Forage Offer From a Saline Wetland of Central Argentina (San Luis Province)

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Abstract

Saline wetlands usually suffer degradation processes, so their exploitation require planning to achieve the conservation of the resource. Our objective was to determine the forage capacity of a saline wetland in the east central province of San Luis, Argentina, called “Bajo Las Saladas”. Three landscape units and five physiognomic types were delimited and its extent, vegetation characteristics and aerial biomass were determined. In those areas, species with forage value were: *Atriplex lampa* and *Atriplex undulata* (Amaranthaceae), *Sporobolus phleoides, Pappophorum caespitosum* and *Distichlis spicata* (Poaceae). Other Amaranthaceae, *Sarcocornia neei*, was a forage of poor value. Considering the total forage production, its use factor, and the consumption of a breeding cow, it was estimated a forage offer in the saline wetland able to sustain 9 breeding cows per 100 ha. It is concluded that the forage use of these saline areas, carrying out pastoral management on a technical basis, could be an attractive economic option without affecting the wetland.

1. Introduction

Wetlands and salt marshes play a variety of environmental functions and are considered a priority for the preservation of biodiversity. However, most of them are influenced by human activity, including its conversion to urban land and even to farmland (De Groot et al. 2002). One of the most common anthropic activity carried out in these environments is the direct grazing by domestic species (Gedan et al. 2009). The effect of grazing on salt marsh vegetation was studied in the northern hemisphere (Doody 2008; Bertness et al. 2002) but the knowledge is less in South American marshes (Di Bella et al. 2020).

Grazing has detrimental effects on salt marsh vegetation due to intense, sometimes selective, defoliation and trampling. This reduces the proportion of rare plant species and affects the regeneration or reestablishment of vegetation cover. However, domestic herbivores may be beneficial in some wetlands by improving floristic diversity (Di Bella et al. 2020). One key issue is the intensity of grazing, which differently affects the spatial structure of wetland vegetation and species composition, depending on factors such as grazing history, climate, and productivity (Milchunas and Lauenroth 1993). Also, grazing leads to soil compaction and the occurrence of bare areas, which frequently enables the upward capillary movement of saline water and surface salts accumulation (Cisneros et al. 1999; Di Bella et al. 2020). This is why the exploitation of wetlands requires site-specific planning in order to achieve the maximum benefit within the framework of environmental conservation (Cronk and Fennessy 2001). One of the main tools for this purpose is the grazing management, and for that it is important to estimate the receptivity of the ecosystem or the carrying capacity of the grazing system. The latter is defined as the maximum number of animals sustained by an environment without being deteriorated (Vallentine 1990). In this context, there are grazing technologies that have been adequate for sustainable management of wetland ecosystems. Also, the receptivity of those systems could be improved by applying sustainable management strategies which change vegetation cover, floristic composition and forage availability. Moreover, in many cases, a decrease in soil salinity and pH and an increase in water infiltration rates could be expected (Di Bella et al., 2020).

Numerous species thrive in saline wetlands worldwide, but among the dicots Asteraceae, Fabaceae, Solanaceae, Verbenaceae and Amaranthaceae stand out. The last is one of the most conspicuous family, including the Chenopodiaceae subfamily (Kadereit et al. 2006). An example is the genus *Atriplex*, which comprises 245 species distributed around the world, but mainly occurring in arid and semi-arid regions (Osmond et al. 1980). In those areas, when herbaceous vegetation reduces growth during dry or cold periods, the “browseable” biomass of *Atriplex* sp. constitutes a food reserve to meet the nutritional needs of livestock. On the other hand, the woody parts of *Atriplex* sp. limit overgrazing of these halophytic shrubs, while their canopy creates a favorable microhabitat for the development of herbaceous vegetation beneath (Mckell 1975). *Sarcocornia* is a genus of halophyte plants, belonging too to the Amaranthaceae family, which also grow in saline areas worldwide. Five species of *Sarcocornia* have been identified in South America (Kadereit et al. 2006). Some species have been used as forage as well as in phytoremediation, energy, ornamentation, and human consumption, receiving good acceptance from different consumers (Ventura and Sagi 2013). Most of these halophytes are succulents, in which the water content per unit area of the leaves is high, the cells increase in size, the leaves or stems become thicker, and the number of leaves per plant decrease (Cronk and Fennessy 2001). The succulence dilutes the internal saline concentration (mainly sodium salts) and, consequently, decreases the negative effects of salts on plants (Zeng et al. 2018).

