Wetland Science in Latin America and the Caribbean Region: Insights into the Andean States

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Abstract: Through a mentoring initiative of the Society of Wetland Scientists International Chapter, including volunteer scientists, students, and early-career professionals, we created a database of 283 organizations focused on wetlands for the Andean States (Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela). This review includes data about organizations spatial distribution among seven countries, their sectors, and their principal research areas as well as Andean Ramsar Sites data. The most representative research areas were hydrogeology, biogeochemistry, and biodiversity (represented by fauna, flora, algae, phytoplankton, and zooplankton). We observed a lack of wetland restoration, mapping, and management research. The academic sector (universities) had the largest number of organizations (176 organizations), followed by government (51), non-profits (46), and the private sector (10). The Andean States harbor a total of 94 Ramsar Sites covering 300,000 km^2 distributed in seven countries. Through this review, we highlight the magnitude of wetland science in the Andean States and hope to support a future wetland scientist network for the Latin American and Caribbean (LAC) region and allow LAC scientists to connect internationally.

INTRODUCTION

The Latin American and Caribbean (LAC) region contains 46 countries and non-independent territories (e.g., Aruba, Curaçao, French Guiana, and Puerto Rico) (FAO 2020). Overall, LAC countries harbor a high number of species of fauna and flora, as well as unique neotropical ecosystems. Countries such as Brazil, Colombia, Costa Rica, Ecuador, Mexico, Peru, and Venezuela are considered "megadiverse countries" because they are home to a large part of the planet's biodiversity (Cancun Declaration 2002). Additionally, the Neotropics support one of the greatest aquatic plant biodiversity and endemism in the world (Murphy et al. 2019). The LAC region contains important and threatened ecosystems known as "biodiversity hotspots" including the Caribbean Islands, Atlantic Forest (Brazil), Mesoamerica, and the tropical Andes, which require greater effort for their conservation since endemic species of plants and vertebrates are being affected by habitat loss and fragmentation (Myers et al. 2000). Across the extensive LAC region, 350 Ramsar Sites are protecting 700,000 km^2 of wetlands and a variety of wetland ecosystems such as mangrove forests, swamp forests with palms, flooded savannah and forests, marshes, and peatlands (Junk and Piedade 2011; Ramsar 2020). Despite the high ecosystem services and economic values estimated for wetlands, especially for mangroves and peatlands, LAC wetlands are extremely threatened and at risk of disappearing. In the last four decades, the estimated wetland losses are around 60% in LAC and worldwide (Junk 2013; Davidson 2014; Darrah et al. 2019; Davidson et al. 2019).

One of the aims of the International Chapter of the Society of Wetland Scientists (SWS) is to increase wetland science and conservation in the LAC region. Through an integrated database for LAC, we seek to link scientists and wetland professionals at an international level, as well as to engage young people in wetland activities. To achieve this objective, the SWS International Chapter in collaboration with volunteers of *Universidad Científica del Sur* in Lima, Peru, including students and early-career professionals, created a database of organizations focused on wetlands for the Andean States. Here we present the results for the Andean States, a region that encompasses seven countries (Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela) with unique biodiversity associated with the Andes Mountains and its varied topography. Our main objectives were to answer these four questions: 1) how many organizations are focused on wetlands?, 2) how are they spatially distributed among the countries?, 3) what are the principal wetland research areas?, and 4) how many Ramsar Sites were designated and how they are spatially distributed? Through this review, we highlight the magnitude of wetland science in the Andean States and offer support for a future wetland scientist network for LAC that allows exchange and connection of Latin American and Caribbean scientists regionally and internationally.

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FIGURE 1. Andean States wetlands: a) Coastal wetland, Albufera de Medio Mundo, Peru, b) Flamingos in a mangrove, San Pedro de Vice, Peru, c) Páramo La Culata, Sierra Nevada, Mérida, Venezuela, d) Bofedal Guitarrachayoc, Peru, e) Laguna Colorada, Ramsar Site, Bolivia. Photo credits: (a, b, d) Hector Aponte; (c, e) Tatiana Lobato de Magalhães, Ph.D., PWS.

