

# Geographical Description of Three Fog Ecosystems in the Atacama Coastal Desert of Chile\*

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## ABSTRACT

During the past century the precipitation measured at the Atacama coastal desert was less than two millimetres as an annual average, 60% of the years Iquique did not receive a drop of rain. These are extremely difficult conditions for vegetation to grow and develop. However, some small ecosystems or oases can still be found at the Cordillera de la Costa. They are maintained with fog water. In almost 7 years of measurements at the oasis of Alto Patache, it was found an average of 7,8 L m<sup>-2</sup> d<sup>-1</sup> of fog water collected by SFC. These fog oases are located in a mega cliff and in mountains close to the sea, also they can be found farther inland along fog corridors. The Alto Patache ecosystem (20°49'S-70°09'W) shows a variety of shrub and herb species, depending on altitude, type and orientation of relief, plateau or cliff. The Pajonales (20°30'S-70°00'W) ecosystem is monospecific, being *Tillandsia landbeckii* (Bromeliaceae) the only species recognized. The Chipana oasis (21°15'S-70°03'W) is composed mainly by cacti *Eulychnia iquiquensis* in association with shrub and herb species. These oases have been studied from a biogeographical point of view. Several parameters regarding flora (number of species), structure of the vegetation (density, coverage, vitality) and geographical features (form of relief, altitude, micro-topography, slope exposure, substrate and soils) were measured and analysed. The results show that the oases studied lie at altitudes between 400 and 1200 m.a.s.l., being altitude, relief exposure to the predominant winds (SW, S) and substrate significant factors of presence and vitality of vegetation.

## 1. INTRODUCTION

The Atacama coastal desert is located in the northern part of Chile and is known for its extreme aridity. With an annual rainfall less than 2 mm in Iquique, the environmental conditions are very restrictive for the development of ecosystems. Fog oases are located usually near the coast, in mountain slopes, cliffs or plains at altitudes between 400 and 1.200 m.a.s.l. However, there are places inland where vegetation is scattered in the Cordillera de la Costa at different distances from the coastline. The location of these ecosystems are directly affected by the presence of stratocumulus cloud that when intercepted by the relief, advective fog is formed. Also, there is frequent orographic clouds in the summit of coastal hills or in the mega cliff that is present along the coast of northern Chile (Figure 1).

These xerophytic vegetation has been studied mainly by botanists, being the most recent surveys done by Rundel (et al., 1997), Muñoz-Schick (et al, 2001), Pinto and Marquet (2002). Geographical studies in relation to vegetation and entomofauna of this fog oases have been done by Cereceda (et al, 1999), Larrain (et al., 2001) and Egaña (et al., 2004). It is

important to study these ecosystems since the expected Climatic Global Change may be a serious problem for its survival and they are not sufficiently known. Some researchers are looking at plant evolution as an indicator of climate change.

## 2. GEOMORPHOLOGY AND CLIMATE

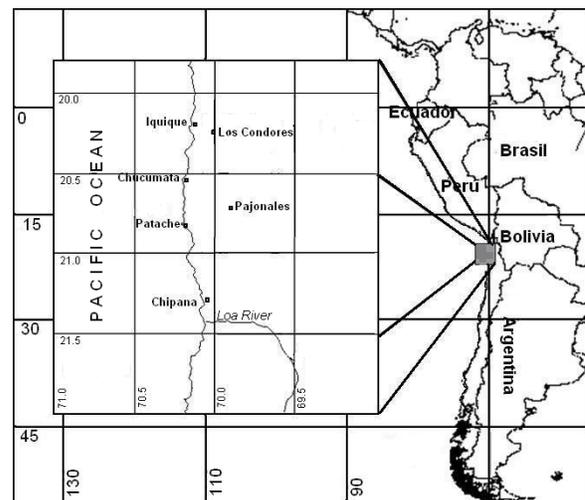


Figure 1. Study area

The fog oases are located in the Cordillera de la Costa, a mountain range that is present along the coast of western South America. In Tarapacá, this mountainous area have summits over 1,500 m of altitude. The area has from west to east a narrow littoral plain of an average of two kilometres, and a small piedmont that leads to a very steep cliff that ranges from 400 m to 1,000 m. The cordillera is formed of a series of hills and plains in a strip of about 50 km between the ocean and an intermediate depression that lies on the base of Los Andes. Corridors or plateaus are formed between the hills of cordillera de la Costa; wind and fog penetrate into the interior of the continent by them. Fog oasis can be observed in the cliff above 400 m, in the high plains near the coastline, and in mountain slopes facing the predominant winds (S, SW) that advect the stratocumulus cloud.