Among the monocots growing in wetlands, the Poaceae family stand out. For example, the cosmopolitan genus *Sporobolus* which grows in tropical, subtropical and temperate regions, and many of its halophilic species are distributed in the Americas (Peterson et al. 2007). Most of them are used as forage resources and also in ecosystems restoration (Khan and Gul 2008). Another notable genus is *Pappophorum*, a perennial grass native to the Americas that grows in arid and saline environments and maintain its good forage quality until seeds ripening (Pensiero et al. 2020). The genus *Distichlis* is also very common. It is considered of very low forage value in environments with good to very good productivity, but in saline areas it constitutes an important forage resource (Bustan et al. 2005; Yensen et al. 1985) and provides the benefit of reducing soil erosion (Pensiero et al. 2020).

Several species of the above mentioned genera are found in the saline wetlands, depressions that interrupt the flat landscape of the Chaco-Pampas sedimentary plain (Rubio et al. 2018). This is a vast arid/semiarid area that extend in South America, mainly covering for deciduous xerophytic forests and the predominant soils are Entisols and Mollisols (Rubio et al. 2018). The area is subjected to extensive grazing of cattle and, to a lesser extent, sheep and goats. Our objective was to estimate forage offer of plant species growing in one of these saline wetlands, located in the province of San Luis, Argentina, as a first step aiming towards the use and the conservation of the forage resource.

2. Materials And Methods

2.1 General characterization of the area

The studied area is located in the border between semiarid and arid zones. The climate is characterized by a negative annual water balance: the annual average rainfall is 697 mm and the mean annual evapotranspiration rate is 781 mm. A dry and cold autumn-winter semester (averaging 10.8 ºC) contrasts sharply with a warm semester (averaging 20.5 ºC) in which almost all the annual rainfall is concentrated. The typical vegetation of the territory consists in an open deciduous forest with trees up to 12 meters high, with *Prosopis caldenia* (caldén) as the dominant species, accompanied by other trees (like *Geoffroea decorticans*), bush, grasses, other herbaceous plants and also specimens of cacti. In many areas the forest has disappeared due to clearing for timber and for cattle grazing. In some places pastures were seeding, being the main species sowed *Eragrostis curvula* (weeping love grass) and *Thinopyrum ponticum* (tall wheatgrass), which behaves as an aggressive invader. The area is subjected to continuous grazing all year round and local data indicate a load capacity of 6–8 livestock unit (LSU) ha-1 (several authors cited by Barbosa 2020).

The study zone, the depression called “Bajo Las Saladas” is located between latitudes 33º 36´ and 33º 37´ South and longitudes 65º 26´ and 65º 25´ West, to the North-Northwest of the city of Villa Mercedes (San Luis, Argentina). The study was carried out in two representative areas of the depression, with a total area of 84.2 ha. The altitude ranges from 536.8 to 528.4 m.a.s.l.

2.2 Characteristics of the studied zone

Photointerpretation was carried out using contact aerial photos at a scale of 1: 20,000 and Google Earth image. Likewise, a topographic survey of the land was carried out. From the detection and delineation of relief, natural vegetation, crops, soil surface characteristics, drainage pattern, land use, etc., three landscapes (High sector, Low sector and Temporary riverbed and ponds) were identified. In them five different vegetation physiognomic types with homogeneous characteristics were recognized (Halophilic bush, Creeping halophilic bush, Dense halophilic meadow, Open halophilic meadow and Saline playa) (Barbosa, 2020).

The dominant soils, and their main characteristics, associated to the vegetation physiognomic types, are shown in Table 1. The soils of the area are sandy loam with variable salinity and alkalinity and with a similar sequence of horizons (A/AC/C). The soils in the Halophilic bush was defined as Typic Ustortents, and in the other physiognomic types defined as Typic Epiaquents (Barbosa et al. 2022).

Table 1
Characteristics of the soils of the different physiognomic types. Minimum and maximum values (*) of total organic carbon (OC) ($g\ kg^{-1}$), total nitrogen (tN) ($g\ kg^{-1}$), pH (1:2.5, electrical conductivity EC (dSm^{-1}), phreatic depth (cm) and soil oxido-reduction potential (ORP, mV) in the A horizons) (Barbosa et al, 2022).

