by Emilia Bocanegra [1], Marisol Manzano [2], Emilio Custodio [3], Gerson Cardoso da Silva Jr.[4] and Teresita Betancur [5]

Comparing management actions in groundwater related wetlands that provide significant services to human welfare in Ibero-America

[1] National University of Mar del Plata (UNMP), Argentina. *E-mail: ebocaneg@mdp.edu.ar*
[2] Technical University of Cartagena (UPCT), Spain. *E-mail: marisol.manzano@upct.es*
[3] Technical University of Catalonia (UPC), Spain. *E-mail: emilio.custodio@upc.edu*
[4] Federal University of Rio de Janeiro (UFRJ), Brazil. *E-mail: gerson@acd.ufrj.br*
[5] University of Antioquia (UA), Colombia. *E-mail: teresita.betancur@udea.edu.co*

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Wetlands are important features of the landscape with a high intrinsic value from geological, hydrological, hydrogeological, ecological and social points of view; this last point is related to the services they provide to mankind. If in the past wetlands were subjected to destructive actions, putting them at risk of degradation and further reduction, currently they are the subject of preferential protection in many countries as a consequence of the recognition of their intrinsic value. Wetlands are especially important in arid and semiarid areas, where many of them are related to, and depend greatly on, groundwater. Also, in wet areas groundwater may play an important role, especially providing resilience to rainfall changes. UNESCO's International Geoscience Programme Project 604 (IGCP 604) has been directed to the consideration of selected wetlands of Ibero-America,the Iberian Peninsula and related archipelagos to relate their physical and water quality characteristics with the services they provide and the drivers of change. After preparing a detailed form based on the objectives of the project and distributing it to selected experts, a total of 64 cases from 13 countries have been gathered. The main characteristics, the services provided, the conservation institutions are discussed and some summarized results are given. These are expected to be a contribution to the systematics of IGCP type studies on wetlands and to establish a common methodology and language among Earth Science and Biological Science researchers and managers. Results indicate that deterioration of the condition of wetlands is mainly due to the lack of integration of protection activities with management. This is crucial for more effective conservation.

Introduction

Wetlands are landscape features characterized by the permanent or temporary presence of shallow water depth or a shallow water table. They have high plant productivity, are rich in wildlife and contain high diversity of species. Since the early stages of civilization, wetlands have been drained, landfilled, and ultimately destroyed, with the purpose of getting arable land, expand human habitats, and avoid diseases – real or assumed-, and also because they were wrongly considered useless. In some areas, the removal of wetlands has reached up to 80% of the original surface (Custodio, 2010). Fortunately, in recent decades wetlands have been acknowledged as essential in supporting the ecological processes that sustain life on the planet. Wetlands are widely recognized as providing an extensive variety of goods and services for humankind, such as food and energy production. Education, recreation and tourism are more and more important worldwide in wetland areas (Acreman and Miller, 2006). They also exert a significant influence on the hydrological cycle and are influenced by its components, especially groundwater.

Many wetlands are related to groundwater and most of them are partially or entirely dependent on it, so that any action related to groundwater exploitation may affect the functioning of wetlands and even their existence. Also, human-triggered modifications of landscape and land use activities may produce significant impacts on wetlands and their functions.

This paper presents a study of management actions carried out in a set of representative Ibero-American and Spanish wetlands that provide important services to human beings, as well as a theoretical analysis of potential synergies arising between those wetland services. This work is a result of the IGCP 604 Project "Groundwater and

Wetlands in Ibero-America", the goal of which was to gain knowledge on the interactions between groundwater, wetlands, and humans in the Ibero-American countries, including the Iberian Peninsula and the related archipelagos, hereafter simply referred to as Ibero-America.

The objective of the IGCP 604 project is to assess the hydrological characteristics of groundwater related wetlands, the services they provide to human populations, and the factors that induce direct changes on wetland services. The main work of the Project consisted of two tasks: (1) development of a conceptual framework to address the systematic study of the interactions between groundwater, wetlands, and human welfare in Ibero-America and (2) collecting, compiling and analyzing selected information available on wetlands linked to groundwater.

The IGCP 604 Project developed between 2011 and 2014 was inspired by the United Nations interdisciplinary scientific program "Millennium Ecosystem Assessment" (MEA, 2005) and Spain's Millennium Ecosystem Assessment project (SMEA, 2011). Also, previous experience on wetlands hydrology and wetlands classification of some of the authors in Europe (INITEC, 1991; PAH, 2004) inspired the idea to launch an inventory of groundwater related wetland in Ibero-America. Identifying and classifying wetlands that provide services to people in their areas of influence allowed a first approach to recording the main characteristics of those wetlands, to assess the status and evolution trends of their services, and to identify the main factors inducing direct changes on the wetlands functioning and their services.

During the project, a network of researchers and scientists from Ibero-American countries provided information on the characteristics of wetlands they know well, how they are related with the underlying and adjacent aquifers, the services they provide to humans, and the main factors that induce changes in the wetlands and their services. The information obtained up to now for13 countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Mexico, Nicaragua, Uruguay and Spain) has been first typified according to the main geographical, morphological, genetic and spatial arrangement characteristics. In the 64 wetlands considered, 22 different hydrological types were identified. Results point to the origin and water source, chemical features, state of knowledge of groundwater-wetland-human interaction, and other aspects of wetlands presented in a similar way to Manzano et al. (2013). They also show the relevance of mass balance calculations, the extent of services and user participation in the management process (Betancur et al., 2013; Bocanegra et al., 2012; 2014).