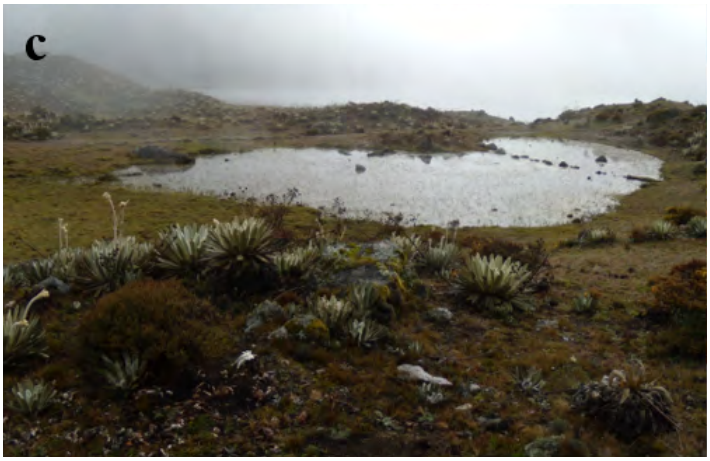


FIGURE 2. Heat maps of wetland organizations distribution in the Andean States and distribution of the major Science fields studied in this region.

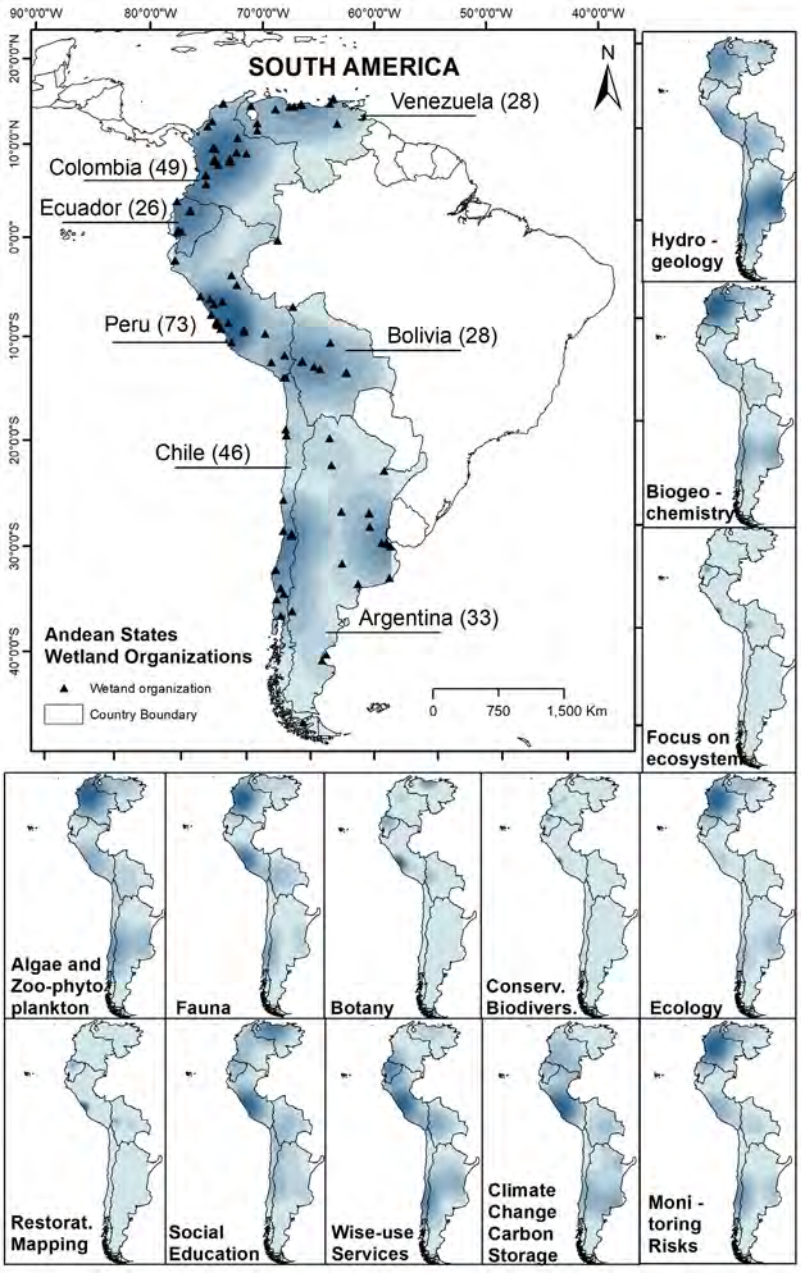
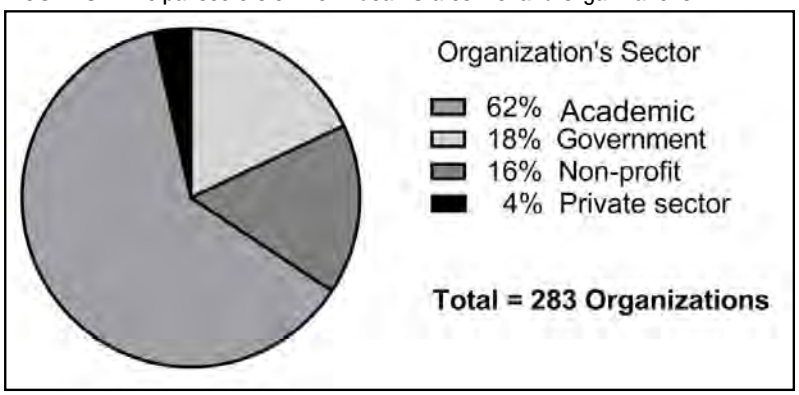