Sub-landscapes	**Physiognomic types**	**OC** gkg^{-1}	**tN** gkg^{-1}	**pH**	**EC** dSm^{-1}	**Phreatic depth (cm)**	**soil ORP** mV
High sector	Halophilic bush	7.3–10.0	0.8–0.9	8.1–8.4	5.6–9.5	50–141	378–419
Low sector	Creeping halophilic bush	4.7–11.7	0.4–0.5	8.6–9.6	16.8–24.4	3–80	402–449
	Open halophilic meadows	6.5–8.5	0.6–0.7	9.1–9.8	14.4–26.3	15–84	330–388
	Dense halophilic meadows	7.3–13.4	1.0-1.1	8.5–9.1	17.2–22.8	12–82	313–419
Temporary riverbed and ponds	Saline playa	9.1–11.5	0.6–0.8	8.6–9.2	13.6–30.3	+ 7–75	103–384

*) Data comes from 8 replicates taken in the halophilic bush, creeping halophilic bush, open halophilic meadows and saline playa and 6 replicates in the dense halophilic meadows

In each physiognomic type, the dominant species were determined through inventories and plant species were identified using current keys (Instituto de Botánica Darwinion 2019). The collected specimens were deposited in the Herbarium of the FICA-UNSL. Figure 1 shows the structure of the vegetation in the different physiognomic types within the study area, as well as their main plant species.

Three monitoring plots were installed in the area occupied by each one of the five physiognomic types studied. The plants aerial biomass was determined by cutting a round area of 1.5 m2, selected at random within each one of the plots. The plant material was dried at 60ºC until constant weight and weighed. In three species, *Atriplex undulata, Sarcocornia neei* and *Distichlis spicata*, succulence was measured from the plant green/dry ratio and the concentration of sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) were extracted by digestion in $HClO_4$ and HNO_3 and determined by atomic absorption spectrophotometer (Kalra 2019).

The animal load of the saline depression was estimated from the data of biomass production of the different physiognomic types. Di Marco (1975- cited by Barbosa 2020) proposed, for the local extensive production systems, that a breeding cow has a forage consumption (dry matter - DM) in the order of 2% of its body weight, when it consumes forages with a digestibility around 55%.

3. Results

The Halophilic bush located in the topographically highest sector of the saline depression includes *Atriplex undulata, Atriplex lampa*, and other species (Table 2). In the sectors where the bush was open, a loose salty layer could be found on soil surface. The topographically lowest sector was occupied by three

Table 2
Physiognomic types and its occupied area, dominant species and other forage species.

Sub-landscapes	Physiognomic types and its occupied area	Dominant species	Main companion forage species
High sector	Halophilic bush (31.9 ha)	*Atriplex undulata, and Atriplex lampa*	*Sarcocornia neei, Sporobolus phleoides, Pappophorum caespitosum*
Low sector	Creeping halophilic bush (4.2 ha)	*Sarcocornia neei*	-
	Open halophilic meadow (22.3 ha)	*Distichlis spicata*	-
	Dense halophilic meadow (12.7 ha)		*Sarcocornia neei*
Temporary riverbed and ponds	Saline playa (13.1 ha)	Nude soil predominates	-

physiognomic types i) Creeping halophilic bush, with the absolute dominance of *Sarcocornia neei*. The bushes were distributed in disperse round patches covering 39% of the area and leaving a great surface of bare soil among them; ii) the Open and iii) the Dense halophilic meadows, with *Distichlis spicata* as the dominant species. In bare areas of the *D. spicata* Open meadow, which suffer temporary flooding, the presence of Cyanophyta-Cyanobacteria algae was common. The topographically most depressed sector was a bare saline playa that presented small ephemeral rills and temporary ponds, flooded during rainy periods due to surface runoff flowing from the topographically upper zones. When the water evaporates these places showed a characteristic surface salt cover and only few and scattered plants of *Sarcocornia neei* and *Distichlis spicata* were observed.

Table 3 shows the vegetation´ dry biomass in the Halophilic bush plots. The four species useful as forage were *Atriplex lampa* and *Atriplex undulata* (the dominant species), *Sporobolus phleoides* and *Pappophorum caes*pitosum. In the Creeping halophilic bush plots, the dominant species, *Sarcocornia neei*, produced the highest dry biomass recorded is this study (Table 4). In the Open halophyte meadow *Distichlis spicata*

Table 3

Average total aerial biomass production (DM) (kg ha^{-1}) in Halophilic bush plots, standard deviation, maximum and minimum values in brackets and % of the total production of the species found.

