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PERSPECTIVES AND NOTES

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Andean hypersaline lakes in the Atacama Desert, northern Chile: Between lithium exploitation and unique biodiversity conservation

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Abstract

Hypersaline lakes or brines are unique ecosystems with unique value and biodiversity that provide economic (mining) and noneconomic services (waterbird habitat). As they are shrinking around the world due to brine diversion and climatic oscillations, this article alerts on the fragility of Andean high-altitude hypersaline lagoons in Salar de Atacama in the hyperarid Atacama Desert, northern Chile. As an integral part of the world's largest lithium exploitation from brine pumped from beneath the Salar, brine diversion and water shortage should compromise lagoons structure, functioning, and their high ecological value as habitat for endangered migratory birds like flamingos. Conserving the unique biodiversity and properties of these lagoons require long-term monitoring, including keystone taxa like the brine shrimp *Artemia*. How Chile will combine biodiversity agreements, treaties on wetlands and endangered birds conservation under the soaring lithium demand to support electromobility? Chile's government has granted new lithium extraction quotas to mining companies until 2030, which raises a concern and shows the difficulty to reconcile profit-driven economic development with nature conservation. As these lagoons may be shrinking and their food web altered, a problem only noticed so far by the declining flamingos, there is an urgent need to consider them in the environmental impact assessment legislation.

KEYWORDS

Atacama Desert, conservation, hypersaline lagoons, lithium exploitation, waterbirds

1 | BACKGROUND

Hypersaline lakes or brines are unique ecosystems with unique biodiversity and scientific value, which also have economic, aesthetic, cultural and recreational value, and represent ~45% of the volume of inland waters (Jellison, Williams, Timms, Alcocer, & Aladin, 2008; Oren, Naftz, Palacios, & Wurtsbaugh, 2009; Williams, 2002). However, saline lakes around the world are shrinking due to climate variability and brine diversion for mineral extraction, affecting noneconomic services like waterbird habitat (Wurtsbaugh et al., 2017). Under this scenario, this article highlights the vulnerable situation of small high-altitude Andean hypersaline lakes or Lagunas (lagoons) located in the Atacama salt flat (Salar) in the Atacama Desert in northern Chile (Figure 1). These lagoons are an integral part of the world's largest lithium reserves and exploitation from

