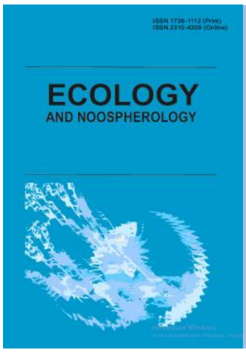

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Soil processes in the Aeolian Litoral Sheet of Doñana National Park (Huelva, SW Spain): the catena of Colón small-lake ecosystem

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The wetlands on the quartz sands aeolian sheet make up one of the ecosystems most recognized and important of the Doñana National Park and Doñana Biological Reserve (South Spain). More than 650 temporal small-lakes have been surveyed in the abundant sand depressions of the aeolian sheet, the most are a hydro-geomorphological dune-small-lake system. This paper studies the pedological processes around Colón small-lake ecosystem wetland (COL), one of the more interesting temporal small-lakes. The movement of fine particles through sand dunes ("sand washing") and their subsequent accumulation in depth is the process responsible for the formation of a large part of the small and medium small-lakes in the Eolian Litoral Sheet of Doñana. Their bodies of water are supported by these clay layers generated corresponding sometimes to ancient soil horizons formed under previous different ecological conditions. The vegetation, the soil morphology and the evolution of the physical-chemical processes studied in this geosystem small-lake of Colón allow understand this phenomenon of chronologies very recent.

Keywords: sand dunes; pedogenesis; small-lakes; Doñana; Spain

Introduction

On the so-called "wet mantle" of the Abalario-Doñana Aeolian Litoral Sheet of the Doñana National Park (Borja, 2011) there is a large set of small and medium-sized small-lakes that make up ecosystems of high ecological value. Its genesis has always been attributed to the rise of the general aquifer whose piezometric surface would cut the undulating relief that makes up the porous and permeable buildings of the existing dunes.

The studies carried out by Borja (2011) revealed, however, that many of these wetlands present a functioning where the formation of their body of water is due to the direct retention of rainwater and the participation of subsurface water that circulates through the interstices of the sands (epigenic type). Others are related to specific discharges from the general aquifer, such is the case of Charco del Toro (hypogenic regime) (Bejarano et al., 2010; Recio et al., 2009), and others such as Navazo del Toro are derived from a mixed situation (mesogenic regime) (Díaz del Olmo et al., 2014).

This epigenic regime is possible given the presence at the bottom of the basins of impermeable and neosynthesized smectitic clay layers generated in earlier pedo-paleopalustrine situations with chronologies of 4.255 +/- 438 BP (Díaz del Olmo et al. 2014; Recio et al., 2014), subsequently transformed by the hydromorphy itself and biological activity of the small-lake ecosystem. This situation leads at the same time to the mixture of the most superficial levels as well as the formation on occasions of an organic-mineral horizon of white color and silty nature where it has been possible to determine new species of diatoms (Blanco et al., 2013; Espejo Alcaide, 2016).

In order to show the formation of these deep impermeable clayey layers, the intensity and speed of these processes of translocation of very fine sands, silts and clays (“sand washing”) and the formation of the small-lake water body, the small wetland of the Colón or Fresno small-lake has been chosen as a model (Fig. 1), where the existing vegetation helps to demonstrate these subsurface water flows established in the gradient of the slope (Recio et al. 2014, a and b).

Material and methods

Three representative soil profiles of the different situations that define the dune-wetland geosystem that make up this Colón small-lake have been studied.

Through a detailed altimetric survey with high-precision GPS (Topcon Hiper GD/GPS L1 model), the detailed georeferenced morphotopography of the small-lake basin and its immediate surroundings was obtained, which allowed correlating the different profiles with the different levels identified (Borja, 2011). Similarly Borja (2011) carried out continuous monitoring (every 15 days) of the wetland's water dynamics based on the measurement of its surface and thickness of the water column, of the subsurface water levels as well as the level of the aquifer regional.