Species	Biomass production (DM)	% of the total
Atriplex spp. (leaves)	503.1 ± 32.4 (474.0–538.2)	22.3
Atriplex spp. (stems) *	847.0 ± 228.0 (704.2–1110.0)	37.5
Baccharis tenella *	36.7 ± 34.9 (4.0–73.4)	1.6
Prosopis strombulifera *	63.4 ± 10.9 (55.6–75.8)	2.8
Sporobolus phleoides	157.9 ± 8.6 (148.0–164.0)	7.0
Sarcocornia neei	558.3 ± 265.1 (306.2–834.8)	24.7
Pappophorum caespitosum	137.7 (97.2–178.2)	4.1

- Not accounted as forage resource

produced 62% of the total dry biomass. The remaining biomass was produced by other species. In the Dense halophyte meadow the total forage production was 370% higher compared to the Open halophyte meadow in which *Distichlis spicata* produced 87% of the harvested dry biomass. Tables 3 and 4 recorded the biomass of *Cressa truxillensis* and other species but they were not considered from the grazing point of view.

Table 5 shows the green biomass/dry biomass ratio and the succulence of the leaves and stems of *Atriplex undulata*, and the leaves of *Sarcocornia. neei* and *Distichlis spicata. Sarcocornia neei* showed the highest

Table 4

Average total aerial biomass production (DM) (kg ha^{-1}) in Creeping halophilic bush and Dense and Open halophilic meadow plots, standard deviation, maximum and minimum values in brackets and % of the total production of the species found.

Physiognomic types / Species	Biomass production (DM)	% of the total
Creeping halophilic bush		
Sarcocornia neei	1799.0 ± 409.5 (1536.0–2270.8)	99.4
Cressa truxillensis *	10.0	0.6
Open halophilic meadows		
Distichlis spicata	286.5 ± 146.5 (186.6–454.6)	61.5
Cressa truxillensis *	178.1 ± 57.9 (112.0–219.6)	38.3
Sarcocornia neei	1.0	0.2
Dense halophilic meadows		
Distichlis spicata	1059,3 ± 181.2 (889,2–1214.9)	87.4
Cressa truxillensis *	152.1 ± 2.8 (149.6–155.0)	12.6

- Not accounted as forage resource

succulence percentage followed by the leaves of *Atriplex undulata* while *Atriplex undulata* stems and *Distichlis spicata* showed the lowest succulence. Plant species showed some differences in the ionic accumulation patterns of the different ions but Na^+ was the main cation accumulated by the three species analyzed, followed by K^+ and, in much lower concentration, Ca^{2+} and Mg^{2+} (Table 6). The leaves of *Atriplex undulata* accumulated more cations than the other two species. The relationship between succulence a total cationic concentration was $R^2 = 0.654$.

Table 5
Green biomass / dry biomass ratio and the succulence percentage ± standard deviation of the analyzed species (n = 3).

Species	Green/dry ratio	Succulence (%)
Distichlis spicata - Open halophilic meadow (leaves)	1.42 ± 0.06	29.65 ± 2.97
Distichlis spicata - Dense halophilic meadow (leaves)	1.63 ± 0.03	38.52 ± 1.03
Sarcocornia neei (leaves)	4.19 ± 0.10	76.07 ± 1.29
Atriplex undulata (leaves)	3.01 ± 0.00	66.67 ± 1.89
Atriplex undulata (stems)	1.45 ± 0.05	31.19 ± 2.38

Table 7 unifies the estimated forage capacity of each physiognomic type: the sum of biomass produced was around 4.5 t ha^{-1}.

4. Discussion

The biomass production of both *Atriplex* species located in the Halophilic bush can be compared with a community of *Atriple*x spp located in a nearby arid zone, in which the forage production was in the order of 1.2 t DM ha^{-1} $year^{-1}$ (Blanco et al. 2001). That yield is clearly higher than that determined in the Halophilic bush of *Atriplex* spp studied here. The nutritional value of the species of this genus generally presents great homogeneity (Silva Colomer and Passera 1990). *A. lampa* has 14–20% crude protein with 65% in vitro digestibility (DM) (Silva Colomer and Passera 1990), while *Atriplex undulata* has 15–18% crude protein and 55–67% digestibility in vitro (DM) (Norman et al. 2013). On the other hand, Na^+ was the main cation accumulated by our *Atriplex undulata*, similar to the concentrations in *Atriplex canescens* and *Atriplex leucoclada* (Mantinzadeh et al. 2019). However, other species of this genus can accumulate higher concentrations of Na^+ and other ions in their tissues, and usually are proposed for the phytoremediation of

Table 6
Average ion concentrations (mg kg^{-1} of dry matter) ± standard deviation measured in the analyzed species (n = 3). For each ion the letters indicate significant differences between the different species or organs (Tukey, $p \leq 0.05$).