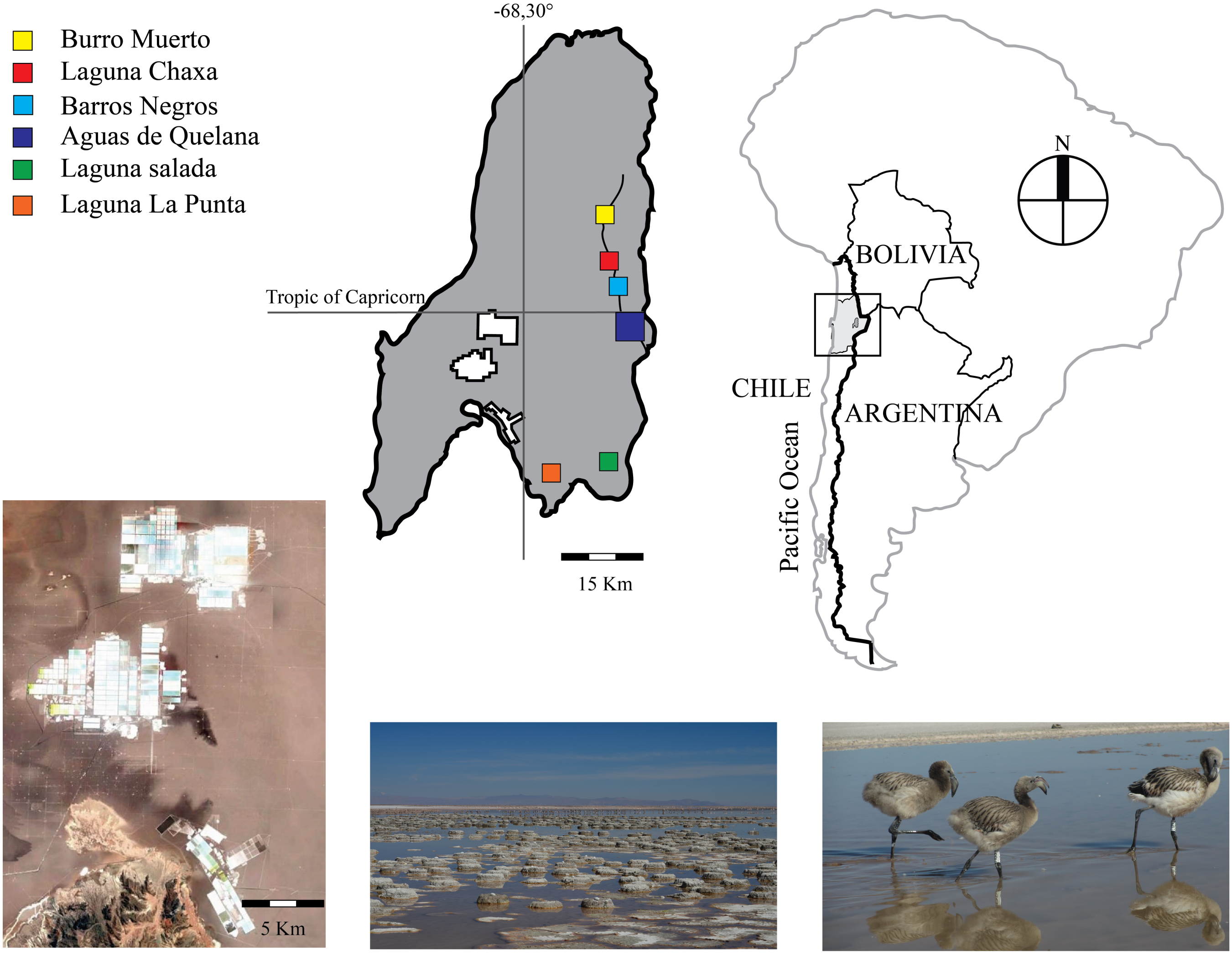

FIGURE 1 Saline lagoons or brines in Salar de Atacama (inset) are natural laboratories to understand how simple ecosystems produce noneconomic services like waterbird habitat. These lagoons have unique extremophile biodiversity and are an integral part of the world's largest lithium exploitation from brine, which is pumped in huge volumes from beneath the Salar surface to concentrate this white gold in evaporating pools (satellite photo). Brine diversion and climatic oscillations in this hyperarid desert may affect size, salinity and functioning of the lakes which may explain the abundance of endangered migratory flamingos feeding and reproducing (nest, center photo) in the lakes (marked nestlings, photo right)

brine pumped from beneath the Salar surface to concentrating lithium in evaporating pools. Brine diversion and climatic oscillations in this hyperarid desert are likely to affect the hydrological balance of the Salar aquifer, and therefore the natural dynamics, salinity and unique biodiversity of these hypersaline lagoons, including the diversity of birds inhabiting them. Regulatory agencies, policymakers responsible for compliance with international agreements on biodiversity and wetland conservation as well as companies exploiting lithium should be aware how such effects could affect the structure, functioning, and overall stability of these unique extreme ecosystems, and the noneconomic service they provide (waterbird habitat).

Saline lakes generally found in arid and semiarid regions where high evaporation rates and a combination of geological, geomorphological, and hydrological conditions allow natural brines to persist as an integral part of salt flats, or closed endorheic basins. There are also relatively small and permanent saline lakes in unusually cold places such as Tibet in China and Patagonia in southern Chile and Argentina (Gajardo, Abatzopoulos, Kappas, & Beardmore, 2002; Van Stappen, 2002). Their wide ecological diversity stems from geographical location, altitude, salinity, temperature, and ionic conditions, and hence they contain regionally endemic biodiversity and have unique limnological features that need to be studied and monitored on a regular and long-term basis to preserve them in a scenario of climatic change and increased human perturbation, that is, water and brine diversion for mineral extraction (Williams, 2002). Wurtsbaugh et al. (2017) recently warned that saline lakes around the world are "shrinking at an alarming rate." Williams had anticipated such risk in 2002 when he predicted that by 2025, permanent saline lakes "will have become smaller and more saline, with extensive if not complete exposure of their beds to the atmosphere." Urmia Lake in Iran and Great Salt Lake in the United States are cases of receding lakebeds, and so represent Williams' prophecy (Williams, 2002; Wurtsbaugh et al., 2017).

