SEEDS BANKS OF DESERT ANNUALS IN AN ARIDITY GRADIENT IN THE SOUTHERN ATACAMA DESERT

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ABSTRACT

Annual plant communities are important components of the biodiversity found in the coastal southern Atacama Desert in Chile. Moreover, they are an important economic resource for the human communities living in that area. These plant communities develop, after heavy rainfall episodes, a phenomenon locally known as the "blooming of the desert". Although the minimum rainfall thresholds for these plants to emerge are relatively well known, little is known about their seed banks, its composition, dynamics and variation across the latitudinal aridity gradient from south to north. This system is interesting to study species coexistence, as well as, to look for exotic plants invasion, since previous studies have shown that exotic annual plants decreases in importance northwards. We hypothesize that, as a result of the gradient, we should find more seeds of annuals in the southern part because of the increase of exotic species. The lowest diversity will be found in the northern limit, while the highest in the middle part of the gradient, coincident with a natural protected area, and less influence of exotics. In terms of seed size and viability, we should find larger and more viable seeds in the southern limit of the gradient, probably contrasting with smaller and more dormant seeds to the north. To test these hypotheses we selected 8 sites along the gradient and collected soil samples after seed set in December 2008 for seed bank determination. According to our hypothesis we found more seeds in the southern part of the gradient. The northern seed banks (Rodillo and Cisne) are characterized by their low number of seeds and low species richness, according with their more extreme aridity. The central and southern seed banks have more than two times higher number and species richness than the northern ones. Southern seed banks (Lagunillas, Romeral and Punta Choros) contain more exotics' seeds; meanwhile central seed banks (Pajonales, Carrizal Bajo and Los Bronces) have less seeds, and less exotics' seeds. These results suggest that the increased seed number in the southern portion of the gradient could be due to an increased number of exotic species, rather than an increased diversity of native annuals. More viable and larger seeds were found in the southern sites, meanwhile, smaller seeds were found to the north indicating the use of a cautious opportunism strategy by these species. This is the first report on seed banks composition of this Atacama Desert area.

INTRODUCTION

Deserts are water-controlled ecosystems with infrequent, discrete and largely unpredictable water inputs (Noy-Meir 1973). Annual plant communities are important components of the biodiversity found in the coastal southern Atacama Desert (26º-30º S) in Chile. In this area, mean annual precipitation decreases northwards (Hajek & di Castri 1975, Juliá et al. 2008), as well as exotic annual plants (Armesto et al. 1993).

Although minimum rainfall thresholds for these plants to emerge are relatively well known, little is known about their seed banks, its composition, dynamics and variation across the gradient. In this study we ask: how does precipitation determine seed banks along the gradient? We hypothesize that: we should find more seeds of annuals in the southern part because of the increase of exotic species. The lowest diversity will be found in the northern limit, while the highest in the middle part of the gradient, coincident with a natural protected area, and less amount of exotics. In terms of seed size and viability, we should find larger and more viable seeds in the southern limit of the gradient, contrasting with smaller and more dormant seeds to the north.

MATERIALS AND METHODS

Study site

The aridity gradient is located in north-central Chile, between 26º-30º S (Figure 1). Precipitation decreases from 131 mm (CV 51%) at Lagunillas (30ºS) to 23 mm (CV 87%) at Chañaral (26º20'S) (Hajek & di Castri 1975, Juliá et al. 2008, Vidiella 1992). Within this area we selected 8 localities every 0.5º of latitude: Rodillo (26º40'), Cisne (27º14'), Pajonales (27º44'), Carrizal (28º3'), Bronces (28º37'), Choros (29º13'), Romeral (29º46') and Lagunillas (30º6'). All localities correspond to flat marine terraces, covered by fossil dunes over a bed of marine sediments (Vidiella 1992). In each locality, we installed 4 semi-permanent plots of 50x20 m, from where the soil samples were taken. In all localities vegetation is composed by annuals, shrubs and geophytes, with a high proportion of annuals (30-60 %), which decrease in importance northwards; maximum richness of native plant species and high endemism occur in the central part of the gradient, meanwhile exotic plants decrease in importance northwards (Armesto et al. 1993).

