ECOLOGICAL STUDIES OF THE TREE FERN *ALSOPHILA AMINTAE* D.S.CONANT (CYATHEACEAE) IN THE CLOUD FOREST OF PUERTO RICO

by

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ABSTRACT

Alsophila amintae D.S.Conant (Cyatheaceae) is an endangered tree fern endemic to the central mountains of Puerto Rico. It was previously known from three populations in Monte Guilarte, Monte Jayuya and Cerro Rosa. The objectives of this study were to determine the abundance and geographical distribution, characterize the habitat, find other possible localities, study the phenology, identify and quantify hybrids and document the effects of natural and anthropogenic disturbances of *A. amintae*. Surveys were conducted in Monte Guilarte, Monte Jayuya and Cerro Rosa in 2014. A total of 149 individuals were found during 2014 to 2017 at elevations ranging from 1050 to 1325 m. A new population was found in the location of Tres Picachos. This species was not found in its type locality of Monte Cerrote, Peñuelas. It grows on inclined slopes up to 55°, soil humidity levels higher than 51% and with an optimal canopy openness of 16 – 17%. The peak for production of new fronds was observed in July. It produced sori throughout the year, with a highest peak of sori production in January. A higher leaf mortality and turnover occurred in September. No hybrids were found with sori; therefore, their fertility could not be determined. Invasive plants such as *Hypolepis nigrescens, Gleichenella pectinata* and *Arthrostylidium sarmentosum* affect *A. amintae*'s growth. The populations of Cerro Maravilla, Cerro Punta and Monte Jayuya are threatened by communication antennas and their maintenance. In conclusion, *A. amintae* has a limited distribution along the Central Cordillera, within strands of Sierra Palm forest and extant populations are reproducing healthily. It is recommended that *A. amintae* remain listed as endangered species, and that management recommendations be taken into consideration to conserve the species.

RESUMEN

Alsophila amintae D.S.Conant (Cyatheaceae) es un helecho arbóreo en peligro de extinción endémico de las montañas al centro de Puerto Rico. Se conocía previamente en tres poblaciones localizadas en Monte Cerrote, Monte Guilarte, Monte Jayuya y Cerro Rosa. Los objetivos de este estudio fueron determinar la abundancia y distribución geográfica, caracterizar el habitáculo, encontrar otras posibles localidades, estudiar la fenología, identificar y cuantificar híbridos y documentar los efectos de disturbios naturales y antropogénicos de *A. amintae*. Se encontró un total de 149 individuos durante el 2014 hasta el 2017 en elevaciones desde 1050 a 1325 m Una nueva poblacion fue encontrada en la localidad de Tres Picachos. Esta especie no fue encontrada en su localidad tipo, Monte Cerrote, Peñuelas. Crece en pendientes inclinadas de hasta 55°, con porciento de humedad de suelo mayor de 51% y una apertura de dosel óptima de 16 –17%. El pico para producción de nuevas frondas fue en Julio. La especie produjo soros durante todo el año, con un pico de producción en enero. La mortandad de fronda y la tasa de reemplazo ocurrieron en Septiembre. No se encontraron híbridos con soros; la fertilidad de los mismos no pudo ser determinada. Plantas invasivas cómo *Hypolepis nigrescens, Gleichenella pectinata* y *Arthrostylidium sarmentosum* affectan el crecimiento de *A. amintae*. Las poblaciones de Cerro Maravilla, Cerro Punta y Monte Jayuya son amenazadas por antenas de comunicación y su mantenimiento. En conclusion, *A. amintae* tiene una distribución limitada a la Cordillera Central, asociada a bosque de Palma de Sierra, y poblaciones existentes se estan reproduciendo saludablemente. Se recomienda que *A. amintae* se mantenga enlistada cómo especie en peligro, y que se tomen en consideración recomendaciones de manejo para conservar la especie.

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DEDICATION

To the poetry of Nature and all its essence.

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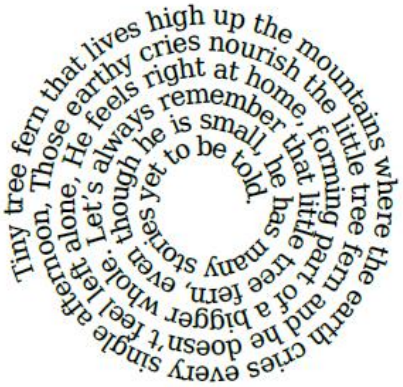

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INTRODUCTION

Alsophila amintae D.S.Conant (Cyatheaceae), previously known as *Cyathea dryopteroides* (Maxon), is a tree fern endemic to the cloud forests of Puerto Rico (Proctor, 1989). It was declared as an endangered plant species on June 16, 1987 (final rule 52 FR 22936) under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service [USFWS], 1987). This species is distinguished from other tree ferns mostly by its small size, the free venation in the pinnae, the presence of apical setae on the scales, a glabrous costae and indusium, and the absence of spines on the trunk (Proctor, 1989).

The habitat of *A. amintae* in cloud forests could have been restricted due to the occurrence of natural disturbances such as hurricanes and landslides, and anthropogenic disturbances that destructed its habitat by the constructing new roads and communication antennas (USFWS, 1991). This perennial species has been documented as present only in Monte Guilarte (Adjuntas), Monte Jayuya (Ponce), Cerro Rosa (Jayuya), and Monte Cerrote (Peñuelas), but has been considered extirpated in the last of these localities (USFWS, 1991).

Little is known about this species, given that ecological studies about its habitat, vegetation aspects and phenology have not been conducted. It is of great importance and concern to know about the ecology and reproductive biology of this cloud forest tree fern to be able to assist in the protection of its populations and eventually in its removal from the Endangered Species List. There is an urgent necessity for the USFWS and the Puerto Rico Department of Natural and Environmental Resources (DNER) to learn about the ecology and reproductive biology of *A. amintae* to be able to provide better protection for the species, promote a

sustainable recovery of the populations and potentially allow its future removal from the Endangered Species List.

The purpose of this research is to study the ecology of *A. amintae* in Puerto Rico in order to assess its current status, develop conservation strategies for this species and promote its removal from the Endangered Species List. This study focused on the following objectives:

1. Determine the abundance and geographic distribution of *A. amintae* in three populations located in Monte Guilarte (Adjuntas), Monte Jayuya (Ponce) and Cerro Rosa (Jayuya).
2. Characterize the habitat in which the populations of *A. amintae* occur.
3. Search for other possible localities for this species in Puerto Rico.
4. Study the phenology of *A. amintae*.
5. Identify and quantify the presence of hybrids of *A. amintae* × *bryophila* and *A. amintae* × *portoricensis*.
6. Document the effects of natural and anthropogenic disturbances in *A. amintae* populations.
7. Collaborate with USFWS and the DNER to update and enhance the management strategies for *A. amintae*.

LITERATURE REVIEW

Taxonomy and classification

The family Cyatheaceae is composed of approximately 500 species with a pantropical-southern temperate distribution (Korall *et al*., 2006; Smith *et al.*, 2006). The members of the family Cyatheaceae differ from other families of the tree fern alliance by having pluricellular hairs and various types of scales in their induments (Kramer and Green, 1990). There have been differences of opinion about the generic subdivision of the family (Holttum and Tryon, 1977). For purposes of classification, scientists studied morphological characteristics, such as presence or absence of indusium and venation pattern, which were often utilized to determine relationships between genera (Gastony, 1973). Holttum (1963) proposed the adoption of a single genus for the family Cyatheaceae, *Cyathea* Sm., which included the subgenera *Cyathea* and *Sphaeropteris*. Tryon (1970) classified Cyatheaceae into six genera: *Alsophila* R.Br., *Nephelea* R.M.Tryon, *Cnemidaria* C.Presl, *Cyathea, Sphaeropteris* Bernh. and *Trichopteris* Spreng. *Alsophila* and *Nephelea* belong to the same evolutionary lineage due to the presence of marginate petiole scales and dark apical setae in both genera (Lucansky, 1976).

Lellinger (1987) utilized Tryon's classification, but proposing four genera in the family Cyatheaceae: *Sphaeropteris, Alsophila* (including *Nephelea*), *Cyathea* and *Cnemidaria*. Proctor (1989) recognized three subgenera within *Cyathea*: *Alsophila* (which included *Hemitelia* R.Br., *Nephelea* and *Trichopteris*), *Cyathea* and *Cnemidaria*. Conant *et al.* (1994, 1995, and 1996) revised the family Cyatheaceae by using phylogenetic studies, which showed three evolutionary lineages within the Cyatheaceae: *Alsophila, Cyathea* and *Sphaeropteris*. More recent studies confirmed that the Cyatheaceae includes the genera *Alsophila*, *Cyathea*, *Cnemidaria* and

Sphaeropteris (Korall *et al*., 2006; Marquez, 2010). Korall *et al*. (2007) studied the DNA sequence data from five plastid regions (rbcL, rbcL-accD IGS, rbcL-atpB IGS, trnG-trnR, and trnL-trnF), and they proposed the following members in the Cyatheaceae family: *Sphaeropteris* (sister to the other three genera), *Cyathea*, *Alsophila* and *Gymnosphaera* + *Cyathea capensis*. These major groups are also mentioned in more recent studies (Korall and Pryer, 2014; Sosa *et al.*, 2016), therefore, this genus-level classification is the most recently accepted. New proposed hypotheses for relationships are continuing to be explored with phylogenetic studies to redefine the genera within the Cyatheaceae family.

Morphological and phylogenetic studies confirm the genus *Alsophila* inclusion within the family Cyatheaceae (Marquez *et al*., 2009). The species of the *Alsophila* genus have the presence of an apical setae in the scales and spores with a ridged surface. Meanwhile, in species from the *Cyathea* genus the apical setae is absent and the spore surface has a network of slender threads (Proctor, 1989). *Alsophila* is considered as a pantropical genus containing approximately 230 species, which are distributed in wet tropics in the Old and New World (Tryon and Lugardon, 1991). This genus includes the following species in Puerto Rico: *A. amintae* D.S.Conant (originally published as *A. aminta* D.S.Conant), *A. brooksi* Maxon (R.M.Tryon), *A. bryophila* R.M.Tryon and *A. portoricensis* (Sprengel ex Kuhn) D.S.Conant (Proctor, 1989). There are certain morphological characteristics that help distinguish all these species. All *Alsophila* species have an erect caudex except for *A. brooksi*, which is prostrate. *Alsophila brooksi* has the smallest caudex (45 cm), following in ascending order by *A. amintae* (up to 1 m), *A. portoricensis* (4 m and up) and *A. bryophila* (7 m) (Proctor, 1989). The presence of black spines in trunk and rachis will only be present in *A. portoricensis* and dense pubescence on the rachis and costae of *A. bryophila*. The blades of *A. amintae, A. bryophila* are pinnate-pinnatifid, in *A. brooksi* they are

pinnate-pinnatifid to 2-pinnate, and in *A. portoricensis* they are 2-pinnate-pinnatifid or nearly 3-pinnate. *Alsophila amintae* and *A. portoricensis* hace cyatheoid indusium, but in the later is pubescent. Meanwhile, the indusium of *A. bryophila* is crescent shaped and glabrous. In *A. brooksi*, the indusium is pubescent.

It has been documented that *Alsophila* in Puerto Rico has the ability to form hybrids with *A. bryophila* and *A. portoricensis* (Conant, 1975, 1976; Conant and Cooper-Driver, 1980).

Alsophila amintae D.S.Conant, was first published as *Cyathea dryopteroides* Maxon (Maxon, 1925). This is the name under which the species was listed as endangered (USFWS, 1987). Tryon (1970) changed the name to *Alsophila dryopteroides*. Conant (1981) proposed a new epithet due to confusion between the species *C. dryopteroides* and its similarly named fertile hybrid with *C. bryophila, C.* × *dryopteroides* Maxon. He used the specific epithet *amintae* in honor of his wife and collection companion Aminta M. Kitfield Conant. Proctor (1989) did not recognize *Alsophila* as a genus and he published a taxonomical key to the subgenus *Alsophila* in Puerto Rico, which includes four species: *Cyathea brooksii* Maxon, *Cyathea bryophila* (R.M.Tryon) Proctor, *Cyathea dryopteroides* Maxon and *Cyathea portoricensis* Sprengel ex Kuhn. Also, the following hybrids of *A. amintae* in Puerto Rico are included: *Cyathea bryophila* × *dryopteroides*, *Cyathea bryophila* × *portoricensis* and *Cyathea dryopteroides* × *portoricensis*; this taxonomical key has been followed throughout this study.

Tropical cloud forest

Cloud forests are high on the list of the world's most threatened ecosystems (Aldrich *et al.*, 1997). This ecosystem is common in many tropical and subtropical regions worldwide, along the Pacific costal line from Mexico to Bolivia, in Africa and in South-East Asia (Eltahir, 2011).

They are characterized by having particularly dense fog concentrations (Hamilton *et al.*, 1995). The frequent mist in the atmosphere gives this ecosystem its most commonly known name-the cloud forest (Stadtmüller, 1987). They are also known as: dwarf forest, elfin woodland, mountain thicket or mossy forest (Robinson, 1997).

Cloud forests normally occur at high elevation mountain summits, but they may also occur at lower elevations. The cloud forest of Gau Island, Fiji is an example of the latter; the elevation near the summit is at 600 m (Watling and Gillison, 1995). They are characterized by having short stature or stunted trees, rich endemic flora, saturated soils, and slow rates of recovery from natural and/or anthropogenic disturbances (Scatena, 1995, Bautista-Cruz and Del Castillo, 2005). Also, organic matter accumulates on the forest floor, producing soil which is rich in nutrients and microbial flora (Grubb, 1977). Several ways to subdivide cloud forests have been presented in the literature (Foster, 2001). In 1987, Stadtmüller established the difference between cloud forests that occur in regions of abundant rainfall and those that occur on arid mountainsides (Sugden and Robins, 1982, 1983; Cavelier and Goldstein, 1989 in Foster, 2001). For example, in the Dhofar region in Oman there is a desert cloud forest which has been subject of many recent studies due to the rarity of finding a cloud forest in arid regions (Bawain, 2012).

The cloud forests support a high biodiversity and endemism. Tropical mountain cloud forests are known for their high percentages of endemic plants and animals (Bruijnzeel, 2001; Kappelle and Brown, 2001; Leo, 1995). These forests have important roles and ecological functions. They serve as refugia for endangered species, which cannot survive in other areas where anthropogenic disturbances are common. They also have the ability to capture rain water by cloud stripping, which occurs when the canopy trees come in contact with clouds and their

water along with rain water falls on the trunks and the soil, eventually arriving to streams and rivers (Bonell and Bruijnzeel, 2005). Canopy leaves and branches which eventually fall and become compost, providing humidity to the soil which helps in capturing the moisture on the forest. This type of forests help maintain the soil cover and reduce the soil erosion; which supports the whole hydrological process (Aldrich *et al.*, 1997).

Epiphytes in the canopy, which are efficient in capturing nutrients from the atmosphere, have evolved to survive in the cloud forest -especially old forests; bryophytes compose most of the ground cover and are capable of trapping substantial amounts of water (Pŏcks, 1980, Cordova and Del Castillo, 2001). Also, mycorrhizal associations in the forests aid in the survival of trees in nutrient-poor environments and play an important role in the cycling of nutrients and their retention in the humus layer (Medina and Cuevas, 1993; Rilling *et al*., 2001).

In Puerto Rico, there are forests that have elevations lower than 1,200 m that are considered cloud forests due to having environmental parameters of humidity, precipitation and temperature of higher elevation cloud forests. Some examples are: the Carite State Forest with elevations up to 903 m (DNER, 2008a), the Maricao State Forest, with the cloud forest at an elevation of 900 m (DNER, 2008b), and in the El Yunque National Forest above 900 m (DNER, 2009). Gleason and Cook (1927) noted that in the cloud forest of the Cordillera Central there was less wind and the canopy was taller than in the cloud forest of El Yunque National Forest, which is located in the north-east part of Puerto Rico and is more exposed to trade winds that arrive to the Island.

The Recuperation Plan for *A. amintae* states that its habitat is found within the cloud forest of Puerto Rico (USFWS, 1991). The cloud forest of Cordillera Central has a canopy that

does not exceed 22 feet in height and has stunted vegetation (USFWS, 1991). Following this type of vegetation is the Sierra Palm forest, which has steep slopes and elevations higher than 457 m (DNER, 2009). Therefore, *Alsophila amintae* grows in the cloud forest associated with areas of Sierra Palm forest.

There is very limited literature regarding the species of this study, *Alsophila amintae*, and its habitat, the cloud forest in Puerto Rico (USFWS, 1991). This is due in part to the unavailability of funding for research, lack of people interested in studying the species and the difficult access to their populations. In 1983, Conant stated *A. amintae* as commonly occurring in shaded ravines within the Cordillera Central limited to the Subtropical Wet Forest and Lower Montane Wet Forest life zones (Ewel and Whitmore, 1973). The available habitat description for this species is from the publication: *Ilex cooki and Cyathea dryopteroides publication* (USFWS, 1991). *Alsophila amintae* is reported from areas with high humidity levels (2362.2 mm of rain annually) and low average temperatures (18.4°C). It also has been documented that it tends to develop in poor nutrient and waterlogged soils which are derived of Upper Cretaceous volcanic and clay rocks which are covered in a layer of humus. This species is adapted to high elevations, such as those found in patches of cloud forests in Puerto Rico, at elevations greater than 830 m.

Ecological studies

The Cyatheaceae clade is composed of approximately 500 species of scaly tree ferns (Smith *et al*., 2006), in the tropics and subtropics (Tryon and Gastony, 1975; Conant *et al*., 1995; Dong, 2009). Tree ferns from this family are characterized by the presence of scales on their caudexes and stipe-bases (Proctor, 1989). Even though they are most common in tropical areas, they are also found in south temperate climates (Kramer, 1990). Found predominantly in

montane areas (Tryon and Lugardon, 1991), they occupy different habitats such as primary forests, secondary or regenerating forests and open habitats (Tryon and Tryon, 1982; Arens and Sánchez-Baracaldo, 1998). In other parts of the world, ferns extend their range from sea level up to 3500 m. Also, it has been found that several species show a distribution pattern related to climatic conditions (Tryon, 1976).

In the New World, there are 30 species of *Alsophila*: sixteen in the Greater Antilles, one of them in the Lesser Antilles, and fourteen in Mexico and Central and South America (Conant, 1983). The *Alsophila* species can be found in montane areas (Tryon, 1970) and are mostly plants from cloud forest or elfin forest habitat (Conant, 1983).

Alsophila amintae is considered to be a rare or endangered species (USFWS, 1987). Rabinowitz (1981) established three aspects to classify rarity, which are as follows: geographical range, habitat specificity and local population size. *Alsophila amintae* is considered rare because its habitat has been modified by human intervention (*e. g.* deforestation for purposes of agriculture), limiting its presence to small areas of the forest. Another reason is the lack of areas with adequate environmental parameters (*e. g.* temperature, humidity) for them to grow.

This species is restricted to the cloud forest area in the Cordillera Central of Puerto Rico. Prior to the present study, it was believed that there were only three populations, located in Monte Guilarte in Adjuntas, Monte Jayuya in Ponce, and Cerro Rosa in Jayuya; with approximately ninety-five individuals distributed among these three populations (Proctor, 1989; USFWS, 1991). Herbarium records document *A. amintae* at or above 1025 m (specimen from Ala de la Piedra, Orocovis, Toro Negro State Forest; Hernández-Muñíz *44* MAPR). But, this species has been documented at lower elevations in Monte Cerrote, Peñuelas (its type location)

at an elevational range of 900 - 1050 m (Maxon, 1925). According to the report of the USFWS (1991) it is believed that this species is no longer extant at that locality.

Tropical forests are exposed to natural and anthropogenic disturbances (Weaver, 1989), which could impact the forest structure and its function (Gomez-Pompa, 1984). Disturbances such as invasive species, high winds, tropical storms, tree-falls, landslides, land use and global warming could affect the distribution, growth rate and survival of species over time in the cloud forest. The presence of native invasive species such as *Gleichenella pectinata* and *Hypolepis repens* in locations near *A. amintae* has been previously documented. Along with *Cyathea arborea*, these edge species are associated with disturbed areas of the forest (Monsegur and Saliva, 2012).

It is known that wind speed increases as land-surface elevation increases (McVicar *et al.*, 2010), and it could affect the forest structure composition and dynamics in tropical forests (Foster *et al.*, 1999). For example, the passage of Hurricane Georges through Puerto Rico in 1998 left the Toro Negro State Forest with noticeable damages (Rosado-Martinez, 1999).

Anthropogenic disturbances such as tree-cutting (deforestation), erosion and fires are common in tropical forests; most of them have been studied over short-term time intervals. Also, the occurrence of landslides in inclined areas could eliminate microhabitats for terrestrial plant species (Rosado-Martinez, 1999).

Land use, such as road and building construction, over time causes disturbances in the ecosystem. This could influence soil conditions, alter species distribution patterns and promote invasion of nonnative species (Foster *et al*., 1999; Thompson *et al*., 2002; Chinea and Helmer, 2003). Road construction (which aids spreading non-native species) nearby or within a mountain

contributes to the elimination of plants, affects plant populations and could promote competition between species and threaten the more susceptible species in that habitat (Auerbach *et al*., 1997; Guariguata and Dupuy, 1997). A study by Olander *et al.* (1998), concluded that road construction in the subtropical cloud forest affected the plant species that were near the road, promoting a slower forest recovery due to alterations in soil patterns and the appearance of exotic vegetation.

There is increasing evidence that cloud forests are also threatened by regional and global warming of the atmosphere (Bruijnzeel, 2001). If greenhouse gas concentrations continue to increase, cloud formation at high altitudes in tropical cloud forests could be affected, thus altering the hydrological cycle (Bensiton *et al*., 1997; Still *et al.,* 1999). The variability of rainfall and increasing droughts can lead to deforestation and habitat fragmentation (Loope and Giambelluca, 1998). For example, Lohse *et al.* (1995) studied the effects of drought that were associated with the ENSO (El Niño Southern Oscillation) effect on successional vegetation on Hawaii. They found there was a relationship between low precipitation and the high mortality of shrub species. The drought caused by the ENSO effect was the mechanism that promoted a shift of dominance of species within the successional vegetation.

Population ecology

Fern sporophyte anatomy and morphology has been subject to many studies, but growth rates and life spans have not been studied in detail (Mehltreter *et al.*, 2010). Specifically, the growth of tree ferns has been poorly studied, mainly because of their slow growth and the need to make observations over long periods of time (Seiler, 1981). A way of studying tree ferns growth rate is by observing the length and width of the trunk over time. Along with trunk height

growth, diameter measurements also have been utilized to study tree ferns age (Schmitt and Windisch, 2006).

Several studies have concluded that growth rates vary among species, preventing reliable estimates of their age (Seiler, 1981; Tanner, 1983; Bittner and Breckle, 1995; Chiou *et al*, 2001; Durand and Goldstein, 2001). For *Cyathea muricata* in Guadeloupe, Prugnolle *et al.* (2000) found that the age of a tree fern can be underestimated when using the trunk height as an estimate. This was because *C. muricata*'s trunk has little growth during the young sporophyte stage, but as it ages, it grows more rapidly. Arens (2001), studied *C. caracasana* and its performance in the Andean cloud forest in Colombia. By studying trunk growth rate, leaf production, life span and spore production, she found that trunk height may be a poor estimate of an individual's age.

Given that some studies have concluded that measuring trunk growth may not be a method of determining the age of a tree fern, another approach utilized is by assessing leaf production rates (Schmitt and Windisch, 2006). For example, in a study by Jones *et al.* (2007) located at La Selva Biological Station, Costa Rica, frond length was utilized to delimit in tree ferns, rather than trunk height. At the end of the study, they concluded that frond length was more strongly correlated with tree fern age than was trunk height.

Vegetative reproduction

Vegetative reproduction occurs in three different forms: apogamy, bud production and rhizome branching (Mehltreter *et al.*, 2010). In Apogamy, a haploid sporophyte develops directly from the prothallus. *Diplazium*, *Dryopteris* and *Pteris* are examples of reproduction by apogamy. When the plant produces vegetative buds that are capable of producing roots and new plants, this

type of reproduction it is called bud production. Examples of bud production are: *Asplenium*, *Ophioglossum* and *Diplazium*. Long creeping rhizomes can extend over large areas and it may not be obvious that plants on one side of a population were physically derived from plants on another. Plants that usually reproduce by this means are of the genus *Gleichenia*, *Sticherus*, *Dicranopteris* and *Pteridium* (Mehltreter e*t al.*, 2010). In the Cyatheaceae family, few cases of vegetative reproduction by apogamy have been reported (in *Alsophila muricata* (Willd.) Desv., *Alsophila Tussacii* Desv. D.S.Conant and *Cyathea horrida* (L.) Sm.) (Stockey, 1918).

Phenology

In general, plant phenology is affected by environmental factors, which is of great importance for understanding plant growth, and therefore, its reproduction (Sharpe and Jernstedt, 1990; Mehltreter, 2008). Plants respond to environmental changes with morphological and physiological adaptations (Arens, 1997; Arens and Sánchez-Baracaldo, 2000). It is a priority to study the reproduction and life history of rare and/or endangered species to promote their conservation and restoration (Carrero-Rivera, 2001). To understand responses of plants to their habitat, their phenology needs to be studied (Farrar *et al.* 2008; Mehltreter, 2008).

Most phenological studies have been focused on studying angiosperms rather than studying ferns. Ferns compose the dominant part of the forest understory vegetation (Lee *et al.*, 2009). Few studies related to the ecology and development of tree ferns have been done (Gomez, 1983; Bittner and Breckle, 1995; Schmitt and Windisch, 2005). Phenological and ecological studies are still needed to understand the tree fern life cycle, its reproduction and its genetic variability (Werth and Cousens, 1990).

When studying fern phenology, researchers have focused on the life history stages of the fronds (Mehltreter *et al*., 2010). There is little understanding about how the environment triggers leaf emergence, fertility and mortality (Mehltreter, 2008). In order to study fern phenology, leaf longevity, growth and timing of leaf emergence must be taken into consideration (Harada and Takada, 1988; Kikuzawa, 1989). Some studies show that fern phenology can be related to environmental variables such as temperature and rainfall in areas where seasons are apparent, with delimited seasons (Farrar and Gooch, 1975; Farrar, 1976; Lee *et al*., 2008). Nevertheless, other studies conclude that the phenology is non-seasonal, especially in the tropics where seasonal changes are not evident (Tryon, 1960). In temperate regions, seasonal leaf phenological patterns are present in deciduous ferns, but in tropical areas, where seasonal changes are not as apparent, those patterns are difficult to detect (Sharpe, 1997). More recent studies are trying to observe the aspects of phenology due to different environmental variables that could have different effects depending on the fern species (Mehltreter, 2008).

For *Cyathea hancockii, C. metteniana and C. podophylla* in northern Taiwan, Lee *et al.* (2009) found that temperature patterns were a factor affecting the phenology parameters (such as leaf emergence and senescence, life span, size, and spore maturation) while precipitation patterns did not have a significant effect. Also, the life span of the fertile fronds of these ferns were usually shorter than the sterile fronds, regardless of seasonality. In a study by Bittner and Breckle (1995), in Costa Rica, tree fern growth parameters were influenced by habitat types. The species that where present in a secondary forest grew three times faster than those of a primary forest. Even though the tree ferns studied were morphologically different, their growth rates were similar in each of the habitats. Also, they found that elevation did not affect the distribution of the species.

It is widely known that palynological data is very useful in taxonomic studies (Kramer and Tryon, 1990). Spores can also be utilized to identify species and hybrids. Scanning Electron Microscopy (SEM) and an appropriate spore treatment are needed to study spore morphology details. Spores can be obtained from the field or from an herbarium specimen. For example, Liu *et al.* (2000), proposed taxonomical subdivisions of 56 Athyrioid fern species in Taiwan, China by using the spore ornamentation of each genus.

In ferns, mature spores have a two-layered wall, with both perispore and exospore, and their protoplast is filled with lipid drops (Tryon and Lugardon, 1991). Spores of *Alsophila* have a trilete form with a reticulate ridge pattern (Gastony, 1973; Conant, 1975; Gastony and Tryon, 1976; Conant and Cooper-Driver, 1980). They are 33 to 47 µm long and they are tetrahedral to globose with prominent angles (Tryon and Lugardon, 1991). The ridged perispore is a key character to identify species of this genus (Liew and Wang, 1976). For the tree fern species, spore morphology can be supplementary to morphological characters, given that the later are easier to corroborate in the wild. In Puerto Rico, spore morphology (perispore and spore surface) can be utilized to distinguish between tree fern species of the genus *Alsophila* and *Cyathea* (Proctor, 1989; Tryon and Lugardon, 1991).

In a comparative analysis of herbarium spores of *Alsophila*, using light microscopy (LM), SEM, and transmission electron microscopy (TEM) techniques, Marquez *et al.* (2009) found that *Alsophila* species from South America produced ridged or cristate ridged spores; a character useful for systematic purposes. The chemical procedures prior to microscopy analysis were important regarding the differences in results. When they used glutaraldehyde plus alcian blue in herbarium samples with TEM, the ultrastructure was not discernable, but by using glutaraldehyde plus ruthenium red, the wall ultrastructure and its elements were evident.

Ferns can disperse their spores from a few meters up to thousands of kilometers (Conant, 1978; Wolf *et al.* 1991). In general, spores have a great capacity for dispersal by wind. Long-distance dispersal of ferns is effective, since many ferns have small, lightweight spores (Barrington, 1993). Spore dispersal could depend on vegetative aspects of the fern, thus, taller ferns could have a higher probability of dispersing their spores at a wider range of distance compared to those who are smaller and nearer the ground. But, understory species may not have this advantage because of very low wind speed in the forest understory, which limits local spore dispersal (Bremer, 2007).

Hybrid studies

Natural hybridization is a relatively common feature among vascular plants and has been demonstrated to play an important role in their evolution (Ellstrand *et al.,* 1996). Hybrids often are better fit than the parentals for the survival in disturbed environments (Arnold, 1992). According to Grant (1981), the frequency of natural hybridization in plants varies with aspects such as life history, pollination syndrome, breeding system, environmental disturbance, and genetic predisposition. In addition, the existence of a hybrid species implies the proximity of its progenitor species at present or at some time in the past. Anderson (1949) inferred that if disturbed environments return to the previous undisturbed state, the original parental plants could replace hybrids.

Hybridization is a widespread and evolutionarily important phenomenon in plants (Stace, 1975; Rieseberg and Wendel, 1993; Ellstrand *et al.*, 1996; Arnold, 1997). It could lead to greater genetic diversity and adaptations to new environments (Stebbins, 1942; Anderson, 1949; Harlan, 1983). Also, it could help preserve germplasm of rare and endangered species (Falk and Holsinger, 1991). But, this could have negative effects such as: the endangerment of plants

localized in small populations, such as islands (Cade, 1983), and outbreeding depression (Falk and Holsinger, 1991), which is when hybrid offspring have lower reproductive success than the parentals (Montalvo and Ellstrand, 2000). The ecological, environmental and economic impacts of hybridization in the wild have not yet been studied in detail (Mehltreter *et al.*, 2010).

Sterile hybrids and fertile hybrid species can be found in ferns (Barrington, 1993). For example, hybrids between species of *Polystichum* in Costa Rica are in large populations intermixed with their parental individuals within a few meters (Barrington, 1985). Hybridization between native and alien fern species is potentially a problem of great concern. Even though their ecological and environmental impact is not clearly understood, the resulting hybrids could be aggressive colonists and therefore might cause problems to native fern communities (Mehltreter *et al.*, 2010).

Hybrids are common in the genus *Alsophila* (Caluff and Serrano, 2002). There are two groups of hybrids within this genus: hybrids with reproduction stabilized by allohomoploidy, which is stabilization of hybrid reproduction at the homoploid level (Conant, 1983). Allohomoploidy occurs when two diploid species reproduce through ingametophytic crossing and produce a F_1 diploid hybrid. That hybrid will have a hermaphrodite gametophyte that will allow intragametophytic selfing, thus creating an F_2 generation of hybrids that will have both recombinant and non recombinant spores. Only the recombinant spores will produce hermaphrodite gametophytes that will be able to reproduce via intra- or intergametophytic selfing and will develop sporophytes that are genetically and morphologically identical; they will have a stabilized reproduction at chromosomic level (they are homozygous at every gene locus) (Conant and Cooper-Driver, 1980).

