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Plant communities on the islands of two Altiplanic salt lakes in the Andean region of Bolivia

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Abstract: This paper reports a quantitative survey of the composition, diversity and structure of the plant communities on six islands of Uyuni and Coipasa salt lakes (Bolivia). Plant communities on each island were examined via the use of 10 transects, along which species richness and abundance were recorded. Seventy-one species were found in total, representing pteridophytes (6%), gymnosperms (1%), monocotyledons (14%) and dicotyledons (79%). About 21% of the species were endemic or faced some degree of threat. The calculation of Shannon-Wiener α-diversity indices and comparisons of community structure revealed similarities between the islands. Indeed these analyses suggest the existence of a single floral assemblage; however, small differences in the plant communities were visually identified during fieldwork. These islands are home to a considerable subset of the Altiplano's flora and appear to have been little disturbed. They should therefore be the subject of surveillance/conservation programs.

Key words: Coipasa salt lake; Uyuni salt lake; community structure; floral composition

INTRODUCTION

The Altiplano is a high intermontane plateau (4,000 m above sea level) surrounded by the Western (Cordillera Occidental) and Eastern (Cordillera Oriental) branches of the Central Andes in South America (Richter et al. 1992). It encompasses the endorrheic Basin of the Bolivian Altiplano, which was formed by Pleistocene lakes that dried out due to evaporation and tributaries reduction. This process left the present day Titicaca and Poopó lakes, the Uyuni, Coipasa and Empexa salt lakes, several rivers, and borate deposits (Clapperton 1983, 1993).

The Uyuni and Coipasa salt lakes have the largest salt crusts of the entire Andean region (Richter et al. 1992). Over the extensive area they occupy, ground elevations are isolated from the adjacent ranges by salt crust, saline soils, and water. The small size and difficulty in accessing these "islands" have prevented human settlement, agriculture, and animal husbandry. The economic potential of the salt lakes, however, has led to government policies that promote resource exploitation and tourism. Along with poor land planning, water contamination, deforestation, and grazing, these policies have led to wider ecosystem deterioration in the region (Luque 2011; Machaca 2011; Flores 2011).

In recent years, comprehensive accounts of the Altiplano's flora have been published, but virtually no studies have been made on the ecosystems sheltered by the types of island described above. A few descriptions (Navarro and Maldonado 2002; Navarro and Ferreira 2004; Navarro 2011) assume these islands to have floral assemblages and plant communities that are no different of the vegetation in surrounding areas, but most studies have simply neglected them.

Despite the economic interest aroused by these salt lakes, the biodiversity of their islands has never been systematically described. The present work is the first to examine the plant communities on six islands in the Uyuni and Coipasa salt lakes. The results help show the importance of these islands in terms of the region's biodiversity, and provide a baseline for future studies.

MATERIALS AND METHODS

Study site

The Uyuni salt lake is the largest lithium brine source in the world (10,582 km^2), while that of Coipasa is the second largest (2,218 km^2) within the Andean region (Richter et al. 1992; Montes de Oca 1997). Both are located in the southwest of the Bolivian Altiplano: Uyuni salt lake is located between 19°36′ S and 20°42′ S,

