



The arid Andean plateau waterscapes and the lithium triangle: flamingos as flagships for conservation of high-altitude wetlands under pressure from mining development

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Received: 18 July 2021 / Accepted: 7 March 2022
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Abstract The high Andean arid plateau extends through Peru, Argentina, Bolivia, and Chile. Within the desert matrix, basins contain wetlands that provide essential resources for human activity, and habitat for biodiversity highly adapted to extreme temperatures, altitudes, and salinity gradients. In these waterscapes, the water balance, even without human intervention, is negative and their unique biodiversity and lifeways are now confronted with an unprecedented level of development from lithium mining for rechargeable batteries. The “lithium triangle” coincides with the areas of highest abundance of the altiplano’s iconic flamingos. Flamingos are an ideal

flagship for conservation because of the landscape scale at which they use wetlands, and Network of Wetlands for Flamingo Conservation, which implies the sustainable use of these wetlands, can be invoked to determine priority conservation actions. Since 2016, mining exploration has increased throughout the region, most notably in Argentina. A review of the Environmental Impact Reports (IIAs) for projects in Catamarca, Argentina, shows that they do not comply with national guidelines: they do not adequately address water budgets, consider protected area status, engage local communities, or consider cumulative and synergistic impacts. While the transition to “green” energy sources holds the promise of mitigating the negative impacts of traditional energy sources responsible for climate change, a truly sustainable energy sector would consider the full life cycle of the battery (“cradle-to-grave”), the social and environmental impacts of mining, and the feedback processes across the coupled socioecological systems, from raw material mining through production, use, recycling, and disposal.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11273-022-09872-6>.

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Keywords Andean flamingo · Puna flamingo · Wetland network · Environmental impact · Lithium · Altiplano

Introduction

The high Andean plateau or *altiplano* is located between the Oriental (eastern) and Occidental (western) mountain ranges in western South America, extending between approximately 16°S and 28°S at an elevation between 3500 and 5500 m.a.s.l., and is second only to the Tibetan Plateau in surface and altitude (Garreaud et al. 2003). The >400,000 km² area defined by rugged topography with expanses of level areas surrounded by volcanoes and snow-capped peaks encompasses the Central Andean Puna ecoregions (Olson et al. 2001). Climate is considered semi-arid to hyper-arid, with most of the region receiving less than 400 mm of precipitation a year in a gradient from higher rainfall in the west (300–600 mm) to lower in the east (60–150 mm) (Morales et al. 2018). Diel temperature variation can reach 25° and wind gusts can exceed 30 m/s (Aceituno 1996). The region is highly influenced by the El Niño Southern Oscillation (ENSO), causing episodes of below average precipitation and warmer than normal air temperatures, with opposite conditions prevailing during La Niña (Garreaud and Aceituno 2001).

Within the desert matrix, the complex hydrogeology and climate interacts to create endorheic and exorheic basins with a diversity of wetlands. We use a broad definition of wetlands, building on that adopted by the Ramsar Convention on Wetlands of International Importance (<https://www.ramsar.org/>), to include areas covered with water, whether freshwater, brackish or saline; permanent or temporary; standing or flowing; including surface water and groundwater. The combination of large diel variability in temperatures, low oxygen availability and high UV radiation at high altitude; and high desiccation potential, salinity, acidity, alkalinity, and chemical concentrations in the high Andean wetlands create habitats for biodiversity highly adapted to these extreme conditions. Because of their presence in otherwise largely dry environments, wetlands in drylands are key providers and may be disproportionately important in terms of biodiversity and other ecosystem services (Millennium Ecosystem Assessment 2005; Izquierdo et al. 2018). Indeed, in some arid or hyper arid settings, wetlands may provide the only supply of fundamental water and food resources (Tooth et al. 2015).

Under global change scenarios, temperature and aridity in the Andean plateau are projected to

increase along with extreme heat events while precipitation is projected to decrease (Pabón-Caicedo et al. 2020; Iturbide et al. 2020) and localized studies have detected increases in average air temperature and decreases in precipitation over the past 3 decades (Bennett et al. 2016; Frau et al. 2021). In addition, mountain ecosystems are considered to be highly sensitive to warming and changes in precipitation (Diaz et al. 2003; La Sorte and Jetz 2010) and shallow wetlands are particularly sensitive to changes in precipitation and evaporation (de la Fuente et al. 2021).

Many of the saline lake brines and flats of the Andean plateau are rich in sodium, lithium, boron, magnesium, and other elements that attract mining, and several national and multinational mining companies have had operations of varying scale throughout the ecoregion for several decades. The scale of mining operations is now significantly changing due to the increasing demand for lithium, which is projected to experience a sixfold increase over the next decade to supply the markets for rechargeable batteries (Bloomberg 2021).

The objective of this paper is to characterize the high-altitude wetlands of the Andean plateau with particular attention to their hydrogeology and unique biodiversity adapted to extreme environmental conditions and sustained in a delicate balance with limited water and variable climate. Our focus is on waterbirds and in particular flamingos as iconic wetland species. In addition, we characterize the lithium brine mining activity in wetlands in Catamarca Province, Argentina, addressing the environmental, regulatory, and local community aspects, as a case study of a Ramsar site with singular biodiversity value currently experiencing mining development at an unprecedented scale. Our goal is to bring attention to a unique complex of wetlands in drylands under pressure from local and global drivers and identify knowledge gaps relevant to conservation, management, and wise use of these wetlands and their resources.

Methods

Hydrogeology, biodiversity, and socioeconomic characterization

We have been conducting ecological research and implementing conservation actions centered on

wetlands in the Andean plateau since 1997. Since the mid 1990s we have integrated multidisciplinary teams conducting research in hydrology, limnology, and social sciences in the region. To characterize the abiotic, biotic, and social ecological systems of the high Andean wetlands, we synthesize the available information from a review of the literature (using keywords altiplano, high altitude/shallow/Andean wetlands, Andes/Andean biodiversity, drylands, extremophiles, lithium mining), from our original research, and from interviews with experts in relevant topics and members of local communities. We also reviewed field guides, species lists, and unpublished reports, management plans, and policy documents. Information on flamingo distribution and abundance was obtained during comprehensive range-wide censuses targeting Andean and Puna flamingos and including other waterbirds that have been carried out systematically since 1997 via a collaborative regional effort led by us and coordinated through the Grupo de Conservación Flamencos Altoandinos (GCFA). In these censuses, direct counts are conducted over a 10-day period during the breeding season at over 250 wetlands by ~20 teams of 4–5 people, covering the global distribution of the Andean and Puna flamingos (Marconi 2010). Regional range-wide flamingo censuses have been carried out every 5 years since 2005 and are integrated with the Neotropical Waterbird Census and the First South American Phalarope Census conducted throughout its winter range in 2020 (Castellino and Lesterhuis 2020).

Lithium mining and Catamarca province case study

We obtained information on lithium brine mining in Argentina, Chile, and Bolivia from public sources including mining industry publications and media. Additionally, we obtained detailed information for Argentina from mining authorities and other government agencies, academia, and private organizations. We conducted annual field expeditions to the Andean plateau in Catamarca lasting ~10 days in January–February (austral summer) from 2017 to 2021. During each expedition we located and georeferenced mining activity and conducted interviews with mining company staff, mining authorities, and local community residents.

We obtained Environmental Impact Statements and Reports (Informe de Impacto Ambiental, IIA)

for mining projects through official solicitation from the Ministerio de Minería (Ministry of Mines) and the Secretaría de Medio Ambiente (Secretary of Environment) of Catamarca Province, Argentina. We compiled and analyzed the current regulatory framework and created a matrix with elements that were required under current regulations and considered best environmental and social practices for mining projects. We reviewed each IIA and coded them using the regulatory matrix.

To determine perceptions and interests related to natural resources in communities in or near the Andean plateau we conducted diagnostic workshops (Montero 2012) in the towns of Fiambalá, Antofagasta de la Sierra, and El Peñón, identifying and ranking the issues to design a training program adjusted to the needs and capacities of each community. In addition, we implemented a survey using a free association technique with three successive prompts (Abric 2001) to 63 anonymous adult participants from the Andean plateau towns of Antofagasta de la Sierra, recruiting volunteers during the Feria de la Puna (Puna Fair) on 17 February 2018, and El Peñón recruiting volunteers from the municipal offices and school on 21 February 2018. Survey participants were given three cards, each one with one word: Mining, Water or Environment, to elicit responses linked to the mining theme. Participants were asked to record on the back of the cards what they thought about each word and what image came to mind when they read it. Informed from the survey of interests and requests for training, since 2019, we implemented a training cycle for ‘Environmental Managers,’ covering basic concepts on wetlands, lithium mining, strategic planning, and participatory environmental monitoring for community members (Marconi and Clark 2020).

Results and discussion

The high Andean waterscapes

The endorheic catchments in high, arid plateaus have a negative hydrological balance because the mean annual evaporation exceeds that of precipitation and rates of groundwater discharge often exceed modern recharge (e.g., van Beek et al. 2011; Gleeson et al. 2012). Mechanisms such as regional-scale groundwater flow between topographic basins and draining

of stored groundwater formed during past, wetter climatic periods, have been proposed to account for imbalances observed in the water budget (Placzek et al. 2013; Corenthal et al. 2016). Recent work in the Salar de Atacama basin in Chile, suggests that effective catchment area can be larger or smaller than the topographic catchment (Liu et al. 2020), and there is evidence showing that interbasin groundwater flow does play an important role in the modern hydrologic balance and of pre-modern (or fossil) groundwater (100 \geq 10,000 yrs) dominating the discharge of water to wetlands in the basin (Moran et al. 2019a, b; Boutt et al. 2021).

Similar work across several topographic watersheds in the Andean plateau of Catamarca Province in Argentina using stable isotope and geochemical data show strong connectivity but also a marked disconnect between recharge and discharge areas and that most of the water discharging to large basin floors is composed of fossil water, yet modern water (days–10 yrs. old) is critical to sustaining many wetlands (Moran et al. 2019a, b). Understanding these waterscapes as interconnected basins and the role of groundwater in the dynamics of surface water is key to addressing water sustainability and security in the region, especially since hydrological regimes are projected to continue to change due to natural and human induced pressures (Boutt et al. 2016; Corenthal et al. 2016) and the concentration of the water demand will have crucial effects on the water supply–demand balance affecting water availability (Pabón-Caicedo et al. 2020).

In the high Andean plateau, the wetland water budget includes inflow from precipitation (rain, snow, hail), surface runoff and groundwater, and discharges primarily through natural evapotranspiration. High Andean plateau wetlands include rivers and streams (both permanent and temporary), salt lakes and salt flats (*salarés*), often with peripheral aquatic habitats of wetlands supported by springs called vegas (wet meadows) or bofedales (peatlands) (Ruthsatz and Movia 1975; Prieto et al. 2003; Izquierdo et al. 2018) that tend to form because primary production exceeds decomposition (Jacobsen and Dangles 2017). Several Andean plateau wetlands are influenced by volcanic activity and have elevated temperatures (e.g., 70 °C) while wetlands receiving meltwater from snow are usually cold (< °C) (Morteani et al. 2014; Jacobsen and Dangles 2017). Below freezing temperatures at

night and during winter can cause wetlands to freeze over completely (Rocha 1997; Caziani et al. 2001). Spatial and temporal (seasonal and inter-annual) variability of high Andean wetlands is high and strongly related to weather conditions and connectivity among surface waters, with groundwater recharge being of major importance (Boutt et al. 2016; Jacobsen and Dangles 2017; de la Fuente et al. 2021; Frau et al. 2021). High Andean wetlands can be considered sentinels for climate change as they are sensitive to glaciers melting, they are located within small watersheds presenting a strong coupling between weather and water flows, and being wetlands in drylands, can be easily detected and delimited using satellite images (Dangles et al. 2017).

Biodiversity and lifeways adapted to extremes

The environments of the high Andes have been identified as important ecoregions of diversity with high levels of endemism, unique traits, and evolutionary novelty (Ibarguchi 2014). The high-altitude characteristics and chemical composition attributable to volcanic activity create environmental conditions in these wetland systems that resemble those of the early Earth and potentially could provide information about the early evolution of life on the planet (Saona Acuña et al. 2020; Vignale et al. 2021). The wetland patches have varied chemistries (Boyle et al. 2004), containing diverse and singular assemblages of organisms, including a flourishing microbial diversity of extremophile microbial mats, microbiolites (Cabrol et al. 2009; Albarracín et al. 2015; Farias et al. 2017) and stromatolites (Fariás 2018); arbuscular mycorrhizal fungi with stress-tolerant life history traits (Silvani et al. 2017); phytoplankton, zooplankton, and microfauna (e.g. Locascio de Mitrovic et al. 2005; Frau et al. 2015) that support a diversity of endemic, resident, and migratory birds (Table 1), some of them completely dependent on water (Fjeldså and Krabbe 1990; Caziani et al. 2001). They also serve as steppingstones during the migration of long-distance migrants, particularly shorebirds (Caziani et al. 2001; Jacobsen and Dangles 2017; Castellino and Lesterhuis 2020). These wetlands are one of the main drivers of bird spatial distribution at high altitude and have a crucial role in preserving bird life (Vuilleumier and Simberloff 1980; Tellería et al. 2006).

