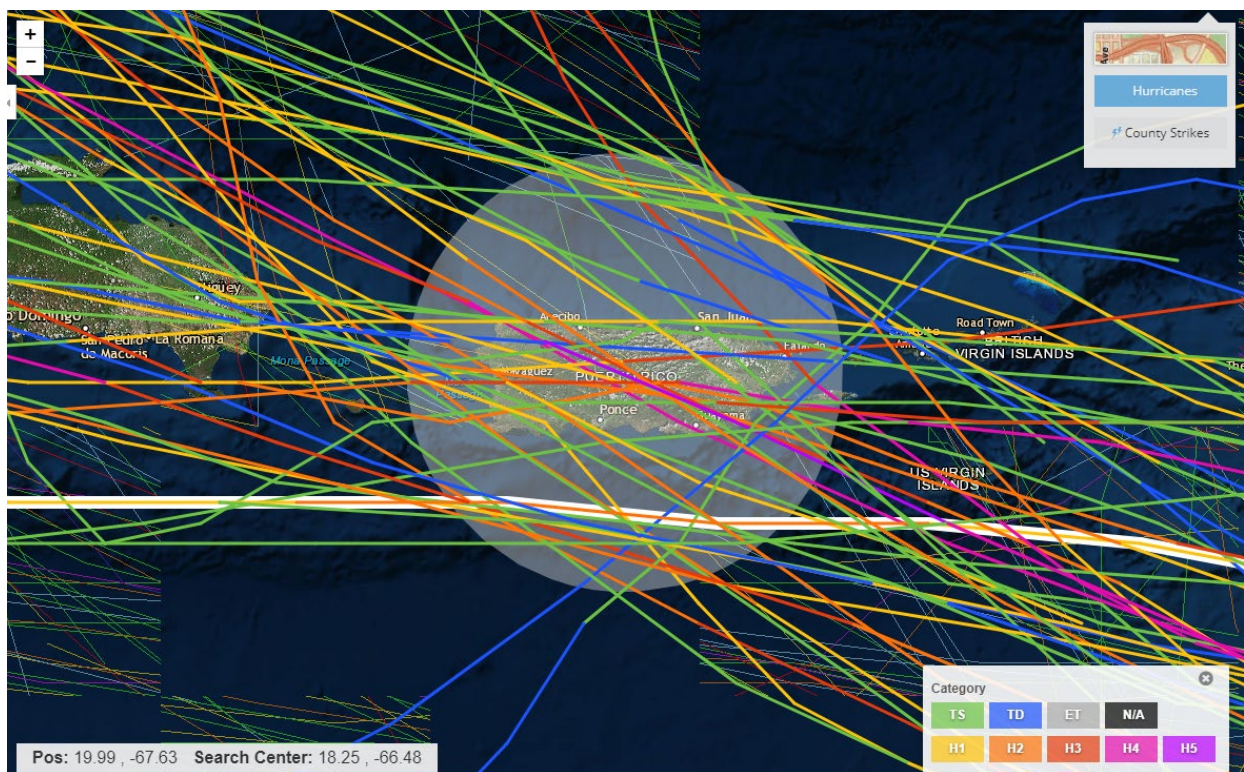
Figure 4.4. Historical hurricane tracks (late 1800s to current) in relation to Puerto Rico (NOAA 2018).
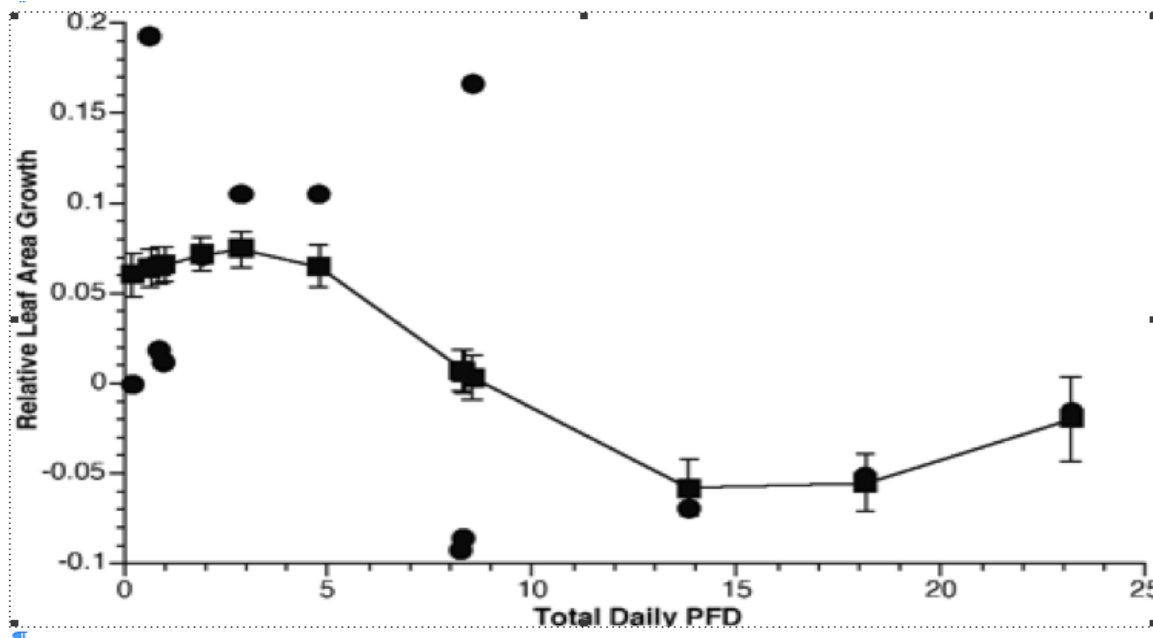
Figure 4.5. Relationship between the Photon Flux density (an index of photosynthetic light availability) and growth rate of individuals at a site. The relationship is clearly on-linear, excess light result in reduced growth rates. Figure not previously published but results mentioned in the Fernández et al., 2003 paper.

Based on the above information, increased frequency of hurricanes is likely, and the inherently low redundancy of *L. eltorosensis* due to its limited range, makes this a primary risk factor. Relocating individual plants as a post-storm response can ameliorate the negative impacts of catastrophic storms, but without this type of management, hurricanes have the potential to have devastating negative consequences to the species viability.

4.7 Conservation Measures

At the time of listing *L. eltoroensis* was not on the Commonwealth list of protected species (56 FR 60933). Commonwealth Law No. 241 (New Wildlife Law of Puerto Rico or *Nueva Ley de Vida Silvestre de Puerto Rico*) was enacted in 1999 to protect, conserve, and enhance native and migratory wildlife species. Specifically, Article 5 of this Law prohibits collection and hunting of wildlife species, including plants within the jurisdiction of Puerto Rico without a permit from the Puerto Rico Department of Natural and Environmental Resources Secretary. This law also

requires authorization from the Secretary for any action that may affect the habitat of any species.

In 2004, *L. eltoroensis* was included in the list of protected species of Regulation 6766 (*Reglamento 6766 para Regir el Manejo de las Especies Vulnerables y en Peligro de Extinción en el Estado Libre Asociado de Puerto Rico*), which governs the management of threatened and endangered species within the Commonwealth of Puerto Rico. Article 2.06 of this Regulation prohibits collecting, cutting, removing, among other activities, listed plant individuals within the jurisdiction of Puerto Rico.

In 2005, the U.S. Congress enacted the Caribbean National Forest Act of 2005 designating El Toro Wilderness Area as a component of the National Wilderness Preservation System under the Wilderness Act (16 U.S.C. 1131 *et seq*.), to preserve its natural conditions, including the species inhabiting the area. In addition, because of the Federal nexus, any action that may affect listed species within EYNF requires Section 7 consultations under the Endangered Species Act.

Another significant conservation measure benefitting *L. eltoroensis* and its habitat since the species was listed is the passing of the Caribbean National Forest Act (2005) officially designating 10,000 acres (4,047 ha) of the EYNF as El Toro Wilderness Area (USFS 2016, p. 32). Currently, a Land and Management Plan is being developed by USFS with the purpose of guiding the general direction of EYNF. This Plan specifically includes a set of standards and guidelines to protect the natural resources within El Toro Wilderness Area, including listed species (USFS 2016, pp. 1, 33-35)

CHAPTER 5: CURRENT CONDITION

5.1 Abundance

Below, we describe all historical and current surveys, and population estimates for *L. eltoroensis*. Surveys were not standardized, so growth rates and reliable estimates of total number of individuals are not available. Compounding this problem is the lack of a habitat model, or a complete census for the species. Our approach to describing viability of the species is limited to qualitative descriptions of individual number of plants and general trends over time. Several experts have made general estimates of abundance for the species, and these are included as well.

Historical Counts (1991-1996)

Early reports of abundance for the species were estimates, and are not based off of standardized, repeated census surveys. As described earlier in the report, at the time of listing, 140 individuals were known within the meta-population of *L. eltoroensis.* The original recovery plan (1996, p. 2), reported the species was only present at six discrete sites, and the population was estimated at approximately 360 individuals within those six known sites. The most likely reason for the increase in number of estimated plants from listing to recovery plan, was increased effort in finding the species, and not from natural population growth.

Post-Hurricane Georges Surveys (2000)

Hurricane Georges was a powerful and long-lived Cape Verde-type Category 4 hurricane which caused severe destruction as it traversed the Caribbean and Gulf of Mexico in September 1998, making eight landfalls along its path. Because of the damage the hurricane potentially inflicted on *L. eltoroensis*, Dr. Raymond Tremblay conducted a post-storm survey in 2000 to determine the status of the species (Tremblay, 2018 Pers. Comm.). Table 5.1 shows the result of these surveys. There were 706 individual plants detected across 72 subpopulations (i.e. host trees). The average number of plants per host tree was 10.5, with some trees having as few as 1 individual present, to a high of 51 individuals. It is important to note that these surveys were limited to detections right on the trails, or a very short distance from the trails, thus this was not a

complete census, and the total number of individuals detected does not represent an estimate of total population size.

Table 5.1. Post-Hurricane Georges conducted in 2000 on Trade Winds and El Toro trails. Subpopulation ID denotes individual host trees, and the number of individuals refers to the number of individual *L. eltoroensis* plants found on each host tree.

