Puya raimondii:

A study in the National Sanctuary of Calipuy in the Andes Mountains of northern Peru

By

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INTRODUCTION

The *Puya raimondii*, dubbed “Queen of the Andes,” is a spectacular high-Andean plant in the bromeliad family with one of the largest flowering stalks of any plant in the world, up to ten meters tall (Lambe, 2009). It is the most prominent constituent of its puna habitat, a high altitude treeless Andean ecosystem, and an emblematic plant of the Andean flora (Hornung-Leoni, 2013). The plant usually occurs around 4,000 m in the Andes Mountains of Peru and Bolivia, but ranges from 3,000 m up to 4,800 m (Lambe, 2009) and solely grows in puna (Hornung-Leoni, 2013). It often occurs in very isolated and small populations. These populations frequently number a few hundred individuals to an estimated 450,000 in one Peruvian protected area: Huascaran National Park. The plant’s scattered distribution and extreme genetic uniformity suggest that the species is vestigial and may be in decline. The number of these plants in Peru may number 800,000 individuals and Bolivia is estimated to have 30,000-35,000 plants (Lambe, 2009). The plant is classified as an “endangered species” according to the IUCN Red List of Threatened Species (Lambe, 2009).

The plant is monocarpic, producing a single gigantic inflorescence at the end of its life; plants take 40 to 100 years to flower (Hornung-Leoni and Sosa, 2005). Only a few individuals within a given population will bloom in any year (Benzing, 2000). During flowering, 6-10 thousand flowers cover the flowering stalk (Valverde, 2009). The flowers provide food for many species of insects and birds (Valverde, 2009). Each plant produces 6-12 million seeds which are very small and wind-dispersed (Valverde, 2009). The leaves of the *Puya raimondii* have spines and protect many other species of birds and insects that construct their nests inside them (Valverde, 2009).

Puya raimondii populations are susceptible to threatening events because they are generally small and very isolated from each other (Lambe, 2009). This has apparently rendered populations extremely homogeneous genetically and so at greater risk to disease, parasites or climactic change (Lambe, 2009). The major risk to most *Puya raimondii* populations is human impact including repeated fires to generate or maintain pasture land and their usage as fuel or building material by local populations. There is fear that the Puyas may ‘capture’ grazing animals with their leaves' inward-curving spines. This is probably rare but not inconceivable (Lambe, 2009).

One nationally protected area located in the Andean mountains of Peru was created specifically to protect this endangered species; the Calipuy National Sanctuary (see Figure 1) was formed on the 8th of January, 1981. It is located in the Department of La Libertad, in the Province of Santiago de Chuco, in the District of Santiago de Chuco. This Sanctuary is 4,500 hectares and is located between 3,450 - 4,361 meters in altitude. A "buffer zone" is situated around the Sanctuary that includes eight small villages and many agricultural fields. This zone ideally is a space that neutralizes different kinds of negative impacts produced by human activities that could affect the Sanctuary: mining, hunting, logging, water use, land management etc. The National Park Service Agency responsible for management of the Sanctuary and its Buffer Zone is: El Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP). Threats to the Sanctuary's management of its *Puya raimondii* population include the invasion of humans into their habitat, livestock, irrigation/water management changes and the direct burning and destruction of individual plants. This species is not adapted to living with a natural fire-cycle as thunderstorms only occur during the cold rainy season at high elevations in the Andes Mountains of Peru and Bolivia (Wikipedia contributors, 2014).

The population of *Puya raimondii* in this protected area is an example of the larger situation threatening the plants throughout their entire distribution. Studying this specific population will produce results applicable to a wider geographic area.

Figure 1: Map of Nationally Protected Areas in Peru with the Calipuy National Sanctuary highlighted.

In the 1960s and even before, the land covered by the Calipuy National Sanctuary and nearby Calipuy National Reserve protected areas formed part of privately owned plantations. The 1969 Agrarian Reform launched by Peru's military government, however, confiscated the land from the plantation owners and handed it to the workers. These workers formed the Agrarian Society of Social Interest, SAIS Libertad N°18, a cooperative that replaced the plantation as the land's new owner and administrator of the area's resources. The cooperative proposed to set aside a reserve of 3,000 hectares to protect the guanaco and encourage tourism (October 1972). The cooperative established boundaries for its lands, marked out by stone walls to prevent cattle from crossing the borders. The cooperative began keeping watch over the resources of the protected area long before the National Institute of Natural Resources (INRENA) intervened. The Calipuy National Sanctuary was officially formed on the 8th of January, 1981 and the management was taken over by INRENA which eventually became SERNANP.

Economic and organizational problems had already undermined the SAIS Libertad cooperative, but its collapse was finally brought about by terrorism in the area in the late 1980s and early 1990s. As guerrilla violence spread, keeping watch over the protected area by the government was no longer possible. After several years of scant government presence in this protected area, a new director was appointed in mid-2001 to run the area, and a series of steps were taken to attempt to recover and manage the designated land (Shoobridge, 2003). During this time about 1/3 of the Sanctuary had become inhabited once again by humans with their buildings, agricultural fields and livestock, even a school; this area became the “Invasion Zone.”

At the time of this study in 2013-2014, six full-time Park Guards lived at the Sanctuary in two separate dwellings (one located on the north side and one on the south side) and conduct surveillance activities especially along well-traveled paths and in the Invasion Zone where dwellings, irrigation canals and agricultural fields are not allowed to be improved upon or grow in size. Free-range livestock grazing has not been allowed in any part of the Sanctuary since 2006.

Objectives:

1. Establish baseline data (a snapshot in time) to compare future data to and to track changes. This is the first step to a continuous monitoring plan.

2. Determine where in the Sanctuary *Puya raimondii* growth rates and reproduction are more successful and why? This can have implications for a wider geographic area/other protected areas.

3. Determine if the population is sustainable by examining: a) mortality rates, b) plant health/condition (reproductive ability), and c) flowering rates.

Establishing base-line conditions of the population of this plant located within the boundaries of the Calipuy National Sanctuary is the first step in setting up a monitoring plan. Altitude, morphology, plant condition, habitat type, and approximate height of each *Puya raimondii* were recorded. The altitude gives distribution parameters for this population. Morphology gives basic structural patterns of this population and indicates reproductive capacity. Conditions such as “living or dead, burned or not burned” give us information about the viability of reproduction for individuals in this population. Habitat information defines the plant’s habitat boundaries within the Sanctuary and infers similarities to a wider, similar geographic area. The approximate height of each plant and its flower gives us basic structural information about this population. Sufficient information was collected for SERNANP to monitor the population and track its reproductive potential over time. With continued monitoring, the Park Guards can determine if the population is growing or declining and more importantly *why*; this will guide the Park Guards’ management and protection of the plant in the future.

METHODS

Description of Study Area

Topography

The Calipuy National Sanctuary is heterogeneous: from plains to rocky outcrops to very steep slopes crossed by small creeks that collect into large basins and lowlands during the rainy season. A soil survey done on a similar site within the same biological zones in Peru (see *Flora*) at the same elevations on the west side of the Andes Mountains found soils on the steep slopes (25 -75%) (14° - 37°) to be “shallow, dark brown sandy loam” and the soils on the moderate slopes (8-25%) (4.5° - 13°) to be “deep, dark brown loam” (Kauffman, 1998). I believe these soils can correlate to the habitat types recorded with “Ichu Grass” (see *Habitat Types*). Based on the geology, in general the soils correlated to the habitat types recorded “Rocky Soil” and “Rocky Outcrops” (see *Habitat Types*) are newly forming so have low nutrients and are course-textured with low water-holding capacity. I categorize my slope classes (low, medium, and high) similarly but not identically to these numbers (see *Habitat Types)*.

The geology in the Sanctuary falls in the Calipuy Group, a formation that stretches from the Oligocene to Miocene in which four stages of volcanism occurred whose current geomorphology presents soft reliefs, abruptly interrupted by Cretaceous outcrops, as well as domical structures resistant to erosive processes (Gálvez, 2013). These reliefs, outcrops, and structures do not exceed 100m from the lowest part of the slopes. It is worth emphasizing the presence of Quaternary coverage, commonly composed of moraine deposits dragged and dropped by Pleistocene glacial processes (Gálvez, 2013).

Climate

There are no climate stations available in or around the Sanctuary so precise measurements are not known. Most precipitation occurs from December to April: 1,200 mm during these months (Shoobridge, 2003) with March being the wettest month. July and August are the driest months: 280-500 mm rainfall during these months (Shoobridge, 2003). “Apparently the amount of water is variable each year, the villagers tell us that every two to three years there is abundant rainfall and then a period of ‘drought’ or very low rainfall. The occurrence of rainfall is very localized and the northeastern part of the Sanctuary receives more rainfall than the southwestern part” (Gálvez, 2013).

The climate of the Andean mountains is strongly correlated with altitude. Key parameters of the altitudinal zones, relevant to the study area, are given in Table 1.

Table 1: Climatic characteristics of altitudinal zones in the Andes Mountains of Peru.

Classes	**Altitude (m)**	**Mean Annual Temp. (°C)**	**Rainfall (mm/yr-1)**	**Limitation**
Humid/semi-frigid	4000 – 4500	5	1000	High frost risk
Humid/cold	3500 – 4000	9	1100	Frost risk
Sub-humid/semi-cold	3000 – 3500	14	850	Some doughtiness

Source: (ONERN, 1975).

Hydrology

The hydrographic network is dendritic where water flows on a seasonal basis through the watersheds in the Sanctuary. There are numerous springs, perennial streams and drainage areas into wetlands throughout the Sanctuary’s hills. At least five irrigation canals some over 100 years old, also crisscross the hillsides and provide water to numerous small villages and dwellings outside and inside the Sanctuary.

Flora

The Calipuy National Sanctuary contains two biological zones: very wet tropical subalpine plain and wet tropical mountainous rainforest (IRENA, 1995).

Most of the plants in the area are medium-sized or small, semi-woody and herbaceous, and grow in rocky terrain. The semi-woody species are usually medium-sized bushes ranging from 0.60 - 1.5 m in height. Vegetation is most abundant on the hillsides as opposed to the rocky tops and outcrops. The main species include: *Puya raimondii*, *Puya angusta, Cheilanthes gruinata, Stenomesson coccineum, Calliandra expansa, Lupinus* sp., *Verbena clavata, Salvia oppsotiflora, Satureja* sp., *Satureja guamaniansis, Urocarpidum* sp., *Arcythopphyllum thymifolium, Baccharis latifolia* and *Baccharis odorata*.

In the Calipuy National Sanctuary there are approximately 55,000* *Puya raimondii* plants both young and old. Juvenile plants possess a dense rosette of stiff sword-shaped leaves that radiate in a near spherical cluster from the top of a simple erect trunk which can be one meter in diameter (Rees, W.E. and Roe, N.A., 1980). In adult plants, this thick trunk is enveloped in layers of dead thorny leaves creating a dense skirt or mantle. Flowers eventually appear from the top of the rosette as a dense blossom that can reach a height of six meters. These plants can be blown over by the wind because they are not sheltered and because they do not put down deep roots.

*See: Recommended management strategies and future research needs in the Calipuy National Sanctuary.

Fauna

Key fauna species in the area include: Andean fox (*Pseudalopex culpaeus*), striped Hog-nosed skunk (*Conepatus semistriatus)*, white tailed deer (*Odocoileus virginianus*) and mountain viscacha (*Lagidium peruanum*). Bird species include: the giant hummingbird (*Patagona gigas)*, mountain caracara (*Phalcoboenus megalopterus)*, variable hawk (*Buteo polyosoma*), American kestrel (*Falco sparverius*), various finch species (*Phrygilus spp.*), shrike-tyrant species (*Agriornis spp.*), cinclodes species (*Cinclodes spp.*), Puna snipe (*Gallinago andina*), and rufous-collared sparrow (*Zonotrichia capensis*).

<u>*Puya raimondii* Plant Inventory</u>

Boundaries

The study area was located outside the Invasion Zone in the Calipuy National Sanctuary. The Invasion Zone is occupied by farmers, their fields, livestock and dwellings. It has been highly disturbed for over 30 years. *Puya raimondii* plants are located throughout the Sanctuary but grow in a far more natural setting outside the Invasion Zone. See the following map (Figure 2) to illustrate these boundaries.