Context

Wetlands related to groundwater

It is widely recognized nowadays that groundwater plays a major role in sustaining a broad range of ecosystems in varied climatic settings. The study of the mechanisms of this relation, types, and distribution of interrelated aquifers and wetlands is a major factor in management actions and nature conservation. The situation is currently serious in many countries and regions due to inappropriate or nonexistent management of aquifers and related wetlands. After Foster and Loucks (2006) this occurs because of factors such as:

- Excessive or inappropriate use of groundwater resources, leading to reduced stream flows and affecting water quality, with severe impacts on the environment;
- Land use changes due to human occupation, either urban, agricultural, tourist or industrial activities;
- Lack of appropriate studies and control to balancegroundwater withdrawal and nature health.

Wetlands are some of the more ecologically important world habitats and comprise a variety of features: peat lands, marshes, coastal lagoons, lakes, river estuaries and deltas, mangroves, and even artificial wetlands, as described by the RAMSAR convention (Ramsar, 2010). There are many types of groundwater-related wetlands. Wetlands are frequently related with groundwater, but it is not an easy task to identify and understand adequately this complex association. As pointed by Ramsar (2010), "even for wetlands of similar type and surface appearance, some can be highly dependent on groundwater for their maintenance whilst others are wholly fed by surface waters". The type and magnitude of the relationship between a particular wetland and groundwater is mostly a function of geological and hydrogeological features. Furthermore, the situation can change spatially, around the wetland area, and overtime. Then, a good understanding of the hydrogeological mechanisms operating is essential for wetland preservation. Managers of the public administrations risk making incorrect decisions on water and wetland management and conservation if the groundwater role is not considered and this should be done in the framework of a correct conceptual model.

The dependence of many wetlands' existence on discharging groundwater is a relatively recent recognized and established fact. Those wetlands have a great variety of origins, shapes, hydrochemistry, and ecological roles. In general they are hydraulically more stable than wetlands dependent on surface water and for this reason they often represent ecological strongholds, enduring prolonged droughts when other sources of water disappear (Custodio, 2010). They may be remnants of past wetter climates in the case of large aquifers, as is the case in the hyper-arid Andean Altiplano (Herrera and Custodio, 2014).

The growing use of groundwater resources worldwide (Margat and van der Gun, 2013; Wada et al., 2012) represents a major threat to groundwater related wetlands since, as recognized by the Millennium Ecosystem Assessment (MEA, 2005), it is one of the two types of ecosystems under greatest pressure from intensive exploitation in many parts of the world. To assess the external hydrological impacts on wetlands, their water balance, rates of water movement and mass transport characteristics must be known, as well as the sometimes long delayed changes (Custodio, 2002; 2012). Still, groundwater is yet to become a widely recognized factor for wetland health and condition, as for example in Portugal and Spain, where the respective Millennium Ecosystem Assessment programs agreed in pointing to the lack of integrated management actions of surface water and groundwater and also to the insufficient valorization of wetlands (Pereira et al., 2010; Santos Martín et al., 2014).

Movement of groundwater to and from wetlands involves complex mechanisms that are beyond the subject of the present paper. Several well-known publications provide good reviews of this issue, such as Winter et al. (1998), Winter (1999), Mitsch and Gosselink (2000), Townley and Trefry (2000), McEwan et al. (2006), Schot and Winter (2006), Custodio (2010) and Ramsar (2010).

Services and wetland management

Wetlands function to deliver a wide range of ecosystem services that contribute to human well-being, such as fish, timber and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, increasing tourism, etc. The projected continued loss and degradation of wetlands will reduce their capacity to mitigate impacts and results in further reduction of human well-being, especially for the poorest people (MEA, 2005).

Often, the groundwater fluxes required for wetland functioning and maintenance are also a source of fresh water for human demand. Both uses are sometimes in competition, so that they affect each other, usually with a clear detriment to wetlands.

From an economic standpoint, the loss or degradation of wetlands and aquifers is a destruction of a natural asset and heritage, besides an economic and property loss that the current or the future society will have to pay for. Making nature and groundwater resources compatible is a difficult task because there are different actors and public administrations involved, the specific legislation - if existent - is often scarce, and the scientific knowledge is insufficient. The way to get the necessary support exceeds generally the common public administration capacity and the civil society has to take the lead through appropriate institutions. Water control councils with user participation and involvement allow government and stakeholders to interact to achieve integrated water resources management, each fulfilling their responsibilities through appropriate means, with an institutional system to compensate for diverse objectives and territorial and time scales. To ensure the protection, conservation, and restoration of wetland ecosystems, the public should first be aware of the importance of making a sustainable use of their resources and the preservation of a common heritage; furthermore, some actions have to be taken. Economic valuation is one of the most commonly used approaches to address this issue. It considers not only intrinsic values but also instrumental values to highlight ecosystem services usually ignored because an appropriate price is not placed upon them (Gómez-Baggethun et al., 2010; Santos-Martín et al., 2014). This approach can be used in setting priorities, evaluating ecosystem management options and allocating budgets, but is not easy to apply, because of ecosystems complexity, with elements not easily translated into economic value. Environmental economists use several methods to measure the economic value of ecosystems. They can be found in texts and papers (see by example Spash, 2000; Birol et al, 2010) and are now common tools in many studies. Their consideration exceeds the purpose of the work carried out. Socio-cultural aspects must be taken into consideration (i.e., cultural, educational, ethical, and other intangible values).

