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Phytogenic Mounds (Nebkhas): Effect of *Tricomaria usillo* on Sand Entrapment in Central-West of Argentina

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Abstract

Nebkhas, developed by the trapping of sand within the body of a plant, were studied in the Médanos Grandes system, arid central Argentina, during the springs of 2009-2010. The dynamics of nebkhas was studied in three draas (megadunes), and considering both orientations: leeward and windward. The Drift Potential (DP) for the study area was 42, evidencing the inactivity of the sand dunes or the scarce activity only in crests. Dominant sand movement is in south-southeast direction, with deflation processes at the southern side of the nebkhas. All nebkhas showed uniformity in the morphometry. *Tricomaria usillo* is the dominant plant species in the nebkha formation process; and results showed a significant positive relationship between nebkha and canopy volumes.

Keywords

Sand Dunes, Nebkhas, Dynamics, Vegetation

1. Introduction

Psammophilous systems occur both in oceanic and continental regions; in these last, they occupy arid environments characterized by wide temperature range, scarce rainfall and high annual water deficit.

These systems encompass wide areas covered with aeolian sands where wind plays a determining role in landscape structure and in plant species distribution, principally due to its desiccant physiological effect and the mechanical action of burial and uncovering of plants ([1] [2]).

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The effect of wind on sand dunes is different between exposures, with the windward slope being subjected to maximal erosion. Wind velocity increases toward the crest; on the lee slope, by expansion of flux, wind and its transport capacity diminish ([3]). This change induced by the topography of sand dunes will influence sand transport ([4]) and, consequently, vegetation composition ([5]-[9]).

Vegetation obstructs the action of wind by retaining particles, functioning as sand traps ([10]-[12]), and generating mounds known as nebkhas. Nebkhas are normally fully developed on the crest of dunes where sand transport is maximal. Nebkhas are considered to be a type of phytogenic sand dunes that show different stages of development ([13]). Their morphology, similar to sand dunes, has direct relation with erosion-deposition processes due to wind acting differentially on each geotope, and it is controlled by growth patterns of shrub that retain the sand ([10] [14]-[17]). According to [18], nehbka dunes typically are formed through ecogeomorphic feedbacks controlled by the interactions between vegetation growth and aeolian sedimentations.

In coincidence with [17], three development stages can be recognized in nebkhas: fixation of aeolian sands by a shrub, growth of nebkhas and shrubs, erosion of nebkhas and degeneration of shrubs.

Nebkhas are dynamic elements of the geomorphology of sandy environments and play a relevant role in the ecological system, thus constituting habitats for smaller fauna (Rodentia, Iguanidae).

Environments with nebkhas are interesting cases where vegetation and aeolian transport are coupled; and where occurs highly heterogeneous distribution of perennial biomass, with little or no perennial plant species between nebkhas. This allows high rates of horizontal aeolian transport in nebkhas that may be part of a positive feedback in which increased aeolian transport leads to increased sediment transport from interspaces to nebkhas ([19]).

The nebkhas have been studied and described in Africa ([17] [20]), northern China ([21], Israel ([13] [22]), Spain ([23]), New Mexico [24]), and the arid zone of Argentina ([25]-[28]), as common geomorphological-biological components of psammophilous environments. They have been indicated on crests of linear semi-fixed dunes [29] and in inter-dune valleys [30].

The structure and formation processes of nebkhas have been studied and discussed for different environments [31]-[34]. Authors as [35] suggested, as a simplification, to associate nebkha formation processes with soil degradation. Others as [28] did not find any chemical difference between soils of nebkhas and the surrounding soils, all nebkhas fixed by no leguminous species, and suggested only the mechanical effect of sand-holding shrubs: first as a barrier and later, as well, with their adventitious roots. In addition, the accumulation characteristics of nebkhas, which have developed extensively in these regions, can be used as a method of reconstructing environmental changes [36].

The composition of nebkhas varies according to where they are formed: in flat areas they contain less than 50% of sand with dominance of loam and clay [21]; while those in inter-dune valleys contain more than 90% of sand [37]. However, nebkhas in psammophilous environments such as on sand dunes are a different type [38].

The nebkhas-vegetation relation has been studied by [20] [39]-[41], among others, and concluded that there is a strong relationship between nebkha morphometry and plant morphology, and the heterogeneity in morphometry is due to differences in plant species cover.

The region of Médanos Grandes has been studied in its geomorphological ([42]-[44] and mineralogical aspects ([45]). According to [45], these sand dunes are composed of lithic fragments (vulcanite, micaceous schist, amphibolites, mylonites, chert, sedimentary and calcite clasts) together with moderate percentages of feldspar with little presence of quartz, that correlate with the Pampean Aeolian Sand Sea and the climatic states suggested by [46] for a period of approximately 77,000 years. [47] indicates for the NW of the area sands with OSL (luminescence optically stimulated) ages of 600 ± 40 and 410 ± 40 years old, and for the N area OSL ages of 4300 ± 500 years at the bottom and of 4090 ± 335 years in the middle of the deposits. [42] differentiates, at 1:100,000 scale, by size, shape and orientation, two depositional formations: draas (mega sand dunes) and dunes. The area is formed by a complex pattern of dunes [48]. In the study area domain mega-barchan dunes with vegetated linear dunes superimposed.