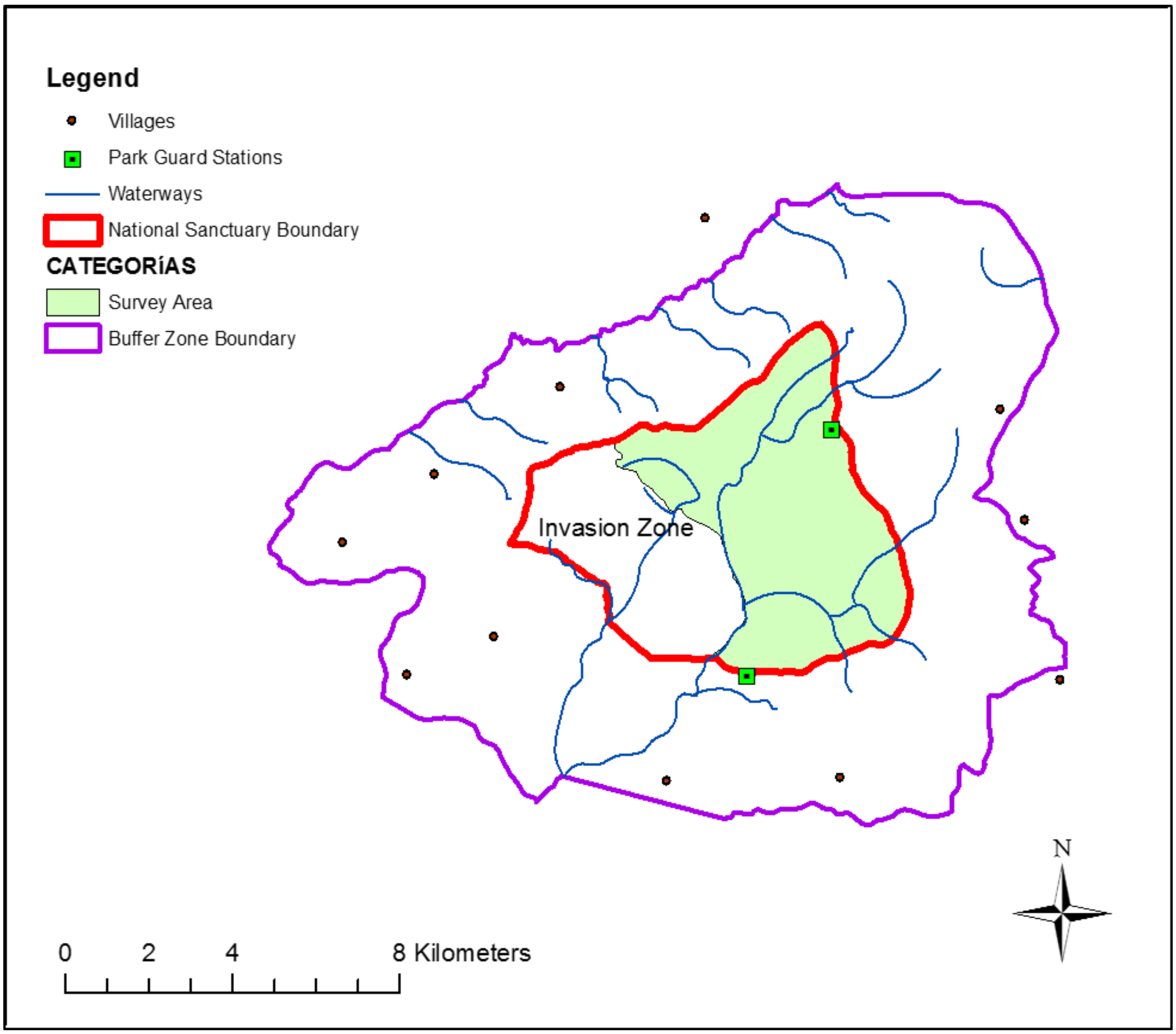


Figure 2: Map of Invasion Zone and Study Area inside the Calipuy National Sanctuary.

Landscape Scale

This plant inventory was completed on foot from the south end of the Sanctuary to the north taking 1.5 years: beginning 24 July 2012 and ending 23 October 2013. A 2.5 m stacked-stone wall encloses the entire Sanctuary and served as an obvious boundary. Each hill was visually divided into sections by drainages. Hills were then systematically hiked up and individual plants were marked with spray paint and information recorded. Because of the plant's obvious stature and prominence on the rocky landscape, individual plants were easy to locate. I concede that some very small stature plants were overlooked in this process.

Field Data Collection

Each *Puya raimondii* had a GPS waypoint and the following information recorded: height (including flowering stalk); morphology (Juvenile, Adult, Flowering or Flowered); living or dead; burned or not burned; observations of animals (birds and mammals, with bird results included in the Appendices); habitat types (based on plant species, soil types, and slope); elevation; presence of fungus; damage by insects (significant or non-significant); and the presence of bird nests (holes in stem of plant or constructed from twigs).

Juvenile plants do not have a visible stem elevating the green "bush" of leaves above the ground, while Adult plants have a thick obvious stem. Most Juvenile plants were less than two meters tall. Flowered plants are dead Adult plants that had flowered in the past while Flowering plants are actively in florescence.

Distinguishing between "significant" and "non-significant" insect damage was done solely by me based on the amount of injured leaves (see Figure 5). This is a qualitative not quantitative category and based on individual judgment of whether the damage will affect the reproductive potential of the plant or not.

Height

Approximate height was recorded using a flexible measuring tape and/or using my body as a reference: knee-1.5 ft., hip-three ft., shoulder-five ft., head-six ft. Larger plants were marked with spray paint at my head, then I stepped back and used hands and fingers to approximate further heights. Flowering stalks were measured separately from the rest of the plants. Plants above one foot tall were measured to the nearest ½ foot and plants less than one foot tall were measured to the nearest inch. The original measurements were done in feet and then converted to meters during data processing.

Morphology

Table 2 illustrates how each *Puya raimondii* plant was placed into 12 different categories.

Table 2: Illustrated morphological differences recorded in each *Puya raimondii* plant (12 categories total).

Name	**Photo**	**Description**	**Key**
Juvenile-alive and unburned		Living juvenile plants without visible stem and not burned.	JU
Juvenile-alive and burned		Living juvenile plants without visible stem and burned.	JB

Juvenile-dead and unburned		Juvenile plants without visible stem, dead, and not burned.	JDU
Juvenile-dead and burned		Juvenile plants without visible stem, dead, and burned.	JDB
Adult-living and unburned		Living adult plants with visible stem and not burned.	AU

Adult-living and burned.		Living adult plants with visible stem and burned.	AB
Adult-dead and unburned.		Adult plants with visible stem, dead, and not burned.	ADU
Adult-dead and burned.		Adult plants with visible stem, dead, and burned.	ADB

Flowering-living and unburned.		Living adult plants with flowering stalk not burned.	FU
Flowering-living and burned.		Living adult plants with flowering stalk, burned.	FB

Flowered-dead and unburned.		Dead adult plants with flowered stalk not burned.	FDU
Flowered-dead and burned.		Dead adult plants with flowered stalk, burned.	FDB

Habitat Types

Visual observations about certain habitat types in which each *Puya raimondii* plant was located were noted by myself and divided into 19 categories (see descriptions below). Plants were found growing out of rocks, on rocky outcrops, in rocky soils, and in soils dominated by Ichu-Grass prairie.

Rocky outcrops are visible exposures of bedrock or ancient superficial deposits where the overlying cover is removed thorough erosion or tectonic uplift (Wikipedia, 2014). Rocky soils contained little to no grass and had many small stones littering the surface. Ichu-Grass prairie consists of stands of various grasses, including fescue, needle grass, bluegrass, and reed bent grass, and is found on the Andean *puna*, or grassland (Kalman, 2003). Hill slopes were measured using a protractor in the field and recorded in degrees.

Rock-when a plant was growing on top of a rock on a hillside.

Rock Valley Floor-when a plant was growing on top of a rock and that rock was located on the floor of a valley (<6° slope).

Rocky Outcrop Valley Floor-when a plant was growing on a rocky outcrop located on the floor of a valley (<6° slope).

Rocky Outcrop Toeslope- when a plant was growing on a rocky outcrop located on the toeslope of a hill, above a flat (<6° slope).

Rocky Outcrop Streambed- when a plant was growing on a rocky outcrop located within a streambed.

Rocky Outcrop Medium Hillside- when a plant was growing on a rocky outcrop located on a medium-sloped hill (16°≤ and ≥ 6° slope).

Rocky Outcrop Steep Hillside- when a plant was growing on a rocky outcrop located on a steep hill slope (≥16° slope).

Rocky Outcrop Hilltop-when a plant was growing on a rocky outcrop located on the top of a hill (<6° slope).

Rocky Soil Valley Floor- when a plant was growing on rocky soil located on the floor of a valley (<6° slope).

Rocky Soil Toeslope- when a plant was growing on rocky soil located on the toeslope of a hill, above a flat (<6° slope).

Rocky Soil Streambed- when a plant was growing on rocky soil located within a streambed.

Rocky Soil Medium Hillslope- when a plant was growing on rocky soil located on a medium-sloped hill (16°≤ and ≥ 6° slope).

Rocky Soil Steep Hillslope- when a plant was growing on rocky soil located on a steep hill slope (≥16° slope).

Rocky Soil Hilltop-when a plant was growing on rocky soil located on the top of a hill (<6° slope).

Ichu Grass Riverbank- when a plant was growing on Ichu-Grass prairie located on a riverbank.

Ichu Grass Medium Hillslope-when a plant was growing on Ichu-Grass prairie located on a medium-sloped hill (16°≤ and ≥ 6° slope).

Ichu Grass Steep Hillslope- when a plant was growing on Ichu-Grass prairie located on a steep hill slope (≥16° slope).

Wet Soil/Drainage Area Medium Slope-when a plant was growing in a drainage area dominated by wetland grasses located on a medium-sloped hill (16°≤ and ≥ 6° slope).

	
Rock	Rocky Outcrop
	
Rocky Soil	Ichu Grass

Figure 3: Pictures of different main habitat types.

Elevation

Using a Garmin Handheld GPS unit, elevations were recorded in meters to an accuracy of three meters.

Fungus

In one part of the Sanctuary, a black fungus was observed that appeared to be affecting the health of 22 *Puya raimondii*. There is another species of *Puya* in the Sanctuary: *Puya angusta*. This species also contains the same fungus. Both species are growing close together in this small portion of the Sanctuary. In the following photos (Figure 4) the fungus can be seen, white and black, on the leaves of the plants.

	
Fungus on *Puya raimondii*	Fungus on *Puya angusta*

Figure 4: Fungus pictured on leaves of *Puya raimondii* and *Puya angusta.*

Insect Damage

Damage from insects was recorded in two categories: “significant” and “not significant.” In the following photos (Figures 5 and 6) the difference between the two categories can be observed and also the insects responsible inside one plant. “Significant” bug damage means that the middle “rosette” of the plant was significantly eaten back or gone altogether. Especially in adult plants, this type of damage would affect the plant’s ability to recover and thus to reproduce in the future. After the rainy season (November - March) many insects were observed hatching within the inner leaves of the *Puya raimondii*, generally flies but also wasps.

	
“Significant” insect damage	“Not significant” insect damage

Figure 5: “Significant” and “Non-significant” insect damage pictured on *Puya raimondii* plants.

Flies hatching inside a *Puya raimondii* “rosette.”

Figure 6: Flies pictured hatching inside “rosette” of *Puya raimondii*.

Presence of Bird Nests

The presence of bird nesting in *Puya raimondii* was recorded. There were two types observed: holes in the flowering stalk of the plants and nests made of sticks located in the leaves of the plants. The following photos (Figure 7) illustrate the two types.

	
Bird nests made with sticks located in leaves of *Puya raimondii*.	Hole in the flowering stalk of *Puya raimondii* plant.

Figure 7: Two types of bird nests found in *Puya raimondii* plants.

Data Analysis

A Garmin handheld GPS unit was used to capture waypoint information for each *Puya raimondii* plant that was subsequently uploaded into ArcGIS 10.1. Digital elevation model (DEM) data for the Sanctuary was obtained from the Shuttle Radar Topography Mission (STRM) dataset - version 4.1. That program provided global 90 meter resolution elevation. More on the program, and data downloads, may be found at the following website: http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. Topography waypoint data was extracted using Extract Multi Value to Points. This resulted in new Excel dataset columns for DEM elevation, slope (degrees), and aspect. The boundary of the study area was demarcated in

ArcGIS 10.1 by hand to create a new polygon. Subsequent topographical layers (slope, aspect, and elevation) were derived using the ArcGIS 10.1 spatial analyst toolbar. Summarized statistics were then reported for the Sanctuary study area (see Table 3) using the relativized data taken from the new Excel dataset columns. Histograms were generated using this same relativized data (see Figures 8 A-C) and also the waypoint location information for each *Puya raimondii* captured in the Garmin handheld GPS unit. The histograms represent a systematic sample of the study area using the DEM.