2 | GREAT SALT LAKE: COEXISTENCE OF ECONOMIC AND NONECONOMIC SERVICES

The Great Salt Lake (GSL) in Utah is a large and permanent hypersaline lake with high economic value stemming from salt mining evaporating ponds and from harvesting resting eggs (cysts) of the brine shrimp *Artemia franciscana*, a keystone species in the food web of this ecosystem. The exploitation of this salt-tolerant extremophile organism (*Artemia*) (Gajardo & Beardmore, 2012) to produce biomass and cysts is a multimillion dollar business because cysts are exported worldwide for aquaculture, as *Artemia* is the most commonly used live diet for rearing fish and shrimp larvae in hatchery facilities (Lavens & Sorgeloos, 2000). However, GSL also provides waterbird habitat, a vital noneconomic service for maintaining global birds diversity. In GSL thousands of waterbirds, such as grebes, gulls, avocets, phalaropes, and ducks, forage mainly on *Artemia* and compete indirectly with the cyst harvest industry. To minimize the risk, managers halt harvest when densities fall below 20,000 cysts/m^3 to ensure food availability and energy requirements (nearly 30,000 adult brine shrimp daily) for approximately 1.5 million Black-necked grebes *Podiceps nigricollis*, which use the lake during their autumn migration to the Southern Hemisphere (Conover & Caudell, 2009).

However, the Great Salt Lake and many other saline lakes around the world are under threat by climatic oscillations, and brine diversion that impacts salinity and reduces lakes size (Wurtsbaugh et al., 2017), affecting their ecosystem structure and functioning (Golubkov, Shadrin, Golubkov, Balushkina, & Litvinchuk, 2018). This article expresses concern on the fragility of high-altitude hypersaline lagoons in the Atacama Desert due to hyper dryness of the Desert, that could get worse, water shortage due to low rainfall and mining activities (including cooper companies in the area) and the huge volume of brine diverted for lithium exploitation. The lack of a baseline is also a matter of concern as it is needed to correlate changes in the lagoons dynamics with waterbird abundance.

3 | LITHIUM-RICH BRINES: THE NEW GOLD

Hypersaline lagoons (>40 g/L; Hammer, 1986) spread over the Salar de Atacama basin (Lat/Long: −23.50069/−68.24984), the largest salt flat and lithium reservoir of the Atacama Desert in northern Chile. The Salar (3,067 km^2), located over 2,300 m above sea level in the Altiplano-Puna region of the Central Andes, is flanked by the Pacific Ocean to the west and the mountains to the east. It contains the world's largest lithium reserves and exploitation from brines (Cubillos, Aguilar, Grágeda, & Dorador, 2018) with the highest average lithium concentration: 1,400 mg/L; range: 900–7,000 (Munk et al., 2016).

Mining companies from Chile (Soquimich, SQM), North America (Albemarle) and recently China (Tianqui Lithium) are expected to obtain huge profits under the current lithium boom, "the new or white gold" (Draper, 2019; Tarascon, 2010). Indeed, lithium has become one of the world's hottest commodity, which explains why Tianqui recently closed a US$ 4.3 million deal to buy a 24% stake in Chile's SQM, one of the world's largest lithium producer from brine, which is a highly cost-effective business. However, the scientific, ecological, recreational, and cultural (for 18 indigenous communities) importance give the Salar a significant noneconomic value not to underestimate. For example, the Salar is a target area for researchers all over the world looking to better understand the ecology of extreme ecosystems (Demergasso et al., 2004; Gajardo & Beardmore, 2012). Likewise, for those studying the origin and limits of life on Earth as an analog to life on Mars (Azua-Bustos et al., 2018), searching microorganisms with medical and biotechnological applications or for those looking for new species in lithium evaporating pools (Cubillos et al., 2018). Except in Tibet and Andean countries like Perú (Laguna Lagunita) and Bolivia (Lake Uyuni, another huge but less exploited lithium reservoir, see Draper, 2019), there are no other salty lagoons over 2,300 m of altitude which makes them extremely vulnerable to water or brine diversion due to aridity of the place (evaporation largely exceeding rainfall). Hypersaline lagoons are integral part of salt deposits of the Salar de Atacama basin that receive surface freshwater from the increasingly diminished river San Pedro and underground water input mainly from the High Andes, but also from occasional flooding due to the "Bolivian or Altiplano winter" occurring between December and March (Azua-Bustos et al., 2018).

Salar de Atacama's lithium richness originated by a combination of geological and climatic factors commonly found in lithium-producing countries in the Andes such as Argentina, Chile, and Bolivia, the so-called lithium triangle. These are: arid climate, a closed evaporitic basin containing a salt flat and salty lagoons or brines, volcanic and hydrothermal activities that leach lithium from volcanic rocks that is drained underground to the basin floor (aquifer), and a prolonged history that has allowed to concentrate brines (see Munk et al., 2016). Several channels and small shallow hypersaline lagoons are important staging areas for interhemispheric migrations for birds such as Baird's Sandpiper (*Calidris bairdii*), Greater yellowlegs (*Tringa melanoleuca*), Lesser yellowlegs (*Tringa flavipes*), and Wilson's phalarope (*Phalaropus tricolor*), but also are habitat for three South American flamingo species: Chilean flamingo (*Phoenicopterus chilensis*), James's flamingo (*Phoenicoparrus jamesi*), and Andean flamingo (*Phoenicoparrus andinus*). Indeed, this is an important reproductive site for the latter species (CONAF, 2000). Four Ramsar sites exist in the area: Salar de Aguas Calientes IV, Salar de Tara, Salar de Pujsa, and Soncor hydrologic system of Salar de Atacama. The latter three sites are part of "Los Flamencos National Reserve," also in the Salar basin, created in 1990 as a protective measure by the Ministry of Agriculture.

