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# Geographical distribution of *Tillandsia* lomas in the Atacama Desert, northern Chile

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**Abstract**

We assessed the geographic distribution of *Tillandsia* lomas in northern Chile, from Arica (18°20′S) to the Loa river (21°25′S) and discussed the factors that might potentially underlie the observed patterns. We carried out extensive field survey complemented with aerial surveys and analysis of specimens deposited in herbaria. We detected over 30 *Tillandsia* stands most of which corresponded to the species *Tillandsia landbeckii* and can be grouped in 10 large systems. Other two species were also detected *Tillandsia marconae* and *Tillandsia virescens*, both of which show a restricted distribution in the area. Our results provide evidence on the wide distribution of *Tillandsia* lomas in northern Chile and its association with fog corridors.


*Keywords:* Atacama Desert; Cordillera de la Costa; *Tillandsia* lomas

## 1. Introduction

The Atacama/Peruvian Coastal Desert, extends for more than 3000 km along a narrow coastal strip from northern Peru (Lat. 5°S) to northern Chile (Lat. 27°S) on the west coast of South America. This desert owes its existence to the combined effect of a stable high-pressure system located in the western Pacific Ocean, the drying effect of the cold northward flowing Humboldt current, and to the rain shadow effect of the Andes, which hold back the penetration of moisture brought by the eastern trade winds. Although this

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desert is continuous from Peru to Chile, it is usually broken down into two main components, the Peruvian Coastal Desert from the area of Tumbes (ca. 5°S) to Tacna (ca. 18°S), and the Atacama Desert from the area of Arica in northern Chile (ca. 18°20′S) to Copiapo (ca. 27°S) (for a general description of the Atacama Desert area see also Rauh, 1985a; Arroyo et al., 1988; Rundel et al., 1991; Marquet, 1994; Marquet et al., 1998; Latorre et al., 2002).

Fog is the most important source of humidity in the Atacama Desert. Fog owes it existence to the regular formation of thick stratocumulus cloud banks below 1000 m, which, when intercepted by isolated mountains or steep coastal slopes of the Coastal cordillera give rise to a fog zone known as *garúa* in Peru and *camanchaca* in Chile. The increased moisture in the fog zone allows for the development of isolated and diverse vegetation formations called *lomas* (small hills), which also develop inland across low altitude areas of the Coastal cordillera that allow for the inland penetration of fog (Abele, 1981) creating a corridor of increased humidity and lomas formations (Pinto, 1999; Muñoz-Schick et al., 2001; Pinto, 2001).

*Tillandsia* or "airplants" are the quintessential inhabitants of lomas formations. Fifteen *Tillandsia* species have been quoted for coastal Peru and northern Chile (Dillon, 1991; Brako and Zarucchi, 1993; Rundel et al., 1997; Rundel and Dillon, 1998). The most noticeable species are the ones that have invaded sandy soils, covering vast areas and forming specialized communities called "*tillandsiales*". Their distribution has been well studied in Peru (Oka and Ogawa, 1984), where is known that they are located in patches from Trujillo (8°S) to Tacna (18°S). Eight sandy species form *tillandsiales* in Peru: *T. capillaris*, *T. landbeckii*, *T. latifolia*, *T. marconae*, *T. paleacea*, *T. purpurea*, *T. recurvata* and *T. werdermannii*. In these usually monospecific communities, plants form parallel bands perpendicular to fog penetration or round mounds (Fukushima, 1969). In northern and central Peru, *Tillandsia* lomas occur at high densities both near the ocean and in inland locations (Rundel and Dillon, 1998). In central Peru, they are located between 600 and 700 m of altitude and their altitudinal range increases southwards reaching between 750 and 1100 m in southern Peru, and between 900 and 1300 m in northern Chile (Oka and Ogawa, 1984; Ono, 1986).

Knowledge of *Tillandsia* species in Chile is limited and fragmentary (Rauh, 1985b; Zizka and Muñoz-Schick, 1993). According to Rauh (1985a), the southern limits of *Tillandsia* lomas are located near Iquique. Similarly, Rundel et al. (1997), probably the most comprehensive study of *Tillandsia* lomas in Chile, indicate that they are rare in Chile and localized mainly to the West of Iquique. However, these studies (see also Cereceda et al., 1999) have been restricted in spatial extent. In this paper we characterize the geographic distribution of *Tillandsia* lomas in northern Chile, as well as their floristic composition and spatial extent of each community. We show that *Tillandsia* lomas are not rare in the region and follow a distinct pattern of distribution associated to the existence of major fog corridors along the costal area.