Subpopulation ID	Trail	Number of individuals
203	Trade Winds	35
901	Trade Winds	
204	Trade Winds	1
205	Trade Winds	7
206	Trade Winds	1
207	Trade Winds	1
209	Trade Winds	2
210	Trade Winds	3
902	Trade Winds	
211	Trade Winds	1
212	Trade Winds	3
213	Trade Winds	2
214	Trade Winds	3
215	Trade Winds	3
216	Trade Winds	2
217	Trade Winds	15
218	Trade Winds	
903	Trade Winds	6

Subpopulation ID	Trail	Number of individuals
219	Trade Winds	19
220	Trade Winds	14
new	Trade Winds	
222	Trade Winds	20
229	Trade Winds	4
231	Trade Winds	2
933	Trade Winds	
232	Trade Winds	1
234	Trade Winds	5
235	Trade Winds	7
236	Trade Winds	18
237	Trade Winds	5
238	Trade Winds	30
239	Trade Winds	10
240	Trade Winds	10
241	Trade Winds	5
242	Trade Winds	20
243	Trade Winds	11
245	Trade Winds	5
246	Trade Winds	6
247	Trade Winds	4
248	Trade Winds	1
new	Trade Winds	11

Subpopulation ID	Trail	Number of individuals
250	Trade Winds	30
251	Trade Winds	11
252	Trade Winds	3
253	Trade Winds	9
254	Trade Winds	6
255	Trade Winds	8
258	Trade Winds	18
259	Trade Winds	2
new	Trade Winds	2
260	Trade Winds	8
261	Trade Winds	2
262	Trade Winds	25
263	Trade Winds	26
264	Trade Winds	30
266	El Toro	8
268	El Toro	51
270	El Toro	25
271	El Toro	35
272	El Toro	4
273	El Toro	26
274	El Toro	6
275	El Toro	7
276	El Toro	13

Subpopulation ID	Trail	Number of individuals
277	El Toro	7
278	El Toro	35
279	El Toro	7
280	El Toro	1
281	El Toro	1
new	El Toro	3
282	El Toro	1
283	El Toro	3
Total Count		**706**

Mark Recapture Surveys (2000-2005)

Starting in September of 2000, Dr. Tremblay started a series of mark-recapture surveys for the species. A total of 12 surveys over the course of approximately 5 years consisted of re-visiting 21 host trees and counting the total number of individuals present. The results of these surveys can be found in Table 5.2. On average, there were 443 individuals present across the 21 sample host trees. The trend line for abundance through time (Figure 5.1) shows the subpopulations surveyed were relatively stable over the 5 year period.

Table 5.2. Results of Dr. Tremblay's mark-recapture surveys for *L. eltoroensis* from 2000-2005 (Tremblay 2018, pers. comm.).

Date of Survey	# of individuals counted
September 2000	404
October 2000	416
November 2000	433
January 2001	449

Date of Survey	# of individuals counted
September 2001	541
February 2002	480
June 2002	428
December 2002	381
September 2003	427
December 2003	471
June 2004	428
January 2005	456
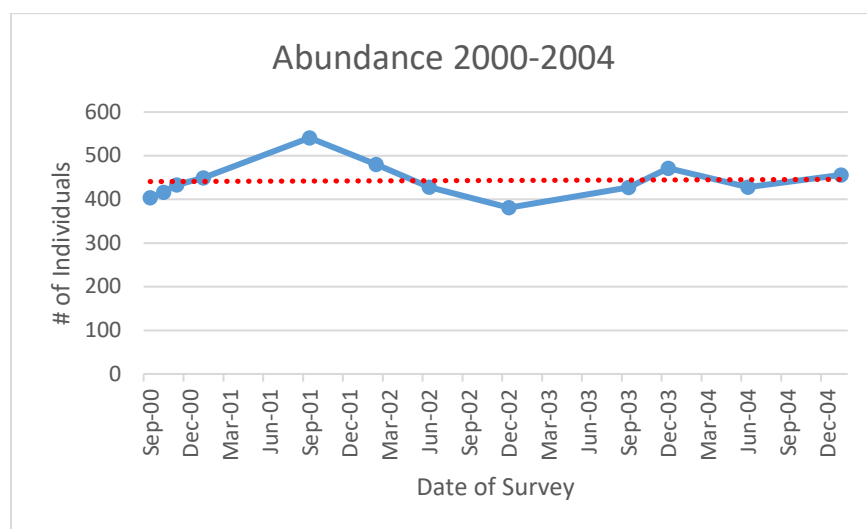
Figure 5.1. Abundance trends in mark-recapture surveys conducted on 21 host trees 2000-2004. Trend line for abundance through time is indicated by the red dashed line.

Rapid Assessment (2014)

On February 14, 2014 Service Staff with the assistance of Dr. Tremblay, visited a section of the Trade Winds Trail of El Yunque National Rain Forest to conduct a rapid assessment of *L. eltoroensis* (Valentin and Labiosa 2014, entire). The purpose of this site visit was to locate *L.*

eltoroensis, conduct a rapid assessment about the current population status of this species and carry out a Five Factor Analysis in Trade Winds Trail located at El Yunque National Forest.

The area was surveyed by walking part of the Trade Winds Trail (from HWY 191 to El Toro Peak) observing every tree trunk searching for *L. eltoroensis.* The rapid assessment included the counting and identification of each observed plant defined by Dr. Tremblay as: seedlings (small plants without a petiole on any stem), juveniles (individuals with at least one lepanthiform sheath on the petiole and no current or previously-produced inflorescences), adults without flowers (individuals that were not currently flowering, but which carried dried inflorescence from a previous flowering event), and adults with flowers or fruits (individuals currently reproductive; have active inflorescences; or having the potential for reproduction) (Figure 5.2). GPS points were taken to mark every tree where *L. eltoroensis* were found.

Results of the rapid assessment were as follows: 37 seedlings, 62 juveniles and 99 adults, for a total of 198 individuals were found (Table 5.3). As part of these observations, 92 flowers and 4 fruits within the 198 plants were found (Table 5.3). All these individuals were observed growing on Sierra Palms (*Prestoea montana*) and Yagrumo (*Cecropia schreberiana*) trunks. Abundant mosses and liverworts up to 1 cm long were observed on the trunks in which the orchid grows. In addition to the abundance of these mosses and liverworts, two species of orchids (*L. dodiana* and *L. woodburyana*) identified by Dr. Tremblay, were observed to be growing on the same tree trunks where *L. eltoroensis* was found. It is important to mention that the surveyed area did not cover the entire Trade Winds Trail, and surveyors did not visit the El Toro Trail or any off-trail portions of potential habitat. Therefore, this number represents only a portion of the entire population.

In conclusion, the visited area showed suitable conditions for the continued existence of this species. The individuals observed were in good health. Since the Trade Winds Trail only receives few visitors during the year, and minimal maintenance activities are conducted, curtailment or modification of this species habitat is not considered a factor that current threat this species. However, surveyors note that natural disturbances such as hurricanes, landslides and climate change could represent a threat to *L. eltoroensis*.
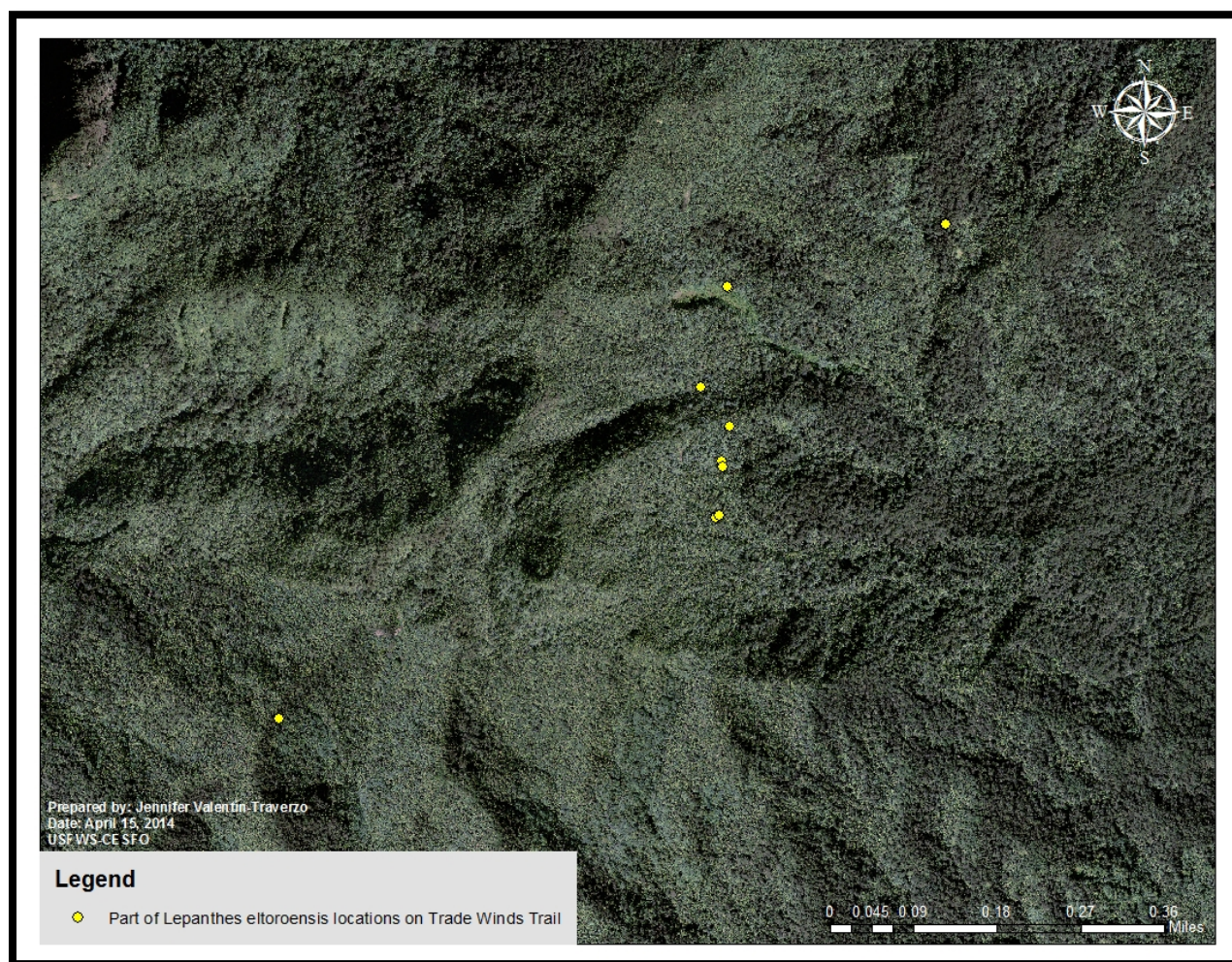
Figure 5.2. Map showing the surveyed area on February 14, 2014. Each point represents a location of a tree with part of the population of *L. eltoroensis*.

Table 5.3. Results of the rapid assessment survey for *L. eltoroensis* conducted along Trade Winds Trail in 2014.

Tree Number	*Altitude (meters)	Seedlings	Juveniles	Adults	Total	Number of flowers	Number of fruits	Comments
934	845m	0	0	1	**1**	2	0	Only one plant found alive.
908	848m	1	1	2	**4**	0	0	Found 12 tags with no plants (12 plants dead). New plants found with no tags.
Tree on the south side of the trail across from 908		7	0	17	**24**	11	1	
906		0	0	0	**0**	0	0	All plants dead. Tags found for 15 plants and all plants were dead.
824		0	1	0	**1**	0	0	Found tags for 8 plants which were dead, apart for the single individual plant which was alive which had no tag.
**1	805m	5	6	15	**26**	10	1	Found at the small prairie
**2	853m	0	0	11	**11**	9	0	Found at the small prairie
**3	835m	11	5	28	**44**	33	0	Found in a Sierra Palm
**4		0	3	0	**3**	0	0	Found in a Sierra Palm
**5	842m	4	5	9	**18**	11	1	Found in a Yagrumo (*Cecropia schreberiana*)
904		4	4	8	**16**	14	0	Found 13 plants with tag that are dead. Found in a Sierra Palm.
266		5	36	7	**48**	2	1	Found 8 plants with tag dead. No new plants found.
229	843m	0	1	1	**2**	0	0	Several individuals were trasplanted to this tree, and we only found 2 individuals alive.
Total:		**37**	**62**	**99**	**198**	**92**	**4**	

*Altitude taken using a Garming 76CSx GPS unit.