In this paper we seek to analyze the dynamics of nebkhas in relation to wind, the intensity of sand movement, and associated shrubs in the continental dune system in the south-southeast of San Juan province.

2. Material and Methods

2.1. Study Area

Médanos Grandes is a static erg located in the south-southeast of San Juan province, Argentina, between 31˚40'S -

67˚42'W and 32˚00'S - 68˚10'W (**Figure 1**). Sand dune height and the few or no possibilities of access constitute a barrier for field work.

The area is part of the South American Arid Diagonal [49] and the Minimum Mean Rainfall Axis of the Vinchina-Bermejo Depression with a mean temperature of 8.4˚C in the coldest month and 25.9˚C in the hottest [50], and rainfalls lower than 150 mm/year. Annual water deficit is approximately 1168 mm [51]. The period with highest frequency of winds, and the driest one, is spring [52].

Psammophytic vegetation includes shrubs and grasses, and it is dominated by *P. urvilleanum* Kunth on active and semi-fixed crests, accompanied by *Aristida mendocina Phil*., *Neobouteloua lophostachya* (Griseb.) Gould., among other herb species, with a cover of between 5% - 35%, and by thicket steppe in inter-sand dunes with *Tricomaria usillo* Hook. & Arn.—*Bulnesia retama* (Gillies ex Hook. & Arn.) Griseb community with low presence of *Larrea divaricata* Cav., *Bougainvillea spinosa* (Cav.) Heimerl., *Junellia aspera* (Gillies & Hook.) Moldenke, *Prosopis flexuosa* DC, *Cercidium praecox* (Ruiz & Pav. ex Hook.) Harms, *Prosopidastrum globosum* (Gill. ex Hook. & Arn.) Burk, *Ephedra boelckei* Roig, etc. with 65% plant cover [53]. *T. usillo*, common in nebkhas, is a shrubby species up to 1.8 m tall and 1.5 m in canopy diameter, normally with 1 or 2 intensively branched stems.

Incursions of off-road vehicles are the only current human pressure, but drivers normally travel the same tracks; in addition, no historic use was recorded.

The dynamics of nebkhas was studied in three draas, considering both orientations: leeward and windward.

2.2. Field Works

We randomly chose 30 nebkhas in total, 15 on the windward slope and 15 on the lee slope of the mega-barchan dunes, in a 1000 m long transect. All studied nebkhas were located on the middle of slopes of mega-dunes, and were randomly chosen with the consideration that they were completely isolated from neighboring nebkhas to avoid the internebkha effects. There are no nebkhas on dune crests. The difficulty of access to the area and the relatively low number of nebkhas allowed us to work only with this sample size.

On each selected nebkha, we inserted 1 mm graduated erosion pins, 20 cm height and 4 mm in diameter, on the north, south, east and west edges, and at the top. At each of these sites we used 3 pins separated by 20 cm, just enough to avoid interferences between them. Height variations (erosion-deposition) were recorded on each pin every fifteen days during the spring of 2009 (September-December). In addition, in each nebkha, we recorded maximum height and maximum (L) and minimum (l) length (along two perpendicular horizontal axes) to calculate volume and relationship between L/l and height.

The dominant plant species in nebkhas is *Tricomaria usillo* (Malpighiaceae). In all nebkhas, we dendrochronologically determined the age of *T. usillo* to estimate the time of nebkha formation. Stem diameter at plant neck height was recorded with metric tape and the relation between stem diameter-plant age was statistically determined.

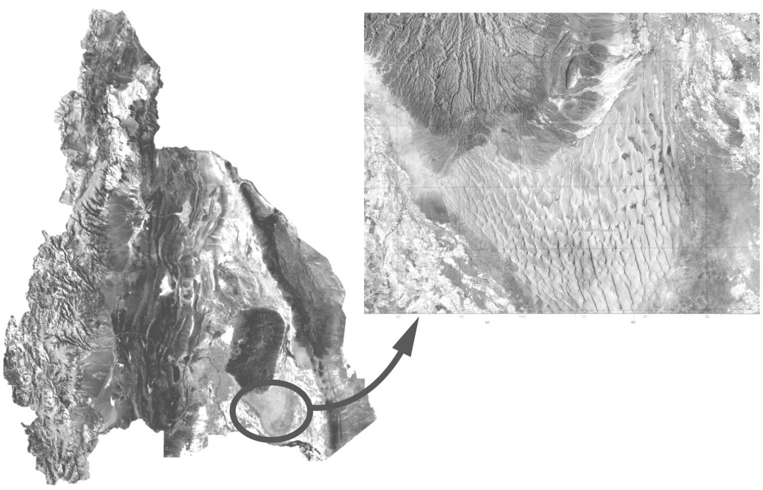

Figure 1. Study area in the south-southeast of San Juan province, Argentina.