Table 1 Birds associated with wetlands in the Andean plateau

	Species	English common name	Status	Endemic	IUCN category
	Tinamidae				
1	<i>Tinamotis pentlandii</i>	Puna Tinamou	R	X	LC
	Rheidae				
2	<i>Rhea pennata garleppi</i>	Lesser Rhea	R		LC
	Podicipedidae				
3	<i>Podiceps occipitalis juninensis</i>	(Northern) Silvery Grebe	R	X	NT
	Phoenicopteridae				
4	<i>Phoenicopterus chilensis</i>	Chilean Flamingo	N		NT
5	<i>Phoenicoparrus andinus</i>	Andean Flamingo	N		VU
6	<i>Phoenicoparrus jamesi</i>	Puna Flamingo	N		NT
	Threskiornithidae				
7	<i>Plegadis ridgwayi</i>	Puna Ibis	R	X	LC
	Accipitridae				
8	<i>Circus cinereus</i>	Cinereous Harrier	R		LC
9	<i>Geranoaetus polyosoma</i>	Variable Hawk	R		LC
	Falconidae				
10	<i>Phalcoboenus megalopterus</i>	Mountain Caracara	R		LC
11	<i>Falco femoralis</i>	Aplomado Falcon	R		LC
12	<i>Falco peregrinus</i>	Peregrine Falcon	R		LC
	Recurvirostridae				
13	<i>Recurvirostra andina</i>	Andean Avocet	R	X	LC
14	<i>Himantopus mexicanus</i>	Black-necked Stilt	R		LC
	Anatidae				
15	<i>Oressochen melanopterus</i>	Andean Goose	R		LC
16	<i>Anas (flavirostris) oxyptera</i>	Inca Teal	R		LC
17	<i>Anas georgica</i>	Yellow-billed Pintail			LC
18	<i>Spatula puna</i>	Puna Teal	R		LC
19	<i>Spatula cyanoptera</i>	Cinnamon Teal	R		LC
20	<i>Lophonetta specularioides alticola</i>	Crested Duck	R		LC
21	<i>Oxyura jamaicensis</i>	Ruddy Duck	R		LC
22	<i>Merganetta armata leucogenys</i>	Torrent Duck	R		LC
	Rallidae				
23	<i>Gallinula galeata</i>	Common Gallinule	R		
24	<i>Fulica ardesiaca</i>	Andean Coot	R		LC
25	<i>Fulica leucoptera</i>	White-winged Coot	R		LC
26	<i>Fulica cornuta</i>	Horned Coot	R	X	NT
27	<i>Fulica armillata</i>	Red-gartered Coot			LC
28	<i>Fulica gigantea</i>	Giant Coot	R	X	
	Charadriidae				
29	<i>Oreopholus ruficollis</i>	Tawny-throated Dotterel	R		LC
30	<i>Vanellus chilensis lampronotus</i>	Southern Lapwing			LC
31	<i>Vanellus resplendens</i>	Andean Lapwing	R		LC
32	<i>Charadrius alticola</i>	Puna Plover	R	X	LC
33	<i>Pluvialis dominica</i>	American Golden Plover	M		LC
34	<i>Phegornis mitchellii</i>	Diademed Sandpiper-Plover	R		LC
	Scolopacidae				

Table 1 (continued)

	Species	English common name	Status	Endemic	IUCN category
35	<i>Gallinago andina</i>	Puna Snipe	R	X	LC
36	<i>Limosa haemastica</i>	Hudsonian Godwit	M		LC
37	<i>Tringa melanoleuca</i>	Greater Yellowlegs	M		LC
38	<i>Tringa flavipes</i>	Lesser Yellowlegs	M		LC
39	<i>Calidris melanotos</i>	Pectoral Sandpiper	M		LC
40	<i>Calidris bairdii</i>	Baird's Sandpiper	M		LC
41	<i>Calidris alba</i>	Sanderling	M		LC
42	<i>Calidris himantopus</i>	Stilt Sandpiper	M		LC
43	<i>Phalaropus tricolor</i>	Wilson's Phalarope	M		LC
	Laridae				
44	<i>Chroicocephalus serranus</i>	Andean Gull	R		LC
45	<i>Leucophaeus pipixcan</i>	Franklin's Gull	M		LC
	Thinocoridae				
46	<i>Attagis gayi</i>	Rufous-bellied Seedsnipe	R		LC
47	<i>Thinocorus orbignyianus</i>	Grey-breasted Seedsnipe	R		LC
48	<i>Thinocorus rumicivorus</i>	Least Seedsnipe	R		LC
	Furnariidae				
49	<i>Cinclodes albiventris</i>	Cream-winged Cinclodes	R		LC
50	<i>Cinclodes atacamensis</i>	White-winged Cinclodes	R		LC
51	<i>Phleocryptes melanops schoenobaenus</i>	Wren-like Rushbird	R		LC
	Tyrannidae				
52	<i>Lessonia oreas</i>	Andean Negrito	R		LC
53	<i>Pseudocopteryx acutipennis</i>	Subtropical Doradito*	M		LC
54	<i>Tachuris rubrigastra alticola</i>	Many-coloured Rush Tyrant	R		LC
55	<i>Muscisaxicola juninensis</i>	Puna Ground Tyrant	R		LC
56	<i>Muscisaxicola albifrons</i>	White-fronted Ground Tyrant	R		LC

*Indicates regional migrant

Endemic birds are those exclusively found on the Andean plateau. Sources: Herzog et al. (2016), Jaramillo (2003), Pearman and Areta (2020), Shulemberg et al. (2007)

Status *M* hemispheric migrant, *N* nomadic, *R* resident, *En* endemic

Few reptiles and amphibians are affiliated with high altitude waters and their occurrence is sporadic (Péfaur and Duellman 1980; Jacobsen and Dangles 2017). For example, in the altiplano of Argentina there are nine species of anurans in three genera (*Pleurodema*, *Rhinella* and *Telmatobius*) adapted to arid, high-altitude environments (Barrionuevo and Abdala 2018). The *Telmatobius* species are entirely aquatic and some of their populations as well some of *Rhinella* spp. are adapted to geothermal streams (Lavilla and Barrionuevo 2005; Pastenes et al. 2017). Native mammals include puma (*Puma*

concolor), Andean or culpeo fox (*Lycalopex culpaeus*), hairy armadillo (*Chaetophractus nationi*); Pampas cat (*Leopardus colocolo*), the endangered Andean cat (*Leopardus jacobitus*) and short-tailed chinchilla (*Chinchilla brevicaudata*); and the commercially valuable vicuña (*Vicugna vicugna*). The high Andean wetlands allow the ranges of these species to straddle the arid mountain landscapes and distance to wetlands was found to determine the distribution of several of these species, most importantly for the culpeo fox, most likely because it uses aquatic birds as prey (Cuyckens et al. 2015).

Human occupation, natural resource use, and threats to biodiversity

Human occupation of the Andean plateau began in the late Pleistocene some 11,000 years ago by hunters and gatherers (Wheeler 1991; Fernandez et al. 1991; Yacobaccio and Morales 2011). Between 1200 and 1533, the Andean highlands saw the flourishing of the Inca civilization, with its administrative, political, and military center in the high-altitude city of Cusco, Peru (Olivera 1992). From mid 1500–1824, the Andean plateau spanned two of the Spanish vice-royalties and colonization and major trade routes from the Río de la Plata to the Alto Perú traversed the plateau (García et al. 2000). During the Inca period and through the colonial periods, mining for metals (copper, silver, gold) contributed to development of the regional economy and infrastructure (Quiroga 2019). Currently, population density in the Andean plateau is relatively low (1 p/km²), although there are several large cities (pop. > 400,000; e.g., La Paz and Oruro, Bolivia; Arequipa, Peru). Rural populations are concentrated in small settlements near water sources and engage primarily in agriculture and raising livestock; small, village-based commercial activities; and municipal employment. Some ethnic groups represented in the region are Uros, Quechua, Aymara, Atacameño, and Diaguita.

In drylands, wetlands may be disproportionately important in terms of ecosystem service provision (Millennium Ecosystem Assessment 2005). The Andean plateau wetlands provide key ecosystem services including food, wool, and fiber provision; soil carbon sequestration, fertility, and nutrient cycling; water provision and regulation; microclimate regulation (Rolando et al. 2017 and references therein); recreation and tourism, cultural and natural heritage, and aesthetics (Gandarillas et al. 2016).

Mining in the altiplano has been present throughout history, from small-scale artisanal mines to major national and multinational investments (Raffino et al. 2013; Gluzman 2007). At present, the Central Andes has one of the richest base metal endowments on Earth. In 2017, the region accounted for the mine production of around 39% of the world's copper, 23% of its silver, 20% of its molybdenum, 14% of its zinc, and 12% of its tin as well as significant shares of other metals including gold and lead (US Geological Survey 2018). At local and regional scales,

since colonial periods and especially as of the 1990s with the growth of industrial-scale, open pit, surface operations, mining has been the main cause of biodiversity loss, degradation of ecosystem services, and social inequity in the high Andean plateau (Svampa and Antonelli 2009).

These wetlands are increasingly threatened by human activities contributing to wetland loss and degradation, notably intensive grazing, especially of non-native livestock (Struelens et al. 2017), water diversion and draining (Rubio et al. 2016), redistribution of the population to urbanized areas (Izquierdo et al. 2018), pollution (Rocha et al. 2021; Quispe Mamani et al. 2021), unregulated tourism, and mining (Izquierdo et al. 2018). Localized impacts on the high Andean wetlands are likely exacerbated by global drivers like climate change (Seth et al. 2010) and energy markets (Gajardo and Redón 2019; Alam and Sepúlveda 2022).

The unique landscapes and wildlife of the Andean wetlands are increasingly promoted by the nature and adventure tourism industry, which has grown with limited regulation in the last three decades (Amilhat-Szary and Guyot 2009; Otárola 2019), becoming the main economic activity in for example, San Pedro de Atacama in Chile and Uyuni in Bolivia (Galaz-Mandakovic Fernández 2014), with a focus on promoting protected areas such as Reserva Nacional Los Flamencos in Chile that received more than one million visitors in 2017 (https://www.chululo.cl/pages/recortes2.php?id=26072018_035344) and Reserva de Fauna Andina Eduardo Avaroa in Bolivia (Drum 2004). Many other wetlands and protected areas in the altiplano are also experiencing increased visitation (Hernández 2016) providing additional sources of income for local residents.

Flamingos as flagships for Andean wetland ecology and conservation

Among birds, flamingos (*Phoenicopteridae*) are iconic species in the high Andean waterscapes, moving from one wetland to another tracking resource availability in space and time, effectively connecting these wetlands as a network of habitats. Flamingos are an important component of a growing nature tourism industry and serve as flagship species for conservation of high-altitude watersheds. The importance of these habitats for three of the world's six species

of flamingo, the Chilean Flamingo (*Phoenicopterus chilensis*), Andean Flamingo (*Phoenicoparrus andinus*), and Puna Flamingo (*P. jamesi*), supported the designation and/or expansion of three national protected areas and eight Ramsar sites throughout their range in the Andes.

Global population estimates for these three flamingo species were difficult to obtain because of their nomadic movements, remote wetland habitats that are difficult to access, and extent of their geographic range. Prior to the late 1990s, global flamingo populations for these three species were estimated based on extrapolations from counts conducted at a few wetland sites (Cordier 1965; Johnson 1967; Kahl 1975; Hurlbert 1978, 1981; Parada 1990) and summer distributions were incomplete, while winter distributions and movement patterns were basically unknown (Caziani et al. 2007). Establishing population trends was difficult given the unreliability of previous population estimates (Federal Register 2010). Comprehensive range-wide censuses targeting Andean and Puna flamingos have been carried out systematically since 1997 via a collaborative regional effort coordinated by the Grupo de Conservación Flamencos Altoandinos (GCFA). These species are primarily restricted to the wetlands of the altiplano of Argentina, Bolivia, Chile, and Peru, and are often referred to as high Andean (or Andean highland) flamingos. The Andean Flamingo shows movements consistent with a partial seasonal migration to lowland wetlands in central Argentina during the non-breeding season (May–October), particularly when some of the high-altitude wetlands freeze over (Romano et al. 2006, 2008, 2009; Caziani et al. 2007; Marconi et al. 2011). Puna Flamingos are occasionally observed in lowland wetlands (Cruz et al. 2013; Dias and Cardozo 2014). Because the broader Chilean Flamingo distribution overlaps with that of the high Andean species, the three flamingo species are counted in wetlands where they are sympatric during the censuses.

Recent population counts estimate the Andean Flamingo population at 77,949 individuals and Puna Flamingos at 154,001 individuals (Marconi et al. 2020). The Chilean Flamingo population previously estimated at 300,000 (Marconi et al. 2011) will likely be revised since the latest direct count that covered 90% of wetlands in the global distribution estimated 515,530 individuals. Results of the systematic censuses show a sustained increasing trend in the global

abundances of the three flamingo species, with close to 70% of the global populations of Andean and Puna flamingos concentrated in wetlands around the tripartite border region of Argentina, Bolivia, and Chile (Marconi et al. 2020) (Fig. 1). This tripartite region also encompasses the most important breeding sites for the Andean and Puna flamingos (Rocha 1997; Rodriguez et al. 2006; Caziani et al. 2007; Torres et al. 2019). Detailed monitoring of colonies in four wetlands in the Los Lipez Ramsar Site in Bolivia estimated over 16,000 chicks of these two species in 2012 (Rocha and Marconi 2012).

The data generated from the regional simultaneous censuses was used to propose a regional conservation strategy based on a Network of Wetlands for Flamingo Conservation (Marconi 2007). The Network strategy adopted an ecosystem approach, incorporating a wide range of goals in terms of biodiversity and promoting integrated wetland ecosystem management based on scientific information, aimed at the sustainable and wise use of shallow saline wetlands. Several criteria were used to select network member sites, a defining one being that it harbors 1% of the global population of one of the two high Andean flamingo species at any time of the year and/or records of breeding colonies of one of the two species.