FIGURE 3. Principal sectors of the Andean States Wetland Organizations.



BACKGROUND

The Andean States

The Andean States of Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela have a variety of ecosystems and climates from 0 to 6,962 m a.s.l., including dry deserts, tropical rainforests, and the snowy highlands (Guerrero et al. 2011). The varied hydrogeomorphology across this region with the different conditions of humidity, precipitation, and temperature determines the characteristics of diverse wetland types. Overall, there are five major Cowardin system types of wetlands in these countries: marine (coastal wetlands, including lagoons, rocky shores, and coral reefs; Figure 1a), estuarine (deltas, tidal marshes, and mangroves; Figure 1b), palustrine (swamps, marshes, and bogs), lacustrine, and riverine types, plus human-made wetlands. In the palustrine type there are many highlands wetlands (e.g., páramos and bofedales; Figure 1c, d), that have been strongly affected by climate change (Junk 2013).

Data Search and Classification

To identify wetland organizations, we reviewed proceedings of wetland scientific meetings such as congresses, workshops, and symposia held in countries of the Andean region from 2010 to 2020. Due to the lack of wetland-specific scientific events in many of these countries, we considered meetings of closely related science fields (e.g., limnology, ecology, and botany).

We followed these four steps:

Step 1: Identification of scientific events held between 2010-2020 to search for organizations focused on wetlands, except for Ecuador, which we included a 2001 wetland event (Table 1).

Step 2: Detailed analysis of the title, abstracts, and keywords of each article found in the proceedings of the scientific events. This step allowed us to filter out papers on wetland issues and the respective authors' affiliated organizations.

Step 3: Production of a list of organizations that conduct research on wetlands for each country.

Step 4: Classification of organizations through an online search, considering the following aspects: (a) *general*: name, acronym, and sector of the organization (i.e., private, governmental, non-profit, and academic); (b) *research areas*: identified major research areas through review of the website of each organization and scien-

tific event publications keywords; (c) *location*: country, state, city, geographical coordinates of each organization; and (d) *point of contact*: website link, name of an associated researcher, and email address.

In addition, we listed the Ramsar Sites for each country, including site code and name, total area, and geographical coordinates for each country (Ramsar 2020).

Data Analysis and Mapping

We created descriptive graphs to represent total numbers of organizations per sector, per each country's regions (organizations located in the country capital and country interior cities), and Ramsar sites for each country, using GraphPad Prism v. 8.4.2. We created heat maps (density maps) to represent the spatial distribution of the organizations, major research areas, and Ramsar Sites in the Andean States, using the Kernel density analysis tool of the ArcGIS v. 9.3. To highlight the wetland research areas developed by each country we created "word cloud" graphs with the keywords of all publications selected in Step 2 of the data search, using an online free-tool (wordclouds.com). This tool works with a list of words, which are displayed in different dimensions and randomly distributed, according to the frequency that each word is found in the list in question.

FINDINGS

Distribution of Wetland Organizations in the Andean States

We identified 283 wetland organizations in the Andean States, with the most located in Peru (26%) followed by Colombia (17%), Chile (16%), Argentina (12%), Bolivia (10%), Venezuela (10%), and Ecuador (9%) (Figure 2). The academic sector (universities) had the largest number of organizations (176 organizations), followed by government (51), non-profits (46), and private sector (10) (Figure 3). The university sector encompasses research groups, laboratories, institutions, museums, faculties, graduate programs, research centers, and consequently are more representative in the number of studies presented in the scientific events we analyzed in this review. Usually, in developing countries the academic sector represents a higher contribution to scientific research than other sectors (Kumar 2017). Some of the more important Andean universities include Pontificia Universidad Católica del Perú, Universidad San Francisco de Quito, Universidad Central de Venezuela, Universidad Nacional de la Plata, Universidad de Los Andes, and Pontificia Universidad Católica de Chile (World University Ranking 2020).