3. Results and discussion

3.1. Nebkha Dynamics

According to the climate data obtained from the Las Chacritas Weather station (unpublished), located 15 km to the north and out of the study area, the highest frequency of winds with velocities over 22 km/hour (critical velocity for sand movement) (**Figure 2**), occurs in the spring period with south-east, east and south being the dominant wind directions.

Considering the Drift Potential (DP), usually used by aeolian geomorphologists ([54] [55]), given by: DP = (U^2 (U-U_t/100∗t)) (where U = wind speed in knots, U_t = 12 knots, t: time when wind blew above the threshold velocity—17%), value for Médanos Grandes system is 42. Obtained value highlights the inactivity of sand dunes or their scarce activity only on crests.

The mean variation in sand erosion-deposition was recorded from height variations on pins (mean of the three pins), in the nebkhas on all three mega-dunes, taking into account exposure and orientation, and for the 30 nebkhas randomly chosen, is shown in **Figure 3** and **Figure 4**, where negative values indicate deflation.

Mean variation in sand movement per exposure and orientation was, on windward slopes: 0.79 cm north, −0.02 cm east, −1.46 cm south and 0.13 cm west, on lee slopes: 0.59 cm north, 0.48 cm east, −0.45 cm south and 0.67 cm west.

The windward slope and south orientation of mega dunes show major sand movements by erosion. The deflation process occurred in the southern side and the deposition process in the northern side of the nebkhas. Lee nebkhas show low aeolian intensity and sand erosion/deposition was more uniformly distributed in all orientations. Erosion dominates on the windward slope, where it reaches its higher values (1.48 cm). In both exposures the south orientation shows erosion processes, coincident with the dominant wind direction. Considering all orientations the major sand accumulation occurred on the lee slope, reaching 1.74 cm in total; whereas on the windward slope it only reached 0.92 cm. The lowest sand deposition rate on the windward was recorded for the west orientation (0.13 cm) and the highest deposition rate in the north orientation (0.79 cm). On lee slopes, the lowest deposition was in the east orientation (0.48 cm) and the highest in the west (0.67 cm). All this would indicate that nebkhas grow through retention of sand eroded mostly from the south orientation. Lee nebkhas continue to grow whereas those on windward slopes are, in general, at the stage of erosion; [13] found similar results for coastal sand dunes of Ashdod (Israel).

The greatest sand movement, but with no significant differences, occurs on the windward slope, consistently with the studies by [56] and [57].

Considering the results of ANOVA test and post hoc LSD (Least Significant Difference) test [58], no statistical differences were found between exposures (p = 0.18) or orientations (p = 0.38) for erosion values, depositions and erosion/deposition rates, due to the high variation in the data.

Contrary to findings for other sand dune systems where crests showed the highest deposition rate and statistical differences between exposures [13], in the Médanos Grandes system erosion dominates on crests, and no nebkhas occur because the only species to grow is *Panicum urvilleanum* Kunth (Poaceae), a herb plant whose cover is lower than 5%, this difference possibly is due to of two different types of dunes in Israel and in San Juan.

According to [57], variations in sand movement on taluses are primarily due to plant cover; in our study case,

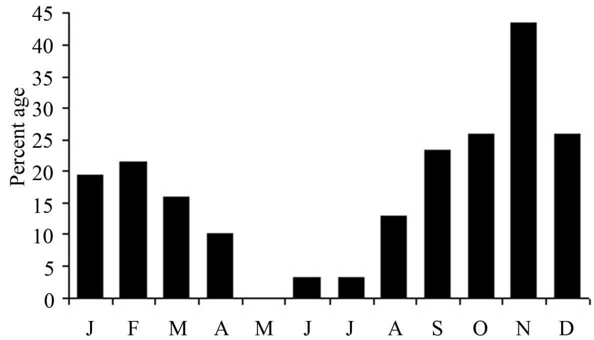

Figure 2. Wind frequencies (in percentage) with velocities over 22 km/hour.