**Trees found without tag number. It is not known whether they were previously tagged trees or trees with new populat

Post-Hurricane Maria Surveys (2018)

Hurricane Maria is regarded as the worst natural disaster on record in Dominica and Puerto Rico. The tenth-most intense Atlantic hurricane on record and the most intense tropical cyclone worldwide of 2017, Maria was the thirteenth named storm, eighth consecutive hurricane, fourth major hurricane, second Category 5 hurricane, and the deadliest storm of the hyperactive 2017 Atlantic hurricane season. At its peak, the hurricane caused catastrophic damage and numerous fatalities across the northeastern Caribbean, compounding recovery efforts in the areas of the Leeward Islands already struck by Hurricane Irma. Maria was the third consecutive major hurricane to threaten the Leeward Islands in two weeks, after Irma had made landfall in several of the islands two weeks prior and Hurricane Jose passed dangerously close shortly afterwards, bringing tropical storm force winds to Barbuda. A recent study on the impact of Hurricane

Maria on vegetation in Puerto Rico using remote sensing found that different land cover types had different sensitivities to Hurricane Maria, where cloud forest was the most sensitive type (Figure 5.3), and that vegetation damage was highly correlated with distance from the storm center (Hu and Smith 2018, p. 827). Since the cloud forest includes elfin, palm, and tall cloud forests, which are much taller than other vegetation, they are much more easily affected by strong winds, and need more time to recover (Hu and Smith 2018, p. 827). A confounding factor is that the taller forests are typically on higher ground, making them more exposed to high winds (Hu and Smith 2018, p. 827). Hurricanes don't just impact the canopy of forests, but also the forest floor. A recent study showed that Hurricanes Irma and Maria deposited a pulse of litter deposition equivalent to or more than the average total annual litterfall input with at least a doubled fraction of woody materials (Liu et al. 2018, p. 367). This pulse of hurricane-induced debris and elevated proportion of woody component may trigger changes in biogeochemical processes and soil communities in these Puerto Rican forests (Liu et al. 2018, p. 367).
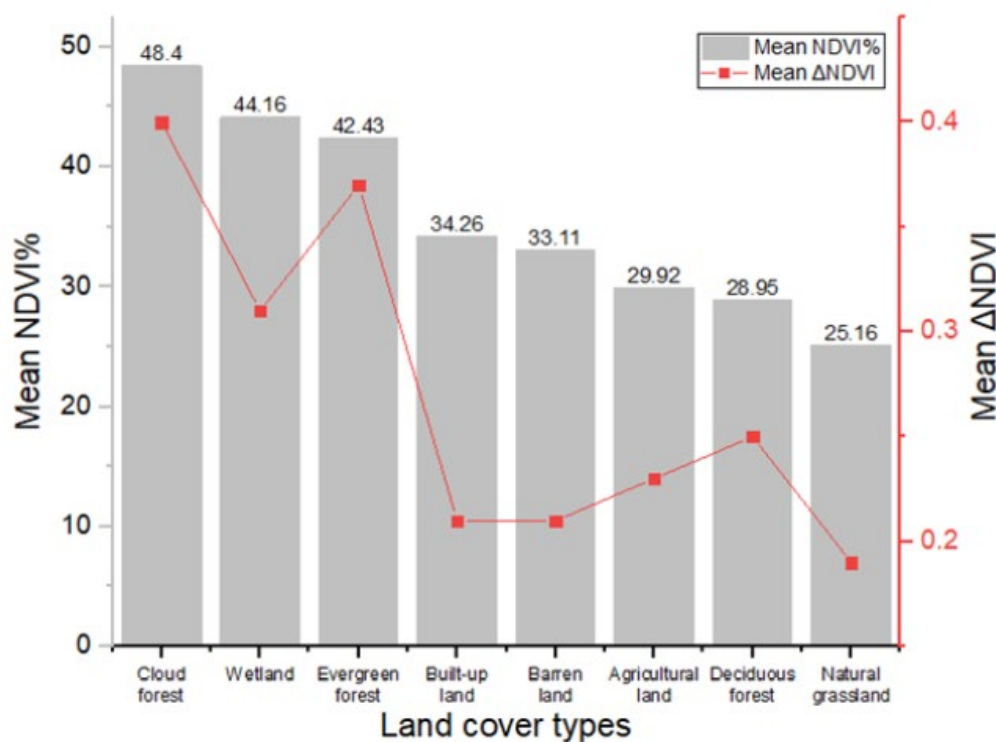

Figure 5.3. Change in vegetation within various land cover types post-Hurricane Maria based on Normalized Difference Vegetation Index (NDVI). *From: Hu and Smith 2018.*

Figure 5.4 shows the distribution of known host trees along El Toro trail for *L. eltoroensis* pre-Hurricane Maria. Recent surveys conducted along El Toro Trail, Feb 13-March 1, 2018, focused on assessing the impacts to the species and its host trees by locating individual *L. eltoroensis* plants, relocating known host trees, and assessing host tree loss and/or condition (Figure 5.5). An important note: only El Toro Trail was surveyed; we do not have post-hurricane data for Trade Winds Trail. Sampling consisted of checking host trees 15 meters on each side of the El Toro Trail, and when a tree was positive for *L. eltoroensis*, the surrounding 5 meter circular buffer was also checked. Table 5.4 summarizes the results of these surveys. Nineteen (19) host trees were not found (assumed to be lost due to the hurricane), with an additional 9 host trees knocked down. There were 322 individuals found on previously marked host trees, and 319 new individuals found, for a total of 641 total plants (Meléndez-Ackerman 2018b, pers. comm.). The total number of plants includes seedlings, juveniles, as well as reproductive and non-reproductive adults. Of the 641 total plants found, 191 individuals were on host trees that were knocked to the ground (Meléndez-Ackerman 2018b, pers. comm.). This is important because *L. eltorensis* does not persist on felled or dead trees. If we assume individuals on felled trees will not survive, then the population will lose approximately 30% of the individuals, a drastic decrease. Unfortunately, we do not have data on the amount or proportion of host trees lost for previous hurricanes (e.g. Hugo and Georges), as these type of data would help to indicate the importance of host trees as a potential limiting factor, considering the limited ability of the species to colonize other hosts. Based on previous efforts, we know individual plants can be moved to new host trees and do quite well, highlighting the importance of relocation in maintaining long term viability in the context of destructive hurricanes such as Hurricane Maria.

Figure 5.4. Distribution of *L. Eltoroensis* host trees along El Toro trail pre-Hurricane Maria.

Figure 5.5. Assessing host tree damage during surveys for *L. eltoroensis.*

Table 5.4. Results of the post-Hurricane Maria survey effort. Of particular note: host condition refers to the condition of the host tree with red text denoting a host tree that was missing (presumably due to hurricane) and blue text denoting new subpopulations found.

Name	Host Species	Host Condition	Trail	Seedlings	Juveniles	Adults	Total
ET-1	Micropholis sp.	Up, Broken Branches	ET	0	17	6	23
ET-2	Prestoea sp.	Up, NO Canopy	ET	0	0	0	0
ET-3		NOT FOUND	ET				
ET-4		NOT FOUND	ET				
ET-5		NOT FOUND	ET				
ET-49	Micropholis sp.	Down	ET	2	14	38	54
ET-6	Micropholis sp.		ET	1	2	1	4
ET-7	Clusia minor		ET	0	0	0	0
ET-8		NOT FOUND	ET				
ET-9	Unknown	Slightly down, Broken Branches	ET	0	0	0	0
ET-10		NOT FOUND	ET				
ET-11	Clusia ninot	Split, Broken branches	ET	0	3	1	4
ET-12		NOT FOUND	ET				
ET-13		NOT FOUND	ET				
ET-14		NOT FOUND	ET				
ET-15	Marcgravia sp. (Liana)	Alive	ET	0	0	2	2
ET-16	Micropholis sp.	Up, NO Canopy	ET	3	18	33	54
ET-17	Micropholis sp.	Up, Broken Branches	ET	0	2	5	7
ET-18	Micropholis sp.	Up	ET	2	3	0	5
ET-50	Micropholis sp.	Up	ET	0	9	14	23

Name	Host Species	Host Condition	Trail	Seedlings	Juveniles	Adults	Total
ET-19	Micropholis sp.	Up, NO Canopy	ET	0	0	0	0
ET-20		Up	ET	0	1	1	2
ET-21	Malgravia rectiflora + Micropholis		ET	1	14	18	33
ET-22	Malgravia rectiflora + Micropholis	Up, WITH Canopy	ET	0	0	4	4
ET-51	CLUSIA sp.	Down, WITH Canopy	ET	0	0	2	2
ET-23	CLUSIA sp.	Down, WITH Canopy	ET	1	4	5	10
ET-24		NOT FOUND	ET				
ET-25	Micropholis sp.**	Split, Broken branches, WITH Canopy	ET	2	8	18	28
ET-26		Up, WITH Canopy	ET	0	1	6	7
ET-27		Up, WITH Canopy	ET	3	8	15	26
ET-52	Micropholis sp.	Up, WITH Canopy	ET	0	9	10	19
ET-28		Up	ET	0	0	2	2
ET-29	Micropholis sp.	Split, Broken branches, WITH Canopy	ET	1	4	5	10
ET-53	Ilex sp	Down, WITH Canopy	ET	0	1	1	2
ET-54		Up	ET	0	2	1	3
ET-56	Clusia sp.	Down, Uprooted	ET	8	6	16	30
ET-57	UNKNOWN	Cut	ET	1	4	1	6
ET-30		NOT FOUND	ET				
ET-31		NOT FOUND	ET				

Name	Host Species	Host Condition	Trail	Seedlings	Juveniles	Adults	Total
ET-32	UNKNOWN	Down	ET	0	2	3	5
ET-34	UNKNOWN		ET	0	0	0	0
ET-33	UNKNOWN	Down, Dead	ET	0	0	0	0
ET-37	UNKNOWN	Split	ET	0	3	7	10
ET-35		NOT FOUND	ET				
ET-36	Clusia sp.	Uprooted	ET	1	3	9	13
ET-38	Clusia sp.		ET	5	18	11	34
ET-39		NOT FOUND	ET				
ET-40		NOT FOUND	ET				
ET-41		NOT FOUND	ET				
ET-42		NOT FOUND	ET				
ET-43		NOT FOUND	ET				
ET-44	Clusia sp.	Broken branches	ET	7	0	5	12
ET-58	Clusia sp.	Broken branches	ET	2	3	26	31
ET-59	UNKNOWN	Down, Broken branches	ET	4	20	32	56
ET-60	Clusia sp.	Cut	ET	0	0	1	1
ET-45		NOT FOUND	ET				
ET-46	UNKNOWN	Up, Broken branches	ET	1	5	0	6
ET-47	Clusia sp.	Broken branches	ET	7	3	11	21
ET-48		NOT FOUND	ET				
ET-61	Clusia sp.	Down, Broken branches	ET	11	9	5	25

Name	Host Species	Host Condition	Trail	Seedlings	Juveniles	Adults	Total
ET-62	UNKNOWN	Up, Broken Branches	ET	14	18	14	46
ET-63	Clusia sp.	Broken Branches	ET	7	10	4	21

Summary

As indicated previously, surveys for *L. eltoroensis* have been infrequent, sparse, and done with varying spatial spread and methodology, making the results difficult to compare over time. An important point is that there has never been a complete census of the entire meta-population because most of the areas off the two main trails (El Toro and Trade Winds) are dangerous and mostly inaccessible. All the estimates from previous surveys are likely to substantially underestimate the true abundance of the species. Table 5.5 synthesizes all of these disparate survey sources for comparison. The best estimate we have for the current total abundance of the species comes from Tremblay (2008, p. 90), in which he indicated that the total number of *L. eltoroensis* could be estimated to be in the range of 3,000 individuals. However, this estimate is based on surveys along the existing Trade Winds Trail, and in his opinion, further populations may occur within suitable habitat outside this trail. No surveys have confirmed this estimate as of yet.