Seeds banks characteristics

Twenty soil samples per plot were randomly taken in each of the four plots located at the eight localities in December 2008 using a 35.4-cm² collecting tube (3 cm diameter X5 cm depth). December samples contain the seeds 1–2 months after seed set of annuals. Samples were taken to the laboratory, initially separated by mechanical sieving (mesh sizes 0.5–3.35 mm) and the smallest seeds were then extracted by flotation.

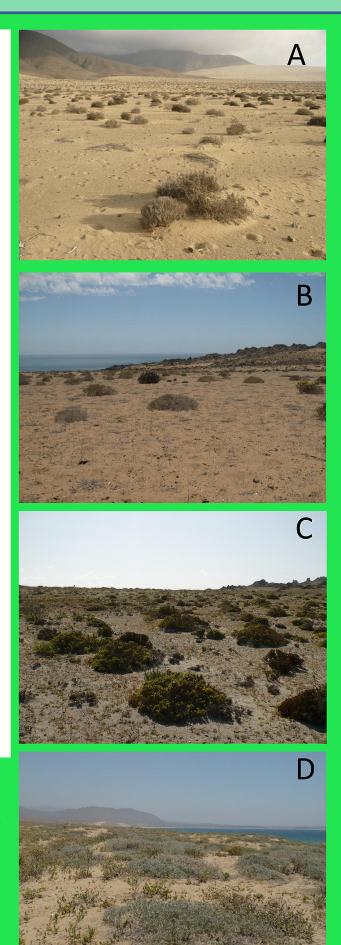


Figure 1. Location of the 8 localities in north-central Chile. Pictures illustrate the change in vegetation cover along the aridity gradient: (A) Rodillo (26º40'S, 70º42'W), (B) Carrizal (28º3'S, 71º8'W), (C) Choros (29º13'S, 71º27'W), and (D) Lagunillas (30º6'S, 71º22').

Seeds were oven-dried and identified to species under a stereoscopic microscope (NIKON SMZ-10) using voucher seeds and Herbarium specimens. All seeds which did not break when softly pushed with a pin were regarded as viable. Tetrazolium chloride testing has been proved to be ineffective for these kind of seeds (Gutiérrez et al. 2000). To measure mean seed mass, 10-100 seeds were weighed in a Sartorius scale and the mean weight per species determined by dividing by seed number. Mean seed size per plot was calculated by averaging the mean seed size of the species present in each plot with over than 100 seeds/m².

Statistical analysis

We compared annual species composition in seeds banks along the gradient using Nonmetrical Multidimensional Scalling (NMS) in the software package PC-ORD (McCune and Mefford 1999). Ordination scores were compared simply using the degree of overlap between 95% confidence intervals calculated and graphed in SigmaPlot (SYSTAT 2006). Annual seed density, species number, viability and mean seed size were analyzed with one-way ANOVA with locality as factor, using the software package SPSS (SPSS 2006). Density values and viability were transformed to meet the requirements of ANOVA ([ln(x+1)] and angular transformations, respectively). Tukey *a-posteriori* tests were used to distinguish homogeneous groups.