Other criteria based on biodiversity value, conservation status, functional connectivity with other sites, and governance aspects helped refine the selection of network sites (Marconi and Sureda 2008). The Network project was officially presented in 2007 and had the immediate formal endorsement of 70% of the administrators of the proposed sites and was incorporated as a subregional project of the Regional Strategy for the Conservation of High Andean Wetlands of the Ramsar Convention (https://www.ramsar.org/sites/default/files/americas_haw_en.pdf). In 2008, three of the four countries in the Network (Bolivia, Chile, Peru) signed a Memorandum of Understanding (MOU) for the conservation of the two high Andean flamingo species in the framework of the Convention on Migratory Species (CMS, <https://www.cms.int/flamingos/>), initiating the process of formulating international management plans by species (e.g., CONAF-Convencion de Ramsar 2015). Since 2007, annual flamingo population monitoring has been carried out at the Network sites (Marconi and Sureda 2008), in addition to the international simultaneous censuses every 5 years. In terms of effective

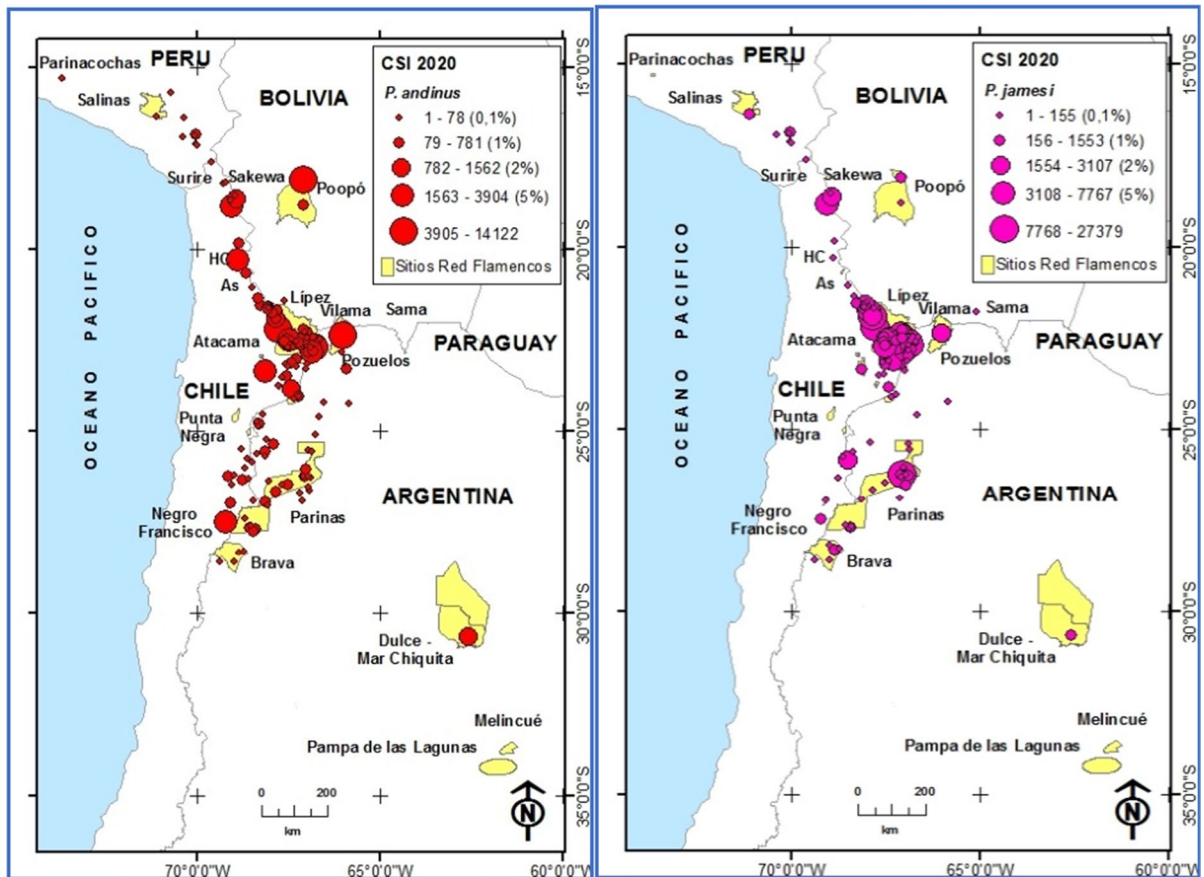


Fig. 1 Distribution and abundance of Andean and Puna flamingos during the regional simultaneous census in January–February 2020

protection, we focused on those sites that did not have any official conservation status, first promoting their designation as Ramsar sites and then complementing them with other national or subnational protected area status (Table 2). Currently the Network of Wetlands for Flamingo Conservation comprises 22 sites (Fig. 2).

Successful community-based conservation actions have been implemented throughout the Network. For example, a co-management agreement between the Corporación Nacional Forestal (CONAF) in Chile, the national agency charged with management of protected areas, and the indigenous Iikanantai (Atacameño) people resulted in a participatory management plan for the Reserva Nacional Los Flamencos (RNLF). The Iikanantai have been trained in tourism administration and management, actively participate in decision-making related to the RNLF, and

manage and reinvest park fees in their territory and projects. These ecotourism related activities complement their traditional economic and cultural practices (CONAF 2008). In Argentina, the communities of El Peñón, Antofagasta de la Sierra, and Fiambalá, Catamarca, had an instrumental role in the participatory management plan developed for the Lagunas Altoandinas y Puneñas de Catamarca Ramsar site (SRLAP-Cat) (Marconi et al. 2013), and local communities in Laguna Pozuelos National Monument, a Ramsar site and Biosphere Reserve, participated in a restoration plan for overgrazed vegas (Amaya et al. 2019).

High Andean wetlands and the “lithium triangle”

Over two thirds of the world’s identified resources of lithium are found in the so-called “lithium triangle” that overlays Argentina, Bolivia, and Chile

Table 2 Ramsar sites in the Network of Wetlands for Flamingo Conservation

	1990		2000		2007-Wetland network		2010	
	Ramsar Sites	Area (ha)	Ramsar Sites	Area (ha)	Ramsar Sites	Area (ha)		Area (ha)
Argentina	Lag. de Pozuelos (1992)	16,224	Lagunas de Vilama (2000)	157,000	Humedal Laguna Melincué (2008)	92,000		
			Bañados del río Dulce y Lag. Mar Chiquita (2002)	996,000	Lagunas Altoandinas y Puneñas de Catamarca (2009)	1,228,000	*Área Natural Protegida Campo de Piedra Pómez (2012)	75,489
			Reserva Laguna Brava (2003)	405,000				
Chile	Complejo Lacustre Negro Francisco y Laguna Santa Rosa (1996)	62,460			Salar Aguas Calientes IV (2009)	15,529		
	Salar de Huasco (1996)	6,000			Salar de Pujsa (2009)	17,397	** Parque Nacional Salar de Huasco (2010)	11,000
	Salar de Surire (1996)	15,858						
	Salar de Tara (1996)	96,439						
	Sistema Hidrológico de Soncor (1996)	67,133						
Bolivia	Laguna Colorada (1990)	60,000	Lagos Poopó and Uru-Uru (2002)		Los Lípez (2009) (incluye Laguna Colorada)	1,427,117		
Perú			Bofedales y Laguna de Salinas (2003)	17,657				
	Area Ramsar sites 1990	324,114	Increase 1990—2000	1,575,657	Increase 2007—2010	2,760,643		
Total area Ramsar sites		324,114		1,899,741		4,660,384		4,660,384

*el ANP Campo de Piedra Pómez is within the Catamarca Ramsar site

**P.N. Salar de Huasco includes the Salar de Huasco Ramsar site

In bold are sites that are partially or entirely included in the national or subnational (provincial, departmental, municipal) protected areas systems of each country. The Network of Wetlands for Flamingo Conservation was launched in 2007 which drove an increase in Ramsar site designation and expansion

(US Geological Survey 2017b) (Fig. 2). Since 2016, exploration projects have grown throughout the region, most notably within Argentina because of favorable political climate, financial incentives, and

world class mineral deposits, increasing lithium production by 60% in 2017 (US Geological Survey 2017a). In Chile, lithium mining expansion is focused in the Salar de Atacama, a Network of Wetlands for

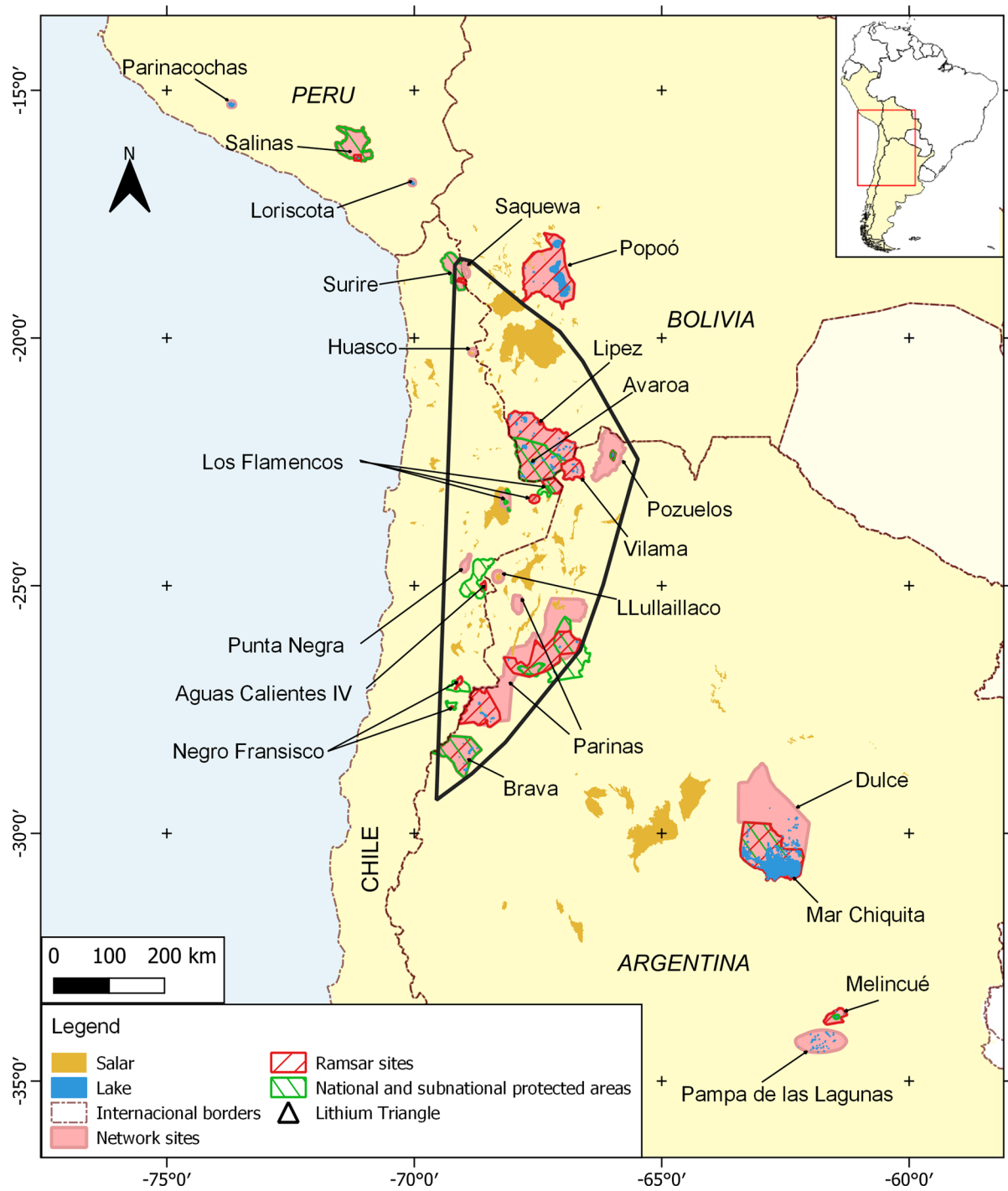


Fig. 2 Map of the sites that are part of the Network of Wetlands for Flamingo Conservation. The “Lithium Triangle” is indicated on the map

Flamingo Conservation site within the national protected area Reserva Nacional Los Flamencos, where lithium has been mined since 1985. In Bolivia lithium exploration is centered in Salar de Uyuni, a known breeding site for flamingos. The geographical area where lithium exploration, exploitation, and expansion is advancing, centered around the tripartite border of Argentina, Bolivia, and Chile, coincides precisely with wetlands with the highest concentrations of Andean and Puna flamingos and their most productive breeding sites. In addition, 14 of the 22 sites in the Network of Wetlands for Flamingo Conservation are encompassed in the lithium triangle (Marconi 2010).

In the arid Andean wetlands, lithium in brine, the point where the life cycle of many new technologies begins, is extracted from saline deposits through slow and inefficient methods, with a large investment and use of natural resources in relation to the final product. The viability of mining is currently based on the externalization of water resource costs. The method consists of evaporating brine in open pools where the different salts precipitate sequentially, recovering the lithium carbonate from the concentrated brine in a treatment plant at the end of the process that also requires copious volumes of fresh water (Flexer et al. 2018; Sticco 2018). Because of the scale, lithium brine mining should be framed as large-scale or mega-mining (Donadío 2009) in relation to the extraction of water: for each ton of lithium carbonate produced between half to a million liters of brine water evaporates, and between 80,000 and 140,000 L of fresh water is used, depending on the technology used, the climatic and meteorological conditions, and the natural lithium concentration. The intensive extraction of brine from groundwater and use of surface water in lithium mining in an area where water is scarce and critical for supporting a unique biodiversity, and on which human communities depend for their livelihoods is a challenge for an industry promoting environmentally sustainable technologies. Researchers are working on less intensive extractive methods (e.g., ionic exchange, reverse osmosis; membrane technology) but these have not been scaled to industrial projects (Flexer et al. 2018, Liu et al. 2019).

The direct impact on wetlands of lithium mining infrastructure and activity in terms of habitat loss, conversion, and degradation include salinization of soils and wetlands, contamination, alteration of water

flows, and land subsidence, with effects on local flora and fauna (Kaunda 2020). A report by Sticco et al. (2021) documented combinations of these factors affecting mining projects in Argentina (Orocobre project in the Salar de Olaroz-Cauchari) and Chile (Sociedad Química y Minera de Chile-SQM project in Salar de Atacama) based on a review of company reports and government records of violations. In addition to the direct impacts, the sustained extraction of groundwater brines and surface waters over decades are likely to affect the hydrological balance, salinity, and unique biodiversity of these wetlands (Gajardo and Redón 2019) and a study in the Salar de Atacama, Chile, has found fast expansion of lithium mining operations to have a strong correlation with the ongoing environmental degradation in the area (Liu et al. 2019). Impacts of water extraction from lithium mining are difficult to ascertain in the short term because of historical climate patterns, variable climate conditions and the occurrence of extreme climatic events (Bennet et al. 2016; Pabón-Cañedo 2020; de la Fuente et al. 2021, Alam and Sepúlveda 2022) and delays in response of environmental variables to complex hydrogeological processes involving the distribution and timing of groundwater recharge magnified by long residence times (> 100 years), deep water tables (> 100 m), groundwater flow paths often crossing topographic boundaries before emerging at basin floors, and often insufficient data (Frau et al. 2021; Moran et al. 2019b).