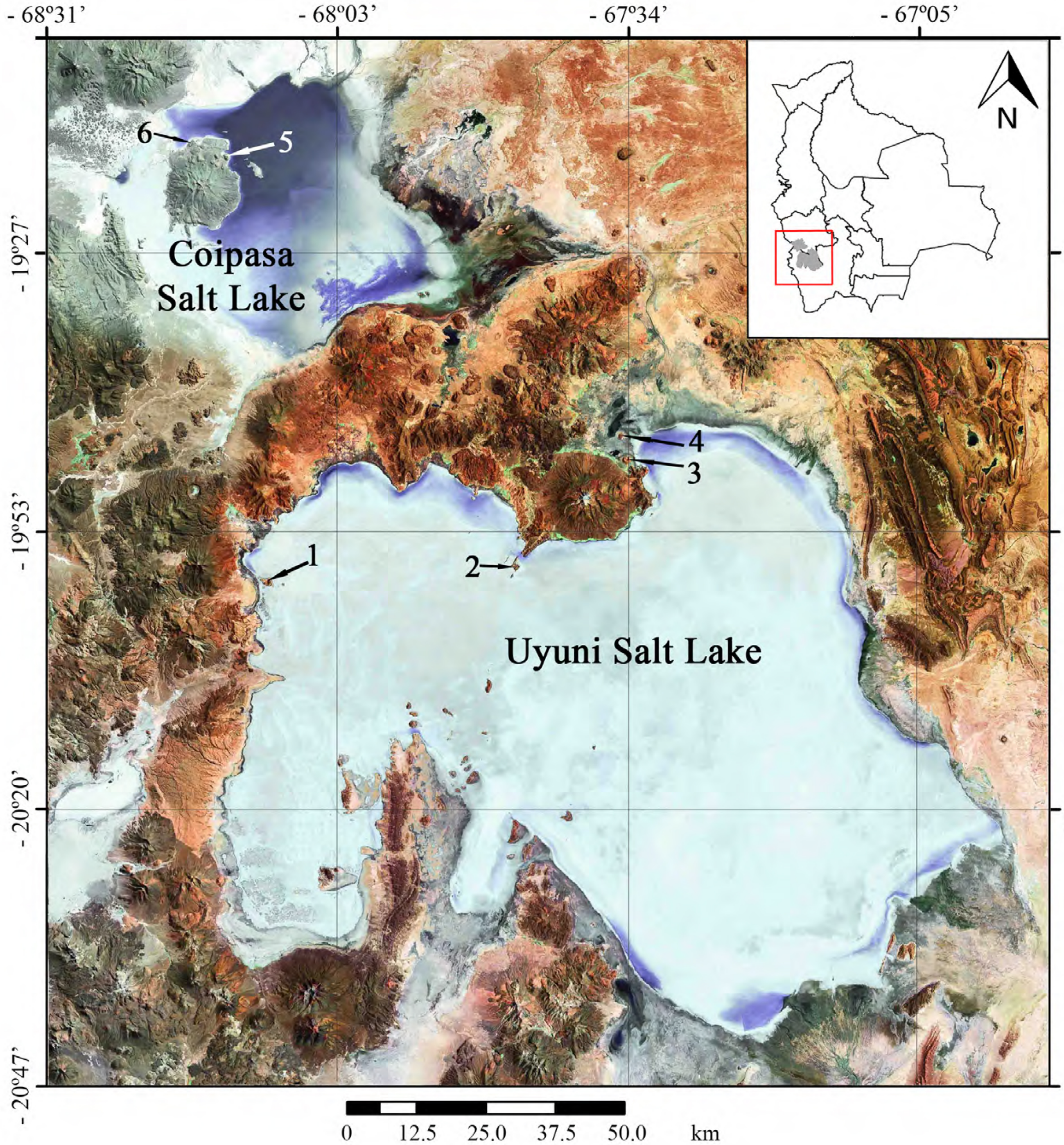

Figure 1. Map of the study area (southwest of the Bolivian Altiplano). Location of the studied islands (1) Chocontaquiza, (2) Tarahi, (3) Hara, (4) Chica Chica in the Uyuni salt lake; and (5) Wallerja, and (6) Incuta in the Coipasa salt lake.

and between 066°55′ W and 068°16′ W at 3,660 m above sea level; Coipasa salt lake is located between 19°08′ S and 19°37′ S, and between 067°51′ W and 068°28′ W at 3,657 m above sea level (Figure 1). The area belongs to the mid-south of the Altiplanic Biogeografic Province (Navarro and Maldonado 2002); this has the lowest precipitation of the region (170 mm per year), a wide range of temperature (ranging from −30°C at night to 15°C during the day), intense solar radiation, strong winds, and saline soils (Ballivián and Risacher 1981; Rafiqpoor et al. 2008). The stress-tolerant vegetation is characterised by small pastures, resinous bushes, cacti, and in some areas *Polylepis* trees (Ibisch et al. 2008).