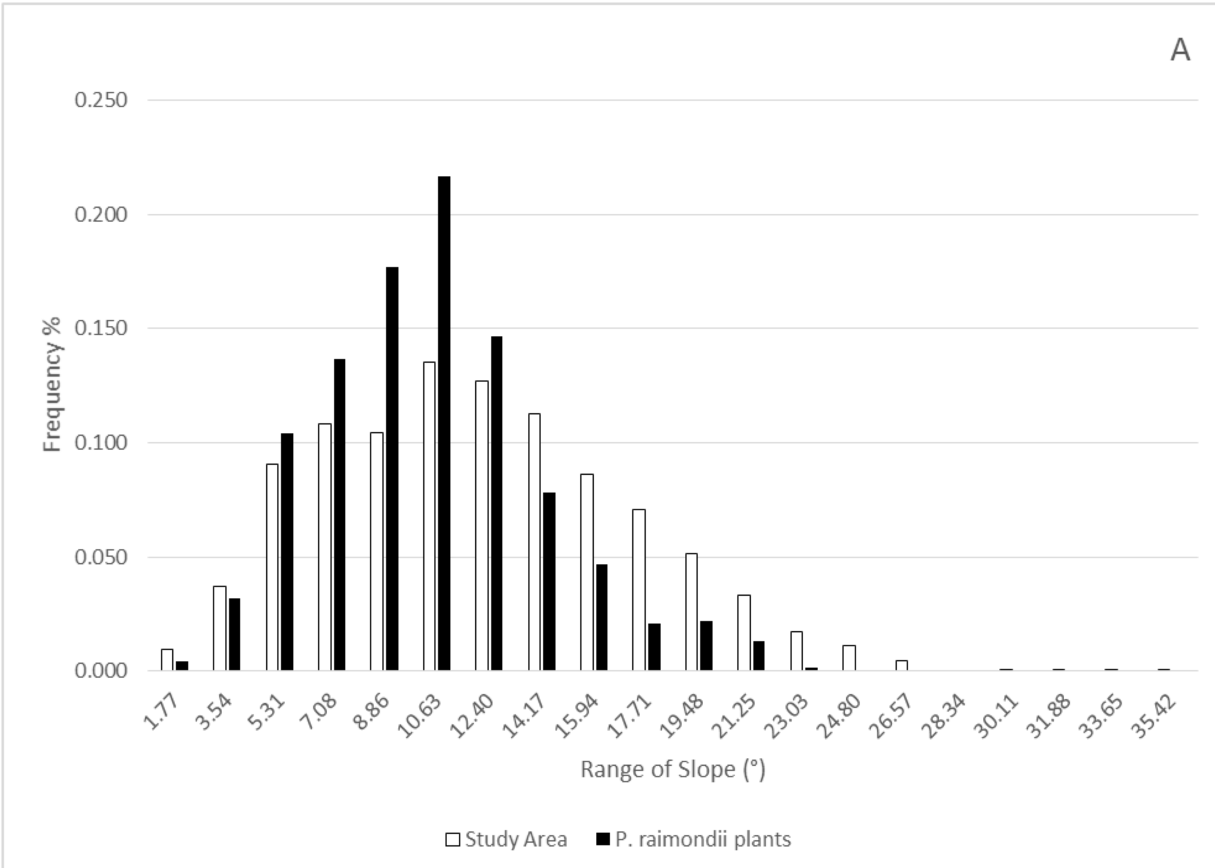
RESULTS

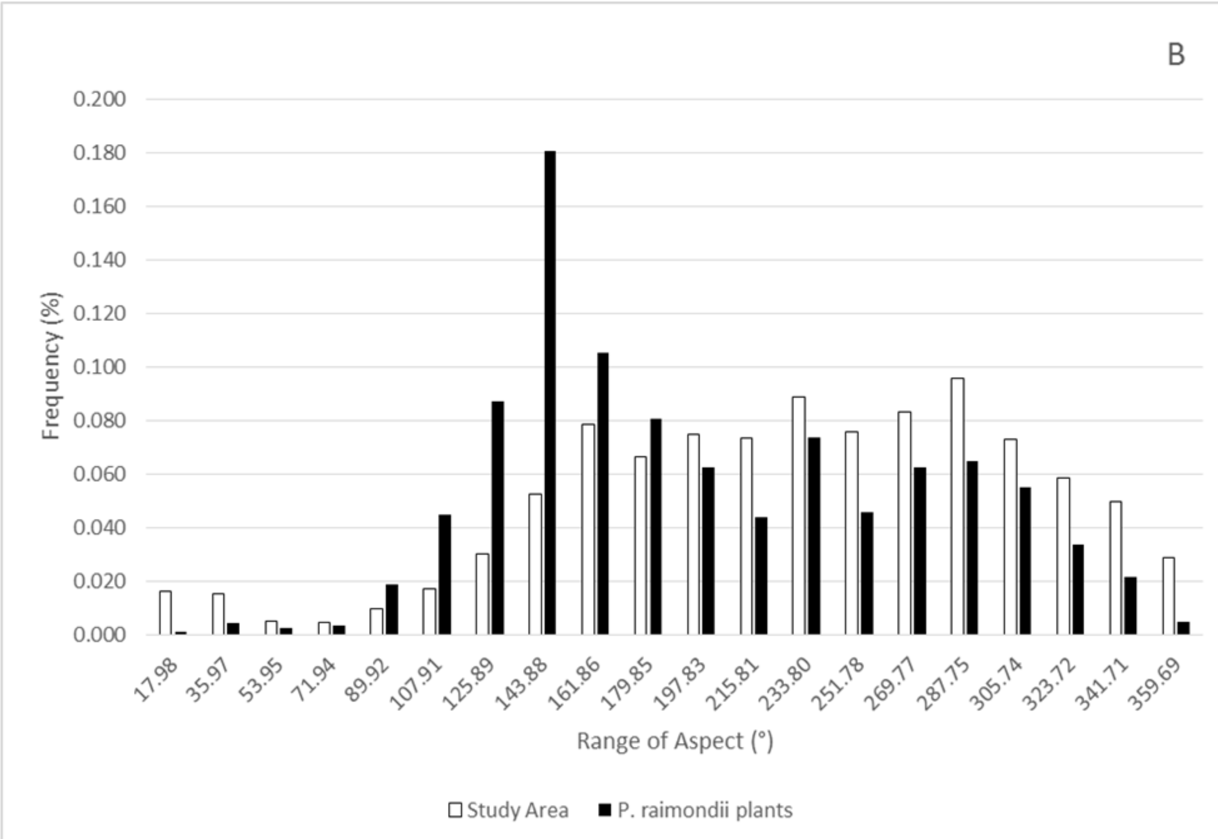
Slope, Aspect, and Elevation

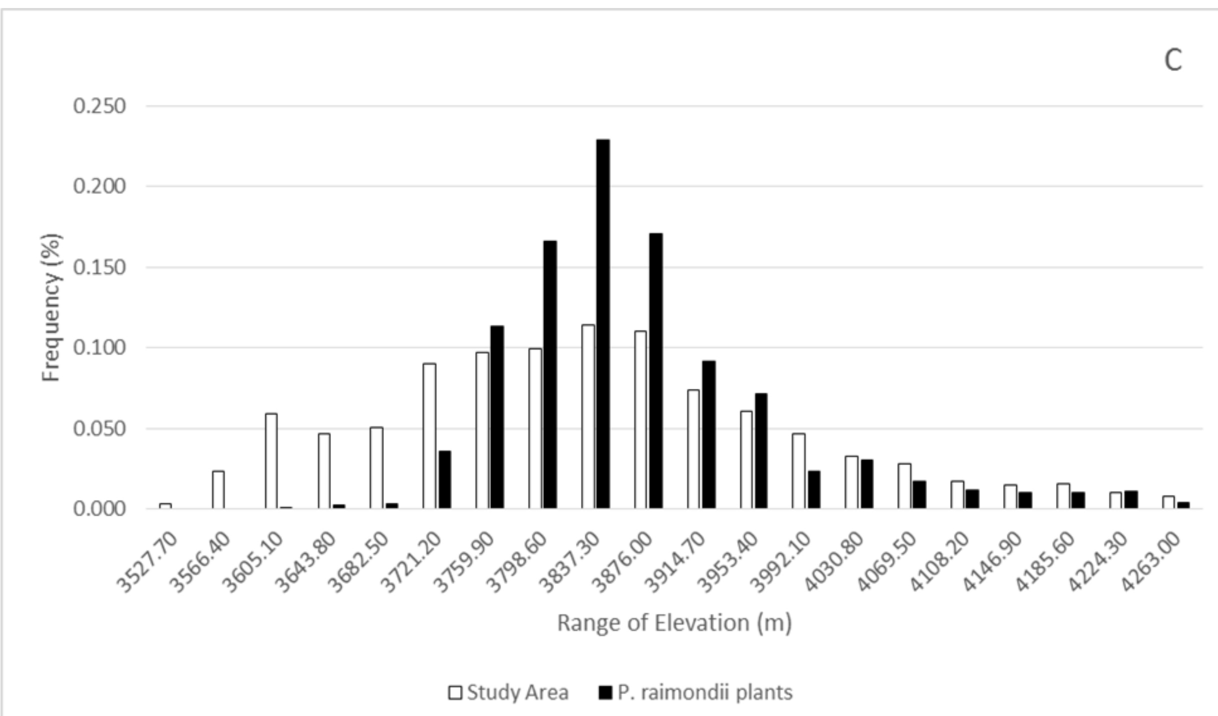
The Sanctuary study area has a range of slopes between 0 - 35°, but over 50% are between 7 - 14° with most of the slopes occurring under 23° (see Table 3 and Figure 8A). Most *Puya raimondii* plants were found in the middle range of these slopes with 65% of the plants found between 6 - 12° (see Figure 8A). The Sanctuary study area has a range of aspects between 0 – 360° with most of the aspects found between 126 - 360° (see Table 3 and Figure 8B). Most *Puya raimondii* plants were found in a narrow range of aspects between 126 – 180° (see Figure 8B). The Sanctuary study area has a range of elevations between 3489 – 4263 meters with most elevations found between 3720 – 3950 meters (see Table 3 and Figure 8C). Most *Puya raimondii* plants were found in a narrow range of elevations between 3840 – 3880 meters (see Figure 8C).

Table 3: Summary statistics of slope, aspect, and elevation for the Sanctuary study area.

Summary Statistics	**Slope (°)**	**Aspect (°)**	**Elevation (m)**
Minimum	0	0.00	3489
Maximum	35	360	4263
Mean	11	221	3817


A
0.250
0.200
0.150
0.100
0.050
0.000
Frequency %
1.77
3.54
5.31
7.08
8.86
10.63
12.40
14.17
15.94
17.71
19.48
21.25
23.03
24.80
26.57
28.34
30.11
31.88
33.65
35.42
Range of Slope (°)
Study Area
P. raimondii plants





Figures 8 A-C: Frequency distributions of the range of slope, aspect, and elevation between the Sanctuary study area and *Puya raimondii* plant occurrences.

Puya raimondii Plant Inventory

Morphology

Of the 55,237* living and dead *Puya raimondii* plants recorded in the Calipuy National Sanctuary 24,519 (44.3%) were Adults and 30,718 (55.7%) were Juveniles. “Flowered” and “Flowering” plants will be considered as sub-sets of Adult plants in separate analyses. All percentages are taken from the total population unless otherwise stated.

Out of 30,718 total Juvenile plants, 603 (2.0%) were dead with 189 of these burned (31.3% of the total dead Juveniles), while 201 (0.7%) showed evidence of fire but were still alive. The range of Juvenile heights found was: 0.3 – 5.5 m and the average height of Juvenile plants were: 0.7 m.

Out of 24,519 total Adult plants counted in the Sanctuary, 5,953 (24.3%) were dead with 5,108 of these burned (85.8% of the total dead Adults), while 3,686 (15%) showed evidence of fire but were still alive. Plants that had already flowered in previous years and were thus dead counted 1,250 (5.1%). The range of Adult heights found was: 1.7 – 6.4 m and the average height of Adult plants were: 2.5 m.

During the inventory in the 2012 flowering season, which was conducted on the south side of the Sanctuary, just three plants were counted as actively “flowering” but at least three other plants were known to be flowering in other parts of the Sanctuary (*personal communication*). Only one of these plants showed evidence of fire but was still flowering. During the inventory in the 2013 flowering season, which was conducted on the north side of the Sanctuary, 287 plants were counted as actively “flowering.” 138 (48%) of these plants showed evidence of fire and were still flowering. During this five-month flowering season (June-October), 14,202 living Adult plants were actually counted, giving a flowering rate of 2.0%. Extrapolating this percentage to the whole Sanctuary for the 2013 flowering season means that a total of 374* plants may have been flowering that year. [*Extrapolating to entire Sanctuary: 18,570 (total living Adults in the Sanctuary) – 14,202 living Adults counted in 2013 = 4,365 (living Adults in rest of Sanctuary) * 0.020 (2% flowering rate) = 87. 87 + 287 actually counted = 374 plants flowering.]