Since the advent of the Integrated Water Resources Management (IWRM) concept (GWP, 2000; Martínez-Santos et al., 2014), surface water-groundwater interactions are related to the interaction of natural and human systems. Thus, the integration concept refers to: (1) the natural system, with its critical importance to the availability and quality of resources, and (2) the human system, which fundamentally determines the use of natural resources and also the production of waste and their eventual pollution and exhaustion of the resource. However, almost any type of wetlands protection should consider wetland management from the point of view of IWRM and more recently of water governance. This approach has yet to be developed all around the world, including in the area of the present work.

Notwithstanding that, various forms of wetland protection exists at international, national and local scales. The two best known international forms of wetlands protection are the Ramsar Convention and the Man and the Biosphere Program. The Ramsar Convention on Wetlands (signed in Ramsar, Iran, in 1971) is an intergovernmental treaty that commits their member countries – those who signed or adhered to it - to maintain the ecological character of their Wetlands of International Importance and to prepare plans for sustainable use of all Ramsar wetlands in their territories. Only wetlands which meet the criteria of international importance that have been developed by the Convention are included as Ramsar sites. These criteria include sites with representative wetlands, rare or unique wetlands of international importance for conservation of biological diversity, and specific criteria based on water birds, fish, and other taxa.

Biosphere Reserves are coastal and continental areas with internationally recognized ecosystems within the Man and the Biosphere Program (MAB) of UNESCO. Each Biosphere Reserve has three basic functions that complement and reinforce each other: (1) conservation of landscapes, ecosystems, species, and populations; (2) economic, cultural, social, and environmentally sustainable development at local level; and (3) "logistics" that provides support for scientific research, monitoring, training and environmental education and the exchange of information on the conservation and sustainable development at the local, regional, national and global level.

Besides these three main protection tools, different countries have different forms of wetland protection at national, regional and local levels.

An example of educational materials currently being prepared for dissemination of groundwater related wetlands issue is given in Figure 1.

Figure 1. Example of educational material prepared for promoting understanding of the importance of groundwater related wetlands. Source: Sandra Patricia Alzate B., University of Antioquia, Colombia.

Methodology

To collect the information to be analyzed, a form was designed and distributed to be filled in by experts. The form consists of five main sections: (1) general aspects of the wetland or wetland area (location, size, type, climate, etc), (2) geological and hydrological aspects (basin genesis, geology, water sources, water flows, hydroperiod, etc.); (3) functionality state and management actions; (4) status and trends of the services provided by the wetland, and (5) factors that induce direct changes on the wetland and its services. The information that can potentially be obtained in each section is diverse and depends on the existence of scientific, technical and managerial work in each wetland, and also on the professional orientation and expertise of the collaborator filling the form. This is critical, as it can lead to bias in the forms and therefore on the conclusions of the work, as discussed below. The full data form is available in the IGCP 604 Project site *(www.mdp.edu.ar/hidrogeologia/IGCP604/index.php)*.

The lists of services and factors inducing changes evaluated are based on the Millenium Ecosystems Assessment report (MEA, 2005) and the Spanish Millenium Ecosystem Assessment project (SMEA, 2011). The provisioning, regulating and cultural services considered can also be seen in the IGCP 604 Project web site. *http://www.mdp.edu.ar/hidrogeologia/IGCP604/description.php*

The main drivers of changes affecting services of wetlands considered in the project are: intensive exploitation of resources, changes in land use, modifications of the hydrological cycle, contamination and pollution, effects associated to changes like chemical and biological water quality, increased erosion or soil destruction, and climate and global changes. In this work, the following information collected in the forms has been analyzed: (1) the existence or not of one of the following four management aspects: Ramsar status, reserve protection, management organization or institution, and involvement of users; (2) the relationships between the existence of management factors and the main services provided by the wetlands; (3) the relationship between the existence of management factors and the main drivers of change affecting the wetlands. To perform the analysis of items (2) and (3), a retrospective approach has been adopted. Thus, to elaborate item (2) it was assumed that the wetland management actions reported were created to protect the wetland services. To elaborate item (3) it was assumed that the recorded wetland management actions were created to protect the wetlands against the factors of change considered.

Finally, synergies between ecosystem services are discussed and a simple conceptual model for evaluation of trade-offs is presented as a first approach to evaluate the synergies between services that could derive from very basic management actions related to an aquifer linked to a wetland: the management of groundwater abstraction in a wetland catchment.