Table 5.5. Summary of surveys with associated abundance for *L. Eltoroensis.*

Survey Time	Survey Type	# of plants	Sampling Frame
2000	Post-hurricane assessment	706	72 host trees—17 on El Toro Trail and 55 on Trade Wind.
Sept 2000	Mark-Recapture	404	21 host trees—subsample along both El Toro and Trade Wind Trails
Oct 2000	Mark-Recapture	416	21 host trees—subsample along both El Toro and Trade Wind Trails
Nov 2000	Mark-Recapture	433	21 host trees—subsample along both El Toro and Trade Wind Trails
Jan 2001	Mark-Recapture	449	21 host trees—subsample along both El Toro and Trade Wind Trails
Sept 2001	Mark-Recapture	541	21 host trees—subsample along both El Toro and Trade Wind Trails
Feb 2002	Mark-Recapture	480	21 host trees—subsample along both El Toro and Trade Wind Trails
June 2002	Mark-Recapture	428	21 host trees—subsample along both El Toro and Trade Wind Trails
Dec 2002	Mark-Recapture	381	21 host trees—subsample along both El Toro and Trade Wind Trails
Sept 2003	Mark-Recapture	427	21 host trees—subsample along both El Toro and Trade Wind Trails
Dec 2003	Mark-Recapture	471	21 host trees—subsample along both El Toro and Trade Wind Trails

Survey Time	Survey Type	# of plants	Sampling Frame
June 2004	Mark-Recapture	428	21 host trees—subsample along both El Toro and Trade Wind Trails
Jan 2005	Mark-Recapture	456	21 host trees—subsample along both El Toro and Trade Wind Trails
2014	Rapid Assessment	198	13 host trees—partial survey on Trade Winds Trail only
2018	Post-Hurricane Assessment	641	62 host trees (19 missing)—El Toro Trail only

In the absence of complete census data, it can be useful to look at general population trends to indicate species health and persistence. Overall data does not indicate a general pattern of population decline, but rather natural fluctuations which the species may be vulnerable to in the context of its threats. It is possible that *L. eltoroensis* experiences declining population growth related to its inherent frequency distribution of population sizes and demographic processes, which may be further negatively influenced by environmental and catastrophic events. For example, opportunities for *L. eltoroensis* establishment may be limited by the fact that fruit production is limited in the species. Less than 20% of individuals reproduce, and moreover, about 60% of host trees have very few individuals (<15) (Tremblay and Velazquez-Castro 2009, p. 213).

Dr. Tremblay, conducted a preliminary analysis (unpublished) to estimate the extinction probability of *L. eltoroensis* using 16 months (between 1995-1996) of survey data from three subpopulations of this orchid (data described in Tremblay 1996, entire). Results showed that the intrinsic population growth rate (lambda) for each site is below 1.00 (i.e., 0.985, 0.998, and 0.987). When converted to yearly rates the lambdas are even lower than 1.00 (i.e., 0.834, 0.865, and 0.855). In all three subpopulations the proportion of plants for each of the different stages (seedlings, juveniles, small adults, and large adults) are expected to decrease except in one of the

models, where adults seem to have a higher survivorship at that particular site (Meléndez-Ackerman and Tremblay 2017, p. 6). Overall, there is insufficient recruitment for population stability. According to Meléndez-Ackerman and Tremblay (2017, p. 6), the extinction of *L. eltoroensis* could be predicted in less than 25 years. If this were true, the species would already be extinct or would have declined drastically over the years, but since the time of listing, the species has faced multiple strong hurricanes in a period of 30 years (Hugo, Georges, Hortense, Irma, and Maria), and we currently know of more individuals than at the time of listing. Thus, the species is certainly vulnerable, but a 25 year prediction for extinction is likely to short, and may be explained by the data used in Dr. Tremblay's simulations as described below.

Dr. Tremblay warns that these simulations must be taken with caution for two main reasons: 1) the data used to calculate some transition probabilities had problems with small sample sizes, and 2) the traditional approach for doing population dynamics analysis using matrices assumes that the parameter estimates are very close to "reality". That may be acceptable for large sample size from large populations, but it is unlikely to be acceptable for small sample size, which is typical of rare, endangered, or difficult to survey species. Dr. Tremblay and his colleagues are working on developing new modelling methodology to address this issue. Long-term work still needs to be done to assess trends.

5.2 Current Resilience

Resiliency refers to the capacity of an ecosystem, population, or organism to recover quickly from disturbance by tolerating or adapting to changes or effects caused by a disturbance or a combination of disturbances. The degree of resiliency of a species is influenced by the health of the populations, including number of individuals, genetic diversity, and habitat quality. Resiliency increases with a higher number of individuals, increasing genetic diversity, or better habitat quality; it decreases with fewer individuals, less genetic diversity, or lowered habitat quality.

Recent surveys of *L. eltoroensis* found that the number of individuals is greater than originally thought at the time of listing (Tremblay 2008, p. 90), and may be as large as 3,000 individual

plants. The distribution of *L. eltorensis* has not been investigated outside of traditional areas (i.e. just off El Toro and Trade Wind Trails); however, some researchers suggest that additional populations may occur within suitable habitat outside this El Toro Trail. In fact, additional individuals have been found near, but outside El Toro Trail (Tremblay 2008, p. 90). If the true population size is near to the 3,000 plant estimate, this suggests the species has the ability to recover from normal stochastic disturbances. Assuming a meta-population size of 3,000 individuals, and observed stable subpopulations from past surveys, we consider the species to be moderately resilient.

5.3 Representation and Redundancy

Representation refers to a species' ability to adapt to changing environmental conditions related to distribution within the species' ecological settings. As described earlier, we did not delineate representative units for the species. However, available data suggests that conditions are present for genetic drift in three species of *Lepanthes* (Tremblay 1997a, p. 92). However, the effect of a genetic drift on the species into the future is uncertain, and *L. eltoroensis* has demonstrated the ability to adapt to changing environmental conditions (i.e., natural disturbances) over time.

Redundancy refers to the ability of a species to compensate for fluctuations in or loss of populations across the species' range such that the loss of a single population has little or no lasting effect on the structure and functioning of the species as a whole. Redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations). *Lepanthes eltoroensis* is endemic to EYNF, and it has not been introduced elsewhere. Although redundancy is inherently low due to the narrow range the species inhabits, it has persisted despite past natural disturbances (i.e. hurricanes, tropical storms, etc.), and is considered more abundant within its habitat than previously thought.

CHAPTER 6: FUTURE CONDITIONS

6.1 Introduction and Summary

The primary stressor affecting the future condition of the *Lepanthes eltoroensis* is climate change and the associated shifts in rainfall, temperature and storm intensities. These stressors account for indirect and direct effects at some level to all life stages and across the species' range. Additive climate change stressors projected for the future include: a) increased number and intensity of strong storms, b) increased temperatures, and c) shifts in the timing and amounts of seasonal precipitation patterns. All of these stressors are predicted to result in shifts in the distribution of life zones present on Puerto Rico, with some of the most dramatic impacts predicted to occur in the tropical and subtropical wet forests in which the species resides. Given the relatively low genetic and environmental plasticity of the species, it potentially does not have the capacity to adapt to these predicted conditions.

The current and ongoing climate change stressors are likely the most influential threat to the species future condition and status (Meléndez-Ackerman and Tremblay 2017, p. 1). Key life history factors of this species which makes it vulnerable to climate change stressors are its restricted range within the tropical and subtropical wet forests within El Yunque National Forest, and low subpopulation sizes (USFWS 2015, pp. 7-10). Global climate change is a natural process; however, the uncontrolled and continued release of large quantities of human emissions into our global atmosphere is accelerating global changes and affecting the planet's ecosystems. The rate and intensity of these global atmospheric warming processes have increased to a point that on a regional and local scale they have the potential to become negative stressors affecting the species habitat.

To examine the potential future condition of *L. eltoroensis*, three future scenarios were examined based on local climate change predictions for Puerto Rico (Khalyani et al. 2016, entire). The scenarios focus on a range of conditions based on climate change scenarios, and are meant to capture the uncertainty associated with the species response to these changes in climate. The range of what is likely to happen in each scenario will be described based on the current

condition and how resilience, representation, and redundancy would be expected to change. The levels of certainty or uncertainty are addressed in each scenario.

Minor stressors are anticipated to remain relatively stable and not expected to change significantly from current condition. These stressors include forest management practices, human development surrounding El Yunque National Forest, and over-collection. If however any one of these stressors would begin to increase and place pressure on the species, it will need to be assessed. For example, if it is found in the near future that forest management practices change within El Yunque National Forest, a reassessment of the species condition would need to be reviewed.

General Patterns of Increasing Temperatures

Over the 20th century, average annual air temperatures in the Caribbean islands have increased by more than 0.6°C or 1.0°F (PRCC 2013, pp. 4-6). In Puerto Rico, station analyses show significant increases in annual and monthly average temperatures and a rise of 0.012ºC/yr to 0.014ºC/yr (0.022 to 0.025ºF/yr) was observed from 1900 to present (PRCC 2013, pp. 4-6). Therefore, Puerto Rico does follow the larger-scale trend in warming, although some locations on the island are warming faster than others.

There is general consensus on continued warming into the future amongst climate modeling studies. Over the coming century, projected temperature increases for the Caribbean are projected to be slightly below the global average of 2.5 - 4°C (4.5 – 7.2°F) by 2100, but slightly above the tropical average (PRCC 2013, pp. 4-5). Projected temperature increases are expected to be significant by late century. Projections for the Caribbean show a greater than 1.5°C rise in annual temperature by 2100, with the greatest warming trends over Cuba, Jamaica, Hispaniola, Central America and northern South America, where the increase is greater than 2°C across all seasons (PRCC 2013, pp. 4-5). Projections for Puerto Rico show as little as 0.02ºC/year warming through 2050, in other words at least 0.8ºC (1.44ºF) by mid-century, and as much as 2-5°C (3.6-9ºF) by the year 2100 (PRCC 2013, pp. 4-5).

Patterns in Extreme Temperature Events

Caribbean trends show the extreme intra-annual temperature range was decreasing (becoming more uniform throughout the year) and that the number of very warm days and nights has been increasing dramatically since the late 1950s, while the number of very cool days and nights have been decreasing (PRCC 2013, p. 6). These trends are consistent in Puerto Rico where there are a greater frequency of days with maximum temperature equal to or above 90°F (32.2°C) and a lower frequency of days with temperature equal to or below 75°F (23.9°C) (PRCC 2013, p. 6).