In some countries, we observed a higher number of organizations in the country's capital region than in the interior (Figure 4), especially in Argentina and Peru. In the latter country, the difference between the capital (57 organizations) and the interior of the country (16) is most evident. On the other hand, we observed the opposite in Bolivia, Chile, Colombia, and Venezuela. Bolivia did not even present any organization located in the constitutional capital (City of Sucre). The highest number of organizations in Bolivia was found in La Paz (13), which is the main political center of the country. The largest number of organizations in Colombia was located in the regions of Cundinamarca and Antioquia, particularly in cities of Bogota (Colombia's capital with 13 organizations) and Medellín (11), which are the main political and economic centers of the country. It is worth noting that a similar case occurred in Ecuador where 14 organizations were observed in the capital Quito and eight in the city of Guayaquil, located in the Guayas State, Southern Ecuador.

Principal Wetland Science Fields

We identified 13 major wetland research areas developed by the 283 organizations (Table 2). The most representative ones in the heat maps were hydrogeology, biogeochemistry, and biodiversity (represented by fauna, flora, algae, phytoplankton, and zooplankton). We observed a lack of wetland restoration, mapping, and management (Figure 2). Overall, the word cloud graphs highlighted keywords as 'macroinvertebrates', '*bofedales*', 'rivers', 'biodiversity', 'conservation', and 'mangroves' (Figure 5a). The hydrology field is highly studied in South American countries (Kandus et al. 2018)

FIGURE 4. Wetland organizations location in the country's capital and interior of the Andean States.

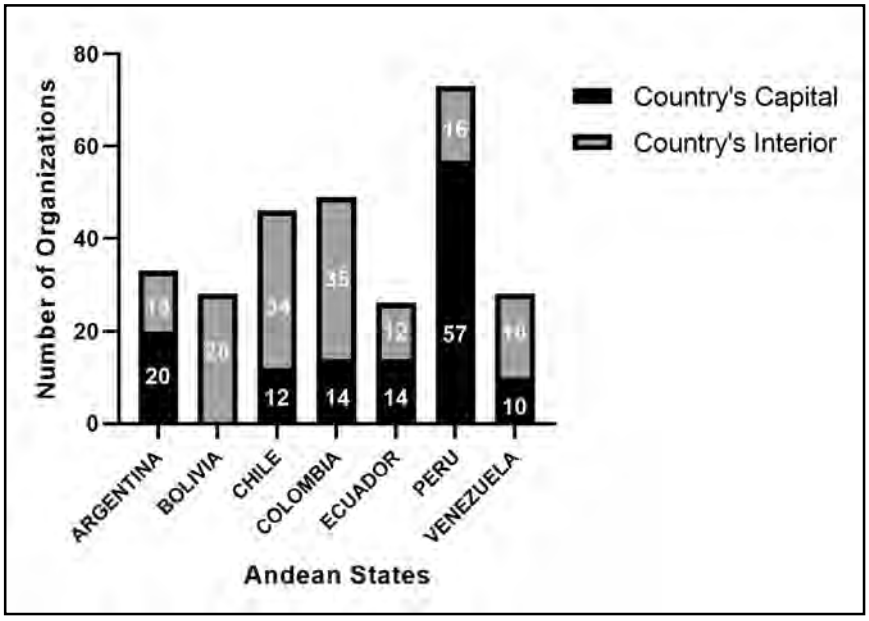


TABLE 1. Proceedings of scientific meetings of the Andean States.

Country	Scientific meeting	Source
Argentina	VI Congreso Argentino de Limnología CAL, 2014	http://sedici.unlp.edu.ar/handle/10915/69018
Bolivia	IV Congreso Boliviano de Ecología, 2014 III Congreso Boliviano de Botánica, 2016	https://www.researchgate.net/publication/262876439_Memorias_del_IV_Congreso_Boliviano_de_Ecologia , https://issuu.com/iasa-usfxch/docs/memoria_congreso_botanica ,
Chile	XIV Congreso Sociedad Chilena de Limnología, 2017	http://sociedadchilenadelimnologia.cl/libro-de-resumenes-xiv-congreso-sociedad-chilena-de-limnologia/
Colombia	IX Seminario Colombiano de Limnología, 2012	https://revistas.udea.edu.co/index.php/actbio/article/view/331656
Ecuador	Humedales Marino - Costeros Continentales, 2001 Segunda Reunión de la Iniciativa Regional para la Conservación y Uso Racional de Manglares y Corales, 2011	https://biblio.flacsoandes.edu.ec/libros/digital/56577.pdf , https://www.ramsar.org/sites/default/files/documents/library/informemanglarescoralesguayaquil2011.pdf
Peru	I Congreso Peruano de Humedales, 2017, II Congreso Peruano de Humedales, 2019	https://copehu2017.wixsite.com/copehu2017/libro-de-resumenes ; https://es.scribd.com/document/429166928/LIBRO-RESUMENES-COPEHU-2019-1-pdf
Venezuela	X Congreso Venezolano de Ecología, 2012	https://revistamipensamiento.files.wordpress.com/2015/10/libro-de-resumenes-x-cve-final.pdf

TABLE 2. Principal research areas of the Andean States' organizations.