Mining operations introduce both subtle and dramatic changes in social systems of host communities. Industrial scale mining has been an important sector of the Andean plateau economy since the 1990s, but the more recent lithium mining boom has seen an increase in polarization and a series of socio-environmental conflicts in the salt flats of Bolivia, Chile, and Argentina (Argento and Puente 2019; Jerez et al. 2021). One of the most conflictive aspects has been the use of water, due to the impact that decreased availability and quality will have on local livelihoods and economic activities (León et al. 2020).

The three countries that make up the lithium triangle manifest the political intention to achieve the integral development of the value chain from the extraction of lithium, processing of lithium carbonate, manufacturing of batteries, through to the manufacturing of electric cars. Faced with the challenges of developing the industry and the technological

capacities, each country starts from a different governance model (León and Muñoz 2019) described as two on opposite extremes and one intermediate (León et al. 2020). Bolivia is characterized by a hierarchical regime, under strong political control of the central government (Obaya 2019). Argentina, on the other hand, has a market governance model, with a regulatory system based on the liberal structural reforms of the 1990s (Svampa and Antonelli 2009). Chile also has hierarchical governance features under the control of the Corporación de Fomento de la Producción (CORFO), a national governmental organization that promotes production (Poveda Bonilla 2020), although by delegating the operation to large private companies, it has adopted characteristics of market governance.

Catamarca province, Argentina: wetlands, waterbirds, and world-class lithium deposits

The high Andean wetlands of Catamarca are located within a 30,000 km² area in the southern end of the Andean plateau, in northwestern Argentina. In 2009, more than a third of the plateau in Catamarca was designated as the Lagunas Altoandinas y Puneñas de Catamarca Ramsar site (SRLAPCat) (<https://rsis Ramsar.org/es/rs/1865>) within the framework of the implementation of the Network of Wetlands for Flamingo Conservation (<http://www.redflamencos-gcfa.org/>). The SRLAPCat consists of two areas designated northern subsite and southern subsite, separated by the Abaucán valley that is traversed by Ruta Nacional 60, an international highway connecting Chile and Argentina. In 2012, a provincial protected area, Campo de Piedra Pómez Natural Protected Area, was created within the Ramsar site, and a participatory planning and management process of the SRLAPCat was started with environmental authorities and local communities (Marconi et al. 2013). The SRLAPCat is an important site for Puna Flamingos during the breeding season, where > 15,000 00 are regularly counted in one wetland, Laguna Grande (Marconi et al. 2011, 2020), as well as a breeding site for both Puna and Andean flamingos (Marconi and Clark 2011; Torres et al. 2019).

As of 2016, when new financial incentives for mining activity were established in Argentina (Decreto Nacional 349/2016), more than a dozen lithium brine exploration projects were launched in Catamarca,

which until then had only one lithium mining project operating since 1998, the Livent Corp. Fénix project in the Salar del Hombre Muerto, a salt flat that straddles Catamarca and Salta provinces and is outside the SRLAPCat protected area (CIMA 2021, 2019). At present, there are 36 mining projects (Table S1) in different stages of development – prospecting, exploration, exploitation – of which 20 (56%) are lithium and four are located within the SRLAPCat (Fig. 3). All the lithium mining projects use evaporation ponds in one or more stages of lithium carbonate production, alternating with direct lithium extraction (DLE) methods such as ionic exchange and inverse osmosis. Other DLE technologies are being developed but are not applied yet at industrial scales (Pramanik et al. 2020; Zante et al. 2020; Zhao et al. 2020a, b) although these are aimed at increasing production efficiency vs. reducing the water footprint or resolving socio environmental conflict (Díaz Paz et al. 2021). Of the 20 lithium mining projects being developed in different stages, 19 aim to produce lithium carbonate for batteries and all are multinational companies, 50% based in Canada, 25% in Australia, and 10% in USA, with a trend towards major shareholding of companies from Asia (<https://panorama-minero.com/noticias/orocobre-y-toyota-tsusho-aprobaron-la-expansion-de-la-etapa-2-del-proyecto-olaroz-por-us295-millones/>; <https://www.newswire.ca/news-releases/catl-increases-investment-in-neo-lithium-866991760.html>).

In Argentina, mining companies must manage environmental permitting and licenses with the provincial government mining authority and the social license with local communities (Genovese 2020). The process to obtain these licenses requires approval of the Environmental Impact Report (Informe de Impacto Ambiental or IIA) by the provincial mining authority. The IIAs in Catamarca do not comply with the national guidelines (Secretaría de Ambiente y Desarrollo Sustentable 2019) that are aligned with international criteria and standards. The structural and functional hydrogeological aspects are underestimated; when water is valued, it is quantified as a commodity, not as an environmental service; they lack an ecosystem approach; and do not consider integrated watershed management. These four key deficiencies lead to an underestimation of the area of direct and indirect impact of each mining project and the quantification and assessment of the identified impacts (Secretaría de Ambiente y Desarrollo Sustentable

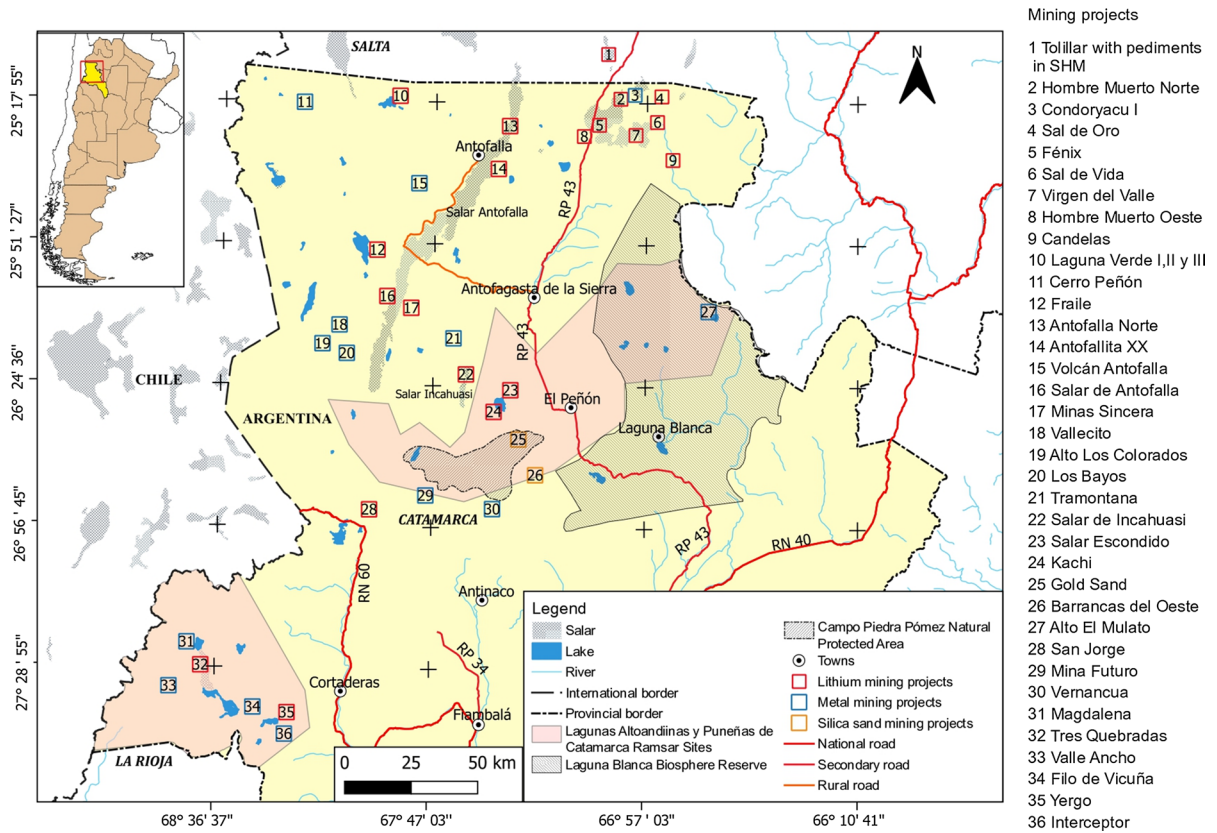


Fig. 3 Map of mining projects in Catamarca province, Argentina, as of 17 July 2021

2019). The IIAs do not recognize or evaluate the cumulative and synergistic environmental impacts (IFC 2013; Minerals Council of Australia 2015) nor do they consider any zoning related to protected areas (Biosphere reserves, Ramsar sites, provincial protected areas) or protection zones for water resources (Decreto Ley 2577/1973), as well as the different traditional uses and customary land holding by local communities and native peoples.

The IIAs are approved only by the mining authority (Código de Minería Ley 1919, Ley 24585/1995; Código de Procedimientos Mineros de la Provincia de Catamarca Ley 5682/2020), without binding intervention from other administrative areas such as environment, water resources, tourism, agriculture or archeological heritage. Commitments emanating from international conventions to which the country is signatory are not considered (i.e., Ramsar Convention, Convention on Migratory Species, UNESCO Man and Biosphere Programme), nor are approaches

for planning and participatory management of protected areas. Access to public environmental information related to mining that is protected by laws and international agreements (Ley 25675/2002, Ley 25831/2003, Acuerdo de Escazú) is regulated by provincial laws (Resolución SEM 330/2016) but in practice is extremely difficult to obtain and is not yet completely available in digital format. Although the IIA procedures include instances of public participation, the terms, requirements, modalities, and forms of access are not systematized, nor do they comply with the minimum requirements detailed in the General Environmental Law (Ley 25675/2002) and Access to Public Environmental Information Law (Ley 25831/2003). In practice, public participation is limited to presentations by mining companies where they present information.

With respect to mining projects and their environmental impact assessment process, we highlight the bias established by the mining authority in the

screening of projects based on the type and its basic information (dimensions, technology, location, etc.) and the determination of the scope of the project that establishes the terms of reference or technical specifications for carrying out the IIA (Secretaría de Ambiente y Desarrollo Sustentable 2019). The mining authority considers every project in the exploration stage as having low environmental impact without consideration of size, technology or location, and based on this screening, establishing a scope for the project whose IIA requires information and analysis that is insufficient for or identification, assessment, and prevention of environmental impacts.

From an exhaustive review of IIAs of mining projects and publicly available information from the mining companies of projects in exploration and exploitation stages, we conclude that the requirements regarding environmental baselines and impact analysis, and subsequent mitigation measures, management plan, and monitoring plan should more be rigorous in the exploration phase since the approval of at this stage necessarily leads to the exploitation stage if financially feasible. Currently, in the exploration stage of a mining project, very little from the regulatory side stops or substantially modifies the project for the exploitation phase. All the IIAs use the Fernández-Vítora et al. (1997) methodology to identify, score, and evaluate environmental and social impacts. In the matrices generated, environmental impacts are usually scored negatively though underestimated, and they are averaged with social impacts that are arbitrarily scored positively. The final combined impact scores are slightly negative, irrelevant, or overly positive. The mitigation measures and environmental monitoring and management programs are adapted from these biased average scores. We analyzed four aspects that we identified as the most relevant and that are systematically underestimated in IIAs, both in the exploration and exploitation stages. These are: (1) hydrogeological aspects, (2) land use planning, (3) cumulative and synergistic impacts and (4), public participation.

Hydrogeological balance and water budgets

Hydrological characterization and water budget models are not presented in the IIAs for the exploration phase of projects (100% of the 11 IIAs reviewed; Table S1). Environmental baselines are incomplete

and simplistic. We were able to obtain three exploitation IIAs for review. One of them is for an expansion of the Livent Corp. Fénix project in Salar del Hombre Muerto (EC & Asociados 2018), one for the launch of the exploitation phase of the Galaxy Lithium S.A. Sal de Vida project in the same salt flat, and the third for the exploitation phase of the LIEX S.A. Tres Quebradas project within the southern subsite of the SRLAP-Cat. The Fénix project proposes using large volumes of groundwater (650 m³/hr for 20 yrs.) which requires the installation of six pumping stations and a 30 km pipeline. Their hydrology model assumes that the only possible scenario is that the continued, sustained pumping of water will not affect the hydrological balance in the Río Los Patos, one of the main affluents to the Salar del Hombre Muerto salt flat wetlands. In other words, that there will be no major infiltration of the river to the aquifer, that infiltration from groundwater to the Salar will not decrease, evapotranspiration will remain the same, and water quality will remain the same. Water volumes used do not specify time units (e.g., hours, days). The IIA states that water extraction volumes will be 10% but does not specify how these calculations were done, if they contemplate seasonal or interannual fluctuations in groundwater recharge or the impact the extraction can have on the physical and chemical properties of the river. For the Sal de Vida exploitation phase, pumping of 130 m³/hr from the same Río Los Patos was approved for a 20-year period. Similar weaknesses in terms of water balance and hydrological models persist in the IIA, as well as a failure to address cumulative impacts on the shared water source. In the Tres Quebradas project, pumping water from the Río Abaucán aquifer was approved to supply the lithium carbonate industrial processing plant adjacent to the town of Fiambalá, with no information on the volume that will be extracted and no hydrogeological models. Without information on the volumes of water in the aquifer, origin of the groundwater (modern or pre-modern) and the relationship of these to the surface water of the river, claims of low impact are speculative. A consequence of damming and diverting water from the Río Trapiche to the Fénix processing in Salar del Hombre Muerto was the permanent desiccation of 32 ha of the Vega Trapiche and total loss of its vegetation (FMC-Minera del Altiplano S.A. 2000; CONHIDRO 2002).