The Dirección Meteorológica de Chile recorded data in the surroundings of Iquique, in Los Córdoros between 1949 and 1966 in the coastal mountain range, 5 km from the sea at 515 m.a.s.l. Since 1970 has recorded data in the littoral plain in Cavanca and in Diego Aracena in Chucumata. Between 2001 and 2003 in Alto Patache, at 750 m.a.s.l., temperature and humidity sensors have been recording data in an hourly basis (Table 1); the information is not sufficient to characterize the climate of the area, but

gives an interesting preliminary approach. It is important to discuss the elements of the climate where these fog oases are located, since factors such as relief, altitude and distance to the sea make a great difference on their behaviour. The conditions will vary if the site studied is within the altitudes of the stratocumulus cloud, above or below. These will alter specially temperature and humidity. Relief is important in wind behaviour and the orographic component in the occurrence of fog and precipitation. As it can be seen in Table 1, annual temperature average is much lower in the high altitudes, there are 6 °C between Diego Aracena at 12 m of altitude and Alto Patache at 750 m. The maximum average temperatures are higher in the littoral plains and the minimum are lower in the coastal range as expected; the absolute minimum of Los Córdoros show a more continental pattern than the other places. The annual temperature difference between the warmest and coldest months is higher in Los Córdoros and Alto Patache, while in the littoral stations the influence of the sea moderate the temperatures. It is remarkable the high relative humidity of Alto Patache, probably due to the persistent fog that can be found there and the altitude that defines a cooler environment. Los Córdoros at 515m often is covered by fog, but is located near the base of the stratocumulus cloud. All the other stations show relative humidity below 70 %.

(T°) Temperature °C (%) Relative humidity (R) Rain mm (WS) Wind speed knots	Los Córdoros 20°15'S-70°07'W 1949-1966 515 masl	Cavanca 20°12'S-70°11'W 1970-1980 6 masl	D. Aracena 20°13'S-70°10'W 1981-2001 12 masl	Alto Patache 20°49'S-70°09'W 2001-2003 750 masl
T° Annual average	14.6	17.9	18.5	12,5
T° Annual maximum average	18.5	21.2	22.0	16,9
T° Annual minimum average	10.1	15.4	16.1	9,6
T° Absolute maximum	30.0	29.4	31.2	30,5
T° Absolute minimum	1.0	7.3	7.6	4,5
Annual temperature difference	8.3	5.6	6.5	7,7
% Annual humidity average	76.9	73.5	68.8	82,8
R Annual average	1.7	0.27	1.27	No data
R Highest daily in the period	16.0	1.5	11.0	No data
Wind direction at 14:00 hour	W	SW	SW	S
Wind speed at 14:00 hour	6.5	5.7	12.7	No data

**Table 1. Temperature, relative humidity, rain, wind direction and wind speed in Los Córdoros, Cavanca, Diego Aracena and Alto Patache in the nearby of Iquique, Tarapacá, Chile (Cereceda, paper in preparation).**

Rain has extremely low average. A study done of the data of these stations between 1899 and 2000, showed in that period an average of 1,7 mm, 60% of the time there was no rain (Cereceda et al., 2004). The relief is an important factor of wind direction and speed. Los Córdoros located in a fog corridor have winds that during the day are from the west and in the early morning, from the east. The other stations that face directly the ocean, show regular winds from the

south and southwest (trade winds) and the speed is considerably higher at Diego Aracena located in an outstanding point (Table 1).