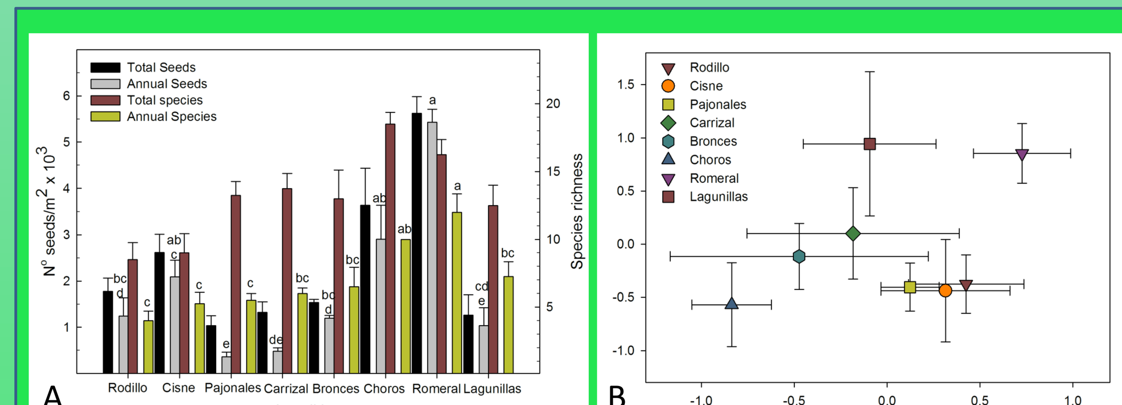
RESULTS

We found 100 species occurring in the seeds banks across the gradient, from which 52 corresponded to annual species, over 20% of them endemics. The most abundant taxa were Nolanaceae, Onagraceae and Portulaceae with 7, 6 and 4 annual species respectively. The most diverse sites were Romeral and Choros with 18 and 15 species each respectively, also the highest number of exotics species occurred in Romeral and Choros with 4 and 2 species respectively. Annual seed banks were different among localities ($F_{(7,24)}$=15.55, P<0.0001), with Romeral having the highest seed density and Pajonales the lowest (Figure 2A). Also, annual species richness was different among localities ($F_{(7,24)}$=8.35, P<0.0001), with Romeral and Choros having the highest species richness per plot; and Rodillo, Cisne and Pajonales having the lowest species richness per plot (Figure 2A). The most abundant native annuals were *Eryngium coquimbanum* at Choros, and *Cistanthe coquimbensis* at Romeral; the most abundant exotic species were *Erodium moschatum* and *E. cicutarium* at Romeral (Table 1). Ordination analysis (NMS) showed the southern localities Romeral, Lagunillas and Choros as different communities than those present in other localities; while the northern localities Cisne, Pajonales and Rodillo also constituted another different group (Figure 2B).

Table 1. Weight and density of the 10 most abundant seed species in the soil at the 8 localities along the aridity gradient. Values are presented ± 1SE. * denotes exotic species.

Species	Density (seeds/m²)								
	Weight (mg)	Rodillo	Cisne	Pajonales	Carrizal	Bronces	Choros	Romeral	Lagunillas
Eryngium coquimbanum	0.15	0	0	0	14.1	7.1	1878.8	98.7	0
	0.00	0	0	0	14.1	7.1	846.8	26.4	0
Quinchamalium chilense	0.20	1001.1	888.3	21.2	0	0	0	0	0
	0.02	421.7	171.1	7.1	0	0	0	0	0
Cistanthe coquimbensis	0.23	0	0	0	0	0	0	1558.1	102.2
	0.01	0	0	0	0	0	0	599.4	84.5
Cistanthe longiscapa	0.07	0	391.3	77.6	70.5	874.2	197.4	0	0
	0.00	0	274.9	44.7	41.1	58.4	76.8	0	0
Erodium moschatum/cicutarium *	3.30	0	0	0	0	0	0	1184.4	0
	0.19	0	0	0	0	0	0	133.4	0
Cistanthe sp. 1	0.13	0	0	0	0	0	0	1001.1	70.5
	0.01	0	0	0	0	0	0	260.6	44.2
Plantago hispidula	2.17	0	0	0	21.2	42.3	239.7	0	535.8
	0.08	0	0	0	21.2	24.4	239.7	0	370.7
Viola pusilla	0.48	0	0	0	0	0	0	793.1	0
	0.03	0	0	0	0	0	0	144.6	0
Nolana sp. 1	0.23	176.3	225.6	0	0	0	0	0	0
	0.03	66.5	87.5	0	0	0	0	0	0
Nolana sp. 2	1.22	0	0	109.3	0	0	250.3	21.2	3.5
	0.17	0	0	39.2	0	0	92.7	21.2	3.5
Other annual species		66.9	581.6	158.6	373.7	271.4	334.9	775.5	324.3
		23.9	247.3	45.1	107.6	63.2	55.9	99.2	164.9
Total annual seeds		**1244.3**	**2086.8**	**366.6**	**479.4**	**1194.9**	**2901.1**	**5432.0**	**1036.4**
		391.1	**364.2**	**93.7**	**75.3**	**58.8**	**736.1**	**279.4**	**388.6**