Land use planning

Within the Andean plateau of Catamarca, there are two types of land zoning: one resulting from the designation of protected areas and the other from the application of the provincial Water Law (Decreto Ley 2577/1973) in terms of its regulation of the use of groundwater to avoid the depletion of aquifers. Within the SRLAPCat, four lithium projects are registered (Fig. 3), two in the northern subsite, the NRG Metals Salar Escondido project and Lake Resources Kachi project, and two in the southern subsite, the Tres Quebradas project and the Portofino Resources Yergo project. From the review of the IIAs of Salar Escondido, Kachi, and Tres Quebradas, it appears that the provincial mining authority frames the screening and scoping of these projects as if they were not within a protected area (Ramsar site), that is, it does not increase the requirements and conditions for the IIA. Even though their location has been identified as being sensitive and having a high conservation value, adequate safeguards have not been established. Regarding the stewardship zone, the entire sub-basin of the Río Los Patos is within a zoning category that restricts the industrial use of surface water and especially groundwater. Despite this protected basin status, the government of Catamarca approved water extraction for both projects for a total of 390 m³/hr por for the life of the project which is 20 years (Decreto Provincial OP 847/2019, Decreto Provincial 770/2020) without requiring that the companies carry out a detailed water balance study prior to extraction. Neither company has presented their annual monitoring reports as of this writing.

Cumulative and synergistic impacts: Salar del Hombre Muerto

Cumulative impacts are those that result from the successive, incremental and/or combined effects of an activity or project when added to the effects of other existing or planned ventures (IFC 2013; Minerals Council of Australia 2015). In the Salar del Hombre Muerto where a lithium mine (Livent Corp. Fénix project) has been operating since 1998, eight lithium brine mining projects have been registered in different mining stages (Fig. 4), all of them located in the same endorheic basin, using the same brine resource and fresh water for mineral processing. Two projects

(Alpha Lithium's Tolillar expansion and Galan Lithium's Hombre Muerto Oeste project) are in the prospecting stage (pre-exploration) which does not require an IIA. Of the other mining projects, we reviewed five IIAs, three for exploration (Posco's Sal de Oro project, Minera del Valle's Virgen del Valle project, and Galan Lithium's Candelas project) and two for exploitation (Fénix, Sal de Vida). Although the most recent projects refer to the existence of projects in the basin to prove the high productivity and quality of the lithium reserves, none of the revised IIAs identify cumulative impacts from the use of the same resource, which is indicated in the national guidelines (Secretaría de Ambiente de la Nación 2019) and the corresponding Cumulative Impact Assessment (CIA) is absent, although it is required by the provincial mining authority (COFEMIN 2019). Cumulative impacts are not considered in the Mitigation Measures or in the Management and Contingency Plans of any of the IIAs reviewed.

The most notable case in terms of the total absence of CIA for the extraction of fresh water from the Río Los Patos, a designated stewardship zone, for processing concentrated lithium brine which, as mentioned above, was approved for two companies (Minera del Altiplano, Galaxy Lithium Argentina) for a total of 3,416,000 m³/yr. This represents 15.6 times the volume of water consumed for domestic use in the town of Antofagasta de la Sierra located in an adjacent basin.

Participation of local communities

In 2018, with various lithium mining projects under exploration in Catamarca, the situation of local communities with respect to mining was diverse. In Fiambalá, the town closest to lithium mining areas in the southern subsite of the SRLAPCat, community members organized in a group whose concern was the protection of water, with support from similar groups from nearby towns. The group, Asamblea Fiambalá Despierta (Fiambalá Awakens Assembly), first learned about the lithium mining activity through local media and requested detailed information and documents from the municipality but never received a response (Environmental Justice Atlas, <https://ejatlas.org/>). At the same time in the northern subsite, in the towns of El Peñón and Antofagasta de la Sierra there seemed to be little interest in the mining activity, even

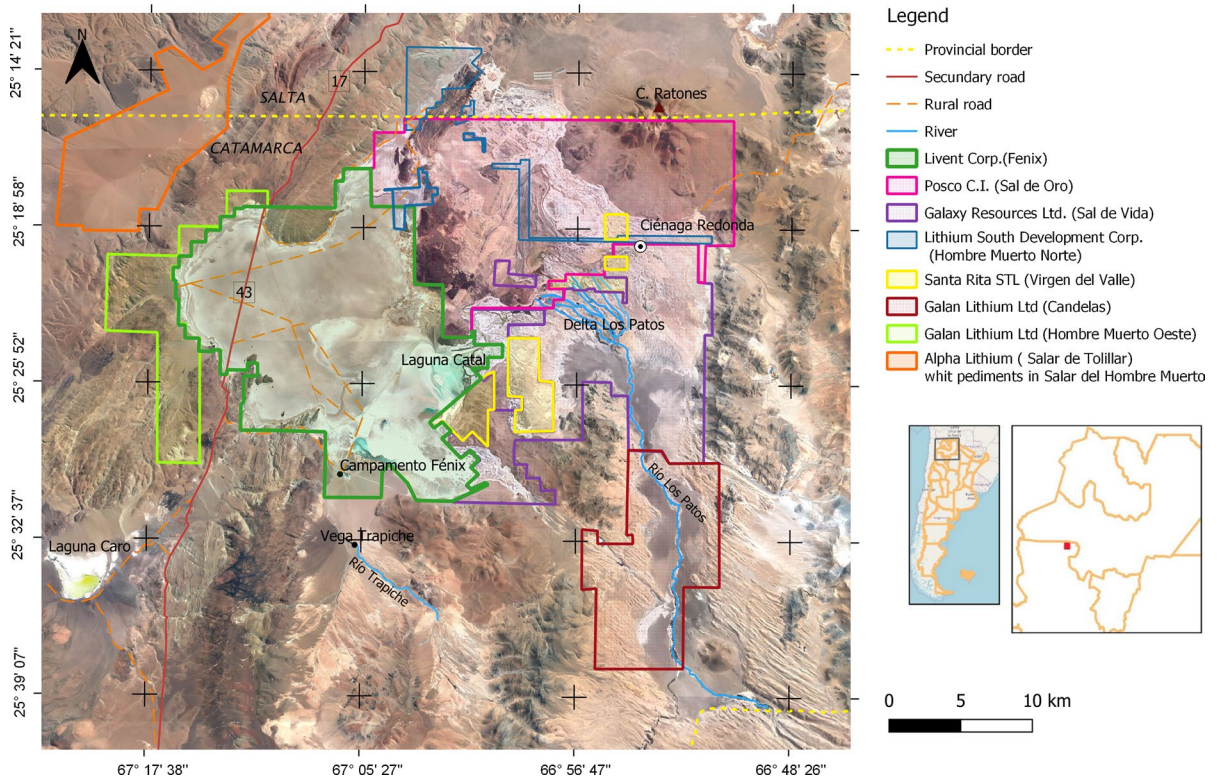


Fig. 4 Map of active mining project in Salar del Hombre Muerto, Argentina as of 17 July 2021

though Antofagasta de la Sierra is 80 km from the lithium mining projects in Salar del Hombre Muerto. The results from our survey of perceptions of mining related to water and environment of community members from January—February 2018 (Table 3) showed that mining is considered an employment opportunity, with negative connotations (35%) or uncertainty regarding the risks of contamination, damage to water and the environment, and competition with livestock raising. The value of water and environment as necessary for life surfaced, as did the need for guidelines for protecting the environment (44%) and demands to the government for information and control of mining companies. In the responses related to mining these were exclusively of mining for metals with no concepts related to extracting brine or mining of salt, a striking result considering the long-term presence of lithium mining in the Salar del Hombre Muerto, and the more recent increase in lithium mining activity. The results of our survey indicate that in the early years of the lithium expansion, there was little outreach from mining companies to communities, and

little interaction between the government and communities in terms of participation in natural resource decision-making. Based on the results of the survey and workshops in Antofagasta de la Sierra, we implemented a training program to build local capacity in environmental monitoring whereby a group of community members in Antofagasta de la Sierra and Salar del Hombre Muerto can now recognize, record, and report changes in the environment, and can navigate the system for requesting information and filing complaints (Marconi and Clark 2020). Community organizing capacity of the community group Asamblea Fiambalá Despierta was also strengthened and they currently are advocating through official channels for the exclusion of industrial scale mining in the southern subsite of the SRLAPCat.

Starting at the exploration stage, the legal framework establishes that projects must be submitted with a detailed description of the activities to be carried out and reports on the environmental impacts of these activities (Ley 24585/1995). In accordance with the provisions of the General

Table 3 Results from surveys conducted in Andean communities

Prompts	Concepts related to dominant reactions. Number in parenthesis is total responses			
	Negative	Positive	Neutral	Ambivalent
Mining	(22) Contamination Destruction No controls	(19) Economic benefit Necessary for development Employment royalties Valuable metals: gold, silver, copper	(15) Conditional approval Missing information Need control Must be responsible Requires environmental protection Be sustainable	(6) Tension between employment and damage to environment Competition with livestock grazing
Water	(20) Fear of water shortage Contamination of water	(20) Value of water Necessary for life	(19) Uncertainty Lack of knowledge Need for care and control Wise use	(0)
Environment	(23) Damage or threat Contamination Risk for future generations	(9) Value of environment Necessary for life future generations Development	(28) Needs protection, management, and conservation	(0)

Environmental Law (Ley 25675/2002) and the free access to public environmental information (Ley 25,831/2003), these documents must be available for public consultation by people who may be affected by the projects. A second opportunity for public participation guaranteed by law (Código de Minería Ley 24585/1995) implies consultation procedures or public hearings convened by the enforcement authority as mandatory instances for the authorization of those activities that may generate negative and significant effects on the environment. If the convening authorities decide contrary to the hearing regarding the project, they must make it public and substantiate it. Of the 18 projects in the exploration or exploitation stage, none have developed a public consultation meeting according to the stated standards. One modality of interaction with local communities is through informative talks given by the mining companies. We detected nine projects that developed informative talks in nearby towns. In the rest of the projects, there is no record in the IIAs or in the official communications of the companies of any interaction with the communities in which information on the project is provided or made explicit. Regarding the availability of public documents, projects and IIAs, we recorded four projects that do not have their files available for public

consultation in the corresponding offices closest to the site.

Conclusions

The development of “green” energy alternatives currently relies on globally accessible sources of lithium to power rechargeable batteries which requires materials to be sourced from previously unexploited mineral reserves. This will displace certain impacts associated with previous mineral development practices into new areas and new communities. In addition, zero emissions at point of use will not significantly reduce risks to climate change if the electricity being used to charge electric batteries is generated using fossil fuels. While the transition to “green” energy sources holds the promise of mitigating the inefficiencies and negative impacts of traditional energy sources responsible for climate change, a truly sustainable energy sector would consider the full life cycle of the battery (“cradle-to-grave”), the social and environmental impacts of mining, and the feedback processes across the coupled human and natural systems, from raw material mining through production, use, recycling, and disposal. The sourcing of much of the world’s lithium in the high Andean wetlands of South America will provide a test as to

how sustainable this “green” technology can be. The Life Cycle Assessment (LCA) of a product is a process to assess the environmental burden, identifying and describing the use of energy, characterizing their sources and raw materials used, as well as the release of waste to the environment. Regarding lithium-ion batteries, there are already studies that systematize LCA inventories, or analyses of “cradle-to-grave” impacts (Ager-Wick Ellingsen et al. 2016; Richa 2016; Tagliaferri et al. 2016). However, these LCA analyses do not incorporate the consumptive use of brine water used in the evaporation process and fresh water for lithium processing. The omission of this resource in the analysis questions the sustainability of the production of lithium batteries. While lithium extraction may be promoted as good for the environment and for certain economies, we are already aware that there have been negative impacts, both environmental and social, associated with the development of this sector in the region (Liu et al. 2019; Marchegiani et al. 2018, 2020).

In the high Andean waterscapes, the water balance, even without human intervention, is negative and their unique biodiversity and lifeways are now confronted with an unprecedented level of extractive activity and development. Understanding of the water balance, including an assessment of the relative ages and sources of the recharge waters and recharge rates is necessary to make predictions about potential impacts of brine extraction. In addition, connectivity among basins through groundwater and surface flows and how fresh water sustains the fragile marginal wetland ecosystems is critical to defining direct and indirect impact zones. The Andean plateau’s iconic flamingos are an ideal flagship for wetland conservation because of the landscape scale at which they use wetland resources, and Network of Wetlands for Flamingo Conservation, which implies the sustainable use of these wetlands, can be invoked to determine priority sites for conservation action.

The conservation of wetlands within the lithium triangle, which coincides with 64% of the priority sites of the Network of Wetlands for Flamingo Conservation, requires an approach at different scales and considering a diversity of stakeholders. At the local level (provinces, departments, or regions), the IIA process should be strengthened by incorporating the consultation of independent experts. Authorities in the relevant specialties with the capacity to generate

modifications, conditions, or the eventual refusal of the project evaluated should be involved in the process, regardless of the agency leading the process. The IIA process must be improved through the production of independent, rigorous, scientific information that is publicly available and that strengthens the IIA. All information should be widely disseminated among stakeholders and affected communities to achieve public participation and free and informed consent, especially with indigenous communities. Instances of public participation should be genuine and culturally sensitive and relevant, recognizing community stewardship of the places that define their wellbeing. The IIA should take a systems approach, considering an integral view of the wetland basin, adapt the definition of the area of influence of the project to the spatial and temporal hydrological and ecological dynamics, and consider cumulative and synergistic impacts of more than one project operating in the same basin or interconnected basins. Adequate guidelines should be provided to address these specific issues.

At the national government level, progress should be made in the approval of standards that provide minimum guidelines for land use zoning that incorporate existing protected areas and environmental legislation, and minimum requirements for an IIA considering the Strategic Environmental Assessment (SEA) and Cumulative Impact Assessment (CIA) processes. The global community (citizens and consumers) should be informed about the value and sensitivity of these unique wetlands in the provision of local and global goods and services and connect this knowledge with the promotion of responsible and informed consumption (FARN, Fundación YUCHAN & Wetlands International 2021).