Models project substantial warming in temperature extremes by the end of the 21st century. It is virtually certain, according to the IPCC, that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale (PRCC 2013, p. 6). For Puerto Rico, climate projections for extreme events show a probable increase in extreme heat days and cold events are expected to become exceedingly rare, and that the projected rate of warming is most rapid in winter (PRCC 2013, p. 6).

Changes in Precipitation

Observed trends in precipitation for the Caribbean as a whole are unclear from the literature. An analysis for the PRCC shows that since 1948 the Caribbean Basin has seen decreasing precipitation (-0.01 to -0.05 mm/day/year), with a greater drying trend for the Eastern Caribbean (PRCC 2013, p. 7). Specifically for Puerto Rico, one analysis of weather station data from the period of 1948 to 2007 found no clear trends in total annual rain-fall for the island as a whole, while another analysis showed decreases in rainfall for the island as a whole (i.e. -0.01 to -0.1 mm/day/year) (PRCC 2013, p. 7). Regionally, there are indications that the southern region of Puerto Rico has experienced positive trends in annual rainfall while the western and a portion of the northern region showed decreases (PRCC 2013, p. 7). Additionally, seasonal trends show negative trends in summer and positive trends in winter (PRCC 2013, p. 7).

There is a lot of uncertainty in the magnitude of precipitation changes in the Caribbean, though a majority of global climate models used by the IPCC show future decreases in precipitation are likely (PRCC 2013, p. 7). Most IPCC models project decreases in annual precipitation, with a few increases, varying from -39 to + 11%, with a median of -12% (PRCC 2013, p. 7). Current evidence suggests drier conditions are more likely for Puerto Rico. Specifically, a PRCCC

analysis found that past and future trends are similar, a decrease of rainfall of - 0.0012 to -0.0032 mm/day/year, that are projected to continue through 2050 (PRCC 2013, p. 7).

Storms and Hurricanes

Reconstruction of the past 5,000 years of intense hurricane activity in the western North Atlantic suggests that hurricane variability has been strongly modulated by El Niño during this time, and that the past 250 years has been relatively active in the context of the past 5,000 years (PRCC 2013, p. 10). Studies suggest that major hurricane activity in the Atlantic was anomalously low in the 1970s and 1980s relative to the past 270 years (PRCC 2013, p. 10). According to the U.S. Global Change Research Program, Atlantic tropical storm and hurricane destructive potential as measured by the Power Dissipation Index (which combines storm intensity, duration, and frequency) has increased (PRCC 2013, p. 10). This increase is substantial since about 1970, and is likely substantial since the 1950s and 60s, in association with warming Atlantic sea surface temperatures (PRCC 2013, p. 10). There have been fluctuations in the number of tropical storms and hurricanes from decade to decade and data uncertainty is larger in the early part of the record compared to the satellite era beginning in 1965 (PRCC 2013, p. 10). Even taking these factors into account, it is likely that the annual number of tropical storms, hurricanes, and major hurricanes in the North Atlantic have increased over the past 100 years, a time in which Atlantic sea surface temperatures also increased (PRCC 2013, p. 10). The evidence is not compelling for significant trends beginning in the late 1800s as uncertainty in the data increases as one proceeds back in time.

Current global climate models are rather poor in simulating tropical cyclones, due in part to the coarse spatial resolution of these models, however the IPCC climate simulations suggests that the North Atlantic and Caribbean will experience a decrease in tropical cyclone frequency, but an increase in the frequency of the most intense events (PRCC 2013, p. 10). Due to the substantial uncertainties about past and future changes in cyclone activity the scientific debate on this subject is expected to remain very active.

Climate Change Effects on Ecosystems in Puerto Rico

The main effect of climate change on Puerto Rico's ecosystems and species will be synergistic, in that already stressed systems will be exposed to additional stressors that push them over their limit of existence, resulting in widespread loss of habitat and unfavorable changes to structure and function. Some ecosystems and species will acclimate to changing environmental conditions better than others. A few general patterns associated with forest ecosystems in Puerto Rico are as follows (PRCC 2013, p. 14):

- Warmer air→lower dew point of air masses→raised orographic cloud base→changes in species composition, forest structure, and ecological function
- Increased seasonality in precipitation and decreased soil moisture availability→altered fruiting and flowering patterns→effects on seedling recruitment, germination, and survival→changes in species composition, forest structure, and ecological function
- Increases in intense storm events→more intense wind and water→increased disturbance→changes in plant successional direction and biomass→novel communities

Potential Shifts in Life Zones

The greatest risk of climate change to the future viability of *Lepanthes eltoroensis* is likely the predicted shifts in the montane wet forest life zones. The Holdridge life zone of a particular area implies the potential vegetation type that can dominate an area (Khalyani et al. 2016, p. 266). The boundaries of life zones in the Holdridge system are based on three climatic measurements: annual precipitation, biotemperature, and the ratio of potential evapotranspiration (PET) to annual precipitation (Holdridge 1947, pp. 367-378). Figure 6.1 shows the distribution of major life zones in Puerto Rico, and including the lower montane wet and rain forests in eastern Puerto Rico where the species is found (Ewel and Whitmore 1973, pp. 41-49; Khalyani et al. 2016, p. 267).

In general, dramatic changes are projected in the life zone distributions in Puerto Rico (Khalyani et al. 2016, p. 279). Decreasing trends are predicted in the areas of wet and moist zones while increasing trends are predicted in the areas of dry zones under three climate change scenarios (Khalyani et al. 2016, p. 273). This shift from wet and moist zones to drier conditions may have profound negative impacts to the species.
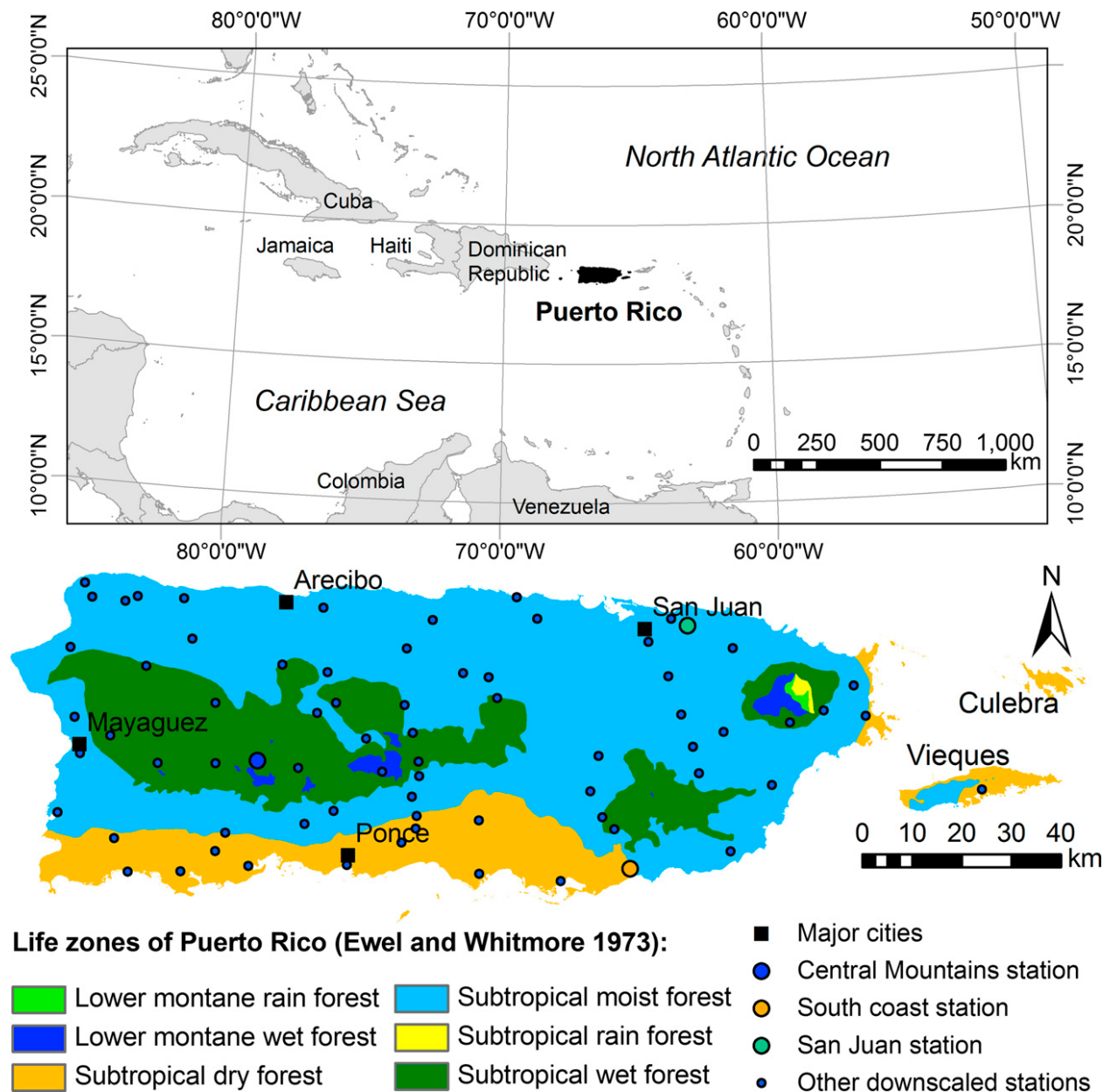
Figure 6.1. Holdridge life zone distribution in Puerto Rico based on Ewel and Whitmore 1973.

6.2 Future Scenarios

Our future scenarios are built around three climate change scenarios available for Puerto Rico. Little information exists on the abundance or growth rate of the meta-population, therefore, a full picture of the health and resilience of the species is uncertain. Because of the lack of available

information on the extent of individual subpopulations across the range of the species and the uncertainty of meta-population structure, our assessment of resiliency is incomplete. Our assessment of future viability includes qualitative descriptions of the likely impacts of climate change under 3 scenarios from the literature, and is intended to capture the uncertainty in the species response to climate stressors, and the lack of current information on abundance and growth rates.

Khalyani et al. (2016, entire) examine climate change implications for Puerto Rico and other tropical islands by interpolating and interpreting statistically downscaled GCM projections. They use three IPCC global emission scenarios: mid-high (A2), mid-low (A1B), and low (B1) (Nakicenovic and Swart 2000, entire). Island-wide and multi-decadal averages of daily precipitation and temperature were estimated; annual cooling degree-days (CDD) were calculated as a proxy index for energy demand; measures of annual no-rainfall days were used as drought indices; and the Holdridge life zone classification was used to map the possible ecological effects of climate change. Below we report the results of this modelling effort and discuss potential impacts to *Lepanthes eltoroensis*. Projections are out to the year 2100.

