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Distribution of wetlands in Argentina estimated from soil charts

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ABSTRACT. We generated a map of wetlands in Argentina from the digital edition of the National Soil Inventory made by the National Institute of Agricultural Technology (Instituto Nacional de Tecnología Agropecuaria, INTA). Potential wetland areas were extracted from the map after an exhaustive analysis of the database and reassignment of the soil classes, by taking into account 1) soil taxonomic classes; 2) constraining factors (waterlogging, flooding, drainage impairment); and 3) cartographic categories, including lakes, lagoons, marshes and salt lakes. Estimated wetland area is about 600,000 km^2, representing 21.5% of the national territory; it increases to 23% when considering salt lakes and deepwater bodies, but their surface is underestimated in the INTA database. Finally, we analyzed the distribution and abundance of wetland areas from different eco-regions of Argentina, and compared our results with current global wetland databases.

Key words: wetlands, soil chart, national inventory, Argentina.

RESUMO. Distribuição de áreas úmidas na Argentina, estimada a partir de mapas de solo. Foi confeccionado um mapa de regiões úmidas da Republica Argentina, a partir da análise e reclassificação da edição digital do Atlas de Solos do pais, editado pelo Instituto Nacional de Tecnologia Agropecuária (INTA). O mapa incluiu áreas úmidas derivadas da análise exaustiva dos campos da base de dados referentes a: 1) classes taxonômicas dos solos; 2) ação de fatores limitantes (alagamento, inundação, deficiências da drenagem); e 3) categorias cartográficas que incluiam lagos, lagoas, esteiros e salinas. A superfície estimada das áreas alagadas é de aproximadamente 600.000 km^2, correspondendo a 21,5% do território nacional. Se acrescentar as superfícies de salinas e corpos de água, essa área ascende para 23%, embora os dados destes últimos sistemas estejam subestimados na base de dados utilizados. Analisaram-se a distribuição e a abundância de áreas alagadas em diferentes ecorregiões do país, e os resultados foram comparados com os obtidos a partir de estimativas realizadas com outras bases de dados.

Palavras-chave: áreas úmidas, pedologia, inventário nacional, Argentina.

Introduction

The term wetland embraces a wide variety of environments, including fluvial forests, marshes, swamps and bogs, among others. There is no consensus on a universal definition (Brinson, 2004). The term is usually employed to denominate systems under waterlogging or flooding conditions, or with soils saturated with water for prolonged periods.

In Argentina, wetlands cover a large surface area and include a broad range of types (Canevari *et al.*, 1998; Malvárez, 1999; Malvárez and Bó, 2004; Blanco and De La Balze, 2004). Until a few decades ago, most wetlands were undisturbed by human activities (except for those in urban areas), such as water use for irrigation, dam building, drainage for agriculture or peat extraction. This situation contrasts with other parts of the world, particularly in temperate regions, where these and other practices have reduced wetland areas to a small fraction of their original abundance (Brinson and Malvárez, 2002).

The hydrological regime is recognized as the main conditioning factor for the structural and functional properties of wetland ecosystems (Mitch and Gosselink, 2000). In this sense, the diagnostic criteria of the U.S. Fish and Wildlife Service for the identification and delimitation of wetlands take into account the presence of 1) surface water; 2) vegetation adapted to both water excess (hydrophitic characters) and to the alternation of periods of water excess and deficit; and 3) hydric soils or soils with signs of hydromorphism (Cowardin *et al.*, 1979).

Historically, wetlands have been associated with hydromorphic, alluvial and halomorphic soils (Shaw and Fredine, 1956). Although the term hydromorphic is used in a wide sense, these soils are usually associated with temporary or permanent waterlogging or flooding marshes, swamps, peatlands and generally with gley soils. The alluvial soils correspond with floodplains and the halomorphic ones with grasslands and coastal salt marshes, or with alkaline continental wetlands (Tiner, 1999).

Soils featuring these properties reflected in their taxonomy and in cartographic units can be considered adequate substitutes (*proxy data*) for delimiting and qualifying the distribution of wetlands over a territory. In this framework, the objective of the present work was to develop a map of the potential extension and distribution of wetlands based on the cartography of soils in Argentina, to compare it with other information sources, and to use it for characterizing the distribution of wetlands at the eco-region level.