Native annual seed density was highest at Romeral and Choros, meanwhile lowest at Pajonales and Carrizal; exotic species seeds were only present in the southern localities Bronces, Choros, Romeral and Lagunillas, but only at Romeral they were abundant in the seed bank (Figure 2C). *Erodium moschatum* and *E. cicutarium* accounted for most of the presence of exotic seeds at Romeral (Table 1). Viable seeds decreased northwards ($F_{(7,24)}$=171.02, P<0.0001), where the most viable seeds were found at Romeral and Choros, and the lower percentage of viable seeds at Rodillo and Pajonales (Figure 2D).



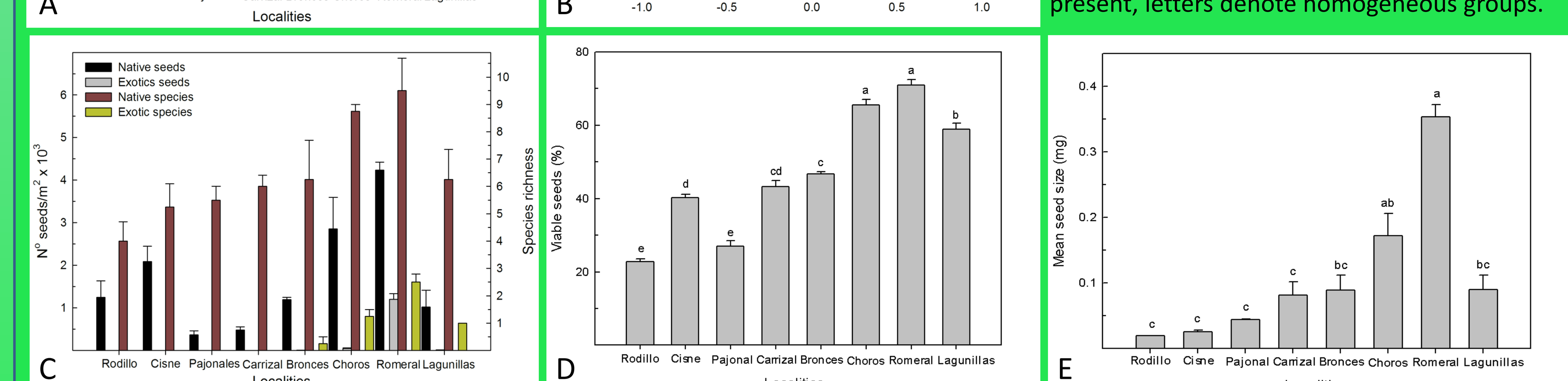


Figure 2. Seeds banks characteristics along the aridity gradient. (A) Abundance and species richness of total and annual seed banks. (B) Ordination analysis (NMS) for annual species composition; bars denote 95% confidence intervals. (C) Abundance and species richness of annual native and exotics seeds banks. (D) Percentage of annual viable seeds, all species pooled. (E) Mean seed size for annual species. In A, C, D and E error bars denote ± 1SE. Were present, letters denote homogeneous groups.