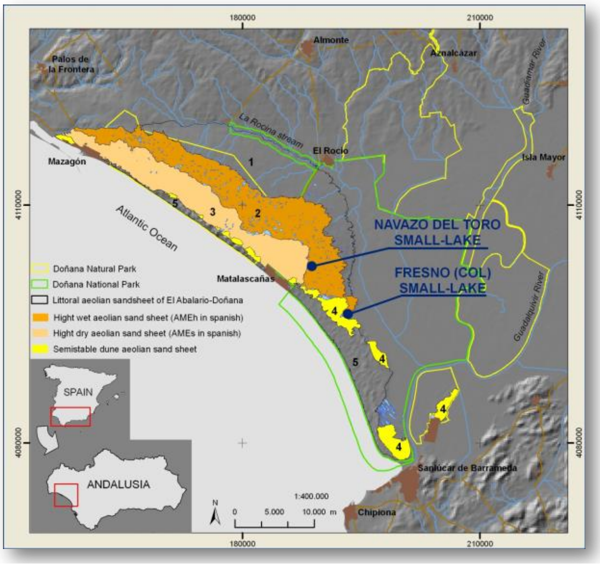

Figure 1. Colón (Fresno) small-lake in Abalario-Doñana Aeolian Litoral Sheet

COL-1 soil profile was opened in the somital zone or crest of the dune that faces the wetland; the COL-2 profile comes to represent the base of the dune slope where the upper basin of the small-lake is positioned, flooded only in years of high rainfall, and in its lower basin occupied annually by its sheet of water the COL-3 soil profile was opened (Fig. 2). The artificial hollow ("zacayón") open as a trough would complete the morphology of his bucket.

The soil profiles have been described and classified according to the standards of FAO (1977) and FAO (2015). The color was determined following the Munsell scale (Munsell, 1990), pH according to Guitián and Carballas (1976) and electrical conductivity (EC) according to USDA (1973) and Duchaufour (1975). Organic matter and organic carbon (C) by Sims and Haby (1971), and the parameters of hygroscopic humidity (H), apparent density (Dap.), real (Dr), porosity (Por) and hydraulic conductivity (H.C.), following the MAPA (1986) methodology. The texture, mineralogy of clays and sands, and magnetic susceptibility (MS) according to the methods described by Soil Survey England and Wales (1982), Brindley and Brown (1980), Montealegre (1976), Parfenoff and Pomerol, (1970) and Dearing (1999) respectively.

The study of the vegetation was carried out through the corresponding sampling and collection in the field and its subsequent determination in the laboratory (Blanca et al. 2011). The OSL (Optically Stimulated Luminescence) dating was carried out in the dating and radiochemistry laboratory of the Autonomous University of Madrid (COL-1 and COL-2).

Results and discussion

In the top zone of the dune (Fig. 2 and 4) a very young soil with few evolution (COL-1) develops with a type A1 C1 horizon profile, about 50 cm thick, olive-brown in color (10YR 7/4 (s), 2.5Y 5/6 (h), and with characteristics of Distric Arenosol (FAO, 2015), which serves as support for isolated stems of *Pinus pinea*, and *Pistacea lentiscus* (Table 1, Fig. 3 and 4).

On the dune slope, at lower levels and forming the upper basin of the wetland, the COL-2 profile develops, with more grayish chroma (10YR 3/2 (h)) and more powerful (about 80 cm of development), and A1 AC1 C1 horizons sequence, which has been classified as Humic Arenosol (FAO, 2015), and supports an abundant population of ferns (*Pteridium aquilina*) and rushes (*Scirpus holoschoenus*) (Fig. 3).