Out of the 1250 “already Flowered” plants, 853 (68%) were burned. These could have been burned during their lives or after they were dead as they continue to stay on the landscape for probably five-ten years after flowering. The range of heights for Flowering/Flowered plants found was: 1.2 – 7.6 m and the average height of Flowering/Flowered plants was: 3.8 m. Inflorescence heights (on top of the plant) ranged between 1.2 – 8.8 m in Flowering/Flowered plants with the average height of inflorescences at 5.1 m (see Tables 4A-C). The average inflorescence was highest between elevations 3900 – 4099 m (5.3 m & 5.4 m average height) but not markedly higher than other elevations (see Table 4C). The average inflorescence was highest in aspects NW and W at 5.5 m and 5.4 m (see Table 4B).

Table 4A: Inflorescence heights (m) distribution over slope classes in the Sanctuary study area.

Slope (°)			
	Low	**Medium**	**High**
Mean Infl. Heights (m)	5.0	5.1	4.7
# Infl. counted	147	716	68
Range Infl. Heights (m)	1.5 - 7.3	1.2 - 8.8	2.4 - 7.9

Table 4B: Inflorescence heights (m) distribution over aspect classes in the Sanctuary study area.

Aspect								
	N	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Mean Infl. Heights (m)	5.0	4.6	4.9	5.0	5.0	4.8	5.4	5.5
# Infl. counted	13	12	45	268	167	119	176	131
Range Infl. Heights (m)	2.6 - 8.8	2.4 - 6.1	3.4 - 6.4	1.5 - 7.9	1.5 - 7.3	1.2 - 7.3	1.8 - 8.1	2.4 - 7.3

Table 4C: Inflorescence heights (m) distribution over elevation classes in the Sanctuary study area.

Elevation (m)								
	A (3400 - 3599)	**B** (3600 - 3699)	**C** (3700 - 3799)	**D** (3800 - 3899)	**E** (3900 - 3999)	**F** (4000 - 4099)	**G** (4100 - 4199)	**H** (4200 - 4299)
Mean Infl. Heights (m)	0	3.5	5.0	5.0	5.3	5.4	4.6	4.3
# Infl. counted	0	4	185	437	196	69	28	12
Range Infl. Heights (m)	0	2.3 - 4.7	1.5 - 7.0	1.2 - 8.1	2.7 - 7.9	1.8 - 8.8	2.4 - 7.3	2.4 - 5.5

Burned plants were seen scattered throughout the entire population of *Puya raimondii* plants in the Sanctuary and higher instances of burned plants did not occur closer to human habitations. See Figure 9 for this distribution and the proximity of villages around the Sanctuary. Not seen on this map are individual family farms which cover all the area in the Buffer Zone of the Sanctuary right to its boundary wall on all sides.

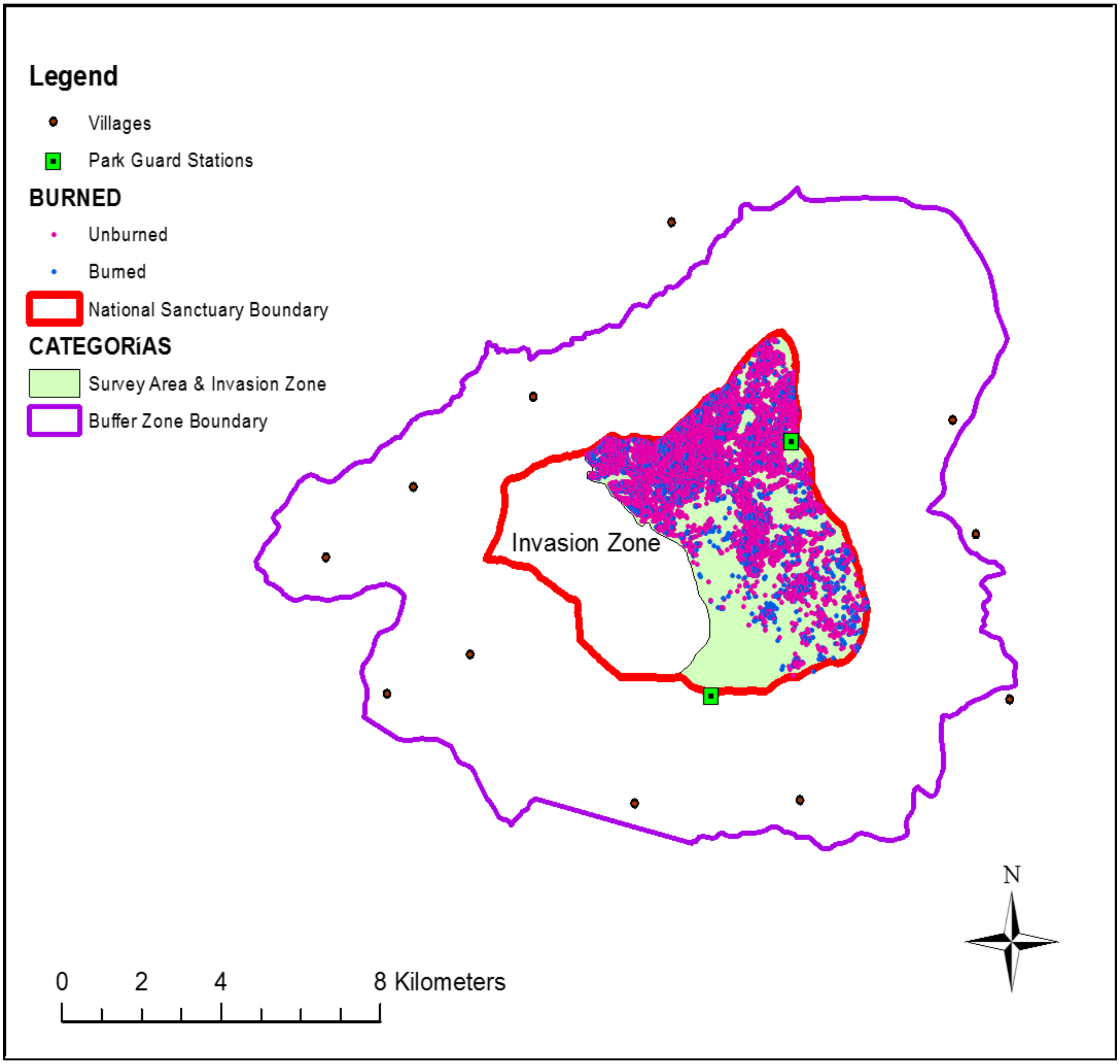


Figure 9: Map of burned *Puya raimondii* plants distribution across Sanctuary study area and in relation to nearby population centers.

*See: Recommended management strategies and future research needs in the Calipuy National Sanctuary.

Habitat Types

The area for each of the habitat types is not available, so all data concerning them will be used with the percentage (%) of plant population instead of the number of plants per hectare. The three habitats that supported the highest percentage of the *Puya raimondii* population were: Rocky Soil Medium Slope (43%), Rocky Outcrop Medium Slope (27%) and Ichu Grass Medium Slope (14%). See Table 5 below for a complete breakdown of plants across habitat types.

Table 5: Total number and percentage (%) of *Puya raimondii* population by morphology across Habitat Types.
*Flowering & Flowered Plants are a sub-set of Adult plants.

	Juvenile		**Adult**		**Flowering***		**Flowered***	
	Total #	**% Pop.**	**Total #**	**% Pop.**	**Total #**	**% Pop.**	**Total #**	**% Pop.**
Rock	162	0.5%	7	<0%	0	0%	1	<0%
Rock Valley Floor	1	<0%	0	0%	0	0%	0	0%
Rocky Outcrop Valley Floor	31	0.1%	30	0.1%	0	0%	0	0%
Rocky Outcrop Toeslope	22	0.1%	19	0.1%	0	0%	0	0%
Rocky Outcrop Streambed	3	<0%	3	<0%	0	0%	0	0%
Rocky Outcrop Medium Slope	10,125	33%	5975	26%	53	18.5%	343	27%
Rocky Outcrop Steep Slope	2293	7.5%	1240	5%	4	1%	94	7.5%
Rocky Outcrop Hilltop	267	0.9%	271	1%	0	0%	25	2%
Rocky Soil Valley Floor	4	<0%	28	0.1%	0	0%	1	<0%
Rocky Soil Toeslope	22	<0%	39	0.2%	0	0%	4	0.3%
Rocky Soil Streambed	40	0.1%	63	0.3%	0	0%	7	0.6%
Rocky Soil Medium Slope	11,891	39%	10,784	47%	168	59%	541	43%
Rocky Soil Steep Slope	1301	4%	940	4%	1	0.3%	54	4%
Rocky Soil Hilltop	89	0.3%	182	0.8%	1	0.3%	17	1%
Ichu Grass Riverbank	11	<0%	23	0.1%	0	0%	1	<0%
Ichu Grass Medium Slope	4415	14%	3344	14.5%	60	21%	164	13%
Ichu Grass Steep Slope	37	0.1%	28	0.1%	0	0%	0	0%
Wet Soil/Drainage Area Medium Slope	4	<0%	2	<0%	0	0%	0	0%

Slope, Aspect, and Elevation

Across all slope classes, Juvenile, Adult, Flowering and Flowered plants all have a higher percentage of plants/ha on medium slopes (75% of population) than on low slopes (19-20% of population) (See Table 6 and Figure 10).

Table 6: *Puya raimondii* distribution by slope class in Sanctuary study area.
*Flowering & Flowered are sub-sets of Adults.

Slope (°)		**Juveniles**			**Adults**			**Flowering & Flowered***		
Class	**Total ha/ % Area**	Plants per ha/% Pop	Mean (°)	Range (°)	Plants per ha/% Pop	Mean (°)	Range (°)	Plants per ha/% Pop	Mean (°)	Range (°)
Low (0-5.99°)	504 ha/ 18%	11.6/ 19%	4.5	0-5.99	9/ 20%	4.5	0-5.99	0.6/ 19%	4.5	0-5.99
Medium (6-15.99°)	1740 ha/63%	13/ 75%	10.0	6.0-15.99	10/ 75%	10	6.0-15.99	0.7/ 75%	10	6.0-15.99
High (16-25°)	520 ha/ 19%	3.6/ 6%	18.5	16-25	2/ 5%	18	16-25	0.2/ 6%	18.6	16-23

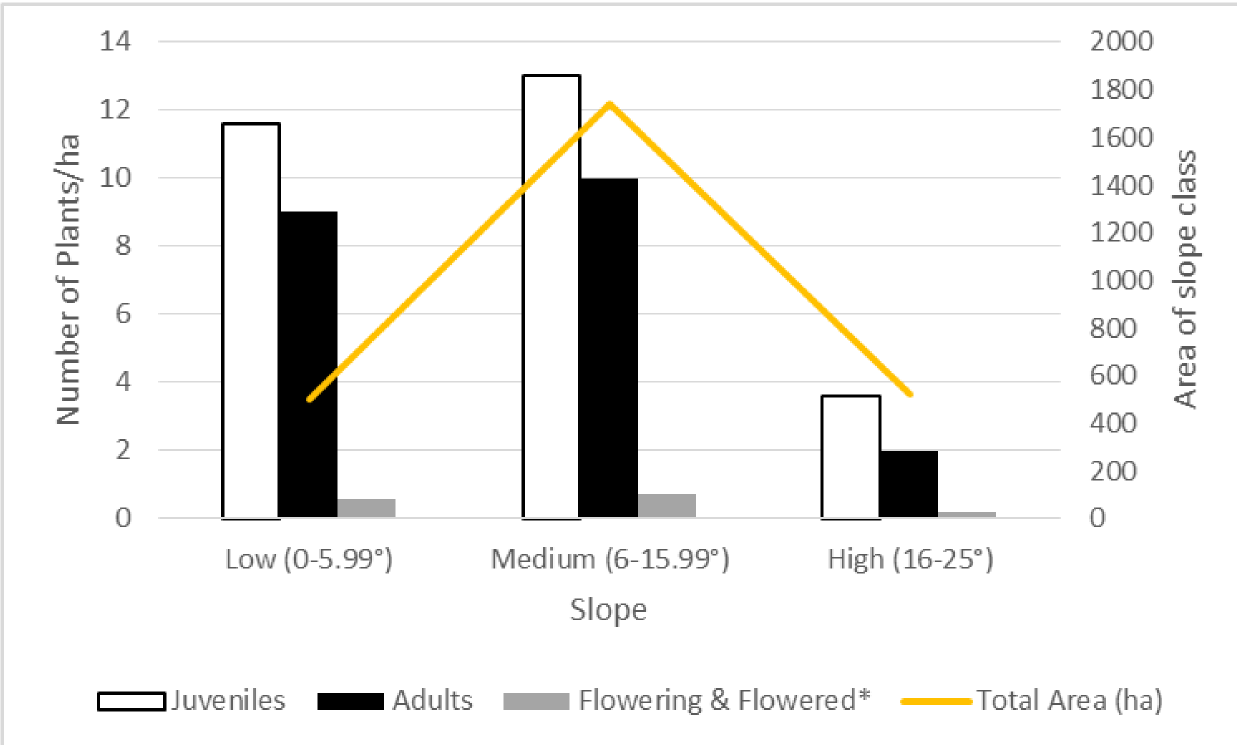


Figure 10: Number of *Puya raimondii* plants/ha in each slope class and total area of each slope class in the Sanctuary study area.
*Flowering & Flowered are sub-sets of Adults.