Features of the study area

Argentina shows a particular ecological profile resulting from its geographic position in the southern portion of South America, its Tertian and Quaternary biogeographical and geomorphological history, and the important environmental gradients along the territory. The combined action of these factors resulted in a great variety of regional ecosystems (Figure 1).

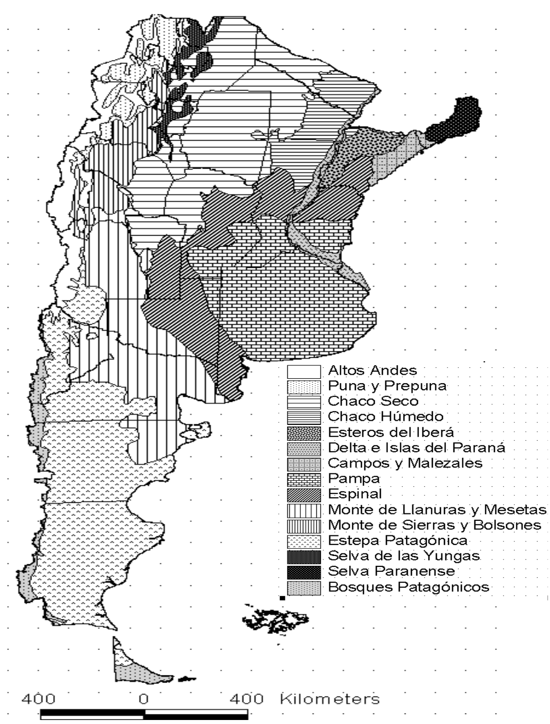

Figure 1. Eco-regions of Argentina.
Source: Burkart *et al.* (1999).

The hardwood forest and subtropical rain forests are close to the Tropic of Capricorn (23ºS), whereas steppes dominated by herbaceous plants and/or shrubs dominate the Patagonian landscape up to 55º South. In the longitudinal direction, grasslands and savannas of the deposition plains together with the Atlantic coastal environment are located east of the Andean environment. Finally, altitudes vary from sea level to the high peaks of the Andes (Table 1).

Table 1. Eco-regions of Argentina. Description of the general plant physiognomy, and ranges of total precipitation, mean annual temperatures and altitude above sea level.

Eco-region	Plant physiognomy	Mean annual temperatures (ºC)	Annual precipitation (mm)	Altitude asl (m)
Altos Andes	Grasslands and shrublands	-10-17	50-300	900-6000
Puna and Prepuna	Mixed steppes (herbaceous plants and shrubs)	-10-30	30-400	1500-4500
Chaco Seco	Open forests and shrublands	18-23	200-700	80-2000
Chaco Húmedo	Mosaic of forests herbaceous prairies and shrublands.	19-23	750-1300	25-170
Esteros del Iberá	Mosaic of herbaceous prairies floating mats and open water bodies.	19-22	1000-1500	20-100
Delta e islas del Paraná	Mosaic of herbaceous prairies, forests, marshes and open water bodies.	4-23	300-1400	0-400
Campos and Malezales	Prairies and savanna types	19-22	1200-1700	30-300
Pampa	Grasslands and herbaceous steppes.	15-18	400-1100	0-100 (up to 1000)
Espinal	Herbaceous steppes with trees (like a savanna type)	13-20	300-1300	0-200 (up to 1400)
Monte de llanuras and mesetas	Shrubland and shrub steppes	7-18	100-200	0-1000
Monte de sierras and bolsones	Shrubland and shrub steppes	-3-20	80-200	400-3000
Estepa patagónica	Mixed steppes (herbaceous plants and shrubs) and shrub steppes	-2-15	100-400	0-1000
Selva de las Yungas	Rain forest	6-23	900-1300	400-3000
Selva Paranaense	Rain forest	20	1600-2000	100-800
Bosques Patagónicos	Forest	5-14	800-4000	0-3700

The Andean System is aligned in the north-south direction, perpendicular to the main wind direction, thus conditioning regional atmospheric circulation, rainfall patterns and the configuration of the drainage network (Figure 2a). Most of the

