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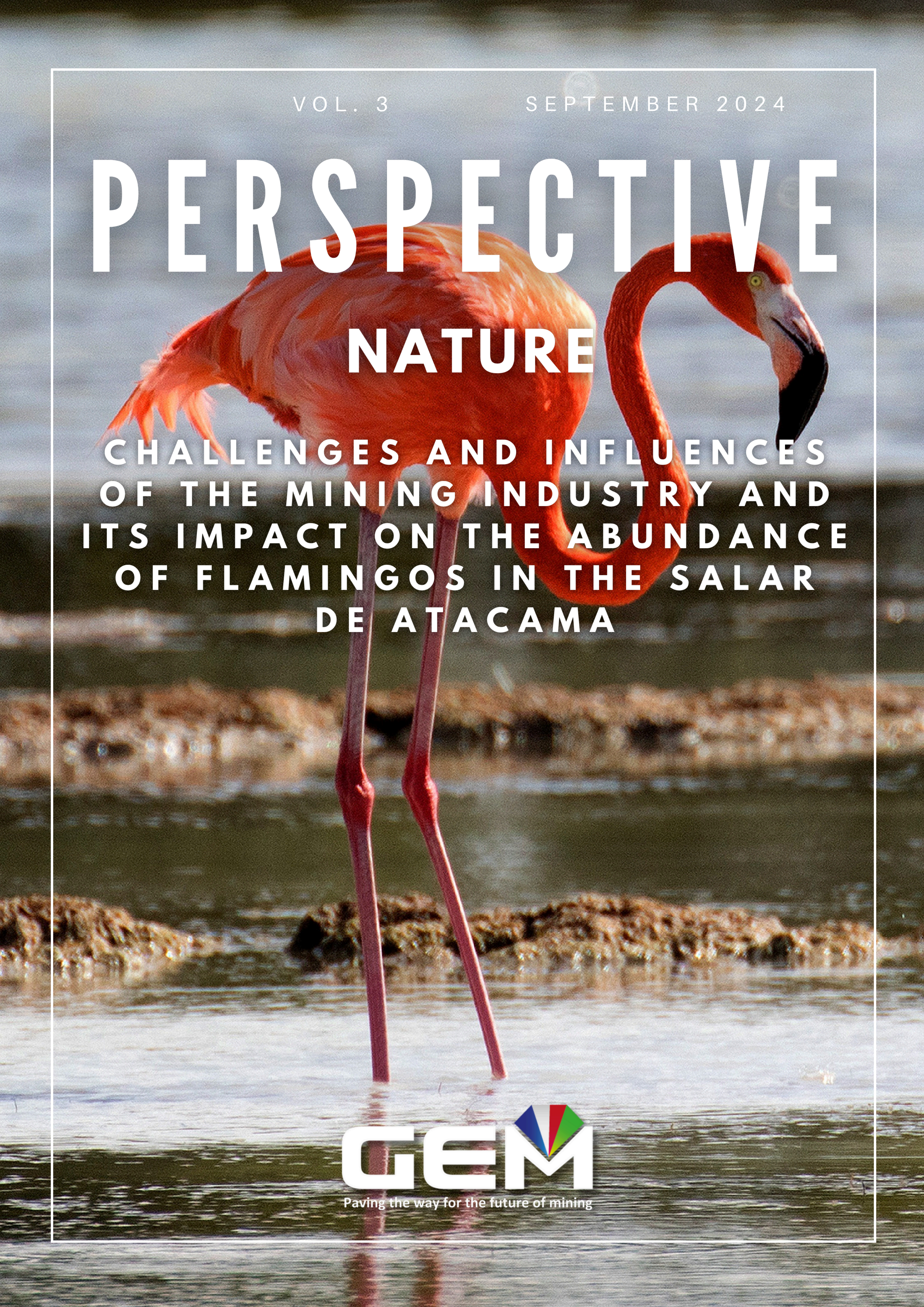
PERSPECTIVE

NATURE

CHALLENGES AND INFLUENCES OF THE MINING INDUSTRY AND ITS IMPACT ON THE ABUNDANCE OF FLAMINGOS IN THE SALAR DE ATACAMA



GEM

Paving the way for the future of mining

INDEX

ABOUT GEM

We are a specialized Industrial Engineering company that provides support to the mining industry in matters related to management and economics. Our expertise covers various fields as we develop the most advanced tools applied in the mining sector. With over 14 years of experience and the successful implementation of more than 400 projects worldwide, we stand out for our solid track record and commitment to excellence in the sector.