## 2. Materials and methods

### 2.1. Study area

The costal zone of the Atacama Desert in northern Chile has a remarkable homogeneous temperature (18 °C). The average annual precipitation at Iquique has been

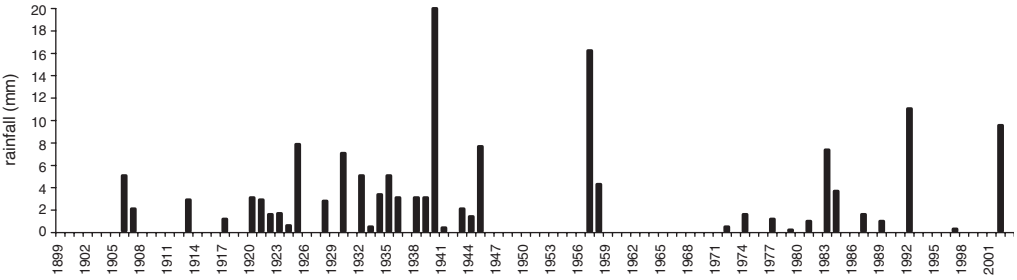


Fig. 1. Precipitation time-series for Iquique (data from Almeyda (1948) and DMC Dirección Metereológica de Chile).

around 2 mm for the last 100 years (Fig. 1). Although always low, precipitation levels are highly variable due to local topographic factors and large-scale climatic phenomena. Topography comes into play as the result of the regular formation of thick stratocumulus cloud banks below 1000 m, which, when intercepted by steep coastal slopes, give rise to a fog zone that allows the development of the *Tillandsia* lomas. The other source of climatic variability is associated with "El Niño Southern Oscillation" (ENSO) an oceanographic phenomenon that creates brief events of heavy rainfall and increases fog duration and intensity (Dillon and Rundel, 1990; Muñoz-Schick et al., 2001).

The characterization of the spatial distribution of *Tillandsia* lomas communities in northern Chile was based on: (1) seven flights along the costal area between Arica (18°20′S) and the Loa river (21°25′S), which allowed us to locate stands for subsequent field surveys. (2) More than 30 field surveys across the region carried out between 2001 and 2004, which allowed for the ground-truthing of the data collected from flight as well as to survey new areas. (3) Analysis of specimens deposited at the Herbario de la Universidad de Concepción (CONC) and Museo de Historia Natural de Santiago (SGO) and finally (4) photo interpretation of existing aerial photographs (scale 1:70,000) from years 1996 SAF (Servicio Aéreo Fotogramétrico) and 1955 IGM (Instituto Geográfico Militar) for the coastal area around Iquique and for selected localities of difficult access near the border with Peru or in restricted access areas (Military owned land). Based on this information we developed a distributional map using a GIS platform (ArcGIS v8.3) based on a digital cartography of the area at scale of 1:250,000 and 1:50,000 for regional and local spatial analyses, respectively. Locality names refer to the nearest toponymy. To analyse the latitudinal variation in area of known Tillandsiales we used a polynomial regression analysis (Sokal and Rohlf, 1995) and fitted a model of the form $Y = a + b \times \mathrm{Lat} + c \times \mathrm{Lat}^2 + d \times \mathrm{Lat}^3$, where latitude South (transformed to centecimal degrees) was used as the independent or predictor variable, and the area of Tillandsiales was the response or dependent variable. Taxonomy follows the recommendations of Smith and Downs (1977), Till and Vitek (1985) and Till (1989).

## 3. Results

In total we recorded more than 30 stands of *Tillandsia* lomas in northern Chile grouped in 10 systems or Loma communities with a distinct distribution and under the influence of a different fog input or corridor. *Tillandsia* loma communities were detected between