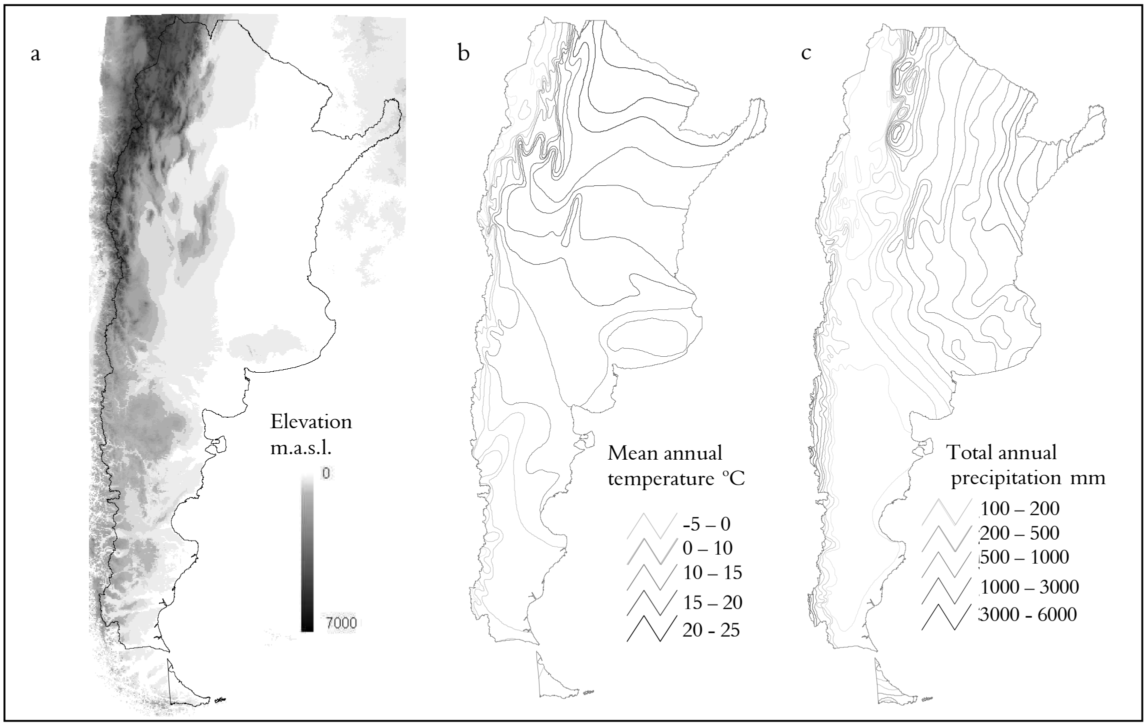

Figure 2. Main environmental gradients of Argentina. a) Map of elevations above sea level, b) Distribution of isotherms (mean annual temperature – ºC), c) isohyets (total annual precipitation – mm).

territory has a temperate-semiarid climate, and a humid subtropical climate associated with the South Atlantic anticyclone is found toward the northeast (Figure 2b and c).

High precipitation conditions related to winds from the South Pacific reappear in a small fringe along the mountain range in the southwest of the country. Like in the rest of South America, snowfalls and a persistent snow cover are exclusively restricted to the Andean System.

In general, wetlands are considered azonal systems due to their dependence on the hydrologic regime and local geomorphological setting, but in Argentina they show marked regional variations. In the framework of the Project Evaluation of Wetlands in South America, Canevari *et al.* (1998), who performed the first evaluation of wetlands in Argentina, identified six wetland regions (Figure 3). According to these authors, the Chaco and the Rio de la Plata Basin regions in the northeast of the country have a remarkable abundance of wetlands, associated primarily with the basins of the Paraguay, Pilcomayo, Bermejo, Paraná and Uruguay rivers. In the arid zones, wetlands are restricted to high-altitude lagoons and salt marshes in the South Andes, and to flood meadows and peatlands in Patagonia.