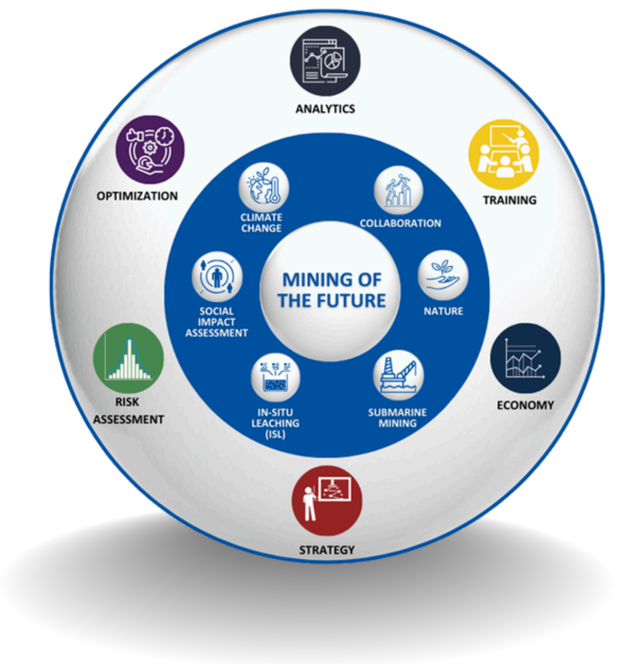
MISSION

We are a company providing products and services in industrial engineering that enable the path for the future of mining while maximizing the business value for our clients.
At GEM, we are committed to becoming a beacon for the global mining industry.

Our core highlights the main service areas of GEM, which include:

Analytics: Use of advanced analytical tools such as machine learning and statistical analysis.
Training: Provision of training on complex topics tailored to specific mining cases.
Economics: Generation of mineral economics studies, market analysis, and econometric analysis.
Evaluation: Identification and quantification of risks with Monte Carlo simulations to evaluate their impact.
Strategy: Support in strategic decision-making to maximize business value.
Optimization: Utilization of tools and programming languages to find optimal solutions.

Additionally, the central image shows GEM's commitment to the future of mining, addressing areas such as climate change, collaboration, social impact assessment, nature, underwater mining, and in-situ leaching.



EDITORIAL

The impact of climate change on the world is transforming not only the natural landscape but also the industrial landscape. Projections under the RCP8.5 climate scenario suggest a future where species will face significant challenges due to temperature variations and other climatic changes.

The mining industry, particularly copper and lithium, presents opportunities but also faces highly challenging conditions. On the one hand, the global demand for critical minerals for the energy transition continues to grow, and on the other hand, mining operations must adapt to an increasingly restricted environment due to social and environmental limitations.

This new global climate change scenario is pushing countries to strengthen their environmental regulations. Chile's recent Law No. 19.300, along with its SEIA regulations, reflects this trend, establishing an even more rigorous regulatory framework to evaluate and mitigate the potential environmental impacts of industrial activities.

In this Perspective, we delve into the complex web of interactions between climate change, mining operations, and local biodiversity. To illustrate this, we study the case of the Salar de Atacama, which lies at the intersection of mining exploitation and biodiversity preservation. Specifically, the study focuses on the abundance of flamingos, considering three emblematic species: (1) the Andean flamingo; (2) the Chilean flamingo; and (3) the James's flamingo. From this study, it is concluded that despite the continued expansion of mining activity in the Salar de Atacama, there have been no direct impacts on the abundance of flamingos.

The delicate interplay between biodiversity, climate change, and human activity (i.e., mining activity) demonstrates that the industry must take an active and proactive role in managing climate risks. By adopting the methodologies and discussions presented in this study, companies would not only comply with new regulations but also gain a competitive advantage in an increasingly sustainability-oriented market.