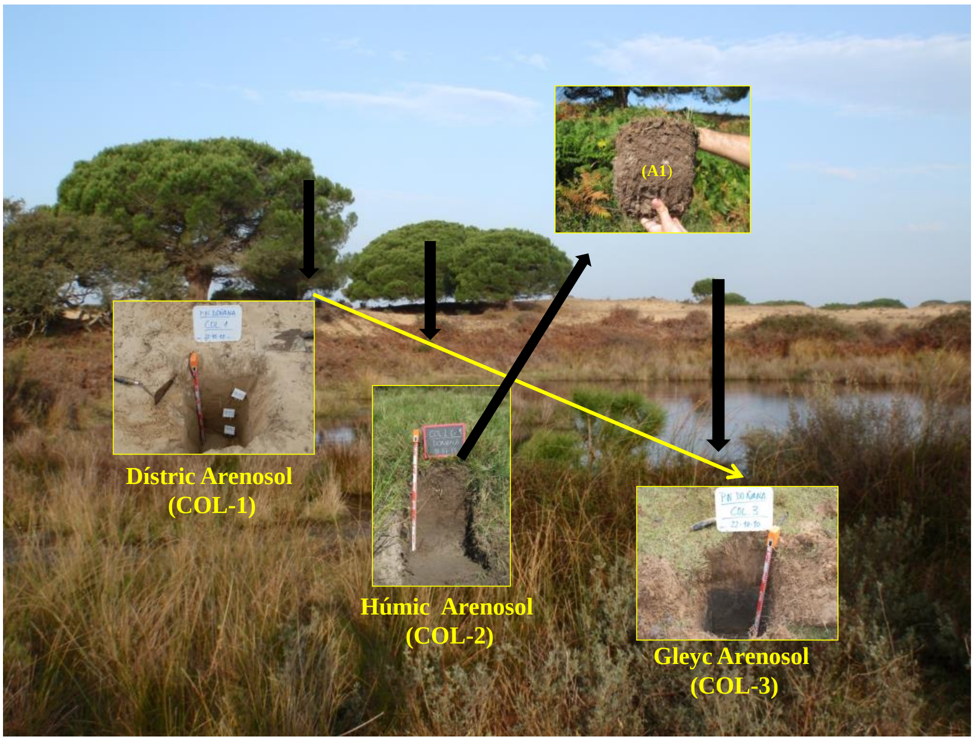

Figure 2. Soils catena in Colón small-lake

In the lower trough, a somewhat more evolved profile of dark and black chroma (10YR 3/1), A1 AC1g C1g horizon sequence and Gleyc Arenosol morphology (COL-3) (FAO, 2015) is developed, which mainly supports grasses (*Agrostis stonolífera*) and coincides with the levels closest to the surface of the aquifer (Table 1; Fig. 2 and 3).

Organic matter (OM) reaches maximum levels in this discharge zone that coincides with the upper basin of the small-lake (4 %) and the population of *Pteridium aquilinus*. It is almost non-existent (0.19 %) in the highest zone where the feet

Table 1
Physical and chemical characterization of soil profiles studied in Colón small-lake
(mr – very fast; r – fast; md – moderately fast; m – moderately)

Profile	Horiz/Prof. (cm)	Colour		pH	E.C.	O.M.	H.C.	Wet.
		(s)	(h)	(H_2O)	(mhs/cm)	(%)	(cm/h)	(%)
COL-1 Dístric Arenosol	AC1 (0–10)	10YR 7/4	2,5Y 5/6	7.10	0.08	0.19	189 (mr)	0.03
	C1 (10–25)	10YR 7/4	2,5Y 5/6	6.60	0.06	0.19	117 (mr)	0.04
	C2 (25–50)	10YR 7/4	2,5Y 5/6	6.40	0.07	0.19	140 (mr)	0.04
	(mean)			**6.70**	**0.07**	**0.19**	**148**	**0.03**
COL-2 Húmic Arenosol	A1 (0–20)	10YR 6/2	10YR 3/2	5.30	0.74	4.06	72 (mr)	0.79
	AC1 (25–50)	10YR 6/2	10YR 3/2	6.00	0.23	1.73	45 (mr)	0.44
	C1 (50–80)	10YR 7/1	10YR 4/2	6,30	0.12	0.43	20 (r)	0.11
	(mean)			**5.86**	**0.36**	**2.07**	**45**	**0.44**
COL-3 Gleyc Arenosol	A1 (0–20)	10YR 6/3	10YR 3/3	6.40	0.63	1.52	7 (md)	0.70
	AC1g (20–30)	10YR 4/1	10YR 2/1	5.60	1.72	1.24	4 (m)	0.50
	C1g (30–55)	10YR 6/1	10YR 3/1	5.10	1.26	0.52	8 (md)	0.11
	(mean)			**5.70**	**1.20**	**1.09**	**6**	**0.43**

of *Pinus pinea* are located, and reaches 1.52 % in the wetland bottom occupied by grasses (*Agrostis stolonifera*) (Table 1; Fig. 6).

Parameters such as pH and salinity (E.C.) (Table 1, Fig. 7) experience a significant change in the dune-wetland gradient. In this way, the COL-1 profile shows an average pH of 6.7, and more acids than 5.7 in the COL-3 profile, despite the confinement of the water in its lower basin. The salinity (E.C.) is also in line with this gradient, being almost non-existent in the dune sands (0.07 mhs/cm as mean value), and 1.20 mhs/cm in the confined-accumulative environment of the small-lake bottom, even reaching maximum values of 1.72 mhs/cm, coinciding with the maximum acidity (5.1).

All the horizons are made up of aeolian sands (Table 3; Fig. 4) and therefore their texture is always sandy, with maximum contents of 99.75 % (Table 3). In the COL-1 profile they are of medium size (0.5–0.25Ø mm) and wind selected (63.52 % average value). On the dune slope this aeolian character disappears, with medium and fine sands predominating, becoming fine and very fine at the base of the catena (COL-3 profile, 27.06 and 43.6 %; Table 3).

The proportion of fines (silts and clays) evolves in the same way, from values of 0.5 % in the upper area of the dune, to 17 % at the base of the dune and the lower basin of the wetland (Table 3, Fig. 5, COL-3 profile), with even higher values in the superficial horizons (20.50 % in the A1 horizon).