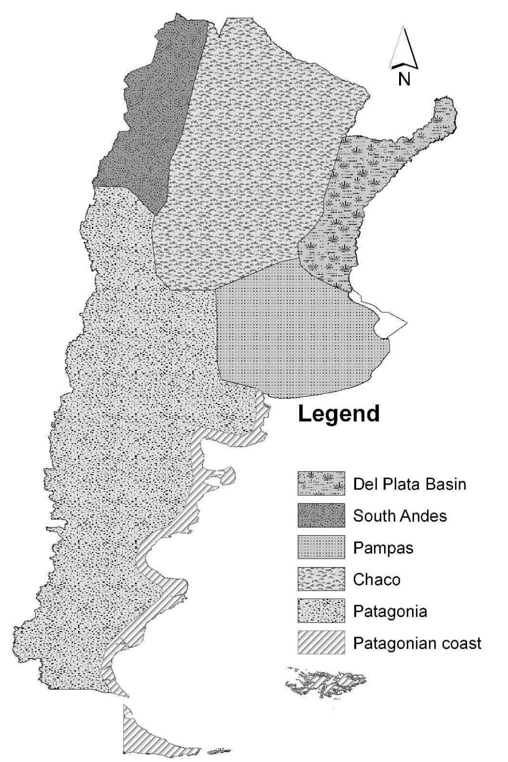

Figure 3. Wetland regions of Argentina.
Source: Canevari *et al.* (1998).

Despite their small surface area, they play a relevant role in providing water and forage to livestock. The Pampa Region, which has a great variety of wetlands characterized by open water and vegetated lagoons, includes the coast of Buenos Aires, with tidal marshes (i.e. Samborombón and Mar Chiquita) standing out from the remaining coastal systems.

Finally, in the Patagonian coast, the marine environment interacts with a very arid terrestrial environment, giving the region a characteristic profile.

Material and methods

This work was based on the National Soil Inventory (INTA, 1995) available on digital format at scale 1:1,000,000. This inventory had been obtained from a soil survey performed at provincial level by the National Institute of Agricultural Technology (Instituto Nacional de Tecnología Agropecuaria, INTA) at scale 1:250,000 (INTA, 1995). The database analysis met the current technical criteria for the diagnosis of hydric soils formulated by the National Resources Conservation Service (Richardson and Vepraskas, 2001). The map of wetlands of Argentina was then obtained by analyzing data on the attributes of the polygons corresponding to different types of soils, followed by their reclassification. Firstly, we surveyed the fields concerning the taxonomic categories of the soil (Order, Suborder, Great Group and Subgroup) and selected those classes indicating the involvement of hydromorphic processes in soil origin and development.

Secondly, we analyzed the fields containing information on the action of constraining factors (primary, secondary or tertiary) for soil development or productive activities, even if they were not reflected in the taxonomic categories. In this case, special attention was paid to waterlogging, flooding, and drainage impairment, since they may indicate wetland occurrence. Thirdly, we considered cartographic categories derived from the database (Simb_c field), suggesting the presence of wetlands such as marshes, lagoons, salt lakes, etc. Finally, we identified polygons not specified as wetlands by the database, as well as those that could not be assigned to any of the categories.

As a further validation of the method, we analyzed the distribution and surface area of wetlands in each eco-region of the country. In addition, the resulting map was compared to the recently created Global Lakes and Wetlands Database (GLWD-3, Lehner and Döll, 2004), which is on a comparable scale (1:1,000,000-1:3,000,000).

Surface calculations were carried out using the Gauss Krüger Zone 3 projection system, with ellipsoid WGS84. Data processing and analysis were performed with ArcView GIS 3.2.

Results and discussion

Figure 4 shows the resulting map of wetlands. Its legend includes six major classes, grouping together 1) areas of wetlands defined by soil taxonomic characters, 2) areas of wetlands derived from the action of constraining factors, 3) water bodies, 4) salt lakes, 5) areas with no information and 6) non-wetlands.

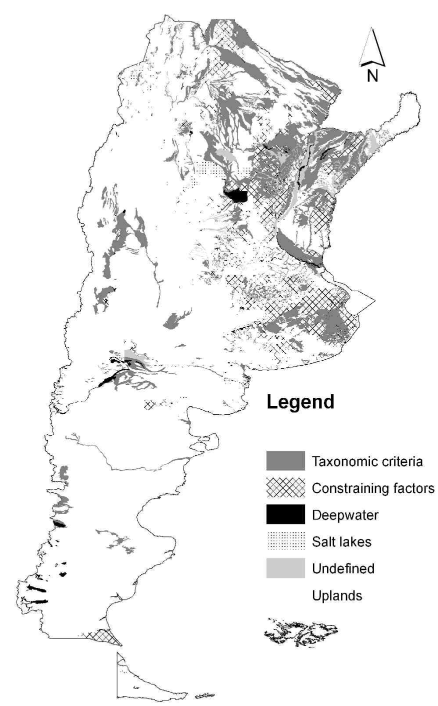

Figure 4. Map of wetlands of Argentina. Estimated from National Soil Chart database.