The species of the genus *Alsophila* tend to hybridize extensively in Puerto Rico (Conant, 1975, 1983). Proctor (1989), gives a list all the possible hybrids of *Alsophila* that can occur in Puerto Rico. This list includes: *Alsophila brooksii* × *portoricensis*, *Alsophila amintae* × *bryophila* (*C.* × *dryopteroides*), *Alsophila bryophila* × *portoricensis* and *Alsophila amintae* × *portoricensis*. It has been documented that *Alsophila amintae* hybridizes with both *A. bryophila* and *A. portoricensis* (Proctor, 1989). Morphological characters such as lamina dissection, pinna shape, and presence of squaminate spines are often used to detect fern hybrids in the wild.

It is known that *A. amintae* has 69 pairs of chromosomes (Conant, 1983); *Alsophila portoricensis* and *A. bryophila* also have 69 pairs of cromosomes. Therefore, their hybrids with *A. amintae* also have the same chromosome number (Proctor, 1989). Conant and Cooper-Driver (1980) studied the hybrids of *Alsophila bryophila*, *A. amintae* and *A. portoricensis* (formerly known as *Nephelea portoricensis* (Spreng. ex Kuhn) R.M. Tryon) in Puerto Rico and found that their fertile hybrids are producing individuals that resemble species present in other islands of the Greater Antilles. The study by Conant and Cooper-Driver (1980) confirms that these hybrids already have a stabilized reproduction at homoploid level, which means that groups of fertile hybrids morphologically identical emerge in groups (or clusters) within the forest.

Alsophila amintae × *bryophila* has only been documented at Jayuya, Puerto Rico. Herbarium specimens show that the hybrid, *Alsophila amintae* × *bryophila*, presents longer, wider and pubescent fronds [*Conant 1964* (GH), *1966* (F, GH, etc.), *Conant and Kitfield 2282* (GH)]. *Alsophila bryophila*, has a trunk up to 7.3 m tall and 10 cm in diameter. Its fronds are 1.4 - 2.6 m long and the stipe is very short, 3.2 - 15 cm long. This species has a densely pubescent rhachis and costae on the fronds. The tan hairs in both sides of the frond and its height are what

principally distinguish *A. bryophila* from *A. amintae* (Proctor, 1989). The hybrid *Alsophila amintae* × *bryophila* has a narrowly elliptical to oblanceolate pinna shape, which is also characteristic of *A. amintae*. In *A. bryophila* the pinna shape is lanceolate to narrowly elliptical. *A. amintae* × *bryophila* has the basal subaphlebioid pinna that is present in *A. amintae* but is absent in *A. bryophila*. The dense pubescence characteristical of *A. bryophila* will be present in its hybrid with *A. amintae* but it will be moderately pubescent.

Herbarium records show that the hybrid *Alsophila amintae* × *portoricensis* has been documented at localities in Adjuntas and Jayuya [Adjuntas (*Conant 1906* (F, GH, etc.), *1915* (GH, etc.); Jayuya, (*Conant 680* (GH, NY, US), *687* (F, etc.), *1705* (GH, NY, US), *1954* (SV), *1960* (K), *1961* (US), *1963* (NY), *Conant and Kitfield* 2259, 2260, 2316, 2321 (GH)]. *Alsophila portoricensis* caudex or trunk grows up to 6 m tall and 8 cm in diameter. Its fronds range from 1.5 -3.5 m long and its stipes from 45 - 74 cm long. The principal characteristic that differentiates this species from *A. amintae* and *A. bryophila* is the presence of spines (about 5 mm long) on the trunk (Proctor, 1989). The hybrid *A. amintae* × *portoricensis* has lance-ovate to narrowly obovate pinna shape, while in *A. amintae* is narrowly elliptical to oblanceolate and in *A. portoricensis* is ovate to obovate. *Alsophila amintae* × *portoricensis* will present curved spines like its parental *A. portoricensis*, but they will be shorter. In the localities where it occurs, *Alsophila amintae* × *portoricensis* is more abundant than either of its parents, and it reproduces sexually; it is suggested that this hybrid could be an incipient allohomoploid species (Conant and Cooper-Driver, 1980).

MATERIALS AND METHODS

Study sites

The localities of Monte Guilarte in Adjuntas, Monte Jayuya in Ponce, and one of the peaks of Cerro Rosa in Jayuya were visited during the year of study (January-November 2014) in order to reconfirm the presence of *A. amintae* in those localities and their reported abundance. The locations of Cerro Punta, Cerro Maravilla and Tres Picachos were also searched.

Abundance

The extant *Alsophila amintae* populations were localized based on herbarium records (JBSD, MAPR, NY, SJ, UPR, UPRRP and US) such as GPS coordinates and additional locality data given by previous collectors. This populations are: Monte Cerrote, Bo. Rucio, Peñuelas, Monte Guilarte, Bo. Guilarte, Adjuntas, Cerro Punta, Bo. Veguitas and Bo. Anón, Jayuya/Ponce, Monte Jayuya, Bo. Anón, Ponce Cerro Maravilla, Bo. Saliente and Bo. Anón, Jayuya/Ponce and Cerro Rosa, Bo. Saliente, Jayuya. USGS topographic maps (7.5-minute series quadrangles, 1960) were also reviewed. In addition, other potential locality for the species, Tres Picachos, was searched and the abundance of individuals was quantified as well. These localities were selected as potential localities due to their high elevations, at a close distance to the surveyed localities. Its type locality, Monte Cerrote, was also searched. For each population, the total area was calculated with the Google Earth Pro (Ver. 7.1.5.1557) program. The area between all the populations was calculated by using convex polygons, and the distances (in ha) between all the populations were calculated with a ruler line in the Google Earth Pro program.

Geographical distribution

The location of each individual was determined with a Garmin *e*trex 30 (Garmin, Switzerland and US) Datum WGS84, and distribution maps, one for all the populations (including the Adjuntas Experimental Substation and the species type locality) and individual maps for each of the populations were made using the ArcGIS 10.4.1 (Esri, US) program. These maps and the discussion that follows are presented in order from west to east throughout the thesis. At the beginning of the survey in January 2014, the individuals of *A. amintae* in the localities of Monte Guilarte, Monte Jayuya and Cerro Rosa were counted and each individual was marked with non-degrading plastic tape (flagging) on the trunk. Individuals that were found on the localities of Cerro Punta, Cerro Maravilla and Tres Picachos were counted and their coordinates were taken as well, but they were not marked with tape. At the end of the study, on November 2014, the individuals were counted again in all three studied populations in order to see if there were changes in the total abundance of *A. amintae*. These current quantitative data were compared with past population estimates.

The elevations of all individuals were used to build a spatial distribution map in ArcGIS 10.4.1 program. Digital topographic maps from the Natural Resources Conservation Service (NRCS) were consulted to verify the elevations. The soil types were determined with the SoilWeb application, developed by the California Soil Resourse Lab at UC-Davis, and UC-ANR in collaboration with USDA-NRCS (Beaudette, 2012).

Morphological comparisons with other species of *Alsophila*: *A. bryophila*, *A. portoricensis* and *A. brooksi* were made to corroborate identification of the species in the field, based on the taxonomical descriptions in Proctor (1989). Three voucher specimens of *A.*

amintae, one for each of the localities, were deposited at the University of Puerto Rico-Mayagüez herbarium (MAPR). Hybrids (*A. amintae* × *portoricensis* and *A. amintae* × *bryophila*) were also collected and deposited in the MAPR herbarium. A collecting permit (OVS-PVS15-SJ-00611-11062013) was obtained from the Department of Natural and Environmental Resources (DNER) before doing this study.

Habitat characterization

I. Slope inclination and orientation

For each individual of Monte Guilarte, Monte Jayuya and Cerro Rosa populations, slope inclination and orientation (aspect) were measured manually with a clinometer and a compass.

II. Soil humidity and pH

Soil humidity and pH were taken on a bimonthly basis with a Kelway Soil Tester (Kel Instruments Co., Inc.) at Monte Guilarte, Monte Jayuya and Cerro Rosa. The instrument's metal tip was buried in the soil, near the trunk of each individual, and measurements were taken. For more accurate results, the metal tip of the instrument was cleaned with distilled water, a soft cloth and conditioning film prior each bimonthly use.

III. Temperature and precipitation

The monthly temperature and precipitation data for 2014 were obtained from Franklin A. Soto at the Adjuntas Experimental Substation (AES), University of Puerto Rico, Mayagüez Campus. Daily mean air temperature (°F) and rain in inches for every month of the year of 2014 were tabulated.

IV. Canopy openness

On each field visit to Monte Guilarte, Monte Jayuya and Cerro Rosa, photos were taken directly above each individual of *A. amintae* with a Nikon Coolpix 4500 4.0 megapixel (Nikon, Japan) with fish eye lens. Once the photos were converted to black and white and analyzed, the percent of canopy openness was obtained for each photo. The percent of canopy openness was obtained by taking the fish eye photos of the forest canopy and processing them using the Gap Light Analyzer program (Frazer *et al.*, 1999).

Natural and anthropogenic disturbances

The frequency of natural disturbances was annotated and quantified monthly, for each individual in the Monte Guilarte, Monte Jayuya and Cerro Rosa populations. Storms affecting the Island were documented during the study. Observations of other natural disturbances, such as landslides and invasive plant species in *A. amintae* populations were taken into consideration. In each visit, senescent Sierra Palm fronds were manually removed from *A. amintae* affected individuals.

Vegetative aspects

Data on trunk diameter and plant height from the base to the apex were taken in all the individuals of the Monte Guilarte, Monte Jayuya and Cerro Rosa populations. The diameter was measured on the middle height of the trunk with a diametric tape. These measurements were only taken at the end of the study.

Phenology of *Alsophila amintae*

I. Fronds

The numbers of live and senescent, sterile and fertile fronds for 40 individuals of *A. amintae* were counted and censused during the morning hours every two months (January, March, May, July, September, and November) of 2014. This was done for the three surveyed populations. Three random fronds from each individual were labeled with flagging tape and monitored throughout the year. The fronds were selected based on age: one frond at the base (old), one in the middle (mature) and one at the stem apex (new). If a marked frond died, another one was substituted for it. The length (from the frond base to the tapering end) and width (on the middle) of these fronds on both juvenile and mature individuals were measured (in cm) bimonthly and averaged for each population.

A way to recognize a juvenile of *A. amintae* is by counting its pinnae. A juvenile has approximately 10 to 21 pinnae in each frond, meanwhile an adult (sterile and/or fertile) has from 22 to 27 pinnae per frond (pers. obs).

II. Spore observation with the Scanning Electron Microscope (SEM)

A fertile frond was put on a white sheet of paper and put under an incandescent light bulb, so the sporangia could open and spores could be collected. Seventeen spores were evaluated under the SEM. To observe *A. amintae* spores under a SEM (model JEOL 5410 LV), the perispore was removed following Hu *et al.* (2010) experimental procedures. The spores were soaked in a 70% ethanol solution and agitated in a vortex mixer to remove the exospore layer. Spores were gold-coated with gold/palladium in a sputter-coater (Bio-Rad, model E-5000), mounted and photographed by Sr. José Almodóvar (Laboratory Technician) at the Microscopy

Laboratory of the Biology Department, University of Puerto Rico at Mayagüez. Spore fertility was determined by observing if the spores were turgid or collapsed.

III. Spore dispersal experiment

Fertile fronds with green sporangia were collected from five random individuals at the Monte Jayuya locality and were taken to the General Botany Laboratory at the University of Puerto Rico at Mayagüez. The corners of pieces of fresh fronds were tied with thread to a piece of wood and placed upside above the paper at a distance equal to the height of the tallest individual found (Fig. 3). The fronds were left overnight. This allowed the sporangia to dehisce and the spores to be dispersed onto the paper. Afterwards, the distance of dispersal (in cm) from the sori (source) to the spores was measured with a ruler.

Hybrids

Herbarium specimens of the hybrids were consulted in order to recognize them in the field. *Alsophila amintae* × *A. bryophila* has pinate-pinnatifid fronds and hairs in areas of the frond and rachis. *Alsophila amintae* × *A. portoricensis* has pinate-pinnatifid fronds and black and slightly curved spines on the trunk. Some of the hybrids are distinguished by having a larger size (up to one meter in height) than that of the parental *A. amintae* and also differences in the sori arrangement. The sori of *Alsophila amintae* × *A. bryophila* are arranged near the margins of the pinnae and appear to be disorganized, while the sori of *Alsophila amintae* × *A. portoricensis* are inframedial and more organized.

The hybrids from Monte Guilarte, Monte Jayuya and Cerro Rosa were identified and counted. The hybrid plants were monitored regularly for production of sori to observe spores

under the SEM of the Biology Department at the University of Puerto Rico at Mayagüez for purposes of comparison.

Statistical analyses

Statistical analyses were done with InfoStat ® Statistical Program (Di Rienzo *et al.*, 2012). Shapiro-Wilks test was performed to confirm the the statistical test assumption of normality and the Levene test for homoscedasticity of residuals. Dispersion and bar graphs, Analysis of Variance and Fisher tests were utilized to analyze environmental parameters, vegetative and phenological aspects.

Management recommendations

The results of this study were used to assess the Recovery Plan of *A. amintae* to give recommendations for the best management of the species.

RESULTS

Abundance

During the year of study (January-November 2014), a total of 107 individuals of *A. amintae* were found (Table 1). The populations of Monte Guilarte and Cerro Punta were revisited in 2015 to 2017 and 42 additional individuals were found, for a total of 149 individuals. Overall, *Alsophila amintae* was found in six populations (Figs. 4 and 5): Monte Guilarte, Cerro Punta, Monte Jayuya, Cerro Maravilla, Tres Picachos and Cerro Rosa. The largest population was in the location of Cerro Punta (47 individuals) and the smallest was Cerro Rosa (7 individuals). In recent visits to the populations of Monte Guilarte, Cerro Punta and Monte Jayuya during 2016 and 2017 an increase in abundance was observed and young *A. amintae* individuals were found growing healthily near the parental plants. For the population of Monte Guilarte, no juveniles were reported during 2014. But, as of 2017, there are newly reported juveniles near the previously surveyed individuals, with an increase of population by three individuals. This was also observed in the location of Monte Jayuya, on a cluster of individuals of *A. amintae* that were previously surveyed during 2014. A cluster that consisted of five individuals was revisited on 2016 and it had juveniles near the parental plants and possible gametophytes of *A. amintae* growing on fallen tree fern trunks of *Cyathea arborea*.

Geographical distribution

All populations of *Alsophila amintae* were found in the understory of the cloud forest, always accompanied by the understory fern *Thelypteris deltoidea*, and the canopy species *Prestoea acuminata* var. *montana*, the Sierra Palm. *Alsophila amintae* populations were on

volcanic rock with clay soils with a layer of recently fallen leaves, and a humus layer which covered the forest floor. This species is associated to Sierra Palm forest.

Table 2 shows the associated species for *A. amintae* for all three studied populations during 2014. Some of the plants associated with this habitat are: *Anthrostylidium sarmentosum, Commelina difusa, Cyathea arborea, Cyathea bryophila, Cyathea portoricensis, Danaea sp., Gleichenella pectinata, Hypolepis nigrescens, Pilea inaequalis* and *Thelypteris deltoidea*. In the locations of Cerro Punta, Monte Jayuya and Cerro Maravilla *Schefflera gleasonii* and *A. sarmentosum* were found. *Anthrostylidium sarmentosum* grows near *A. amintae* individuals in Monte Jayuya, but it was also growing above individuals in Cerro Punta and Cerro Maravilla.

These species are commonly found in disturbed areas (edges of the forest and/or near antennas). *Hypolepis nigrescens* was found in the locations of Monte Jayuya, Cerro Maravilla and Tres Picachos.

The soil association of Monte Guilarte, Monte Jayuya and Cerro Maravilla is Los Guineos – Maricao, in Cerro Punta is Maraguez and in Cerro Rosa and Tres Picachos it is Los Guineos – Maricao Rock Outcrop. They are well drained, moderately permeable, very acidic, clay soils (Beaudette, 2012).

Their areas ranged from 0.1 to 1.7 ha (Table 3). Based on this present study, it is estimated that *A. amintae* occupies a total area of 4.1 ha in Puerto Rico, which is 0.0004% of the total area of the Island.

Alsophila amintae has an elevational range of 1050 to 1325 m which was utilized to construct the spatial distribution map (Fig. 6). This map includes potential localities within this elevational range based on the individual found at the lowest and at the highest elevations.

The Monte Guilarte population (Fig. 7) is found within the Monte Guilarte Commonwealth Forest (Municipality of Adjuntas, Bo. Guilarte, 18.14145, -66.76942). This population is 4.8 km from the AES. It is located on the north-west face of one of the mountains, near the hiking trail to El Cerro, within the Monte Guilarte State Forest. The population is found going to the right side of the trail and 20-30 m down the slope. The individuals were at an elevation range from 1050 to 1181 m (Table 1).

A total of eight individuals were found in Monte Guilarte at the beginning of the survey. All of them were adults. At the end of the year of study, four more individuals were found, for a total of 12 individuals for this population. On a recent visit (February, 2017) to this population a more complete search was done and three additional individuals were found, for a total of 15 individuals (Table 1). Two of those individuals were new reports of juveniles for Monte Guilarte, which means that the population is reproducing healthily. At this location, some individuals tend to grow in small groups (clusters) of two individuals. The Monte Guilarte population covers an area of 0.7 ha.

The Cerro Punta population (Fig. 8) is found within within the Toro Negro State Forest (Municipalities of Jayuya and Ponce, between Bo. Veguitas and Bo. Anón, 18.17209, -66.59116). This population is 22.0 km from the AES. The studied population is located on the north-east face of the mountain, going down slope after passing a small (one floor) building on

the parking lot. The individuals were at an elevation range from 1299 to 1312 m (Table 1). Seven individuals were found, near the antenna closest to the small building.

In a most recent visit to this locality by biologists from United States Fish & Wildlife Service (USFWS), Fairchild Tropical Botanic Gardens (FTBG) and University of Puerto Rico (UPR) in February, 2017, approximately 40 individuals were found in two additional areas (Table 1). The biggest group of individuals were on the north-east side of the building, near a curve of the main road that goes up to Cerro Punta. The second area was located on the north-west side of the antenna located on the west side of Cerro Punta. The area for this population (including the newly found individuals) is 1.7 ha.

The Monte Jayuya population (Fig. 9) is found within within the Toro Negro State Forest (Municipalities Ponce, Bo. Anón, 18.16720, -66.57624). This population is 25.5 km from the AES, and is located on the north-east side of the communication antennas of the highest building. The individuals were located down the slope from the road to the antennas, near Rte. 143. The range of elevation for this population is from 1255 to 1325 m (Table 1).

At the beginning of the survey a total of 23 individuals were found. By the end of the survey, a total of 40 individuals were found for this location. In this population, the species is distributed in clusters with a minimum of two individuals. The biggest cluster was composed of five individuals. Four of the individuals of *A. amintae* in this population were juveniles. The population covers an area of 0.2 ha.

The Cerro Maravilla population (Fig. 10) is found within within the Toro Negro State Forest (Municipalities of Jayuya and Ponce, Bo. Saliente and Bo. Anón, 18.15409, -66.55334).

This population is 26.1 km from the AES, and it is located on the north-east side of the mountain. The individuals are found near the east side of one of the lowest antennas, and going down the steep slope slope approximately 10-15 m. The Anón River had to be crossed to reach the *A. amintae* population. The range of elevation for this population is from 1299 to 1312 m (Table 1). In this population, 28 individuals were found, six of them were juveniles. This population overs an area of 0.8 ha.

The population of Tres Picachos (Fig. 11) is located within the Tres Picachos Commonwealth Forest (Municipalities of Jayuya and Ciales, Bo. Saliente y Bo. Toro Negro, 18.21527, -66.54105). This population is at 27.4 km from AES. It is located on the north-east side of the first peak, on the right side of the hiking trail, going down the slope. The range of elevation for this population is from 1078 to 1103 m (Table 1).

On this locality, 12 individuals were found. They were located on small clusters of three to four individuals. *Alsophila amintae* covers an area of 0.9 ha on this population.

The Cerro Rosa population is localized within the Toro Negro State Forest (Municipality of Jayuya, Bo. Saliente, 18.18025, -66.53979) (Fig. 12). This population is at 27.7 km from the AES, and it is located on the north-west side of the peak that was surveyed. Individuals of *A. amintae* were found going up a very steep slope, and almost near the top of the peak. This population was the farthest one from roads, buildings and constructions. The range of elevation for this population is from 1169 to 1184 m. In order to reach the plants' location, the Saliente River was crossed.

In this population, eight individuals were found. At the end of the study, only seven individuals remained. One of the individuals found in this population was a juvenile. The area for this population covers 0.3 ha.

The distances between all the peaks where this species is found are summarized in Table 4. The maximum distance between *A. amintae* populations was 25.5 km, between Monte Guilarte and Cerro Rosa. The minimum distance was of 1.6 km, between the Cerro Punta and Monte Jayuya populations. The Monte Guilarte population is the most isolated; it is 20.6 km from the Monte Jayuya Population and 25.5 km from the Cerro Rosa population. The Monte Jayuya population is 6.4 km from the Cerro Rosa Population. The type location of Monte Cerrote in Peñuelas municipality was also visited, but no individuals were found in this area.

Habitat characterization

I. Slope inclination and aspect

The typical slope inclination varied among the six populations of *A. amintae* (Table 5). The lowest typical slope inclination found was in the Monte Jayuya population (10º), while the highest was in the Cerro Punta and Cerro Rosa populations (55º). Most of the populations studied, including the new populations found, were distributed along the north-east facing slopes of the mountains. Only the Monte Guilarte and Cerro Rosa populations were in the north-west side of the mountain. In the steepest location (which is Cerro Rosa), the individuals are found in a small flat terrain area.

II. Soil humidity and pH

The soil humidity and pH were measured bi-monthly (Table 6). The mean humidity percentage was 69.1 ± 15.3% and it ranged from 30 – 100%. The humidity percentage in Monte Guilarte was higher in September (80%) and lower in May (48%). For Monte Jayuya, the highest humidity percentage (81%) was in September and the lowest in the month of May (57%). In Cerro Rosa, the highest humidity percentage also occurred in September (85%) and the lowest in July (65%). This type of data was not obtained for the locality of Monte Cerrote.

The range of soil humidity for juveniles was from 30.0 – 95.0% ± 14.7 and soil pH was from 5.6 – 7.0 ± 0.4 (Table 7). In adults, the range of soil humidity was from 30.0 – 100.0 ± 15.3 and the soil pH from 5.0 – 7.0 ± 0.3. For the three studied populations, the soil pH values ranged from 6.2 – 6.9 (Table 6).

III. Temperature and precipitation

Data on temperature and precipitation were obtained from the Adjuntas Experimental Substation. The AES coordinates are: 18.174444, -66.797778, and its elevation is 548.6 m. This Substation ranged from 4.8 to 27.7 km from the studied populations (Table 4).

The minimum recorded air temperature (50°F) was on the 14th of January, and the maximum air temperature (87.4°F) was on July 27. The lowest average temperature was 66.8°F in January, and the highest was 73.2°F in July (Table 8).

The total annual precipitation recorded for 2014 was 1866.9 mm. The highest monthly precipitation (591.8 mm) was documented in August. This was due in part to the heavy rains of

tropical storm Bertha, which occurred on August 3, 2014. Meanwhile, the lowest total precipitation (15.24 mm) was documented in the month of January.

IV. Canopy openness

Percentage of canopy openness was calculated only for the three studied populations every two months (Table 9; Fig. 13). The overall average percentage of canopy openness was 14.4 ± 4.3 (Table 10).

Natural and anthropogenic disturbances

I. Natural disturbances

During the year of study (2014), there were several atmospheric events that affected the Island. On August 3, 2014, tropical storm Bertha passed through the south-west of Puerto Rico with wind gusts of 39 mph (at Merceditas Airport, Ponce) (Votaw, 2014). It left more than 254 mm of rain on the Central and Western interior of the Island (NOAA, 2014), without affecting the individuals of *A. amintae* in the three studied populations and with a minimal damage to their habitat. During the third week of August (August 21 - 24), a secondary rainfall event (of than 330.2 inches of rain) affected the Island (Brown, 2015). This event later became Hurricane Cristobal. The localities were visited later in September; none of the individuals were affected by this event. Later, on October 14, tropical storm Gonzalo passed through Puerto Rico. The highest wind gust record (from data buoy Fajardo National Oceanic Athmospheric Administration, National Ocean Service, Puerto Rico Seismic Network Station FRDP4) (Brown, 2015) was 40 mph and no floods or heavy rainfalls were documented (Votaw, 2014). This event did not directly affect any of the individuals surveyed in this study.

The falling of senescent Sierra Palm fronds on *A. amintae* individuals (Fig. 14) was a continuous and natural event throughout the year. This event was present in every visit to the studied populations (Table 11). The senescent Sierra Palm fronds fell over the rosette and fronds of the individuals, shading most of the plant area from the sun, which probably reduces the opportunity for the fronds to continue expanding and perform photosynthesis. This created gaps in the canopy, allowing the light to enter and reach the plants. This can have both positive and negative effects in *A. amintae*. More light exposure could reduce seedling germination but could promote faster frond growth. In each visit, the senescent palm fronds were manually removed from the affected individuals.

Table 12 summarizes the number of individuals affected by natural disturbances. The locations of Monte Guilarte and Cerro Rosa were the less affected by these type of disturbances. Under the presence of habitat disturbances, some plant species affect the habitat of *A. amintae*. *Arthrostylidium sarmentosum* Pilg., is a native bamboo species grows beside *A. amintae*. It was common near most the individuals found in Monte Jayuya, Cerro Maravilla and Tres Picachos populations. In Monte Guilarte and Cerro Rosa populations this bamboo species was absent near the individuals. Even though it was present in Cerro Maravilla, it did not seem to affect the growth of the individuals of *A. amintae* there. Only two individuals found in Tres Picachos were affected by the invasive bamboo, which was growing above and near the plants (Fig. 15). The population most affected by this invasive plant was Monte Jayuya. *Alsophila amintae* individuals that were near the antennas were the most affected by this bamboo. Also, the native fern *Hypolepis nigrescens* Hook. is present on the edges of Monte Jayuya, near the communication antennas. These species have destroyed *A. amintae*'s habitat (pers. comm.) and are considered a natural disturbance.

Another natural disturbance that could affect this species are landslides. In this case, landslides seem to not have affected *A. amintae* individuals in any of the studied and visited populations. This event was not observed throughout the year of study.

II. Anthropogenic disturbances

Table 13 summarizes the number of individuals of *A. amintae* that were affected by antropogenic disturbances such as land use, contamination and experimentation (which included frond tagging, frond collecting for spore dispersal experiment and herbarium vouchers and spore collecting for propagation studies by FTBG). The locations of Tres Picachos and Cerro Rosa were the less affected by these type of disturbances.

The habitat removal caused by the construction of antennas is a disturbance for *A. amintae*. When the antennas were constructed certain areas on the top of the mountains were deforested and perhaps *A. amintae* could have been previously present. Communication antennas are located near the populations at Cerro Punta, Monte Jayuya and Cerro Maravilla.

The Cerro Punta population, which was the smallest one, consisting of seven individuals, was located on Rte. 143, km. 18.5. In this locality, the individual CP-4 was the closest to one of the communication antennas (18.172539, -66.590953), at a distance of 32.8 m. These antennas are located at an elevation of 1300 m and are owned by the Puerto Rico Public Broadcasting Corporation and by Sistema Universitario Ana G. Méndez, Inc. At the Cerro Punta population, car tires, glass, garbage bags, aluminum cans, plastic bottles and antennae maintenance materials were found around *A. amintae* individuals (Fig. 16). Rubber cables utilized for the maintenance of the communications antennas (Fig. 17) were buried near the individual CP-4.

In Monte Jayuya, the individual closest to one of the communication antennas (18.167344, -66.576811) was MJ-3. This individual was at a distance of 36.4 m from the closest antenna. Pipes that extend to the communication antennas buildings are present near areas where *A. amintae* was located.

The Cerro Maravilla population has several communication antennas located at an elevation of 1200 m. The individual CM-28 was the nearest one (18.15301, -66.55424) at a distance of 65.2 m from the nearest antenna.

In the Monte Guilarte population communication towers are not present, therefore, this popupation is not exposed to this disturbance. There was evidence of anthropogenic disturbance such as littering. Food packages, plastic bottles and cans were found near this population. Individuals closer to the hiking trail were more exposed to this type of anthropogenic disturbance. Trash was found near the trail (up to approximately 2 m off the trail), going down the steep area. The individual nearest to the trail was at a distance of approximately 10 m.

Vegetative aspects

I. Trunk height and diameter

Table 14 and Figure 18 summarize the mean height and diameter of the trunk of *A. amintae* for the studied populations. Apart from adults, there were juveniles present only at Monte Jayuya and Cerro Rosa populations.

In the Monte Guilarte population, all nine surveyed individuals were fertile adults. The mean trunk height was 12.9 ± 4.2 cm (Table 15). The mean trunk diameter was 4.4 ± 0.8 cm. For the Monte Jayuya population, the mean trunk height of *A. amintae* for adult individuals was 15.5

± 8.0 cm. The mean trunk diameter for adults was 4.0 ± 0.7 cm. In the Cerro Rosa population, the mean adult trunk height was 37.7 ± 14.9 cm. Its mean adult trunk diameter was 4.6 ± 0.8 cm. The tallest adult individual was found on this population, with a height 61.0 cm and a diameter of 4.0 cm. Also, this population only had one juvenile (CR-7), which had a height of 15.2 cm and a trunk diameter of 4.0 cm. This individual was the tallest juvenile among all the juveniles in all three studied populations. This measurement was utilized to establish parameters for recognizing juvenile individuals in the field.

Phenology of *Alsophila amintae*

I. Frond production, survival and mortality

A total of 40 individuals were utilized to collect the phenological observations during 2014. Phenology was recorded every two months, during the morning hours (9:00-11:00 AM). Data from one adult (fertile) individual in Cerro Rosa (CR-9) was excluded from the phenological analysis because it was not found on the second visit (March) of the survey. This individual was presumed to have died during the previous two months.

In juveniles, the average number of live fronds per plant was 3.9 ± 1.1 (Table 16); which was lower than in adults. An average of 1.3 ± 1.0 senescent fronds was recorded; up to four senescent fronds per individual. During the year of study, one juvenile became an adult (*i. e*. produced sori) at the second month of survey (March). This occurred at the Cerro Rosa locality (CR-7); therefore, a mean of 0.7 ± 1.6 was obtained for fertile frond production. This individual produced up to six fertile fronds during that year. For sterile fronds, the mean was 3.2 ± 1.5; they produced up to six sterile fronds per individual annually.

For all populations, the mean number of fronds produced (live fronds) per adult plant was 5.7 ± 1.9 (Fig. 19); it ranged from two to twelve fronds. An average of 2.4 ± 1.7 senescent fronds were counted for that year. It was found that an adult individual could have a maximum of seven senescent fronds annually. For adult sterile fronds, a mean of 2.1 ± 1.7 was obtained. The maximum number of sterile fronds was the same as the fertile fronds per year. A mean of 3.6 ± 1.7 was obtained for fertile fronds; a maximum number of adult fertile fronds per year was seven per individual.

In all populations (for both adults and juveniles), the highest frond production occurred in the month of January (6.1 ± 0.3), and the lowest was in March (4.4 ± 0.3) (Fig. 19).

There was a peak of average number of senescent fronds in the month of September (3.9 ± 1.5). The lowest month for mean number of senescent fronds was November (0.8 ± 0.9).

The peak of fertile frond production was in July (Fig. 19). Regarding mean fertile frond production in juveniles, only one individual produced fertile fronds with sori, thus becoming an adult during the course of study. This juvenile from Cerro Rosa population had a mean fertile frond production of 3.5 ± 0.3 annually.

The average frond life expectancy is five to seven months and that leaf turnover (higher frond mortality and senescence) occurs in the month of September (Fig. 19).