900 and 1200 m altitude (Fig. 2), in a linear area of 470 km from Arica (18°20′S) to the Loa River (21°25′S) with a large distributional gap (ca. 120 km) from Camarones (19°15′S) to Iquique (20°12′S). These communities are located from 3 to 45 km inland and form either continuous units of a couple of kilometers or isolated patches in sandy plains, small ravine bottoms or slopes, mainly exposed to the W and SW at the top of small hills (Table 1, Fig. 3). A total of three species were detected: *T. landbeckii*, *T. marconae* and *T. virescens.* However, most *Tillandsia* lomas are formed almost exclusively by *T. landbeckii* with one exception (*T. marconae* at Arica). The other species *T. virescens* was found forming small isolated patches associated to two *T. landbeckii* lomas. Tillandsiales can be grouped in ten large systems: 5 at the Arica province and 5 at the Iquique province, covering an approximate area of 69 $km^2$ (Table 1). Area is a non-monotonic function of latitude with a maximum between Lat. 20°13′S to 20°48′S (Fig. 4). Latitude explains a significant proportion of variance in area ($R^2 = 0.92$, $p = 0.014$). In the following section we provide a detailed account of each of the 10 different *Tillandsia* Loma communities or systems we recorded.

### 3.1. Arica

1. *Río Lluta*: This system is formed by five *Tillandsia* stands composed of small patches mainly in the northern side of the valley, at Quebrada de Mollepampa (18°22′S, 70°04′W) and throughout Cordón de San Martín (18°23′S) from 70°03′ to 70°00′W to later reemerge at 69°57′W in front of the locality of Molinos. At the valley's southern slope there are small patches at Cerro Hospicio (18°25′S, 70°01′W), at Quebrada Cardones' northern slope, tributary of the Lluta River (18°24′S, from 69°57′ to 69°56′W). A *Tillandsia* loma formed mainly of *T. marconae* is located at Portezuelo de Poconchile or Pampa Dos Cruces, at the road that joins the Azapa Valley with the Lluta Valley (18°28′S from 70°05′ to 70°04′W).
2. *Quebrada de Azapa*: The system is formed by *Tillandsia* stands distributed on both sides of the ravine, one on the northern slope at Cerros de Chuño (18°32′S, 70°04′W) and two on the south side, at Cerro Pan de Azucar's slope (18°36′S, 70°01′W) and on the plain (18°37′S, 70°04′W). At Quebrada del Diablo, a northern tributary of the Azapa Valley, the *Tillandsia* lomas can be found to the south of the old International road to Bolivia. It is formed by two *Tillandsia* stands distributed on both sides of the ravine's slopes (18°30′S, 70°05′W). The south-facing slope has isolated dead patches.
3. *Quebrada La Higuera*: Southern tributary of the Azapa Valley. *Tillandsia* stands can be found at northern slope (18°42′S, 70°09′W).
4. *Quebrada Vitor*: The system is formed by a large *Tillandsia* lomas found on the northern end of Pampa Camarones (18°52′S, from 70°07′ to 70°01′W) between 970 and 1200 m altitude. It can be accessed from the south on route 5 through Cuesta Chaca. It is practically dead, formed by 50 cm high sandy round mounds with evidence of dead *Tillandsia* layers. However, at 1000 m altitude small cushions of live plants can be observed. This represents only 1% of the population.
5. *Quebrada Camarones*: This system is formed by three *Tillandsia* stands at the southern end of Pampa Camarones, at Cerro Ballenatos (19°04′S, from 70°07′ to 70°05′W), at the northeast of Cerro Cuya (19°09′S, 70°08′W) and at Quebrada de Suca (19°14′S, 69°54′W). The latter can be seen from route 5 near Cuesta Chiza.