The first class was defined using the following soil suborders as indicators of wetland presence, since they are related to hydromorphic processes: Alfisols of Suborders Aqualfs, Entisols Aquents and Fluvents, Inceptisols Aquepts, Mollisols Aquic and Aquolls and Histosols Saprists and polygons corresponding to Mollisols of Suborders Udolls and Ustolls corresponding to subgroup Aquic (Table 2). This class covered a surface area of about 380,000 km^2.

The second class comprised polygons lacking characters used as taxonomic indicators for wetland soils but having constraints of first, second and third order by waterlogging, flooding, or drainage impairment; it occupied a total surface area of 200,000 km^2. The class water bodies covered a surface area of 27,000 km^2 and was composed of all the polygons reported in the database as lakes, lagoons, rivers, dams or permanently flooded freshwater marshes (locally called esteros), with no other additional information; they coincided with deep water environments except for the esteros. The class salt lakes (21,000 km^2) is recorded as such in the database without any additional information. A surface area of 51,000 km^2 could not be identified, whereas about 2,100,000 km^2 were defined as non-wetlands.

Table 2. Taxonomic classes included within the class of wetlands defined by soil taxonomic criteria for Argentina.

Order	Suborder	Great Group	SubGroups	Estimated Surface (km^2)
Alfisol	Aqualf	Albacualf	Tipic/Udolic/Ustalfic/Vertic	8133.38
		Fragiacualf	Tipic	736.59
		Natracualf	Albic/Glosic/Albic Glosic/ Molic/Tipic	97576.23
		Ocracualf	Aeric/Aeric Umbric/Molic/ Tipic/Vertic	456.21
Entisol	Aquent	Fluvaquent	Molic/Tapt argic/Tipic	2334.66
		Haplaquent	Aeric/Tapto argic/Tipic	9864.84
		Hidraquent	-	19.72
		Psamaquent	Humacuéptico/Saprico/Típico	8546.39
	Fluvent	Torrifluvent	Tipic	57704.89
		Udifluvent	Aquic/Molic/Tipic	5944.75
		Ustifluvent	Aquic/Molic/Tipic	58059.35
	Fluventes	Torrifluventes	Tipic	1996.85
Inceptisol	Aquept	Halaquept	Aerico/Tipic	8110.13
		Haplaquept	Aeric/Entic/Tipic / Vermic	14293.42
		Humaquept	Fluvaquentic	192.92
Molisol	Aquic	Haplaquol	Vertic	55.44
	Aquol	Argiaquol	Abruptic/Tipic /Vertic	16972.82
		Criaquol	Tipic	5289.23
		Duraquol	Natric/Tipic	1201.79
		Haplaquol	Histic/Tipic /Vertic	10077.63
		Natraquol	Tipic	55310.82
	Udol/ Ustol	Hapludol/ Haplustol	Aquic	13793.04
Histosol	Saprist	Medisaprist	Fibric	874.41

According to our results, the percentage of surface area with a high probability of including wetlands is about 21.5% of the country's surface, and it increases to 23% when the areas of salt lakes and water bodies are added. As a conservative measure, the class undetermined was considered a non-wetland surface.

The resulting wetland surface for Argentina seems to be higher than those reported for other countries. Mitch and Gosselink (2000), who compared different estimates of the world, pointed out that the surface of wetlands is likely to vary between 4 and 6% of the continental area, of which at least 56% would be located in tropical and subtropical regions. Recently, Lehner and Döll (2004) estimated that wetlands cover 6.2-7.6% of the Earth's surface and 2% more when lakes and dams are included.

Table 3 presents a comparison matrix between our results and the database of lakes and wetlands (GLWD) by Lehner and Döll (2004). There was an agreement of 75% between the datasets, although this was principally due to the coincidence of areas without wetlands.