Despite the international recognition of these hypersaline lagoons and wetlands as invaluable natural resources, conservation efforts are needed to maintain their intrinsic value and biodiversity under a future scenario of continued or even increased aridity, water shortage and increased brine diversion by lithium companies. Salar de Atacama has longstanding arid climate stability (aridity index: 0, 0326) with evaporation rate (1,440 mm/year) exceeding rainfall (39 mm/year) (Munk et al., 2016; see also Cubillos et al., 2018). Nevertheless, highly unusual summer rains (December–March) have flooded the area in recent years (Azua-Bustos et al., 2018).

4 | HYPERSALINE LAGOONS: NATURAL BIODIVERSITY LABORATORIES

Due to high salinity, hypersaline lagoons have reduced biodiversity and relatively simple trophic webs compared to other aquatic systems, making them particularly sensitive to brine diversion, hydrological, and salinity fluctuations. These lagoons are therefore considered low-diversity natural laboratories (Gajardo, Sorgeloos, & Beardmore, 2006) useful for scientists to demonstrate policy makers, environmental regulators, local communities and miners how a unique and extreme ecosystem functions to produce noneconomic services like habitat for aquatic birds. Such knowledge is required to implement integral management and conservation measures to mitigate adverse anthropogenic or climate impacts (Figure 2). Thus, a way to counterbalance the impact of lithium activities in the Salar de Atacama basin would be monitoring on a regular and long-term basis the dynamics of these hypersaline ecosystems with emphasis on critical indicators such as *Artemia* abundance. The role of *Artemia* becomes relevant in the food web as the animal regulates the presence of other food items, for example, it grazes on bacteria and phytoplankton biomass to obtain energy and nutrients to complete its life cycle under the stringent conditions that challenge survival and reproduction. Bacterial diversity in brines is high but depending on salinity (Demergasso et al., 2008; Dorador et al., 2009), a subsample being represented in the gut microbiota of *Artemia* (Quiroz, Triadó-Margarit, Casamayor, & Gajardo, 2015), which in turn affects its fitness (Nougué, Gallet, Chevin, & Lenormand, 2015). This means that salinity changes affecting the gut microbial communities would very likely affect *Artemia* survival and reproduction. Different copepods species also control *Artemia* abundance, at lower or high salinities (Anufriieva, 2015), as reported by the long-term studies of salt lakes in Crimea, Ukraine (Belmonte et al., 2012; Shadrin, Yakovenko, & Anufriieva, 2019) as well as waterbirds, as explained previously for GSL, and parasites (Redón, Amat, Sánchez, & Green, 2015). Thus, any change in salinity or other brine parameters should affect the whole food web. Regretfully *Artemia* is known by specialists mainly, but it is somewhat invisible to most people, which is not the case with waterbirds. Therefore, waterbird presence in the area, mostly flamingos, are the flagship to promote conservation of hypersaline lagoons (Green & Elmberg, 2014).

5 | THREATS TO THE ECOSYSTEM

What can be expected for the high-altitude lagoons of Salar de Atacama under the increasing lithium demand to support the future fleet of electric vehicles? Of course, production will increase and so the volume of the lithium-rich brine pumped from beneath the Salar salt crust (about 50 m depth), estimated to be ~185,100 m^3/day, according to Jerez (2018), while the amount of freshwater used by lithium companies is also significant, ~22,800 m^3/day. The Chilean government recently granted SQM a new contract to expand lithium production to reach a total of 2.2 million tons by 2030 (Soquimich, 2018), after years of dispute for alleged brine overdrawn and other contract-related matters that according to CORFO, Chile's Development Agency, could cause a severe risk to the ecosystem and its brine reserves. As brine reserves are undetermined, concern has raised among regulators on what would be the reasonable or sustainable level of brine sucked under the new expansion agreement. The brine and freshwater conflict could translate into detrimental and perhaps irreversible effects on the biodiversity and dynamics of hypersaline ecosystems