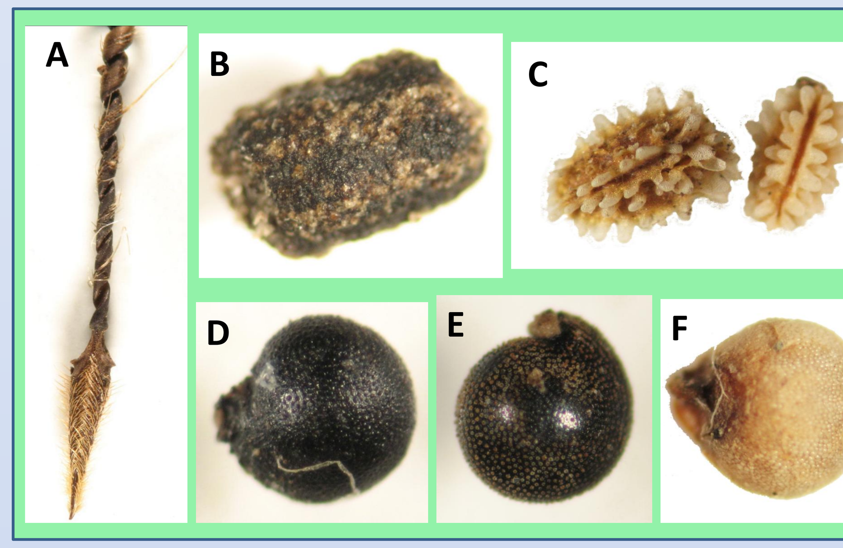


Figure 3. Seeds from the southern Atacama Desert. (A) *Erodium moschatum*, exotic. (B) *Nolana baccata*, endemic. (C) *Eryngium coquimbanum*, endemic. (D) *Cistanthe longiscapa*, endemic. (E) *Cistanthe arenaria*, native. (F) *Quinchamalium chilense*, native. (G) *Plantago hispidula*, endemic. (H) *Viola pusilla*, endemic. (I) *Cruckshanksia pumilla*, endemic.

Finally, bigger seeds were found at the southern localities ($F_{(7,24)}$=30.47, P<0.0001), at Romeral and Choros, meanwhile the smallest seeds were found in the northern localities (Rodillo, Cisne, Pajonales and Carrizal) (Figure 2E). The bigger seeds at Romeral and Choros corresponded to the endemic *Plantago hispidula* and the exotics *Erodium moschatum* and *E. cicutarium*; northern seed banks were made up mainly of *Cistanthe* spp., which have very small seed sizes (Table 1).

DISCUSSION

This study provides the first report on seed banks composition and abundance for this Atacama Desert area. This information is important to understand how plant communities respond to uncertain and decreasing rainfall regimes in desert environments, and is critical for the management and conservation of natural resources given the high proportion of endemism and the current threats to biodiversity in that area.

Our results clearly show how precipitation becomes the dominant controlling factor for biological processes. Effectively, annual plant diversity and seed abundance in the seed bank decreases northwards; this may not be true for seed banks at Rodillo and Cisne (situated in the northern tip of the gradient, with unusually high abundance of *Quichamalium chilense*) and could be due to specific microclimate site characteristics. Ordination analysis (NMS) for species composition in the gradient shows how annual plant communities differ, the northern localities (Rodillo, Cisne and Pajonales) showed very close communities, central localities (Carrizal, Bronces and Choros) constitute another group with high variation in species composition, and Lagunillas (though closer to the central ones) and Romeral constitute the last group. Romeral seeds banks has the highest abundance of exotics and is the most disturbed among our localities, which may be explaining why it appears almost in a single group.

Seeds banks abundance are comparable with others reports of seeds abundance in arid ecosystems. Gutiérrez and Meserve (2003) reported seeds abundance in relation to El Niño Southern Oscillation (ENSO) at Parque Nacional Bosque Fray Jorge in north-central Chile (30º38') with close to 5000 annual seeds/m² in non-ENSO years, this amount of seeds are similar to those registered at Romeral in this study, given that 2008 was a non-ENSO year. Considering the most abundant species (Table 1), Pake and Venable (1996) reported for the Sonoran Desert comparatively lower abundance of desert annuals than reported here. Localities with less abundance of seeds in their seed banks (Rodillo, Pajonales, Carrizal and Bronces) have lower seeds density than previously reported for other arid environments.

Evidence to support the use of a cautious opportunism strategy (Noy-Meir 1973) it's been provided here. Seed size and viability did show differences among localities in the gradient. Larger and more viable seeds were found in the southern limit of the gradient, contrasting with smaller and less viable seeds to the north (probably more dormant given the lower amount of precipitation of those localities). Finally, our results show similarities as wel as differences in species composition and abundances, respectively, with those reported by Vidiella (1992) for Rodillo, Carrizal, Choros and Lagunillas. Vidiella (1992) found the highest abundance of seedlings from Lagunillas soil samples, whereas we found the higher abundance of seeds at Choros.

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