Results and Discussion

Data Collection

A total of 64 wetlands and wetland areas from 13 countries (Figure 2) have been evaluated. This seems a rather small number of wetlands since it is well known the large number of wetlands existing in some areas, such as the Amazonia in Brazil and neighboring countries, the wet Pampa in Argentina, or many areas in Colombia and Paraguay, but many have neither specific studies nor protection measures, since they are commonly located in extensively used areas for agriculture and farming, or just sparsely inhabited. The most interesting wetlands were those related with semiarid and arid areas, where they represent important features the services of which are significant and in many cases highly dependent on groundwater. From this point of view, the number of wetlands for which data has been gathered can be considered as quite important since to fill the forms a detailed knowledge is needed as well as specific studies, protection interests, and public awareness of the importance, and the time available to contribute.

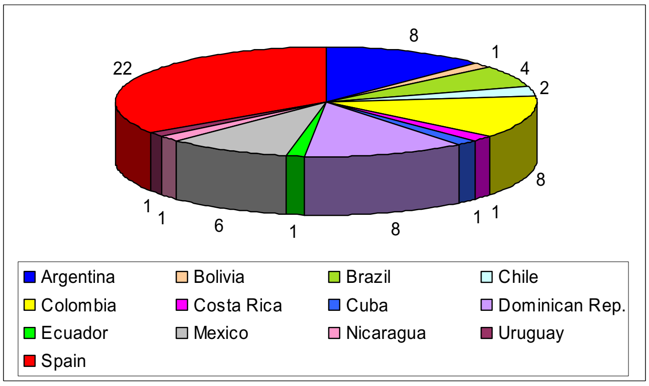


Figure 2. Number of forms received from each of the different contributing countries.

General characteristics of wetlands

The wetlands inventories belong to the types shown in Figure 3. Regarding their geomorphological genesis, the most frequent processes are coastal dynamics and flood plain dynamics, followed by erosion, tectonics, dissolution and, in a few cases, volcanism or meandering and active or stabilized dune relief. Also, three types of artificial wetlands can be considered: coastal saltworks, particularly common in Spain, Brazil, Chile and Argentina, but also present in other countries; areas with excavated canals, omnipresent on the coasts of most studied countries, built for varying purposes (drainage to prevent floods, sanitation, land reclaiming for agriculture, etc.); and lagoons in quarries, which represent major environmental problems in many places, such as in Rio de Janeiro metropolitan area, where quarrying has led to extensive damage to phreatic water table aquifers (Tubbs et al., 2011) and was a serious problem in the Llobregat delta, near Barcelona where they were refilled with wastes and industrial refuse.

In relation to the water sources, in most of the wetlands the main water source is the water table, followed by direct precipitation, runoff from the watershed, tidal flows, river water, and groundwater from deep aquifers.

With respect to the water flows operating, most of the wetlands are transit or flow- through ones, a few are endorheic, some are variable, modified by events, and the remaining are closed basins (without any outflow, either surficial or underground). Regarding the hydroperiod, most of the wetlands are permanent, some are seasonal, and several wetlands complexes are reported as including both permanent and temporal wetlands.

The reviewed wetlands have highly variable salinity and chemical characteristics. There are several cases of mesotrophic, eutrophic, and oligotrophic wetlands. With regard to their functionality, most wetlands have their functioning modified by the construction of water infrastructure. The general hydrological characteristics are shown in Fig.4.

Relationship between wetland management actions and valuable services for human well-being

Of the 64 wetlands evaluated, 28 are Ramsar sites, 52 have wildlife reserve status or similar status, 44 wetlands have a management body or institution, and in 20 of them users are involved in wetland management.

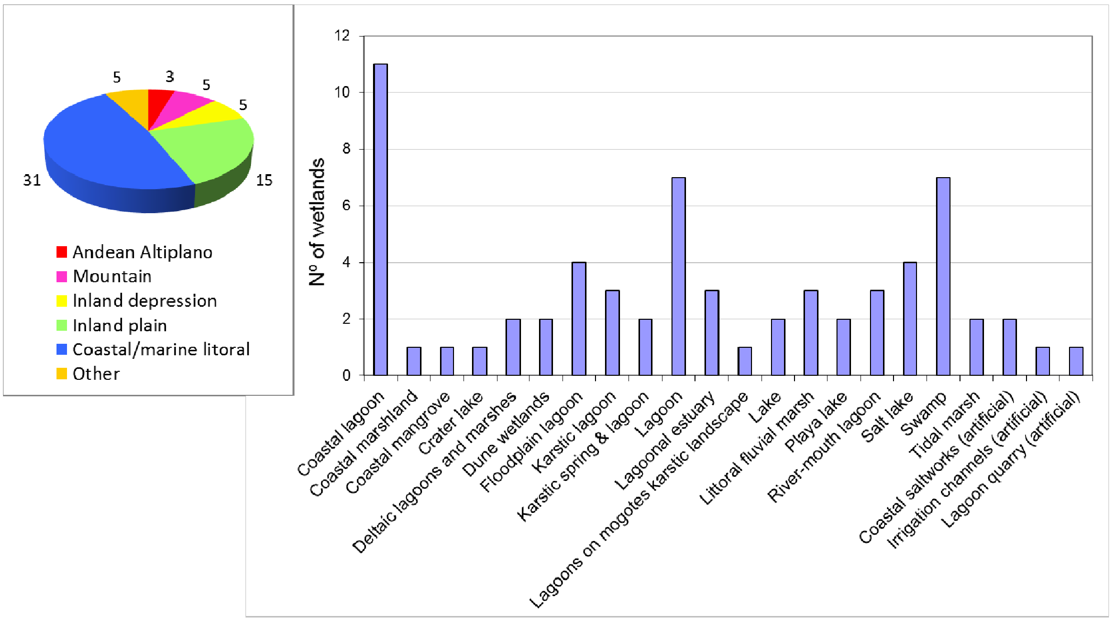


Figure 3. Wetland classification according to geomorphological features (pie chart on the left) and main types of reviewed wetlands (histogram on the right).