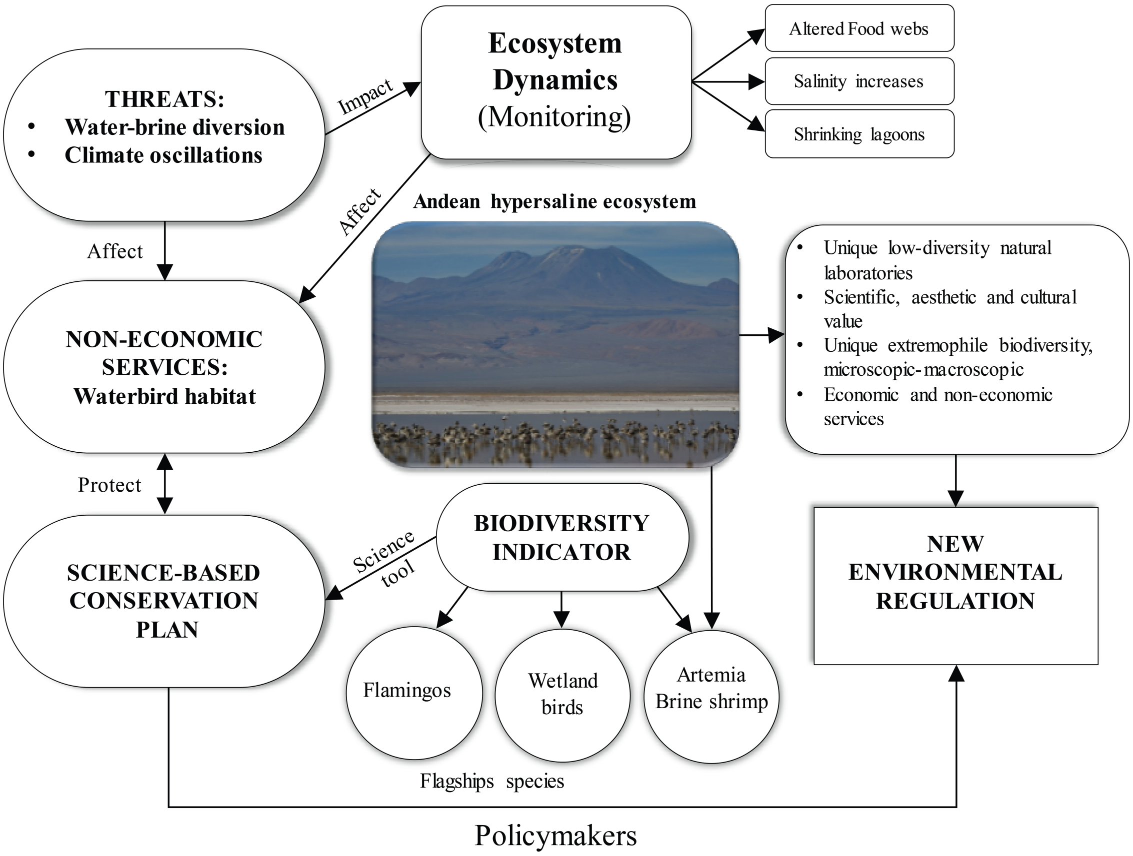

FIGURE 2 A conceptual framework for conserving hypersaline lagoons and waterbird habitat in Salar de Atacama in a scenario of increasing lithium exploitation from brine and climate change

and their noneconomic services (Figure 2). Freshwater is a critically limiting factor in Salar de Atacama, which is shared by indigenous communities, lithium and copper companies, and tourist resorts.

6 | BIODIVERSITY INDICATORS

Potential impacts expected on these unique extreme natural laboratories are difficult to quantify in advance without long-term monitoring programs and critical indicators to detect biological and limnologic effects, such as changes in species composition, functional roles, biotic interactions, water levels, and salinity increases or severe fluctuations (Figure 2). Those effects can be particularly notable for charismatic species like flamingos that are common in hypersaline wetlands or lakes of the Andean Altiplano (Hurlbert & Keith, 1979; Hurlbert, López, & Keith, 1984). For instance, reduced reproductive success in the Andean flamingo was detected during the 2017–2018 period at several nesting sites (Figure 1) in the National Flamingos Reserve, according to professionals of the National Forestry Corporation (CONAF), the administrative body in charge of the place. The reproductive season was extremely poor compared to historical records, as the flamingo population hardly reached the minimum number of 1,000 "polluelos" (nestlings) and "pre-volantones" for safe tagging (Figure 1). Due to the low number observed, CONAF halted tagging animals in 2018 and expressed concern for the situation considering the Andean flamingo's conservation status is designated as vulnerable by the International Union for the Conservation of Nature (IUCN) (BirdLife International, 2016a, 2016b). This situation repeated the summer of 2019, and according to local people's knowledge, it would be a consequence of the shrinking of wetlands in Los Flamencos Reserve, where an important conservation program exists. The probable shrinking of the lagoon's surface should affect the quality of shore sediments flamingos use to build their nests, and the lagoon dynamics and food availability. Indeed, flamingo's distribution depends on food abundance and quality. While some species feed on *Artemia*, others have a bill adapted to feed a range of small organisms found in shallow waters. Species are highly selective and food items found in their feces vary (bacteria, microalgae, and invertebrates) (Hurlbert, 1982; Tobar et al., 2012).