Across all aspects, Juvenile, Adult, Flowering and Flowered plants all have a significant preference for west aspects (54-60% of population) rather than east and southeast aspects (11-16% of population) (see Table 7 and Figure 11). It seems significant that the plants prefer west aspects but this aspect class only occurs on 2% of the Sanctuary study area (see Table 7). This might be because 65% of the west aspect contains elevations from 3700-3999 meters (Classes C, D, and E) (see Figure 12) which are most of the elevations preferred by *Puya raimondii*, but it only contains 5% of elevations from 4200-4299 meters (Group H) (see Figure 12) which is also a preferred elevation by 15-21% of *Puya raimondii* plants (see Table 8). The west aspect also contains more than 74% medium and low slopes (see Figure 13) which are the slopes most preferred by 89% of *Puya raimondii* plants (see Table 6). There was not a sampling bias between slope and elevation as I compared the west aspects to its two abutting aspects: southwest and northwest.

Table 7: *Puya raimondii* distribution by aspect class in Sanctuary study area.
*Flowering & Flowered are sub-sets of Adults.

Aspect (°)		**Juveniles**			**Adults**			**Flowering & Flowered***		
Class	**Total ha/% Area**	Plants per ha/% Pop	Mean (°)	Range (°)	Plants per ha/ % Pop	Mean (°)	Range (°)	Plants per ha/% Pop	Mean (°)	Range (°)
N (337.6-22.59°)	167 ha/ 6%	2.4/ 1%	9/ 345	338-21	1.3/ 1%	9/ 350	338-22	0.1/ 1%	8/ 348	339-21
NE (22.6-67.59°)	54 ha/ 2%	5/ 2.5%	43	24-65	4/ 3%	43	26-65	0.4/ 4%	45.5	28.6-65
E (67.6-112.59°)	95 ha/ 3%	27/ 15%	98	68-112	22.5/ 16%	99	68-112	1/ 11%	97	68-112
SE (112.6-157.59°)	376 ha/ 13.5%	27/ 15%	136	113-158	20/ 14%	135.5	113-158	1/ 12%	136.5	113-158
S (157.6-202.59°)	513 ha/ 18.5%	10/ 6%	178	158-202.5	8/ 6%	177	159-202.5	0.6/ 6%	176.5	158.6-202
SW (202.6-247.59°)	553 ha/ 20%	8/ 5%	226	202.6-247.5	6/ 4%	225	203-247.5	0.4/ 4%	228	203-246
W (247.6-292.59°)	46 ha/ 2%	97/ 54%	271	248-292	73.5/ 54%	271.5	248-292	6/ 60%	273	248-291
NW (292.6-337.59°)	961 ha/ 35%	3/ 1.5%	310	292.6-337	2/ 2%	310	292.6-337	0.2/ 2%	312	293-337

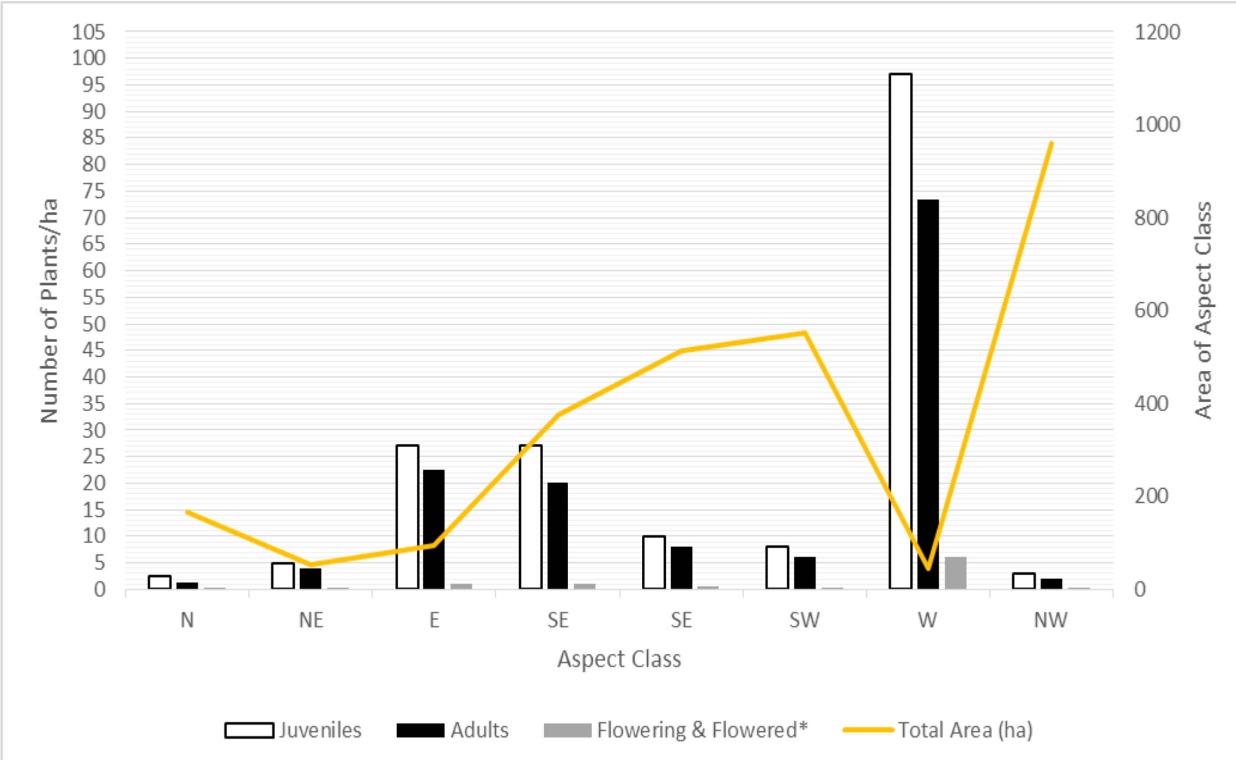


Figure 11: Number of *Puya raimondii* plants/ha in each aspect class and total area of each aspect class in the Sanctuary study area. *Flowering & Flowered are sub-sets of Adults.

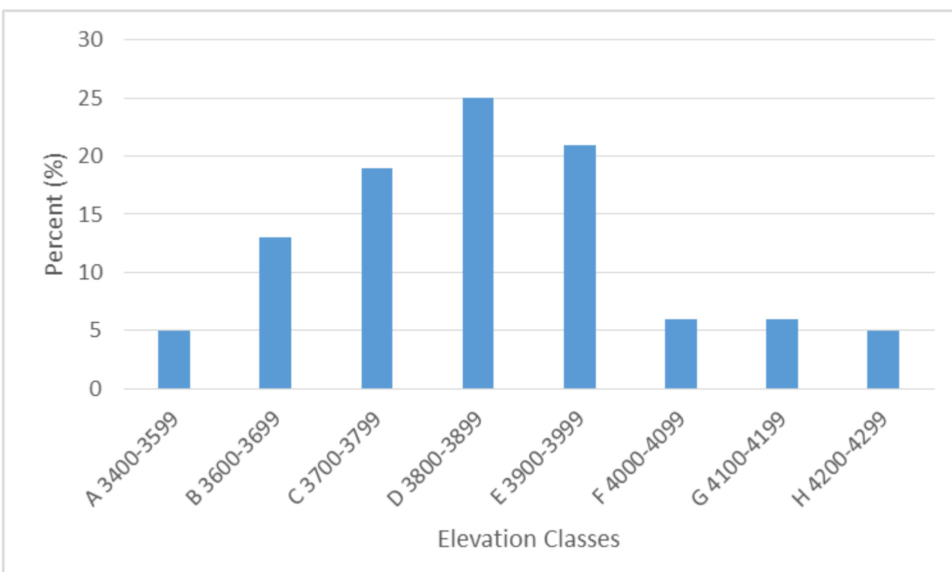


Figure 12: Percentage of elevation classes in the west aspect.

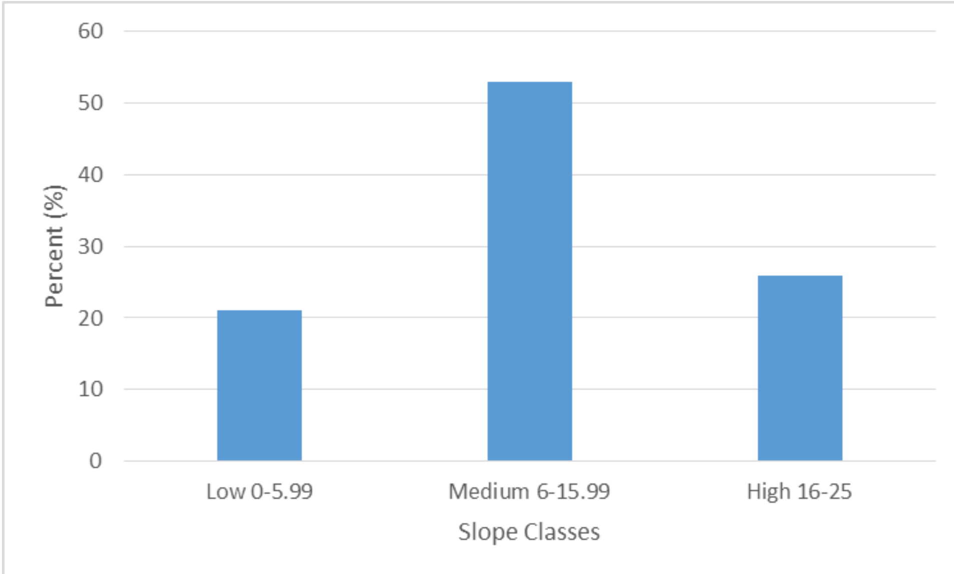


Figure 13: Percentage of slope classes in the west aspect.

Across all elevation classes, Juvenile, Adult, Flowering/Flowered plants have a higher representative population in class D (27% of population) but class D also contains 26% of the area in the Sanctuary study area. Class H only contains 1% of the area in the Sanctuary study area but has 15-21% of the *Puya raimondii* population. Class G only contains 4% of the area in the Sanctuary study area but has 7-11.5% of the *Puya raimondii* population. Class F only contains 7% of the area in the Sanctuary study area but has 12% of the *Puya raimondii* population. (See Table 8 and Figure 14). So *Puya raimondii* seem to prefer the highest elevations in the Sanctuary study area (Classes F-H). This could be because their population's total distribution range is 3,000-4,800 m (mean 3,900 m).