Interlayered sedimentary (Cordillera Oriental) and volcanic rocks (Cordillera Occidental) rise within these salt lakes to form islands of different size and altitude. For the present work, four islands of the Uyuni and two of the Coipasa salt lake (Figure 2) were chosen on the basis of their reaching a minimum altitude of 110 m above the level of the surrounding lake. This

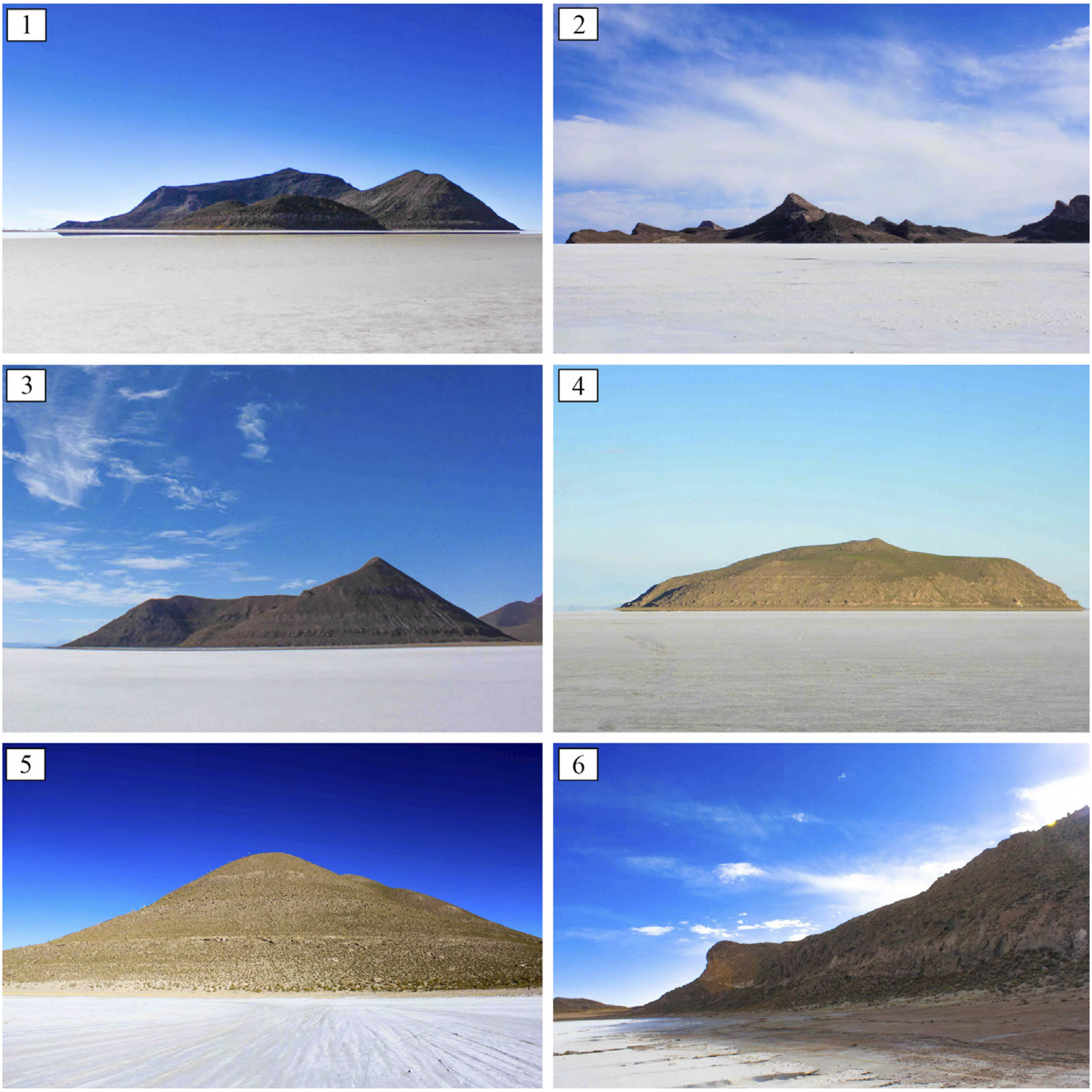

Figure 2. Uyuni salt lake: (1) Chocontaquiza Island, (2) Tarahi Island, (3) Hara Island, (4) Chica Chica Island. Coipasa salt lake: (5) Wallerja Island, (6) Incuta Island. (Photographs: Coca-Salazar).

allowed their plant communities to be assessed along an altitudinal gradient.