Precipitation and Drought Indices

Precipitation is projected to decrease faster in the wetter regions of Puerto Rico, with more differences apparent in the later periods of the century (Khalyani et al. 2016, p. 274). Drought intensity showed a projected linear increase across the entire island across all GCM scenarios, although the trends of change in drought extremes were different for different geographic areas (Khalyani et al. 2016, p. 274). The inter-annual variability increased and dominated from the wet to dry sampling stations, with the highest fluctuations in the southern coastal region (Khalyani et al. 2016, p. 274). In general, all three climate scenarios showed similar patterns of changes in precipitation and drought intensity and extremes, but the total increases were higher for the A-2 scenario (Figure 6.2). Also, for all three climate scenarios, significant decreases in precipitation for the northern wet forests are not predicted until after 2040 (Figure 6.2).
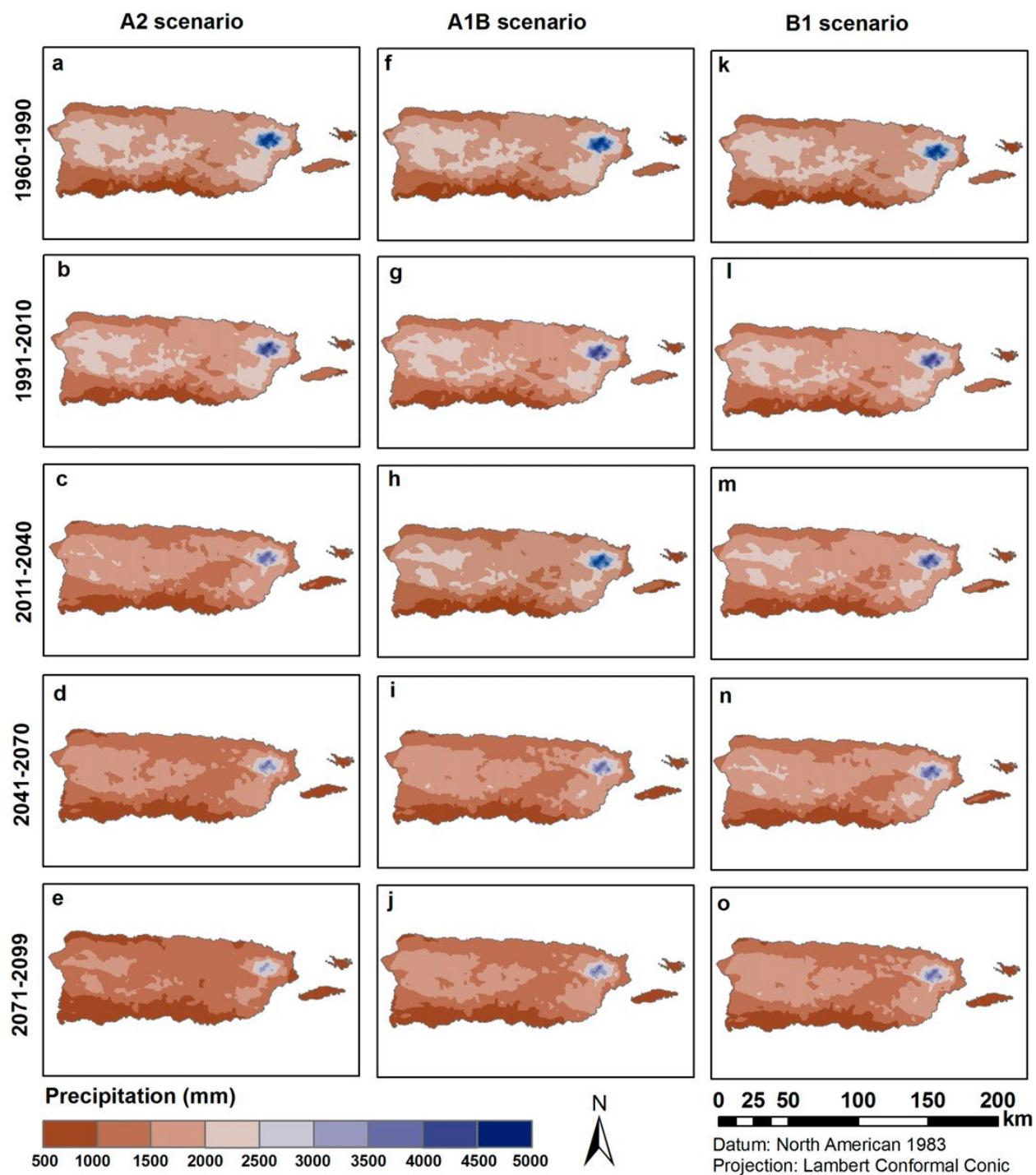
Figure 6.2. Annual precipitation projections for Puerto Rico under three GCM scenarios. (*From:* Khalyani et al. 2016)

Temperature

All three GCM scenarios predict increases in temperature. The projected means from the all-model ensemble showed increases of 7.5–9.0, 6.4–7.6, and 4.6–5.4^{0}C under the A2, A1B, and B1 scenarios respectively (Khalyani et al. 2016, p. 275). The projected increase in temperature and CDDs suggests energy demand will increase across the island. Like with precipitation, projected increases in temperature are not substantial until after 2040, and the 3 scenarios differentiate the most from each other in the later time intervals. For example, the last two time intervals in the A2 scenario showed higher rates of changes relative to the other period of the century (Figure 6.3) and also relative to the last two periods in the A1B and B1 scenarios.
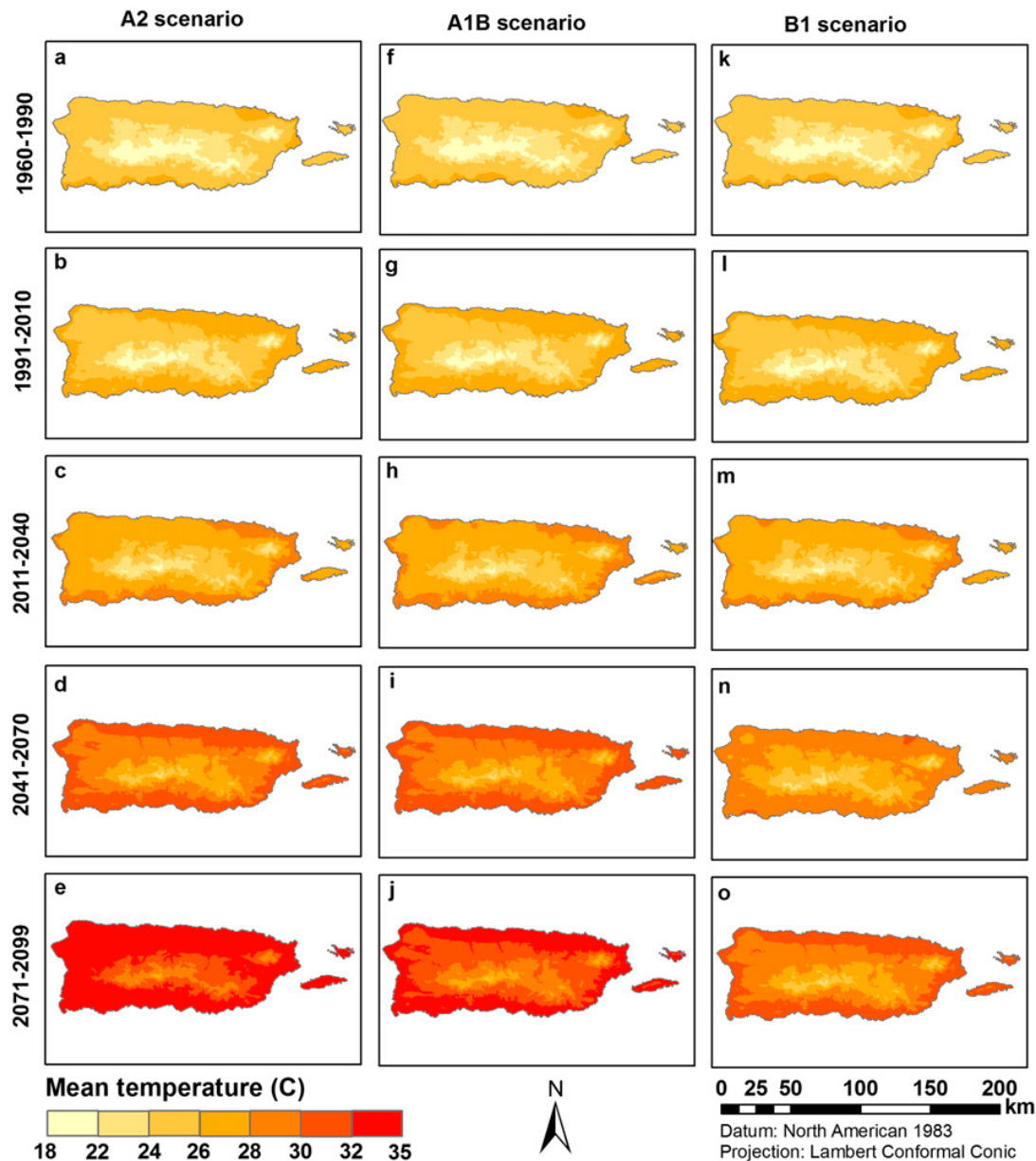
Figure 6.3. Temperature projections for Puerto Rico under three GCM scenarios. (*From:* Khalyani et al. 2016)

Life Zones

Dramatic changes are projected in the life zone distributions in Puerto Rico (Figure 6.4). Because life zones are derived from the climate variables investigated, it is no surprise that the general changes in patterns seen in the life zone distributions are similar to the changes in the climatic variables (Figure 6.5). For example, the humidity shifting from rain, wet, and moist zones to drier zones was identified by the changes in annual precipitation and PET ratio