The means and ranges for frond length and width in juveniles and adults during the year of study are on Table 17. The maximum frond length for juveniles was 58.4 cm and for frond width, a maximum of 24.9 cm was obtained. The maximum frond length for adults was 94.8 cm and for frond width 28.0 cm.

II. Spore observation with the Scanning Electron Microscope (SEM)

The spores of *A. amintae* had a normal appearance, and they were not collapsed (Fig. 20). They had a trilete form characteristic of the spores of the *Alsophila* genus. The size of the trilete spores was of approximately 33 µm. The reticulate pattern of ridges on the perispore could not be observed due to the difficulty of the endospore removal.

III. Spore dispersal experiment

Frond dispersal mean and ranges are in Table 18. A total of 234 spore trails were measured to assess spore dispersal. The mean spore dispersal distance for this experiment was 5.5 ± 2.5 cm. The spore dispersal ranged from 1.0 to 10.0 cm from the rachis of the frond (Fig. 21). It was found that the spores tend to fall away at approximately 0.5 cm (width) from the pinnae.

Hybrids

The presence of *Alsophila bryophila* and *Alsophila portoricensis* within the habitat of *A. amintae* was confirmed (Table 19; Figs 22 and 23). The elevations for all hybrids ranged from 1085 to 1316 m (Table 20). The hybrids were found in open areas (more exposed to open canopy) and in the understory area, within *A. amintae* populations and they appeared to be healthy. No spore-bearing fronds were found on any of the plants identified as hybrids.

The highest number of hybrids for *A. amintae* was in the location of Monte Jayuya (15 individuals). The most abundand hybrid was *A. amintae* × *bryophila* (Tables 19 and 20).

DISCUSSION

Alsophila amintae is endemic to the cloud forest of Puerto Rico. It is located within the montane rain forest (Toro Negro) and subtropical rain forest (Monte Guilarte) life zones (Ewel and Whitmore, 1973) at an elevation ranging from 1050 to 1325 m. Five populations (Monte Guilarte, Cerro Punta, Monte Jayuya, Cerro Maravilla and Cerro Rosa) were confirmed with herbarium data. This study confirms the presence of this species in a sixth locality of Tres Picachos. The possible existence of *A. amintae* on patches of Sierra Palm between the peaks of Adjuntas, Jayuya, Ponce and Ciales) is not discarded. The localization of this species is restricted to shaded ravines in the highest peaks of the Cordillera Central in Puerto Rico.

Before this study, four extant populations were reported in 2013, with a total of 105 individuals: 10 in Monte Guilarte, 70 in Monte Jayuya and about 25 individuals in Cerro Rosa (USFWS, 2013). A total of 149 individuals were found for this species. One individual (from Cerro Rosa population) died during the year of study.

Alsophila amintae was first collected in Monte Cerrote, Peñuelas by Britton and Brown in 1915 (*5424* PH), but it is no longer documented at this location. An exhaustive search for this species was made at this locality, but it was not found. This locality was near a community of houses and private lands. Monte Cerrote has the lowest elevation (1000 – 1050 m) of all the localities where this species has been recorded (USFWS, 1991). In this locality, there were few patches of Sierra Palm forest, which were not explored. The Sierra Palm fronds cover the canopy of the understory, providing the ideal shade for *A. amintae* populations to grow.

Changes in land use and human disturbances over time may have caused its disappearance on that locality. Habitat conditions where the species is found, such as lower soil

humidity, higher temperatures and levels of canopy openness are not appropriate for common species associated with *A. amintae* (*e. g. Alsophila bryophila, Cyathea arborea, Pilea inaequalis* and *Thelypteris deltoidea*). This parameters were not measured during the visit to Monte Cerrote. If future visits are programmed to this location it is recommended that taking this data should be useful for comparing that habitat with the extant locations of *A. amintae* and observe if there have been environmental changes which could explain the absence of this species in Monte Cerrote.

In Monte Guilarte, *A. amintae* was first discovered by Roy O. Woodbury in the late 1970's (Table 21). In 1981, Vivaldi *et al*. reported 10 individuals as present in that locality. Herbarium records for Monte Guilarte (Fig. 25) show that this species was previously documented at two different sites, but only the one located on the north-west face is reported in this study. A total of 15 individuals were found (Table 1; Fig. 7). The locality that Woodbury discovered near Hacienda Rosario (due west side of Monte Guilarte) (Fig. 29) was was not visited due to the difficultness to arrive to this area. If this locality is still extant, this will increase the population number and the distribution range of *A. amintae* in Monte Guilarte.

The population of Monte Jayuya was first discovered by Sargent in 1943 (USFWS, 2013). Prior to the present study, more than 70 individuals were found at this location (USFWS, 2013). During the year of study, 40 individuals of *A. amintae* were found. Possibly there are more individuals on other areas of the forest that were left unsearched due to difficult access (thick vegetation and steep slopes) to explore. Two herbarium records from Conant (*1851, 1856* NY) apparently were located alongside what is today Rte. 143, at lower elevations (at approximately 1150 m). These localities were searched and the species was not found. It is

unlikely that *A. amintae* is at areas near the Rte. 143 due to the presence of the road and the presence of *Gleichenella pectinata* thickets on both sides of the road.

Cerro Rosa locality has two peaks, and in 1989, Proctor reported finding 25 individuals on the upper-east slope of the peak that falls within the municipality of Ciales. Visits to the peak where Proctor found *A. amintae* back in 1989 could not be done due to lack of time (it takes up to four hours to climb up only one of the peaks) and difficulty in to reaching that population. In the present study, the surveyed population, which consisted in eight individuals, was located on the upper north-west slope of the other peak of Cerro Rosa (Fig. 12) within the municipality of Jayuya. The presence of *A. amintae* in other localities around both peaks of Cerro Rosa and at similar elevations cannot be discarded. An herbarium specimen shows the presence of *A. amintae* on the north-facing slope, near the summit of the peak that was surveyed in this study (Fig 27).

The population in the locality of Cerro Punta was recorded by Conant & Kitfield (*2277* NY) in 1973 at an elevation of 1219 m (Table 21). On the first visit to the Cerro Punta locality, only four individuals were found. On later visits (2016 and 2017), approximately 40 additional individuals were found, making it the population with the highest number of individuals.

Alsophila amintae was discovered in 1993 on Cerro Maravilla (18.156111, -66.5550) (Breckon *et al. 4430* MAPR), and this herbarium record was not accounted for the Recovery Plan review of 2013. This should be taken into consideration. The specimen was collected on the east side, at an elevation of 1200 m, and below the communication antennas. This adds another population for this species that could be utilized in the future for recuperation purposes. During the year of study a total of 28 individuals were found at this location (Table 1). These individuals were located nearer the antennas, while the herbarium specimen apparently comes from near the

Veguitas River, but this is because of an error in the coordinates; the specimen is supposed to be located near the antennas.

The population of Tres Picachos is a new report for the species; there are no herbarium records for that area. In this locality, 17 individuals were found (Table 1). This population was probably not previously found because of the difficulty of exploration within this area. The individuals were present at an elevation that ranged from 1083 to 1103 m. If the other two peaks of Tres Picachos were to be explored in the future, the elevation range and similar environmental conditions have to be taken into account prior their exploration.

Alsophila amintae is present within the Cordillera Central, specifically in the municipalities of Adjuntas, the border between Ponce and Jayuya, and the border between Jayuya and Ciales. It grows on the highest peaks of the Island. In all the populations, most of the individuals were on varied slope inclinations (10° – 55°), humidity levels higher than 51% and understory locations where the sun partially entered mostly through Sierra Palm (*Prestoea acuminata* var. *montana*) fronds. Senescent Sierra Palm fronds (Fig.14) were observed to fall on and near *A. amintae* individuals. On every visit to Monte Jayuya this event was always observed, especially for adult *A. amintae* individuals that were in groups (clusters) of two to four and were a meter or less from other *A. amintae* individuals (Fig. 28). The individuals that grew in clusters were very healthy; on every visit, they had 8 – 10 live fronds.

The elevation gradient and the associated vegetation appear to be important parameters related to the presence of *A. amintae* in the cloud forest. A spatial distribution map (Fig. 6) was made with presence data obtained during the year of study. It predicted a potential distribution of *A. amintae* in localities within a range of elevations of 1050 – 1325 m, which are the elevations where the species was found. The presence of populations of *A. amintae* in areas of cloud forest

should not be restricted to the elevational parameter. This map does not consider the presence of similar associated vegetation to be present in a range of elevations different than that of the surveyed and the additionally found locations. For example, near the peak of Monte Cerrote in Peñuelas, patches of Sierra Palm forest could be observed, but they appeared to be at elevations lower than 1050 m. If those patches are explored and *A. amintae* is present, this corroborates that the elevation is not the only parameter related to its habitat.

Associated species such as the understory fern *Thelypteris deltoidea* was utilized as a reference species to find *A. amintae* populations. This fern is very common and is easy to identify, mostly because of the reduced lower pinnae on the frond. Its elevational range varies from 430 to 1100 m, but it has been observed at higher elevations (pers. obs.). Tree ferns such as, *Alsophila bryophila*, *A. portoricensis* and *Cyathea arborea* and are commonly found on the habitat of *A. amintae*. *Cyathea arborea* is a native tree fern commonly found throughout the Island (50-1250 m) and it prefers humid mountain areas with landslides, open clearings, hillsides and secondary moist forest glades (Proctor, 1989). It is recognizable due to its size (10 – 15 m), the presence of oval scars and the absence of spines in its trunk, and the absence of hairs on the rachis and costa. The terrestrial fern *Danaea* sp. was only present in the populations of Monte Guilarte and Tres Picachos, but it could be utilized to recognize *A. amintae*'s habitat in peaks nearby those locations. Even though it has a wide elevational range (20 – 1050 m), it was also found at higher elevations (pers. obs). It has fertile and sterile distichous fronds (dimorphic) that are distinguishable by their size; the fertile fronds tend to be smaller and narrower. The rachis is nodose (1 – 4) with brown scales and the sporangia cover most of the abaxial surface of the fertile pinnae (Proctor, 1989).

If natural or anthropogenic disturbances (*e.g.* forest edges, antenna towers) are present in

possible locations for *A. amintae*, species such as *Arthrostylidium sarmentosum*, *Gleichenella pectinata* and *Hypolepis nigrescens* should be considered as associated species. *Arthrostylidium sarmentosum* is a slender bamboo species that grows on moist forests, usually in patches on trees at the edge of the forest and also creeping at the ground level near/above *A. amintae*. It has an elevational range from 350 – 1330 m. (Axelrod, 2011). *Gleichenella pectinata* and *H. nigrescens* are creeping ferns that grow in extensive patches on moist borders, open hillsides and near exposed areas of the forest. *Gleichenella pectinata* is recognized by its dichotomous branching, with the pinnae arranged in opposite pairs. It grows at an elevational range from sea level to 1300 m (Proctor, 1989). *Hypolepis nigrescens* has opposite pinnae arrangement with slightly curved, sharp spines. Its range of elevation is from 1078 – 1300 m) and its locally frequent in moist montane thickets and borders of clearings at high elevations (Proctor, 1989).

The range of distribution of *A. amintae* appears to be confined to a small number of populations in the cloud forest. This species showed a distribution of small clusters of individuals in Monte Guilarte, Monte Jayuya and Tres Picachos. In this study, a cluster is defined by a group of more than two plants at a distance of at least two meters from other groups of individuals. *Alsophila amintae* individuals could be observed growing in pairs, one near the other, or even in groups of three (Fig. 28). In these cases, the groups of two or three individuals consisted of plants that were less than a meter apart. Jones *et al.* (2007) discussed two probable causes for clumped distributions: patchy distribution of microhabitats and dispersal limitations. A patchy distribution is defined as a group of individuals that share the same habitat resources (microhabitat). They have resources (*e. g.* nutrients in the soil, high humidity levels) that perhaps are less common or absent in other areas of a forest. In addition, when the species is not able to

disperse its spores at a long distance or it is capable of reproducing vegetatively, more individuals will grow near the parental plants (Mehlreter *et al*., 2010).

In Monte Jayuya, it was rare to find an individual by itself, and it was more common to observe small patches containing at least two individuals. In Cerro Rosa, this clumped distribution was not observed so clearly due to the small number of individuals found at that location. This was one of the locations with the steepest slopes (Table 5), which could explain a more isolated distribution of *A. amintae* in this area. Compared with the other locations where *A. amintae* is present, Cerro Rosa had areas with big rocks which had to be climbed; those rocks made spatial gaps between the individuals.

Although in this study individuals were found on the north-east and north-west slopes of the mountains (Table 5), four herbarium specimens [(Dent *33*, Quiñonez-López 3 (UPRRP), Pérez-Muñoz, *2* and Breckon, *3094* (MAPR)] also document the presence of *A. amintae* on the south-east face of the mountains. These localities need to be visited and properly searched for the presence of *A. amintae* individuals. The existence of other localities, especially on the southeast facing slopes along the Cordillera Central, cannot be discarded.

This species geographical distribution is limited due to several reasons. The soil humidity levels of its habitat should be above 51%; it was the lowest soil humidity percentage obtained for *A. amintae*. Apart from the elevational gradient, there are other abiotic factors that influence its presence in the cloud forest. Following Guisan and Zimmerman (2002) and Huston (2002), the parameters are: limiting factors (temperature, soil composition and water), disturbances, and availability of resources.

The year of 2014 was the 8th hottest and the 11th driest year ever recorded for the Island (NOAA, 2014), with an average temperature of 78.5°F. The lowest mean temperature for the

AES was 66.78°F in the month of January was and the highest mean temperature was 73.20°F in July. *Alsophila amintae* is in a habitat protected by the canopy, which reduces the air temperatures and maintains high humidity levels of the soil at the understory level (Mehltreter *et al*., 2010). Mean temperatures from the AES (Table 8) are not the same as those of the understory of the forest where populations of *A. amintae* are located, therefore they can not be considered to study the habitat of this species. Soil and/or air temperature meters could be utilized within the understory habitat of *A. amintae* to get precise data that could be utilized to correlate with phenological aspects of this species. Also, data from other meteorological stations should be considered for further studies regarding this species. For example, data from the El Verde Station, within Toro Negro State Forest for 2014 shows an average temperature of 79.3°F (Ramirez, 2017a). This type of data could be useful for studying this species, but many dates in which the measurements were taken are not documented.

Soils where *A. amintae* grows are classified as clay soil (classified as ultisols), which is highly acidic (NCSS, 1986, 2006). However, the observed pH levels of the soil sampled in this study (Table 6) were found to be almost neutral (pH=7.0). What would explain the almost neutral soil pH results is the high amount of annual rain, and the presence of a layer of humus in the soil (which prevents dehydration). For further studies regarding soil pH, soil sampling could be done in different plots to compare areas with different percentages (*e. g*. 0, 25, 50, 75 and 100%) of leaf cover to see if this factor affects the soil pH in areas where *A. amintae* is located. The pH of the soil of *A. amintae*'s populations ranged from 6.4 to 6.9 (Table 7). Studies confirm that almost neutral pH are common in humid climates, the high annual precipitation levels have an influence in those soils (McCauley *et al*., 2009). Another probable reason for the obtained results could be the low accuracy or the Soil Meter readings or a poor calibration. Another

possible way of obtaining accurate results for soil pH could be by taking a soil sample at a correct sampling depth (with respect to the length of the rhizome zone) near each *A. amintae* individual in a monthly basis and analyzing them in a laboratory (Peters and Laboski, 2013).

Plants in steep areas are more exposed to water movements, highly weathered terrains from frequent rainfall and suceptible to landslides than those on flat terrain (Holland and Steyn, 1975). In all locations, there were individuals that were located in steep areas (*e.g*. the first four individuals found downslope at Monte Guilarte) where the trees nearby were more widely separated one from another, thus creating more light gaps. For example, the individual (MG-3) with the highest mean percentage of canopy openness (21.5%) was found in Monte Guilarte. This individual was in a steep location (45º, NW), down the trail. Other individuals were on less steep - even almost flat - areas, with trees near them and they were covered by the shade of the trees with low percentage of light arriving (*e. g.* MG-2; from 4.5 to 11.7%) to them from the canopy gaps. The canopy openness did not affect the distribution of the species on its location. For *A. amintae*, the optimal percentage of canopy openness obtained from this study (16 to 17%) was in the month of July. It is concluded that *A. amintae* prefers to grow on areas with shade (low radiation) at the understory level on more enclosed and protected areas of the forest. The data obtained from *A. amintae* invidivuals shows that frond growth (length and width) does not depend on the variation in percentage of canopy openness, but at least 4.48% (Appendix 2) of the canopy openness needs to be available for the plant to perform its biological processes. If the percentage of canopy openness could be measured again, perhaps a camera with a higher resolution could provide more precise results. Also, more photo repetitions could be done. Instead of taking one photo per individual bi-monthly, at least three photos could be taken at the same position (zero zenith angle) for each individual at the same hour (in the morning hours and

previously consulting weather conditions) on a monthly basis to have accurate results (McCarthy and Robinson, 2003).

In ferns, there are two ways for a young sporophyte to be added to a population: as genets (sporelings) via sexual reproduction or as ramets, which are a result of vegetative reproduction. Throughout the year of study, it was observed that *A. amintae* was capable of sexual reproduction by producing gametophytes near the parental plants in the understory. Both sexual and vegetative reproduction has been recorded in the genus *Alsophila*; one example being *A. setosa*, which not only reproduces sexually but also vegetatively by ramets (Schmitt and Windisch, 2006). Vegetative reproduction of *A. amintae* is not common or does not occur, which could be confirmed by further research with the species.

Due to the short trunk of *A. amintae*, and the difficulty to visually observe the frond scars, counting the scars to estimate the species age was not practical. Schmitt and Windisch (2006) utilized two approaches to estimate the age of tree ferns of the genus *Alsophila*. The first one was utilizing the total length of the trunk to make a relationship with average annual increase in trunk height. They concluded that studying the number of scars and trunk growth did not help to determine the approximate age of *Alsophila setosa*, a tree fern in southern Brazil. The second was by counting the total number of scars along the caudex and relating that to the average annual leaf production. They found that frond production of *A. setosa* over a three-year period, which is longer than that of the present study, provided acceptable age estimates for tree ferns.

An approach that would help to determine the age of *A. amintae* individuals could be by counting the number of scars on the trunk (caudex) and relating that to average annual leaf production. By putting white modeling clay on the surface of the trunk, this could aid in counting the number of frond petiole scars present on each of the individuals. Given that the smallest

surveyed individual measured 5.1 cm, and the largest individual measured 45.7 cm, they could be placed in 5 cm size classes, so their growth rate could be averaged and trunk age estimated.

Trunk height and diameter (Table 14) are not useful for determining if an individual is a juvenile or an adult during one year of study, although this data may be useful for long-term surveys. An adult in Monte Jayuya measured 2.8 cm in diameter, while a juvenile at that same location measured 3.2 cm. Frond width numbers were almost the same for juveniles and adults. In juveniles, it ranged from 10.2 to 24.9 cm and in adults from 10.2 to 27.9. The juveniles that were measured had a range of frond length of 24.0 to 58.4, and adults had a range of 23.7 to 94.8 cm. An accurate way of determining if an individual is a juvenile or an adult is by counting its pinnae. A recognizable juvenile of *A. amintae* has approximately 10 to 21 pinnae in each frond, meanwhile an adult (sterile and/or fertile) has from 22 to 27 pinnae per frond (pers. obs).

A number of individuals with the greatest trunk height (*i. e*. MJ-4) were juveniles. It is important to note that juveniles were determined by measuring the height of the smallest fertile individual (7.6 cm) among all the populations. The individual (adult) with the greatest trunk height (MJ-2) was not the one with highest fertile frond production for that year. Therefore, trunk height cannot be correlated with fertile frond production.

In Puerto Rico, there is a prominent dry season (which is from December to April), and a rainy season (from May to October) (Carter and Elsner, 1997). But at the understory level the microclimate is aseasonal, with low transpiration rates (Sharpe, 1997). In *A. amintae*, frond patterns related to month were observed (Fig. 20) regardless of the apparent aseasonality of the understory forest.

A maximum mean frond production occurred in the month of January (during the dry season) for the year of 2014. Their number remained constant thoughout the year, except in January, where a maximum of 12 fronds where produced. During this month, the total precipitation was at its lowest (16.0 mm) (Table 8). The precipitation data obtained from the AES can not be utilized to analyze relationships between the fern phenology because it is generalized for the whole Island of Puerto Rico and not at the understory level of the cloud forest. These type of data should be obtained from other meteorological stations nearer the *A. amintae* populations, within the Toro Negro State Forest. There is available precipitation data from the El Verde Station (for 2014) that shows a mean annual precipitation of 8.8 mm. This data is useful but is incomplete because the dates of many measurements are not documented (Ramirez, 2017b).

A higher production of fronds would be associated to high precipitation levels, which were observed in all the surveyed months. It appears that even if the soil humidity levels vary during the year, the humus produced by senescent fronds of *A. amintae* covers the soil and prevents dehydration (De Macedo *et al*., 2002).

Sterile fronds of *A. amintae* developed continuously throughout the year and did not showed a synchronicity pattern. The maximum number of sterile fronds occurred in July (during the rainy season), when the mean air temperature was at its highest (73.20°F) (Table 8).

Alsophila amintae's populations produced 40 ± 2.3 fertile fronds per month, and 241 ± 3.3 per year. The minimum fertile frond length was 10.2 cm and its width 26.7 cm. The fertile frond production seems to gradually increase in the summer and throughout the rest of the calendar year and continue increasing until the first part of the next year (in the dry season). The

peak of fertile frond production was in the month of January, and then it went gradually down again until the summer (June and July). Thoughout the year, the fertile frond production was constant (Fig. 19).

A frond is considered fertile when it has an adult form, is more dissected and complex than the sterile frond and juvenile frond, and has the capacity to bear spores (Mehltreter *et al*., 2010). Fertile fronds showed a faster decay (after releasing spores) than fronds that did not produce spores. The production of fertile fronds was constant throughout the year (Fig. 19). The fertility of the fronds included documentations of fronds with both green and brown colored sori. The frond was recognized as fertile until the release of the spores. In this study, a frond was considered fertile when it reached 23.7 cm in length and 17.8 cm in width. The smallest fertile frond measured 23.7 cm in length. The high proportion of individuals with fertile fronds (80%) indicates that *A. amintae* has the potential to increase in population size.

A continuous leaf senescence was observed in *A. amintae* throughout the year. The peak of leaf mortality was in the month of September, and at its lowest in November (Fig 19). Studies with *Cyathea hancockii, Cyathea metteniana and Cyathea podophylla* in northern Taiwan show that fertile fronds tend to die at a faster rate than sterile fronds (Lee *et al.*, 2009). This pattern also occurs in other fern species (*e.g. Cyathea spinulosa*, *Plagiogyria dunnii*, and *Plagiogyria adanata*), for which the senescence of their fertile fronds is faster than that of the sterile ones because of physiological responses to climatic variables such as short photoperiods and lower temperatures (Lee *et al*., 2009). In a study with *Cyathea corcovadensis* in Southern Brazil by Krüger *et al*. (2014) the pattern for senescent fronds was continuous and irregular. This type of

pattern is considered nonseasonal. If frond phenology was surveyed each month instead of bi-monthly, perhaps irregularities between months could have been observed.

This dispersal experiment only gives a simple idea of spore dispersal in *A. amintae*, without considering other environmental parameters such as rainfall, canopy openness, temperatures, storm winds (which occur from June to November), and also the fronds' distance from the ground. In the case of *Alsophila amintae,* rain could promote the dispersion of spores, especiallly in slopes (downslope colonization) rather than the wind, because the wind is not a common factor occurring in the understory. If there are warm temperatures during the day, this could promote spores to be released high into the atmosphere (Ricklefs *et al*., 1995).

Alsophila amintae individuals that were located near the antennas (edge of the forest) tended to be smaller (*i. e.* Monte Jayuya), only producing three fronds at a time with few sori or none at all. The environmental conditions were the same as the other areas where *A. amintae* was present. But, the presence of patches of the climbing bamboo *Arthrostylidium sarmentosum* near the individuals of *A. amintae* appears to be affecting their frond growth. The possible competition of *A. amintae* with *A. sarmentosum* should be studied in detail in the populations of Cerro Punta, Monte Jayuya and Cerro Maravilla. The anthropogenic disturbance of the communication antennas promoted the growth of *A. sarmentosum* in those areas where the canopy is more open.

Alsophila amintae and its hybrid *Alsophila amintae* × *portoricensis* have been documented in the Maricao State Forest (Along Río Maricao, above Criadero de Peces), [Proctor *40474* (US)], near Hacienda Rosario, Bo. Guilarte, Adjuntas [Conant *1915*, *3460* (US)] (Fig. 29), Bo. Anón y Saliente and Monte Jayuya [Conant *1705* (US, NY), *1707* (MAPR, NY), *1990* (US),

1961 (US), *1963* (NY)] (Fig. 30); they are reported by herbarium records (Table 22). There was only one herbarium specimen for the hybrid *Alsophila amintae* × *bryophila* [Conant *1966* (US)] in Monte Jayuya. The herbarium specimens were corroborated. In a visit to the Maricao State Forest, the hybrid *Alsophila amintae* × *portoricensis* (at 467 m of elevation) was not found. Proctor described the specimen as creeping with a subterranean caudex. This description does not follow the morphological characteristics present in both parental species. When the specimen was corrobored, it was found that it was misidentified as *A. amintae* × *portoricensis* when in fact it was *A. brooksi*.

Even though during 2014 not a single *Alsophila amintae* hybrid was found bearing spores, Conant (1983) found that their spores were fertile. In his study, he found that hybrids of *A. amintae* are reproducing between themselves at a higher rate than either of their parents and they had a 43% germination rate. He then theorized that *A. amintae* may have a stabilized reproduction by allohomoploidy (Conant, 1983). Both *A. amintae* and its hybrids have the same chromosome count (n=69) (Proctor, 1989). Perhaps, they have also been reproducing vegetatively by apogamy (Chiou *et al.*, 2006). This form of reproduction has yet to be studied in hybrids of *A. amintae*. This would explain the high numbers of hybrids growing and reproducing in the wild.

STATUS AND RECOVERY

Alsophila amintae is listed under The Engandered Species Act of 1973 and classified as endangered as of July 16, 1987 (USFWS, 1987). Given that the habitat of *A. amintae* is restricted, this species is considered endangered due to its habitat modification and destruction.

On January 31, 1991, the recovery plan for *Cyathea dryopteroides* (= *Alsophila amintae*) was approved to protect the species from becoming extinct in Puerto Rico (USFWS, 1991). Its purpose is to prevent its habitat loss and reverse the population decline of this species.

Information about the geographical distribution and abundance of *A. amintae* is essential to effectively manage the species' recuperation in the wild. This study provides information for six populations. The populations of Cerro Punta, Cerro Maravilla and Tres Picachos must be added to the species' strategy plan, and a new protected status should be given to the newly discovered populations. The spatial distribution map made with presence data that was obtained from this research (Fig. 6) could aid USFWS in finding new populations in the future. This map includes an elevational gradient from 1050 to 1325 m, which limits the species to be present only near high peaks of the Adjuntas and Jayuya municipalities. Locations near the Inabón River (Ponce) and high peaks on the Cordillera Central such as La Silla de Calderón (Adjuntas), Cerro Saliente (Jayuya), and Cerro el Bolo (Orocovis - Villalba) should be explored for potential undiscovered *A. amintae* populations. An herbarium specimen (Hernández-Muñíz *44* MAPR) documents *A. amintae* in Ala de la Piedra, Orocovis at 1025 m (Table 21; Fig. 31). Even though, this elevation is lower than the range found during this study, this locality should be searched in order to verify the presence of an additional potential population of *A. amintae* in that

municipality. Perhaps, a more accurate map could be done by integrating not only the elevational range of the species but also with environmental parameters such as temperature, precipitation. Also, the presence of the species in additional locations of Puerto Rico could be more related with the associated vegetation present in *A. amintae*'s habitat rather than the elevational range. The Massenerhebung effect (mountain mass elevation effect) is defined by the presence of floristically similar vegetation at lower altitudes on isolated peaks than on larger mountains masses, which is more common (Flenley, 1995). If this effect is taken into consideration, then the presence of *A. amintae* on isolated peaks with elevations lower than 1050 m could be justified (*e. g.* Monte Cerrote, Peñuelas).

Surveys for new potential sites within the Cordillera Central should be based on the established environmental parameters for its habitat, one of the most important being elevation. This region of Puerto Rico has not been completely explored for the presence of *A. amintae*, perhaps due to the difficult geography where this species' habitat is localized.

Alsophila amintae has a small range of distribution, mostly limited by elevation and the presence of associated species. Also, the number of individuals present in most of the populations is smaller than the number of its hybrids. The hybrids for this species are more capable of adapting to changes in environment, whereas *A. amintae* is restricted to a specific habitat. It is recommended that the spatial competition between *A. amintae* and its hybrids within the populations be studied.

The habitat requirements such as elevation, slope and aspect, pH and soil humidity and canopy openness for this species were defined based on the three studied localities. Temperature and precipitation parameters from the AES were not useful to study the habitat of *A. amintae*

because these data was obtained from a locality where the type of habitat, the temperature, precipitation and elevation are different from that of where *A. amintae* is present. Temperature and precipitation data can also be obtained from the Temperature Monitoring Stations located in Toro Negro State Forest and Cerro Maravilla.

These data can be utilized to make important decisions regarding the species' reintroduction to new potential localities. It is recommended that *A. amintae* individuals should be reintroduced in areas where environmental impacts of communication antennas and littering are not present, such as Monte Guilarte, Tres Picachos and Cerro Rosa.

The extant populations of *A. amintae* should be protected and the following should be taken in consideration. In Cerro Punta, Monte Jayuya and Cerro Maravilla, further constructions should be limited. To establish collaborative efforts with the owners and managers of the communication facilities to protect the localities where this species is found.

At present, all the studied populations fall within public property of the Estado Libre Asociado de Puerto Rico and managed by the DNER. Monte Guilarte and Tres Picachos are designated as State Forests and the other localities are part of the Toro Negro State Forest.

Collaborative efforts with the the Department of Transportation and Public Works (DTPW) and the DNER should be maintained. The roads that are currently used to arrive to the communication antennas and the panoramic Rte. 143 are located near *A. amintae*'s populations, and this should be considered if modifications are ever made to those roads. The use of areas for activities that do not promote the conservation of the species should be avoided and access to the public should be limited.

The populations of Cerro Punta, Cerro Maravilla and Tres Picachos should continue to be studied for comparison purposes and to increase the knowledge about the species.

The Law number 13 of May 16, 1972 of administration of terrains of Puerto Rico, as amended, states the appropriate use of terrain areas for the well-being of the inhabitants of Puerto Rico and the conservation of public natural areas as well. The Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), of June 30, 2016, promotes the sale or rent of public natural resources at a fast pace for the sole purpose of paying the bondholders debt. Section 503 of the PROMESA act (federal law) authorizes that in a state of emergency, the acceleration and review of projects should be implemented for economic benefits (Austin, 2016). This could affect the process of permits, reduce environmental evaluations and eliminate the public hearings. Given that only 0.0004% of the total area of Puerto Rico is potential habitat for *A. amintae* (≥ 1050 m in elevation), the loss of protection to those areas could imply the extinction of the species. The protection of *A. amintae* could delay permits for the development of infrastructural projects that could benefit the Island economically, such as the recent 275 million dollars investment made by the AT&T Company to build more cellphone communication towers on the peaks of Puerto Rico (El Nuevo Día, 2017).

As of May, 2017, a petition from the Telecommunications Regulatory Board was made to the Environmental Quality Board of Puerto Rico to typify the construction of telecommunication towers as a categorical exclusion (Alvarado León, 2017). The evaluation and permission for their construction will be accelerated and the environmental impacts will be ignored in order to speed up the permit process. The areas impacted by construction of antennas are not delimited to the space that they occupy, they also include the construction of roads and other modifications to

arrive to them. If this is petition is approved the habitat of native species such as *A. amintae* could be removed.