The protection areas recorded include various designations: Natural Reserve, Multiple Use Reserve, Reserve of Natural Resources, Wildlife Reserve, Natural Wildlife Reserve, Protected Areas, Strategic Ecosystems, Wildlife Sanctuary, Parkland, and Special Protection Areas (SPA), among others.

The management bodies are made up by national, regional, provincial or municipal authorities; only in one case the manager is a university and in another case it is a private foundation. The following regional or national bodies are recorded in the inventory: State Water Resources Council; Regional Autonomous Corporation; National System of Conservation Areas; Autonomous Government Board; River Basin Authority; Ministry of the Environment; Ministry of Agri-culture; National Commission on Protected Areas, among others. At local level, designations such as City Hall or Municipal and Environ-mental Management Plan of a Wetland Ecological Park are found.

With respect to the involvement of users in wetland management, this happens through organs like 'conservation committee', 'committee of fishermen', 'water users committee', and NGOs (non-governmental organizations). In the agricultural sector, the involvement is through participation of landowners, community of groundwater users, governing board, etc.

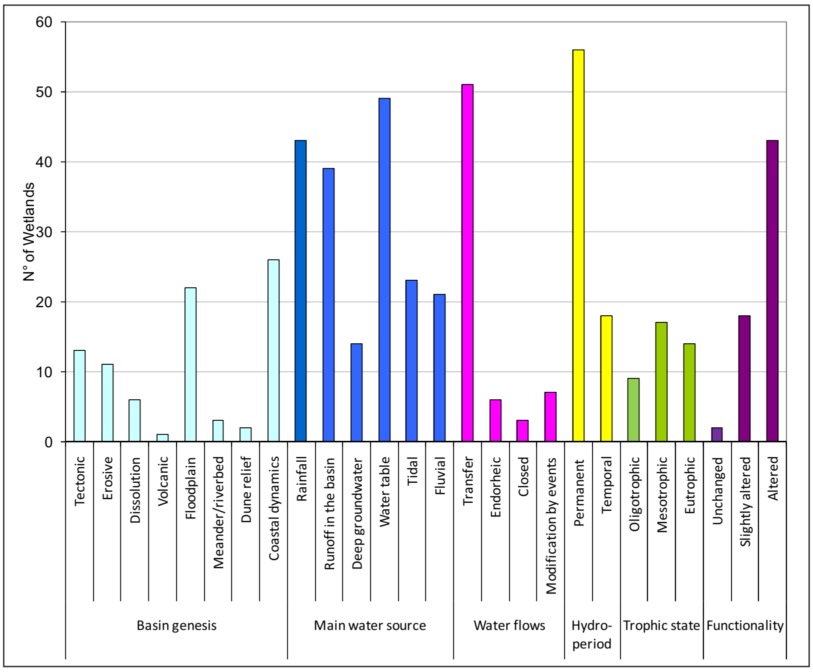
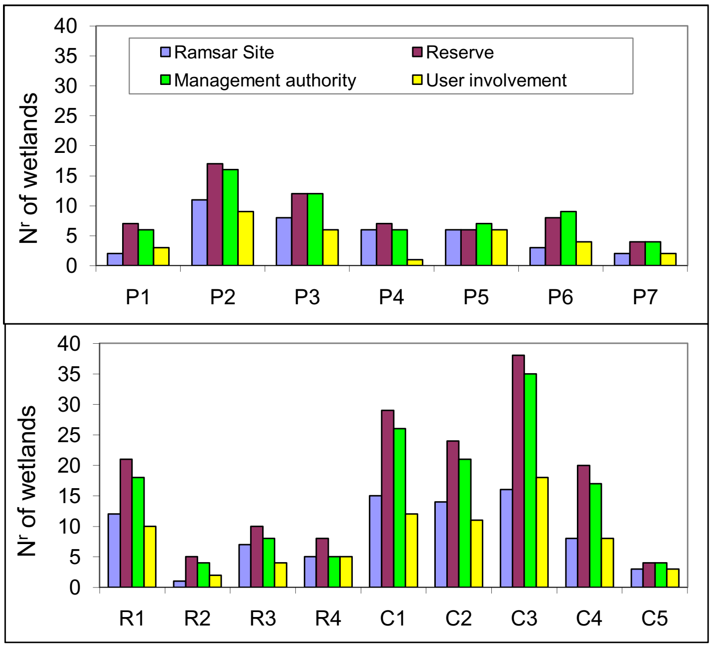


Figure 4. Hydrologic characterization of the 64 wetlands. Each bar shows the number of wetlands with the corresponding characteristic in the group. As a wetland may present different aspects or the responder may have selected only one answer, the total of cases represented may exceed 64. But in other forms the answer may have been left blank reducing the overall total.