Fog has been surveyed since 1997 in Alto Patache at 850 m.a.s.l. and in Cerro Guatalaya (20°12' S / 70°00' W) at 1,065 m in an inland site, 14 km from the coast. No other measurements have been done in Tarapacá. Larrain (et al., 2002) reported an average for Alto Patache of 7,8 L m<sup>-2</sup>d<sup>-1</sup> of fog water collected and for

Cerro Guatalaya,  $0,93 \text{ L m}^{-2}\text{d}^{-1}$ . Figure 2 shows the extreme seasonal variation. GOES images (Figure 3) has showed that the maximum expansion of the stratocumulus cloud in the continental area of Tarapacá occurred during August 2001 at 7:30 GMT and the minimum at 16:30 GMT (03:30 and 12:30 local time). This means that in winter, places in the altitude of the stratocumulus cloud will have high

probability of fog during the night especially after midnight until dawn and around midday probably the site will be in sunshine. At sunset fog begins to roll from the cliff near the sea into the Cordillera de la Costa by the corridors. The altitude of the cloud base varies along the year, according to the inversion layer; it is lower in winter and higher in summer.

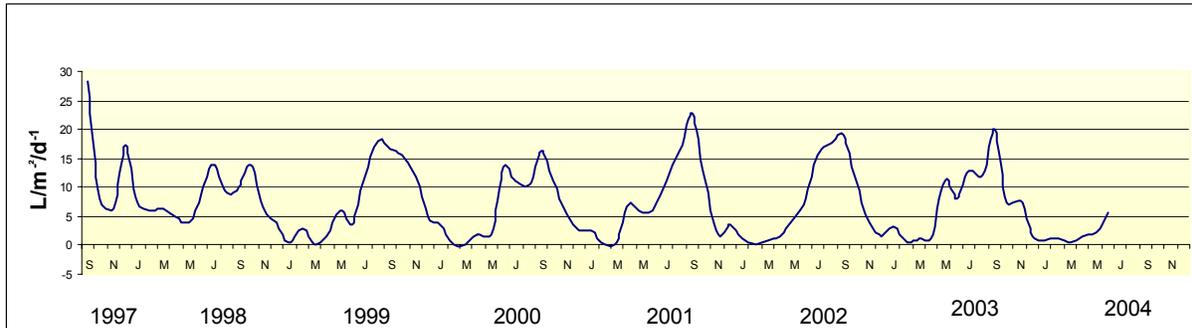


Figure 2. Fog water collections at Alto Patache at 850 m.a.s.l.

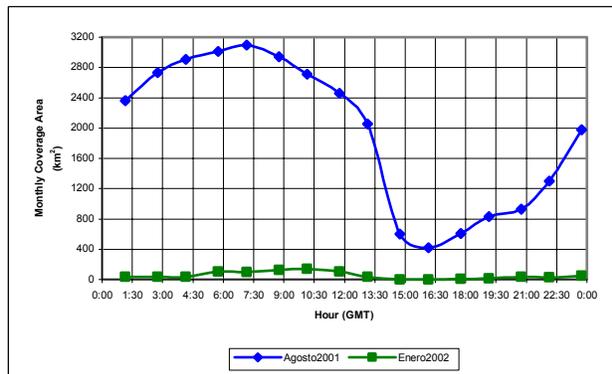


Figure 3. Hourly Stratocumulus Continental Coverage. Comparison August 2001 and January 2002

### 3. THE FOG OASES

The following characteristics will be described for each oasis: geomorphological feature, exposition, altitude, slopes, microtopography and substrate, and type of vegetation, species and vitality. The methodology used has been described in Cereceda et al, 1999, in Cereceda et al, 2003 and Egaña et al., 2004. Basically it consists in the selection of transects and sampling sites for the identification of species, number of plants, and evaluation of vitality. The geographical parameters are measured in maps and in the sampling plots in the field.

#### 3.1. Alto Patache oasis

Is an oasis of herbs, shrubs and cacti. The sampling area that is described here is located in a cliff facing south, 3 km from the coastline and from 350 m to 850 m. The slope varies from  $24^\circ$  to  $53^\circ$  and it is formed

in the upper part of the cliff by rocky substrate frequently cracked (fissures) with small terraces and sandy environment in the lower altitudes. In 18 sampling sites of  $25 \text{ m}^2$  were studied.