Table 2
Physical and mineralogical properties of soil profiles (c – common; f – frequent; o – occasional; r – rare)

Profil	Horiz/Prof. (cm)	Dapr. (g/cm^3)	Dreal (g/cm^3)	Por. (%)	Ilmenite. (%)	M. S. ($\chi 10^{-9}$)
COL-1 Dístric Arenosol	AC1 (0–10)	1.62	2.70	40	14.11 (c)	128
	C1 (10–25)	1.63	2.81	42	10.05 (f)	116
	C2 (25–50)	1.61	2.79	42	15.89 (c)	120
	(mean)	**1.62**	**2.76**	**41**	**13.50**	**121**
COL-2 Húmic Arenosol	A1 (0–20)	1.26	2.43	48	8.50 (f)	104
	AC1 (25–50)	1.32	2.63	50	1.43 (o)	68
	C1 (50–80)	1.54	2.63	41	2.80 (o)	44
	(mean)	**1.37**	**2.56**	**46**	**4.24**	**72**
COL-3 Gleyc Arenosol	A1 (0–20)	1.34	2.56	48	2.99 (o)	60
	AC1g (20–30)	1.39	2.56	46	0.83 (r)	52
	C1g (30–55)	1.57	2.77	43	0.51 (r)	36
	(mean)	**1.43**	**2.63**	**45**	**1.44**	**49**

This textural evolution and movement of fine particles down the gradient is reflected in the hydraulic conductivity (H.C.) with values from 148 cm/h ("very fast") in the proper dune sands that begin the catena, to 6 cm/h ("moderately fast") in the lower wetland basin (Table 1, Fig. 4) (MAPA, 1986). This comes to represent 96 % in the slowdown of these interstitial water flows, and therefore cause the accumulation of water at the base of it. Despite the fact that the hydraulic conductivity continues to be "very fast" in the area of the dune slope, values of 45 cm/h would be enough to produce a large brake and discharge on the surface (Fig. 5).

Despite the textural change caused by this movement of particles ("sand washing"), the porosity presents similar values around 41–46 % (Table 2, Fig. 6) as it evolves from designs of large interconnected pores to smaller ones and disorganized related to the finer texture. Perhaps the low thickness of the profiles motivates the existence of insignificant differences between the apparent (Dapr.) and real (Dreal.) density values found throughout the catena (Table 3) (Recio et al., 2014).

The mineralogical analysis shows that despite the low clay contents present, the presence of an interstratified layer is detected at 12–14 Ä in the clays of the COL-1 profile, an