Natural or anthropogenic disturbances could pose a threat for the survival of this species. The greatest natural threat for *A. amintae* is the presence of invasive plants such as *Gleichenella pectinata* (which grows on the edge of Monte Jayuya), *Hypolepis nigrescens* and *Arthrostylidium sarmentosum*. It is important to note that the later species has never being mentioned on the Recovery Plan, the 5-Year Review nor the Population Assesment at Monte Jayuya as present in *A. amintae*'s habitat. Removing these species is a challenging task, and is not recommended. Also, even though during this research the effects of hurricanes could not be seen, if this atmospheric event happens in the future, it will be important to study its effects on *A. amintae* populations.

The presence of anthropogenic disturbances was only observed near three populations (Monte Guilarte, Cerro Punta, Monte Jayuya and Cerro Maravilla). Apparently, trash was thrown from the roads where the communication antennas buildings are located. This trash consisted of materials used for the maintenance of the antennas, car tires, trash bags, cans, and glass and plastic bottles. This study concludes that even if there were these types of disturbances occurring nearby, the species was not directly affected, but prevention of increasing littering must be taken into consideration. Management measures, such as the placement of trash cans and signs in strategic places (*i. e.* near the observation platform and the Puerto Rican flags) in the touristic areas of Cerro Punta and Cerro Maravilla are recommended, if funds are available, to promote the protection of the environment. At Cerro Punta, they can be placed at the parking lot and at

the observation platform, and at Cerro Maravilla outside the buildings where workers from the communication antennas visit continuously.

Damage of listed plant species is prohibited and is considered a criminal penalty, based on the Commonwealth's 1985 Regulation to Govern the Management of Threatened and Endangered Species. The maintenance and future construction of communication antennas must not threaten the extant *A. amintae* populations. Therefore, public education on plant conservation values and regulations concerning *A. amintae* should be implemented. Environmental education for children could be made possible by coordinating talks and pamphlets about the species with Bosque del Pueblo and Bosque La Olimpia (both located in Adjuntas) and expand those activities to other municipalities where the populations of *A. amintae* are also present. Workers at the impacted areas should also be educated, perhaps by giving talks and information to them. Also, posters with educational information could be placed in the public forests. This effort should include the participation of agencies (*e. g.* DNER, USFWS). This will aid the understanding about the presence and conservation importance of this rare species whose habitat is near the communication antennas. Another way of implementing education is by developing a field guide that will aid in the identification of *A. amintae* and its hybrids in their habitat. It is important that communication between the USFWS should be maintained with the Department of Transportation and Public Works and the Regulatory Committee of Telecommunications in Puerto Rico. Also, interagency collaborations with the Department of Education of Puerto Rico, DNER, and public and private universities needs to be encouraged.

The spatial distribution map prepared for this study focuses on the parameter of elevation gradient, and this should be considered of primordial importance when searching for new

locations to introduce the species. Reintroduction of *A. amintae* is recommended for the populations with little or no anthropogenic disturbance, such as Monte Guilarte, Tres Picachos and both peaks of Cerro Rosa. The possible establishment of this species in El Yunque National Forest (USFWS, 2013) is not recommended because the environmental conditions and associated species are not similar to those where *A. amintae* is present within the Central Cordillera.

Ex situ propagation of material, with genetic material from different populations, could be done in a laboratory, and these individuals could be established in those populations to promote more genetic variability for the species. Spores can be collected, germinated and the sporophytes can eventually be transplanted to the localities. Another approach would be to collect fertile fronds with closed sori and put them in the soil near *A. amintae* individuals in other populations.

As part of an effort to conserve the species of this study, experimental studies regarding spore propagation and genetic studies of *A. amintae* were performed at the Fairchild Tropical Botanic Gardens in Florida (FTBG). The spores collected from individuals of the Monte Jayuya population showed 16 genetic lines; 13 of them were sent to the USDA's National Center for Genetic Resources Preservation for long-term cryogenic storage (Jennifer Possley, pers. comm.) (FTBG, 2015; not published). If more spores from the other five extant localities are collected and sent to FTBG for genetic studies and long-term cryogenic storage, the genetic variability for this species could be preserved.

The other three genetic lines were sowed at the Fairchild Tropical Botanic Gardens. Spores were germinated in the laboratory and gametophytes and sporophytes were grown in pots (Appendix 4). These sporophytes will be part of the *ex-situ* plant collection at FTBG in Florida,

and if the opportunity appears, they are going to be sent to Puerto Rico to be reintroduced in the wild (Jennifer Possley, pers. comm.), in collaboration with local agencies. The collected spores from Monte Jayuya population showed a germination rate of more than 70% (FTBG, 2015; not published). *Alsophila amintae* individuals should be reintroduced in already established populations that are located in areas with little or no anthropogenic impact. This could be done in populations such as the one in Monte Guilarte, where communication antennas are not present. Reintroduction of *A. amintae* can also be done in populations such as Tres Picachos and both peaks of Cerro Rosa, but the difficulty to arrive to *A. amintae* populations has to be taken into consideration prior reintroduction.

Genetic studies of extant populations should be performed to see if there are gene differences between them; a bottleneck effect could be already occurring in the populations. Then, propagules from small populations can be planted in those same populations to strengthen them and create more genetic diversity within the populations. Studies of the development with propagules from different populations should be an option to explore. Their establishment in available populations should be considered, but this is recommended when genetic variability studies are made.

Before this study was done, little or no information regarding the reproductive biology of *A. amintae* was available. During the year of study, no evidence of vegetative reproduction was observed, but one year of study was not sufficient time to observe that this species (in all three studied populations) was not propagating vegetatively. Future research regarding vegetative propagation is recommended (point 325, under the third objective [Research] of the Recovery Plan). Information on vegetative aspects (trunk height and width) and phenology (frond survival, mortality, sorus production, etc.) of *A. amintae* was studied in the localities of Monte Guilarte,

Monte Jayuya and Cerro Rosa for one year. Additional studies regarding spore dispersal in the forest are recommended.

Alsophila amintae showed a maximum fertile frond production during July (Fig. 19). This information is important for spore collection and germination purposes. Studies are recommended to find the best suitable conditions for spore germination, viability and *ex-situ* plant conservation. These studies should include the *ex-situ* monitoring of environmental aspects like soil humidity, temperature and percentage of canopy openness. Germination experiments are already been made by FTBG, with a viability rate for the Monte Jayuya population. Further germination experiments are recommended for all known populations. Constant communication with FTBG and USFWS is also recommended regarding the recuperation of this species. The cooperation between USFWS and the University of Puerto Rico is highly recommended because in this way the recuperation of endemic and endangered species (such as the one in this study) can be done with the contribution of information and expertise of the academia. The participation of undergraduate students as volunteers in these types of studies not only could provide valuable information for USFWS, but it also aids in the learning process of the student and prepare them with the necessary practical experience for their careers in the biological sciences. As part of the graduate student thesis research, communication with USFWS with the student is intrinsically important. This will aid the graduate student in completing thesis research for his/her master's degree and at the same time it will contribute to the progress of Recovery Plans for species that have yet to be studied.

The establishment, growth and recruitment of young sporophytes (or juveniles) has yet to be studied. Defining appropriate habitat requirements for population enhancement or

introduction utilizing *ex-situ* material is important. Environmental conditions such as soil humidity levels and changes in temperature could affect this species' germination and growth.

The number of *A. amintae* populations and individuals necessary to ensure the species' stability, security and self-perpetuation has yet to be determined. Morphological, physiological, competition, hervibory and ecological studies are needed. These studies can be complemented with molecular data to observe if local adaptation of this species has occurred.

The recovery plan for this species (USFWS, 1991) states that if the criteria are met (protection of existing populations and their habitats, and the establishment of new populations in appropriated localities), the species should be removed from the federal list in 2025. At the present time (2017), most of the criteria are still not met, and some of them are in progress. Therefore, a change of date for the species' delisting should be considered. Based on this study, some aspects of the recovery plan can be updated and/or changed.

CONCLUSIONS

1. *Alsophila amintae* is currently known from six localities along the Cordillera Central in Puerto Rico and occupies a total area of 4.08 ha.
2. A total of 149 individuals of *A. amintae* were found during 2014 to 2017.
3. The elevation range for this species is 1050 – 1325 m and it is potentially found in 0.0004% of the total area of Puerto Rico. This, along with species associated with *A. amintae*'s habitat are the most important environmental parameters identified in this study and help in finding possible localities where this species can be found.
4. *Alsophila amintae* did not reproduce vegetatively during the year of study.
5. *Alsophila amintae* was observed reproducing via spores, and young sporophytes were observed nearby the adult plants.
6. The average life span of fronds is approximately five to seven months.
7. Maximum leaf turnover appears to occur in September, which is in the rainy season in Puerto Rico.
8. Spore production occurs throughout the year, but in July a higher number of fertile fronds is produced.
9. The hybrids *A. amintae* × *bryophila* and *A. amintae* × *portoricensis* did not produce spores during the year of study, so the viability of their spores could not be analyzed.
10. Tropical storms did not cause a serious effect on *A. amintae* populations during the year of study.
11. The falling of Sierra Palm fronds seems to be a common event within the understory of the forest. This event did not cause the death of any individual of *A. amintae*.

12. Invasive plants in the understory, such as *Arthrostylidium sarmentosum*, *Hypolepis nigrescens* and *Gleichenella pectinata* (mostly at the edge of the Monte Jayuya population) could affect *Alsophila amintae* by competing for habitat area.
13. Illegal dumping of trash caused by the maintenance of communication antennas near the populations of Cerro Punta and Cerro Maravilla and Monte Jayuya did not cause a direct effect on *A. amintae* populations.

RECOMMENDATIONS

1. Search for additional locations within the Cordillera Central for additional *A. amintae* populations, based on the established environmental parameters for its habitat.
2. The biggest population of *A. amintae* consists of 47 individuals and is located in Cerro Punta. This population along with the one in Monte Jayuya can be utilized for future studies regarding *A. amintae* and/or reintroduction purposes of the species in the future.
3. Reintroduction of *A. amintae* individuals in areas where the environmental impacts of communication antennas and littering are not present, such as Monte Guilarte, Tres Picachos and Cerro Rosa.
4. Determine if there is spatial competition between *A. amintae* and its hybrids within the populations.
5. Maintain *A. amintae* free of invasive plants such as *Gleichenella pectinata*, *Hypolepis nigrescens* and *Arthrostylidium sarmentosum* that have been shown to limit its growth and habitat areas.
6. Conduct soil studies to find the best suitable conditions for its spore germination of *A. amintae*.
7. Given that recent genetic studies (from FBTG) have been carried out with individuals from Monte Jayuya, do genetic variability studies among the other existent populations of *A. amintae* to see if there are different genetic lines.
8. Conduct morphological studies that complement genetic studies and see if local adaptation for this species has occurred.

9. Educate general and management personnel of the antennas by giving talks and information that will aid the understanding about the presence and conservation importance of this rare species whose habitat is near the communication antennas.
10. Develop a field guide that will aid personnel of the communication antennas and the public to identify *A. amintae* and its habitat.
11. Place signs in visible areas of Cerro Punta and Cerro Maravilla to promote the protection of the environment. These signs should contain information regarding laws and regulations that protect endemic and endangered plant species in the area and the penalties for violating those laws and regulations.
12. Place trash cans in strategic places in the touristic areas of Cerro Punta and Cerro Maravilla. At Cerro Punta, they can be placed at the base before going up the stairs and at the observation platform, and, at Cerro Maravilla outside the buildings where workers from the communication antennas visit continuously.

LITERATURE CITED

Aldrich, M., Billington, C., Edwards, M., and Laidlaw, R. 1997. A global directory of Tropical Montane Cloud Forests. (Eds.), World Conservation Monitoring Centre, Cambridge, UK 268 pp.

Alvarado-León, G. E. 2017. Proposal made for liberalization of antennas. El Nuevo Día. Available from: http://www.elnuevodia.com/english/english/nota/proposalmadeforliberalizationofantennas-2319866/.

Anderson, E. 1949. Introgressive Hybridization. Wiley and Sons, New York, 109 pp.

Arens, N. C. 1997. Responses of leaf anatomy to light environment in the tree fern *Cyathea caracasana* (Cyatheaceae) and its application to some ancient seed ferns. Palaios 12: 84-94.

_____. 2001. Variation in performance of the tree fern *Cyathea caracasana* (Cyatheaceae) across a successional mosaic in an Andean cloud forest. Amer. J. Bot. 88: 545-51.

_____ and Sánchez-Baracaldo, P. 1998. Distribution of tree ferns (Cyatheaceae) across a successional mosaic in an Andean cloud forest, Nariño, Colombia. Amer. Fern J. 88: 60-71.

_____ and _____. 2000. Variation in tree fern stipe length with canopy height: tracking preferred habitat through morphological change. Amer. Fern J. 90: 1-15.

Arnold, M. L. 1992. Natural hybridization as an evolutionary process. Annu. Rev. Ecol. Syst. 23: 237-262.

Auerbach, N. A., Walker M. D., Walker D. A. 1997. Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. Ecol. Appl. 7: 218-235.

Austin, A. 2016. The Puerto Rico Oversight, Manageíament, and Economic Stability Act (PROMESA; H.R. 5278, S. 2328) report. Congressional Research Service 47 pp.

Axelrod, F. S. 2011. A systematic vademecum to the vascular plants of Puerto Rico. Botanical Research Inst of Texas 420 pp.

Barrington, D. S. 1985. Hybridization in Costa Rican *Polystichum*. Proc. Roy. Soc. Edinburgh, B. Biol. Sci. 86B: 335-340.

_____. 1993. Ecological and historical factors in fern biogeography. J. Biogeogr. 20(3): 275-279.

Bautista-Cruz, A. and Del Castillo, R. F. 2005. Soil changes during secondary succession in a tropical montane cloud forest area. Soil Sci. Soc. Am. J. 69: 906-914.

Bawain, A. M. A. 2012. Influence of vegetation on water fluxes at the ground level in a semi-arid cloud forest in Oman. Ph.D. Thesis, Chemisch-Geowissenschaftliche Fakultät der Friedrich-Schiller-Universität Jena, Germany 93 pp.

Beaudette, D. E. 2012. SoilWeb (Version 1.3) [Computer software]. Available from: https://casoilresource.lawr.ucdavis.edu/soilweb-apps/.

Bensiton, M., Diaz, H. F. and Bradley, R. S., 1997. Climatic change at high elevation sites: an overview. Clim. Change 36: 233-251.

Bittner, J. and Breckle, S.-W. 1995. The growth rate and age of tree fern trunks in relation to habitats. Amer. Fern J. 85: 37-42.

Bonell, M., and Bruijnzeel, L. (Eds.). 2005. Forests, water and people in the Humid Tropics: past, present and future hydrological research for integrated land and water management (International hydrology series). Cambridge: Cambridge University Press. 953 pp.

Bremer, P. 2007. The colonization of a former sea-floor by ferns. Ph.D. Thesis. Wageningen University, Netherlands 168 pp.

Brown, D. P. 2015. National Hurricane Center tropical cyclone report: Hurricane Gonzalo. NOAA-NWS 30 pp.

Bruijnzeel, L. A. 2001. Hydrology of tropical montane cloud forests: A Reassessment. Land Use and Water Resources Research 1: 1.1-1.18.

_____ and Proctor, J. 1995. Hydrology and biogeochemistry of tropical montane cloud forests: what do we really know? In: L.S. Hamilton, J.O. Juvik and F.N. Scatena, (Eds.), Tropical Montane Cloud Forests. Ecological Studies, Springer-Verlag, New York, 110: 38-78.

Cade, T. J. 1983. Hybridization and gene exchange among birds in relation to conservation. Biol. Conserv. 288-309.

Caluff, M. G. and Serrano, G. 2002. Cuban novelties in the genus *Alsophila* (Cyatheaceae). Novit. Florae Cuben. 6: 303-309.

Carrero-Rivera, G. 2001. Population ecology and reproductive biology of endangered *Buxus vahlii* Baillon (Buxaceae). M. S. Thesis, University of Puerto Rico, Mayagüez Campus 104 pp.

Carter, M. M. and Elsner, J. B. 1997: A statistical method for forecasting rainfall over Puerto Rico. Weather Forecasting 12(3): 515-525.

Cavelier, J. and Goldstein, G. 1989. Mist and fog interception in elfin cloud forests in Columbia and Venezuela. J. Trop. Ecol. 5: 309-322.

Chiou, W. -L., Lin, J. C. and Wang, J. Y. 2001. The phenology of *Cibotium taiwanese* (Dicksoniaceae). Taiwan J. Forest Sci. 16: 209-15.

Chiou, W. L., Huang, Y. M., Hsieh, T. H. and Hsu, S. Y. 2006. *Diplazium megaphyllum* (Bak.) Christ, a rare fern in Taiwan, reproduces by apogamy. Taiwan J. For. Sci. 21: 39-47.

Conant, D. S. 1975. Hybrids in American Cyatheaceae. Rhodora 77: 441-455.

_____. 1976. Ecogeographic and systematic studies in American Cyatheaceae. Ph.D. Thesis, Harvard University, Cambridge, Massachusetts, US 156 pp.

_____. 1981. *Alsophila amintae* D.S.Conant. Rhodora 83: 149.

_____. 1983. A revision of the genus *Alsophila* (Cyatheaceae) in the Americas. J. Arnold Arbor. 64: 333-382.

_____ and Cooper-Driver, G. 1980. Autogamous allohomoploidy in *Alsophila* and *Nephelea* (Cyatheaceae): A new hypothesis for speciation in homoploid homosporous ferns. Amer. J. Bot. 67: 1269-1288.

_____, Raubeson, L. A., Attwood, D. K., Pereram S., Zimmer, E. A., Sweere, J. A. and Stein, D. B. 1996. Phylogenetic and evolutionary implications of combined analysis of DNA and morphology in the Cyatheaceae. In J. M. Camus, M. Gibby and R. J. Johns (Eds.), Pteridology in Perspective. Royal Botanical Gardens, Kew, London pp. 231-248.

_____, Raubeson, L. A., Attwood, D. K. and Stein, D. B. 1995. The relationships of Papuasian Cyatheaceae to New World tree ferns. Amer. Fern J. 85: 328-340.

_____, Stein, D. B., Valinskim A. E. C. and Sudarsanam, P. 1994. Phylogenetic implications of chloroplast DNA variation in the Cyatheaceae. I. Syst. Bot. 19: 60-72.

Cordova, J., and Del Castillo, R. F. 2001. Changes in epiphyte cover in three chronosequences in a tropical montane cloud forest in Mexico. In G. Gottsberger and S. Liede (Ed.) Life forms and dynamics in tropical forests. Dissertations Botanical 346. Brüder Borntraeger Verlagsbuchhandlung, Stuttgart, Germany 79-94.

De Macedo, J. R., Do Amaral, M. O., Araujo, T. B., Araújo, J. and de Sousa Lima, J. 2002. Estimation of field capacity and moisture retention based on regression analysis involving chemical and physical properties in Alfisols and Ultisols of the state of Rio de Janeiro. Comm. Soil Sci. Plant Anal. 33 (13–14): 2037–2055.

Department of Natural and Environmental Resources. 1976. The master plan for commonwealth forest of Puerto Rico. Dr. Emilio Colón, prepared by area of planning and evaluation. Río Piedras, Puerto Rico 258 pp.

_____. 2006. Bosque seco de Guánica: Reserva biosférica internacional. Panfleto Informativo. 2 pp.

_____. 2008a. Bosques de Puerto Rico: El bosque estatal de Carite. Hojas De Nuestro Ambiente. 2 pp.

_____. 2008b. Bosques de Puerto Rico: El bosque estatal de Maricao. Hojas De Nuestro Ambiente. 2 pp.

_____. 2009. Bosques de Puerto Rico: El bosque nacional del Yunque. Hojas De Nuestro Ambiente. 2 pp.

Di Rienzo J. A., Casanoves F., Balzarini M. G., Gonzalez L., Tablada M., Robledo C. W. InfoStat (versión 2012). InfoStat Group, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Argentina. Available from: http://www.infostat.com.ar.

Dong, S.-Y. 2009. Hainan Tree Ferns (Cyatheaceae): Morphological, ecological and phytogeographical observations. Ann. Bot. Fenn. 46: 381-388.

Durand, L. Z. and Goldstein, G. 2001. Growth, leaf characteristics, and spore production in native and invasive tree ferns in Hawaii. Amer. Fern J. 91: 25-35.

El Nuevo Día. May 11, 2017. AT&T anunció una inversion de $275 millones en Puerto Rico. Available from: http://www.elnuevodia.com/negocios/empresas/nota/attanunciaunamillonariainversionenpuertorico-2319973/.

Ellstrand, T., Richard, W. and Loren, H. R. 1996. Distribution of spontaneous plant hybrids. Proc. Natl. Acad. Sci. 93(10): 5090-5093.

Eltahir, E. A. B. 2011. Desert Cloud Forests: Adapting a unique ecosystem to climate change. Program on Forests (PROFOR), Washington DC 37 pp.

Ewel, J. J. and Whitmore, J. L. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. ITF-18. Institute of Tropical Forestry, Río Piedras, Puerto Rico. 259 pp.

Fairchild Tropic Botanical Gardens. 2015. Determining propagation and spore storage potential of three rare Puerto Rican ferns. Fairchild Tropical Botanic Garden, Florida, US 16 pp.

Falk, D. A. and Holsinger, K. E. 1991. Genetics and conservation of rare plants. Oxford Univ. Press, New York, US 304 pp.

Farrar, D. R. 1976. Spore retention and release from overwintering fern fronds. Amer. Fern J. 66: 49-52.

_____ and R. D. Gooch. 1975. Fern reproduction at Woodman Hollow, Central Iowa: preliminary observation and a consideration of the feasibility of studying fern reproductive biology in nature. Proc. Iowa Acad. Sci. 82: 119-122.

_____, Dassler, C., Watkins, J. E., Jr. and Skelton, C. 2008. Gametophyte ecology. In biology and evolution of ferns and lycophytes, ed. T. A. Ranker and C. H. Haufler. Cambridge University Press, Cambridge, UK 222-56.

Flenley, J. R. 1995. Cloud forest, the Massenerhebung effect, and ultraviolet insolation. In: Hamilton L.S., Juvik J.O., Scatena F.N. (Eds.) Tropical Montane Cloud Forests. Ecological Studies (Analysis and Synthesis), vol. 110. Springer, New York, NY.

Foster, P. 2001. The potential negative impacts of global climate change on tropical montane cloud forests. Earth Sci. Rev. 55: 73-106.

Foster, D. R., Fluet, M. and Boose, E. R. 1999. Human or natural disturbance: Landscape-scale dynamics of the tropical forests of Puerto Rico. Ecol. Appl. 9: 555-572.

Frazer, G. W., Canham, C. D., and Lertzman, K. P. 1999. Gap Light Analyzer (GLA) (Version 2.0) [Computer software]. Available from: http://www.caryinstitute.org/science-program/our-scientists/dr-charles-d-canham/gap-light-analyzer-gla.

Gastony, G. J. 1973. A revision of the fern genus *Nephelea*. Contr. Gray Herb. 203: 81-148.

_____ and Tryon, R. M. 1976. Spore morphology in the Cyatheaceae. 2. The genera *Lophosoria*, *Metaxya*, *Alsophila* and *Nephelea*. 63:738-758.

Gleason, H. A. and Cook, M. T. 1927. Plant ecology of Puerto Rico. In New York Acad. Sci. Scientific survey of Puerto Rico and the Virgin Islands 7: 1-173.

Gomez, L. D. 1983. Cyatheaceae and Dicksoniaceae (Rabos de Mico, Tree Ferns). In: D.H. Janzen (Ed.), Costa Rican Natural History. University of Chicago Press, Chicago, USA 225-226.

Gomez-Pompa, A. 1984. Tropical deforestation and Maya silviculture: an ecological paradox. Tulanne Stud. Zool. Bot. 26: 19-37.

Grant, V. 1981. Plant speciation. Columbia University Press, New York, US 563 pp.

Grubb, P. J. 1977. Control of forest distribution and growth and distribution on wet tropical mountains: with special reference to mineral nutrition. Annu. Rev. Ecol. Syst. 8: 83-107.

Guariguata, M. R., Dupuy, J. M. 1997. Forest regeneration in abandoned logging roads in lowland Costa Rica. Biotropica 29(1): 15-28.

Guisan, A. and Zimmerman, N. E. 2000. Predictive habitat distribution models in ecology. Ecol. Model. 135: 147-186.

Hamilton, L. S., Juvik, J. O., and Scatena, F. 1995. Tropical montane cloud forests, ecological Studies 110: 407 pp.

Harada, Y., and Takada, T. 1988. Optimal timing of leaf expansion and shedding in a seasonally varying environment. Plant Species Biol. 3: 89-97.

Harlan, J. R. 1983. Some merging of plant populations. In Genetics and Conservation (Schonewald Cox, C. M., Chambers, S. M., MacBryde, B. and Thomas, W. L. Eds.) The Benjamin Cummins Publishing Co., Menlo Park, California, USA 267-276.

Holland, P. G. and Steyn, D. G. 1975. Vegetational responses to latitudinal variations in slope angle and aspect. J. Biogeogr. 2: 179-183.

Holttum, R. E. 1963. Cyatheaceae. Fl. Males. II, 1: 65-176.

Hu, X. Y., Zhai, J. W., Wang, F. G. and Xu, X. L. 2010. Simple treatment to investigate spore ornamentation of ferns for SEM observation from herbarium specimens. Pak. J. Bot. 42 (4): 2335-2338.

Huston, M. A., 2002. Introductory essay: critical issues for improving predictions. In: Scott, J. M., Heglund, P. J., Samson, F., Haufler, J., Morrison, M., Raphael, M., Wall, B. (Eds.), Predicting Species Occurrences: Issues of Accuracy and Scale. Island Press, Covelo, California 7-21.

Jones, M. M., Olivas, R. P., Tuomisto, H. and Clark, D. B. 2007. Environmental and neighborhood effects on tree fern distributions in a neotropical lowland rain forest. J. Veg. Sci. 18: 13-24.

Kappelle, M., and Brown, A. D. 2001. Bosques nublados del Neotrópico, Instituto Nacional de Biodiversidad-Heredia, Costa Rica 704 pp.

Kikuzawa, K. 1989. Ecology and evolution of phenological pattern, leaf longevity and leaf habit. Evol. Trend Plant. 3: 105-110.

Korall, P., Conant, D. S., Metzgar, J. S., Schneider, H., and Pryer, K. M. 2007. A molecular phylogeny of scaly tree ferns (Cyatheaceae). Amer. J. Bot. 94: 873-886.

_____, Pryer, K. M., Metzgar, J. S., Schneider, H and Conant, D. S. 2006. Tree ferns: Monophyletic groups and their relationships as revealed by four protein-coding plastid loci. Mol. Phyl. Evol. 39: 830-845.

_____ and Pryer, K. M. 2014. Global biogeography of scaly tree ferns (Cyatheaceae): evidence for Gondwanan vicariance and limited transoceanic dispersal. J. Biogeogr. 41: 402-413.

Kramer, K. U. 1990. The families and genera of vascular plants. In: Kramer, K. U., and P. S. Green (Eds.), Pteridophytes and gymnosperms. Springer-Verlag, Berlin. 1: 94-99.

_____ and Green, P. S. (Eds.) 1990. The families and genera of vascular plants. vol. 1. Pteridophytes and Gymnosperms. Springer-Verlag, Berlin.

_____ and Tryon, R. M. 1990. Introduction to the treatment of pteridophytes. In: Kramer, K. U. and Green, P. S. (Eds.), The families and genera of vascular plants. vol. 1. Pteridophytes and Gymnosperms. Springer-Verlag, Berlin. 12-13.

Krüger, M., Schneider, P. H. and Schmitt, J. L. 2014. Phenology, caudex growth and age estimation of *Cyathea corcovadensis* (Raddi) Domin (Cyatheaceae) in a subtropical forest in southern Brazil. Acta Bot. Bras 28 2: 274-280.

Lee, P. H., Huang, Y. N. and Chiou, W. L. 2008. The phenology of *Osmunda claytoniana* L. in the Tataka area, central Taiwan. Taiwan J. For. Sci. 23: 71-79.

_____, Lin, T. T. and Chiou, W. L. 2009. Phenology of 16 species of ferns in a subtropical forest of northeastern Taiwan. Journal of Plant Res. 122: 61-67.

Lellinger, D. B. 1987. The disposition of *Trichopteris* (Cyatheaceae). Amer. Fern J. 77: 90-94.

Leo, M. 1995. The importance of tropical montane cloud forest for preserving vertebrate endemism in Peru: The Río Abiseo National Park as a case study. Springer-Verlag, Berlin. 110: 198-211.

Liew, F. S. and Wang, S. C. 1976. Scanning electron microscopical studies on the spores of Pteridophytes. VIII. The tree fern family (Cyatheaceae) and its allied species found in Taiwan. Taiwania 21: 251-267.

Liu, Y.-C., Kuo, C.- M. and Liu, H. - Y. 2000. SEM studies on spore in Taiwanese fern genera I. Athyrioids. Taiwania 45: 181-200.

Loope, L. L. and Giambelluca, T. W. 1998. Vulnerability of island tropical montane forest to climate change, with special reference to East Maui, Hawaii. Clim. Change 39: 503-517.

Lucansky, T. W. 1976. Anatomical studies of the Neotropical Cyatheaceae. I. *Alsophila* and *Nephelea*. Amer. Fern. J. 66: 93-101.

Marquez, G. J. 2010. La familia Cyatheaceae (Pteridophyta) en Argentina. Bol. Soc. Argent. Bot. 45(1-2): 173-183.

_____, Morbelli, M. A. and Giudice, G. E. 2009. Comparative analysis of spores of *Alsophila* (Cyatheaceae) species from southern South America. Rev. Palaeobot. Palynol. 156: 165-176.

Maxon, W. R. 1925. *Cyathea dryopteroides* Maxon. Amer. Fern J. 14: 99.

McCauley, A., Jones, C., Jacobsen, J. 2009. Soil pH and organic matter. Montana State University Extension. Nutrient Management Module. No. 8.

McCarthy, B. C., Robison, Scott, A. 2003. Canopy openness, understory light environments, and oak regeneration. In: Sutherland, Elaine K.; Hutchinson, Todd F., (Eds.) Characteristics of mixed oak forest ecosystems in southern Ohio prior to the reintroduction of fire. Gen. Tech. Rep. NE-299. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 57-66 pp.

McVicar, T. R., Van Niel, T. G., Roderick, M. L., Li, L. T., Mo, X. G., Zimmermann, N. E., and Schmatz, D. R.. 2010. Observational evidence from two mountainous regions that near-surface wind speeds are declining more rapidly at higher elevations than lower elevations: 1960-2006, Geophys. Res. Lett. 37.

Medina, E. and Cuevas, E. 1993. Mineral nutrition: humid tropical forests. Prog. Bot. 55: 115-129.

Montalvo, A. M., and Ellstrand, N. C. 2000. Transplantation of the subshrub Lotus scoparius: testing the home-site advantage hypothesis. Conserv. Biol. 14(4): 1034-1045.

National Cooperative Soil Survey. 1986. Los Guineos Series. Available from: https://soilseries.sc.egov.usda.gov/OSD_Docs/L/LOS_GUINEOS.html

_____. 2006. Maricao Series. Available from: https://soilseries.sc.egov.usda.gov/OSD_Docs/M/MARICAO.html

National Oceanic and Athmospheric Administration. 2014. National Hurricane Center tropical cyclone report. Hurricane Bertha. 16 pp.

National Oceanic and Athmospheric Administration. 2014. State of the climate: National overview for October 2014, published online November 2014, retrieved on March 27, 2017 from http://www.ncdc.noaa.gov/sotc/national/201410.

National Weather Service. 2014. Climate review for Puerto Rico and the U.S. Virgin Islands. 38 pp.

Olander, L. P., Scatena, F. N. and Silver, W. L. 1998. Impacts of disturbance initiated by road construction in a subtropical cloud forest in the Luquillo Experimental Forest, Puerto Rico. For. Ecol. Manag. 109: 33-49.

Peters, J. B. and Laboski, A. M. 2013. Sampling soils for testing. University of Wisconsin Cooperative Extension. Available from: http://www.soils.wisc.edu/extension/pubs/A2100.pdf

Pŏcks, T. 1980. The epiphytic biomass and its effect on the water balance of two rain forest types in Uluguru Mountains (Tanzania East Africa). Acta Bot. Acad. Scient. Hungaricæ 26: 143-167.