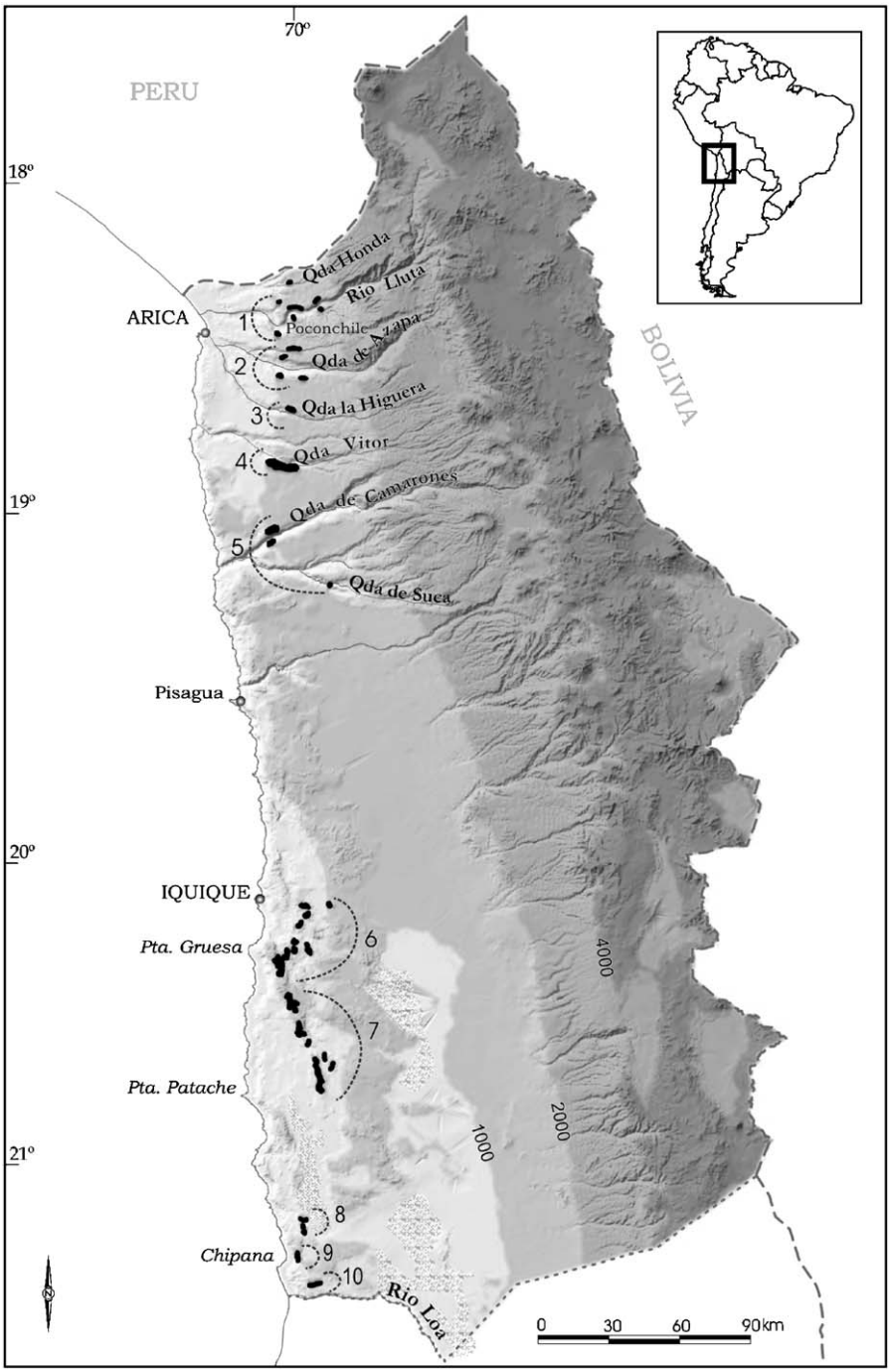


Fig. 2. Distribution of *Tillandsia* lomas formations in the Coastal Atacama Desert, northern Chile. Numbers identify the systems described in the text.

Table 1
*Tillandsia* loma systems registered in northern Chile

| Species | Province | No. | *Tillandsia* lomas systems | Latitude | Area ($km^2$) | Total ($km^2$) |
|---|---|---|---|---|---|---|
| *T. landbeckii* | Arica | 1 | Quebrada río Lluta | 18°23′S–18°28′S | 2.3 | 28.7 |
| *T. marconae* | | 1 | Quebrada río Lluta | 18°23′S–18°28′S | 0.6 | |
| *T. landbeckii* | | 2 | Quebrada Azapa | 18°30′S–18°37′S | 3.3 | |
| *T. landbeckii* | | 3 | Quebrada La Higuera | 18°42′S | 1.4 | |
| *T. landbeckii* | | 4 | Quebrada Vitor | 18°52′S | 14.9 | |
| *T. landbeckii* | | 5 | Quebrada Camarones | 19°04′S–19°14′S | 6.2 | |
| *T. landbeckii* + *T. virescens* | Iquique | 6 | C° Guanacos–C° Isla | 20°12′S–20°26′S | 18.5 | 39.9 |
| *T. landbeckii* | | 7 | C° Oyarbide–C° Pajonales | 20°29′S–20°48′S | 17.6 | |
| *T. landbeckii* | | 8 | Cerro Península | 21°12′S | 1.2 | |
| *T. landbeckii* + loma rich in species | | 9 | Cerro Chipana | 21°18′S | 1.1 | |
| *T. landbeckii* | | 10 | Quebrada río Loa | 21°23′S | 1.5 | 68.6 |

Fig. 3. Monospecific stand of *Tillandsia landbeckii* at Cerro Guanacos. Photo by A. Kirberg.