Data collection and analysis

At the end of the wet season of 2011 (March to May), 10 transects of 60 m × 2 m (modified from Villarreal et al. 2006) were laid on each island in order to record the vegetation present. The total area sampled per island was 1,200 m^2. Three transects were set up on the edge of each island (i.e., adjacent to the salt lake), five on the mountainsides, and two on the summit area. The required size, number and altitudinal distribution of the transects was established based on preliminary fieldwork and analyses (rarefaction curves). Plant species were collected for taxonomic examination. Species abundance was recorded by direct counting along the transects.

All specimens collected were processed and identified following conventional herbarium methods (Arrázola and Mercado 2004), and deposited at the Herbario Forestal Nacional Martín Cárdenas (BOLV). The habit (annual herb, perennial herb, shrub, or cactus) of each species was determined, along with its International Union for Conservation of Nature (IUCN) Red List category and endemism (Ministerio de Medio Ambiente y Agua 2012).

Species richness (number of species) and the Shannon-Wiener α-diversity index (Magurran 1989) were calculated for each island. The vegetation on different islands was compared via Kruskal-Wallis tests and Sorensen β-diversity (Bray-Curtis) indices (Herrera 2000). Comparisons of species abundance among transects were also performed (Kruskal-Wallis tests) to identify changes along the altitudinal gradient of each island. Finally, the quantitative structure of the vegetation was described based on plant density.

RESULTS

Seventy-one species were recorded (Table 1) distributed across 26 families and 58 genera; pteridophytes (6%), gymnosperms (1%), monocotyledons (14%), and dicotyledons (79%) were all represented. The families Asteraceae (19 species), Poaceae (7 species) and Cactaceae (5 species) were the most diverse, and together accounted for 44% of the species richness. Forty-nine genera were represented by a single species, the remaining nine by two or three species. Nine of the species recorded were identified as endemic to the Altiplano, and eight appeared classified under some IUCN Red List category (Table 1). The vegetation recorded included 34 species of herbs (48%), 32 species of shrubs (45%), and 5 species of cactus (7%). Herbaceous species were the most abundant on all islands, accounting for 86% of individual plants. Shrubs and cacti accounted for only 14%.

Table 2 shows the species richness, Shannon-Wiener α-diversity, and Sorensen β-diversity indices for the

Table 1. List of species found on the studied islands. Life Form (a-h = annual herb, p-h = perennial herb, s = shrub, c=cactus), endemism, Red List category (EN = endangered, VU = vulnerable, LC = least concern, DD = deficient data), and voucher information is shown for each.

	Families/Species	Life form	Endemism	Red List category	Voucher
	PTERIDOPHYTS				
	Pteridaceae				
1	*Cheilanthes pruinata* Kaulf.	p-h			27012
2	*Cheilanthes ternifolia* (Cav.) T. Moore	p-h			27013
3	*Notholaena nivea* var. *flava* Hook.	p-h			27045
4	*Notholaena nivea* var. *tenera* (Gillies ex Hook.) Griseb.	p-h			27046
	GYMNOSPERMS				
	Ephedraceae				
5	*Ephedra breana* Phil.	s	Endemic		27021
	MONOCOTYLEDONS				
	Amaryllidaceae				
6	*Clinanthus chihuanhuayu* (Cárdenas) Meerow	p-h			27019
	Bromeliaceae				
7	*Tillandsia virescens* Ruiz & Pav.	p-h			27069
	Juncaceae				
8	*Juncus* cf. *stipulatus* Nees & Meyen	p-h			27031
	Poaceae				
9	*Agrostis tolucensis* Kunth	a-h			27002
10	*Aristida asplundii* Henrard	a-h			27004
11	*Chondrosum simplex* (Lag.) Kunth	a-h			27016
12	*Distichlis humilis* Phil.	a-h			27020
13	*Munroa decumbens* Torr.	a-h			27040
14	*Nassella brachyphylla* (Trin.) E. Desv.	p-h		LC	27044
15	*Stipa curviseta* Hitchc.	p-h			27064
	DICOTYLEDONS				
	Amaranthaceae				
16	*Atriplex deserticola* Phil.	s			27006
17	*Atriplex imbricata* (Moq.) D. Dietr.	s		EN	27007
18	*Suaeda foliosa* Moq.	s			27065
19	*Gomphrena* cf. *meyeniana* Walp.	a-h			27014
	Apocinaceae				
20	*Philibertia gilliesii* var. *gracilis* (D. Don) T. Mey.	p-h			27057
	Asteraceae				
21	*Baccharis boliviensis* (Wedd.) Cabrera	s			27008
22	*Baccharis tola* Phil.	s			27009
23	*Chersodoma jodopapa* (Sch. Bip.) Cabrera	s			27015
24	*Chuquiraga atacamensis* Kuntze	s	Endemic		27017
25	*Chuquiraga spinosa* Less.	s	Endemic		27018
26	*Gamochaeta* sp. Wedd.	a-h			27025
27	*Gutierrezia gilliesii* Griseb.	s			27027