Proctor, G. R. 1989. Ferns of Puerto Rico and the Virgin Islands. Mem. N. Y. Bot. Gard. 53:389 pp.

Prugnolle, F. Rousteau, A. and Belin-Depoux, M. 2000. Occupation spatiale de *Cyathea muricata* Willd. (Cyatheaceae) en forêt dense humide guadeloupéenne. I. À l'échelle de l'individu. Acta Bot. Gallica. 147: 361-74.

Rabinowitz, D. 1981. Seven forms of rarity. The biological aspects of rare plant conservation. (Ed.): H. Synge. John Wiley, New York, USA 205-17.

Ramirez, A. 2017a. Minimum and Maximum temperature at El Verde Field Station, Río Grande, Puerto Rico since October 1992. Dataset, El Verde Field Station.

Ramirez, A. 2017b. Rainfall at El Verde Field Station, Río Grande, Puerto Rico since 1975. Dataset, El Verde Field Station.

Ricklefs, R., Kalin-Arroyo, M. T., Latham, R. E. 1995. The distribution of global biodiversity. In UNEP Global Biodiversity Assessment, ed. V. Heywood. Cambridge: Cambridge University Press for the United Nations Environmental Program 139-173.

Rilling, M. C., Wright, S. F., Nichols, K. A., Schmidt, W. F. and Torn, M. S. 2001. Large contribution of arbuscular mycorrhizal fungi to soil carbon pools in tropical forest soils. Plant and Soil 233: 167-177.

Robinson, K. 1997. Where dwarfs reign: A tropical rain forest in Puerto Rico. Editorial de la Universidad de Puerto Rico, San Juan, Puerto Rico 241 pp.

Rosado-Martínez, A. 1999. A floristic study of the cryptogamic flora in the Sierra palm forest of the Toro Negro Commonwealth Forest in Central Puerto Rico following Hurricane Georges. M. S. Thesis. University of Puerto Rico, Mayagüez Campus, Puerto Rico 96 pp.

Scatena, F. N., 1995. The management of Luquillo elfin cloud forest ecosystems: irreversible decisions in a nonsubstitutable ecosystem. In: Hamilton, L. S., Juvik, J. O., Scatena, F. N. (Eds.), Tropical Montane Cloud Forests: Proceedings of an International Symposium. Springer-Verlag, New York, US 191-198.

Schmitt, J. L. and Windisch, P. G. 2005. Aspectos ecológicos de *Alsophila setosa* Kaulf. (Cyatheaceae, Pteridophyta) no sul do Brasil. Acta Botanica Brasilica 19: 861-867.

_____ and _____. 2006. Growth rates and age estimates of *Alsophila setosa* Kaulf. in southern Brazil. Amer. Fern J. 96: 103-11.

Seiler, R. L. 1981. Leaf turnover rates and natural history of the Central American tree fern *Alsophila salvinii*. Amer. Fern J. 71(3): 75-81.

Sharpe, J. M. 1997. Leaf growth and demography of the rheophytic fern *Thelypteris angustifolia* (Willdenow) Proctor in a Puerto Rican rainforest. Plant Ecol. 130: 203-12.

Sharpe, J. M. and Jernstedt, J. A. 1990. Leaf growth and demography of the dimorphic herbaceous layer fern *Danaea wendlandii* (Marattiaceae) in a Costa Rican rain forest. Amer. J. Bot. 77: 1040-1049.

Smith, A. R., Pryer, K. M., Schuettpelz, E., Korall, P., Schneider, H. and Wolf, P. G. 2006. A classification for extant ferns. Taxon 55(3): 705-731.

Stadtmüller, T. 1987. Cloud forests in the humid tropics. A bibliographic review. The United Nations University, Tokyo and CATIE, Turrialba, Costa Rica 82 pp.

Stebbins, G. 1942. Polyploid complexes in relation to ecology and the history of floras. Amer. Nat. 76: 36-45.

Still, C. J., Foster P. N. and Schneider S. H. 1999. Simulating the effects of climate change on tropical montane cloud forests. Nature 789: 608-610.

Stockey, A. G. 1918. Apogamy in Cyatheaceae. Bot. Gaz. 65: 97-102.

Sugden, A. M. and Robins, R. J. 1982. The ecological, geographic and taxonomic relationships of an isolated Columbian cloud forest, with some implications for island biogeography. J. Arnold Arbor. 63: 31-61.

_____ and _____. 1983. Determinants of species composition in some isolated neotropical cloud forests. In: Sutton, S.L., Whitmore, T.C., Chadwick, A.C. (Eds.), Tropical Rain Forest: Ecol. Manag. Blackwell Scientific, Oxford, England 43-56.

Tanner, E. V. J. 1983. Leaf demography and growth of the tree-fern *Cyathea pubescens* Mett. *ex* Kuhn in Jamaica. Bot. J. Linnean Soc. 87: 213-227.

Thompson, J., Brokaw, N., Zimmerman, J. K., Waide, R. B., Everham III, E. M., Lodge, D. J., Taylor, C. M., García-Montiel, D. and Fluet, M. 2002. Land use history, environment, and tree composition in a tropical forest. Ecol. Appl. 12: 1344-1363.

Tryon, A. and Lugardon, B. 1991. Spores of the Pteridophyta. Surface, wall structure and diversity based on electron microscope studies. Springer-Verlag, New York, US 648 pp.

Tryon, R. M. 1960. The ecology of Peruvian ferns. Amer. Fern J. 50: 46-55.

_____. 1970. The classification of the Cyatheaceae. Contr. Gray Herb. 200: 3-50.

_____. 1972. Endemic areas and geographic speciation in Tropical American Ferns. Biotropica 4: 121-131.

_____. 1976. A revision of the genus *Cyathea*. Contr. Gray Herb. 206: 19-98.

_____. 1986. The biogeography of species, with special reference to the ferns. Bot. Rev. 52, 117-156.

_____ and Gastony, G. J. 1975. The biogeography of endemism in Cyatheaceae. Fern Gaz. 11: 73-79.

_____ and Tryon, A. F. 1982. Ferns and allied plants with special reference to tropical America. Springer-Verlag, New York, US 857 pp.

United States Fish and Wildlife Service. 1987. Endangered and threatened wildlife and lants; Determination of endangered status for *Cyathea dryopteroides* and *Ilex cookii*. Federal Register 52: 22936.

_____. 1991. *Ilex cookii* / *Cyathea dryopteroides* recovery plan. U. S. Department of the Interior, Fish and Wildlife Service, Southeast Region, Atlanta, Georgia, US 22 pp.

_____. 2013. Helecho de bosque enano or elfin tree fern (*Cyathea dryopteroides*). 5-year review: Summary and evaluation. U. S. Department of the Interior, Fish and Wildlife Service, Southeast Region, Caribbean Ecological Services Field Office, Boquerón, Puerto Rico 18 pp.

Vivaldi, J. L, Woodbury, R. O., and Díaz-Soltero, H. 1981. Status report *Alsophila dryopteroides* (Maxon) Tryon. Unpublished status report submitted to the U.S. Fish and Wildlife Service, Atlanta, Georgia, US 41 pp.

Votaw, G. S. 2014. Hurricane Gonzalo. National Oceanic and Athmospheric Administration, National Weather Service 7 pp.

Watling, D. and Gillison, A. N. 1995. Endangered species in low elevation cloud forest on Gau island, Fiji. In: Tropical Montane Cloud Forests. Ecol. Studies Hamilton, L.S., Juvik, J.O. and F.N. Scatena (Eds.), Springer-Verlag, New York, 110: 333-342.

Weaver, J. E., Clements, F. E. 1938. Plant ecology. New York: McGraw-Hill 601 pp.

Werth, C. R. and Cousens, M. I. 1990. Summary: the contributions of population studies on ferns. Amer. Fern J. 80: 183-190.

Wolf, P. G., Schneider, H. Ranker, T. A, Sheffield, E. and Haufler, C. H. 1991. Estimates of gene flow, genetic substructure and population heterozygosity in braken (*Pteridium aquilinum*). Biol. J. Linn. Soc. 42:407-423.

TABLES

Table 1. Individuals of *Alsophila amintae* in Monte Guilarte, Monte Jayuya and Cerro Rosa surveyed from January to November of 2014, and additional individuals found at other localities through early 2017.

Locality	Life stage	Latitude, Longitude	Altitude (m)	Individual #
Monte Guilarte	Adult	18.14145, -66.76942	1181	MG-1
	Adult	18.14147, -66.76948	1180	MG-2
	Adult	18.14146, -66.76941	1176	MG-3
	Adult	18.14151, -66.76949	1180	MG-4
	Adult	18.14153, -66.76955	1178	MG-5
	Adult	18.14162, -66.76940	1179	MG-6
	Adult	18.14178, -66.76962	1169	MG-7
	Adult	18.14184, -66.76952	1179	MG-8
	Adult	18.14178, -66.76965	1084	MG-9
	Adult	18.14178, -66.76965	1068	MG-10
	Adult	18.14130, -66.76987	1068	MG-11
	Adult	18.14131, -66.76988	1050	MG-12
	Juvenile	18.141395, -66.76945	1173	MG-13
	Juvenile	18.141392, -66.76946	1174	MG-14
	Adult	18.141347, -66.76958	1171	MG-15
Cerro Punta	Juvenile	18.17209, -66.59116	1299	CP-1
	Adult	18.17217, -66.59116	1309	CP-2
	Adult	18.17203, -66.59115	1296	CP-3
	Adult	18.17229, -66.59112	1312	CP-4
	Adult	18.17247, -66.59255	1297	CP-5
	Adult	18.17241, -66.59258	1294	CP-6
	Juvenile	18.17250, -66.59258	1293	CP-7
	Juvenile	18.17253, -66.59259	1300	CP-8
	Adult	18.17255, -66.59236	1322	CP-9
	Adult	18.17233, -66.59112	1318	CP-10
	Adult	18.17356, -66.5910	1295	CP-11
	Adult	18.17356, -66.5910	1295	CP-12
	Adult	18.17355, -66.5911	1290	CP-13
	Adult	18.17357, -66.59113	1293	CP-14
	Adult	18.17355, -66.59117	1290	CP-15
	Adult	18.40688, -66.90430	1273	CP-16
	Adult	18.17320, -66.59126	1302	CP-17
	Adult	18.173335, -66.59128	1301	CP-18
	Juvenile	18.173378, -66.59115	1299	CP-19
	Adult	18.173425, -66.59132	1296	CP-20
	Adult	18.173538, -66.59124	1293	CP-21
	Adult	18.173492, -66.59112	1295	CP-22
	Adult	18.173455, -66.59110	1299	CP-23
	Adult	18.173560, -66.59114	1299	CP-24

Table 1. Continued.

Locality	Life stage	Latitude, Longitude	Altitude (m)	Individual #
Cerro Punta (Continued)	Juvenile	18.173388, -66.59097	1312	CP-25
	Adult	18.17345, -66.591464	1290	CP-26
	Adult	18.173101, -66.591142	1306	CP-27
	Adult	18.173232, -66.591341	1296	CP-28
	Adult	18.173317, -66.591339	1294	CP-29
	Adult	18.173346, -66.591364	1301	CP-30
	Adult	18.173283, -66.591376	1304	CP-31
	Adult	18.173351, -66.591390	1297	CP-32
	Juvenile	18.173409, -66.591343	1297	CP-33
	Juvenile	18.173420, -66.591320	1290	CP-34
	Adult	18.173631, -66.591151	1299	CP-35
	Adult	18.173599, -66.591130	1299	CP-36
	Adult	18.173493, -66.591079	1302	CP-37
	Adult	18.173501, -66.591102	1301	CP-38
	Adult	18.173532, -66.591062	1299	CP-39
	Adult	18.173452, -66.590948	1314	CP-40
Monte Jayuya	Adult	18.16720, -66.57624	1255	MJ-1
	Adult	18.16725, -66.57630	1260	MJ-2
	Adult	18.16720, -66.57650	1318	MJ-3
	Adult	18.16717, -66.57692	1321	MJ-4
	Adult	18.16736, -66.57594	1325	MJ-5
	Adult	18.16736, -66.57594	1325	MJ-6
	Adult	18.16758, -66.57574	1325	MJ-7
	Adult	18.16760, -66.57557	1324	MJ-8
	Juvenile	18.16762, -66.57565	1324	MJ-9
	Adult	18.16762, -66.57565	1324	MJ-10
	Adult	18.16763, -66.57565	1324	MJ-11
	Juvenile	18.16761, -66.57563	1323	MJ-12
	Adult	18.16761, -66.57563	1323	MJ-13
	Adult	18.16760, -66.57563	1323	MJ-14
	Adult	18.16761, -66.57561	1324	MJ-15
	Juvenile	18.16761, -66.57554	1324	MJ-16
	Adult	18.16760, -66.57552	1324	MJ-17
	Adult	18.16760, -66.57552	1324	MJ-18
	Adult	18.16763, -66.57550	1323	MJ-19
	Adult	18.16764, -66.57554	1325	MJ-20
	Juvenile	18.16764, -66.57554	1325	MJ-21
	Adult	18.16762, -66.57558	1325	MJ-22
	Adult	18.16764, -66.57554	1325	MJ-23

Table 1. Continued.

Locality	Life stage	Latitude, Longitude	Altitude (m)	Individual #
Cerro Maravilla	Adult	18.15409, -66.55334	1175	CM-1
	Adult	18.15404, -66.55323	1172	CM-2
	Adult	18.15331, -66.55513	1187	CM-3
	Juvenile	18.15332, -66.55513	1188	CM-4
	Adult	18.15332, -66.55514	1188	CM-5
	Adult	18.15332, -66.55515	1188	CM-6
	Adult	18.15339, -66.55517	1185	CM-7
	Adult	18.15350, -66.55514	1185	CM-8
	Adult	18.15349, -66.55510	1185	CM-9
	Juvenile	18.15351, -66.55509	1186	CM-10
	Adult	18.15351, -66.55509	1186	CM-11
	Adult	18.15356, -66.55507	1186	CM-12
	Adult	18.15357, -66.55508	1186	CM-13
	Adult	18.15356, -66.55508	1185	CM-14
	Juvenile	18.15356, -66.55508	1185	CM-15
	Adult	18.15355, -66.55511	1185	CM-16
	Adult	18.15353, -66.55512	1185	CM-17
	Adult	18.15353, -66.55506	1189	CM-18
	Adult	18.15352, -66.55506	1189	CM-19
	Adult	18.15352, -66.55506	1189	CM-20
	Adult	18.15351, -66.55504	1189	CM-21
	Adult	18.15352, -66.55503	1189	CM-22
	Juvenile	18.15352, -66.55504	1189	CM-23
	Juvenile	18.15352, -66.55493	1193	CM-24
	Adult	18.15351, -66.55492	1193	CM-25
	Adult	18.15351, -66.55492	1193	CM-26
	Juvenile	18.15349, -66.55488	1195	CM-27
	Adult	18.15338, -66.55470	1202	CM-28
Tres Picachos	Adult	18.21527, -66.54105	1089	TP-1
	Adult	18.21489, -66.54076	1087	TP-2
	Juvenile	18.21497, -66.54074	1082	TP-3
	Adult	18.21463, -66.53985	1103	TP-4
	Adult	18.21463, -66.53985	1083	TP-5
	Adult	18.21463, -66.53985	1083	TP-6
	Juvenile	18.21463, -66.53985	1083	TP-7
	Juvenile	18.21463, -66.53985	1082	TP-8
	Adult	18.21508, -66.54064	1078	TP-9
	Adult	18.21499, -66.54082	1085	TP-10

Table 1. Continued.

Locality	Life stage	Latitude, Longitude	Altitude (m)	Individual #
Tres Picachos (Continued)	Adult	18.21510, -66.54069	1088	TP-11
	Adult	18.21518, -66.54083	1089	TP-12
Cerro Rosa	Adult	18.18025, -66.53979	1184	CR-1
	Adult	18.18038, -66.53978	1172	CR-2
	Adult	18.18041, -66.53971	1176	CR-3
	Adult	18.18026, -66.53955	1177	CR-4
	Adult	18.18134, -66.54015	1159	CR-5
	Adult	18.18134, -66.54015	1170	CR-6
	Juvenile	18.18064, -66.53951	1171	CR-7
	Adult	18.18064, -66.53951	1169	CR-8

Table 2. List of plant species associated with populations of *Alsophila amintae* surveyed from January to November of 2014. Species were not collected, instead they were recognized *in-situ*.

		Population					
Family	Species	MG	CP	MJ	CM	TP	CR
Arecaceae	*Prestoea acuminata* (Willd.) H.E.Moore var. *montana* (Graham) A.J.Hend. & Galeano	+	+	+	+	+	+
Araliaceae	*Schefflera gleasonii* (Britton & P.Wilson) Alain		+	+	+		
Bromeliaceae	*Guzmania lingulata* Mez	+	+	+	+	+	+
Commelinaceae	*Commelina difusa* Zoll. Ex C.B.Clarke	+	+	+			
Cyatheaceae	*Cyathea arborea* (L.) J. E.Smith	+	+	+	+	+	+
Cyatheaceae	*Cyathea bryophila* (R.Tryon) Proctor	+	+	+	+	+	+
Cyatheaceae	*Cyathea furfuracea* (Baker)	+	+	+			
Cyatheaceae	*Cyathea portoricensis* Sprengel ex Kuhn	+	+	+	+	+	+
Cyatheaceae	*Cyathea tenera* (J. Smith ex Hooker) Moore		+	+	+		
Dennstaedtiaceae	*Hypolepis nigrescens* Hooker			+	+	+	
Gleicheniaceae	*Gleichenella pectinata* (Willd.) Ching			+	+	+	
Gleicheniaceae	*Sticherus bifidus* (Willd.) Ching			+			
Marattiaceae	*Danaea* Sp. Sm.	+				+	
Poaceae	*Arthrostylidium sarmentosum* Pilg.		+	+	+		
Thelypteridaceae	*Thelypteris deltoidea* (Swartz) Proctor	+	+	+	+	+	+
Urticaceae	*Pilea inaequalis* (Juss. ex Poir.) Wedd.	+	+	+	+	+	+

Table 3. Areas that *Alsophila amintae* occupies in each of the populations identified from 2014 to 2017.

Locality	Area (ha)
Monte Guilarte	0.07
Cerro Punta	1.75
Monte Jayuya	0.18
Cerro Maravilla	0.81
Tres Picachos	0.95
Cerro Rosa	0.32

Table 4. Distances between the six peaks where *Alsophila amintae* were found from January 2014 to early 2017. The distances are measured in kilometers. The longest distance (25.51 km) was between Monte Guilarte and Cerro Rosa, while the shortest distance (1.60 km) was between Cerro Punta and Monte Jayuya. The longest and shortest distances are in bold.

	MG	CP	MJ	CM	TP	CR
Monte Guilarte (MG)	−	19.16	20.57	22.73	24.68	**25.51**
Cerro Punta (CP)	19.16	−	**1.60**	4.40	5.50	7.09
Monte Jayuya (MJ)	20.57	**1.60**	−	2.69	4.03	6.41
Cerro Maravilla (CM)	22.73	4.40	2.69	−	3.36	6.84
Tres Picachos (TP)	24.68	5.50	4.03	3.36	−	3.68
Cerro Rosa (CR)	**25.51**	7.09	6.41	6.84	3.68	−

Table 5. Typical slope inclination and aspect of *Alsophila amintae* populations identified in 2014.

Locality	Slope inclination	Aspect
Monte Guilarte	45º	NW
Cerro Punta	30º, 55º	NE
Monte Jayuya	10º	NE
Cerro Maravilla	25º	NE
Tres Picachos	35º	NE
Cerro Rosa	55º	NW

Table 6. Mean percentage of soil humidity and pH by month in three populations of *Alsophila amintae* in 2014. (Mean humidity was 69.1%, S.D. 15.3%; range from 30 – 100% and mean pH was 6.5, S. D. 0.34; range from 5.0 – 7.0). Lowest and highest humidity percentage are in bold.

Month	Monte Guilarte		Monte Jayuya		Cerro Rosa	
	Humidity %	pH	Humidity %	pH	Humidity %	pH
January	64	6.7	74	6.3	80	6.7
March	55	6.7	69	6.6	75	6.9
May	**51**	6.6	**57**	6.2	73	6.8
July	48	6.4	64	6.2	**65**	6.9
September	**80**	6.4	**81**	6.3	**85**	6.9
November	72	6.6	75	6.6	71	6.8

Table 7. Summary statistics for soil humidity percentage and pH for juvenile and adult individuals of *Alsophila amintae* in all three studied populations during 2014.

	Soil humidity (%)		Soil pH	
	Juvenile	Adult	Juvenile	Adult
N	30	210	30	211
Mean	73.5	68.5	6.5	6.5
S. D.	14.7	15.3	0.4	0.3
Minimum	30.0	30.0	5.6	5.0
Maximum	95.0	100.0	7.0	7.0

Table 8. Average temperature and total precipitation for 2014 from the Adjuntas Experimental Substation of the University of Puerto Rico, Mayagüez Campus. Total annual precipitation is shown. Lowest and highest mean air temperatures and precipitations are in bold.

Month	Air Temperature (°F)	Precipitation (mm)
January	**66.78**	**16.0**
February	66.85	53.6
March	67.19	119.6
April	69.64	242.8
May	70.89	214.6
June	72.73	34.0
July	**73.20**	71.9
August	72.09	**591.3**
September	72.89	135.9
October	72.09	190.0
November	70.58	125.2
December	68.26	70.9
Total:		**1,865.9**

Table 9. Percentage of canopy openness (mean and range) by month in three populations of *Alsophila amintae* in the year 2014.

Month	Monte Guilarte	Monte Jayuya	Cerro Rosa
January	10.3 (4.5 - 23.1)	14.1 (9.5 - 30.1)	10.3 (8.9 - 13.7)
March	10.1 (8.5 - 17.3)	11.6 (8.7 - 22.5)	11.9 (4.9 - 16.2)
May	15.8 (10.3 - 25.8)	13.6 (9.6 – 17.9)	13.7 (7.8 - 18.1)
July	16.3 (11.7 – 22.0)	16.9 (12.3 - 20.5)	18.2 (15.7 - 24.3)
September	11.1 (5.5 - 19.8)	15.1 (7.0 - 24.2)	12.6 (5.6 - 21.8)
November	14.4 (10.3 - 22.7)	16.6 (13.0 - 26.6)	17.6 (15.0 – 20.9)

Table 10. Summary statistics for percentage of canopy openness in all studied populations of *Alsophila amintae* during 2014.

Variable	n	Mean	S.D.	Minimum	Maximum
% Canopy Openness	240	14.4	4.3	4.5	30.1

Table 11. Number of falling Sierra Palm fronds affecting *Alsophila amintae* in three populations studied in 2014.

Month	Monte Guilarte	Monte Jayuya	Cerro Rosa
January	3	4	1
March	1	1	2
May	4	2	0
July	3	5	2
September	5	7	1
November	1	3	0

Table 12. Number of individuals affected by natural disturbances (invasive plant species) at surveyed localities during January to November, 2014.

Month	Monte Guilarte	Monte Jayuya	Cerro Rosa
January	0	5	0
March	0	4	0
May	0	3	0
July	0	5	0
September	0	4	0
November	0	3	0

Table 13. Individuals of *Alsophila amintae* affected by anthropogenic disturbances in impacted localities during January to November, 2014.

Locality	Land Use	Contamination	Experimentation
Monte Guilarte	4	4	9
Cerro Punta	1	1	0
Monte Jayuya	2	0	23
Cerro Maravilla	2	0	0
Tres Picachos	0	0	0
Cerro Rosa	0	1	8

Table 14. Trunk height and diameter of *Alsophila amintae* individuals in the three populations surveyed in 2014.

Locality	Trunk height (cm)	Diameter (cm)	Individual #	Life stage
Monte Guilarte	11.4	4.0	MG-1	Adult
	12.7	5.7	MG-2	Adult
	8.9	3.6	MG-3	Adult
	10.2	4.8	MG-4	Adult
	12.7	4.8	MG-5	Adult
	10.2	3.2	MG-6	Adult
	22.9	4.8	MG-7	Adult
	15.2	3.6	MG-8	Adult
	11.4	4.4	MG-9	Adult
Monte Jayuya	25.4	3.6	MJ-1	Adult
	35.6	5.3	MJ-2	Adult
	25.4	4.0	MJ-3	Adult
	26.7	3.6	MJ-4	Adult
	12.7	8.9	MJ-5	Juvenile
	17.8	4.0	MJ-6	Adult
	17.8	4.4	MJ-7	Adult
	5.1	3.2	MJ-8	Adult
	7.6	3.2	MJ-9	Adult
	8.9	4.0	MJ-10	Adult
	5.1	3.2	MJ-11	Juvenile
	24.1	3.6	MJ-12	Adult
	22.9	2.8	MJ-13	Adult
	10.2	4.8	MJ-14	Adult
	10.2	4.8	MJ-15	Adult
	10.2	4.0	MJ-16	Adult
	15.2	3.2	MJ-17	Juvenile
	7.6	3.2	MJ-18	Juvenile
	10.2	4.8	MJ-19	Adult
	7.6	4.4	MJ-20	Adult
	7.6	4.4	MJ-21	Adult
	10.2	4.9	MJ-22	Adult
	17.8	4.5	MJ-23	Adult
Cerro Rosa	43.2	4.8	CR-1	Adult
	45.7	6.1	CR-2	Adult
	30.5	3.6	CR-3	Adult
	61.0	4.0	CR-4	Adult
	17.8	4.4	CR-5	Adult
	43.2	4.8	CR-6	Adult
	15.2	4.0	CR-7	Juvenile
	22.9	4.0	CR-8	Adult

Table 15. Mean, standard deviation and range (in cm) of *Alsophila amintae* trunk height in the three locations studied in 2014.

		Monte Guilarte			Monte Jayuya			Cerro Rosa		
Trunk measurement (cm)	Stage	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
Height	Juvenile	0	0	0	11.75	0.72	5.08-15.24	15.24	0	0
Height	Adult	12.84	0.89	8.89-22.86	15.51	0.80	7.62-35.56	37.74	0.82	17.78-60.96
Diameter	Juvenile	0	0	0	3.54	0.39	3.23-4.04	4.04	0	0
Diameter	Adult	4.36	0.78	3.23-5.66	4.04	0.74	2.83-5.26	4.56	0.80	3.64-6.07

Table 16. Summary statistics for mean number of live, senescent, fertile and sterile fronds for juveniles and adults in three populations of *Alsophila amintae* studied in 2014.

Number of:

			Juvenile		
	Mean	n	S.D.	Minimum	Maximum
Live fronds	3.9	30	1.1	2.0	6.0
Senescent fronds	1.3	30	1.1	0	4.0
Fertile fronds	0.7	30	1.6	0	5.0
Sterile fronds	3.2	30	1.5	0	6.0
			Adult		
Live fronds	5.7	211	1.9	2.0	12.0
Senescent fronds	2.4	211	1.7	0	7.0
Fertile fronds	3.6	211	1.7	0	7.0
Sterile fronds	2.1	211	1.7	0	7.0

Table 17. Summary statistics for frond length and width for juveniles and adults of *Alsophila amintae* in all three populations studied in 2014.

Frond length (cm)					
Life Stage: Juvenile					
Locality	Mean	n	S.D.	Minimum	Maximum
Monte Guilarte	0	0	0	0	0
Monte Jayuya	34.3	24	6.0	23.9	48.7
Cerro Rosa	53.1	6	4.3	48.3	58.4

Frond length (cm)					
Life Stage: Adult					
Locality	Mean	n	S.D.	Minimum	Maximum
Monte Guilarte	72.2	54	12.7	55.0	94.8
Monte Jayuya	60.1	114	14.5	23.7	92.0
Cerro Rosa	54.7	43	11.8	23.7	80.9

Frond width (cm)					
Life Stage: Juvenile					
Locality	Mean	n	S.D.	Minimum	Maximum
Monte Guilarte	0	0	0	0	0
Monte Jayuya	15.7	24	3.9	10.2	23.3
Cerro Rosa	21.7	6	2.3	17.8	24.9

Frond width (cm)					
Life Stage: Adult					
Locality	Mean	n	S.D.	Minimum	Maximum
Monte Guilarte	20.3	54	3.4	10.16	27.9
Monte Jayuya	20.9	114	3.5	11.85	27.9
Cerro Rosa	20.2	43	3.4	11.01	25.4

Table 18. Mean and range of spore dispersal (distance from rachis) in an experiment sampling seven fronds of *Alsophila amintae*.

Frond number	Dispersal mean (cm)	Dispersal range (cm)
1	6.3	2.5 - 10.0
2	2.7	1.0 - 5.0
3	5.9	2.0 - 9.0
4	3.9	1.0 - 6.5
5	7.0	2.5 - 10.0
6	3.8	1.0 - 6.0
7	6.8	2.0 - 10.0

Table 19. Observed presence (**+**) of other *Alsophila* species and their hybrids with *Alsophila amintae* in localities studied in 2014.

Location	*A. amintae*	*A. bryophila*	*A. amintae* × *bryophila*	*A. portoricensis*	*A. amintae* × *portoricensis*	*A. bryophila* × *portoricensis*
Monte Guilarte	+	+	0	+	+	0
Cerro Punta	+	+	0	+	0	+
Monte Jayuya	+	+	+	+	+	+
Cerro Maravilla	+	+	+	+	0	+
Tres Picachos	+	+	+	0	0	0
Cerro Rosa	+	0	0	+	0	0

Table 20. *Alsophila amintae* hybrids found in Monte Guilarte, Monte Jayuya and Cerro Rosa and additional searched localities of Cerro Punta, Cerro Maravilla and Tres Picachos.

Hybrid	Locality	Apparent Life stage	Latitude, Longitude	Altitude (m)
A. amintae × *portoricensis*	Monte Guilarte	Adult	18.160946, -66.989937	1085
	Monte Jayuya	Juvenile	18.167639, -66.57475	1294
		Juvenile	18.167472, -66.5750	1293
		Juvenile	18.167528, -66.575139	1293
		Juvenile	18.167361, -66.575194	1294
		Juvenile	18.1675, -66.575222	1188
		Juvenile	18.167361, -66.575167	1298
A. amintae × *bryophila*	Monte Jayuya	Adult	18.167448, -66.570025	1325
		Juvenile	18.166889, -66.576667	1215
		Juvenile	18.166917, -66.576556	1217
		Juvenile	18.166806, -66.576556	1215
		Juvenile	18.167167, -66.576083	1225
		Juvenile	18.167278, -66.5760	1230
		Juvenile	18.167472, -66.575889	1254
		Juvenile	18.167333, -66.575972	1307
		Juvenile	18.167361, -66.576083	1316
		Juvenile	18.167472, -66.57575	1303
	Cerro Maravilla	Adult	18.15339, -66.55517	1185
	Tres Picachos	Adult	18.21346, -66.53831	1028

Table 21. Herbarium specimens examined for *Alsophila amintae*. Collections are ordered by date. Localities are organized by municipality and barrio. Latitudes and longitudes are included only for specimens that could be georeferenced.