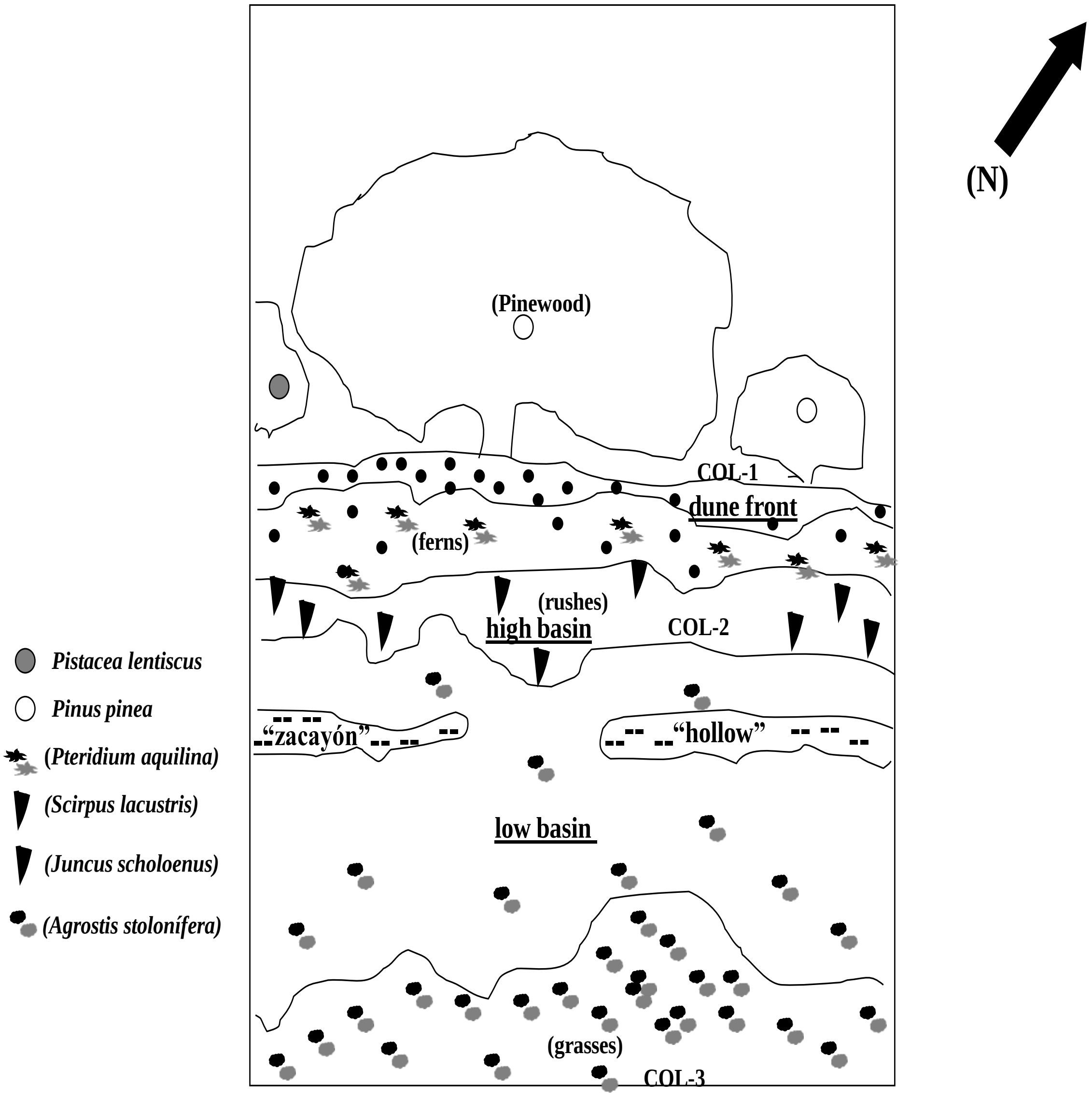

Figure 3. Scheme of the surrounding vegetation

Table 3
Distribution particule size

Profil	Horiz/Prof. (cm)	Sand fraccions						Silt+Clay
		2–1	1–0,5	0,5–0,25	0,25–0,125	0,125–0,063	Total	
				mm (%)	(%)	(%)		
COL-1 Dístric Arenosol	AC1 (0–10)	0.00	0.20	58.38	38.54	2.86	99.00	1.00
	C1 (10–25)	0.00	1.98	68.45	37.03	2.09	99.75	0.25
	C2 (25–50)	0.00	0.81	63.73	33.29	2.14	99.75	0.25
	(mean)	**0.00**	**0.99**	**63.52**	**36.28**	**2.36**	**99.50**	**0.50**
COL-2 Humic Arenosol	A1 (0–20)	0.16	4.75	45.80	38.78	10.40	88.55	11.45
	AC1 (25–50)	0.47	8.33	32.97	40.72	17.49	87.30	12.70
	C1 (50–80)	0.89	11.71	34.46	35.19	17.73	90.95	9.05
	(mean)	**0.50**	**8.26**	**37.79**	**38.23**	**15.20**	**88.94**	**11.06**
COL-3 Gleyc Arenosol	A1 (0–20)	0.75	6.66	25.91	42.32	24.33	79.50	20.50
	AC1g (20–30)	0.62	6.26	25.87	42.85	24.37	80.20	19.80
	C1g (30–55)	1.08	7.22	29.40	44.31	17.97	89.20	10.80
	(mean)	**0.81**	**6.71**	**27.06**	**43.16**	**22.22**	**82.97**	**17.03**

incipient vermiculitation process that evolves under the protection of acidity and the organic matter present, and which reaches a maximum on the surface of the COL-2 profile. The illite and kaolinite clays inherited from the aeolized parent substrate are the predominant ones, and the absence of neosynthesized smectites in the confined small-lake bottom itself (COL-3 profile, Table 4) would be indicative of the recent nature with which all these dynamic processes occur (Díaz del Olmo et al., 2014; Recio et al., 2014).

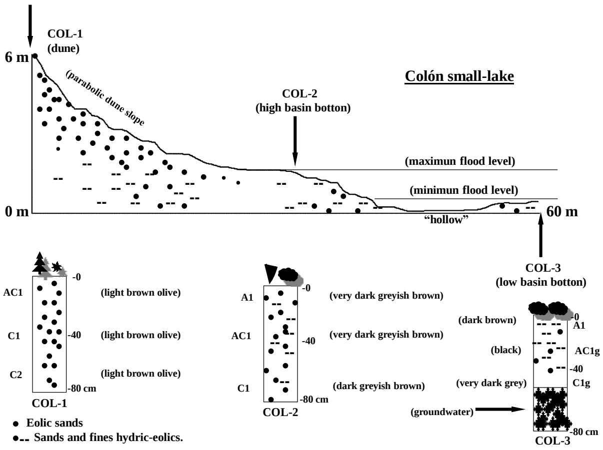

Figure 4. Depth, sequence horizons and chroma of the profiles studied

Table 4
Semiquantitative analysis of clay fraction (V – vermiculite; Sm – smectites; K – kaolinite; I – illite)

Profil	Horiz (cm)	(V) (%)	(Sm) (%)	(I) (%)	(K) (%)
COL-1 Dystric Arenosol	AC1	(interstratified) (12A)			
	C1	0	0	69	31
	C2	(interstratified) (12 A)			
COL-2 Humic Arenosol	A1	13	0	46	41
	AC1	5	0	67	28
	C1	0	0	86	14
COL-3 Gleyc Arenosol	A1	0	0	75	25
	AC1g	0	0	74	26
	C1g	0	0	93	7