Continued

Table 1. *Continued.*

	Families/Species	Life form	Endemism	Red List category	Voucher
28	*Haplopappus rigidus* Phil.	s	Endemic		27029
29	*Lophopappus cuneatus* R.E. Fr.	s			27037
30	*Mutisia hamata* Reiche	s			27041
31	*Mutisia lanigera* Wedd.	s	Endemic	VU	27042
32	*Mutisia ledifolia* Decne. Ex Wedd.	s			27043
33	*Parastrephia lepidophylla* (Wedd.) Cabrera	s		EN	27051
34	*Parastrephia lucida* (Meyen) Cabrera	s			27052
35	*Parastrephia quadrangularis* (Meyen) Cabrera	s		VU	27053
36	*Senecio phylloleptus* Cuatrec.	s	Endemic		27058
37	*Senecio viridis* Phil.	s			27059
38	*Stevia* cf. *mandonii* Sch. Bip.	a-h			27063
39	*Tagetes multiflora* Kunth	a-h			27066
	Boragianceae				
40	*Phacelia pinnatifida* Griseb. Ex Wedd.	a-h			27054
	Brassicaceae				
41	*Halimolobus hispidula* O.E. Schulz	a-h			27028
42	*Lepidium bonariense* L.	a-h			27035
43	*Sisymbrium irio* L.	a-h			27060
	Cactaceae				
44	*Lobivia ferox* Britton & Rose	c			27036
45	*Opuntia armata* Backeb.	c			27047
46	*Opuntia boliviana* Salm-Dick	c			27048
47	*Opuntia soehrensii* Britton & Rose	c			27049
48	*Trichocereus atacamensis* (Phil.) W.T. Marshall	c		EN	27070
	Caryophyllaceae				
49	*Cardionema ramosissimum* A. Nelson & J.F. Macbr.	a-h			27011
50	*Spergularia pazensis* (Rusby) Rossbach	a-h			27062
	Euphorbiaceae				
51	*Euphorbia ovalifolia* Kostel.	a-h			27022
	Fabaceae				
52	*Adesmia polyphylla* Phil.	s			27001
53	*Astragalus arequipensis* Vogel	s			27005
54	*Hofmannseggia minor* (Phil.) Ulibarri	a-h		VU	27030
55	*Lupinus chilensis* C.P. Sm.	p-h			27038
	Frankeniaceae				
56	*Anthobryum triandrum* (J. Rémy) Surgis	s			27003
	Krameriaceae				
57	*Krameria lappacea* (Dombey) Burdet & B.B. Simpson	s			27033
	Lamiaceae				
58	*Salvia gilliesii* Benth.	s			27057
	Loasaceae				
59	*Caiophora chuquitensis* C. Presl	a-h			27010
	Malvaceae				
60	*Tarassa tenella* (Cav.) Krapov.	a-h			27067
	Oxalidaceae				
61	*Oxalis bisfracta* Turcz.	a-h			27050
	Polemoniaceae				
62	*Gilia laciniata* Ruiz & Pav.	a-h			27026
	Portulacaceae				
63	*Portulaca rotundifolia* R.E. Fr.	a-h			27056
	Rosaceae				
64	*Tetraglochin cristatum* (Britton) Rothm.	s			27068
	Solanaceae				
65	*Fabiana densa* Remy	s			27023
66	*Fabiana squamata* Phil.	s	Endemic		27024
67	*Lycium chanar* Phil.	s			27039
68	*Solanum brevicaule* Bitter	a-h			27061
	Verbenaceae				
69	*Acantholippia punensis* (Phil.) Botta	s			27000
70	*Junellia seriphioides* (Gillies & Hook.) Moldenke	s	Endemic		27032
71	*Lampaya castellani* Moldenke	s	Endemic	VU	27034