Collector(s)	Herbarium	Date	Latitude, Longitude/ Altitude (m)	Locality
N. L. Britton & S. Brown 1976	NY	1915 Mar 15	18.113333, -66.705278 900-1050 m	Peñuelas-Rucio, near Adjuntas
R. O. Woodbury s.n.	SJ	1962 Jul 29	18.164444, -66.571667 1219 m	Jayuya-Saliente
D.S. Conant 595	NY	1973 Jun 23	1219 m	Jayuya-Veguitas Cerro Punta Rte. 143, km 18.5
D.S. Conant 682	NY	1973 Nov 25	1219 m	Jayuya-Veguitas Cerro Punta Rte. 143, km 18.5
D.S. Conant 689	JBSD	1973 Oct 25	1219 m	Jayuya-Veguitas Cerro Punta Rte. 143, km 18.5
D.S. Conant 1760	NY	1975 Ago 8	18.168056, -66.583333 0.3912"W 1150 m	Jayuya-Saliente Rte. 143, km 18.5
D.S. Conant 1812	US	1975 Aug 14	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
D.S. Conant 1851	NY	1975 Aug 16	18.141389, -66.768889 1200 m	Adjuntas-Guilarte 80 km SW of San Juan
D.S. Conant 1856	NY	1975 Aug 16	18.140833, -66.769444 1100-1150 m	Adjuntas-Guilarte Upper slopes of Monte Guilarte
D.S. Conant 1859	NY	1975 Aug 16	18.140833, -66.769444 1100-1150 m	Adjuntas-Guilarte Upper slopes of Monte Guilarte
D.S. Conant 1956	US	1975 Aug 20	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
D.S. Conant 1966	NY	1975 Aug 20	18.168333, -66.583333 1150 m	Jayuya-Saliente Rte. 143, km 18.5
D.S Conant 1700	US	1975 Jul 30	18.140984, -66.769443 1100-1150 m	Adjuntas-Guilarte Upper slopes of Monte Guilarte
D.S. Conant & A.M. Kitfield 2277	NY	1976 Mar 29	1150 m	Jayuya-Veguitas Cerro Punta Rte. 143, km 18.5
D.S. Conant & A.M. Kitfield 2281	NY	1976 Mar 29	18.168056, -66.583333 1150 m	Jayuya-Saliente Rte. 143, km 18.5

Table 21. Continued.

Collector(s)	Herbarium	Date	Latitude, Longitude/ Altitude (m)	Locality
D.S. Conant 2309	US	1976 Mar 31	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
D.S. Conant 2312	US	1976 Mar 31	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
R.O. Woodbury s.n.	UPR, MAPR	1976 May 9	18.140833, -66.769444 1100-1150 m	Adjuntas-Guilarte Upper slopes of Monte Guilarte
J. Hernández - Muñíz 44	MAPR	1982 Oct 30	18.151944, -66.546389 1025 m	Orocovis-Ala de la Piedra Rte. 143, km 18.8-19.4
G. R. Proctor 39431	SJ	1983 Aug 26	18.166389, -66.575556 1230-1240 m	Jayuya-Saliente N side of Rte.143, km 18.1
G. R. Proctor 40114	NY, SJ	1984 Jan 26	18.140833, -66.769444 1100-1150 m	Adjuntas-Guilarte Upper slopes of Monte Guilarte
G. Breckon & D.S. Conant 3094	MAPR	1985 Sept 21	18.166667, -66.571389 1230 m	Jayuya-Saliente Rte. 143, km 18.5
C. Pérez-Muñoz 2	MAPR	1985 Sept 22	18.166667, -66.57139 1230 m	Jayuya-Saliente Rte. 143, km 18.5
H. Quiñonez-López 3	UPRRP	1985 Sept 22	18.166667, -66.574444 1230 m	Jayuya-Saliente SE slope Monte Jayuya N side of Rte. 143, km 18.5
S.J. Dent 33	UPRRP	1985 Sept 22	18.166667, -66.574444 1230 m	Jayuya-Saliente SE slope Monte Jayuya N side of Rte. 143, km 18.5
M. Mejía & G. Breckon 2160	MAPR	1987 Sept 12	18.162778, -66.526389 1160 m	Jayuya-Saliente Intersecting Rte. 143, and 149
G. R. Proctor *et al.* 43970	SJ	1987 Sept 27	18.17750, -66.539167 1200-1230 m	Jayuya-Saliente Mountain ridge c. 0.8 km due W. of Cerro Rosa
G. R. Proctor *et al.* 44609	SJ, UPRRP	1988 Mar 26	18.178611, -66.531667 1250 m	Ciales-Toro Negro Upper E slope near summit of Cerro Rosa
G. Breckon *et al.* 4430	MAPR	1993 Nov 28	18.156111, -66.5550 1200 m	Jayuya- Saliente E side Cerro Maravilla
G. Breckon & P. Acevedo 4686	MAPR, UPRRP	1996 Jan 23	18.168333, -66.575556 1190 m	Ponce-Anón Rte. 143, km 18.9

Table 21. Continued.

Collector(s)	Herbarium	Date	Latitude, Longitude/ Altitude (m)	Locality
M. Lehnert *et al.* 1688	URPRP	2010 Jan 27	18.165833, -66.571667 1260-1280 m	Jayuya-Saliente Rte. 143, km 18.5
M. Lehnert *et al.* 1716	UPRRP	2010 Jan 29	18.133333, -66.766667 1100 m	Adjuntas-Guilarte Upper slopes, trail to the summit of Monte Guilarte

Table 22. Herbarium specimens examined for *Alsophila amintae* hybrids. Collections are ordered by date. Localities are organized by municipality and barrio.

Hybrid	Collector(s)	Herbarium	Date	Latitude, Longitude/ Altitude (m)	Locality
A. amintae × *bryophila*	D.S. Conant **1966**	US	1975 Aug 20	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **1915**	US	1975 Aug 18	18.141366, -66.779795 1100-1150 m	Adjuntas-Guilarte ca. 80 km SW of San Juan
A. amintae × *portoricensis*	D.S. Conant **1990**	US	1975 Aug 21	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **1705**	US, NY	1975 Jul 30	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **3460**	US	1979 Jan 3	18.140736, -66.780104 1150 m	Adjuntas-Guilarte ca. 80 km SW of San Juan
A. amintae × *portoricensis*	D.S. Conant **1961**	US	1975 Aug 20	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **1707**	MAPR, NY	1975 Jul 30	18.167448, -66.570025 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **1963**	NY	1975 Ago 20	18.168333, -66.583333 1150 m	Jayuya-Saliente Rte. 143, km 18.5
A. amintae × *portoricensis*	D.S. Conant **687**	UPRRP, UPR	1973 Oct 25	1219 m	Jayuya-Veguitas Cerro Punta Rte. 143, km 18.5

FIGURES

Figure 1. A tagged *Alsophila amintae* juvenile at the Monte Jayuya population. The red field desk is utilized for scaling purposes. Photo from July, 2016.

Figure 2. Sori are key characters for identification of *Alsophila amintae*, other species of *Alsophila* (*A. bryophila* and *A. portoricensis*) and their hybrids. Sori of *A. amintae* are arranged on the underside of the frond. The sori are mature but some of them are not yet open.

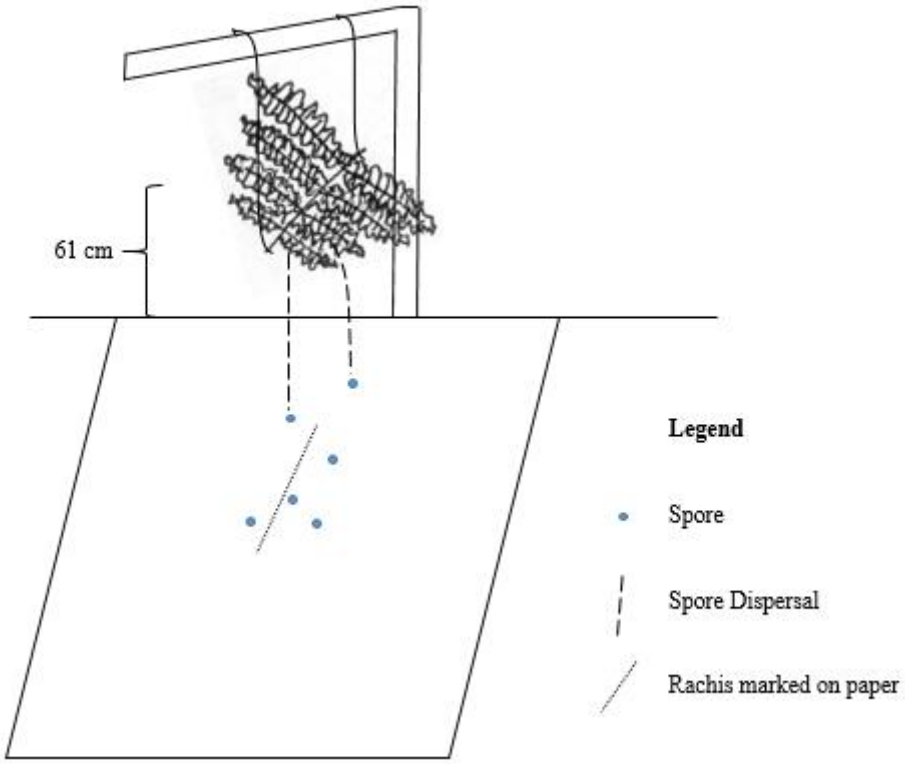

Figure 3. Spore dispersal experiment. Pieces of fronds of *Alsophila amintae* were placed on a white paper to delineate the rachis and afterwards they were tied with thread to a piece of wood at a height equal to that of the tallest individual observed in the study (as reference). Tied fronds were left overnight so spores could fall on the white paper. The distance (in cm) of spore dispersal from the rachis was measured.

Figure 4. Map showing *Alsophila amintae* locations (red stars) in Puerto Rico and the Adjuntas Experimental Substation (green dot).

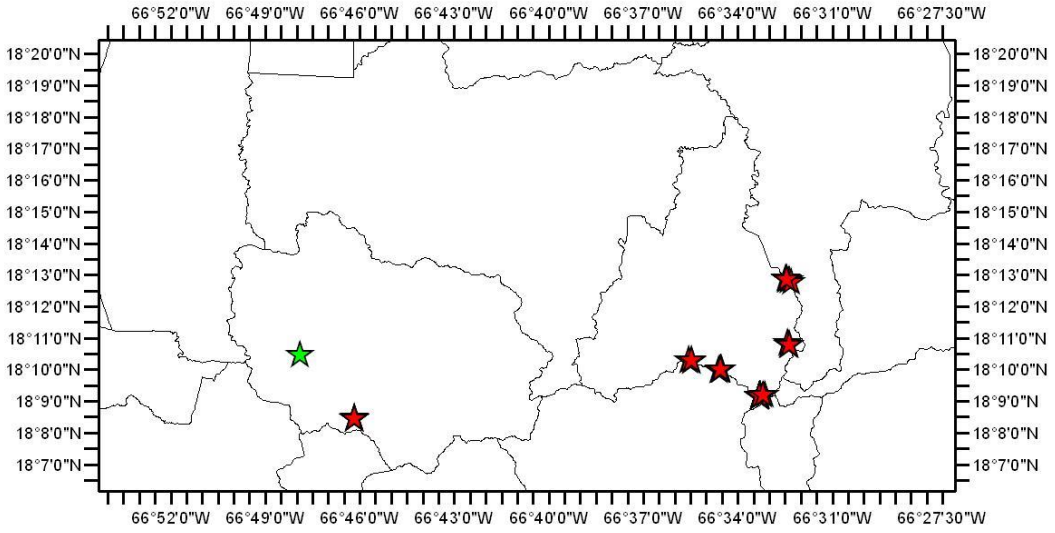

Figure 5. Map showing *Alsophila amintae* locations (red stars) identified from 2014 to 2017 in the Central Cordillera of Puerto Rico and the Adjuntas Experimental Substation (green star). From left to right: Adjuntas Experimental Substation, Monte Guilarte, Cerro Punta, Monte Jayuya, Cerro Maravilla, Tres Picachos and Cerro Rosa.

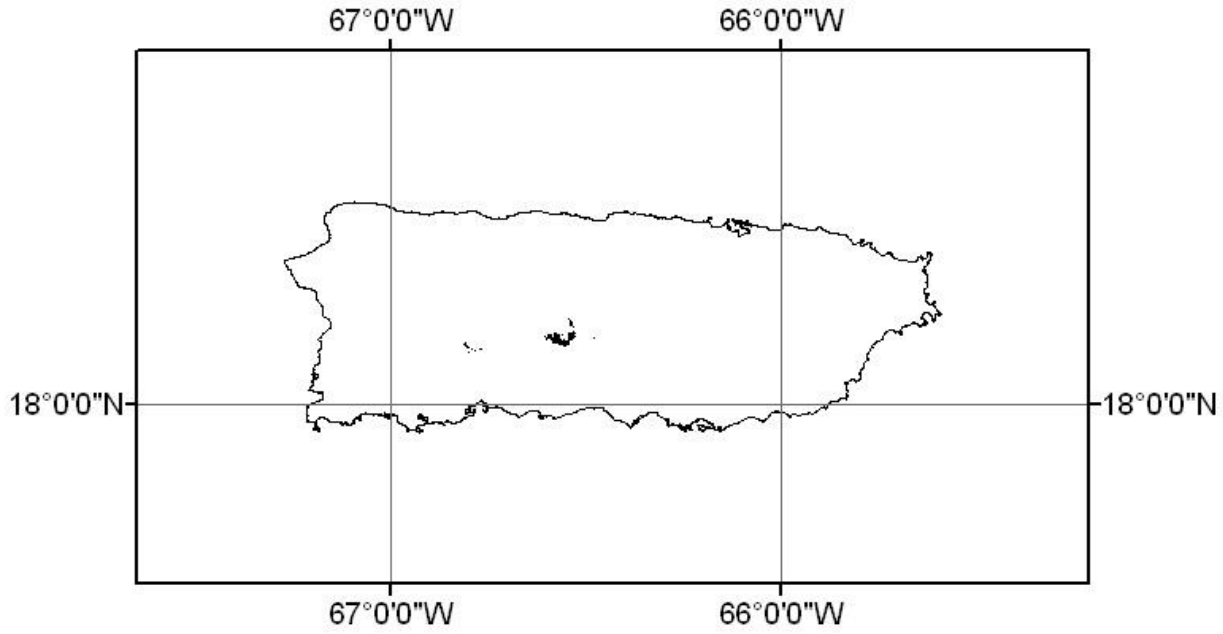

Figure 6. Spatial distribution map of Puerto Rico showing elevations ranging from 1050 to 1325 m, the elevations where *Alsophila amintae* can potentially be found.

Figure 7. Map of the geographical distribution of *Alsophila amintae* (red stars) in Monte Guilarte, Bo. Guilarte, Adjuntas, Puerto Rico. During the study period (January, 2014 to November, 2014) a total of 10 individuals were observed in this population. In February, 2017 an additional 5 individuals were found.

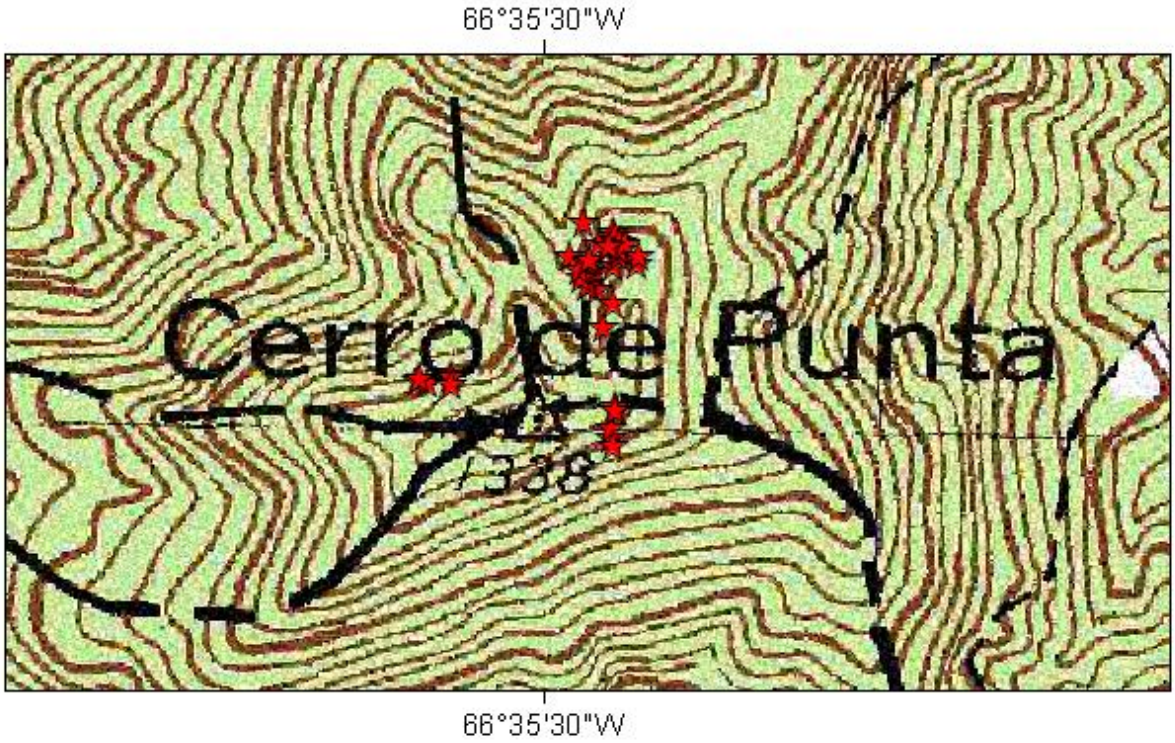

Figure 8. Map of the geographical distribution of *Alsophila amintae* (red stars) in Cerro de Punta, Bo.Veguitas and Bo. Anón, in Jayuya and Ponce municipalities, respectively. During the study period (January, 2014 to November, 2014) a total of seven individuals were observed in this population. In February, 2017 an additional 40 individuals were found.

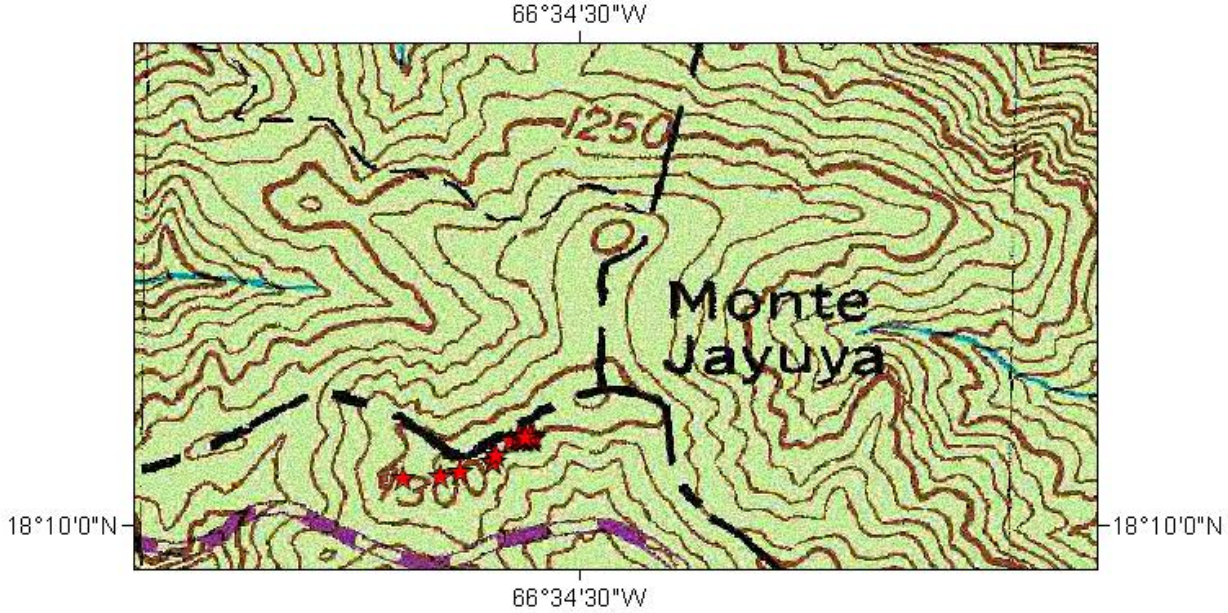

Figure 9. Map of the geographical distribution of *Alsophila amintae* in Monte Jayuya, Bo. Anón, Ponce, Puerto Rico. During the study period (January, 2014 to November, 2014) a total of 40 individuals were observed in this population.

Figure 10. Map of the geographical distribution of *Alsophila amintae* in Cerro Maravilla, Bo. Saliente and Bo. Anón, on the border between Jayuya and Ponce municipalities, respectively. Only one individual is in Ponce area. During the study period (January, 2014 to November, 2014) a total of 28 individuals were observed in this population.

Figure 11. Map of the geographical distribution of *Alsophila amintae* in Tres Picachos, Bo. Saliente y Bo. Toro Negro, Municipalities of Jayuya and Ciales, Puerto Rico. During the study period (January, 2014 to November, 2014) a total of 12 individuals were observed in this population.

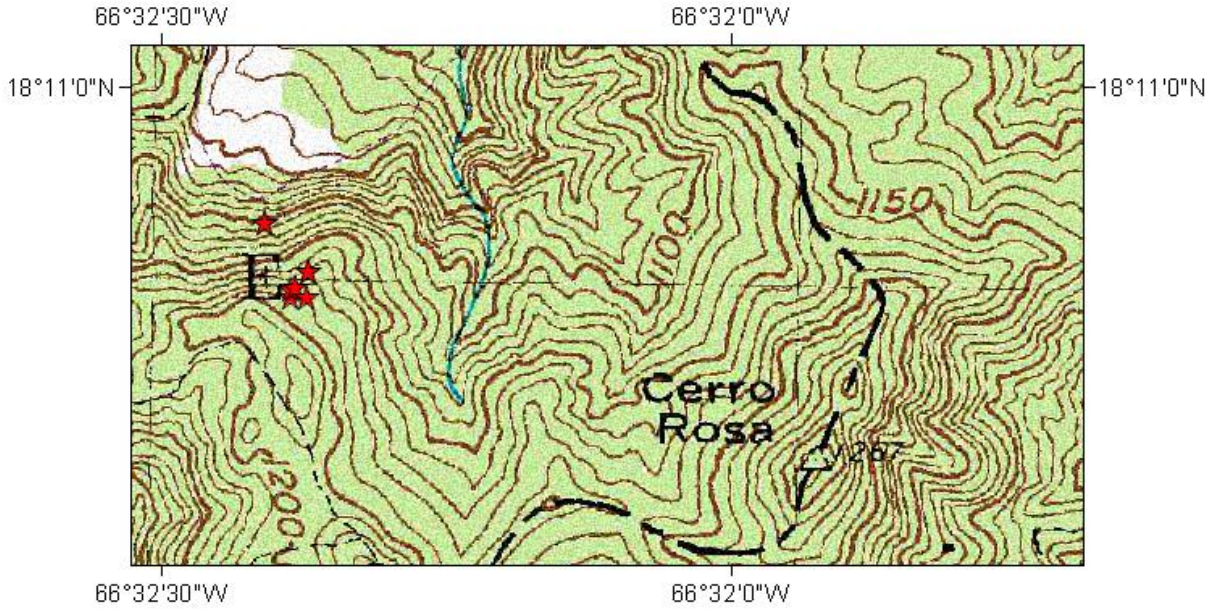

Figure 12. Map of the geographical distribution of *Alsophila amintae* in Cerro Rosa, Bo. Saliente, Jayuya, Puerto Rico. During the study period (January, 2014 to November, 2014) a total of 8 individuals were observed in this population. At the second month of the study one of the individuals was found dead.

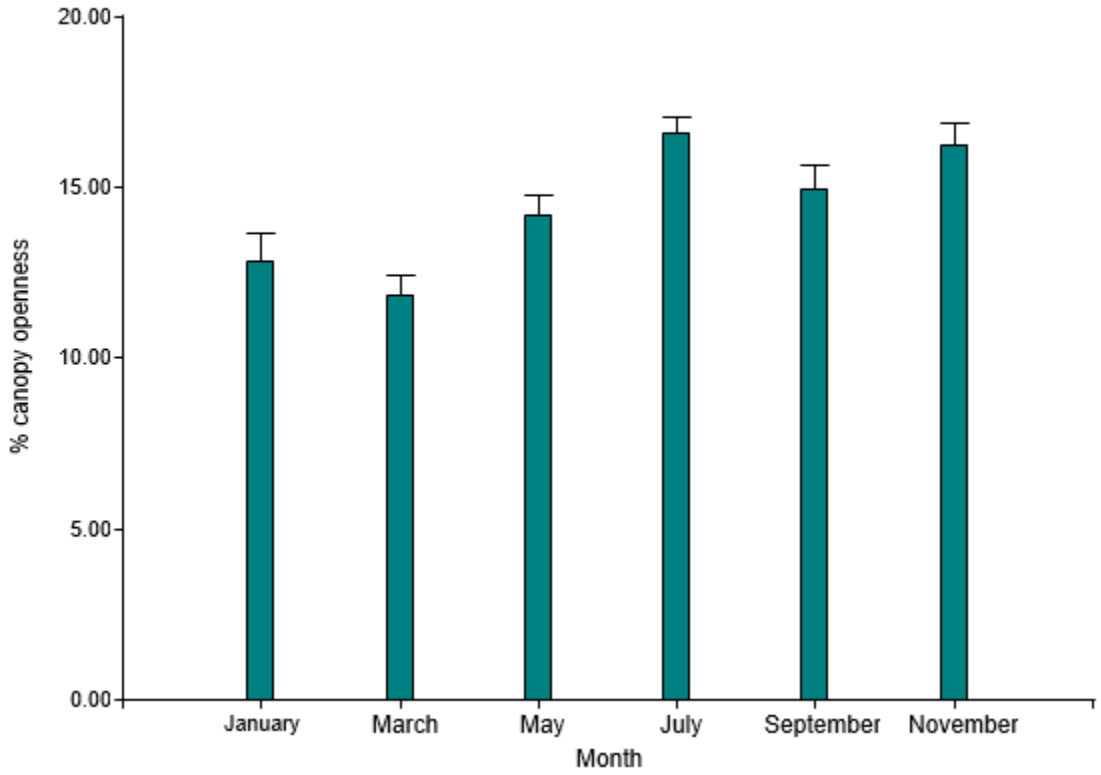

Figure 13. Mean percentage of canopy openness for the three populations of *Alsophila amintae* studied during 2014. Error bars denote standard deviation.

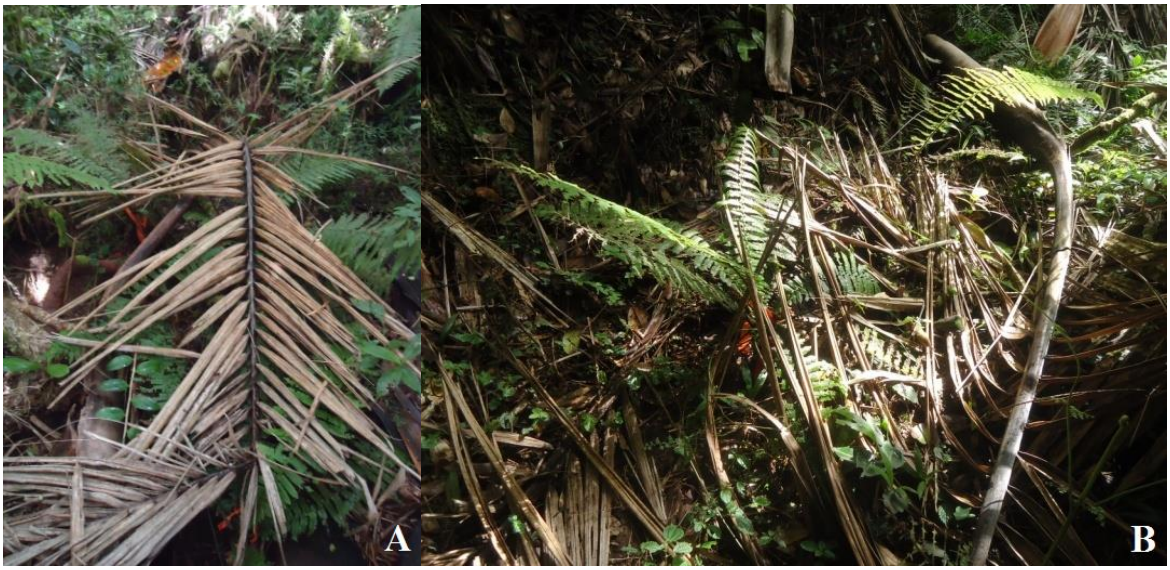

Figure 14. Falling of Sierra Palm fronds on *Alsophila amintae* individuals in the Monte Jayuya population.

Figure 15. *Arthrostylidium sarmentosum* growing above and near *Alsophila amintae* individuals in the Tres Picachos population.

Figure 16. Some anthropogenic disturbances found near the *Alsophila amintae* populations. Among them were car tires, rubber cables, plastic or glass bottles and aluminum cans that people threw down the hill.

Figure 17. Individual of *Alsophila amintae* found in Cerro Punta, Adjuntas. Near the individual, a long rubber cable can be seen partly buried in the ground. These cables are commonly used for the maintenance and repair of the communications antennas.

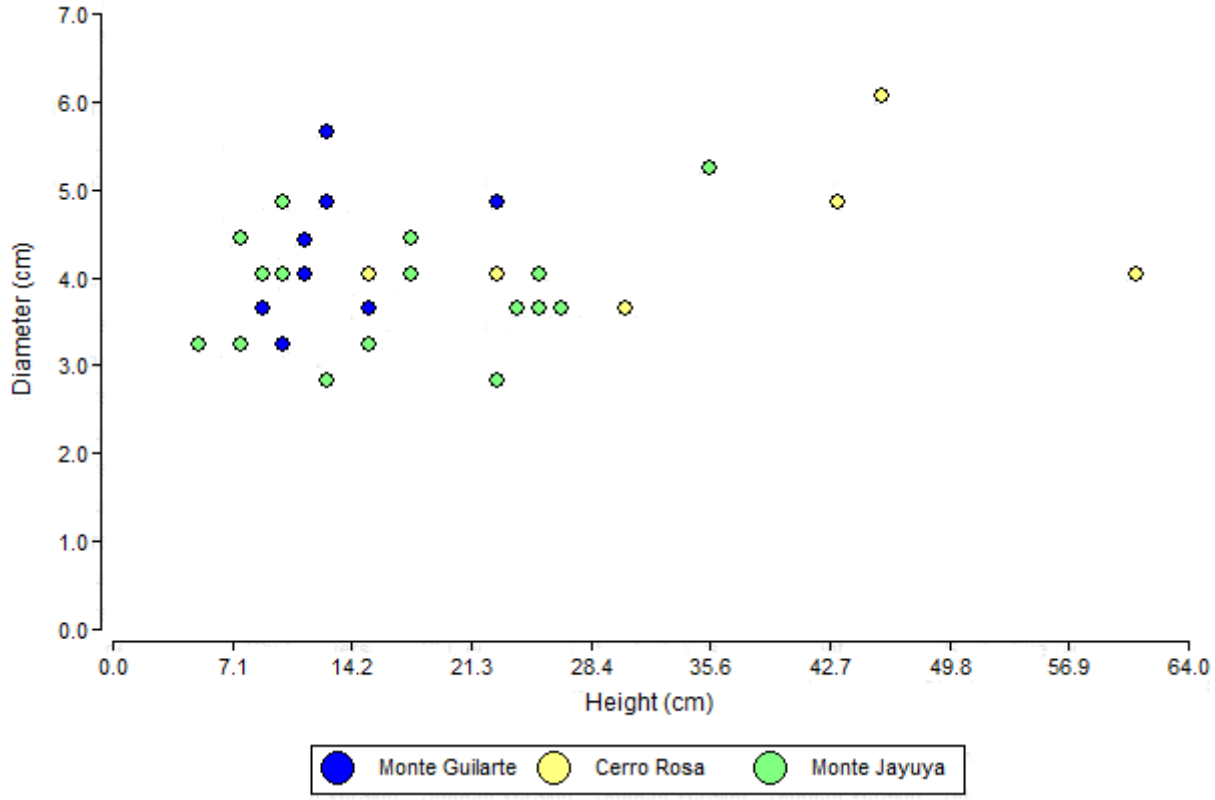

Figure 18. Relationship between *Alsophila amintae* height and diameter in all three studied populations.