To ensure the true sustainable use of these wetlands, it will be necessary to support research to determine the hydrogeological dynamics of all basins of the Andean plateau, to reduce the high cost of water in mining processes, establish zoning based on scientific information to protect the most valuable and vulnerable wetlands, and ensure participation of communities; all while strengthening international, national, and local regulation in all stages of the production of lithium batteries. Without an integrated approach to the social-ecological system centered on the high Andean wetlands that considers the long term sustainability of processes that define

the hydrogeology, ecology, and livelihoods dependent on these wetlands, the so called lithium triangle runs the risk of becoming an environmental sacrifice zone (Lerner 2010) where rural communities with little access to resources are exposed to environmental injustices in conflicts defined by deep power differences and human rights violations, where the loss and degradation of the environment implies the displacement of communities and the erosion of their wellbeing.

Acknowledgements We thank the members of the Grupo de Conservación Flamencos Altoandinos (GCFA) for providing a regional framework for this work. We are grateful to the communities of Antofagasta de la Sierra, El Peñón, and Fiambalá for their trust and permanent support for our field work in Catamarca. Fundación Humedales/Wetlands International incorporated the altiplano of Catamarca and mining issues to its Saving High Andean Wetlands for People and Nature Program, facilitating the continuity of our work. We thank María Yapura for GIS and mapping support and Ricardo Clark for compiling the information on Table 1.

Author contributions PM, FA, AC conceived of the work, conducted the research and analysis, and prepared the manuscript.

Funding P. Marconi and A. Clark were funded by Fundación YUCHAN, Argentina; F. Arengo was funded by the American Museum of Natural History, USA. Funding for field work related to the project was provided by the Disney Conservation Fund, International Flamingo Foundation, and Fundación Humedales Argentina/Wetlands International.

Data availability All sources are available; most are peer reviewed.

Code availability N/A.

Declarations

Conflict of interest The authors declare no conflicts of interest or competing interests.

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References

- Abric JC (2001) *Prácticas sociales y representaciones*. Ediciones Coyoacán, Mexico
- Aceituno P (1996) Elementos del clima en el Altiplano Sudamericano. *Revista Geofísica-IPGH* 44:37–55. http://dof.uchile.cl/rene/PUBS/OTHERS/Aceituno_96.pdf. Accessed 30 Mar 2022
- Acuerdo Regional sobre el Acceso a la Información, la Participación Pública y el Acceso a la Justicia en Asuntos Ambientales en América Latina y el Caribe (Acuerdo de Escazú) Ley N°27.566. <https://observatoriop10.cepal.org/es/instrumentos/ley-que-aprueba-acuerdo-escazu-ley-no-27566>
- Saona Acuña LA, Soria MN, Villafañe PG, Stepanenko T, Farías ME (2020) Arsenic and its biological role: from early earth to current Andean microbial ecosystems. In: Farías ME (ed) *Microbial ecosystems in central Andes extreme environments*. Springer, Cham, pp 275–284. https://doi.org/10.1007/978-3-030-36192-1_19
- Albarracín VH, Kurth D, Ordoñez OF, Belfiore C, Luccini E, Salum GM, Piacentini RD, Farías ME (2015) High up: a remote reservoir of microbial extremophiles in central Andean wetlands. *Front Microbiol* 6:1404. <https://doi.org/10.3389/fmicb.2015.01404>
- Ager-Wick Ellingsen L, Singh B, Strømman AH (2016) The size and range effect: lifecycle greenhouse gas emissions of electric vehicles. *Environ Res Lett* 11(5):054010
- Amaya NE, Blanco DE, Chamorro Cuestas AF, Gonnet JM, Hegoburu C, Sosa HJ (2019) *Conservación y manejo de vegas altoandinas en Argentina y Perú. Dos estudios de caso*. Fundación Humedales/Wetlands International. Buenos Aires, Argentina
- Amilhat-Szary AL and Guyot S (2009). El turismo transfronterizo en los Andes centrales: prolegómenos sobre una geopolítica/Cross-border tourism in the Central Andes: preliminary remarks on tourism geopolitics. *Si Somos Americanos. Revista de Estudios Transfronterizos* 9(2):63–100
- Argento M, Puente F. (2019). Entre el boom del litio y la defensa de la vida. Salares, agua, territorios y comunidades en la región atacameña. In: Fornillo B. (ed) *Litio en Sudamérica. Geopolítica, energía y territorios*. CLACSO, Buenos Aires, pp 173–220. <https://www.jstor.org/stable/j.ctvtwx25t.9>
- Alam MA, Sepúlveda R (2022) Environmental degradation through mining for energy resources: the case of the shrinking Laguna Santa Rosa wetland in the Atacama region of Chile. *Energy Geosci*. <https://doi.org/10.1016/j.engeos.2021.11.006>
- Barrionuevo JS, Abdala CS (2018) Herpetofauna de la Puna argentina: una síntesis. In: Grau HR, Babot MJ, Izquierdo A, Grau A (eds) *Serie de Conservación de la Naturaleza 24: La Puna argentina: naturaleza y cultura*. Fundación Miguel Lillo, Tucumán, pp 209–228. <http://www.lillo.org.ar/index.php/publicaciones/serie-conservacion-de-la-naturaleza/v24>
- Bennett M, New M, Marino J, Sillero-Zubiri C (2016) Climate complexity in the Central Andes: a study case on

- empirically-based local variations in the dry Puna. *J Arid Environ* 128:40–49. <https://doi.org/10.1016/j.jaridenv.2016.01.004>
- Bloomberg NEF (2021) Electric Vehicle Outlook. Executive Summary. <https://about.bnef.com/electric-vehicle-outlook/>.
- Boutt DF, Hynek SA, Munk LA, Corenthal LG (2016) Rapid recharge of fresh water to the halite-hosted brine aquifer of Salar de Atacama, Chile. *Hydrol Processes* 30(25):4720–4740. <https://doi.org/10.1002/hyp.10994>
- Boutt DF, Corenthal LG, Moran BJ, Munk LA, Hynek SA (2021) Imbalance in the modern hydrologic budget of topographic catchments along the western slope of the Andes (21–25° S): implications for groundwater recharge assessment. *Hydrogeol J* 29(3):985–1007. <https://doi.org/10.31223/osf.io/p5tsq>
- Boyle TP, Caziani SM, Waltermire RG (2004) Landsat TM inventory and assessment of waterbird habitat in the southern altiplano of South America. *Wetl Ecol Manag* 12(6):563–573. <https://doi.org/10.1007/s11273-005-1761-2>
- Cabrol NA, Grin EA, Chong G, Minkley E, Hock AN, Yu Y, Bebout L, Fleming E, Häder DP, Demergasso C, Gibson J (2009) The high-lakes project. *J Geophys Res: Biogeosci.* <https://doi.org/10.1029/2008JG000818>
- Castellino M, Lesterhuis A. (2020). Censo simultáneo de falarpos 2020-Resumen y resultados. Manomet-WHSRN
- Caziani SM, Derlindati EJ, Tálamo A, Sureda AL, Trucco CE, Nicolossi G (2001) Waterbird richness in altiplano wetlands of northwestern Argentina. *Waterbirds* 24:103–117. <https://doi.org/10.2307/1522249>
- Caziani SM, Rocha Olivio O, Rodríguez Ramírez E, Romano M, Derlindati EJ, Talamo A, Ricalde D, Quiroga C, Contreras JP, Valqui M, Sosa H (2007) Seasonal distribution, abundance, and nesting of Puna, Andean, and Chilean flamingos. *The Condor* 109(2):276–287. <https://doi.org/10.1093/condor/109.2.276>
- CIMA (2021) https://informacionminera.produccion.gob.ar/sifim_proyectos_mineros_tabla.html. Accessed 28 Mar 2022
- Código de Minería Ley 1919 (1887) <https://www.argentina.gob.ar/normativa/nacional/ley-1919-43797/actualizacion>. Accessed 28 Mar 2022.
- Código de Minería Ley 24585 (1995) Modificación – Medio Ambiente <https://www.argentina.gob.ar/normativa/nacional/ley-24585-30096>.
- Código de Procedimientos Mineros Catamarca Ley 5682 (2020) <http://www.saij.gob.ar/5682-local-catamarca-codigo-procedimientos-mineros-provincia-catamarca-lpk0005682-2020-12-10/123456789-0abc-defg-286-5000kvorpyel?&o=1530&f=Total%7CFecha%7CEstado%20de%20Vigencia%7CTema%5B%2C1%5D%7COrgano%5B%2C1%5D%7CAutor%5B%2C1%5D%7CJurisdicci%F3n%7CTribunal%5B%2C1%5D%7CPublicaci%F3n%5B%2C1%5D%7CColecci%F3n%20tem%Etica%5B%2C1%5D%7CTipo%20de%20Document&t=1072261>. Accessed 28 Mar 2022.
- COFEMIN (2019) Protocolo de Buenas Prácticas para la Exploración y Producción de Litio en Salares en Jujuy, Salta y Catamarca, concordado entre las Provincias de Jujuy, Salta y Catamarca y Secretaría de Política Minera del Ministerio de Producción de la Nación
- CONAF (2008) Actualización plan de manejo participativo Reserva Nacional Los Flamencos. Región de Antofagasta, Chile. <http://bosques.ciren.cl/handle/123456789/6753..> Accessed 28 Mar 2022.
- CONAF-Convencion de Ramsar (2015) Plan de acción para la conservación y uso sustentable de humedales altoandinos. https://www.conaf.cl/wp-content/files_mf/1369258304PACHA.pdf. Accessed 28 Mar 2022
- CONHIDRO Consultora Ambiental (2002) Estudio de Impacto Ambiental y Social del Proyecto Fénix, Salar del Hombre Muerto, Provincia de Catamarca. 59 pp
- Cordier C (1965) Op zoek naar flamingo's in de Andes. *Zoo Antwerp* 30:83–88
- Corenthal LG, Boutt DF, Hynek SA, Munk LA (2016) Regional groundwater flow and accumulation of a massive evaporite deposit at the margin of the Chilean Altiplano. *Geophys Res Lett* 43(15):8017–8025. <https://doi.org/10.1002/2016GL070076>
- Cruz NN, Barisón C, Romano M, Arengo F, Derlindati EJ, Barberis I (2013) A new record of James's Flamingo (*Phoenicoparrus jamesi*) from Laguna Melincué, a lowland wetland in east-central Argentina. *Wilson J Ornithol* 125(1):217–221. <https://doi.org/10.1676/12-111.1>
- Cuyckens GA, Perovic PG, Cristobal L (2015) How are wetlands and biological interactions related to carnivore distributions at high altitude. *J Arid Environ* 115:14–18. <https://doi.org/10.1016/j.jaridenv.2014.12.009>
- Dangles O, Rabatel A, Kraemer M, Zeballos G, Soruco A, Jacobsen D, Anthelme F (2017) Ecosystem sentinels for climate change? Evidence of wetland cover changes over the last 30 years in the tropical Andes. *PLoS ONE* 12(5):e0175814
- de la Fuente A, Meruane C, Suárez F (2021) Long-term spatiotemporal variability in high Andean wetlands in northern Chile. *Sci Total Environ* 756:143830. <https://doi.org/10.1016/j.scitotenv.2020.143830>
- Decreto Ley 2577 (1973) Ley de Aguas de la Provincia <https://www.argentina.gob.ar/sites/default/files/agua-catamarca.pdf>. Accessed 28 Mar 2022
- Decreto Nacional 349 (2016) Derechos de exportación - Aliquotas. <https://www.argentina.gob.ar/normativa/nacional/decreto-349-2016-258595>. Accessed 28 Mar 2022
- Decreto Provincial 770 (2020) Autorización de extracción de agua del río Los Patos para proyecto Sal de Vida (Galaxy Lithium S.A.)
- Decreto Provincial OP 847 (2019) Autorización de extracción de agua del río Los Patos para proyecto Fénix (Minera del Altiplano S.A.)
- Dias RA, Cardozo JB (2014) First record of the Puna Flamingo *Phoenicoparrus jamesi* (Sclater 1886)(Aves: Phoenicopteridae) for the Atlantic coast of South America. *Check List* 10(5):1150–1151. <https://doi.org/10.15560/10.5.1150>
- Diaz HF, Grosjean M, Graumlich L (2003) Climate variability and change in high elevation regions: past, present and future. *Clim Change* 59(1):1–4. <https://doi.org/10.1023/A:1024416227887>
- Diaz Paz WF, Escosteguy ML, Clavijo A., Seghezzo L, Iribarnegaray M (2021) Transición energética y producción