The number of shrubs measured were 186 in  $450 \text{ m}^2$ . The species most frequent in the sampling area were *Lycium leiostemum*, *Nolana sedifolia*, *Frankenia chilensis*, *Atriplex taltalensis*, *Ephedra breana* and *Lycopersicon chilense*. 44% of the individuals were alive, the coverage in the plots was 15% and the density was  $0,37 \text{ individual/m}^2$ . The most frequent species were *Lycium leiostemum* and *Nolana sedifolia*, with 63 and 50% of absolute frequency. The most abundant species was *Frankenia chilensis*, that means that was regularly present in all the plots of  $25\text{m}^2$ . The most frequent herbs in the sampling area were *Alstroemeria lutea*, *Oxalis thyrsoides*, *Leucocoryne appendiculata* and *Oziroë biflora*. According to the Whitford Dispersion Index, 86% of the species tend to cluster or to live in association. A correlation analysis was done between the phytosociological and environmental parameters and the results showed that altitude and slope are the most relevant factor in the location of the vegetation. Another interesting result was the importance of the substrate and orientation with equal importance in the presence and vitality of vegetation. Rocky and cracked substrate are good fog water collectors and also good reservoirs where plants can protect themselves from the wind and with their long roots can look for water and nutrients.

#### 3.2. Alto Chipana oasis

Is an oasis composed mainly by the cactus *Eulychnia*

*iquiquensis* and some small sub shrubs and herbs that live on the fog water that their trunks collect. It is a cactus that in the sampling area has an average size of 2,4 m high with a maximum of 8 m and the average diameter in its base is 0,26 m; some old alive individuals of 0,70 m in its base were found. The study area is located in a mountain of 1,152 m of altitude at 3 km from the coastline and in one of the surveys done, 156 individuals were measured between 840 and 965 m.a.s.l. where the first and last cactus was found. However, *Eulychnia iquiquensis* can be seen at altitudes between 300 and 1,000 m. The slopes where the cacti were studied had an average of 23° and the substrate was mainly gravel of different sizes. The general vitality was 40%, and there are many dead cacti that are still standing with its structure complete. An average of regeneration of the population of 8% was found in the sampling area, where juvenile individuals of different sizes were recognized. The associated species found in the sampling area were: *Frankenia chilensis*, *Ophryosporus floribundus*, *Solanum brachyanterum* and *Atriplex taltalensis*. Also some geophytes such as *Oxalis thyrsoides* and *Alstroemeria violacea*. The environmental factor that was found as predominant was the orientation of the relief to the predominant wind from the sea (S, SW and SE). It is interesting that in the last 200 m there were no cacti.

### 3.3. Pajonales oasis

Only one species has been recognized in this fog oasis, the Bromeliaceae, *Tillandsia landbeckii*. It does not anchor itself in the soil and live practically only on fog water. The oasis is located in a fog corridor (W-E) of 40 km of width that connects the coast with the above mentioned intermediate depression; the oasis is formed by a series of inselbergs that form a mountain range of 13,7 km in direction N-S, the highest summits are in Pajonales III (1,072 m) and in Pajonales I (1,215 m). It lies 23 km from the coast and its substrate is formed of sand. The bands of *Tillandsia landbeckii* are located at altitudes between 850 m and 1,215 m. Altitude and relief exposition are important factors: 74% of the vegetation in Pajonales III is located in slopes facing in directions from SE to W; and in that orientation, plants are more abundant and with better vitality.

### 4. CONCLUSIONS

The mean annual rainfall of less than 2 mm confirm the fact that the studied oases of cacti, shrubs and *Tillandsia landbeckii* are maintained by fog water and have special climatic behaviour in relation to temperature, humidity and wind. These elements are

different in the meteorological stations located in the littoral plains and the ones in the Cordillera de la Costa.

In the studies of the relation of vegetation and climate, meteorological data must be analysed carefully with regard to the geographical parameters discussed here.

Altitude is the most important factor in the presence of vegetation of all the oases studied and is related to the top and base of the stratocumulus cloud frequent in the area. The orientation of the relief to the S and SW winds is also very important in all the sites. In Alto Patache the microtopography and substrate is decisive; in Alto Chipana, the relief orientation and in Pajonales the presence of the mountain range that intercept a fog corridor.

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