Field of Science	Sub-topics
Wetland wise-use and services	Sustainable aquaculture, Fishery, Economic valuation, Ecological valuation, Ecosystem processes, Carbon stock, Management of wetlands, Sustainable development, Ecotourism.
Focus on ecosystem	Mangroves, Marine and coastal ecosystems, Estuaries, Coastal wetlands, Highland Andean bogs, "Bofedales", Peatlands, Rivers, Basin, Brackish lagoons, Bolivian Amazonia, Pantanal.
Hydrogeology	Sediments, Groundwater, Geomorphology, Geological characterization, Hydraulic parameters, Reservoir, Hydrology, Physicochemical parameters, Hydro systems, Tropical river fluvial, Tributaries, Lake and river water bodies, Fluvial ecosystem dynamics, Water drainage of rains, Watersheds, Hydrobiological resources, Hydrodynamics, Management of water resources, Model ecohydrology of biodiversity, River valleys, Lotic environments, Riversides, Pampas streams, Geological evolution.
Climate Change and Carbon Storage	Climate change, Particulate organic carbon, Adaptation to climate change, Carbon storage, Climate variability.
Conservation and Biodiversity	Biodiversity, Conservation, Endangered species, Ramsar Sites, Taxonomy.
Fauna	Birdlife, Ichthyofauna, Macroinvertebrates, Benthic Macroinvertebrates, Wildlife, Macrobenthos, Entomofauna, Ornithology, Mastozoology, Herpetology, Bivalves.
Botany	Flora, Aquatic plants, Vascular macrophyte index, Vascular flora.
Algae and Zoo-phytoplankton	Zooplankton, Biological communities, Phytoplankton composition, Algal blooms, Microalgae, Taxonomic composition of microalgae, Cyanobacteria, Protozoa, Perifiton, Diatoms.
Biogeochemistry	Water quality, Water pollution, Physicochemical parameters.
Monitoring and Risk analysis	Environmental impact, Indicators of physical habitat, Bioindicators, Water quality, Vulnerability, Water contamination, Biological evaluation of wetlands, Species monitoring, Toxicity, Bioaccumulation, Heavy metals, Ecohydrological indicators, Limnological status index, Microplastics.
Social and Educational	Research dissemination, Environmental education, Socio-economic evaluation, Environmental policy, Traditional management, Sustainable development.
Ecology	Ecological state, Trophic state, Ecosystem processes, Lotic communities, Evapotranspiration, Plant ecology, Phenology, Population dynamics, Eutrophication, Limnology, Migration.
Restoration, Management and Mapping	Reforestation and Restoration, Environmental legislation, Wetland inventory,, Territorial management, Remote sensing, Environmental enforcement and policy.

as well as macroinvertebrates, especially in Argentina and Colombia (Ramírez and Gutiérrez 2014). For Argentina, Chile, and Colombia we observed that the principal words of the word cloud graphs were 'macroinvertebrates', 'algae', 'zooplankton', 'phytoplankton', and 'water quality', which is coherent with the heat maps' results (Figure 5 b, d, and e).

Wetland biodiversity and conservation is probably the most relevant research area for the Andean States since this region harbors ecosystems such as the tropical Andes (an important 'hotspot' considered to be a highly diverse ecosystem) and a large area of tropical forests with diverse wetland types (Myers et al. 2000; Junk 2013). Several organizations have been focusing on specific ecosystems such as mangrove forests and coastal wetlands, particularly in Ecuador, Peru, and Venezuela. Despite the widely recognized importance of the coastal wetlands and mangroves for carbon storage (Hamilton et al. 2020) and protection against natural disasters, they remain highly threatened (Davidson 2014; Davidson et al. 2019). For example, Ecuador reported 80% mangrove forest loss in the last decade as a result of aquaculture development (Hamilton et al. 2020). Yet, Venezuela has focused mainly on wetlands associated with the Orinoco River, coastal deltas and lagoons, which have suffered high deterioration, as well as flora studies (Lárez and Prada 2015; Suárez 2016; Marrero and Rodríguez 2017).