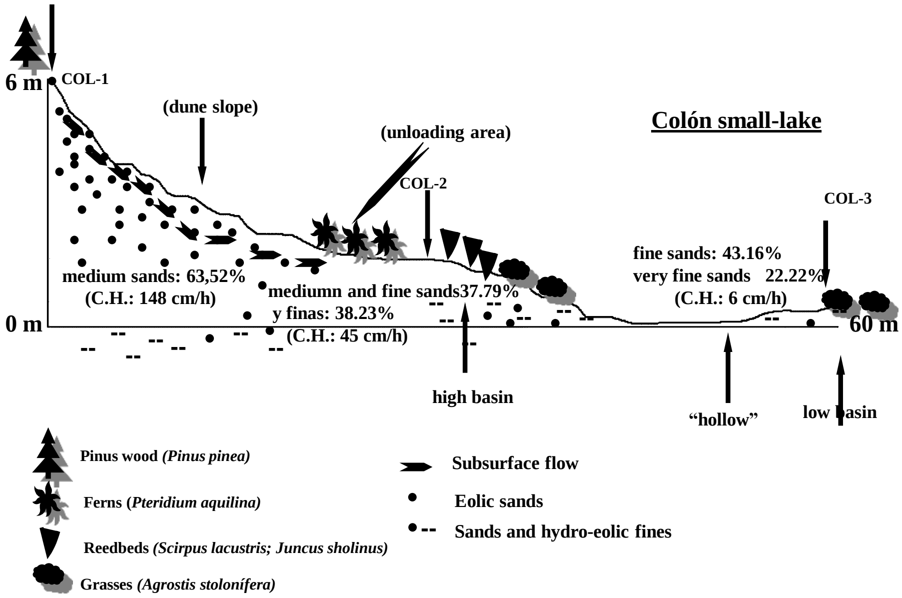

Figure 5. Vegetation, sand distribution, mean values of hydraulic conductivity and pedological and superficial flow regime

As representative of the mass of alterable ferromagnesian minerals present (Recio et al., 2009 and 2011), the Fig. 7 shows the ilminite contents in the different horizons (Table 2). "Very common" in the dune (COL-1, mean value of 13.5 %) becomes almost "occasional" and even "rare" at the bottom of the trough (COL-3, 1.44 % as mean value), a consequence of the alteration processes and at the same time responsible for the iron oxy-hydroxide stains that appear in the C1g horizon. In relation to all this would be the values of magnetic susceptibility (M.S.) ($128–36\chi10^{-9}$), indicative of the greater alteration that occurs as we descend in the soil category studied (121, 72 and $49\chi10^{-9}$ respectively) (Table 2).

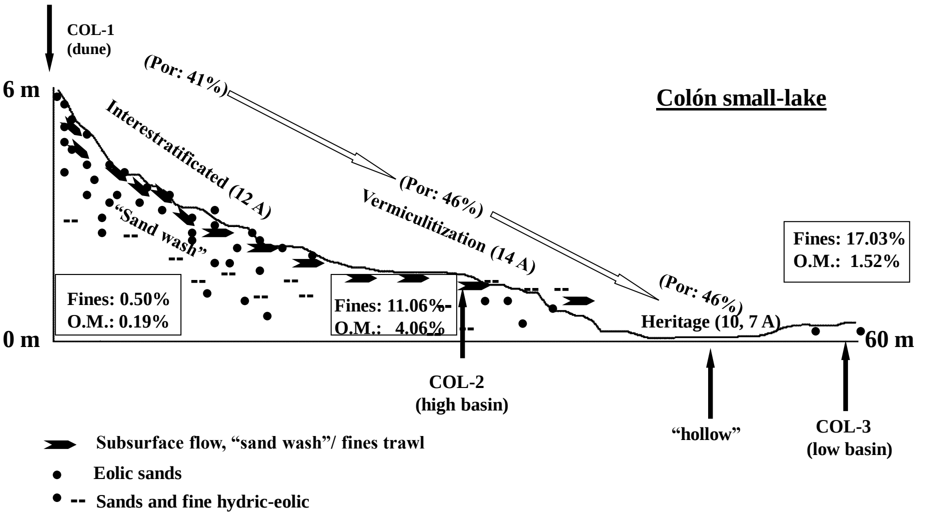

Figure 6. "Sand washing" and clay formation, porosity gradient (Por.), fines (silt and clay) and organic matter (OM) contained in the studied catena