Table 2. Location, geological origin, and diversity descriptors for each island.

Salt lake	Island	Geologic Origin	Species Richness	Shannon α-diversity	Sorensen β-diversity Chocontaquiza	Tarahi	Chica Chica	Hara	Wallerja	Incuta
Uyuni	Chocontaquiza	Sedimentary rocks	41	2.52	–	0.56	0.81	0.92	0.66	0.45
Uyuni	Tarahi	Sedimentary rocks	47	1.90		–	0.73	0.62	0.88	0.85
Uyuni	Chica Chica	Stratovulcan deposits	40	2.75			–	0.88	0.84	0.60
Uyuni	Hara	Stratovulcan deposits	41	2.40				–	0.73	0.50
Coipasa	Wallerja	Stratovulcan deposits	44	2.29					–	0.74
Coipasa	Incuta	Stratovulcan deposits	42	2.18						-

different islands. The values of these descriptors indicate their plant communities to be similar. Indeed, no differences in vegetation were detected by the Kruskal-Wallis test (Hc=4.03; P>0.05). However, seven species restricted to the Uyuni islands (*Atriplex deserticola* Phil., *Fabiana squamata* Phil., *Krameria lappacea* [Dombey] Burdet & B.B., *Clinanthus chihuanhuayu* [Cárdenas] Meerow, *Oxalis bisfracta* Turcz, *Solanum brevicaule* Bitter, and *Caiophora chuquitensis* C. Presl) were recorded, as were three restricted to the Coipasa islands (*Cardionema ramosissimum* A. Nelson & J.F. Macbr., *Chilantes pruinata* Kaulf., and *Lupinus chilensis* C.P. Sm.).

No significant differences were seen in terms of species abundance along the altitudinal gradient of any island (Hc=2.21, P>0.05) (although the species present changed). The most abundant shrubs were *Baccharis boliviensis* (Wedd.) Cabrera (7,181.9 ± 1,107.1 ind/ha), *Fabiana densa* Remy (6,618.1 ± 1,681.5 ind/ha), and *Junellia seriphioides* (Gillies & Hook.) Moldenke (1,952.8 ± 470.6 ind/ha). These species represented 48% of all woody individuals. The shrub *Atriplex imbricata* (Moq.) D. Dietr. was abundant on the Uyuni islands (5,147.9 ± 1,049.6 ind/ha) but almost absent from the Coipasa islands (<10 individuals). The most abundant cacti were *Opuntia boliviana* Salm-Dick (1,459.7 ± 278.9 ind/ha), *Opuntia soehrensii* Britton & Rose (987.5 ± 380.9 ind/ha) and *Trichocereus atacamensis* (Phil.) W.T. Marshall (458.3 ± 72.8 ind/ha). Ferns were mainly represented by *Cheilantes ternifolia* (Cav.) T. Moore (563.9 ± 313 ind/ha), *Cheilantes pruinata* (479.2 ± 189.6 ind/ha) and *Notholaena nivea* var. *flava* Hook. (243.1 ± 118.9 ind/ha). Cacti and ferns together represented 11.8% of total woody individuals. Finally, *Agrostis tolucensis* Kunth (68,379.2 ± 2,669.2 ind/ha), *Spergularia pazensis* (Rusby) Rossbach (41,240.3 ± 9,067.0 ind/ha), *Tagetes multiflora* Kunth (26,348.7 ± 1,774.1 ind/ha) and *Euphorbia ovalifolia* Kostel. (13,794.4 ± 3,892.0 ind/ha) were the most abundant herbs, together accounting for 71.7% of the total herbaceous individuals. Quantitatively, these species shaped all the plant communities examined.