Bofedales, a highland Andean wetland ecosystem is highlighted by the word cloud graphs in Bolivia and Peru (Figure 5 c, g). This ecosystem is important due to water and human-food resources, biodiversity, and for livestock activities as well as for climate change and carbon accumulation studies (Maldonado 2014). However, the *bofedales* are one of the most vulnerable ecosystems in the world that are being affected by climate change, as high temperatures will alter peatland distribution and extension (Dangles et al. 2014; Huamán et al. 2020). Peru also stands out in the study of the use and valuation of ecosystem functions, as well as for studies of avifauna, mainly in coastal wetlands that shelter both local and migratory birds (Rivas and Cuellar 2017) (Figures 2 and 5).

Ramsar Sites in the Andean States

All countries of the Andes are Ramsar Convention signatories. Overall this region harbors a total of 94 Ramsar Sites covering 300,000 km^2 distributed in seven countries, Argentina (23 sites), Ecuador (19), Chile (14), Peru (13), Bolivia (11), Colombia (nine), and Venezuela (five) (Figures 6 and 7) (Ramsar 2020). The first Andean Ramsar Site was designated in 1981 (Carlos Anwandter Sanctuary, Chile), while the most recent one was designed in 2018 (Tongoy Bay Coastal Wetland, Chile) (Ramsar 2020). Ramsar wetlands are mostly distributed in the Argentinean and Ecuadorian territory. Another large portion of these sites are distributed in Northern Peru and Southern Bolivia (Figure 6). The majority of the Andean Ramsar Sites are beautiful and scenic places with tourism importance (e.g., the Laguna Colorada in Southern Bolivia) (Figure 1e).