Species	Na^+	K^+	Ca^{2+}	Mg^{2+}
D. spicata in Dense halophilic meados (leaves)	27201 ± 3261 a	4038 ± 489 a	172 ± 11.2 a	181 ± 27.6 a
D. spicata in Open halophilic meadow (leaves)	17190 ± 2824 b	4082 ± 545 a	330 ± 53.9 b	244 ± 29.6 b
Sarcocornia neei in Creeping halophilic bush (leaves)	47438 ± 5343 c	2883 ± 674 b	431 ± 84.6	348 ± 60 c
Atriplex undulata in Halophilic bush (leaves)	67659 ± 6351 d	8341 ± 997 c	725 ± 96.2 d	573 ± 53.5 d
Atriplex undulata in Halophilic bush (stems)	9537 ± 1377 e	4778 ± 303 a	391 ± 41.1 bc	253 ± 36.1 b

saline soils, such as *Atriplex nummularia* (Freire et al. 2020) or *Atriplex halim*us and *A. hortensis* (Suaire et al. 2016).

The other prominent component of the Halophyte bush, *Pappophorum caespitosum*, is one of the few grasses of fodder value growing in saline soils located in the driest and warm areas of the Chaco-Pampean plain (Pensiero et al. 2020). Concentrations of 9–10% crude protein has been recorded for this species (Attia-Ismail 2015). *Sporobolus phleoides* is the other grazed grass in the present study, although its forage quality is unknown. Known species are *Sporobolus rigen*s, which presented 3–5% protein, 41–43% acid detergent

Table 7
Synthesis of the forage offer and estimated livestock units (LSU) by the area of each physiognomic type.

Physiognomic type	Annual total biomass (DM) (kg ha $year^{-1}$)	Total load as LSU ha^{-1}
Halophilic bush	1357	5.9
Creeping halophilic bush	1799	0.4
Open halophilic meadow	287	0.9
Dense halophilic meadow	1059	1.8
Saline playa	0	0

fiber and 72% neutral detergent fiber, 15–16% lignin and 7–8% ash, *Sporobolus indi*cus, 6% crude protein, 45% acid detergent fiber and 10% ash, and *Sporobolus airoides*, shows 6–9% crude protein (several local authors cited by Barbosa 2020).

The species of *Sarcocornia* are considered a forage of low quality (Cantero et al. 1998; Rodríguez et al. 2016). *Sarcocornia neei*, for example, is characterized by a high content of phenolic compounds (Riquelme et al. 2016) which reduce plant palatability to herbivores (Hjalten et al. 1994). This fact can explain the preference of grazing animals for other more digestible food resources (Attia-Ismail 2015). In accordance, several local studies (Barbosa 2020) and authors' visual observation in the Creeping halophilic bush found that native *Sarcocornia* species can be little consumed by livestock. *Sarcocornia neei* contains up to 6.5% protein according to Cervellini and Angeletti 2015 (cited by Barbosa, 2020) while Riquelme et al. (2016) indicated protein contents from 7 to 13%. Comparing with other *Sarcocornia* species (Riquelme et al. 2016), *Sarcocornia neei* accumulate high concentration of sodium salts.

The participation of *Distichlis* spp. in the diet of different herbivores has been demonstrated by micro-histological analysis and its identification in the feces (Holechek et al. 1982). *Distichlis* spp. constituted an important part of the bovine diet in saline and alkaline soils of the Flooding Pampas and also has also been identified in the diet of cattle, horses and goats as well as in American camelids, both in the Patagonia and the Andean Puna (several local authors cited by Barbosa 2020). The biomass production of *Distichlis spicat*a, the dominant species in Open and Dense halophilic meadows, is clearly lower when compared other situations: A *Distichlis humilis* field showed a forage production around 2.1 t DM ha^{-1} year^{-1} (Biurrun et al. 2010) and in a humid area with alkaline soils, a community of salt grass production was close to 2.5 t forage DM ha^{-1} year^{-1} (Hidalgo et al. 1998). *Distichlis* species grows throughout the whole year, although summer is the main productive season. Thus, cattle always have the possibility of finding plants with green leaves to eat along the year. Values of 5–12% crude protein and 18–53% in vitro digestibility were found in *Distichlis spicata* (Hidalgo et al. 1998). *Distichlis spicata* showed the lowest percentage of succulence in the present study, since it is a grass that does not accumulate large amount of water in its tissues. However, *Distichlis spicata* grown in Dense meadow had a higher percentage of water than plants grown in Open meadow, probably due to its lower level of transpiration (Table 5). Probably for the same reason, mean Na^+ concentrations found in the Open meadow plants were higher than when the species grew up in the Dense meadow (Table 6). In any case, *Distichlis spicata* showed the lowest ionic concentration in leaves of the studied species.