Therefore, long-term monitoring of the crustacean *Artemia* should help to get a more comprehensive picture of the ecosystem dynamics considering its crucial role in the trophic ecology of these lagoons as well as to predict cascading effects at different trophic levels. The brine shrimp *Artemia* is a particular case of an invertebrate displaying unique adaptation to cope with salt and other stresses brine impose on survival and reproduction (Gajardo & Beardmore, 2012). The dispersal of *Artemia* and other halophilic invertebrates and parasites is tightly linked to waterbirds, either by attaching themselves to birds or by surviving the passage of cysts through their guts (Green & Figuerola, 2005; Muñoz, Amat, Green, Figuerola, & Gómez, 2013). Flamingos are long-distance *Artemia* dispersers commonly found in the Andean Altiplano feeding or breeding (Hurlbert, 1982; Hurlbert et al., 1984; Hurlbert & Keith, 1979). Thus, brine shrimp presence and abundance in a given brine depend on waterbirds and the interaction with many other species or regulators, including other invertebrates (Anufriieva, 2015; Shadrin et al., 2019) and parasites (Redón et al., 2015). The crustacean is, therefore, an indicator of habitat degradation, one of the main causes of biodiversity loss in *Artemia* in the western Mediterranean (Amat, Hontoria, Navarro, Vieira, & Mura, 2007), and is a probable predictor of waterbirds presence and reproduction. For example, the introduction of *Artemia* in salty lakes in Tibet generated a new ecosystem dynamics that attracted birds not previously present in the lake (Jia, Anufriieva, Liu, Kong, & Shadrin, 2015).

In short, the risk attached to the lack of knowledge on how hypersaline lakes function to produce noneconomic services like waterbird habitat, and how water and brine diversion may be affecting such service would prevent stakeholders from understanding a biodiversity-related problem, and hence to take adequate corrective measures. Thus, scientific efforts on hypersaline ecosystems and their diversity should be prioritized (Figure 2), looking for ecological strategies to maintain a healthy food web structure. Although joint efforts do exist between SQM, CONAF and researchers to conserve terrestrial flora and fauna, including flamingos (SQM sustainable report 2017), systematic studies on the dynamics of hypersaline lakes are inexistent. Their vulnerable situation is due to the inherent difficulty to reconcile profit-driven economic development with the conservation of nature, a problem underlying the current global biodiversity crisis. Likewise, this case shows the often disconnected relationship between scientists, conservation practitioners, industry (miners), and policymakers. Therefore, the role of scientists is essential to preserve these unique hypersaline ecosystems and their waterbird diversity of global importance. These lakes or brines should be an integral part of the environmental impact assessment legislation.

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CONFLICT OF INTEREST

The authors do not have any potential conflict of interest to declare.

AUTHOR CONTRIBUTIONS

G.G. conceived the manuscript and wrote the first draft. S.R. read, commented, and improved the manuscript. Both authors reviewed and approved its final version.

ETHICS STATEMENT

No ethical considerations apply to this review. It highlights the collective responsibility attached to protecting unique biodiversity and ecosystems.

DATA ACCESSIBILITY

Data sharing does not apply to this article, as no new data were created.

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REFERENCES

Amat, F., Hontoria, F., Navarro, J. C., Vieira, N., & Mura, G. (2007). Biodiversity loss in the genus *Artemia* in the Western Mediterranean region. *Limnetica*, *26*(2), 387–404.

Anufriieva, E. V. (2015). Do copepods inhabit hypersaline waters worldwide? A short review and discussion. *Chinese Journal of Oceanology and Limnology*, *33*(6), 1354–1361.