The services to human wellbeing provided by most of the wetlands in which some type of wetland management operates are (Figure 5): water supply for different uses (P2), natural production of food resources (P3), regulation of hydrological regimes (R1), landscape and aesthetic (C3), educational (C2), tourism (C1), and cultural identity and sense of belonging (C4).

Taking a retrospective point of view and assuming that the wetlands management actions reported were created to protect the wetlands services, Figure 5 could be interpreted in the following way:

- Most of the wetlands in which the provisioning services P2 and P3 and the regulation service R1 are relevant are protected by some type of Reserve regulation and also have a Manage-ment Authority. In many of them, the local users are involved to some degree in the wet-land management. This would mean that both protection and regulation were addressed to protect wetlands which perform these three services, but also that those services are significantly active because of the protection.
- The former paragraph also suggests that user involvement in wetland management is especially active in wetlands whose water is used for the



Provisioning Services	ID
Supply of good quality water	P1
Water supply for different uses	P2
Natural production of food resources	P3
Artificial production of food resources	P4
Production of biological source materials	P5
Production of mineral source materials	P6
Natural species of medicinal interest	P7
Regulating Services	ID
Hydrological regimes	R1
Water purification	R2
Erosion regulation	R3
Local climate regulation	R4
Cultural Services	ID
Tourism	C1
Educational	C2
Landscape and aesthetic	C3
Cultural identity and sense of belonging	C4
Religious and spiritual	C5

Figure 5. Number of wetlands having any of the four wetland management actions evaluated and the high level of services to human well-being that they provide.

different local uses and also in those wetlands that regulate locally the hydrological regimes. Altogether this suggests that local population benefits highly from those wetland services.

- Of the three types of services evaluated, cultural services are those performed by the largest number of wetlands. Most of these wetlands are also protected by some type of Reserve regulation, have a Management Authority, and users are involved in the management. The back analysis suggests that protection and regulation help to strengthen cultural services over regulation and provisioning services in the studied wetlands. However, this is probably an apparent result of a situation observed along the last two decades around the world: cultural aspects related to water (and to environment in general) have been growing outstandingly. The main cause behind is that water impacts every area of people's lives and for that reason water (and water sources) conservation has become a popular subject. Thus, educational activities related to the environment in general, and to water and wetlands in particular, are common at all public levels around the world.

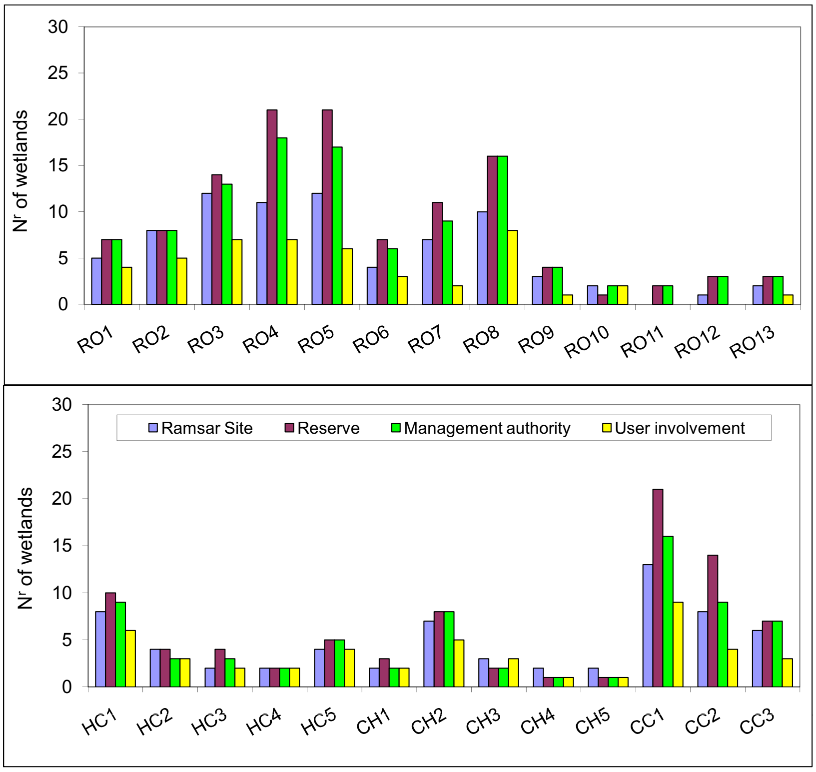
From the available data it seems that the four analyzed management actions for wetlands that provide high services have a similar response in terms of number of wetlands that benefit from these management measures. In general, the protection figure of Reserve or similar and the existence of a management agency are more demanding than the designation of Ramsar sites and user participation.

Relationship between wetland management actions and high impact drivers of change

The main drivers of change affecting wetlands with management actions are (Figure 6): abstraction of groundwater, both next to the wetland (RO3) and in the wetland basin (RO4); biological exploitation carried out by cropping (RO5) and by fishing (RO8); changes in land use due to extensive agriculture (LU5), ranching (LU6) and urbanization (LU7); agricultural diffuse pollution (P1); modification of the hydrological cycle due to drainage (HC1); effects associated with changes in biological water quality, (CH2); and effects of precipitation (CC1) and temperature (CC2) modification due to climate and global changes.