Table 8: *Puya raimondii* distribution by elevation class in Sanctuary study area.
*Flowering & Flowered are sub-sets of Adults

Elevation (m)		**Juveniles**			**Adults**			**Flowering & Flowered***		
Class	**Total ha/% Area**	Plants per ha/% Pop	Mean (m)	Range (m)	Plants per ha/% Pop	Mean (m)	Range (m)	Plants per ha/% Pop	Mean (m)	Range (m)
A (3400-3599 m)	207 ha/ 7.5%	0.03/ .04%	3574	3529-3599	0.1/ 0.2%	3572	3416-3599	0.005/ 0.1%	3592	3592 (1)
B (3600-3699 m)	391 ha/ 14.3%	0.70/ 0.90%	3672	3601-3699	0.7/ 1.3%	3671	3600-3699	0.02/ 0.5%	3672	3629-3698
C (3700-3799 m)	710 ha/ 25.7%	11.4/ 14%	3760	3700-3799	8/ 16%	3764	3700-3799	0.5/ 12%	3769	3700-3799
D (3800-3899 m)	728 ha/ 26.3%	20/ 25%	3845	3800-3899	15/ 29%	3847	3800-3899	1/ 25%	3846	3800-3899
E (3900-3999 m)	396 ha/ 14.3%	12/ 15%	3940	3900-3999	10/ 19%	3937	3900-3999	0.8/ 21%	3940	3900-3997
F (4000-4099 m)	185.5 ha/ 6.7%	10/ 12%	4041	4000-4099	6/ 12%	4039	4000-4099	0.6/ 15%	4038	4000-4097
G (4100-4199 m)	106 ha/ 3.8%	9/ 11.5%	4150	4100-4199	4/ 7%	4150	4100-4199	0.3/ 8%	4149	4102-4197
H (4200-4299 m)	39 ha/ 1.4%	16/ 21%	4236	4200-4279	8/ 15%	4233	4200-4279	0.7/ 18%	4240	4200-4275

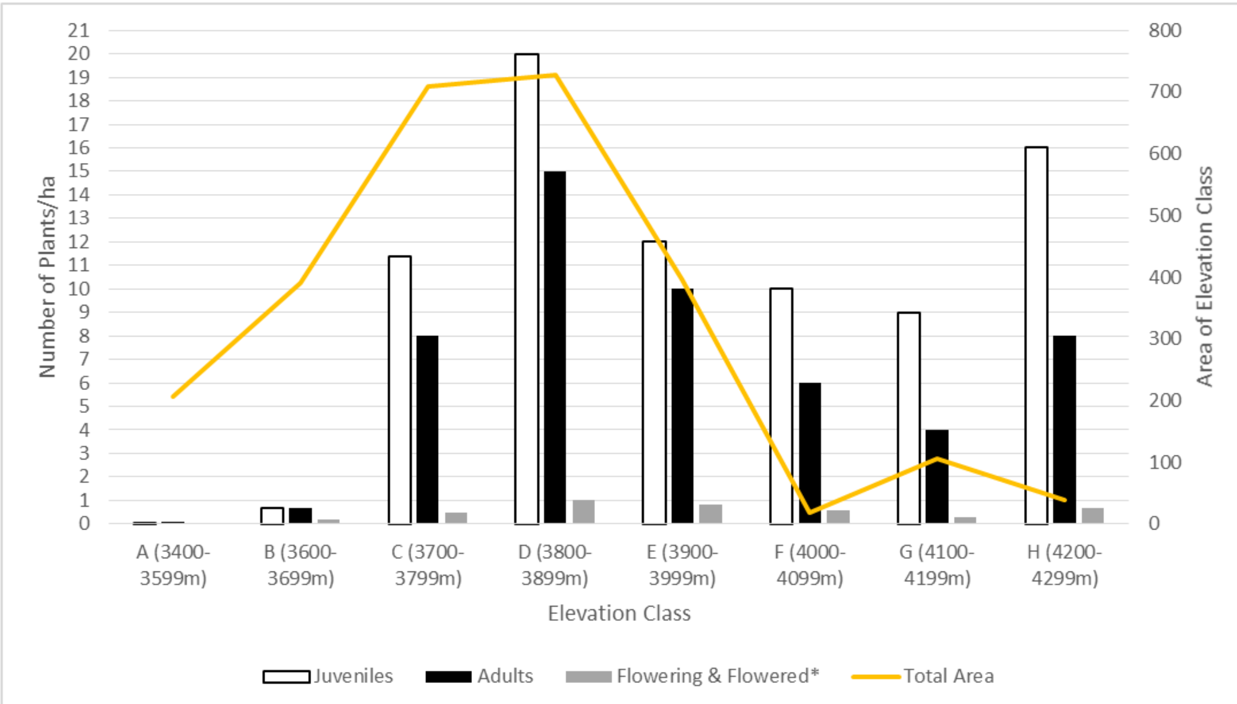


Figure 14: Number of *Puya raimondii* plants/ha by elevation class and total area of each elevation class in the Sanctuary study area.
*Flowering & Flowered are sub-sets of Adults.

Fungus

The black fungus observed during the inventory was only found on 22 *Puya raimondii* plants in the entire Sanctuary in one very specific area.

Insect Damage

In regards to insect damage, 5,292 total plants surveyed (9.6%) were affected to some degree and 1,071 of these (20.2%) were damaged “significantly.” Broken down, this means 3,982 (12.9%) Juvenile plants were affected to some degree and 972 (24.4%) of these were damaged “significantly” or 3.2% of all Juvenile plants in the Sanctuary. For Adult plants, 1,310 (5.4%) were affected by insect damage to some degree and 99 (7.6%) of these were damaged “significantly” or 0.2% of all Adult plants in the Sanctuary. Only three Flowering plants in the entire Sanctuary were noted as having some degree of insect damage and 0 of these were “significantly” damaged. Insect damage numbers may be low in all Adult plants due to the dissimilar heights of damaged areas on the plants and the height of me.

In the entire *Puya raimondii* population, 148 (3.5%) of all the plants that were affected to some degree by insect damage had also been burned. 41 of all the plants that were affected "significantly" by insects had also been burned (3.8%). So plants weakened by burning do not seem to attract further or higher instances of insect damage.

There is no significant difference between the number of plants/ha and insect damaged plants/ha across Slope classes or Aspect classes. There is a difference between the number of plants/ha and insect damaged plants/ha in Elevation classes only that insect damaged plants are not seen in high numbers at high elevations (Class H: 4200-4299m) perhaps due to freezing weather (see Figures 14 and 15).

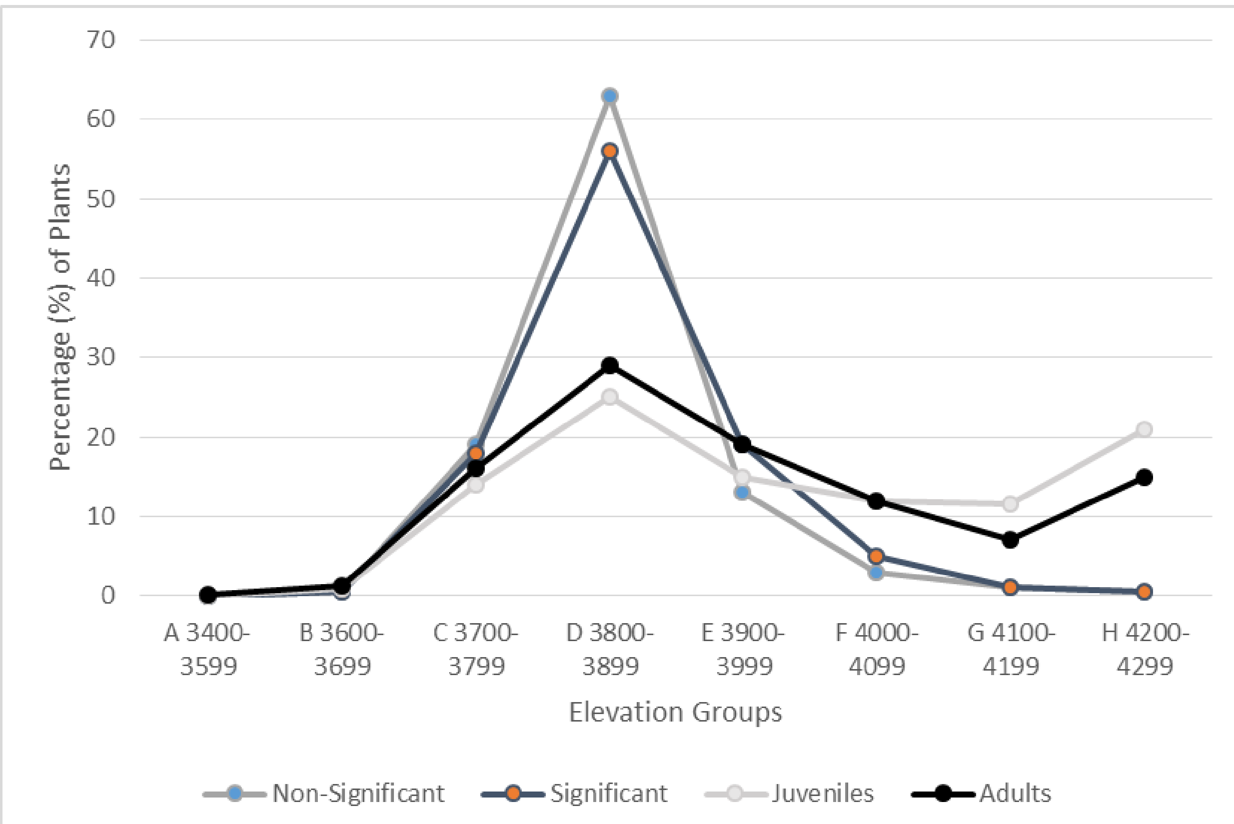


Figure 15: Percentage of *Puya raimondii* plants with insect damage (Non-Significant & Significant) compared to Juvenile and Adult plants across elevation classes.

Presence of Bird Nests

There were two types of bird nests observed: holes in the flowering stalk of the plants and nests made of sticks located in the leaves of the plants. In total, 1,011 bird nests or holes were found on 905 plants. Bird nests were found in 20 Juvenile plants and one of these had multiple nests (between two-five nests/plant). Bird nests were found in 754 Adult plants (excluding Flowering/Flowered plants), 67 of these plants had multiple nests and 44 of these nests were found in dead plants. Bird nests were found in 36 out of 287 (12.5%) Flowering plants during the survey and four of these had multiple nests. Bird nests were found in 95 out of 1,250 (7.6%) already Flowered plants during the survey and 14 of these had multiple nests. Juvenile plants only contain 2.2% of the total plants with bird nests, while Adult plants (excluding Flowering/Flowered plants) contain 83% of the total plants with bird nests. Flowering plants contained 4% of the total bird nests while flowered plants contained 10.5% of the total bird nests. (See list of birds identified in Appendices).

DISCUSSION

The *Puya raimondii* population surviving in the Calipuy National Sanctuary serves as an example of the larger situation threatening the endangered plants throughout their entire range in the Andes Mountains of Peru and Bolivia. The immediate threat to *Puya raimondii* is humans and their impacts through fire, agricultural land management and use of the plant as building materials. Other threats to consider are low genetic diversity and climate change. Since 2001, the Peruvian National Government has made significant progress in the management and maintenance of these plants in the Calipuy National Sanctuary. Six full-time Park Guards live in the Sanctuary and conduct regular surveillance activities throughout its territory and have regular educational events with the surrounding populations. Numerous assessments by Peruvian SERNANP and contracted officials have been completed in the Sanctuary including evaluations of the Invasion Zone, base-line data collections of flora and birds, and an evaluation of wetlands, springs and water canals. Free-range livestock grazing has been prohibited in the Sanctuary since 2006. In addition, this study itself serves to establish baseline data to compare and track changes to the *Puya raimondii* population over time and is the first step to a continuous monitoring plan for the endangered plants in the Sanctuary.

Where in the Sanctuary does the *Puya raimondii* prefer to grow?

The population density of the *Puya raimondii* plants is higher on the northern side of the Sanctuary. This does not appear to be related to the distance to human populations, so what is it about the physical environment that the plants are responding to?

Unfortunately we can only make educated guesses with our preliminary data when comparing the north and south sides of the Sanctuary. Personal communication has told us that the northern side may receive more rainfall. I observed more Ichu Grass habitat on the northern side and this may be an indicator of more nutrient-rich soils. The south side appears to have steeper hillsides which are *Puya raimondii*'s least preferred slope class.

But we can make some predictions about *Puya raimondii*'s responses to its environment over different slopes, aspects, elevations, and habitats found in the Sanctuary:

(1) When comparing number of plants/hectare across slope, *Puya raimondii* prefers Medium (6-15.99°) slopes which constitute 63% of the area of the Sanctuary only slightly to Low (0-5.99°) slopes which constitute 18% of the area of the Sanctuary (see Table 5). High slopes (16–25°) are seen at almost the same amount as Low slopes (19%), but only 6% of the *Puya raimondii* population prefer them while 19% of the population prefer Low slopes (see Table 6 and Figure 9). I would attribute this to less erosive factors working at these lower slope classes on soils and seeds, thicker soil horizons, and so the increased availability of nutrients and water.

(2) When comparing number of plants/hectare across aspect, *Puya raimondii* prefers west aspects which only constitute 2% of the area of the Sanctuary (see Table 7 and Figure 11). Why is this? Possibly because 65% of the west aspect contains elevations of 3700-3999 meters, which are preferred by *Puya raimondii* plants (see Figure 12). The west aspect also has over 50% medium slopes which is the slope most preferred by *Puya raimondii* plants (see Figure 13). I do not know why we are not seeing more plants in the abutting aspects: southwest and northwest.