- de litio: principales debates y desafíos para la gestión del agua en Argentina. In: Brannstrom C, Seghezze L, Gorayeb A (eds) *Metodologías e Abordagens para a Descarbonização Justa na América do Sul*. Universidade Federal do Ceará. In press
- Donadio E (2009) Ecologists and large-scale mining operations, thoughts about why and how become involved in the mining-environmental conflict. *Ecol Austral* 19(03):247–254
- Drumm A (2004) Evaluation of the pilot fee system at Eduardo Avaroa reserve and recommendations for the Bolivian protected area system. The Nature Conservancy, Arlington, VA
- EC & Asociados (2018) Proyecto Fénix. Estudio de Impacto Ambiental y Social Aprovechamiento de Agua Subterránea y Conducción a Planta Fénix. Acueducto Los Patos. 584 pp.
- Farias ME (2018) Ecosistemas microbianos de la Puna: El inmenso valor de lo diminuto. In: Grau HR, Babot MJ, Izquierdo A, Grau A (eds) *Serie de Conservación de la Naturaleza 24: La Puna argentina: naturaleza y cultura*. Fundación Miguel Lillo, Tucumán, pp 96–111. <http://www.lillo.org.ar/index.php/publicaciones/serie-conse rvacion-de-la-naturaleza/v24>
- Farias ME, Rasuk MC, Gallagher KL, Contreras M, Kurth D, Fernandez AB, Poiré D, Novoa F, Visscher PT (2017) Prokaryotic diversity and biogeochemical characteristics of benthic microbial ecosystems at La Brava, a hypersaline lake at Salar de Atacama Chile. *PLoS ONE* 12(11):e0186867. <https://doi.org/10.1371/journal.pone.0186867>
- Frau D, Moran BJ, Arango F, Marconi P, Battauz Y, Mora C, Manzo R, Mayora G, Boutt DF (2021) Hydroclimatological patterns and limnological characteristics of unique wetland systems on the Argentine high Andean plateau. *Hydrology* 8(4):164. <https://doi.org/10.3390/hydrology8040164>
- FARN, Fundación YUCHAN & Wetlands International (2021) Conservación de humedales altoandinos y una minería de litio ajustada a estándares sociales y ambientales. Programa Conservando los humedales altoandinos para la gente y la naturaleza.
- Federal Register (2010) 50 CFR Part 17. Endangered and threatened wildlife and plants; listing three foreign bird species from latin America and the Caribbean as endangered throughout their range; final rule. <https://www.federalregister.gov/documents/2010/08/17/2010-19965/endangered-and-threatened-wildlife-and-plants-listing-three-foreign-bird-species-from-latin-america>. Accessed 28 Mar 2022
- Galaz-Mandakovic Fernandez D (2014) Uyuni, capital turística de Bolivia Aproximaciones antropológicas a un fenómeno visual posmoderno desbordante. *Teoría y Praxis* 16:147–173. <https://www.redalyc.org/pdf/4561/456145102007.pdf>. Accessed 29 Mar 2022
- Fernandez J, Markgraf V, Panarello HO, Alberio M, Angiolini FE, Valencio S, Arriaga M (1991) Late Pleistocene/Early Holocene environments and climates, fauna, and human occupation in the Argentine Altiplano. *Geochronology* 6:251–272
- Fernández-Vítora VC, Ripoll VC, Ripoll LAC, Garro VR (1997) *Guía metodológica para la evaluación del impacto ambiental* (No. PA 333.72 C66.). Mundi-prensa, Madrid.
- Fjeldså J, Krabbe NK (1990) *Birds of the High Andes*. Museum Tusulanum Press, Copenhagen
- FMC-Minera del Altiplano S.A. (2000) Diagnóstico y monitoreo ambiental en el Río Trapiche (Catamarca). FMC—Minera del Altiplano S.A. Catamarca
- Frau D, Battauz Y, Mayora G, Marconi P (2015) Controlling factors in planktonic communities over a salinity gradient in high-altitude lakes. *Annales De Limnol-Int J Limnol* 51(3):261–272. <https://doi.org/10.1051/limn/2015020>
- Flexer V, Baspineiro CF, Galli CI (2018) Lithium recovery from brines: a vital raw material for green energies with a potential environmental impact in its mining and processing. *Sci Total Environ* 639:1188–1204. <https://doi.org/10.1016/j.scitotenv.2018.05.223>
- Gajardo G, Redón S (2019) Andean hypersaline lakes in the Atacama Desert, northern Chile: between lithium exploitation and unique biodiversity conservation. *Conserv Sci Pract* 1(9):e94. <https://doi.org/10.1111/csp2.94>
- Gandarillas V, Jiang Y, Irvine K (2016) Assessing the services of high mountain wetlands in tropical Andes: a case study of Caripe wetlands at Bolivian Altiplano. *Ecosyst Serv* 19:51–64. <https://doi.org/10.1016/j.ecoser.2016.04.006>
- García SP, Rolandi D, Olivera D (2000) Puna e historia: Antofagasta de la Sierra, Catamarca. Asociación Amigos del Instituto Nacional de Antropología, Buenos Aires
- Garreaud R, Aceituno P (2001) Interannual rainfall variability over the South American Altiplano. *J Clim* 14(12):2779–2789. [https://doi.org/10.1175/1520-0442\(2001\)014%3c2779:IRVOTS%3e2.0.CO;2](https://doi.org/10.1175/1520-0442(2001)014%3c2779:IRVOTS%3e2.0.CO;2)
- Garreaud R, Vuille M, Clement AC (2003) The climate of the Altiplano: observed current conditions and mechanisms of past changes. *Palaeogeogr Palaeoclimatol Palaeoecol* 194(1–3):5–22. [https://doi.org/10.1016/S0031-0182\(03\)00269-4](https://doi.org/10.1016/S0031-0182(03)00269-4)
- Genovese A (2020) Línea de base normativa ambiental-minera in primer informe semestral saving high Andean wetlands for people and nature project. Unpublished report, Wetlands International, pp 7
- Gleeson T, Wada Y, Bierkens MFP, van Beek LPH (2012) Water balance of global aquifers revealed by groundwater footprint. *Nature* 488:197–200. <https://doi.org/10.1038/nature11295>
- Gluzman G (2007) Minería y metalurgia en la antigua gobernación del Tucumán (siglos XVI-XVII): Colonial Tucumán 16th and 17th Centuries. *Mem Am* 15:157–184
- Hernández FM (2016). Paisaje desértico, autenticidad y aislamiento como teatralidad turística. El caso de la Puna jujeña (Argentina). *Revista de Análisis Turístico*, no 22, 2o semestre 2016, pp. 56–74
- Herzog SK, Terrill RS, Jahn AE, Remsen JV Jr, Maillard ZO, García-Solíz VH, MacLeod R, McCormick A, Vidoz JQ (2016) *Birds of Bolivia*. Bolivia, Asociación Armonía, p 491
- Hurlbert SH (1978) Andean lakes and flamingo investigations. Technical report 1. Department of Biology, San Diego State University, San Diego

- Hurlbert SH (1981) Andean lakes and flamingo investigations. Technical report 2. Department of Biology, San Diego State University, San Diego
- Ibarguchi G (2014) From Southern Cone arid lands, across Atacama, to the Altiplano: biodiversity and conservation at the ends of the world. *Biodiversity* 15(4):255–264. <https://doi.org/10.1080/14888386.2014.973446>
- IFC (2013) Good Practice Handbook Cumulative Impact Assessment, p 102 https://www.ifc.org/wps/wcm/connect/58fb524c-3f82-462b-918f-0ca1af135334/IFC_GoodPracticeHandbook_CumulativeImpactAssessment.pdf?MOD=AJPERES&CVID=kbnYgI5
- Iturbide M, Gutiérrez JM, Alves LM, Bedia J, Cerezo-Mota R, Cimadevilla E, Cofiño AS, Di Luca A, Faria SH, Gorodetskaya IV, Hauser M (2020) An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets. *Earth System Science Data* 12(4):2959–70. <https://doi.org/10.5194/essd-12-2959-2020>
- Izquierdo AE, Aragón R, Navarro CJ, Casagrande E (2018) Humedales de la Puna: principales proveedores de servicios ecosistémicos de la región. In: Grau HR, Babot MJ, Izquierdo A, Grau A (eds) Serie de Conservación de la Naturaleza 24: La Puna argentina: naturaleza y cultura. Fundación Miguel Lillo, Tucumán, pp 96–111 <http://www.lillo.org.ar/index.php/publicaciones/serie-conse rvacion-de-la-naturaleza/v24>
- Jacobsen D, Dangles O (2017) Ecology of high altitude waters. Oxford University Press, Oxford
- Johnson AW (1967) The birds of Chile v. II. Platt Establecimientos Graficos, Buenos Aires
- Jaramillo A (2003) Birds of Chile. Princeton University Press, New Jersey, p 240
- Jerez B, Garcés I, Torres R (2021) Lithium extractivism and water injustices in the Salar de Atacama, Chile: The colonial shadow of green electromobility. *Political Geography*. 87:102382. <https://doi.org/10.1016/j.polgeo.2021.102382>
- Kahl MP (1975) Distribution and numbers: a summary. In: Kear J, Duplaix-Hall N (eds) Flamingos. T&AD Poyser, Berkhamsted, pp 93–102
- Kaunda RB (2020) Potential environmental impacts of lithium mining. *J Energy Natural Resour Law* 38(3):237–244. <https://doi.org/10.1080/02646811.2020.1754596>
- La Sorte FA, Jetz W (2010) Projected range contractions of montane biodiversity under global warming. *Proc R Soc b Biol Sci* 277(1699):3401–3410. <https://doi.org/10.1098/rspb.2010.0612>
- Lavilla EO, Barrionuevo JS (2005) El género *Telmatobius* en la República Argentina: una síntesis. *Monografías De Herpetología* 7:115–165
- León M, Muñoz C (2019) Guía para la elaboración de estudios de caso sobre la gobernanza de los recursos naturales. Serie Recursos Naturales y Desarrollo 192 (LC/TS.2019/52). Comisión Económica para América Latina y el Caribe (CEPAL), Santiago.
- León M, Muñoz C, Sánchez J (eds) (2020) La gobernanza del litio y el cobre en los países andinos. Documentos de Proyectos (LC/TS.2020/124), Comisión Económica para América Latina y el Caribe (CEPAL), Santiago, 169 pp. <https://www.cepal.org/fr/node/52897>. Accessed 29 Mar 2022
- Ley 25675 (2002) Ley General del Ambiente <https://www.argentina.gob.ar/normativa/nacional/ley-25675-79980/texto>. Accessed 29 Mar 2022
- Ley 25831 (2003) Regimen de Libre Acceso a la Información Pública Ambiental <http://servicios.infoleg.gob.ar/infolegInternet/anexos/90000-94999/91548/norma.htm>. Accessed 29 Mar 2022
- Lerner S (2010) Sacrifice zones: the front lines of toxic chemical exposure in the United States. MIT Press, Cambridge
- Liu W, Agusdinata DB, Myint SW (2019) Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile. *Int J Appl Earth Obs Geoinf* 80:145–156. <https://doi.org/10.1016/j.jag.2019.04.016>
- Liu Y, Wagener T, Beck HE, Hartmann A (2020) What is the hydrologically effective area of a catchment? *Environ Res Lett* 15(10):104024. <https://doi.org/10.1088/1748-9326/aba7e5>
- Locascio de Mitrovic C, Villagra de Gamundi A, Juárez J, Ceruolo M (2005) Características limnológicas y zooplankton de cinco lagunas de la Puna—Argentina. *Ecología En Bolivia* 40:10–24
- Marchegiani P (2018) La imprescindible mirada ambiental en la toma de decisiones sobre el litio. In: Di Pangrasio A, Napoli A, Nordenstahl S (eds) Informe Ambiental 2018. Fundación Ambiente y Recursos Naturales, Buenos Aires, pp 269–293 https://farn.org.ar/wp-content/uploads/2020/06/2018_IAF.pdf. Accessed 28 Mar 2022
- Marchegiani P, Morgera E, Parks L (2020) Indigenous peoples' rights to natural resources in Argentina: the challenges of impact assessment, consent and fair and equitable benefit-sharing in cases of lithium mining. *Int J Hum Rights* 24(2–3):224–240. <https://doi.org/10.1080/13642987.2019.1677617>
- Marconi P (2007) Proyecto Red de Humedales Altoandinos y Ecosistemas Asociados, basada en la distribución de las dos especies de Flamencos Altoandinos. In: Castro Lucic M, Fernández Reyes L (eds) Gestión Sostenible de Humedales. Universidad de Chile, Santiago, pp 211–226
- Marconi P (2010) Manual de Monitoreo de Condiciones Ecológicas para el Manejo Integrado de la Red de Humedales de Importancia para la Conservación de Flamencos Altoandinos. Fundación Yuchan, Salta, Argentina. pp 79
- Marconi P, Clark R (2011) First confirmed nesting record of Andean Flamingo *Phoenicoparrus andinus* in Catamarca, Argentina, and remarks on its breeding ecology. *Cotinga* 33:150–151
- Marconi P, Clark A (2020) Primer informe semestral saving high Andean wetlands for people and nature project. Unpublished report, Wetlands International, pp 7
- Marconi P, Sureda AL (2008) High Andean Flamingo Wetland Network: evaluation of degree of implementation of priority sites-preliminary results. *Flamingo* 18:48–53
- Marconi P, Sureda AL, Arengo F, Aguilar MS, Amado N, Alza L, Rocha O, Torres R, Moschione F, Romano M, Sosa H (2011) Fourth simultaneous flamingo census in South America: preliminary results. *Flamingo* 18:48–53