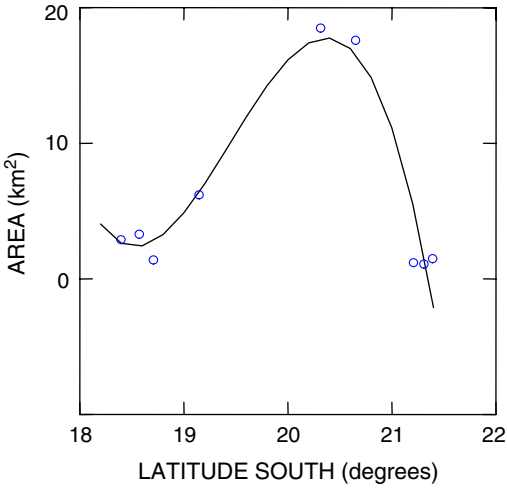


Fig. 4. Latitudinal distribution of the area covered by recorded *Tillandsia* lomas along the Coastal Atacama Desert, northern Chile. The system found at Quebrada Vitor was excluded from the analysis as it is composed of mostly dead mounds covered by sand.

### 3.2. Iquique

6. *Cerro Guanacos—Cerro Isla*: This *Tillandia* loma community goes inland at a 45° angle to the NE from the coast. The system includes at least eleven *Tillandsia* stands, distributed from Cerro Guanacos (20°23′S, 70°06′W) near the coast to Cerro Isla (20°13′S, 69°54′W) further inland. The largest systems are found between Cerro Guanaco and Cerro Oyarbide (20°25′S, 70°05′W). Other *Tillandsia* stands are located at Cerro Huantajaya (20°13′S, 70°W), Minas Viejas (20°15′S, 69°59′W), Cerro Carpas (20°17′S, 70°01′W) and El Godo (20°20′S, 70°02′W). For this system we recorded the presence of *T. virescens* growing on rocks in two *Tillandsia* stands, Cerro Isla and Cerro Carpas.
7. *Cerro Oyarbide Sur—Cerro Pajonal*: This system goes inland at a 25° angle to the SE from the coast. The system includes at least six *Tillandsia* stands, distributed from Cerro Oyarbide Sur (20°30′S, 70°03′W) to Cerro Pajonal (20°48′S, 69°57′W). The widest one is found between Cerro Oyarbide Sur and Cerro Soronal (20°34′S, 70°02′W). Other *Tillandsia* stands are found south-west of Salar Soronal (20°37′S, 70°W) and at Cerro Pajonal III (20°41′S, 69°59′W).
8. *Cerro Península*: This system is formed by at least four *Tillandsia* stands distributed at the mountain ranges to the west and south of Cerro Península (21°10′S, 70°W), at the southern end of Salar Grande. It is formed by sparse and isolated stands of *Tillandsia.*
9. *Cerro Chipana*: This *Tillandsia* loma community is located at the southern range of Cerro Chipana (21°16′S, 70°01′W). It is close to the coast and shares its habitat with shrubby and herbaceous lomas. Between the most characteristic species, we can find the cactus *Eulychnia iquiquensis*; shrubs such as *Tetragonia angustifolia*, *Lycium deserti*, *Ophryosporus floribundus*, *Nolana peruviana* and *Nolana sedifolia*; geophytes such as *Oxalis thyrsoidea*, *Alstroemeria violacea*, *Leucocoryne appendiculata*, *Oziroe biflora*;

and annual herbs such as *Polyachyrus* and *Cristaria* among others. At this site *T. landbeckii* was also detected growing on cacti.

10. *Quebrada Rio Loa*: This *Tillandsia* loma community was only recorded through an air survey. It is composed of isolated stands to the north of the Loa river west of Cerro Quebradillas (21°23′S, 96°58′W).

## 4. Discussion

Of the 15 species recorded in the coastal desert of Peru, eight of them form *Tillandsia* lomas. From these only three are present in the coastal Atacama Desert in northern Chile: *T. landbeckii*, *T. marconae* and *T. virescens*. The *Tillandsia* lomas in Chile are formed by *T. landbeckii* and *T. marconae*, being *T. landbeckii* the dominant species.