(3) When comparing number of plants/hectare across elevation, *Puya raimondii* seems to prefer elevations between 3700-3999 m which constitute 66% of the Sanctuary

area (see Table 8 and Figure 12). But with only 1.4% of the Sanctuary area, elevation class H has between 15-21% of the *Puya raimondii* population. Elevation classes F and G have similar low percent of total area with high percent of *Puya raimondii* population. So the highest elevations in the Sanctuary study area are actually the most preferred. Because the plant's normal range is 3,000-4,800 m (mean 3900 m), this could be due to past livestock management and burning in the lower elevations of the Sanctuary or competition with dense populations of wetland or graminoid plant populations in the lower elevations of the Sanctuary where more nutrient-rich soils exist. We do not see more plants in the highest elevation classes simply because there is not a lot of this area available.

(4) When comparing the percentage of all morphologic types of *Puya raimondii* plants across habitat types, they prefer Rocky Soil (43%) to Rocky Outcrops (27%) and Ichu Grass (14%), but these percentages are all found on medium slopes (see Table 5). These are distinctly "preferred" habitats and/or slopes as the next highest percentage of plants on the habitat Rocky Outcrop Hilltop only consists of 1.2% of the entire population.

<u>Answer: In the Sanctuary study area, *Puya raimondii* prefers medium slopes, the west aspect, the highest elevations available, and rocky soils.</u>

Where in the Sanctuary is reproduction more successful and why?

The height of *Puya raimondii* inflorescences can be a measure of better reproductive success since a taller inflorescence can hold more flowers and thus more seeds and pollen. Inflorescence heights were recorded on 931 plants during the plant inventory. We can make some predictions about *Puya raimondii*'s reproductive success across different slopes, aspects, elevations, and habitats found in the Sanctuary (see Tables 4A-C):

(1) When comparing *Puya raimondii* average inflorescence heights between burned and unburned plants, they are virtually equal at 5.095 m on unburned plants and

5.087 m on burned plants. So burning does not seem to affect inflorescence heights, a surprising discovery.

(2) When comparing *Puya raimondii* average inflorescence heights over elevation (see Figure 8), they are highest (5.4 m high) between 4000-4099 meters in elevation with very similar results (5.3 m high) between 3900-3999 meters in elevation. They are only 3.5 m high between 3600-3699 meters in elevation and 4.3 m high at 4200-4299 meters in elevation. The lower inflorescence heights at lower elevations I do not completely understand since lower elevations at the foot of hills usually contain higher-nutrient soils and more available moisture which can have positive effects on flower heights. Perhaps there is more competition for those nutrients and/or water with other plant species at lower elevations. The lower heights at higher elevations could be due to wind influence being stronger at the crest of hills and the large, heavy inflorescence being at risk of toppling the plant over. But all the elevations existing in the Sanctuary are within the *Puya raimondii*'s usual range (3,000–4,800 m) so all the elevations available could be preferred in the larger context.

(3) When comparing *Puya raimondii* average inflorescence heights over aspect, they are 5.5 m on northwest aspects, one of the population's least preferred, and 5.3 m on west aspects, the population's most preferred aspect. The northeast aspect has the lowest average inflorescence heights at 4.6m but this is not the *least* preferred aspect for Flowering/Flowered plants (see Table 7) though it *is* low preference at 4%. So there is not a significant influence seen between aspect classes and inflorescence heights. This is probably due to the Sanctuary's close distance to the Equator so all the aspects get equal amounts of solar radiation and thus heat load which could have an effect on inflorescence rates.

(4) When comparing *Puya raimondii* average inflorescence heights over slopes, they are very similar: 5.1 meters high on medium slopes, 5.0 meters high on steep slopes, and 4.7 meters high on low slopes. So there is not a significant influence seen between slope classes and inflorescence heights. This may be because the puna habitat in the Andes Mountains overall has a higher range of slope classes seen in just this Sanctuary alone and the slopes in the Sanctuary are all preferred in the larger context.

(5) When comparing *Puya raimondii* average inflorescence heights across habitat types, their heights are tallest on a Rocky Outcrop at the toe-slope of a hill (8.1 m) and on Ichu Grass on a riverbank (6.4 m), both sites where high-nutrient soils and higher moisture content can exist but both these sites contained just one flowering plant each. The next tallest inflorescences were found on Rocky Soils on hilltops (average 5.4 m between nine different plants). I would not expect these sites to have high nutrient soils but possibly higher moisture content since they are located at higher elevations. The higher topographic location would also be advantageous for their wind-distributed seeds.

(6) When comparing only the tallest *Puya raimondii* inflorescence heights across habitat types, the three tallest inflorescences inventoried are on Ichu Grass on a medium-sloped hill (8.8 m), on a Rocky Outcrop at the toe-slope of a hill (8.1 m), and two plants (7.9 m each) on Rocky Soil, one on a medium-sloped hill and one on a steep-sloped hill. All four of these plants are located across all the habitat types in terms of soil and slope, so neither of these types seems to have a significant effect on inflorescence height.

(7) The highest numbers of Flowering/Flowered plants were still found on Rocky Soil (709 total plants), Rocky Outcrops (396 total plants), and Ichu Grass (224 total plants) all on medium slopes (see Table 5). Both this slope class and these habitat types are preferred by all *Puya raimondii* plants.

(8) When comparing Flowering/Flowered plant's distance to water, there was not a direct correlation. But neither small waterways, canals nor drainages are marked on the map I used. This could be an area to investigate in the future because I know these inventories are being conducted in the Sanctuary now.

(9) When comparing the distinctive age classes alone: Juvenile, Adult and Flowering/Flowered, these classes do not have distinct preferences for different elevations, aspects, slopes or habitats but all the different age classes of plants prefer the same areas to live and reproduce.

Answer: Burning, aspect, distance to large waterways, soil and habitat types do not seem to affect inflorescence heights of *Puya raimondii.* Reproduction does seem to be most successful at 3900-4099 meters in elevation on NW and W aspects on medium slopes. This is similar to the preferences of all *Puya raimondii* plants.

Is the *Puya raimondii* population sustainable in the Calipuy National Sanctuary?

The results of this study support the determination that this *Puya raimondii* population is sustaining itself. Six major findings support this conclusion:

(1) Out of the 55,237 plants surveyed, only 2% of the Juvenile plants and 24.3% of the Adult plants were found to be dead. Of the dead Adults, 5.1% had already flowered in previous years. This leaves 88.1% of the total plant population alive, 98% of all Juvenile plants and 75.5% of all Adult plants.

(2) Out of the 30,718 Juvenile plants, only 0.6% was found to be burned. Of the 24,519 Adult plants, 20.8% were found to be burned. Evidence of burning can persist for decades on the Puya plants so the contrast in percentage burned between Juveniles and Adults suggests that there has been little burning in recent years. There was only one fire observed during the 18-month inventory that affected 11 plants but killed none. Plants that showed evidence of fire but were still alive counted 0.7% of the living Juveniles and 15% of the living Adults. Burning alone does not seem to have an effect on the plant's ability to flower and reproduce but can render the stem weaker and more vulnerable to toppling.

(3) Insect damage over the entire Sanctuary only affected 5,292 plants and 1,071 of these were damaged significantly enough to probably prevent the plants from recovering to reproduce in the future (1.9%). Adult plants would be the most vulnerable to irrecoverable injury but significant insect damage only accounted for 5.8% of the total living Adult population.

(4) During the entire study, 290 plants were counted as actively in-flower (three in 2012 and 287 in 2013). Only parts of the total Sanctuary were surveyed during the plant's five-month flowering season both years (June-October) so up to 400 plants could've flowered in these two years (2% of all living Adult plants). It is normal for the plants to have an abundant flowering year every five-seven years (*personal communication with Biologist in Huascaran National Park*). SERNANP in the Calipuy National Sanctuary has been keeping annual counts of flowering plants since 1999 and some *Puya raimondii* plants in the Sanctuary have been flowering every year since then with the most abundant flowering year before 2013 being 2010 (*personal communication with Calipuy Sanctuary Biologist).*

(5) A black fungus was observed that only affected 22 of the *Puya raimondii* plants in a small area of the Sanctuary. This area bears monitoring in the future but is not an immediate threat to the whole population.

(6) During the time of this study, actively Flowering plants numbered 290 with 47.8% of these burned. Only four of these burned but actively Flowering plants were actually observed to have fallen over: 1.4% of all the Flowering plants. So even if burned, *Puya raimondii* plants have a good chance of surviving to flower.

Answer: In conclusion, there are 28,969 (94.3%) healthy Juvenile plants (not burned, have non-significant insect and/or fungal damage, and are alive) available for reproduction in the future and 14,633 (59.7%) healthy Adult plants (not burned, have non-significant insect and/or fungal damage, and are alive) available for reproduction in the future. In other words, 79% of the *Puya raimondii* population has reproductive potential and the effects of burning have been reduced.

Is the *Puya raimondii* population sustainable over its entire range?

In this larger context, the biggest threats facing this endangered species, besides the influence of humans and their land management, are its scattered distribution and extreme genetic uniformity. Conservation of rare species must have maintenance of genetic diversity as a high priority (Pullin, 2002). These two factors are probably due to the effects of the last glacial cycle and human management of their habitat since then. The earliest evidences of human presence in Peruvian territory have been dated to approximately 9,000 years BCE (Dillehay, 2004). The last glacial period within the current ice age occurred during the last years of the Pleistocene (12,000-110,000 years ago) with the maximum extent of glaciers being 22,000 years ago (Clayton, 2006). These dynamics leave the entire *Puya raimondii* population at greater risk to disease, parasites, or climactic change (Lambe, 2009). The Calipuy National Sanctuary is the largest northern-most population seen in the plant's current vestigial range. Using studied *Puya raimondii* populations in Peru, we can make inferences over the plant's entire range:

(1) The nearest significant *Puya raimondii* population to the Calipuy National Sanctuary is at least 125 miles south in the Huascaran National Park where the *Puya raimondii* population is estimated to contain up to 450,000 plants (Lambe, 2009). This is too far for the exchange of genetic material to occur naturally. A scientific study published in 2013 using leaf tissue samples analyzed genetic variations in populations of *Puya raimondii* in Huascaran National Park and a neighboring mountain area in Peru. For *Puya raimondii*, this 2013 study is only preceded by two other works (Sgorbati et al. 2004, Sculte et al. 2010). Previous studies in *Puya raimondii* determined the genetic structure of eight *Puya raimondii* populations in Huascaran and detected only 14 genotypes (Sgorbati et al. 2004). Only a few of the 217 AFLP (amplified fragment length polymorphism) marker loci screened were polymorphic and four populations were completely monomorphic, suggesting inbreeding. But the 2013 study results contrasts with the earlier results, finding 96.3% polymorphism (Hornung-Leoni, 2013). The authors attribute this to comparing two different localities separated by barriers. So *Puya raimondii*'s very scattered distribution could still harbor sufficient quantities of genetic variances. Not enough studies have been done on this subject to make a definite determination.

(2) Any plant with limited genetic diversity is vulnerable to large-scale disturbance. Climate change is something the *Puya raimondii* has probably dealt with since the last glacial period and it is well adapted for it. Due to its arrangement of "troughed" leaves that are angled towards the stem, considerable amounts of water are available, even after a light

shower to the plant (Rees and Roe, 1980). The water runs down the stem to be taken up by the roots. It also uses crassulacean acid metabolism (CAM) photosynthesis to create sugars. This adaptation allows bromeliads in hot or dry climates to open their stomates at night rather than during the day, which reduces water loss (Rex, 2007). So if hotter temperatures become more common in the region, and thus dryer, the plant has adaptations to temper those effects. If the climate in the area becomes wetter, the plants themselves would probably be fine but could other plant species move into its habitat? Extrapolating my plant inventory to other populations of *Puya raimondii*, this could be possible in the Rocky Soils habitat. The soils in the Rocky Outcrops are probably too thin and do not retain enough nutrients to become prime habitat for other plant species. If Rocky Soils, especially on medium and low slopes where more nutrients can be retained, become invaded by more plant species, the *Puya raimondii* will probably continue to reproduce. *Puya raimondii* seem to be competing well with grasses in the Sanctuary's Ichu Grass habitats now, especially after the grazing pressure and/or fires have been alleviated: 14% of the *Puya raimondii* population in the Sanctuary live in this habitat. It will be interesting to see if this percentage increases over time and that can perhaps help answer the question to how *Puya raimondii* will react to climate change over its entire range.

(3) Extrapolating my plant inventory data to other populations of *Puya raimondii*, disease and/or parasites do not seem to be making a significant influence on the plant's reproductive success. I also have not read any mention of them in published works or heard about them in my personal correspondence.