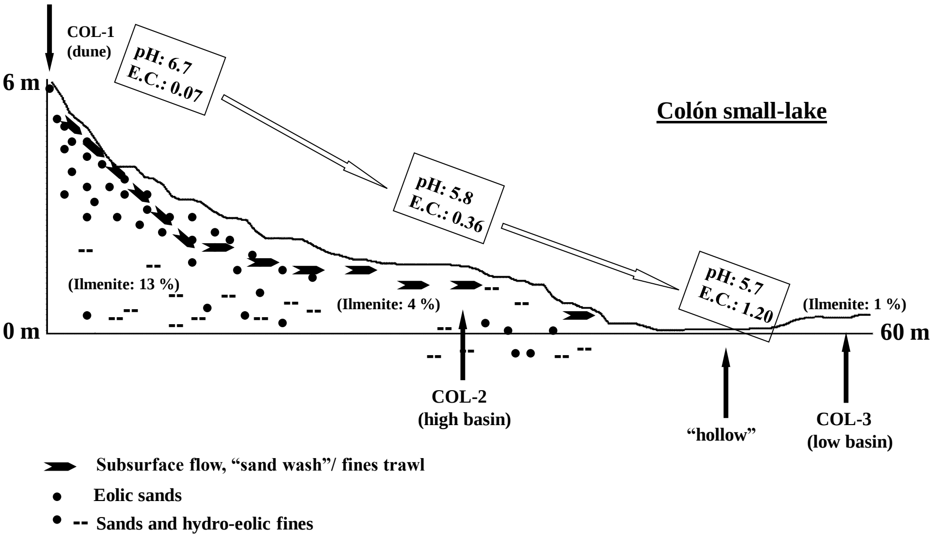

Figure 7. pH variation, electrical conductivity (E.C.) and presence of ilmenite

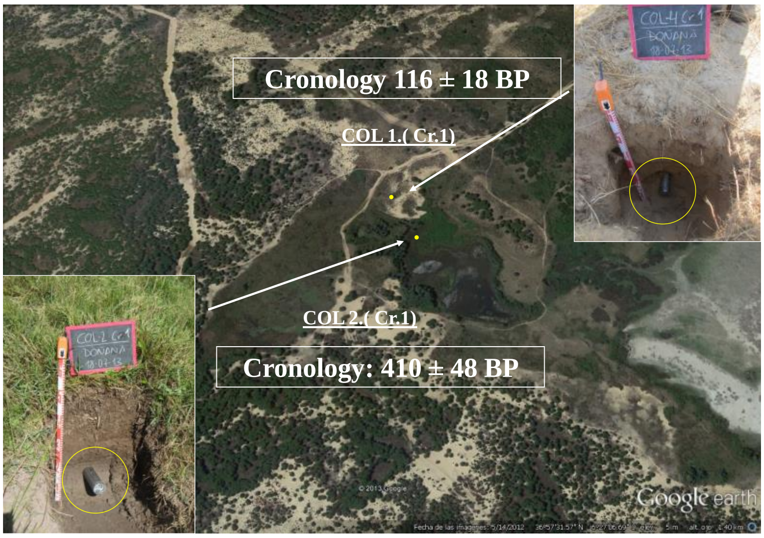

Figure 8. OSL cronology: sand dune (COL-1) and profile COL-2

The chronology obtained by OSL corresponding to the C1 horizons of the COL-1 (+50 cm) and COL-2 (+80 cm) profiles helps to evaluate the speed with which these processes occur and also to get closer to the chronology and formation of the current wetland. Based on this, the dune that faces the wetland would present a chronology of 116yBP, and the more chromic and darker horizons of the upper basin (COL-2) show an age of around 410yBP (Fig. 8).

Conclusion

The Colón small-lake ecosystem shows a very marked seasonal character, a high mineralization of the organic matter of its bottom and an acid nature and absence of salts in its waters.

The distribution of the fern-based vegetation in the discharge zone, grasses and rushes in the levels closest to its lower basin, and pines and mastics in the highest zone, coincides with the subsurface water flows established in the catena studied, responsible at the same time for the existing pedological evolution.

This pedological evolution is signified by current processes of migration and washing of fines along the slope ("sand washing"), slowing of the circulation of interstitial water, and the genesis and current dynamics of the wetland. Vermiculitation processes, a rapid alteration of the ferromagnesian minerals, and the absence of neosynthesized smectites would add to these weathering processes.

References

Blanca, G., B. Cabezudo, M. Cueto, C. Morales, C. Salazar (Editores) (2011). Claves de la Flora Vascular de Andalucía Oriental. Universidades de Granada, Almería, Jaén y Málaga. Granada. 802 pp. (in Spanish).

Blanco, S., Álvarez-Blanco, I., Cejudo-Figueiras, C., Recio, J. M., Borja, C., Bécares, E., Díaz-Olmo, F., Cámara, R. (2013). The diatom flora in temporary ponds of Doñana National Park (southwest Spain): five new taxa. Nordic Journal of Botany, 31, 1–11.