According to Rauh (1985a) the southern limit of *Tillandsia* lomas is located in Iquique. However, our data shows that they are also found further south near the Loa River. The southern limit of *Tillandsia* lomas is probably set by the intensity of fog flux, and this decreases for north to south along the coast in northern Chile (Larraín et al., 2002). Similarly, the altitudinal limits as well as how far inland these communities can develop, is likely set by fog moisture availability. In fact, Cereceda et al. (2002) report a drastic decrease in fog fluxes when comparing coastal (3 km from coastline) against inland (12 km from coast) sites (8.5 and 1.1 $l\,m^{-2}\,day^{-1}$, respectively).

At a finer scale, *Tillandsia* loma communities are strongly associated with the coastal topography and located in areas where there is enough fog and where the inland penetration of moisture is allowed (e.g. areas serving as fog corridors along the Coastal Cordillera see Cereceda et al., 2002). In Arica these areas are associated to deeps ravines. In Iquique instead they are associated with corridors formed when high altitudes (around 1300 m) are present near the coastline and where the cliff is relatively lower (400–600 m) allowing fog entry. Deep ravines allow fog penetration at greater distances from the coast. This fact can be observed at Lluta Valley, where *Tillandsia* lomas are found at 45 km from the coast. In Tacna, southern Peru, the coastal cliff disappears and the slope softly climbs from the coast allowing greater inland fog entrance where they go as far as 60 km from the coast. The fog corridors that feed the two larger *Tillandsia* loma systems are located between Iquique and Patache (20°13′S and 20°48′S). The largest concentrations of continuous *Tillandsia* stands are located at the starting end of these corridors, 8 km from the coast. They are located in sandy plain areas and are fed by the sand that is carried by the wind from the large dune formations located to the west.

*Tillandsia* lomas in Chile, as the ones in southern Peru, are located only in the upper border of the fog ecosystems. The only *Tillandsia* loma that shares its habitat with shrubby and herbaceous vegetation is found at Cerro Chipana, which is the one closest to the coast (3 km). They are generally monospecific communities as indicated by Rundel et al. (1997); however, we found two exceptions to this trend: the *Tillandsia* loma found at Portezuelo de Poconchile in Arica that comprises two species: *T. marconae* and *T. landbeckii* and the one in Cerro Carpas and Cerro Isla in Iquique where *T. landbeckii* shares its habitat with a small population of *T. virescens*.

In general, most records of *Tillandsia* in Chile have been linked to the presence of roads, which in part explains why most authors believed that *Tillandsia* were only restricted to a very few spots in northern Chile (e.g. Abele, 1981; Rauh, 1985a, b; Rundel et al., 1997;

Cereceda et al., 1999). However, this study demonstrates that *Tillandsia* lomas in Chile are more widely distributed than previously believed due to lack of exhaustive surveys, as the one herein reported. Other records of *T. landbeckii* that were not visited by land during this research, although they were detected by means of aerial photographs, were the ones at Quebrada Honda, Pampa de Chaca and Quebrada La Higuera (Fig. 2). For Pampa Chaca there are specimens of *T. landbeckii* collected by Kuschel in 1946 (SGO), Sudzuki in 1948 (SGO) and Ricardi in 1972 (CONC).

The *Tillandsia* lomas herein reported were found in different level of degradation. Our field observations sustain the claim that in general they reach more cover and form more extensive and well-developed belts near the coast and become more sparse inland. Almost all *Tillandsia* lomas show in their lower limits (ca. 900–960 m) evidence of dead *Tillandsia* buried under the sand. Similarly, we found a complete stand (Quebrada Vitor) in the same condition composed of dead individuals buried in the sand. This phenomenon might be linked to changes in the intensity of fog fluxes. Thus, as suggested by Rundel et al. (1997) *Tillandsia* lomas deserve special attention as bioindicators of climatic changes.

In addition to natural perturbations, recreational activities associated to desert rallies by motorcycles and 4 wheel drive vehicles are becoming progressively more common and massive, emerging as a threat to lomas communities as they dislodge plants and run over *Tillandsia* stands. A regulation and better control of these activities is highly desirable, even though *T. landbeckii* is not endangered due to its large abundance and distribution in the region. However, *T. marconae* and *T. virescens* should be considered as vulnerable, since the first species was detected in only one site (Portezuelo de Poconchile) and the second one is very rare and localized. Unfortunately, so far no lomas community is within any protected area in this region. We hope this situation will change in the near future.

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