Azua-Bustos, A., Fairén, A. G., González-Silva, C., Ascaso, C., Carrizo, D., Fernández-Martínez, M. A., … Parro, V. (2018). Unprecedented rains decimate surface microbial communities in the hyperarid core of the Atacama Desert. *Scientific Reports*, *8*, 16706. https://doi.org/, https://doi.org/10.1038/s41598-018-35051-w

Belmonte, G., Moscatello, S., Batogova, E. A., Pavlovskaya, T., Shadrin, N. V., & Litvinchuk, L. F. (2012). Fauna of hypersaline lakes of Crimea (Ukraine). *Thalassia Salentina*, *34*, 11–24. https://doi.org/10.1285/i15910725v34p11

BirdLife International. (2016a). *Phoenicoparrus andinus*. The IUCN Red List of Threatened Species. https://doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22697387A93611749.en. (Downloaded on December 2018).

BirdLife International. (2016b). The IUCN Red List of Threatened Species. https://doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22697398A93612106.en. (Downloaded on December 2018).

CONAF. (2000). Informe de la temporada de nidificación de flamencos en el norte de Chile. Corporación Nacional Forestal, 24 p.

Conover, M. R., & Caudell, J. N. (2009). Energy budgets for eared grebes on the Great Salt Lake and implications for harvest of brine shrimp. *Journal of Wildlife Management*, *73*, 1134–1139.

Cubillos, C. F., Aguilar, P., Grágeda, M., & Dorador, C. (2018). Microbial communities from the world's largest lithium reserve, Salar de Atacama, Chile: Life at high LiCl concentrations. *Journal of Geophysical Research. Biogeosciences*, *123*, 3668–3681. https://doi.org/10.1029/2018JG004621

Demergasso, C., Casamayor, E. O., Chong, G., Galleguillos, P., Escudero, L., & Pedrós-Alió, C. (2004). Distribution of prokaryotic genetic diversity in Athalassohaline lakes of the Atacama Desert, northern Chile. *FEMS Microbiology Ecology*, *48*, 57–69. https://doi.org/10.1016/j.femsec.2003.12.013

Demergasso, C., Escudero, L., Casamayor, E. O., Chong, G., Balagué, V., & Pedrós-Alió, C. (2008). Novelty and spatio–temporal heterogeneity in the bacterial diversity of hypersaline Lake Tebenquiche (Salar de Atacama). *Extremophiles*, *12*(4), 491–504.

Dorador, C., Meneses, D., Urtuvia, V., Demergasso, C., Vila, I., Witzel, K. P., & Imhoff, J. F. (2009). Diversity of *Bacteroidetes* in high-altitude saline evaporitic basins in northern Chile. *Journal of Geophysical Research*, *114*, G00D05. https://doi.org/10.1029/2008JG000837

Draper, R. (2019). The rush for white gold. National Geographic, February 2019, 80–91.

Gajardo, G., Abatzopoulos, T. J., Kappas, I., & Beardmore, J. A. (2002). Evolution and speciation. In T. J. Abatzopoulos, J. A. Beardmore, J. S. Clegg, & P. Sorgeloos (Eds.), *Artemia: Basic and applied biology* (pp. 225–250). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Gajardo, G., & Beardmore, J. A. (2012). The brine shrimp *Artemia*: Adapted to critical life conditions. *Frontiers in Physiology*, *3*, 185. https://doi.org/10.3389/fphys.2012.00185

Gajardo, G., Sorgeloos, P., & Beardmore, J. A. (2006). Inland hypersaline lakes and the brine shrimp *Artemia* as simple models for biodiversity analysis at the population level. *Saline Systems*, *2*, 14. https://doi.org/10.1186/1746-1448-2-14

Golubkov, S. M., Shadrin, N. V., Golubkov, M. S., Balushkina, E. V., & Litvinchuk, L. F. (2018). Food chains and their dynamics in ecosystems of shallow lakes with different water salinities. *Russian Journal of Ecology*, *49*(5), 442–448. https://doi.org/10.1134/S1067413618050053

Green, A. J., & Elmberg, J. (2014). Ecosystem services provided by waterbirds. *Biological Reviews*, *89*(1), 105–122.

Green, A. J., & Figuerola, J. (2005). Recent advances in the study of long-distance dispersal of aquatic invertebrates via birds. *Diversity and Distributions*, *11*, 149–156.

Hammer, U. T. (1986). *Saline lake ecosystems of the world* (Vol. 59). Heidelberg, Germany: Springer-Nature.

Hurlbert, S. (1982). Limnological studies of flamingo diets and distributions. *National Geographic Society Research Reports*, *14*, 351–356.

Hurlbert, S., & Keith, J. O. (1979). Distribution and spatial patterning of flamingos in the Andean Altiplano. *Auk*, *96*, 328–342.