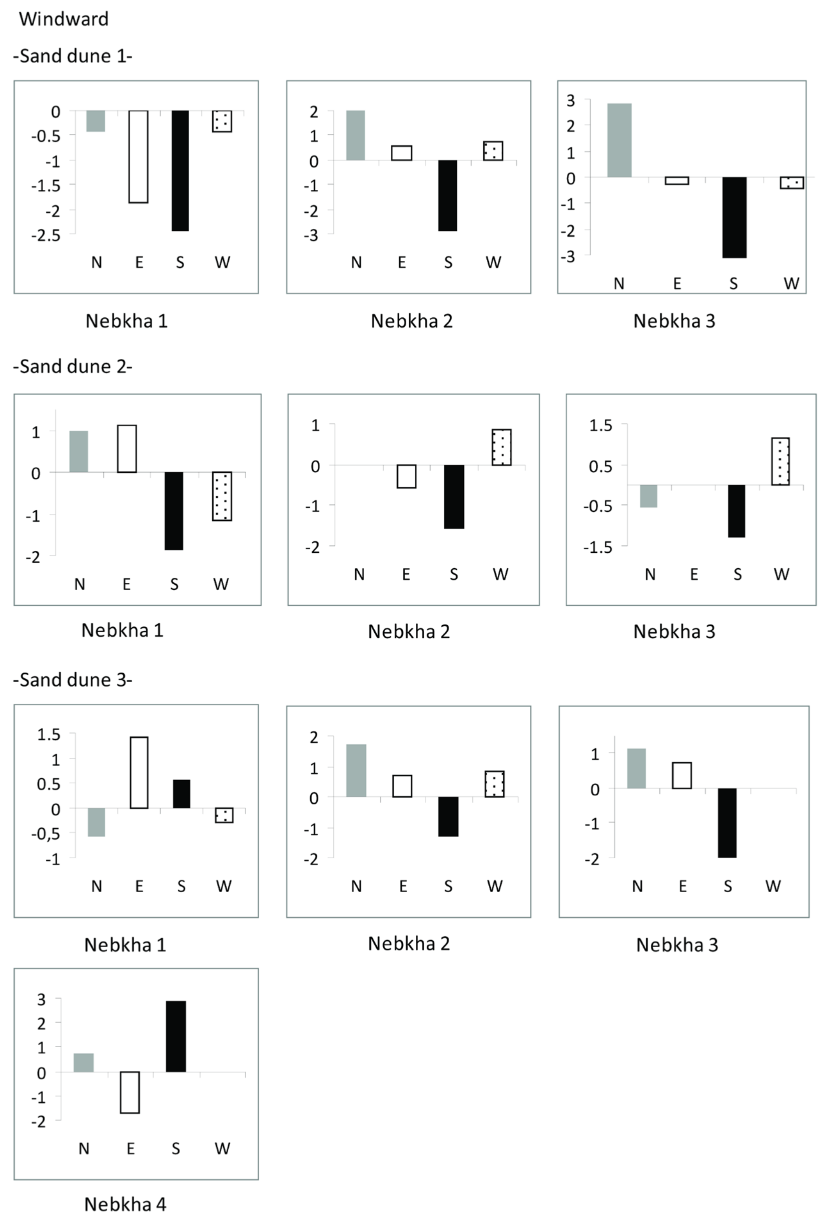

Figure 3. Sand erosion/deposition in windward nebkhas.

in both exposures, plant cover varied between 20% - 40%, which would explain the non-significant differences found in the mean rate of constant sand accumulation between both exposures. On the other hand, the floristic homogeneity found in our case can be related to their being fixed sand dunes with similar plant cover and floristic composition. Overall, a shrubland with 20% - 40% cover is dominant, where *T. usillo* is accompanied by *Junellia aspera*, *Cercidium praecox*, *Larrea divaricata*, *Prosopidastrum globosum*, *Bulnesia retama* and *Ephedra boelckei*.

No differences in sand movement or floristic composition were found between exposures in the Médanos Grandes plant-fixed sand dune system, whilst strong correlations between plant community distribution and topography were found in coastal sand dunes with intense sand movement [5].

3.2. Nebkha-Shrub Relationship

Nebkhas vary in shape and size [24], however those studied in Médanos Grandes were homogenous with their