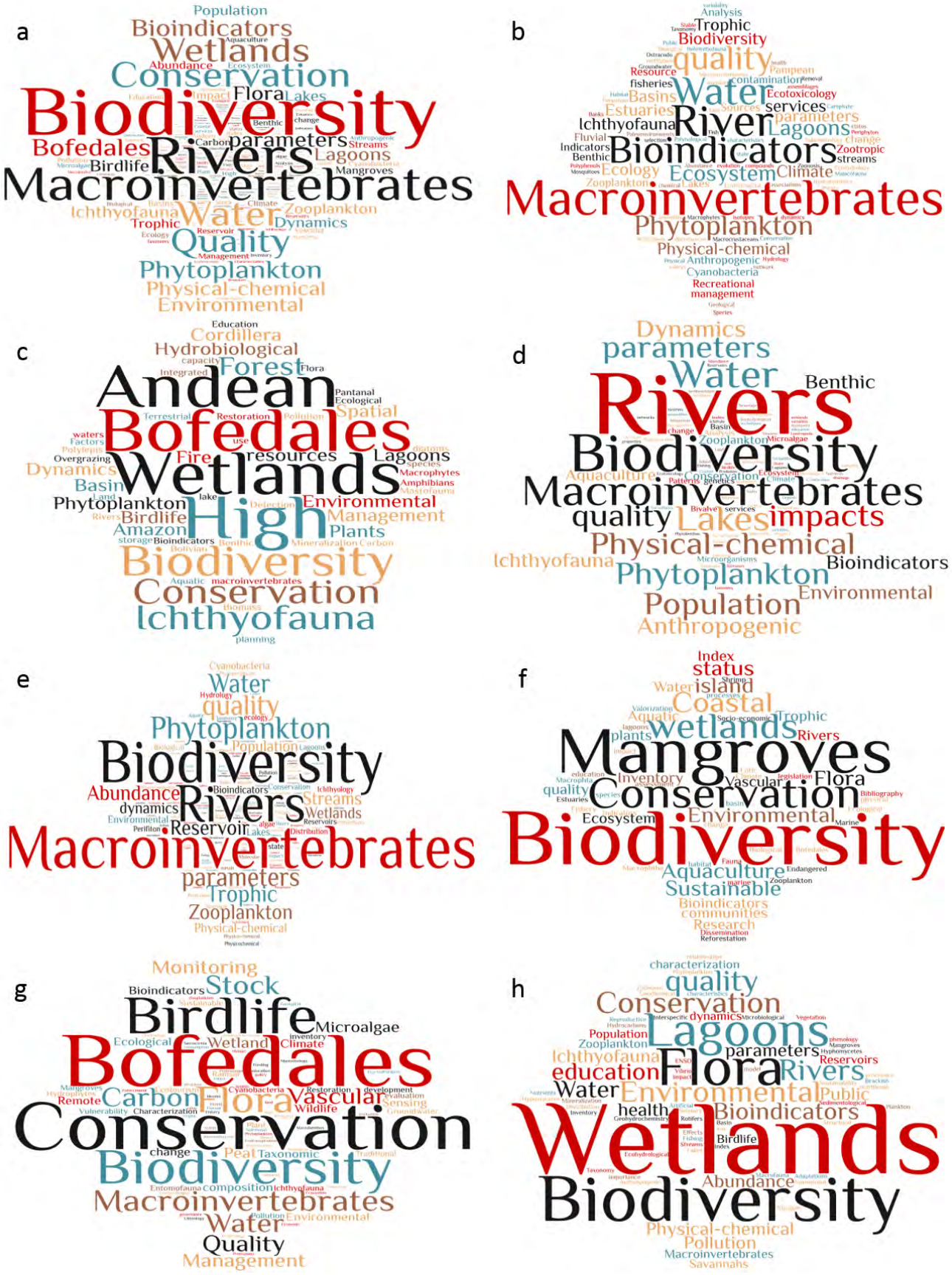
CONCLUSIONS AND INSIGHTS INTO WETLAND SCIENCE IN THE ANDEAN STATES

Even though the Andean region is extremely important for wetland biodiversity due to its diversity of ecosystems as well as endemic flora and fauna (Junk and Piedade 2011; Marreno and Rodríguez 2017; Murphy et al. 2019) throughout the region, there is a lack of wetland-focused scientific events, associations, and societies. We can highlight the following wetland scientific local meetings: Argentinean Congress of Limnology, Chilean Society of Limnology Congress, Colombian Seminar of Limnology, Marine Coastal and Continental Wetlands Meeting, Regional Initiative for the Conservation and Wise-use of Mangroves and Corals Meeting, and the Peruvian Congress of Wetlands (Table 1). We carefully analyzed their proceedings, as well as some local scientific events related to wetlands such as the Bolivian Congress of Ecology, Bolivian Congress of Botany, and Venezuelan Congress of Ecology to highlight the efforts of researchers involved with local organizations. The creation of this Andean wetland organizations database with 283 organizations is a first step to recognize this wetland science community and promote a LAC wetland-network.

This review allowed us to identify research areas that stand out in the Andean States such as biodiversity (mainly avifauna, macroinvertebrates, botany, phytoplankton, and zooplankton), ecology, hydrogeology, and water quality. As emerging areas that have the potential to be developed in the Andean region, we believe research in education, climate change, sustainable use, and ecosystem services valuation could be expanded. Yet, we consider that restoration, mapping, management, and wetland policy are less represented in the Andean States and extra efforts are needed to develop and research these important issues in the region. Additionally, identifying wetlands research areas and topics in Venezuela was a challenge due to the scarcity of information about wetlands on digital platforms, probably because the political scenario of the last decades, where wetland science and conservation were not a priority (Lobato-de Magalhães et al. 2016).

Overall, we observed a high number of wetland organizations and Ramsar Sites in the Andean States, which reinforces the countries' government commitment to preserving wetland biodiversity and ecosystem services. The observed number of wetland research organizations reflects

FIGURE 5. Word cloud graphs using the keywords from research presented on Scientific meetings' proceedings in the Andean States: a) Overall in Andean States, b) Argentina, c) Bolivia, d) Chile, e) Colombia, f) Ecuador, g) Peru, h) Venezuela.



the potential of scientific production in the region, the human capital available to generate it, and efforts to bring this wetland scientific-knowledge closer to the population and decision-makers locally. This review is an approach to understanding the potential of the LAC region to address wetland science and contribute to the international scientific wetland community. It is also important that, in the coming years, alliances are sought between research and conservation groups of LAC and other regions (e.g., Global Environmental Facility "GEF Humedales", Wetlands International, and World Wildlife Fund). A good example of such joint work is what is currently happening with the Coastal Wetlands Initiative (humedalescosteros.org), which seeks to protect the Pacific desert wetlands corridor and to generate synergies between researchers and partners in Chile, Ecuador, and Peru.

Finally, the elaboration of this review reflects the role of the SWS in creating opportunities to integrate scientists from diverse countries. More efforts are needed to further wetland science and conservation in the LAC region. However, review paper initiatives focused on wetland organizations and research topics including other LAC regions can create the appropriate scenario that will allow successful coordination of wetland science and conservation in the LAC region. Additionally, through an SWS-LAC network, we could connect wetland scientists and allow them to disseminate their efforts on wetland research to other Latin American and Caribbean scientists and internationally. ■

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FIGURE 6. Ramsar Sites distribution in the Andean States.