- Marconi P, Clark A, Trucco C, Costilla M, Montañez F, Clark R, Frau D, Battauz Y, Mosqueira M (2013) Conservación de chorlos y playeros migratorios en los Humedales Altoandinos de Catamarca. Final Report. BirdLife International, Cambridge
- Marconi P, Arengo F, Castro A, Rocha O, Valqui M, Aguilar S, Barberis I, Castellino M, Castro L, Derlindati E, Michelutti M, Michelutti P, Moschione F, Musmeci L, Ortiz E, Romano M, Sosa H, Sepúlveda D, Sureda AL (2020) Sixth international simultaneous census of three flamingo species in the Southern Cone of South America: preliminary analysis. *Flamingo* e3:67–75. <http://www.flamingo-sg.org/flamingo-2020/>
- Millennium Ecosystem Assessment (2005) Volume I: current state & trends assessment. Island Press, Washington
- Minerals Council of Australia (2015). Cumulative Environmental Impact Assessment Industry Guide. P 52 http://www.minerals.org.au/sites/default/files/Cumulative_Environmental_Impact_Assessment_Industry_Guide_FINAL_0.pdf
- Montero M (2012) Hacer para transformar: el método en la psicología comunitaria. Paidós, Buenos Aires.
- Morales MS, Duncan AC, Neukom R, Rojas JF, Villalba R. (2018) Variabilidad hidroclimática en el sur del Altiplano: pasado, presente y futuro. In: Grau HR, Babot MJ, Izquierdo A, Grau A (eds) Serie de Conservación de la Naturaleza 24: La Puna argentina: naturaleza y cultura. Fundación Miguel Lillo, Tucumán, pp 75–91 <http://www.lillo.org.ar/index.php/publicaciones/serie-conse rvacion-de-la-naturaleza/v24>
- Moran BJ, Boutt DF, Munk LA (2019a) Stable and radioisotope systematics reveal fossil water as fundamental characteristic of arid orogenic-scale groundwater systems. *Water Resour Res* 55(12):11295–11315. <https://doi.org/10.1029/2019WR026386>
- Moran BJ, Boutt DF, Munk LA, Marconi P, Fisher JD, Arengo F, Frau D (2019b) Revealing paleo-groundwater and interbasin flow as fundamental to water and mineral resource sustainability on the arid Altiplano-Puna plateau. AGU Fall Meet Abstr 2019:H11N-1711
- Morteani G, Möller P, Dulski P, Preinfalk C (2014) Major, trace element and stable isotope composition of water and muds precipitated from the hot springs of Bolivia: are the waters of the spring's potential ore forming fluids. *Geochemistry* 74(1):49–62. <https://doi.org/10.1016/j.chemer.2013.06.002>
- Obaya M (2019) Estudio de caso sobre la gobernanza del litio en el Estado Plurinacional de Bolivia. Documentos de Proyectos (LC/TS.2019/49). Comisión Económica para América Latina y el Caribe (CEPAL), Santiago
- Olivera DE (1992) Tecnología y estrategias de adaptación en el formativo (Agro-Alfarero Temprano) de la Puna Meridional Argentina. Un caso de estudio: Antofagasta de la Sierra (Pcia. de Catamarca, R.A.). Dissertation, Universidad Nacional de La Plata, La Plata
- Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GV, Underwood EC, D'amico JA, Itoua I, Strand HE, Morrison JC, Loucks CJ (2001) Terrestrial ecoregions of the world: a new map of life on earth. A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *Bioscience* 51(11):933–938
- Otárola RM (2019) El turismo como banalización del paisaje indígena en San Pedro de Atacama-Chile. *Revista Antropologías Del Sur* 6(12):261–281
- Pabón-Caicedo JD, Arias PA, Carril AF, Espinoza JC, Borrel LF, Goubanova K, Lavado-Casimiro W, Masiokas M, Solman S, Villalba R (2020) Observed and projected hydroclimate changes in the Andes. *Front Earth Sci* 17(8):61. <https://doi.org/10.3389/feart.2020.00061>
- Parada M (1990) Flamencos en el norte de Chile: distribución, abundancia y fluctuaciones estacionales. In: Parada M, Rottmann J, Guerra C (eds) I taller internacional de especialistas en flamencos sudamericanos. Corporación Nacional Forestal – New York Zoological Society, San Pedro de Atacama, pp 54–66
- Pastenes L, Valdivieso C, Di Genova A, Travisany D, Hart A, Montecino M, Orellana A, Gonzalez M, Gutiérrez RA, Allende ML, Maass A (2017) Global gene expression analysis provides insight into local adaptation to geothermal streams in tadpoles of the Andean toad *Rhinella spinulosa*. *Sci Rep* 7(1):1966. <https://doi.org/10.1038/s41598-017-01982-z>
- Péfaur JE, Duellman WE (1980) Community structure in high Andean herpetofaunas. *Trans Kans Acad Sci* 1903:45–65. <https://doi.org/10.2307/3627715>
- Pearman M, Areta JJ (2020) Birds of Argentina and South-west Atlantic. Bloomsbury Publishing, Helm Field Guides, p 479
- Placzek CJ, Quade J, Patchett PJ (2013) A 130 ka reconstruction of rainfall on the Bolivian Altiplano. *Earth Planet Sci Lett* 363:97–108. <https://doi.org/10.1016/j.epsl.2012.12.017>
- Poveda Bonilla R (2020) Estudio de caso de la gobernanza del litio en Chile. Serie Recursos Naturales y Desarrollo 195 (LC/TS.2020/40). Comisión Económica para América Latina y el Caribe (CEPAL), Santiago
- Pramanik, B. K., Asif, M. B., Roychand, R., Shu, L., Jegatheesan, V., Bhuiyan, M., & Hai, F. I. (2020). Lithium recovery from salt-lake brine: impact of competing cations, pretreatment and preconcentration. *Chemosphere*, 260, 127623. <https://www.sciencedirect.com/science/article/abs/pii/S004565352031818X>
- Prieto G, Alzérreca H, Laura J, Luna D, Laguna S (2003) Características y distribución de los bofedales en el ámbito boliviano del sistema T.D.P.S. In: Rocha O, Sáez C (eds) Uso Pastoril de los Humedales Altoandinos de Argentina, Bolivia, Chile y Perú. La Paz, pp 13–40
- Quiroga L (2019) Las minas del inca y el valle de Pasinas (Siglos XV-XVI, Gobernación del Tucumán, Virreinato del Perú). *Intercambios. Estudios de Historia y Etnohistoria* 4(4)
- Quispe Mamani MC, Benavides JF, Feriz García D, Luque-Fernández CR, Tanco AP, Paredes LN (2021) Diversity of aquatic macroinvertebrates and water quality of the High Andean wetlands of Chalhuanca. *Arequipa-Peru Biodivers J* 12(2):517–528
- Resolución SEM 330 (2016) Secretaría de Estado de Minería de Catamarca. Participación Ciudadana. <http://www.mineria.catamarca.gov.ar/legislacion/consulta/55>

- Raffino RA, Gobbo DJ, Iácona A, Moralejo RA (2013) La minería y metalurgia de los Inkas del Kollasuyu. V Congreso Nacional de Arqueología Histórica 2013:1. Editorial Académica Española, Buenos Aires
- Richa K (2016) Sustainable management of lithium-ion batteries after use in electric vehicles. Dissertation, Rochester Institute of Technology, Rochester
- Rocha O (1997) Fluctuaciones poblacionales de tres especies de flamencos en Laguna Colorada. *Rev Boliv De Ecol* 2:67–76
- Rocha O, Marconi P (2012) Monitoring of 2011–2012 breeding colonies and populations of High-Andean Flamingos (*Phoenicoparrus andinus* y *P. jamesi*) in Argentina and Bolivia. Final Report (unpubl) to Convention on Migratory Species, CMS
- Rocha O, Pacheco LF, Ayala GR, Varela F, Arengo F (2021) Trace metals and metalloids in Andean flamingos (*Phoenicoparrus andinus*) and Puna flamingos (*P. jamesi*) at two wetlands with different risk of exposure in the Bolivian Altiplano. *Environ Monit Assess* 193(8):1–7. <https://doi.org/10.1007/s10661-021-09340-3>
- Rodríguez Ramírez E, Contreras JP, Amado Pool N, Santoro Vargas A, Valenzuela Vergara I (2006) Conservación de flamencos altoandinos en el norte de Chile: Estado actual y plan de conservación. Corporación Nacional Forestal, CONAF. Antofagasta, Chile. <http://bosques.ciren.cl/handle/123456789/7024>. Accessed 29 Mar 2022
- Rolando JL, Turin C, Ramírez DA, Mares V, Moneris J, Quiroz R (2017) Key ecosystem services and ecological intensification of agriculture in the tropical high-Andean Puna as affected by land-use and climate changes. *Agr Ecosyst Environ* 236:221–233. <https://doi.org/10.1016/j.agee.2016.12.010>
- Romano M, Barberis I, Pagano F, Romig J (2006) Flamingos: winter abundance in Laguna Melincué. *Flamingo* 14:17
- Romano MC, Barberis IM, Pagano F, Marconi PM, Arengo F (2008) Winter monitoring of Andean and Chilean flamingos in lowland wetlands of central Argentina. *Flamingo* 16:45–47
- Romano M, Barberis IM, Derlindati EJ, Pagano F, Marconi PM, Arengo F (2009) Variation in abundance of Andean and Chilean Flamingos wintering in lowland wetlands of central Argentina in two contrasting years. *Flamingo* 17:11–16
- Rubio MC, Rubio MC, Salomón M, Abraham EM (2016) Conservation of ecosystem services in high-altitude Andean wetlands: social participation in the creation of a natural protected area. *Ecol Austral* 27:177–192. <https://doi.org/10.25260/EA.17.27.1.1.271>
- Ruthsatz B, Movia CP (1975) Relevamiento de las estepas andinas del noreste de la provincia de Jujuy, República Argentina. Fundación para la educación, la ciencia y la cultura, Buenos Aires
- Secretaría de Ambiente y Desarrollo Sustentable-Presidencia de la Nación, Argentina (2019) Guía para la elaboración de estudios de impactos ambientales. <https://www.argentina.gob.ar/ambiente/desarrollo-sostenible/evaluacion-ambiental/guias-de-evaluacion-ambiental/eae>
- Seth A, Thibeault J, García M, Valdivia C (2010) Making sense of twenty-first-century climate change in the Altiplano: observed trends and CMIP3 projections. *Ann Assoc Am Geogr* 100(4):835–847. <https://doi.org/10.1080/00045608.2010.500193>
- Schulenberg TS, Stotz DF, Lane DF, O'Neill, Parker TH (2007) *Birds of Perú*. Princeton University Press, New Jersey, p 656
- Silvani VA, Colombo RP, Scorza MV, Bidondo LF, Rothen CP, Scotti A, Fracchia S, Godeas A (2017) Arbuscular mycorrhizal fungal diversity in high-altitude hypersaline Andean wetlands studied by 454-sequencing and morphological approaches. *Symbiosis* 72(2):143–152. <https://doi.org/10.1007/s13199-016-0454-3>
- Sticco M (2018) ¡Litio al agua! *Pulso Ambiental* 10: No todo lo que brilla es litio, pp 17–18. https://farn.org.ar/wp-content/uploads/2020/06/REVISTAPULSO_N10_LITIO-web_compressed.pdf. Accessed 28 Mar 2022
- Sticco M, Guerra G, Kwaterna V, Valdés S (2021) Impactos ambientales de la explotación de litio en los humedales y recursos hídricos del Altiplano. Fundación para la Conservación y el Uso Sustentable de los Humedales/Wetlands International <https://lac.wetlands.org/noticia/el-impacto-de-la-mineria-de-litio-en-los-humedales-altoandinos/>. Accessed 28 Mar 2022
- Struelens Q, Gonzales Pomar K, Loza Herrera S, Nina Huanca G, Dangles O, Rebaudo F (2017) Market access and community size influence pastoral management of native and exotic livestock species: A case study in communities of the Cordillera Real in Bolivia's high Andean wetlands. *PLoS One* 12(12):e0189409. <https://doi.org/10.1371/journal.pone.0189409>
- Svampa M, Antonelli MA (2009) Minería transnacional, narrativas del desarrollo y resistencias sociales. Editorial Biblos, Buenos Aires, 320 pp
- Tagliaferri C, Evangelisti S, Acconcia F, Domenech T, Ekins P, Barletta D, Lettieri P (2016) Life cycle assessment of future electric and hybrid vehicles: a cradle-to-grave systems engineering approach. *Chem Eng Res Des* 112:298–309. <https://doi.org/10.1016/j.cherd.2016.07.003>
- Tellería JL, Venero JL, Santos T (2006) Conserving birdlife of Peruvian highland bogs: effects of patch-size and habitat quality on species richness and bird numbers. *Ardeola* 53(2):271–83. https://www.ucm.es/data/cont/media/www/pag-33468/2006_Ardeola_53_271.pdf. Accessed 28 Mar 2022
- Tooth S, Grenfell M, Thomas A, Ellery WN (2015) Wetlands in Drylands: 'Hotspots' of Ecosystem Services in Marginal Environments. *GSDR Science Brief* 1–4. <http://wetlandsindrylands.net/wp-content/uploads/2015/10/Brief-for-GSDR-2015-Wetlands-in-Drylands-TOOTH-ET-AL.pdf>. Accessed 29 Mar 2022
- Torres R, Marconi P, Castro LB, Moschione F, Bruno G, Michelutti P, Casimiro, S, Derlindati EJ (2019) New nesting sites of the threatened Andean Flamingo in Argentina. *Flamingo* e1:3–10. <http://www.flamingo-sg.org/wp-content/uploads/2020/01/Paper-1-Torres-et-al.-Flamingo-2019.pdf>. Accessed 29 Mar 2022
- US Geological Survey (2017a) Mineral commodity summaries 2017a. <https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2017a-lithi.pdf>. Accessed 17 July 2021
- US Geological Survey (2018) Mineral commodity summaries 2018. <https://doi.org/10.3133/70194932>. Accessed 29 Mar 2022

- US Geological Survey (2017b) Argentina Lithium Map-Data Sources and Explanatory Notes. Administrative Report. Office of International Programs (OIP) and National Minerals Information Center (NMIC). Reston, VA. https://www.argentina.gob.ar/sites/default/files/argentina_lithium_map_geopdf_data_explanatory_document_2017b_nov_06.pdf Accessed 17 July 2021
- van Beek LP, Wada Y, Bierkens MF (2011) Global monthly water stress: 1. Water balance and water availability. *Water Resour Res*. <https://doi.org/10.1029/2010WR009791>
- Vignale FA, Lencina AI, Stepanenko TM, Soria MN, Saona LA, Kurth D, Guzmán D, Foster JS, Poiré DG, Villafañe PG, Albarraçín VH (2021) Lithifying and non-lithifying microbial ecosystems in the wetlands and salt flats of the central Andes. *Microb Ecol* 17:1–7. <https://doi.org/10.1007/s00248-021-01725-8>
- Vuilleumier F, Simberloff DS (1980) Ecology versus history as determinants of patchy and insular distributions of high Andean birds. *Evolut Biol* 12:235–379
- Wheeler, J.C. 1991. Origen, evolución y status actual. In Fernández-Baca S (ed) *Avances y perspectivas del conocimiento de los camélidos sudamericanos*. Oficina Regional de la FAO para América Latina y el Caribe, Santiago, pp 11–48
- Yacobaccio H, Morales M (2011) Ambientes pleistocénicos y ocupación humana temprana en la Puna argentina. *Boletín De Arqueología PUCP* 15:337–356
- Zante G, Boltoeva M, Masmoudi A, Barillon R, Trebouet D (2020) Highly selective transport of lithium across a supported liquid membrane. *J Fluor Chem* 236:109593
- Zhao X, Feng M, Jiao Y, Zhang Y, Wang Y, Sha Z (2020a) Lithium extraction from brine in an ionic selective desalination battery. *Desalination* 481:114360
- Zhao Y, Wang H, Li Y, Wang M, Xiang X (2020b) An integrated membrane process for preparation of lithium hydroxide from high Mg/Li ratio salt lake brine. *Desalination* 493:114620. <https://doi.org/10.1016/j.desal.2020.114620>

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