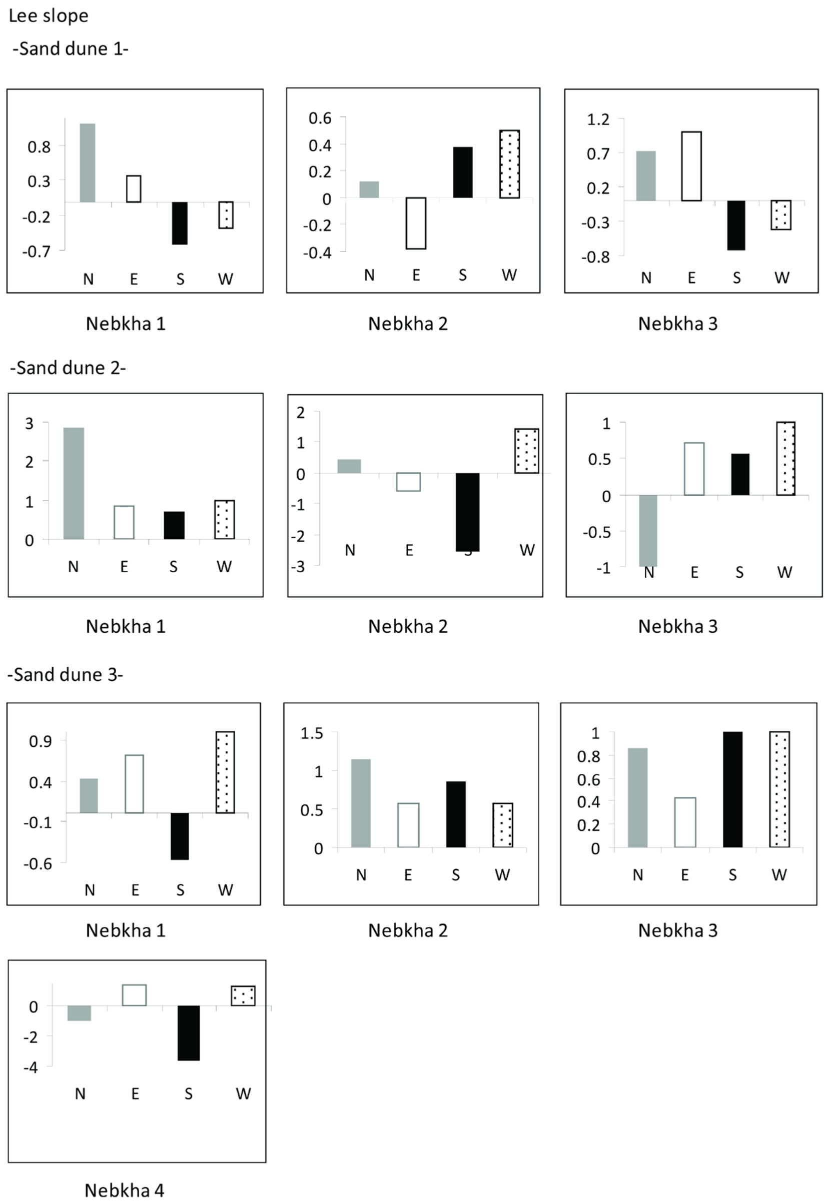

Figure 4. Sand erosion/deposition in lee nebkhas.

mean height being respectively 0.62 ± 0.24 cm and 0.51 ± 0.20 cm on windward and lee slope, and their largest diameters being 4.71 ± 1.5 m and 4.25 ± 1.3 m, respectively. The relationship between L/l rate and height shows a correlation coefficient of $r^2 = 0.84$ ($p < 0.01$) at 95% confidence level, with height being a good estimator of the L/l relationship and thus of the size of the nebkha. The resulting equation was L/l = 0.94 + 0.74∗height. Similar results were found by [20] in nebkhas of Burkina Faso. On the other hand, data show uniformity in the morphometry of all nebkhas.

The shrub always present in nebkhas was *Tricomaria usillo* and, in some cases accompanied by *Junellia aspera* (in 3 nebkhas), *Bulnesia retama* (in 2), *Bougainvillea spinosa* (in 2), *Prosopis flexuosa* (in 1).

For all nebkhas, the stem diameter at plant neck height was recorded and the age of *T. usillo* was dendrochronologically determined. The stem diameter varied between 2.50 and 4.50 cm and the age of plants between 45 - 55 years old. The statiscal relationship obtained between stem diameter and age was: age = 35.515 + (2.5956∗diam.) ($n = 30$; $\alpha = 0.05$; $r^2 = 0.54$).

Taking into account nebkhas of different volumes and the age of *T. usillo*, estimated from diameters, the mean rate of constant sand accumulation for each geotope was estimated as being 0.140 m^3/year and 0.155 m^3/year for windward and lee slope respectively. The constant rate of growth in height was estimated as being 0.02 cm/year and 0.04 cm/year, for windward and lee slope, similar to estimate by [59] for nebkhas with *Ephedra ochreata* (0.02 cm/year) and with *Larrea divaricata* (0.03 cm/year) in the south of Mendoza province.

The mean dimensions of *T. usillo* canopies in the study area were: in windward, 137 cm in height, 107 cm in diameter and 0.45 m^3 in volume, and in lee slope, 135 cm in height, 113 cm in diameter and 0.48 m^3 in volume. Linear regression analysis showed a significant positive relationship between nebkha volume and canopy volume ($\alpha = 0.1$, winward: $r^2 = 0.88$, lee slope: $r^2 = 0.75$), results that agree with those of [60] who found the same relation with *Caragana tibetica* in arid lands of Mongolia.

4. Conclusion

The Médanos Grandes psammophilous system belongs to a low aeolian energy environment; in addition, it is stabilized by vegetation and shows no significant differences in sand movement between windward and lee slope. Consequently, the mean constant rate of sand accumulation is low. However, predominant winds from the south-southeast determine erosion on the windward slope and deposition on the lee slope, and therefore nebkhas superimposed on draas would indicate slow growth on the lee slope and moderate deterioration on the windward slope. In conclusion, nebkhas in this psammophilous environment were formed primarily by aeolian processes. In addition, this study indicates that *T. usillo* has significant effects on sand entrapment and in nebkha formation. Nebkhas are certainly a reliable indicator of sand dune dynamics, even in stable systems, such as the one studied here, where no vegetation or soil degradation processes were found to be related to this dynamics. Nebkhas that had been on lee slope now occurs on the windward and in erosion phase.