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PATRICIO FAÚNDEZ
SPECIALIST ENGINEER GEM

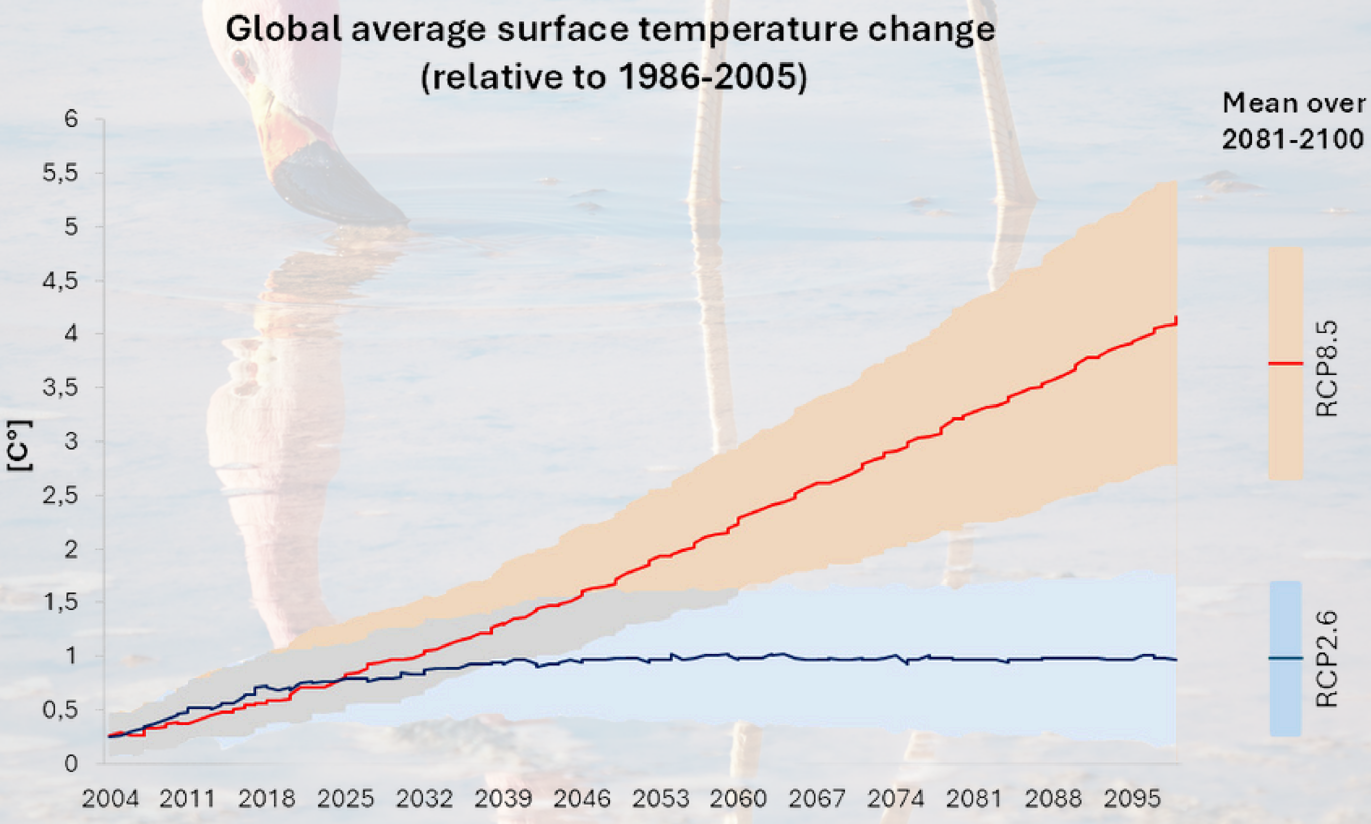
INTRODUCTION

Climate change, characterized by shifts in temperature, precipitation patterns, and extreme weather events, is a global phenomenon with far-reaching ecological consequences. The scientific community relies on Representative Concentration Pathway (RCP) scenarios to model future climate conditions.

These models help envision different possible climate scenarios. Future RCP scenarios are based on greenhouse gas (GHG) concentrations and other climate-related factors adopted by the Intergovernmental Panel on Climate Change (IPCC). RCPs are labeled with numbers that represent different levels of change in solar radiation by the year 2100 (2.6, 4.5, 6, and 8.5 [W/m²], respectively).

These numbers help illustrate how global warming might vary. RCP2.6 represents an optimistic scenario, where GHG concentrations decrease in the coming years, leading to a global temperature increase of between 0.5 and 3.1 [°F]. On the other hand, the RCP8.5 scenario represents the opposite case, following the current trend of CO_2 emissions, which implies a global temperature increase of between 4.7 and 8.6 [°F] by the end of the period, as shown in **Figure 1**.