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(Khalyani et al. 2016, p. 275). Also, the changes from subtropical to tropical were identified by the changes in temperature. The subtropical rain forest, disappears after the first time interval. Generally, decreasing trends were observed in the areas of wet and moist zones while increasing trends were observed in the areas of dry zones in all three scenarios. It is interesting to note that loss of wet and moist zones in the northeastern mountains that *Lepanthes eltorensis* is not predicted to be substantial, and seems to stay relatively stable until after 2070 (Figure 6.4). This may be due to possible buffering effects of elevation across the island, which is discussed in the next section.
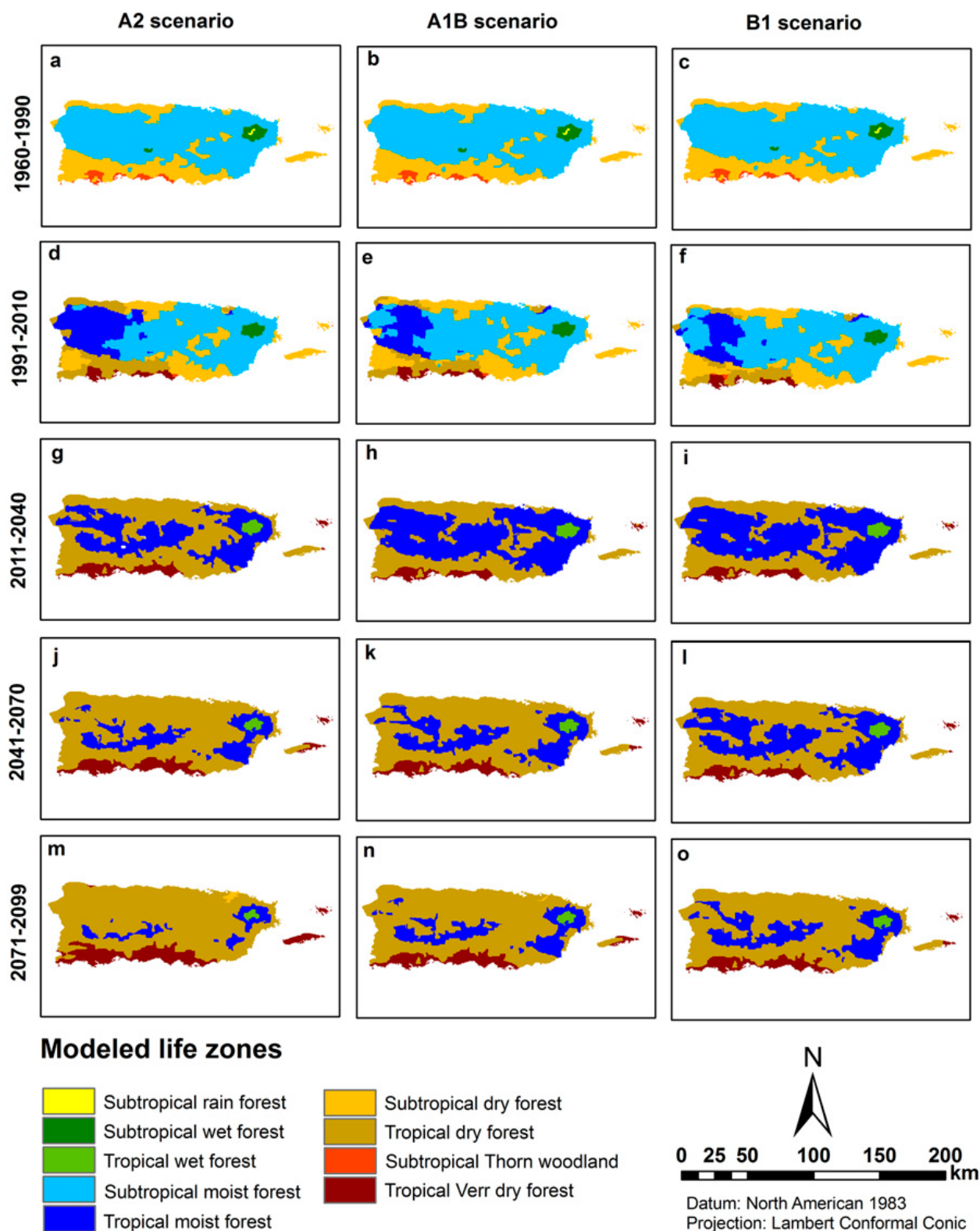
Figure 6.4. Projections for life zone distribution changes in Puerto Rico under three GCM scenarios. (*From:* Khalyani et al. 2016)

Dynamic Down-scaled Climate Model

The USGS Southeast Climate Adaptation Center recently ran a dynamic downscaling of a single future global climate model for the Caribbean which provides sufficient resolution to resolve local orographic features, which is important because the local orography includes mountains that force a steep precipitation gradient that results in a diversity of habitats that are sensitive to changes in climate (Bhardwaj et al. 2018, p. 133). The projections of this model for Puerto Rico have some key differences compared to Khalyani et al. (2016, entire). In terms of patterns of precipitation, the USGS models predict an overall drying of the island and a reduction in extreme rainfall occurrence, however, there seems to be a "buffer" to the amount of drying for some higher elevations (Figure 6.5), which is very different than the results of the Khalyani et al. (2016, entire) statistical downscaling model (Bowden 2018, pers. comm.). Although decreases in precipitation are predicted to be buffered at higher elevations (i.e. areas that *L. eltoroensis* inhabit), it is important to mention that the models show that soil moisture can still decrease as evaporation potential increases (Bowden 2018, pers. comm.). Subsequent results and reports related to temperature and life zone projections are currently being analyzed, and once published could help to refine and inform our approach to future viability for *L. eltoroensis*.
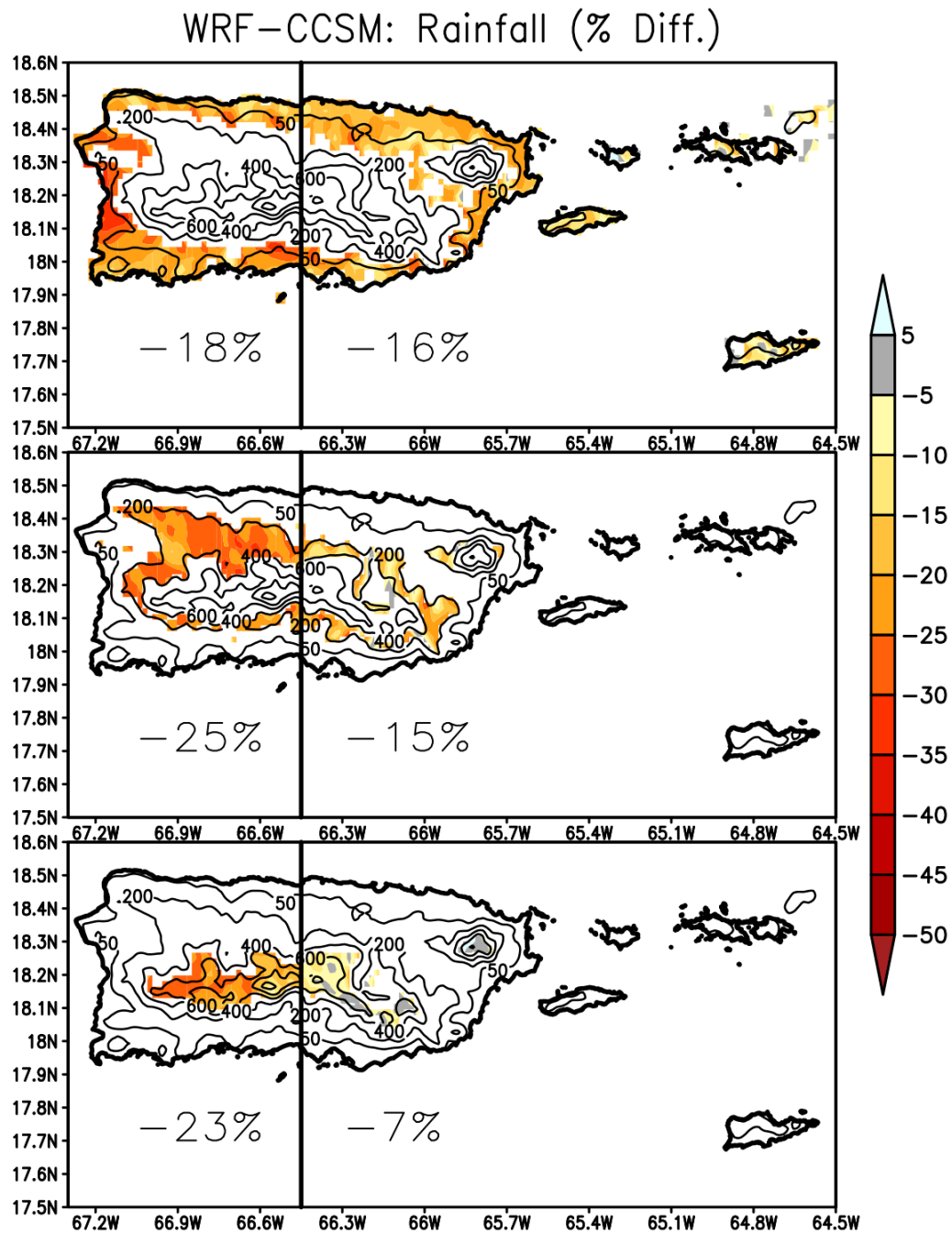
Figure 6.5. Percent change in total rainfall during the wet season (May-October; shaded) averaged over model elevations of less than 150m (top), between 150-450m (middle) and above 450 (bottom).

Climate Change Summary

Table 6.1. and Figure 6.5 summarize the anticipated projections under 3 GCM scenarios (A2, A1B1, and B1) for emissions, precipitation, temperature/drought, and life zone distribution changes. In general, emissions increase, precipitation declines, temperature and total dry days increase, and subtropical rain and wet forests are lost, while all wet and moist forest types decrease in Puerto Rico. These changes are anticipated to be more dramatic under the A2 scenario, while A1B1 and B1 projections are similar amongst all climate metrics.

Table 6.1. Summary of climate metrics in Puerto Rico under 3 GCM scenarios (A2, A1B1, and B1).

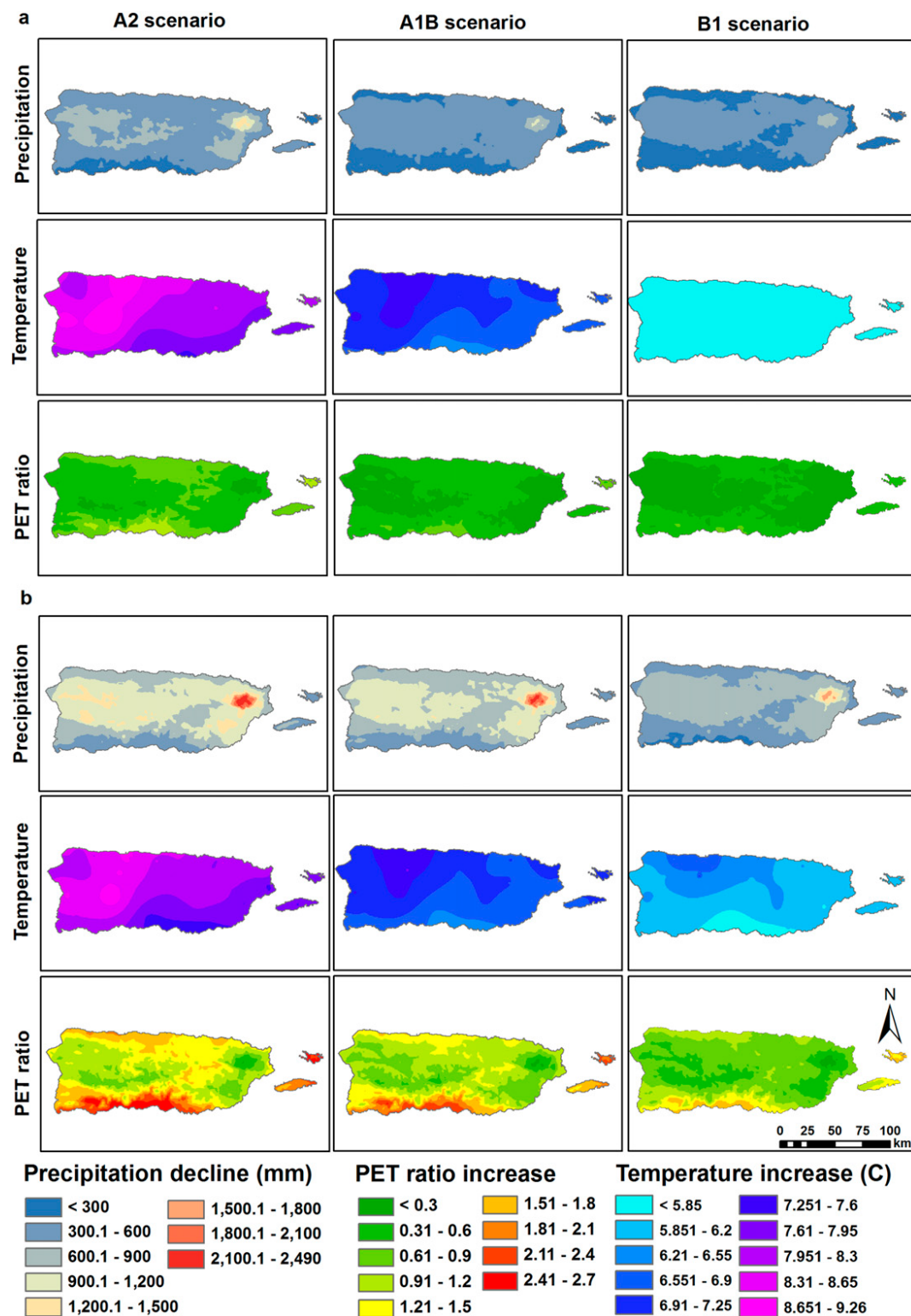|	*Emissions*	*Precipitation*	*Temperature/Drought*	*Life Zone Distribution*
A2 Scenario	Mid-high	Mean decline in rainfall (510-916 mm)	• Mean temperature increase (7.5-9° C) • Total dry days increase by 21%	Loss of subtropical rain and wet forests; **dramatic** decreasing trends in all wet and moist forest types.
A1B1 Scenario	Mid-low	Mean decline in rainfall (354-842 mm)	• Mean temperature increase (6.4-7.6° C) • Total dry days increase by 16%	Loss of subtropical rain and wet forests; decreasing trends in all wet and moist forest types.
B1 Scenario	Low	Mean decline in rainfall (312-619 mm)	• Mean temperature increase (4.6-5.4° C) • Total dry days increase by 17%	Loss of subtropical rain and wet forests; decreasing trends in all wet and moist forest types.