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References

[1] Braun-Blanquet, J. (1979) Fitosociología. Bases para el estudio de las comunidades vegetales. Blume, España, 820 p.

[2] Ennos, A. (1997) Wind as an Ecological Factor. *Trends in Ecology and Evolution*, **12**, 108-111. http://dx.doi.org/10.1016/S0169-5347(96)10066-5

[3] Gutierrez Elorza, M. (2001) Geomorfología Climática. Omega, España, 617 p.

[4] Qian, G., Dong, Z., Luo, W. and Wang, H. (2009) Variations of Horizontal and Vertical Velocities over Two-Dimensional Transverse Dunes: A Wind Tunnel Simulation of the Effect of Windward Slope. *Journal of Arid Environment*, **73**, 1109-1116. http://dx.doi.org/10.1016/j.jaridenv.2009.06.006

[5] Moreno Casasola, P. (1986) Sand Movement as a Factor in the Distribution of Plant Communities in a Coastal Dune System. *Plant Ecology*, **65**, 67-76. http://dx.doi.org/10.1007/BF00044876

[6] González Loyarte, M., Martínez Carretero, E. and Roig, F.A. (1990) Forest of *Prosopis flexuosa* Var. Flexuosa (Leguminosae) in the NE of Mendoza. I. Structure and Dynamism in the Area of the "Telteca Natural Reserve". *Documents Phytosociologiques*, **12**, 285-289.

[7] González Loyarte, M. (2003) Relaciones entre granulometría, comunidades vegetales y procesos hídricos y eólicos en un piedemonte de los Andes centrales de Argentina. *Ecología Austral*, **13**, 27-48.

[8] Méndez, E. (1992) Conservación de nuestros ecosistemas naturales. I. Los médanos de Potrerillos, Lujan de Cuyo, Mendoza. *Multequina*, **1**, 19-23.

[9] Lortie, C. and Cushman, H. (2007) Effects of a Directional Abiotic Gradient on Plant Community Dynamics and Invasion in a Coastal Dune System. *Journal of Ecology*, **95**, 468-481. http://dx.doi.org/10.1111/j.1365-2745.2007.01231.x

[10] Cooke, R., Warren, A. and Goudie, A. (1993) Desert Geomorphology. UCL Press, London, 526 p.

[11] Gunatilaka, A. and Mwango, A. (1987) Continental Sabkha Pans and Associated Nebkhas in Southern Kuwait, Arabian

Gulf. In: Frostick, L.E. and Reid, I., Eds., *Deserts Sediments*: *Ancient and Modern*, Geological Society Special Publication, No. 35, London. http://dx.doi.org/10.1144/gsl.sp.1987.035.01.13

[12] Strahler, A. (1982) Geografía Física. Omega, Barcelona, 780 p.

[13] Ardon, K., Tsoar, H. and Blumberg, D.G. (2009) Dynamics of Nebkhas Superimposed on a Parabolic Dune and Their Effect on the Dune Dynamics. *Journal of Arid Environments*, **73**, 1014-1022. http://dx.doi.org/10.1016/j.jaridenv.2009.04.021

[14] Hesp, P. and McLachlan, A. (2000) Morphology, Dynamics, Ecology and Fauna of *Arctotheca populifolia* and *Gazania rigens* Nabkha Dunes. *Journal of Arid Environments*, **44**, 155-172. http://dx.doi.org/10.1006/jare.1999.0590

[15] Lancaster, N. (1988) Development of Linear Dunes in the Southwestern Kalahari, Southern Africa. *Journal of Arid Environments*, **14**, 233-244.

[16] Lancaster, N. (1995) The Geomorphology of Desert Dunes. Routledge, London, 290 p. http://dx.doi.org/10.4324/9780203413128

[17] Tengberg, A. and Chen, D. (1998) A Comparative Analysis of Nebkhas in Central Tunisia And Northern Burkina Faso. *Geomorphology*, **22**, 181-192. http://dx.doi.org/10.1016/S0169-555X(97)00068-8

[18] Nield, J.M., Gillies, J A. and Nickling, W.G. (2014) Nebkha Patterns in Semi-Arid Environments. American Geophysical Union Fall Meeting 2014, Abstract #EP33D-03.

[19] Baas, A.C.W. and Nield, J.M. (2007) Modeling Vegetated Dune Landscapes. *Geophysical Research Letters*, **34**, Article ID: L06405.