Table 3. Comparison matrix between four wetland classes obtained from our map and from the study by Lehner and Döll (2004). Values are expressed in km^2 and the percentages of agreement are shown in italic font. Marginal percentages in brackets represent overall surface of Argentina according to each classification.

		GLWD-3				
		Wetlands	Water bodies	Salt lakes	Non-wetlands	Total results
Results	Wetlands	60965.72	5293.04	3760.51	527490.94	597510.21
		10.20	*0.89*	*0.63*	*88.28*	(21.41)
	Water bodies	3642.03	9329.15	630.19	13493.18	27094.54
		13.44	*34.43*	*2.33*	*49.8*	(0.97)
	Salt lakes	385.49	767.56	9954.18	10225.49	21332.72
		1.81	*3.6*	*46.66*	*47.93*	*(0.76)*
	Non-wetlands	37621.38	22066.79	20030.28	2092137.40	2171855.85
		1.73	*1.02*	*0.92*	*96.33*	(77.83)
	Total GLWD-3	98972.59	28127.39	33744.97	2629853.83	2790698.78
		(3.54)	(1.00)	(1.21)	(94.24)	

The surfaces of wetlands, salt lakes and water bodies estimated using GLWD-3 data were markedly lower (around 6%) than those estimated by us. The percentage of agreement was only 10.2% for wetland areas, and 88.28% of the areas indicated in the map as wetlands were annotated as non-wetlands in GLWD-3. These discrepancies may be accounted for by the global nature of the GLWD-3 database compared with the degree of detail in the resulting regional-scale map.

Figure 4 shows the large area occupied by wetlands in the humid northern region of Argentina, which are associated with sectors of the vast Chaco-Pampa Plain (*e.g.* Bajos Submeridionales and Pampa deprimida), and the fluvial courses related to del Plata Basin. Some large unique systems such as the Esteros del Iberá, the Mar Chiquita Lagoon in Córdoba Province and the Paraná River Delta can also be identified. In the rest of the territory, the wetlands tend to be located at particular sites, such as river valleys, depressions and at the foot of hills or mountains. This is the case for the flood meadows (locally called mallines) in Patagonia and the oasis in the arid center and north-west of the country, which show a reduced or null spatial expression when represented at the same scale as the wetlands mentioned above. In Tierra del Fuego, at the southern tip of the country, the database does not include information on peatland systems (locally called turberas), despite their large extension and economic importance (Blanco and De La Balze, 2004; Malvárez *et al.*, 2004).

In the littoral zone along the marine-estuarine coast of Buenos Aires Province, the only identified wetland areas were the littoral lagoon of Mar Chiquita and nearby areas, the tidal plain of the Bahía Blanca estuary and the mouths of Colorado, Negro, Sauce and Quequén rivers. Instead, the tidal plain of the Samborombón Bay remained in the class non-wetland, similarly to most of the Patagonian coast.

The entire free-water surface was underestimated, with lakes and dams being the only large water bodies. Water courses and other small water mirrors were not documented.

The figure 5 shows the area occupied by the resulting wetlands per eco-region. As expected, the eco-regions located on the axis of the Río de la Plata Basin showed a larger proportion of wetlands. The eco-regions Esteros de Iberá, Delta e islas del Río Paraná, the Chaco Húmedo and Campos y Malezales exhibit a wide variety of soil orders and suborders, revealing great landscape heterogeneity in terms of wetlands (Figure 6).

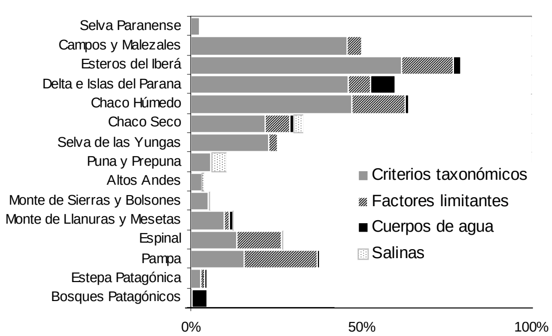

Figure 5. Proportion of wetlands, water bodies and salt lakes in the Eco-regions of Argentina.