The area occupied by the different plant communities (Table 2) weighted by the average of the total biomass registered in each one of them (Table 7) allows the estimation of the animal receptivity of the studied area. In present case, the global data of forage production could be considered with a use factor of 40%. Considering a 400 kg breeding cow as a livestock unit, with a daily intake around 8 kg DM per day (Di Marco 1975- cited by Barbosa, 2020) means a forage consumption around 2920 kg DM year^{-1}. Taking into account this value, it was calculated that the "Bajo Las Saladas" can sustain 9 breeding cows per 100 ha. In present case, forage managing have to consider not only the surfaces of each physiognomic type and the biomass production, but that all the studied species have spring-summer-autumn growth (Pensiero et al. 2020).

5. Concluding Remarks

The information collected in present study shows that the forage offer of a saline wetlands such as the "Bajo Las Saladas" could be an attractive option for animal production, since their biomass production is significant. The estimated LSU of 9.0 breeding cows per 100 ha indicates that this saline wetlands could sustain a biomass production of the same order of magnitude than that in the zonal deciduous forest. The partial forage production capacity of each physiognomic type must be spatially managed on technical bases to avoid degrading the vegetation and soils. That is, vegetation and livestock need to be managed in small areas, which collides the traditional local way of grazing all year round in the large plots, as is common in the surrounding forest.

Declarations

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Data availability: Data are available on request from Osvaldo A. Barbosa.

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37. Statements & declarations

Figures

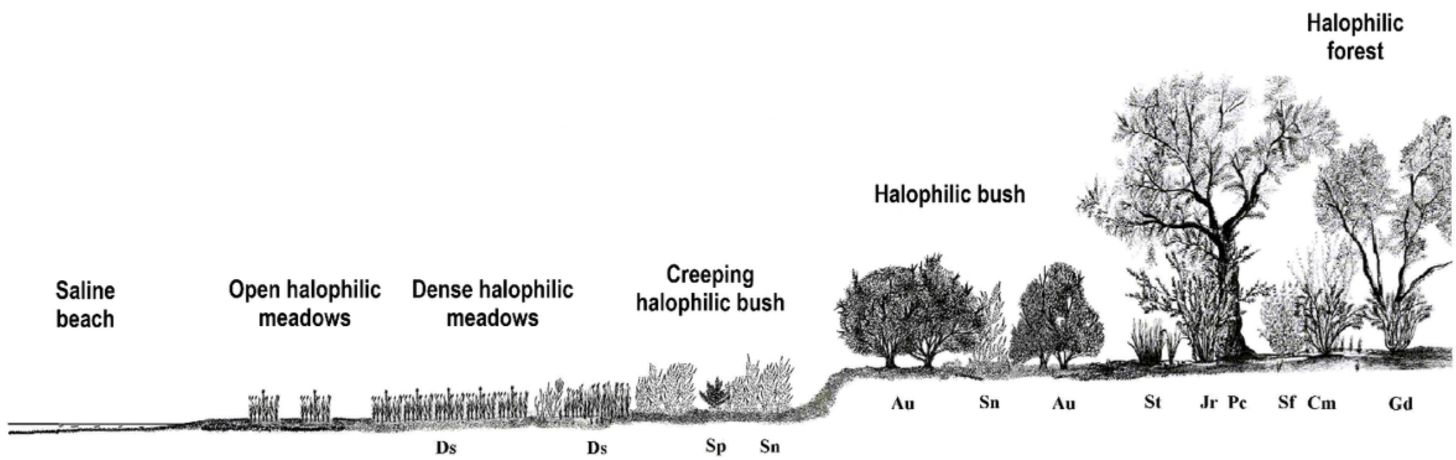

Figure 1

Schematic cross-section of vegetation distribution in the study area showing the six physiognomic types of vegetation identified. From the right to left: Gd: *Geoffroea decorticans;* Cm: *Condalia microphylla*; Sf: *Schinus johnstonii;* Pc: *Prosopis caldenia;* Jr: *Jodina rhombifolia;* St: *Stipa sp.;* Au: *Atriplex sp.;* Sp: *Sesuvium portulacastrum;* Sn: *Sarcocornia neei;* Ds: *Distichlis spicata.*