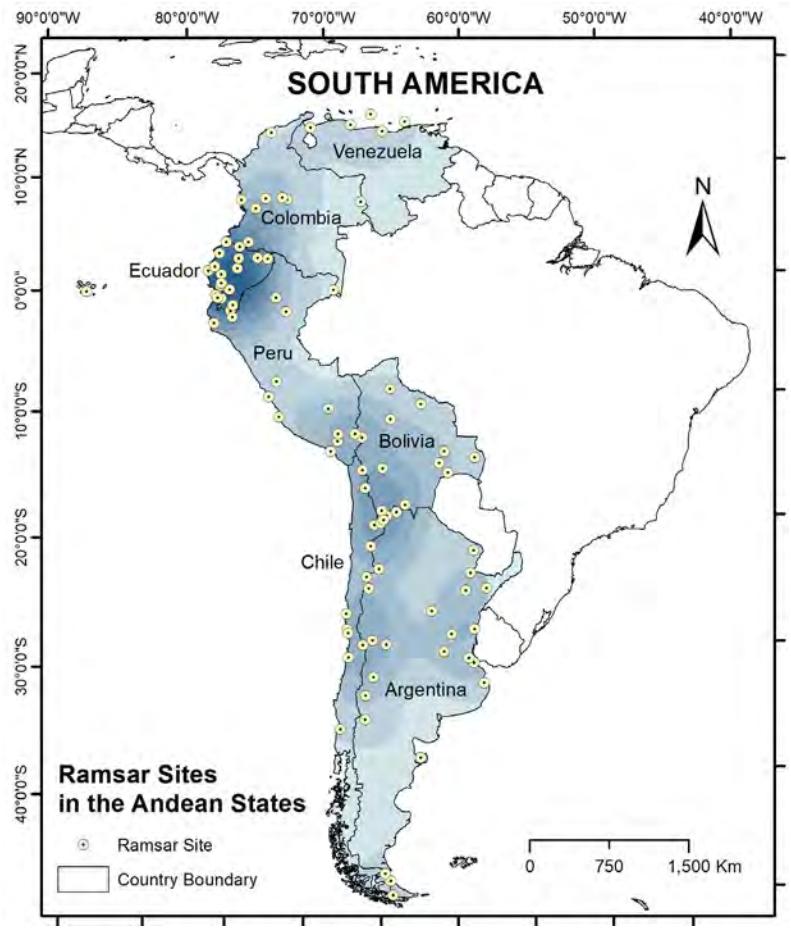
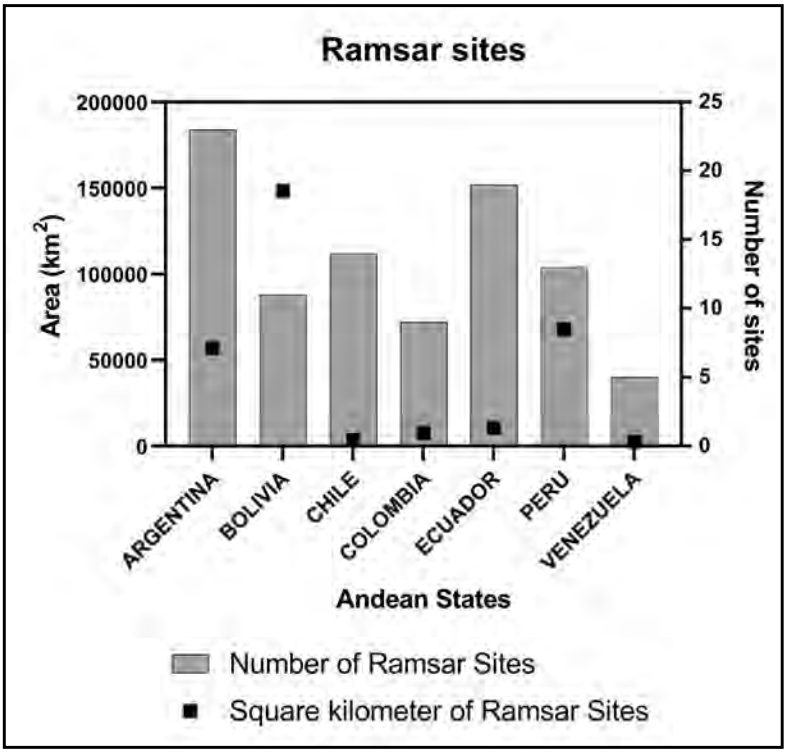


FIGURE 7. Ramsar Sites in the Andean States, number of sites and total area (km2).



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