Hurlbert, S., López, M., & Keith, J. (1984). Wilson's phalarope in the Central Andes and its interaction with the Chilean flamingo. *Revista Chilena de Historia Natural*, *57*, 47–57.

Jellison, R., Williams, W. D., Timms, B., Alcocer, J., & Aladin, N. D. (2008). Salt lakes: Values, threats and future. In N. V. C. Polunin (Ed.), *Aquatic ecosystems: Trends and global prospects* (pp. 94–110). Cambridge, England: Cambridge University Press.

Jerez, B. (2018). Impacto socioambiental de la extracción de litio en las cuencas de los salares altoandinos del cono sur. Berlín, Alemania. Retrieved from: https://www.ecoportal.net/temas-especiales

Jia, Q., Anufriieva, E., Liu, X., Kong, F., & Shadrin, N. (2015). Intentional introduction of *Artemia sinica* (Anostraca) in the high-altitude Tibetan Lake Dangxiong Co: The new population and consequences for the environment and for humans. *Chinese Journal of Oceanology and Limnology*, *33*(6), 1451–1460.

Lavens, P., & Sorgeloos, P. (2000). The history, present status and prospects of the availability of *Artemia* cysts for aquaculture. *Aquaculture*, *181*, 397–403.

Munk, L. A., Hynek, S. A., Bradley, D. C., Boutt, D., Labay, K., & Jochens, H. (2016). Lithium brines: A global perspective. *Reviews in Economic Geology*, *18*, 339–365.

Muñoz, J., Amat, F., Green, A. J., Figuerola, J., & Gómez, A. (2013). Bird migratory flyways influence the phylogeography of the invasive brine shrimp Artemia franciscana in its native American range. *PeerJ*, *1*, e200. https://doi.org/10.7717/peerj.200

Nougué, O., Gallet, R., Chevin, L. M., & Lenormand, T. (2015). Niche limits of symbiotic gut microbiota constrain the salinity tolerance of brine shrimp. *The American Naturalist*, *186*(3), 390–403.

Oren, A., Naftz, D., Palacios, P. & Wurtsbaugh, W. A. (2009). Saline lakes around the world: Unique systems with unique values. Natural Resources and Environmental Issues, Vol. XV. S.J. and Jessie E. Quinney Natural Resources Research Library.

Quiroz, M., Triadó-Margarit, X., Casamayor, E. O., & Gajardo, G. (2015). Comparison of Artemia–bacteria associations in brines, laboratory cultures and the gut environment: A study based on Chilean hypersaline environments. *Extremophiles*, *19*(1), 135–147.

Redón, S., Amat, F., Sánchez, M. I., & Green, A. J. (2015). Comparing cestode infections and their consequences for host fitness in two sexual branchiopods: Alien *Artemia franciscana* and native *A. salina* from syntopic-populations. *PeerJ*, *3*, e1073. https://doi.org/10.7717/peerj.1073

Shadrin, N., Yakovenko, V., & Anufriieva, E. (2019). Suppression of *Artemia spp*. (Crustacea, Anostraca) populations by predators in the Crimean hypersaline lakes: A review of the evidence. *International Review of Hydrobiology*, *104*, 5–13. https://doi.org/10.1002/iroh.201801966

Soquimich (SQM). (2018). SQM y CORFO sellan acuerdo. News (January 1, 2018) retrieved from https://www.sqm.com/en/noticia/sqm-y-corfo-sellan-acuerdo/. Not available in English.

Tarascon, J. M. (2010). Is lithium the new gold? *Nature Chemistry*, *2*(6), 510.

Tobar, C., Rau, J. R., Iriarte, A., Villalobos, R., Lagos, N., Cursach, J., … Gantz, A. (2012). Composition, diversity and size of diatoms consumed by the Andean flamingo (*Phoenicoparrus andinus*) in Salar de Punta Negra, Antofagasta region, northern Chile. *Ornitologia Neotropical*, *23*, 243–250.

Van Stappen, G. (2002). Zoogeography. In T. J. Abatzopoulos, J. A. Beardmore, J. S. Clegg, & P. Sorgeloos (Eds.), *Artemia: Basic and applied biology*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Williams, W. D. (2002). Environmental threats to salt lakes and the likely status of inland saline ecosystems in 2025. *Environmental Conservation*, *29*(2), 154–167.

Wurtsbaugh, W. A., Miller, C., Null, S., DeRose, J. R., Wilcock, P., Hahnenberger, M., … Moore, J. (2017). Decline of the world's saline lakes. *Nature Geoscience*, *10*(11), 816–821. https://doi.org/10.1038/NGEO3052

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