[20] Tengberg, A. (1995) Nebkha Dunes as Indicators of Wind Erosion and Land Degradation in the Sahel Zone of Burkina Faso. *Journal of Arid Environments*, **30**, 265-282. http://dx.doi.org/10.1016/S0140-1963(05)80002-3

[21] Wang, X., Wang, T., Dong, Z., Liu, X. and Qian, G. (2006) Nebkha Development and Its Significance to Wind Erosion and Land Degradation in Semi-Arid Northern China. *Journal of Arid Environments*, **65**, 129-141. http://dx.doi.org/10.1016/j.jaridenv.2005.06.030

[22] Tsoar, H. and Blumberg, D.G. (2002) Formation of Parabolic Dunes from Barchan and Transverse Dunes along Israel's Mediterranean Coast. *Earth Surface Processes and Landforms*, **27**, 1147-1161. http://dx.doi.org/10.1002/esp.417

[23] Gutierrez Elorza, M., Desir, G. and Gutierrez-Santolalla, F. (2002) Yardangs in the Semiarid Central Sector of the Ebro Depression (NE Spain). *Geomorphology*, **44**, 155-170. http://dx.doi.org/10.1016/S0169-555X(01)00151-9

[24] Langford, R. (2000) Nabkha (Coppice Dune) Fields of South-Central New Mexico, USA. *Journal of Arid Environments*, **46**, 25-41. http://dx.doi.org/10.1006/jare.2000.0650

[25] Hueck, K. (1951) Dos problemas fitogeográficos de la cuenca de Andalgalá. (Provincia de Catamarca). *Boletín Sociedad Argentina de Botánica*, **3**, 224-234.

[26] Morello, J. (1956) Estudios Botánicos en las Regiones Áridas de la Argentina. Reacciones de las plantas a los movimientos de suelos en Neuquén Extra-andino. *Revista Agronómica del Noroeste Argentino*, **2**, 79-152.

[27] Dalmasso, A., Horno, M. and Candia, R. (1998) Utilización de especies nativas en la fijación de médanos. In: Cargill, F., Ed., *Erosión, Sistemas de Producción, Manejo y Conservación del suelo y agua*, 221-290.

[28] MartÍnez Carretero, E. (2004) La Provincia Fitogeográfica de la Payunia. *Boletín Sociedad Argentina de Botánica*, **39**, 195-226.

[29] Purdie, R. (1984) Land Systems of the Simpson Desert Region. CSIRO Natural Resources Series 2, 71 p.

[30] Thomas, D.S.G. (1988) The Geomorphological Role of Vegetation in the Dune Systems of the Kalahari. In: Dardis, G.F. and Moon, B.P., Eds., *Geomorphological Studies in Southern Africa*, Balkema, Rotterdam.

[31] Hesp, P.A. (1981) The Formation of Shadow Dunes. *Sedimentary Petrology*, **51**, 101-112.

[32] Hesp, P. and McLachlan, A. (2000) Morphology, Dynamics, Ecology and Fauna of Arctotheca Populifolia and Gazania Rigens Nabkha Dunes. *Journal of Arid Environments*, **44**, 155-172. http://dx.doi.org/10.1006/jare.1999.0590

[33] Coque, R. (1962) La Tunisie Pré-Saharienne. Etude Géomorphologique. Colin, Paris, 476 p.

[34] Toutain, B. (1977) Essais de régénération mécanique de quelques parcours sahéliens dégradés. *Revue d'Elevage et de Medicine veterinaire des Pays tropicaux*, **30**, 191-198.

[35] Dougill, A.J. and Thomas, A.D. (2002) Nebkha dunes in the Molopo Basin, South Africa and Botswana, formation controls and their validity as indicators of soil degradation. *Journal of Arid Environments*, **50**, 413-428. http://dx.doi.org/10.1006/jare.2001.0909

[36] Lang, L., Wang, X., Hasi, E. and Hua, T. (2013) Nebkha (Coppice Dune) Formation and Significance to Environmental Change Reconstructions in Arid and Semiarid Areas. *Journal of Geographical Sciences*, **23**, 344-358. http://dx.doi.org/10.1007/s11442-013-1014-x

[37] EL-Bana, M., Nijs, I. and Kockelbergh, F. (2002) Microenvironmental and Vegetational Heterogeneity Induced by Phytogenic nebkhas in an Arid Coastal Ecosystem. *Plant and Soil*, **247**, 283-293. http://dx.doi.org/10.1023/A:1021548711206

[38] Link, S.O., Waugh, W.J., Downs, J.L., Thiede, M.E., Chatters, J.C. and Gee, G.W. (1994) Effects of Coppice Dune Topography and Vegetation on Soil Water Dyamics in a Cold-Desert Ecosystem. *Journal of Arid Environments*, **27**, 265-278. http://dx.doi.org/10.1006/jare.1994.1063

[39] Vali, A. and Pourkhosravani, M. (2009) A Comparative Evaluation of Relationship between Nebkha Morphometry and Plant Morphology, Case Study, Khair Abad Desert in Sirjan. *Geography and Environmental Planning*, **20**, 119-134.

[40] Mosleh, A., Azimzadeh, H., Ekhtesasi, M., Immantalab, N. and Dolati, A. (2014) Investigation of Morphological Changes and Nebkha Formation in *Capparis decidua* and C. *spinosa* in Arid Lands. *Journal of Range and Watershed Management* (*Iranian Journal of Natural Resources*), **67**, 475-485.