Taking a retrospective point of view and assuming that wetlands management actions in operation were created to protect the wetlands against the factors of change mentioned above, or to mitigate them, Figure 5 could illustrate the following facts:

- Management measures pay particular attention to the protection of wetlands in which the ecological function of groundwater can be affected by quantity issues related to the negative impacts on the wetland flora and fauna due to intensive exploitation of aquifers and deterioration of water quality related to diffuse pollution, mainly from fertilizers and pesticides.
- Intensive biological exploitation by cropping and fishing, in many cases to meet the subsistence needs of growing populations and the development of an unsustainable trade, are also factors that have received attention in the management of wetlands.
- Protection figures are also related to wetlands affected by changes in land use due to: (a) extensive agriculture, which involves the complete replacement of the original vegetation cover, loss of habitat for wetland-dependent species, occurrence of typical plants and animals of land ecosystems, and deterioration of water quality and wildlife effects due to the use of agrochemicals, (b) extensive livestock, which cause changes in the species composition of plants and reduction of vegetation cover due to overgrazing, loss of biodiversity by the indiscriminate use of fire for promoting the regrowth of pastures, soil compaction and loss of water quality, and (c) urbanization, including infrastructure works, that affect the dynamics of wetlands and urban and industrial untreated water discharges deteriorating water quality and affecting biodiversity.
- Management measures also address the impacts of global and



Main direct drivers of change			ID
Intensive resource exploitation	Water abstraction	From wetland	RO1
		From tributaries	RO2
		Groundwater next to the wetland	RO3
		Groundwater basin	RO4
	Biological exploitation	Cropping	RO5
		Forest	RO6
		Cattle raising	RO7
		Fishing	RO8
		Others	RO9
	Mineral exploitation	Fuel	RO10
		Salts	RO11
		Soils	RO12
		Rocks	RO13
Changes in land use		Deforestation	LU1
		Reforestation	LU2
		Forest management	LU3
		Replacement of species	LU4
		Extensive agriculture	LU5
		Extensive cattle raising	LU6
		Urbanization	LU7
		Roads	LU8
Pollution		Agricultural diffuse pollution	P1
		Atmospheric diffuse pollution	P2
		Urban/industrial point source pollution	P3
Modification of hydrological cycle		Drainage	HC1
		Input of excess irrigation	HC2
		Storage usage	HC3
		Artificial recharge	HC4
		Input of urban wastewater	HC5
Effects associated with changes		Mineral water quality	CH1
		Biological water quality	CH2
		Oxidation by lowering water table	CH3
		Increased erosion	CH4
		Soil destruction	CH5
Global and climate changes		Rainfall	CC1
		Temperature	CC2
		Sea level rise	CC3

Figure 6. Number of wetlands that include any of the four management actions considered and high impact drivers of change affecting them.

climate changes, which may increase the impacts of other drivers of degradation in wetlands. For example, a reduction of precipitation will increase the problems related to water demand and changes in air, rain water, and wetland water temperature will affect the distribution of birds and many fish species, not only causing migration but also reducing species populations.

Though this retrospective approach provides only conjectural deductions, their plausibility is supported by the fact that wetlands having some kind of management actions are charismatic wetlands, those that from the point of view of their services have been landscape elements of significant relevance for the local populations throughout history.

Trade-offs between wetlands services

Ecosystem services trade-offs occur when the provision of one service reduces as a consequence of an increase in the provision of another service. Trade-offs may be an outcome of natural processes, but most commonly they are the result of management choices. Rodríguez et al. (2005) proposed a classification of ecosystem service trade-offs along three axes: spatial, temporal and reversibility. This scheme has subsequently been applied to almost all types of

Table 1. Simple conceptual model of trade-offs between services derived from a groundwater management action in a wetland catchment. Modified after Bocanegra et al. (2014).

Action	Management of groundwater abstraction in a wetland basin
Objective	Increase or maintain base flow discharge to the wetland
Services that would benefit (services identifications refer to those in Figure 5)	P2: More water would be available for whatever use and a longer time along the year. P3: The natural production of vegetables and animals will increase by a larger and lasting water availability. P4: The same reasons would allow increasing controlled agricultural production. P5: They would induce an increase in the production of biological source materials. R1: Wetlands originating streams would favour a lasting and more stable flow. R2: Wetland water quality would benefit from dilution due to increased groundwater discharge. R4: More stable local climate conditions due to the increased and lasting air humidity and thermal gradients. C1, C2, C3, C4 and C5: Increase benefits from the more lasting wetland conditions that induce them.
Winners	The users (humans or not) of all the wetland services.
Services that would be damaged	The erosion control service (R3 in Figure 5) may eventually decrease if the size of the wetland basin were not large enough to accommodate runoff during flooding episodes. This would depend not only on the wetland basin dimensions, but also on the climatic characteristics and on the topography of the wetland catchment.
Losers	Intensive groundwater exploitation would have to be reduced and the economic income related to the use of groundwater may be affected.

ecosystems, including wetlands (see Cohen-Shacham et al., 2011; Morardet et al., 2010; Garmendia et al., 2012; Balvanera et al., 2012, among others).

Analysis of ecosystem services trade-offs for particular wetlands have not been performed in this work. However a simple conceptual model (Table 1) is presented that could be applied to many of the inventoried wetlands as a first approach to evaluating the synergies between services that could derive from a very basic management action related to an aquifer linked to a wetland: the management of groundwater abstraction in a wetland catchment.