Answer: Genetic studies bear looking into for the future of the *Puya raimondii* plants while monitoring populations over time may yield more information on the influences of climate change and disease and/or parasites. I feel the *Puya raimondii* can be sustainable at least in small populations so far.

Recommended management strategies and future research needs in the Calipuy National Sanctuary.

The management of the *Puya raimondii* population located in the Calipuy National Sanctuary has seen significant strides forward since 2001. The on-sight presence of six full-time Park Guards, the environmental education in surrounding communities located in the Sanctuary's Buffer Zone, continued prohibition on free-range livestock grazing within the Sanctuary boundaries, and the strict monitoring of the human habitations located in the Invasion Zone should all continue in the future. But there are things SERNANP could continue to improve upon:

(1) I believe there is a northern section of the Sanctuary that has yet to be surveyed by myself or in a similar inventory of *Puya raimondii* done by a French volunteer, Joly Guillaume, in 2011 (see and compare Figures 16 & 17 below). This section should be surveyed by someone for more accurate statistics of the *Puya raimondii* in the entire Sanctuary.

Figure 16: Map of Invasion Zone boundary done by French volunteer, Joly Guillaume in 2011.

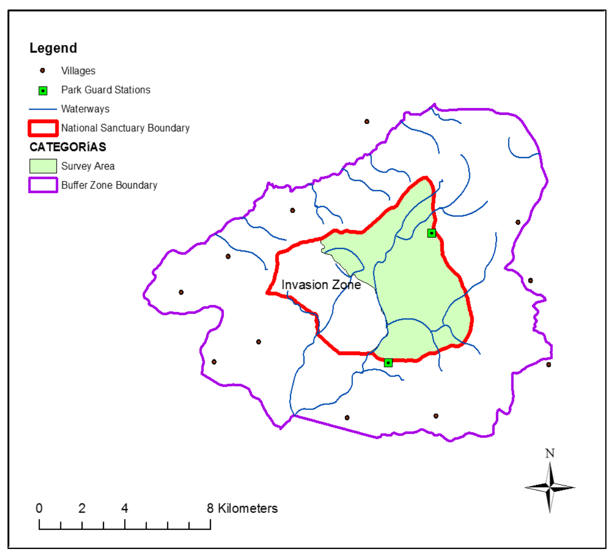


Figure 17: Map of Invasion Zone boundary done by Shannon Zuschlag in 2013.

(2) This *Puya raimondii* inventory conducted in 2012-2013 established base-line conditions of the population of this plant located within the boundaries of the Sanctuary. At least

five permanent monitoring plots are currently being established in strategic areas around the Sanctuary so Park Guards can more accurately monitor the *Puya raimondii* population and track its reproductive behavior over time. This monitoring should include insect and fungal damage because climate changes could make the entire plant population more vulnerable to their effects and should also track the success of *Puya raimondii* plants in the Ichu Grass habitat. With continuous monitoring, the Park Guards can determine if the population is growing or declining and *changing*; this will guide the Sanctuary official's management and protection of the plant in the future and can give other Protected Areas in Peru and Bolivia valuable information about their own *Puya raimondii* populations and possible management strategies.

(3) Even basic climate information like daily rainfall and temperature would have large predictive possibilities for any experiments/management strategies conducted in the Sanctuary in the future. I recommend that basic climate stations be set up and maintained at both Park Guard Stations within the Sanctuary.

(4) I recommend that the Calipuy National Sanctuary conduct a similar genetic study among *Puya raimondii* plants in the Sanctuary and in scattered populations outside the Sanctuary known to SERNANP personnel to determine that genetic variation is present and then test it against the Huascaran plant populations. Depending on the findings, they can consider transplanting plots of genetically diverse *Puya raimondii* plants from Huascaran and/or the extremely small populations scattered outside the Sanctuary. There is an obvious problem with the fact that the plants may not flower for up to 100 years. A variety of size and age of seedlings will be necessary to test for differences in success over time.

(5) As more inventories are conducted in the Sanctuary like the mapping of small waterways, canals, wetlands and drainages, SERNANP can use the now existing *Puya raimondii* waypoints and information in ArcGIS or in Excel spreadsheets to make further inferences about the population and its interactions with the environment.

(6) Only 4% of the *Puya raimondii* plants in the Sanctuary were observed to contain bird nests, but as there are no trees in the puna landscape, these plants may have larger

reproductive impacts on certain bird species populations. It is not implied in the literature whether particular birds or insects rely exclusively on the *Puya raimondii* for food or shelter. But further studies into these subjects are recommended for a more complete picture of the *Puya raimondii's* role in the ecosystem.

CONCLUSION

Sadly, even if monitoring and maintenance are carried out, even if genetic exchange of material is successful over time, this endangered plant's habitat has undergone extreme fragmentation over the course of human history in Peru and its reproductive success is not ultimately possible over its entire range. Small populations could continue to be sustainable in particular areas like the Calipuy National Sanctuary and Huascaran National Park but unless reproductive corridors allowing the natural exchange of genetic materials can be established across hundreds of miles of the Andes mountains, these small sustainable "islands" will be all that is left of the *Puya raimondii* with human intervention and their science being a surrogate for natural selection. Taking into account the extreme poverty present in the highlands of Peru and Bolivia, the idea of giving up huge tracts of agricultural land for the continuation of a prehistoric plant species has very little probability.

Is it worth it to protect the vestiges of an ancient species of plant? The plant is not a "keystone species" within the puna habitat now as the habitat is extensive throughout the Andes Mountains in South America and there are only very small pockets of the *Puya raimondii* plants left within it. I feel that the Calipuy National Sanctuary is a place where people can observe the behaviors of an endangered species in a "natural enough" setting and still experience a connection with a primordial landscape. The national government of Peru obviously feels that there is value in investing time, money and energy into the maintenance of protected areas set up to safeguard this ancient and emblematic species of the Andes Mountains.

APPENDICES

Over the course of the plant inventory I kept a list of birds identified using the text: "Birds of Peru" (Schulenberg, 2012). I added this to the list of birds already identified in a previous inventory supplied by SERNANP and completed in 2012 (Boyd, David R. Rosario, 2012).

Order	Family	Scientific Name	Common Name	Endemic to Peru
ACCIPITRIFORMES	ACCIPITRIDAE	*Buteo polyosoma*	Variable Hawk	
ANSERIFORMES	ANTIDAE	*Anas bahamensis*	Yellow billed/Speckled teal	
APODIFORMES	TROCHILLIDAE	*Aglaeactis cupripennis*	Shining Sunbeam	
APODIFORMES	TROCHILLIDAE	*Colibri coruscans*	Sparkling Violetear	
APODIFORMES	TROCHILLIDAE	*Metallura phoebe*	Black Metaltail	x
APODIFORMES	TROCHILLIDAE	*Oreotrochilus estella*	Andean Hillstar	
APODIFORMES	TROCHILLIDAE	*Patagona gigas*	Giant Hummingbird	
APODIFORMES	TROCHILLIDAE	*Polyonymus caroli*	Bronze-tailed comet	x
CAPRIMULGIFORMES	CAPRIMULGIDAE	*Caprimulgus longirostris*	Band-winged Nightjar	
CHARADRIIFORMES	CHARADIRIIDAE	*Vanellus resplendens*	Andean Lapwing	
CHARADRIIFORMES	SCOLOPACIDAE	*Gallinago andina*	Puna/Andean Snipe	
COLUMBIFORMES	COLUMBIDAE	*Metriopelia cecilae*	Bare-Faced Ground Dove	
FALCONIFORMES	FALCONIDAE	*Falco femoralis*	Aplomado Falcon	
FALCONIFORMES	FALCONIDAE	*Falco sparverius*	American Kestrel	
FALCONIFORMES	FALCONIDAE	*Phalcoboenus megalopterus*	Mountain Caracara	

PASSERIFORMES	EMBEREZIDAE	*Catamenia analis*	Band-Tailed Seedeater	
PASSERIFORMES	EMBEREZIDAE	*Catamenia inornata*	Plain-Colored Seedeater	
PASSERIFORMES	EMBEREZIDAE	*Diglossa brunneiventris*	Black-throated Flowerpiercer	
PASSERIFORMES	EMBEREZIDAE	*Incaspiza personata*	Rufous-Backed Inca-Finch	x
PASSERIFORMES	EMBEREZIDAE	*Phrygilus alaudinus*	Band Tailed Sierra Finch	
PASSERIFORMES	EMBEREZIDAE	*Phrygilus fruticetti*	Mourning Sierra Finch	
PASSERIFORMES	EMEREZIDAE	*Phrygilus plebejus*	Ash-breasted Sierra finch	
PASSERIFORMES	EMBEREZIDAE	*Phrygilus punensis*	Peruvian Sierra Finch	
PASSERIFORMES	EMBEREZIDAE	*Phrygilus unicolor*	Plumbeous Sierra-Finch	
PASSERIFORMES	EMBERIZIDAE	*Sicalis luteola*	Grassland Yellow Finch	
PASSERIFORMES	EMBERIZIDAE	*Sicalis uropygialis*	Bright-Rumped Yellow-Finch	
PASSERIFORMES	EMBEREZIDAE	*Zonotrichia capensis*	Rufous-collared sparrow	
PASSERIFORMES	FRINGILLIDAE	*Cardulelis magellanica*	Hooded Sisken	
PASSERIFORMES	FRINGILLIDAE	*Carduelis uropygialis*	Yellow-Rumped Siskin	
PASSERIFORMES	FURNARIIDAE	*Asthenes dorbignyi huancavelicae*	Creamy-Breasted Canastero	

PASSERIFORMES	FURNARIIDAE	*Asthenes humilis*	Streak-throated Canastero	
PASSERIFORMES	FURNARIIDAE	*Cinclodes atacamensis*	White-winged Cinclodes	
PASSERIFORMES	FURNARIIDAE	*Cinclodes fuscus*	Bar-winged Cinclodes	
PASSERIFORMES	FURNARIIDAE	*Cinclodes palliates*	White-bellied Cinclodes	x
PASSERIFORMES	FURNARIIDAE	*Geositta tenuirostris*	Slender Billed Miner	
PASSERIFORMES	FURNARIIDAE	*Leptasthenura pileata*	Rusty-Crowned Tit-Spinetail	x
PASSERIFORMES	FURNARIIDAE	*Leptasthenura striata albigularis*	Streaked Tit-Spinetail	
PASSERIFORMES	FURNARIIDAE	*Upucerthia serrana*	Striated Earthcreeper	x
PASSERIFORMES	HIRUNDINIDAE	*Pygochelidon cyanoleuca*	Blue and White Sparrow	
PASSERIFORMES	MOTACILLIDAE	*Anthus bogotensis*	Paramo Pipit	
PASSERIFORMES	THRAUPIDAE	*Conirostrum cinereum*	Cinerous Conebill	
PASSERIFORMES	THRAUPIDAE	*Sicalis olivascens*	Greenish Yellow-Finch	
PASSERIFORMES	TROGLODYTIDAE	*Traglodytes aedon*	House Wren	
PASSERIFORMES	TYRANNIDAE	*Agriornis albicauda*	White-Tailed Shrike Tyrant	
PASSERIFORMES	TYRANNIDAE	*Anairetes flavirostris*	Yellow-billed Tit-Tyrant	

PASSERIFORMES	TYRANNIDAE	*Agriornis montanus*	Black-billed Shrike Tyrant	
PASSERIFORMES	TYRANNIDAE	*Musciaxicola griseus*	Taczanowski's Ground-Tyrant	
PASSERIFORMES	TYRANNIDAE	*Musicisaxicola maculirostrs*	Spot Billed Ground Tyrant	
PASSERIFORMES	TYRANNIDAE	*Ochtheoeca leucophrys*	White-Browned Chat-tyrant	
PASSERIFORMES	TYRANNIDAE	*Ochthoeca oenanthoides*	D'Orbigny's Chat-Tyrant	
PASSERIFORMES	TYRANNIDAE	*Ochthoeca rufipectoralis*	Rufous Breasted Chat Tyrant	
PICIFORMES	PICIDAE	*Colaptes rupicola*	Andean Flicker	
STRIGIFORMES	STRIGIDAE	*Bubo virginianus*	Great Horned Owl	
STRIGIFORMES	TYTONIDAE	*Tyto alba*	Barn Owl	
TINAMIFORMES	TINAMIDAE	*Norhoprocta ornate*	Ornate Tinamou	
TINAMIFORMES	TINAMIDAE	*Nothopracta ornate branickii*	Darwin's Nothura	
TINAMIFORMES	TINAMIDAE	*Nothoprocta pentlandii*	Andean Tinamou	

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