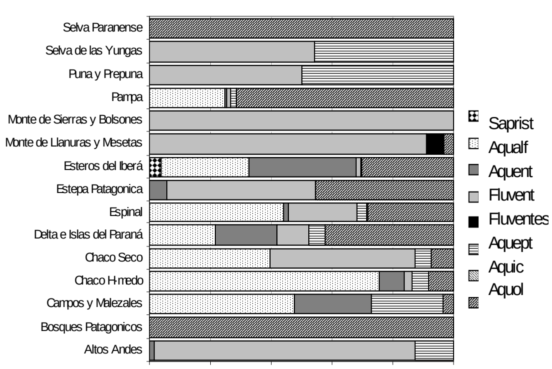

Figure 6. Abundance of each soil suborder in relation to total surface of soil suborders indicating presence of wetlands in the Eco-regions of Argentina.

On the other hand, the salt lakes are only represented in the arid zones, reaching significant values in the Puna, Prepuna and Chaco Seco. In general, the wetland surface is reduced in the arid eco-regions, as observed in Figure 5 for the Puna and Prepuna, the Monte de Sierras y Bolsones, the Monte de planicies y mesetas, the Altos Andes and the Estepa patagónica.

The soils of most of the areas capable of supporting wetlands in these arid eco-regions correspond to Entisols of suborder Fluvent. They are associated with alluvial deposits, which may have a doubtful correspondence with wetlands. The Inceptisols of Suborder Aquepts dominate in the Puna and Prepuna, and the Suborder Aquolls (Order Mollisols) in the Patagonian steppe. Among the arid eco-regions, the wetland areas are more abundant in the Chaco Seco, with the suborder Aqualfs (Order Alfisols) as the most represented soil class.

The poor presence of wetlands in the eco-regions Bosques patagónicos and Selva Paranaense was consistent with the local topography. Wetland soils in this case are mainly represented by Suborder Aquolls, belonging to Order Mollisols. In contrast, the Selva de las Yungas showed an unexpectedly high proportion of wetlands, but they belong to Suborders Fluvent and Aquepts. The wetland areas in the eco-regions of Espinal and Pampa exceeded 30% of the eco-region surface, and contrary to the other cases, there was an equal proportion of wetlands resulting from taxonomic criteria and from constraining factors. Finally, only Histosols were detected in the Esteros of Iberá.

Conclusion

The national inventories of wetlands are currently recognized as essential tools for designing the policies and other measures leading to their conservation and rational use. Regional inventories provide useful information about the relative ranking of regional and/or local issues, in order to optimize the implementation of strategic decisions for the conservation and recovery of wetlands, and to conduct impact evaluation studies.

Resource inventories have traditionally been aimed at answering questions concerning, for example, their type, location and abundance. However, the increasing need for a more effective management has expanded the scope to include wetland functioning and the assessment of consequences resulting from environmental changes and human impacts.

In this scenario, our map makes a contribution to the current knowledge of wetlands in Argentina and is the first one to provide detailed information on wetland areas at the national level. It assumes a definition of wetland that goes beyond local terms, without specific reference to any particular site (marisma, estero). The map was constructed using clearly defined criteria based on taxonomy, constraining factors and cartography, which are repeatable by other technicians.

It is worthy to mention some limitations of our work. The soil map from which our map was developed is likely to be biased toward an agronomical approach because it is based on the database of the National Institute of Agricultural Technology (INTA, 1995). As a result, sites consistent with the presence of wetlands but having no immediate production are poorly detailed. This is the case, among others, for the pericoastal areas of Samborombón named in the database as "marine transgression plains" or for the coastal sector without available information. In addition, the fact that the soil survey is at a fixed scale leads to underestimation of the wetlands in some regions of the country, because of their spatial expression. These wetlands are small patches included in a terrestrial matrix. Examples of this are Patagonian landscapes with isolated wetland patches, such as the mallines and turberas. Instead, the database yields a better fit when wetlands define the landscape, as in wetland macrosystems (sensu Neiff, 2004) of del Plata Basin. Finally, there is a lack of homogeneity in the database due to the fact that the original survey was performed at provincial level, which led to dissimilar criteria and efforts.

The criteria adopted to construct the map might be controversial, but are a standing point for analysis. Indeed, this map of wetlands is a model that can be contrasted with other variables indicating or conditioning the presence or abundance of wetlands, or capable of accounting for their functioning and patterns of change.

Acknowledgements

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