The following main results of the present work allow identification of the most relevant trade-offs to be evaluated in the basins of most of the studied wetlands:

- Most of the inventoried wetlands are linked to water table aquifers and groundwater is a significant water source for them. Thus, any natural or anthropic process modifying the water fluxes between a wetland and the aquifer result in a modification of the wetland services.
- Most of the inventoried wetlands are of the flow-through type, which means that changes in wetland water quantity and quality will influence not only the own wetland services but also the services of other ecosystems located downstream: water courses, deltas, mashes, forests, agricultural land, shoreline, etc.
- Most of the inventoried wetlands provide at least two outstanding provisioning services and one relevant regulating service for human well-being: water supply for whatever use, natural production of food, and regulation of hydrological regime. There is a perception by the local populations that living near wetlands benefits them. These can be understood as indicators of the relative good state of conservation of most of the wetlands and their catchments. However, the current growth of urban areas in many countries of South America, with the consequent increasing needs of water and food supply for the population, allows forecasting of fast deterioration of some catchments and wetlands functions, as well as the services they provide to human well-being, in the near future.

Conclusions

In the framework of the IGCP 604 project *Groundwater and wetlands in Ibero-America*, hydrogeological, morphological, ecological, and ecosystem services data of 64 groundwater-related wetlands located in 13 countries have been collected between 2011 and 2014. Different parts of this information have previously been presented in national and international congresses in Latin America and Europe. The aim of this work has been to analyse: 1) the relationships between the management actions carried out in the studied wetlands and the main services they provide to human well-being, and 2) the relationships between the existence of management structures and a set of drivers of change affecting wetland functioning. Both aspects were evaluated for the set of wetlands reported as having these four types of management actions: Ramsar site, Reserve protection, Management Institution, and Users involvement in wetland management. The analyses were performed using a retrospective approach: it was assumed that the management actions reported were designed both to protect the provision of specific wetlands services and to protect the wetlands against the drivers of change considered in the study.

With respect to the first objective, the services to human wellbeing provided by most of the wetlands in which any of the four management actions considered operate are: water supply for different uses, natural production of food resources, regulation of hydrological regimes, landscape and aesthetic, educational, tourism, and cultural identity, and sense of belonging. The first three services can be considered as great contributions to human well-being. Most of the wetlands providing them have more than one type of management action: a relevant result is that most of those wetlands have a Management Authority and local users are involved to some degree in the wetland management. Applying a retrospective approach, this would signify that both protection and regulation were addressed to protect wetlands that perform these three basic services, but also that those services are significantly active because of the protection. It also suggests that user involvement in wetland management is especially active in wetlands whose water is the source to satisfy the different local uses and also in those wetlands that produce local regulation of hydrological regimes. Altogether, this suggests that local population benefits highly of those services. In fact, this is a commonly observed situation around the world and it is both the reason and the result of the close historical relationship between the activities of human beings living near wetlands and the wetlands functioning.

An additional result is that, among the three types of services evaluated, cultural services are the ones performed by the largest number of wetlands. The back analysis suggests that protection and regulation help to strengthen cultural services over regulation and provisioning services. However, this could be an apparent result, as cultural aspects related to water have been growing around the world in the last 15 years, turning water conservation into a popular subject. Thus, educational activities related to water and wetlands are common at all levels around the world.

With respect to the second objective, the main drivers of change affecting wetlands having any of the four types of management actions considered are: abstraction of groundwater next to the wetland; abstraction of groundwater in the wetland basin; biological exploitation (cropping and fishing); changes in land use due to extensive agriculture, ranching and urbanization; agricultural diffuse pollution; modification of the hydrological cycle due to drainage; effects associated to changes in biological water quality; and effects of precipitation and temperature modification due to climate and global changes. Using the retrospective approach, the following conclusions could be drawn:

- The existing management actions are devoted to protect wetlands where the ecological function of groundwater can be negatively affected by intensive exploitation of aquifers, by deterioration of wetland water quality through diffuse pollution, and where intensive biological exploitation by cropping and fishing would decrease the provision of food and other resources.
- Protection also focuses on wetlands affected by: changes in land use due to extensive agriculture, extensive livestock, and urbanization; and global and climate changes (which may increase the impacts of other drivers of degradation in wetlands).

The situation observed in the Ibero-American wetlands indicates that, although many of the most important wetlands in the study area are protected under different designations, this has not prevented the deterioration of their state, mainly due to the lack of integration and engagement of those protection activities in regional management plans of the territory. Regional planning is crucial if more effective conservation is desired.

Management measures aimed at preservation of wetlands, here recognized as strategic ecosystems that provide welfare services to human societies, can and should include the implementation of international instruments such as the declaration of RAMSAR-site but should, above all, involve commitment of national and local actors, including management organisations, scientists and citizens. This is the only path to adequate use and preservation.

From the transdisciplinary standpoint, the project has provided a systematization of wetland characteristics and services that can be used in other projects and studies by groundwater experts and that establishes a bridge to better understanding of what wetland ecologists and biologists do, in collaboration. From that point of view, the project contributes to future correlation and a significant geological input for collaboration with other scientific fields.

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