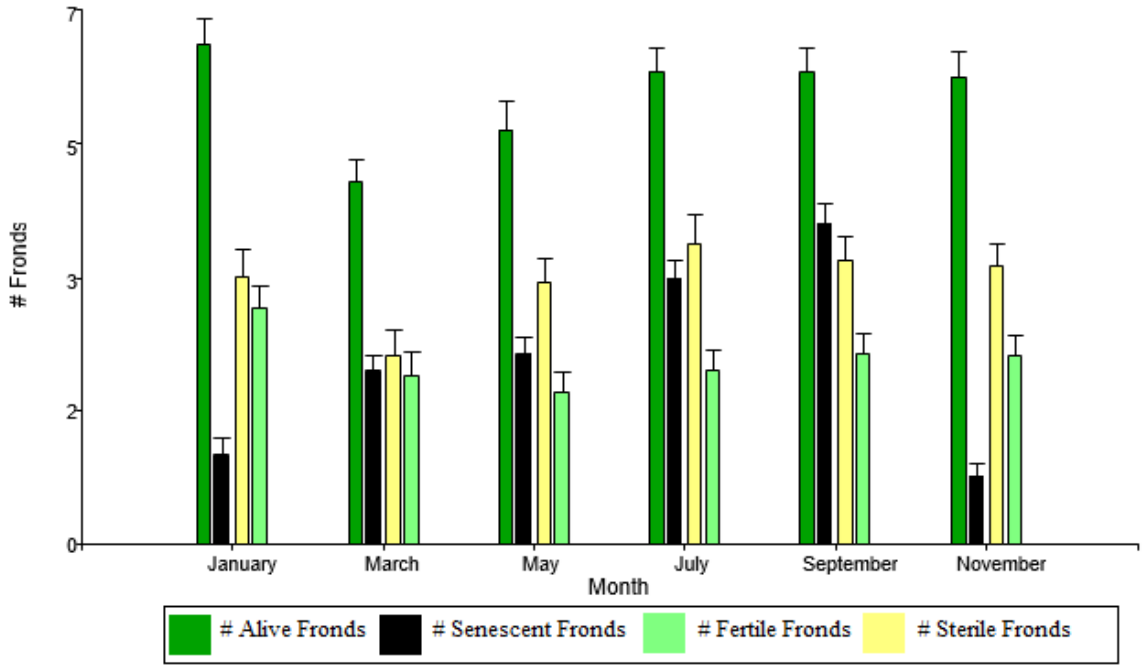

Figure 19. Mean number of alive, senescent, fertile and sterile fronds produced by all three populations of *Alsophila amintae* during 2014. Error bars denote standard deviation.

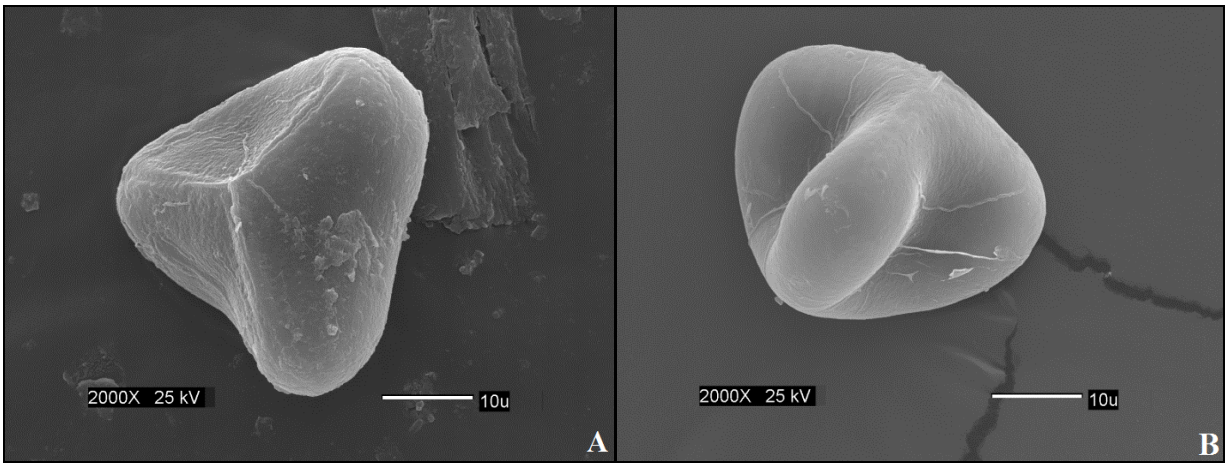

Figure 20. *Alsophila amintae* mature spores, as observed under the Scanning Electron Microscope.

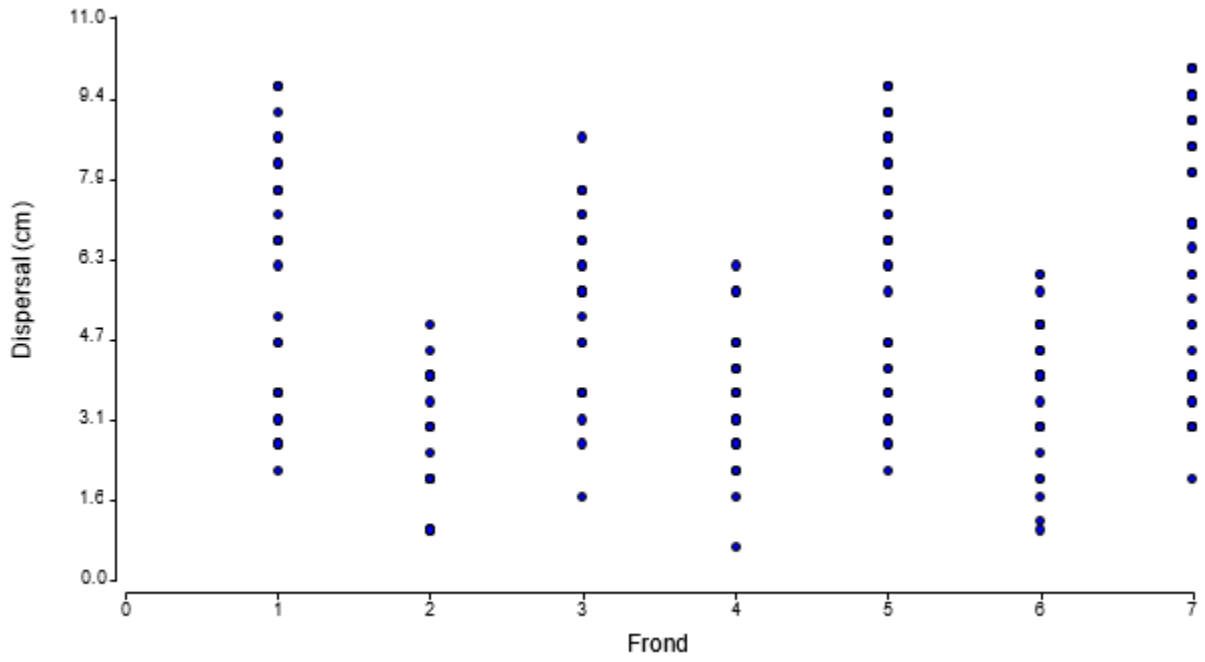

Figure 21. Spore dispersal (distance from rachis) in an experiment where seven fronds of *Alsophila amintae* were utilized to observe spore dispersal over a white sheet of paper.

Figure 22. An *Alsophila amintae* × *bryophila* hybrid. It shows a pubescent costa generally found in one parent (*A.bryophila*) and a frond morphology more similar to the other parent (*A. amintae*).

Figure 23. An *Alsophila amintae* × *portoricensis* hybrid. It shows slightly curved spines on its trunk and a frond morphology similar to its parental plant, *A. portoricensis*.

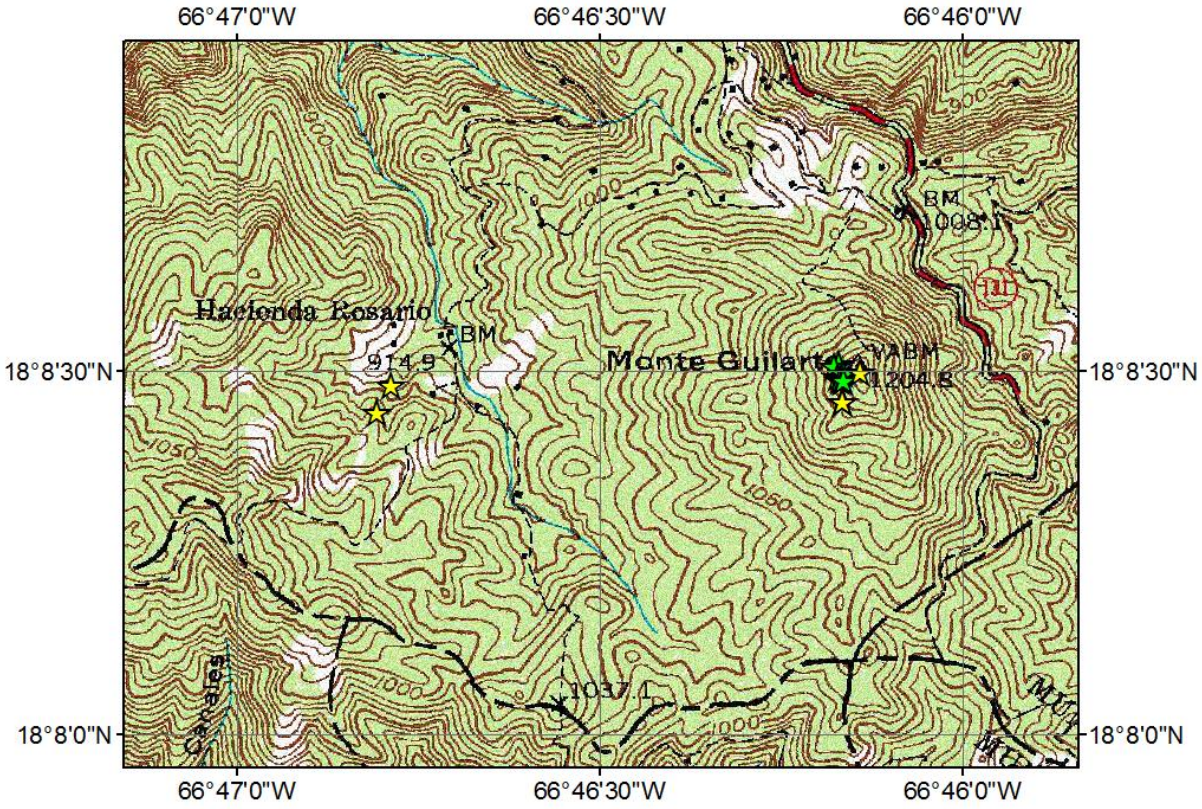

Figure 24. Map of location of *Alsophila amintae* herbarium specimens and individuals found in Bo. Guilarte, Adjuntas, Puerto Rico during 2014. Yellow stars represent herbarium specimens and green stars represent individuals collected on this study.

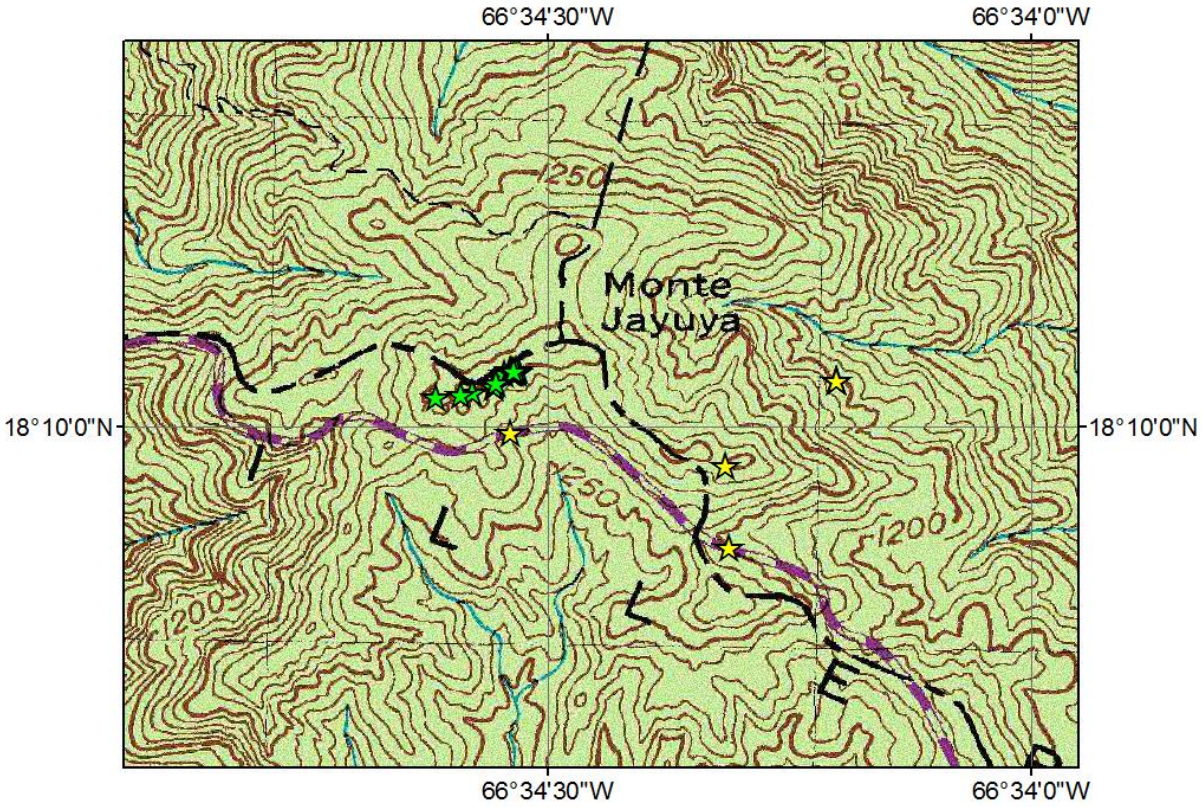

Figure 25. Map of location of *Alsophila amintae* herbarium specimens and individuals found in Ponce and Jayuya municipalities (Bo. Anón y Saliente), Puerto Rico during 2014. Yellow stars represent herbarium specimens and green stars represent individuals collected on this study.

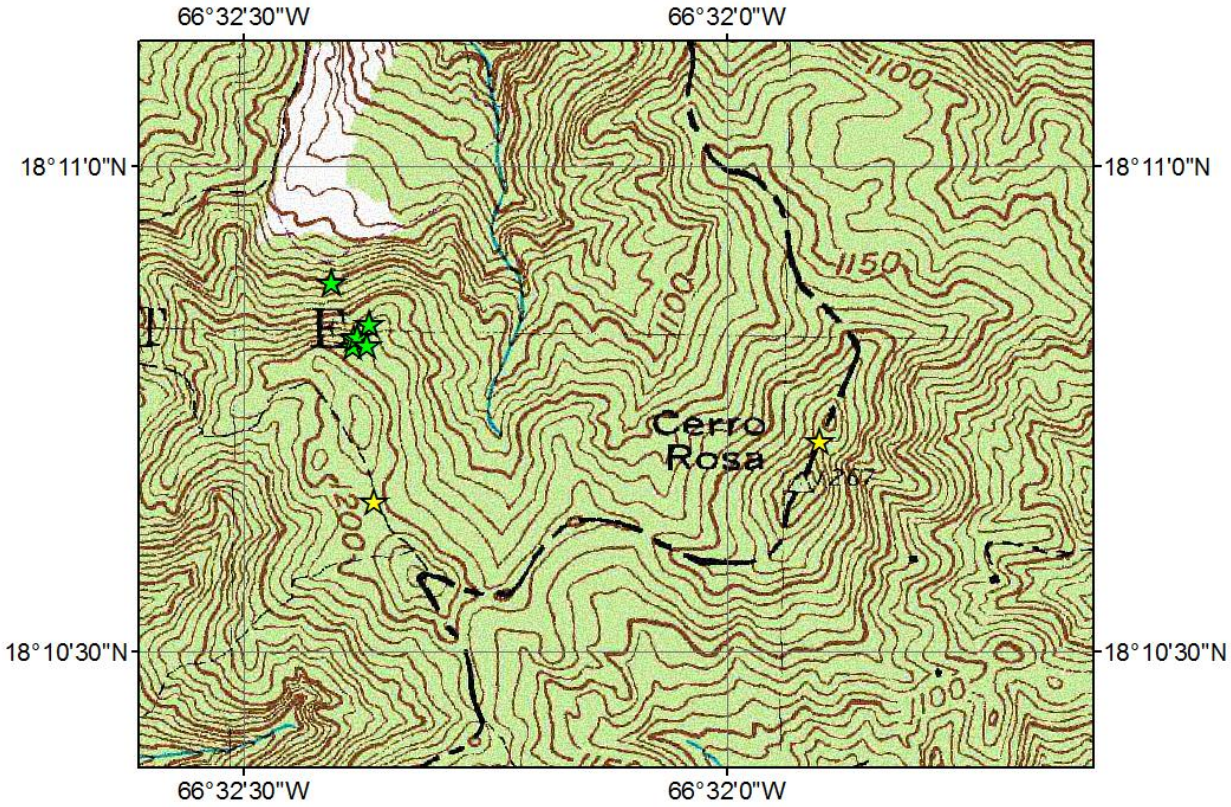

Figure 26. Map of location of *Alsophila amintae* herbarium specimens and individuals found in Jayuya and Ciales municipalities, Puerto Rico during 2014. Yellow stars represent herbarium specimens and green stars represent individuals collected on this study.

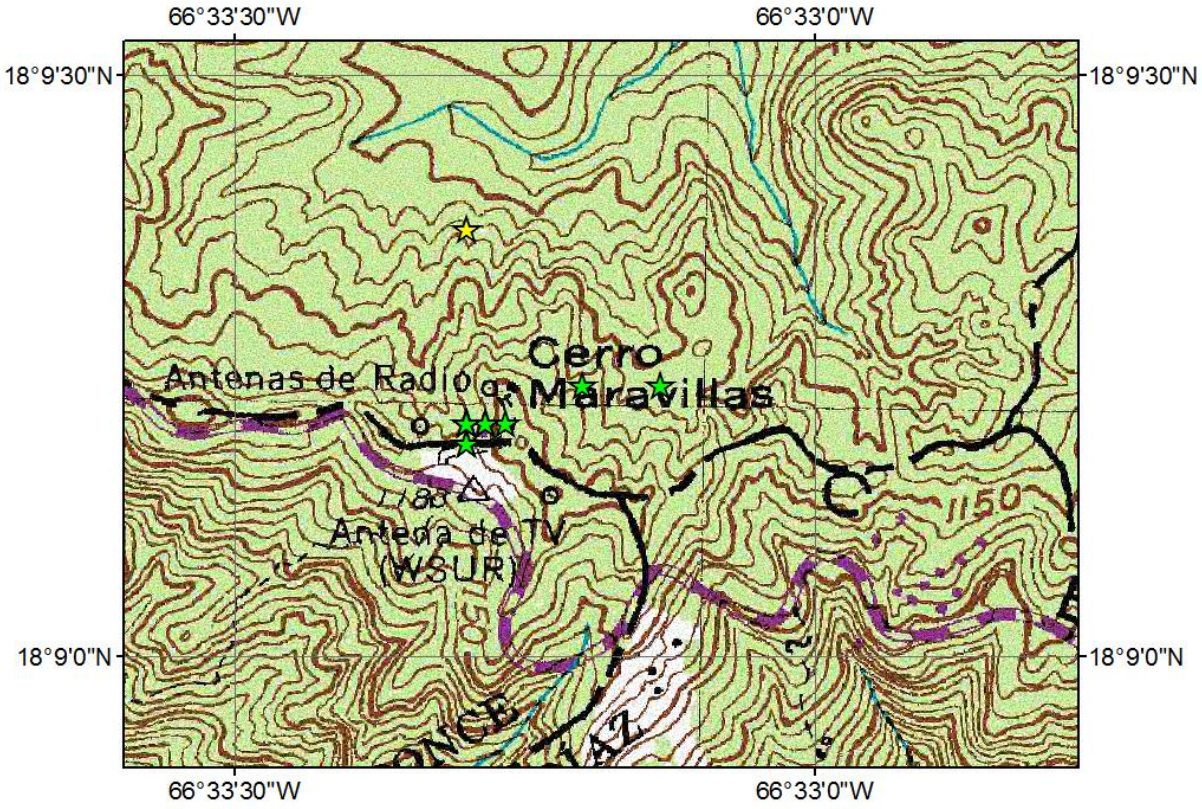

Figure 27. Map of location of *Alsophila amintae* herbarium specimens and individuals found in Jayuya and Ciales municipalities, Puerto Rico during 2014. Yellow stars represent herbarium specimens and green stars represent individuals collected on this study.

Figure 28. Two individuals of *Alsophila amintae* individuals in Monte Jayuya population, Municipality of Bo. Anón, Ponce, Puerto Rico.

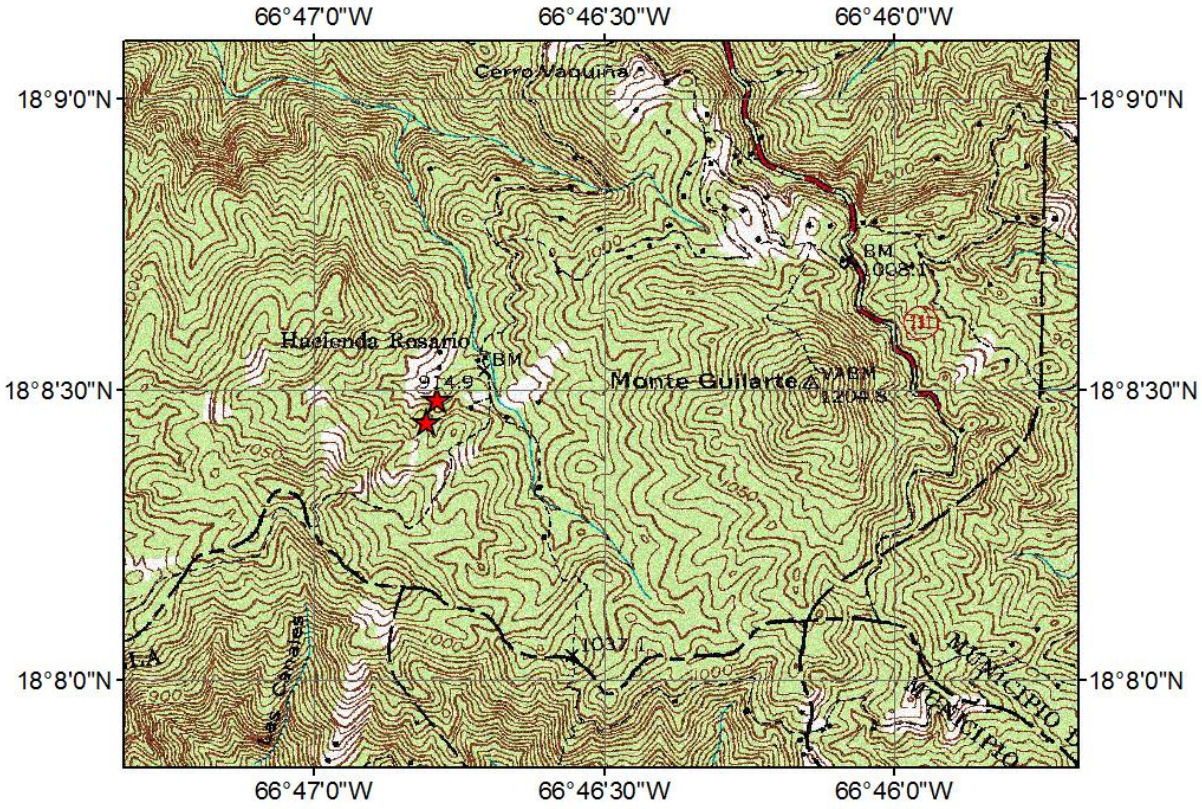

Figure 29. Map of location of *Alsophila amintae* hybrid herbarium specimens that were found near Hacienda Rosario, Bo. Guilarte, Adjuntas, Puerto Rico.

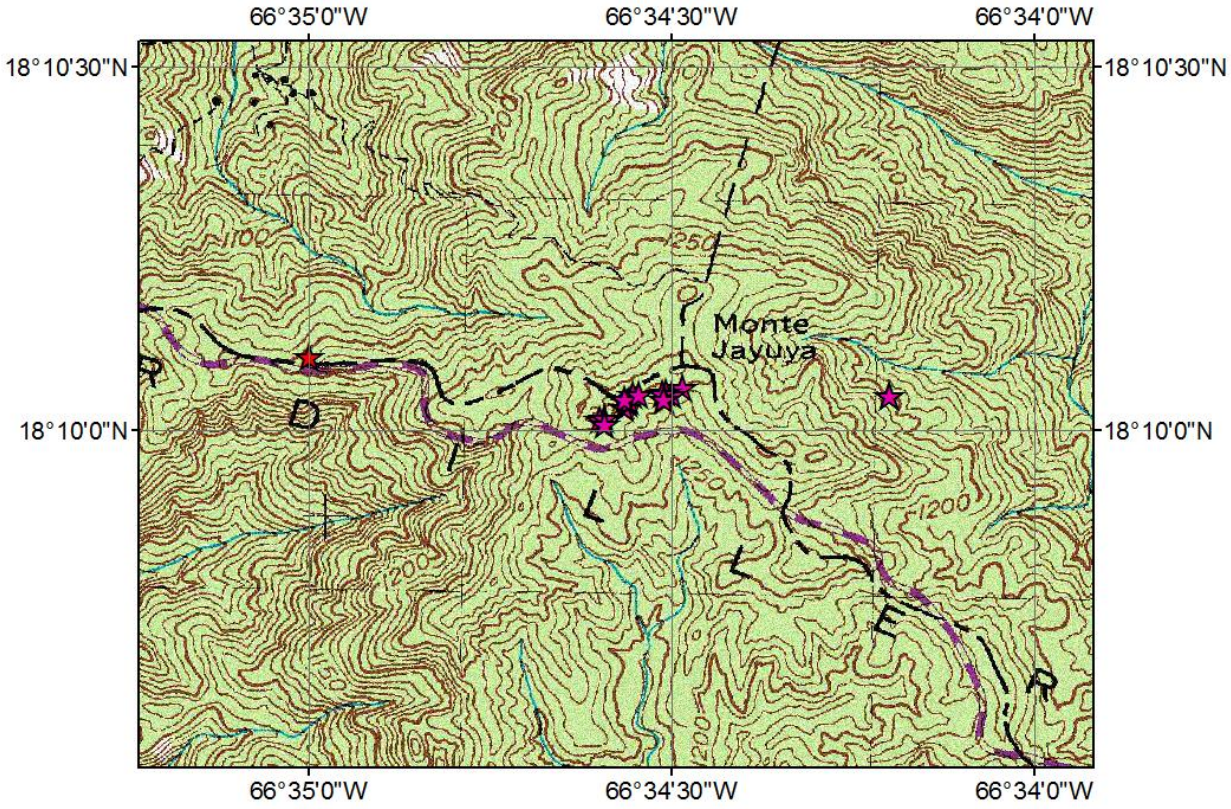

Figure 30. Map of location of *Alsophila amintae* hybrid herbarium specimens and hybrids that were found in Bo. Saliente y Anón, between Ponce and Jayuya municipalities, Puerto Rico. Red stars represent herbarium collection hybrids and pink stars represent hybrids that were found during 2014.

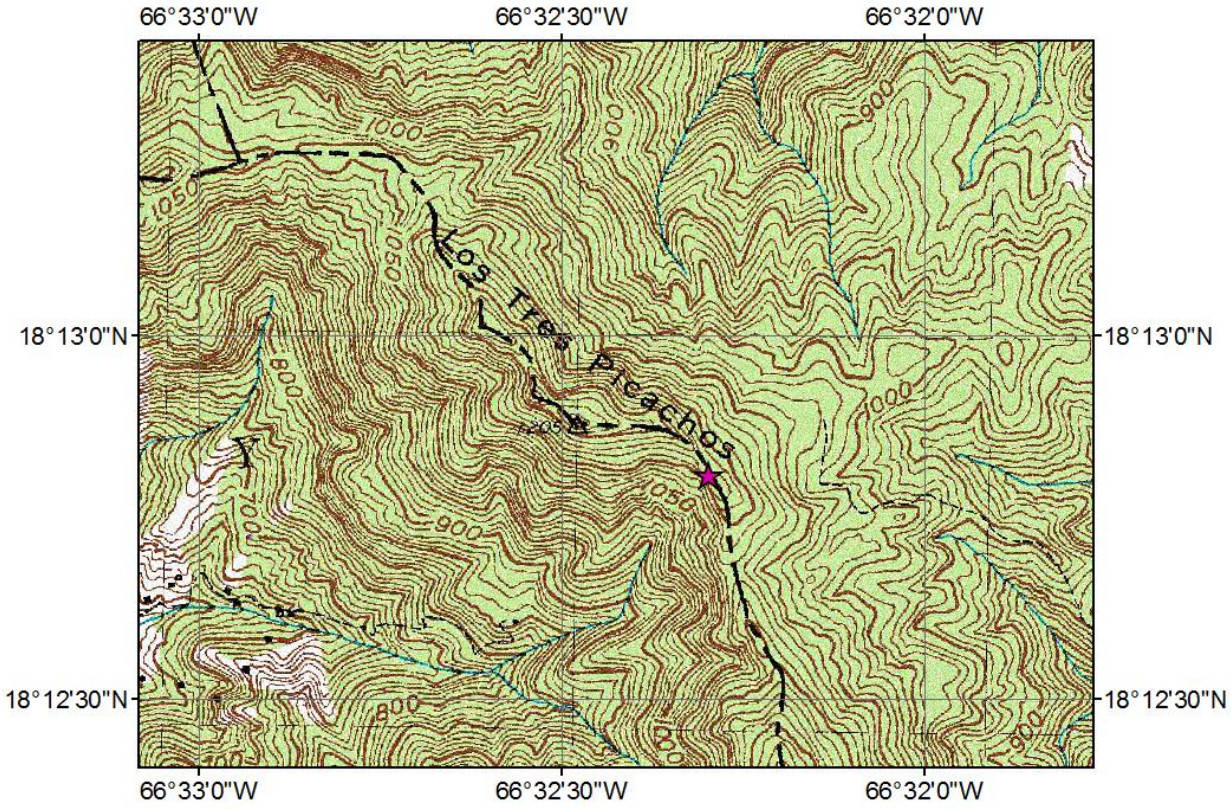

Figure 31. Map of location of a *Alsophila amintae* herbarium specimen that was found in Ala de la Piedra, between Jayuya and Orocovis municipalities, Puerto Rico.

APPENDIXES

Appendix 1. Collected data for humidity percentage and pH for all the populations of *Alsophila amintae* during 2014.