DISCUSSION

The species recorded make up some 30% of the 235 listed by Navarro and Maldonado (2002) for the Central Altiplanic Section, and are in line with other descriptions for this area (Navarro 1997; Montes de Oca et al. 2003; Navarro and Ferreira 2004, Ibish et al. 2008). The most diverse families — Asteraceae, Poaceae and Cactaceae — recorded were also mentioned by Montes de Oca et al. (2003). Verbenaceae and Brassicaceae were the next most diverse, as Montes de Oca also reported. Altogether, 21% of the species recorded were endemic or faced some degree of threat. These islands are therefore home to important fragments of floral diversity in the region.

Compared to the Altiplano as a whole, the species richness values for the islands were low. The Shannon-Wiener α-diversity indices were similar to those published in previous reports for the region (Ortuño et al. 2006), however, other authors have reported higher values for the Altiplano (Muñoz and Bonacic 2006; Galán de Mera et al. 2010). Since the examined plant communities are isolated from the adjacent mountain ranges (the minimum distance to the closest is 3 km) and from each other (the minimum distance between islands is 6.5 km), the low species richness and α-diversity values might be thought explicable by the island biogeography theory. They might also be explained, however, by the absence of human settlements, agriculture and animal husbandry — all of which increase the species richness and α-diversity of plant communities (Galán de Mera et al. 2010). The present findings thus suggest these ecosystems have suffered little disturbance. This is reinforced by the fact that islands have been preserved as sanctuaries by the native human population (T. Vargas, pers. comm. March 2011).

The lack of any statistical differences among the transects for the same areas on different islands suggests that their plant communities are composed of a dominant or single species assemblage. Nevertheless, a smooth change in vegetation was perceived along the altitudinal gradient on each island, and different plant communities were visually identified related to changes in microhabitat. Thus, while the transect size was sufficient to record plant communities as a whole, it was insufficient to detect changes due to microhabitat.

In the border areas adjacent to the salt lakes, three plant communities were visually identified: (1) salt-flat vegetation of seasonally inundated areas characterized by *Anthobryum triandrum* (J. Rémy) Surgis, and *Distichlis humilis* Phil.; (2) evergreen scrubs of Altiplano sand dunes characterized by *Lampaya castellani* Moldenke and *Acatholippia punensis* (Phil.) Botta; (3) and halophilous vegetation in salt meadows characterized by the xeromorphic scrubs *Atriplex imbricata* (Moq.) D. Dietr. and *Suaeda foliosa* Moq. (Navarro and Maldonado 2002; Navarro and Ferreira 2004; Navarro 2011). Cacti and ferns were completely absent from these areas.

The mountainsides were dominated by two types of xeromorphic scrub accompanied by columnar cacti and ferns similar to those of the alluvial terraces in the adjacent ranges. Two plant communities were identified: (1) succulent–spiny vegetation characterized by *Trichocereus atacamensis* and *Baccharis boliviensis*, and (2) the Thola resinous-scrub community characterized by *Baccharis boliviensis*, *Fabiana densa*, and *Parastrephia quadrangularis* (Meyen) Cabrera (Navarro and Maldonado 2002; Navarro and Ferreira 2004; Navarro 2011). Finally, the tops of the islands were formed by a subset of the mountainside communities with a reduction in terms of species richness and abundance, especially of herbs and ferns.

No community dominated by pastures was observed on any island. Such communities are characteristic of Altiplano landscapes but are thought to be a result of grazing (Genin and Fernández 1994). The observation reinforces the idea that these islands have suffered little disturbance.

The examined islands are important fragments in the maintenance of the Altiplano's floral diversity — they shelter several species assemblages as well as endemic and endangered species. Given that their plant communities show few signs of disturbance, these islands should be the subject of surveillance and conservation programs, especially in view of increasing human activity on the salt lakes. More work is needed to accurately describe their communities at the microhabitat level.

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