[41] Zhou, H., Zhao, W.-Z., Luo, W.-C. and Liu, B. (2015) Species Diversity and Vegetation Distribution in Nebkhas of *Nitraria tangutorum* in the Desert Steppes of China. *Ecological Research*, **30**, 735-744. http://dx.doi.org/10.1007/s11284-015-1277-z

[42] Cevallos, F. (1996) Mares de arena de sombra de montaña, Comparación entre un sistema fósil (Miembro El Palque) y un sistema actual (Desierto Médanos Grandes). Tesis de Licenciatura, Universidad Nacional de San Juan, San Juan, 104 p.

[43] Suvires, G. (1985) Geomorfología del sector suroriental de la provincia de San Juan y Edafología del Cuaternario de un sector de la planicie aluvial del río Bermejo. Tesis Doctoral, Universidad Nacional de San Juan, San Juan, 155 p.

[44] Suvires, G. (1991) Paleoformas eólicas y fluviales en regiones desérticas del centro oeste de Argentina. *Bamberger Geographische Schrifften*, **1**, 125-133.

[45] Tripaldi, A. (2002) Sedimentología y evolución del campo de dunas de Médanos Grandes. San Juan-Argentina. *Revista de la Asociación Sedimentológica Argentina*, **9**, 65-82.

[46] Iriondo, M. and Krohling, D. (1996) Los sedimentos eólicos del noreste de la llanura pampeana (Cuaternario Superior). XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos, *Actas*, **4**, 27-48.

[47] Tripaldi, A., Forman, S.L., Cicciou, P.L. and Reijenstein, H. (2006) Estratigrafía y edad de depósitos eólicos holocenos del campo de dunas Médanos Grandes. Provincia de San Juan, Argentina. IV Congreso Latinoamericano de Sedimentología y IX Reunión Argentina de Sedimentología, *Actas*, **1**.

[48] Kocurek, G. and Ewing, R.C. (2005) Aeolian dune Field Self-Organization Implications for the Formation of Simple versus Complex Dune-Field Patterns. *Geomorphology*, **72**, 94-105. http://dx.doi.org/10.1016/j.geomorph.2005.05.005

[49] Martínez Carretero, E. (2013) La Diagonal Árida Argentina, entidad bioclimática. In: Pérez, D, Rovere, A.E. and Rodriguez Araujo, M.E., Eds., *Restauración ecológica en la Diagonal Árida de la Argentina*, Vázquez Mazzini.

[50] Poblete, A. (1999) Configuración Espacial del Clima de San Juan. Síntesis del Cuaternario de la Provincia de San Juan.

[51] Berra, A. and Ciancaglini, N. (1979) Mapas de evapotranspiración potencial de la provincia de Mendoza. *Cuaderno Técnico*, **1-79**, 1-37.

[52] Meteored. http://clima.meteored.com/clima-en-san+juan+aero-873110-2010-.html

[53] Pastrán, M.G. (2012) La vegetación de los Médanos Grandes, provincia de San Juan, análisis florístico y sinecológico. Tesis doctoral, PROBIOL, Universidad Nacional de Cuyo, Mendoza-Argentina, 139 p.

[54] Tsoar, H. (2005) Sand Dunes Mobility and Stability in Relation to Climate. *Physica A*, *Statistical Mechanics and Its Applications*, **357**, 50-56. http://dx.doi.org/10.1016/j.physa.2005.05.067

[55] Yizhaq, H., Ashkenazy, Y., Tsoar, H. (2007) Why Do Active and Stabilized Dunes Coexist under the Same Climatic Conditions? *Physical Rewiew Letters*, **98**, Article Number: 188001. http://dx.doi.org/10.1103/PhysRevLett.98.188001

[56] Bértola, G. and Cortizo, L. (2005) Transporte de arena en médanos litorales activos y colgados del sudeste de Buenos Aires. *Revista de la Asociación Geológica Argentina*, **60**, 174-184.

[57] Wiggs, G., David, S., Bullard, T. and Livingstone, I. (1995) Dune Mobility and Vegetation Cover in the Southwest Kalahari Desert. *Earth Surface Processes and Landforms*, **20**, 515-529. http://dx.doi.org/10.1002/esp.3290200604

[58] Sokal, R. and Rohlf, F. (1995) Biometry. W.H. Freeman and Company, New York, 887 p.

[59] Ruiz Leal, A. and Roig, F. (1959) Erial de vegetación en montículos. *Boletín Estudios Geográficos*, **6**, 161-209.

[60] Zhang, P., Yang, J., Zhao, L. Bao, S. and Song, B. (2011) Effect of *Caragana tibetica* Nebkhas on Sand Entrapment and Fertile Islands in Steppe-Desert Ecotones on the Inner Mongolia Plateu. *Plant & Soil*, **347**, 79-90. http://dx.doi.org/10.1007/s11104-011-0813-z