Locality	Individual #	Month	Humidity %	pH
Monte Guilarte	MG-1	January	60	7.0
	MG-2	January	70	6.9
	MG-3	January	73	6.5
	MG-4	January	81	6.2
	MG-5	January	50	6.9
	MG-6	January	53	7.0
	MG-7	January	40	6.9
	MG-8	January	77	6.5
	MG-9	January	70	6.2
	MG-1	March	60	6.0
	MG-2	March	53	6.5
	MG-3	March	70	6.5
	MG-4	March	50	6.5
	MG-5	March	50	6.5
	MG-6	March	50	6.8
	MG-7	March	50	6.5
	MG-8	March	60	6.5
	MG-9	March	50	6.8
	MG-1	May	40	6.9
	MG-2	May	40	7.0
	MG-3	May	40	6.0
	MG-4	May	55	6.5
	MG-5	May	40	6.9

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Guilarte (Continued)	MG-6	May	66	6.7
	MG-7	May	60	6.5
	MG-8	May	65	6.5
	MG-9	May	50	6.8
	MG-1	July	60	6.8
	MG-2	July	60	6.8
	MG-3	July	30	6.2
	MG-4	July	45	6.7
	MG-5	July	60	6.2
	MG-6	July	30	6.5
	MG-7	July	60	6.0
	MG-8	July	60	6.3
	MG-9	July	30	6.0
	MG-1	September	70	6.3
	MG-2	September	80	6.5
	MG-3	September	90	6.6
	MG-4	September	90	6.0
	MG-5	September	68	6.4
	MG-6	September	85	6.6
	MG-7	September	81	6.4
	MG-8	September	80	6.3
	MG-9	September	80	6.4
	MG-1	November	72	6.6

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Guilarte (Continued)	MG-3	November	90	6.5
	MG-2	November	80	6.4
	MG-4	November	55	6.5
	MG-5	November	54	6.6
	MG-6	November	85	6.7
	MG-7	November	60	6.0
	MG-8	November	80	6.9
	MG-9	November	71	7.0
Monte Jayuya	MJ-1	January	75	6.4
	MJ-2	January	75	6.3
	MJ-3	January	80	6.5
	MJ-4	January	85	6.0
	MJ-5	January	70	6.0
	MJ-6	January	60	6.0
	MJ-7	January	50	6.3
	MJ-8	January	80	6.5
	MJ-9	January	80	6.5
	MJ-10	January	50	6.7
	MJ-11	January	60	6.0
	MJ-12	January	70	6.1
	MJ-13	January	80	6.5
	MJ-14	January	70	6.5

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-15	January	80	6.7
	MJ-16	January	90	6.7
	MJ-17	January	95	6.8
	MJ-18	January	60	6.9
	MJ-19	January	60	6.0
	MJ-20	January	70	6.0
	MJ-21	January	75	6.3
	MJ-22	January	90	6.4
	MJ-23	January	90	6.4
	MJ-1	March	52	6.8
	MJ-2	March	40	7.0
	MJ-3	March	70	6.5
	MJ-4	March	30	7.0
	MJ-5	March	63	6.9
	MJ-6	March	50	6.5
	MJ-7	March	95	6.0
	MJ-8	March	50	6.8
	MJ-9	March	60	6.5
	MJ-10	March	100	6.5
	MJ-11	March	95	6.4
	MJ-12	March	80	6.4
	MJ-13	March	70	6.3

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-14	March	70	6.5
	MJ-15	March	67	6.2
	MJ-16	March	72	6.0
	MJ-17	March	60	6.5
	MJ-18	March	70	6.3
	MJ-19	March	50	6.5
	MJ-20	March	80	6.5
	MJ-21	March	80	5.9
	MJ-22	March	95	5.0
	MJ-23	March	80	6.0
	MJ-1	May	50	5.8
	MJ-2	May	60	6.3
	MJ-3	May	50	6.3
	MJ-4	May	60	6.5
	MJ-5	May	45	6.0
	MJ-6	May	45	6.0
	MJ-7	May	50	6.0
	MJ-8	May	50	5.6
	MJ-9	May	75	5.8
	MJ-10	May	85	5.8
	MJ-11	May	89	6.0
	MJ-12	May	50	6.5

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-13	May	40	6.9
	MJ-14	May	50	6.8
	MJ-15	May	65	6.5
	MJ-16	May	57	6.2
	MJ-17	May	60	6.3
	MJ-18	May	50	6.2
	MJ-19	May	55	6.0
	MJ-20	May	55	6.5
	MJ-21	May	60	6.3
	MJ-22	May	55	6.1
	MJ-23	May	60	6.0
	MJ-1	July	60	6.8
	MJ-2	July	50	6.9
	MJ-3	July	30	6.5
	MJ-4	July	80	6.5
	MJ-5	July	40	6.8
	MJ-6	July	100	6.0
	MJ-7	July	75	6.7
	MJ-8	July	70	6.7
	MJ-9	July	60	6.5
	MJ-10	July	50	6.8
	MJ-11	July	50	6.5

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-12	July	60	6.5
	MJ-13	July	80	6.0
	MJ-14	July	62	6.2
	MJ-15	July	50	6.5
	MJ-16	July	65	6.5
	MJ-17	July	60	6.5
	MJ-18	July	75	6.5
	MJ-19	July	70	6.7
	MJ-20	July	80	6.0
	MJ-21	July	80	6.0
	MJ-22	July	70	6.7
	MJ-23	July	50	6.5
	MJ-1	September	81	6.3
	MJ-2	September	90	6.5
	MJ-3	September	70	6.0
	MJ-4	September	80	6.0
	MJ-5	September	85	6.5
	MJ-6	September	80	6.7
	MJ-7	September	80	6.0
	MJ-8	September	83	6.0
	MJ-9	September	83	6.3
	MJ-10	September	75	6.5

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-11	September	75	6.9
	MJ-12	September	75	6.8
	MJ-13	September	90	6.7
	MJ-14	September	81	6.0
	MJ-15	September	82	6.0
	MJ-16	September	82	6.3
	MJ-17	September	87	6.4
	MJ-18	September	85	6.4
	MJ-19	September	84	6.2
	MJ-20	September	75	6.0
	MJ-21	September	75	6.3
	MJ-22	September	90	6.5
	MJ-23	September	85	6.4
	MJ-1	November	60	6.5
	MJ-2	November	75	6.6
	MJ-3	November	70	6.9
	MJ-4	November	75	6.5
	MJ-5	November	65	6.0
	MJ-6	November	60	6.5
	MJ-7	November	75	6.5
	MJ-8	November	80	6.7
	MJ-9	November	80	6.8

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Monte Jayuya (Continued)	MJ-10	November	95	6.0
	MJ-11	November	90	6.6
	MJ-12	November	85	6.7
	MJ-13	November	75	6.7
	MJ-14	November	70	6.9
	MJ-15	November	70	6.8
	MJ-16	November	85	7.0
	MJ-17	November	85	6.9
	MJ-18	November	80	7.0
	MJ-19	November	70	6.6
	MJ-20	November	65	6.5
	MJ-21	November	69	6.4
	MJ-22	November	75	6.5
	MJ-23	November	70	6.6
Cerro Rosa	CR-1	January	70	6.9
	CR-2	January	90	6.5
	CR-3	January	80	6.6
	CR-4	January	70	6.5
	CR-5	January	80	6.7
	CR-6	January	90	7.0
	CR-7	January	80	6.4
	CR-8	January	80	6.7

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Cerro Rosa (Continued)	CR-1	March	70	6.9
	CR-2	March	70	7.0
	CR-3	March	75	7.0
	CR-4	March	95	6.9
	CR-5	March	70	6.8
	CR-6	March	80	6.8
	CR-7	March	65	6.8
	CR-8	March	65	6.8
	CR-1	May	80	6.8
	CR-2	May	48	7.0
	CR-3	May	60	7.0
	CR-4	May	81	6.9
	CR-5	May	70	6.8
	CR-6	May	80	6.9
	CR-7	May	90	7.0
	CR-8	May	80	6.5
	CR-1	July	80	6.9
	CR-2	July	55	6.9
	CR-3	July	40	6.7
	CR-4	July	70	6.6
	CR-5	July	70	7.0
	CR-6	July	80	6.9

Appendix 1. Continued.

Locality	Individual #	Month	Humidity %	pH
Cerro Rosa (Continued)	CR-7	July	59	6.9
	CR-8	July	73	7.0
	CR-1	September	76	7.0
	CR-2	September	70	7.0
	CR-3	September	78	6.9
	CR-4	September	80	6.7
	CR-5	September	70	6.7
	CR-6	September	100	7.0
	CR-7	September	100	6.9
	CR-8	September	100	7.0
	CR-1	November	80	6.9
	CR-2	November	70	6.8
	CR-3	November	73	7.0
	CR-4	November	80	6.9
	CR-5	November	70	6.8
	CR-6	November	65	6.7
	CR-7	November	65	6.5
	CR-8	November	70	6.8

Appendix 2. Collected data for percentage of canopy openness for all the populations of *Alsophila amintae* during 2014.

Locality	Individual #	Month	% Canopy Openness
Monte Guilarte	MG-1	January	11.1
	MG-2	January	4.5
	MG-3	January	23.1
	MG-4	January	10.3
	MG-5	January	15.0
	MG-6	January	5.5
	MG-7	January	11.7
	MG-8	January	10.3
	MG-9	January	20.3
	MG-1	March	10.1
	MG-2	March	8.5
	MG-3	March	17.3
	MG-4	March	9.0
	MG-5	March	10.1
	MG-6	March	15.5
	MG-7	March	13.2
	MG-8	March	15.1
	MG-9	March	13.0
	MG-1	May	15.8
	MG-2	May	10.3
	MG-3	May	25.8
	MG-4	May	17.8
	MG-5	May	13.0
	MG-6	May	12.0
	MG-7	May	11.7
	MG-8	May	20.3
	MG-9	May	11.7
	MG-1	July	16.3
	MG-2	July	11.7
	MG-3	July	22.0
	MG-4	July	20.1
	MG-5	July	12.5
	MG-6	July	12.0
	MG-7	July	13.0
	MG-8	July	21.0
	MG-9	July	11.7
	MG-1	September	11.1
	MG-2	September	5.5
	MG-3	September	19.8
	MG-4	September	18.0

Appendix 2. Continued.

Locality	Individual #	Month	% Canopy Openness
Monte Guilarte (Continued)	MG-5	September	15.7
	MG-6	September	19.6
	MG-7	September	19.9
	MG-8	September	17.8
	MG-9	September	16.7
	MG-1	November	14.4
	MG-2	November	10.3
	MG-3	November	22.7
	MG-4	November	20.3
	MG-5	November	11.6
	MG-6	November	12.0
	MG-7	November	11.0
	MG-8	November	15.0
	MG-9	November	11.0
Monte Jayuya	MJ-1	January	14.0
	MJ-2	January	9.5
	MJ-3	January	30.1
	MJ-4	January	18.3
	MJ-5	January	18.0
	MJ-6	January	13.9
	MJ-7	January	9.5
	MJ-8	January	19.5
	MJ-9	January	9.5
	MJ-10	January	9.9
	MJ-11	January	9.5
	MJ-12	January	12.6
	MJ-13	January	14.0
	MJ-14	January	9.6
	MJ-15	January	11.4
	MJ-16	January	25.1
	MJ-17	January	16.0
	MJ-18	January	14.1
	MJ-19	January	13.0
	MJ-20	January	10.0
	MJ-21	January	10.2
	MJ-22	January	13.0
	MJ-23	January	11.0
	MJ-1	March	11.6
	MJ-2	March	8.7
	MJ-3	March	22.5
	MJ-4	March	12.0

Appendix 2. Continued.

Locality	Individual #	Month	% Canopy Openness
Monte Jayuya (Continued)	MJ-5	March	20.0
	MJ-6	March	9.0
	MJ-7	March	16.5
	MJ-8	March	11.4
	MJ-9	March	11.5
	MJ-10	March	8.9
	MJ-11	March	8.7
	MJ-12	March	10.5
	MJ-13	March	9.0
	MJ-14	March	10.1
	MJ-15	March	9.0
	MJ-16	March	9.0
	MJ-17	March	8.9
	MJ-18	March	14.3
	MJ-19	March	13.0
	MJ-20	March	11.0
	MJ-21	March	8.8
	MJ-22	March	10.5
	MJ-23	March	11.0
	MJ-1	May	13.6
	MJ-2	May	9.6
	MJ-3	May	17.9
	MJ-4	May	12.0
	MJ-5	May	10.0
	MJ-6	May	14.0
	MJ-7	May	14.0
	MJ-8	May	12.0
	MJ-9	May	17.0
	MJ-10	May	17.9
	MJ-11	May	16.5
	MJ-12	May	10.2
	MJ-13	May	11.9
	MJ-14	May	12.6
	MJ-15	May	12.6
	MJ-16	May	11.3
	MJ-17	May	13.6
	MJ-18	May	13.6
	MJ-19	May	11.7
	MJ-20	May	15.6
	MJ-21	May	13.9
	MJ-22	May	17.0
	MJ-23	May	13.6

Appendix 2. Continued.

Locality	Individual #	Month	% Canopy Openness
Monte Jayuya (Continued)	MJ-1	July	16.9
	MJ-2	July	12.3
	MJ-3	July	20.5
	MJ-4	July	19.0
	MJ-5	July	13.0
	MJ-6	July	15.5
	MJ-7	July	15.0
	MJ-8	July	17.0
	MJ-9	July	16.9
	MJ-10	July	18.2
	MJ-11	July	18.7
	MJ-12	July	18.0
	MJ-13	July	14.0
	MJ-14	July	17.5
	MJ-15	July	19.0
	MJ-16	July	16.7
	MJ-17	July	14.3
	MJ-18	July	16.9
	MJ-19	July	16.7
	MJ-20	July	20.2
	MJ-21	July	16.5
	MJ-22	July	17.0
	MJ-23	July	18.1
	MJ-1	September	15.1
	MJ-2	September	7.0
	MJ-3	September	24.2
	MJ-4	September	20.0
	MJ-5	September	17.0
	MJ-6	September	10.0
	MJ-7	September	10.1
	MJ-8	September	10.2
	MJ-9	September	19.3
	MJ-10	September	15.8
	MJ-11	September	15.5
	MJ-12	September	15.5
	MJ-13	September	16.0
	MJ-14	September	17.6
	MJ-15	September	19.6
	MJ-16	September	15.1
	MJ-17	September	7.9

Appendix 2. Continued.

Locality	Individual #	Month	% Canopy Openness
Monte Jayuya (Continued)	MJ-18	September	16.0
	MJ-19	September	16.0
	MJ-20	September	13.4
	MJ-21	September	15.7
	MJ-22	September	14.6
	MJ-23	September	16.5
	MJ-1	November	16.6
	MJ-2	November	13.0
	MJ-3	November	26.6
	MJ-4	November	18.7
	MJ-5	November	22.2
	MJ-6	November	18.2
	MJ-7	November	15.0
	MJ-8	November	15.0
	MJ-9	November	14.6
	MJ-10	November	19.0
	MJ-11	November	16.1
	MJ-12	November	14.0
	MJ-13	November	14.0
	MJ-14	November	15.0
	MJ-15	November	25.0
	MJ-16	November	13.0
	MJ-17	November	13.0
	MJ-18	November	13.2
	MJ-19	November	14.0
	MJ-20	November	21.6
	MJ-21	November	17.0
	MJ-22	November	13.5
	MJ-23	November	14.5
Cerro Rosa	CR-1	January	10.3
	CR-2	January	8.9
	CR-3	January	13.7
	CR-4	January	9.0
	CR-5	January	10.0
	CR-6	January	9.6
	CR-7	January	10.5
	CR-8	January	10.3
	CR-1	March	11.9
	CR-2	March	4.9
	CR-3	March	16.2
	CR-4	March	16.0
	CR-5	March	10.2

Appendix 2. Continued.

Locality	Individual #	Month	% Canopy Openness
Cerro Rosa (Continued)	CR-6	March	12.3
	CR-7	March	12.5
	CR-8	March	11.4
	CR-1	May	13.7
	CR-2	May	7.8
	CR-3	May	18.1
	CR-4	May	17.6
	CR-5	May	10.2
	CR-6	May	11.0
	CR-7	May	13.6
	CR-8	May	17.5
	CR-1	July	22.3
	CR-2	July	16.9
	CR-3	July	19.7
	CR-4	July	15.7
	CR-5	July	16.6
	CR-6	July	21.1
	CR-7	July	16.0
	CR-8	July	17.0
	CR-1	September	12.6
	CR-2	September	5.6
	CR-3	September	21.8
	CR-4	September	20.0
	CR-5	September	13.0
	CR-6	September	5.6
	CR-7	September	9.9
	CR-8	September	12.4
	CR-1	November	17.6
	CR-2	November	15.0
	CR-3	November	20.9
	CR-4	November	16.9
	CR-5	November	17.5
	CR-6	November	17.4
	CR-7	November	17.2
	CR-8	November	18.1

Appendix 3. Frond production, survival and mortality of *Alsophila amintae* for all populations in 2014. Frond length and width of each individual were averaged.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
MG-1	Adult	January	6	0	3	3	66.0	10.2
MG-2	Adult	January	10	1	7	3	76.2	21.2
MG-2	Adult	January	5	0	2	3	59.3	19.0
MG-4	Adult	January	7	1	6	2	88.0	19.5
MG-5	Adult	January	6	0	6	0	76.2	13.5
MG-6	Adult	January	5	0	2	3	94.0	22.4
MG-7	Adult	January	5	0	3	2	64.4	16.9
MG-8	Adult	January	6	0	6	0	85.5	24.5
MG-9	Adult	January	3	3	3	0	82.1	24.5
MG-1	Adult	March	4	2	3	1	67.7	21.2
MG-2	Adult	March	7	4	4	3	90.6	25.0
MG-3	Adult	March	5	0	2	3	55.9	19.5
MG-4	Adult	March	3	3	0	3	83.8	27.1
MG-5	Adult	March	5	3	5	0	61.0	21.2
MG-6	Adult	March	3	4	0	3	94.8	22.4
MG-7	Adult	March	3	2	0	3	83.0	22.9
MG-8	Adult	March	4	2	3	1	72.8	25.4
MG-9	Adult	March	3	2	2	1	72.0	22.9
MG-1	Adult	May	3	4	2	1	67.7	20.3
MG-2	Adult	May	8	0	5	3	57.6	19.5
MG-3	Adult	May	5	4	5	0	90.6	28.0
MG-4	Adult	May	5	5	5	0	72.0	21.2
MG-5	Adult	May	7	4	4	3	85.5	24.1
MG-6	Adult	May	3	1	2	1	67.7	20.3
MG-7	Adult	May	3	3	3	0	87.2	21.2
MG-8	Adult	May	4	1	3	1	92.3	24.5
MG-9	Adult	May	3	0	0	3	61.0	18.6
MG-1	Adult	July	4	5	3	1	62.2	18.6
MG-2	Adult	July	6	6	4	2	62.6	21.2
MG-3	Adult	July	5	5	3	2	56.3	19.5
MG-4	Adult	July	4	4	4	0	65.2	21.2
MG-5	Adult	July	8	5	7	1	92.3	25.8
MG-6	Adult	July	5	2	2	3	58.4	18.6
MG-7	Adult	July	5	3	4	1	76.2	20.3
MG-8	Adult	July	6	3	4	2	59.3	18.2
MG-9	Adult	July	4	4	4	0	82.1	23.7
MG-1	Adult	September	5	4	3	2	61.4	16.0
MG-2	Adult	September	8	5	5	3	61.5	16.0

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
MG-3	Adult	September	5	6	3	2	55.0	19.7
MG-4	Adult	September	5	4	3	2	65.0	20.1
MG-5	Adult	September	7	5	3	5	91.9	17.0
MG-6	Adult	September	6	4	5	1	57.7	16.1
MG-7	Adult	September	4	6	4	0	75.9	17.8
MG-8	Adult	September	6	3	3	3	58.1	18.2
MG-9	Adult	September	3	5	1	2	81.3	16.0
MG-1	Adult	November	6	1	3	3	63.4	17.6
MG-2	Adult	November	7	1	6	1	63.6	16.0
MG-3	Adult	November	6	0	4	2	57.4	20.0
MG-4	Adult	November	6	1	3	3	68.0	23.6
MG-5	Adult	November	7	1	2	5	93.0	18.0
MG-6	Adult	November	5	0	3	2	59.3	17.2
MG-7	Adult	November	3	0	3	0	77.6	20.7
MG-8	Adult	November	6	0	5	1	58.1	21.3
MG-9	Adult	November	4	0	0	4	83.0	19.8
MJ-1	Adult	January	9	4	4	5	68.6	26.7
MJ-2	Adult	January	8	4	6	2	75.3	22.9
MJ-3	Adult	January	4	1	4	0	59.3	24.5
MJ-4	Juvenile	January	4	2	0	5	34.7	16.9
MJ-5	Adult	January	3	1	0	3	51.6	17.8
MJ-6	Adult	January	8	0	6	2	63.5	18.2
MJ-7	Adult	January	9	0	6	3	62.2	20.7
MJ-8	Juvenile	January	4	0	0	4	31.2	21.2
MJ-9	Adult	January	8	0	5	3	61.0	20.3
MJ-10	Adult	January	7	0	3	4	60.1	26.7
MJ-11	Juvenile	January	6	0	0	6	28.8	21.8
MJ-12	Adult	January	7	2	3	4	54.2	11.8
MJ-13	Adult	January	4	0	1	3	42.3	22.9
MJ-14	Adult	January	8	0	3	5	23.7	17.8
MJ-15	Adult	January	6	0	3	3	52.5	14.8
MJ-16	Juvenile	January	4	0	0	4	38.1	20.3
MJ-17	Adult	January	8	2	4	4	72.8	14.8
MJ-18	Adult	January	6	1	5	1	75.3	17.8
MJ-19	Adult	January	6	1	4	2	62.6	28.0
MJ-20	Adult	January	5	1	1	4	76.2	27.9
MJ-21	Adult	January	6	0	4	2	66.9	21.6
MJ-22	Adult	January	8	1	4	4	73.7	16.5
MJ-23	Adult	January	8	0	3	5	77.0	22.0
MJ-1	Adult	March	8	4	6	2	59.3	24.5

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
MJ-2	Adult	March	7	2	3	2	66.0	23.7
MJ-3	Adult	March	4	1	4	0	72.8	20.3
MJ-4	Juvenile	March	4	0	0	4	48.7	12.3
MJ-5	Adult	March	3	1	3	0	32.4	17.3
MJ-6	Adult	March	7	0	0	7	51.2	20.3
MJ-7	Adult	March	7	0	7	0	68.6	21.2
MJ-8	Juvenile	March	2	1	0	2	35.5	16.1
MJ-9	Adult	March	5	2	0	5	63.9	24.5
MJ-10	Adult	March	4	3	4	0	72.8	14.4
MJ-11	Juvenile	March	4	1	0	4	30.0	11.8
MJ-12	Adult	March	4	2	4	0	28.8	22.0
MJ-13	Adult	March	3	2	3	0	62.6	16.9
MJ-14	Adult	March	5	3	5	0	40.6	15.2
MJ-15	Adult	March	2	4	1	1	26.2	18.6
MJ-16	Juvenile	March	3	1	0	3	40.1	13.5
MJ-17	Adult	March	5	1	0	5	35.6	25.4
MJ-18	Adult	March	3	2	0	3	39.8	16.9
MJ-19	Adult	March	2	3	2	0	88.0	16.9
MJ-20	Adult	March	4	3	3	1	92.0	21.2
MJ-21	Adult	March	4	3	3	1	58.4	20.5
MJ-22	Adult	March	5	2	0	5	44.0	23.7
MJ-23	Adult	March	5	3	5	0	68.6	24.5
MJ-1	Adult	May	10	2	5	5	60.7	19.5
MJ-2	Adult	May	8	1	5	3	67.7	25.0
MJ-3	Adult	May	5	1	3	2	69.6	25.7
MJ-4	Juvenile	May	4	0	0	4	47.3	18.8
MJ-5	Adult	May	3	1	3	0	49.4	19.5
MJ-6	Adult	May	9	2	7	2	64.3	20.3
MJ-7	Adult	May	9	2	6	3	61.7	17.8
MJ-8	Juvenile	May	3	2	0	3	23.9	20.7
MJ-9	Adult	May	9	4	4	5	62.5	27.1
MJ-10	Adult	May	4	3	4	0	70.3	18.6
MJ-11	Juvenile	May	5	2	0	5	31.7	12.3
MJ-12	Adult	May	6	2	4	2	75.3	22.9
MJ-13	Adult	May	3	2	3	0	33.9	19.1
MJ-14	Adult	May	6	3	4	2	26.2	13.5
MJ-15	Adult	May	3	4	2	1	46.1	13.5
MJ-16	Juvenile	May	3	1	0	3	44.1	13.7
MJ-17	Adult	May	7	2	4	3	47.2	25.0
MJ-18	Adult	May	5	3	3	2	50.7	19.7

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
MJ-19	Adult	May	4	2	2	2	77.1	17.8
MJ-20	Adult	May	3	4	3	0	90.1	20.5
MJ-21	Adult	May	3	3	3	0	59.5	18.4
MJ-22	Adult	May	5	1	3	2	53.4	23.1
MJ-23	Adult	May	5	4	5	0	62.2	22.7
MJ-1	Adult	July	5	2	4	1	61.0	23.3
MJ-2	Adult	July	8	4	4	4	72.8	21.6
MJ-3	Adult	July	7	2	7	0	59.3	27.0
MJ-4	Juvenile	July	3	2	0	3	33.0	20.9
MJ-5	Adult	July	7	2	7	0	57.1	21.9
MJ-6	Adult	July	5	3	1	4	54.6	23.6
MJ-7	Adult	July	7	4	7	0	56.7	22.2
MJ-8	Juvenile	July	5	1	0	5	33.9	14.6
MJ-9	Adult	July	4	3	1	3	29.6	21.2
MJ-10	Adult	July	6	6	1	5	53.2	15.7
MJ-11	Juvenile	July	4	2	0	4	34.3	17.8
MJ-12	Adult	July	5	1	2	3	79.7	23.2
MJ-13	Adult	July	6	4	6	0	68.2	21.2
MJ-14	Adult	July	5	5	4	1	64.3	20.3
MJ-15	Adult	July	8	6	5	3	48.4	23.4
MJ-16	Juvenile	July	3	4	0	3	37.7	23.4
MJ-17	Adult	July	9	4	7	2	71.1	19.9
MJ-18	Adult	July	8	2	4	4	64.3	22.3
MJ-19	Adult	July	5	3	3	2	62.2	26.7
MJ-20	Adult	July	7	1	5	2	83.0	24.5
MJ-21	Adult	July	10	4	6	4	82.1	25.6
MJ-22	Adult	July	8	3	6	2	63.9	22.0
MJ-23	Adult	July	6	1	5	1	76.7	24.2
MJ-1	Adult	September	7	3	4	3	43.1	20.3
MJ-2	Adult	September	7	3	3	4	61.4	23.0
MJ-3	Adult	September	8	4	5	3	62.8	20.3
MJ-4	Juvenile	September	4	3	0	4	30.3	12.2
MJ-5	Adult	September	7	4	4	3	55.1	16.8
MJ-6	Adult	September	6	6	3	3	49.1	20.7
MJ-7	Adult	September	8	2	6	2	52.6	20.0
MJ-8	Juvenile	September	3	1	0	3	31.1	15.7
MJ-9	Adult	September	5	4	5	0	30.7	20.8
MJ-10	Adult	September	6	7	2	4	52.6	15.0
MJ-11	Juvenile	September	3	2	0	3	30.1	10.
MJ-12	Adult	September	6	3	5	1	75.4	21.7

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
MJ-13	Adult	September	5	2	4	1	67.4	16.6
MJ-14	Adult	September	7	6	3	4	50.8	15.5
MJ-15	Adult	September	7	6	5	2	41.5	18.3
MJ-16	Juvenile	September	4	2	0	4	33.6	10.2
MJ-17	Adult	September	8	5	6	2	70.6	25.4
MJ-18	Adult	September	9	4	5	4	64.0	16.9
MJ-19	Adult	September	6	5	3	3	57.4	16.9
MJ-20	Adult	September	6	2	5	1	74.5	21.2
MJ-21	Adult	September	9	4	5	4	70.0	20.5
MJ-22	Adult	September	6	3	4	2	58.0	23.7
MJ-23	Adult	September	5	1	5	0	69.5	24.5
MJ-1	Adult	November	5	1	2	3	49.6	22.6
MJ-2	Adult	November	6	2	5	1	75.3	23.3
MJ-3	Adult	November	6	1	4	2	59.3	20.3
MJ-4	Juvenile	November	3	2	0	3	32.0	13.7
MJ-5	Adult	November	5	1	2	3	51.6	20.3
MJ-6	Adult	November	5	0	4	1	63.5	21.4
MJ-7	Adult	November	6	0	6	0	62.2	20.7
MJ-8	Juvenile	November	2	0	0	2	31.2	16.0
MJ-9	Adult	November	6	0	5	1	60.7	21.0
MJ-10	Adult	November	5	1	3	2	60.0	17.8
MJ-11	Juvenile	November	3	1	0	3	27.5	12.3
MJ-12	Adult	November	4	0	4	0	54.3	25.1
MJ-13	Adult	November	6	1	4	2	42.0	17.8
MJ-14	Adult	November	9	0	5	4	23.7	15.8
MJ-15	Adult	November	9	0	4	5	52.5	19.0
MJ-16	Juvenile	November	3	0	0	3	36.4	11.3
MJ-17	Adult	November	8	1	4	4	72.8	25.8
MJ-18	Adult	November	10	0	4	6	75.3	17.8
MJ-19	Adult	November	6	1	5	1	62.6	17.8
MJ-20	Adult	November	8	0	6	2	77.2	23.2
MJ-21	Adult	November	9	1	3	6	66.7	20.3
MJ-22	Adult	November	6	1	6	0	74.6	23.1
MJ-23	Adult	November	7	1	5	2	77.0	25.3
CR-1	Adult	January	3	1	0	3	45.7	23.7
CR-2	Adult	January	12	0	6	6	53.3	19.5
CR-3	Adult	January	4	4	3	1	55.9	22.9
CR-4	Adult	January	5	4	3	2	80.9	22.4
CR-5	Adult	January	7	3	6	1	47.4	19.0
CR-6	Adult	January	6	2	6	0	58.4	20.3

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
CR-7	Juvenile	January	6	3	2	4	56.3	22.0
CR-8	Adult	January	5	0	0	5	64.3	20.7
CR-1	Adult	March	2	3	5	0	53.3	19.5
CR-2	Adult	March	9	3	3	6	58.4	18.6
CR-3	Adult	March	5	4	3	2	71.1	23.7
CR-4	Adult	March	6	4	4	2	39.0	19.5
CR-5	Adult	March	6	1	2	4	58.4	19.0
CR-6	Adult	March	6	2	4	2	55.0	20.7
CR-7	Adult	March	4	1	3	1	48.3	17.8
CR-8	Adult	March	3	1	0	3	66.0	23.7
CR-1	Adult	May	7	4	3	4	66.0	23.7
CR-2	Adult	May	7	2	4	3	35.6	16.5
CR-3	Adult	May	7	3	5	2	54.6	18.6
CR-4	Adult	May	6	3	5	1	64.3	23.3
CR-5	Adult	May	3	4	2	1	40.2	16.5
CR-6	Adult	May	5	3	4	1	72.0	24.1
CR-7	Adult	May	4	0	4	0	58.4	22.9
CR-8	Adult	May	2	2	0	2	23.7	11.0
CR-1	Adult	July	6	5	4	2	56.7	25.4
CR-2	Adult	July	9	4	3	6	50.6	24.0
CR-3	Adult	July	8	3	6	2	54.8	19.0
CR-4	Adult	July	5	3	5	0	76.3	19.1
CR-5	Adult	July	3	2	2	1	48.0	23.8
CR-6	Adult	July	5	3	3	2	58.6	19.2
CR-7	Adult	July	5	2	5	0	56.0	24.9
CR-8	Adult	July	4	3	0	4	56.0	12.7
CR-1	Adult	September	3	6	3	0	52.1	23.6
CR-2	Adult	September	10	5	4	6	41.7	20.6
CR-3	Adult	September	6	5	5	1	45.7	18.3
CR-4	Adult	September	5	4	5	0	72.4	19.4
CR-5	Adult	September	3	3	3	0	41.4	21.5
CR-6	Adult	September	4	4	3	1	57.0	19.0
CR-7	Adult	September	6	3	5	1	49.5	21.7
CR-8	Adult	September	5	4	0	5	46.9	13.2
CR-1	Adult	November	5	2	4	1	52.1	25.4
CR-2	Adult	November	8	3	3	5	41.7	22.6
CR-3	Adult	November	7	2	4	3	54.3	19.0
CR-4	Adult	November	5	2	4	1	78.2	22.3
CR-5	Adult	November	4	3	2	2	44.6	16.4
CR-6	Adult	November	5	2	4	1	57.7	24.1

Appendix 3. Continued.

Individual #	Life Stage	Month	# Live Fronds	# Dead Fronds	# Fertile Fronds	# Sterile Fronds	Frond Length (cm)	Frond Width (cm)
CR-7	Adult	November	6	1	4	2	50.0	21.0
CR-8	Adult	November	3	0	2	1	50.2	14.1

Appendix 4. Propagation experiment developed by the Fairchild Tropical Botanic Garden (Florida, US) from November 2014 to February 2017. A. *Alsophila amintae* juveniles at Monte Jayuya in November, 2014. Small sporophytes shown inside the yellow circle. Senescent Sierra Palm pinnae surrounding the individuals. B. Spores were collected from the Monte Jayuya population in November, 2014 and they were propagated by Horticulturist Mike Freedman. The small sporophytes of *A. amintae* were grown *ex-situ* at Fairchild Tropical Botanic Gardens in July, 2015. C. *Alsophila amintae* sporophytes growing in November, 2015. D. Juveniles of *A. amintae* were transplanted to pots in April, 2016. E. *Alsophila amintae* juveniles in February 2017. Some frond yellowing is shown. The pot soil has fertilizer. All photos were taken by Jennifer Possley.

Appendix 4. Continued.

Appendix 4. Continued.

Appendix 4. Continued.

Appendix 4. Continued.