Figure 6.6. Summary of the anticipated projections under 3 GCM scenarios (A2, A1B1, and B1) for emissions, precipitation, temperature/drought, and life zone distribution changes (Khalyani et al. 2016, pp. 265-282)

6.3 Future Viability Approach

Climate change is the primary risk factor in our scenarios, and our assessment of future viability will focus on the 3 climate scenarios discussed above from Kahlyani et al. (2016, entire), at the years 2040 and 2100. A summary of anticipated general trends in future resilience, redundancy, and representation are provided in Table 6.2. General descriptions of our 3 scenarios are as follows:

2040

- Under *all emission scenarios*, resiliency is projected to remain moderate. There is very little projected contraction of the wet and moist forests within this timeframe. Although increasing catastrophic hurricanes are possible, relocation of plants can ameliorate some of these impacts. Overall, the viability of the species is predicted to remain stable.

2100

- Under a *high emission scenario*, resiliency decreases substantially (from moderate to very low), with extinction possible. There is severe contraction of the wet and moist forests, and compounding this is the potential impacts from increasing catastrophic hurricanes. Relocation of plants can ameliorate some of these impacts, but overall, the viability of the species drops dramatically.

- Under a *moderate emission scenario*, resiliency decreases (from moderate to low), with extirpation unlikely. Although there is a contraction of the wet and moist forests, it is not as severe as the high emission scenario. Catastrophic hurricanes are important pulse disturbances, but because there is still plenty of available habitat, recolonization and meta-population dynamics result in the opportunity for the species to bounce back.

- Under a *low emission scenario*, resilience decreases as under the moderate emission scenario (from moderate to low). The amount of contraction in the wet and moist forests is similar to the moderate scenario, so the same details apply. Conservation measures such as relocation of individuals post-hurricane is considered to be likely in this scenario, and if implemented, the species has an opportunity to maintain its moderate resilience.

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Table 6.2. Summary of anticipated general trends in future resilience, redundancy, and representation for *L. eltoroensis* based on climate change projections.

Metapopulation Resilience	Species Redundancy	Species Representation
Resilience remains moderate out to the year 2040.	**Redundancy is stable** out to the year 2040.	Current condition of low genetic and environmental diversity, and little breadth to rely on if some is lost.
Reduced resiliency expected to occur across all future scenarios out to the year 2100.	**Reduced redundancy** expected with all scenarios out to the year 2100.	Recent data strongly suggests that conditions are present for genetic drift.
The level of reduced resiliency becomes a matter of scale in timing and intensity of changes in temperature and precipitation based on emission scenarios.	Great uncertainty in the full extent of the species range (i.e. no surveys done off of the 2 main trails), making it problematic to estimate current redundancy.	Not a large difference in habitat types (i.e. no representative units assessed)
Reduction or loss of suitable habitat is the main reason for reduced abundance and resiliency under future scenarios.	Although the species has a very limited range, it has persisted through many hurricanes in the past.	Expect loss of subpopulations and subsequent loss of connectivity at the year 2100.
Hurricanes impact habitat by destruction and blow-down of host trees, thus decreasing resilience post-storm.	A level of redundancy is retained because the species only occurs on protected conversation lands of the El Yunque National Forest. Although these habitats will be impacted by loss due to long term climate change.	Loss of connectivity could lead to inbreeding depression, which may already exist currently.
Relocation of plants on blown-down trees is likely in the low emission scenario, and may	Shifts in vegetation from wet to dry conditions will be expected to reduce the quality and quantity of	

Metapopulation Resilience	Species Redundancy	Species Representation
emilorate the negative impacts of hurricanes.	suitable habitat as climatic conditions change over time.	
Host tree abundance numbers are low and are expected to remain low or become reduced, which is further complicated by the low ability of the species to migrate and recolonize new hosts.	There will be a reduced time for recovery of habitat and subpopulations from the impacts of hurricanes and the expected increase in storm frequency as predicted.	

6.4 Viability Summary

Aspects of the biological and ecological traits of the species, represented by narrow tolerance to changes in humidity, light, and temperature, infrequent reproduction, low effective population size, low gene flow and low genetic diversity, and restricted distribution, all contribute to naturally low levels of resiliency, redundancy, and representation of the species. These factors are exacerbated by the effects of hurricanes, which can decimate the number of *L. eltoroensis* individuals by killing their host trees or through habitat modification (vegetation openings) that increase light penetration and temperatures that affect the species and its microhabitat. The representation of *L. eltoroensis* is affected by the low number of adult individuals that contribute offspring to the next generation (i.e., effective population size), and low genetic exchange among individuals from different host trees.

Projections on climate change predicts increases in temperature and reduction in precipitation, particularly in wetter regions like EYNF, and shift of the life zones of Puerto Rico from humid to drier (Khalyani et al. 2016, p. 280), although ongoing research suggests higher elevations may have a buffering effect on declining trends in precipitation (Bowden 2018, pers. comm.). Also, substantial changes in precipitation and temperature are not predicted until the latter half of the century, thus viability is anticipated to remain relatively stable through 2040. At the year 2100,

substantial changes in temperature and precipitation regimes are predicted to have direct implications for the survival of *L. eltoroensis* and are anticipated to reduce the viability of the species under all scenarios due to its specific biological and ecological requirements, and narrow distribution. Probably of utmost importance is the projected shift of the life zones of Puerto Rico from humid to drier. This includes changes in relative area and distribution pattern of the life zones, and the disappearance of humid life zones (Khalyani et al. 2016, p. 280). The areas projected to shift from moist to drier forest will not likely have sufficient climatic support for moist forests regardless of the local conditions, resulting in loss of large areas of rain and moist forests (Khalyani et al. 2016, p. 280). Decreased rainfall in northeastern Puerto Rico (i.e., EYNF) can cause migration, distribution changes, and potential extirpation of many species that depend on the unique environmental conditions of the rain forest (Weaver and Gould 2013, p. 62).

In the latter half of the century, the above projections will likely have direct implications for *L. eltoroensis* because the acreage of the lower montane wet forest life zone it occupies would decrease, resulting in less habitat available for the species. Also, epiphytes like *L. eltoroensis* will experience moisture stress due to higher temperatures and less cloud cover with a rising cloud base, affecting their growth and flowering (Nadkarni and Solano 2002, p. 584).

Local experts hypothesize that predicted changes may have direct or at least indirect effects on *L. eltoroensis* based on what it is known either about itself or from the biology of closely related species. Potential direct effects include reduced number of seedlings as number of dry days increase, reduced number of fruits as minimum average temperature increases, and reduced number of adults as maximum temperature increases (Olaya-Arenas et al. 2009, p. 2042). Indirect effects are related to potential changes in bryophyte cover and composition due to climate change. Data from related species showed that orchid density, growth, and establishment were positively associated with bryophyte species richness (Crain 2012, pp. 15-16; Garcia-Cancel et al., 2013, p. 6). Therefore, a change in forest temperature and humidity could affect the establishment and distribution of bryophytes, hence *L. eltoroensis*.

However, persistence of the species through repeated past hurricanes and other storms suggests the species has the ability to recover and adapt from disturbances, and relocation of individuals from blown-down host trees further accelerates the recovery of the species post-hurricane. In fact, many researchers at ENYF have concluded, hurricanes are the main organizing force of the forests. The forests goes through a cycle that averages sixty years, starting with great impact by winds and rain of a hurricane, and then sixty years of re-growth. In those sixty years of re-growth, complete changes in the species that dominate the landscape can occur. By measuring changes in tree growth rate, density and size, researchers have observed how the forest can incorporate the energy of the hurricane. Although, the hurricane appears destructive, it can in fact be constructive, because it makes the area more productive; it rejuvenates the forest.

Because we do not have sufficient information to estimate the full extent of the species range or a reasonable estimate of total meta-population size, we do not have a complete current resilience estimate, which makes future projections problematic. The most recent surveys of *L. eltoroensis* found that the number of individuals is greater (about 3,000) than originally thought at the time of listing (Tremblay 2008, p. 90). The distribution of *L. eltorensis* has not been investigated outside traditional areas; however, some researchers suggest that additional populations may occur within suitable habitat outside this El Toro Trail. In fact, additional individuals have been found near, but outside El Toro Trail (Tremblay 2008, p. 90).

In order to make more specific estimates related to future viability, additional surveys outside of traditionally surveyed areas, and an associated habitat model are needed. If a habitat model can be constructed, we can make better estimates of the impacts of climate change to more specific variables such as soil types and temperature and precipitation requirements. Recently researchers at the University of Puerto Rico (UPR) have been funded to evaluate the current population status of *L. eltoroensis,* and to model its demographic variation in response to climatic variability (i.e., temperature and relative humidity) in an effort to evaluate the influence that climate change will have on the persistence of this species in its environment. Data gathered during this project will be used to characterize the microhabitat variation between areas with and without *L. eltoroensis*, and to develop a habitat selection model to evaluate the relationship between the presence and absence of plants and landscape level variables such as elevation, forest type, aspect, and temperature. Additionally, the data gathered will allow developing a

monitoring infrastructure to model the demographic responses of *L. eltoroensis* to climate variation. This research will update the distribution and status of *L. eltoroensis* within EYNF, and assess natural threats affecting these populations, particularly climate change.

Because we do not have a habitat model or range-wide surveys, we only report general trends. In general, we anticipate the species to remain stable up to the year 2040. In the latter half of the century, the range of the species will likely contract due to changes in climatic variables leading to loss of wet and tropical montane habitats. This loss can be further exacerbated by an increase in the frequency and severity of hurricanes. The species is only known to occur on El Yunque National Forest, which means that development and deleterious forest management practices are unlikely to negatively impact the species any time soon, and, because the species occurs on protected lands, there is potential for conservation management, particularly the relocation of plants post-hurricane, to alleviate the negative impacts of hurricanes and tropical storms.

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