Bejarano, R., Cámara, R., Borja, C., Díaz-Olmo, F., Borja, F. (2010). Caracterización de los bosques de Sabina (Juniperus turbinata Guss) del entorno de la laguna de Charco del Toro (Parque Nacional de Doñana): aproximación a una metodología alternativa para el estudio de la vegetación. VI Congreso Español de Biogeografía (in Spanish).

Borja, C. (2011). Lagunas de Doñana (Huelva): génesis, dinámica y modelo hidrogeomorfológicos. Tesis Doctoral. Universidad de Sevilla. 531 págs (in Spanish).

Borja, F., Díaz-Olmo, F., Borja, C., Recio, J. M., Cámara, R. (2014). El manto eólico litoral de El Abalario-Doñana (Huelva, SW de España). Aproximación a la secuencia eólica del Holoceno medio-superior. Jornadas de Investigación sobre la Conservación de Doñana. Sevilla. 17–18 (in Spanish).

Brindley, G. W., Brown, G. (1980). Crystal structure of clay minerals and their X-ray identification. Mineralogical Society London. London.

Dearing, J. A. (1999). Environmental magnetic susceptibility: using the Bartington MS2 system 2nd. Edi. Chi. Publ. Kenilworth, United Kingdom.

Díaz-Olmo, F., Recio, J. M., Borja, C., Cámara, R., Borja, F. (2014). Edafogénesis y formación de humedales en el Manto Eólico Litoral del Abalario-Doñana (Huelva, SW de España). La laguna de Navazo del Toro. Jornadas de Investigación sobre la Conservación de Doñana. Sevilla. 39 (in Spanish).

Duchaufour, Ph. (1975). Edafología. Edit. Toray-Masson. Barcelona, 476 pp. (in Spanish).

Espejo, E. (2016). Humedales sobre el manto dunar del Espacio Doñana (Huelva). Caracterización físico-química y biológica de sedimentos orgánicos. Trabajo Fin de Grado, Facultad de Ciencias, Universidad de Córdoba (España) (in Spanish).

FAO (1977). Guía para la descripción de perfiles de suelos. F. A. O., Roma (in Spanish).

FAO (2015). World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Rome, 192 pp.

Guitián, F., Carballas, T. (1976). Técnicas de análisis de suelos. Edit. Pico-Sacro. Santiago, 288 pp. (in Spanish).

MAPA (1986). Métodos de análisis del Ministerio de Agricultura, Pesca y Alimentación. Public. Secretaría General Técnica. Madrid (in Spanish).

Montealegre, L. (1976). Mineralogía de sedimentos y suelos de la Depresión del Guadalquivir. PhD Thesis. Universidad de Granada, 600 pp. (in Spanish).

Munsell, C. (1990). Munsell Soil Color Charts. Koll Morgen Instrument Corporation. Maryland (EE.UU).

Parfenoff, A., Pomerol, C. H. (1970). Les minéraux en grains. Méthodes d`´etude et determination. Masson et Cie. Éditeurs. Paris. 550 pp. (in Spanish).

Recio, J. M., Díaz-Olmo, F., Borja, C., Borja, F., Cámara, R. (2009). Changes in the recent pedogenesis. Role of the hydromorphism in two small-lake of the Doñana National Park (Huelva, SW Spain). Ecol Noospherol,, 20, 145–147.

Recio, J. M., Díaz-Olmo, F., Borja, C., Cámara, R., Borja, F. (2011). Soil processes and wetlands formation on dunes of Doñana National Park (Andalusia, Spain). III International Scientific Conference, Irkutsk (Rusia), 101–102.

Recio, J. M., Díaz-Olmo, F., Borja, C., Cámara, R., Borja, F. (2014a). Procesos edafogenéticos en el manto eólico litoral del Abalario-Doñana (Huelva, SW de España): la laguna de Colón. Jornadas de Investigación sobre la Conservación de Doñana. Sevilla. 54–55 (in Spanish).

Recio, J. M., Cámara, R., Borja, C., Díaz-Olmo, F., Borja, F. (2014b). Edafogénesis sobre el Manto Eólico Litoral de Abalario-Doñana (Huelva, España): el perfil SOJ-2 del sabinar de Ojillo. VIII Congreso Español de Biogeografía. Sevilla. 73–77 (in Spanish).

Sims, J. R, Haby, V. A. (1971). Simplied colorimetric determination of soil organic matter. Soil Sci; CXII, 137–141.

Soil Survey England and Wales (1982). Soil Survey laboratory methods. Technical monographs nº6. Harpenden (England); 83 pp.

USDA (1973). Diagnóstico y rehabilitación de suelos salinos y sódicos Edit. Limusa (México), 172 pp. (in Spanish).