FIGURE 1. GLOBAL AVERAGE SURFACE TEMPERATURE CHANGE



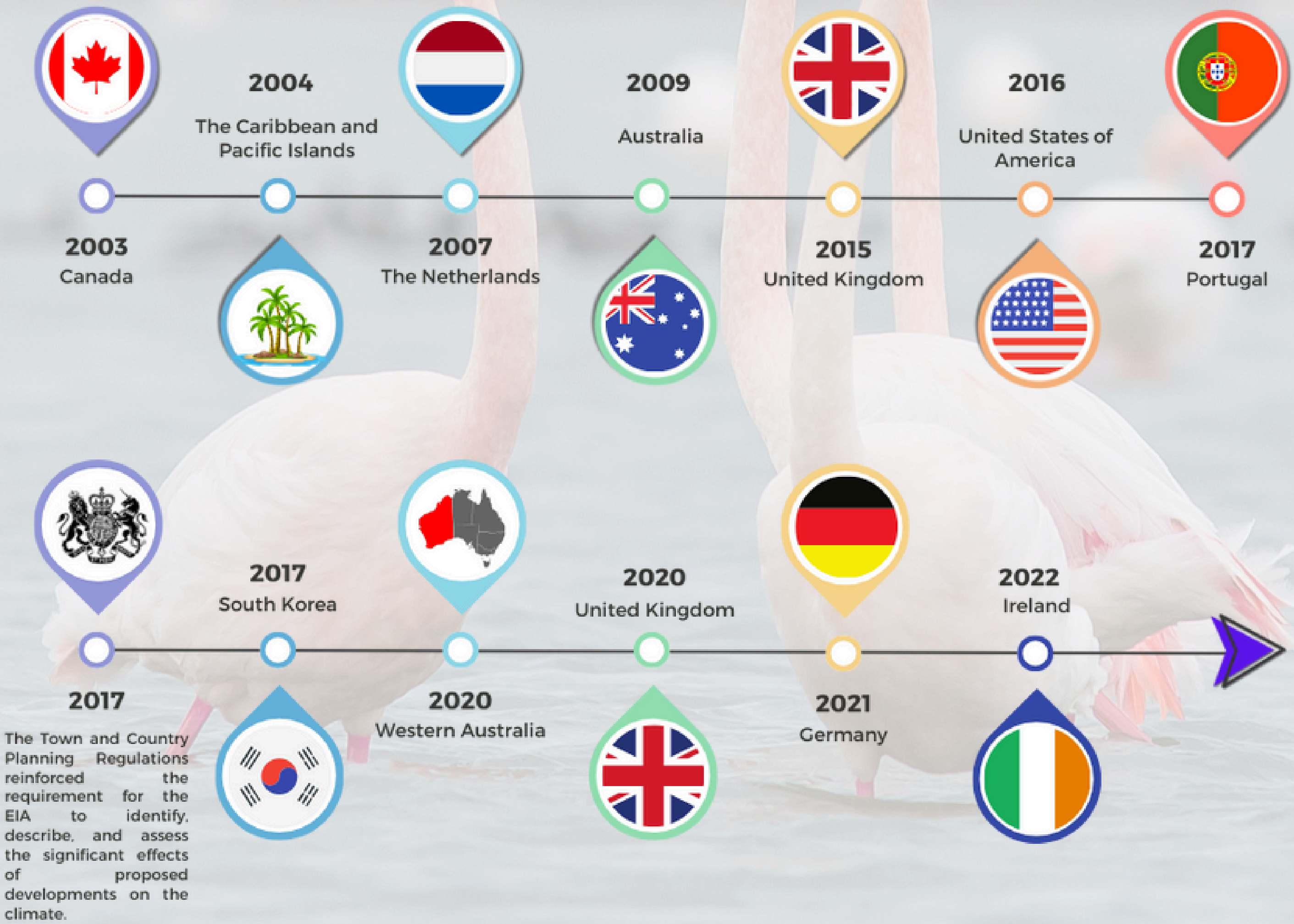
Source: Onw elaboration based on IPCC (2014)

On the other hand, Environmental Impact Assessments (EIAs) have emerged, representing thorough studies to evaluate potential consequences that may be ecological, social, and economic. By understanding the long-term impacts on biodiversity, informed decisions can be made to create strategies that protect biodiversity amidst the escalating GHG emissions described by the RCP8.5 scenario.

Initially focused on local issues, EIAs became a regulatory tool in the mid-20th century, gradually expanding to address global environmental challenges. The integration of climate change aspects into state laws marked a significant shift, recognizing its widespread impact on ecosystems. Global examples show that countries are incorporating climate change into their EIA frameworks, collectively committing to addressing anthropogenic impacts across the planet.

In the study conducted by Mayembe et al. (2023), an extensive analysis was carried out, reviewing EIA regimes integrated into state-level climate change regulations to varying degrees. Figure 2 highlights cases of complete and successful integration of climate change into EIAs, as documented by the authors.

FIGURE 2. TIMELINE OF EIA INTEGRATION IN DIFFERENT COUNTRIES



Source: own elaboration

In these regions, environmental laws require that projects align with greenhouse gas emission regulations and include discussions on climate change in their proposals. Finally, Austria, Spain, and South Africa, as well as global organizations like the World Bank and the International Finance Corporation, lead in climate change assessment, mandating that project impacts be analyzed and recognizing their importance in various standards and guidelines.

In Chile, climate change became a mandatory aspect of the law in 2023, when the Chilean Environmental Assessment Service (SEA) implemented a new mandate to raise awareness and promote mitigation in the Environmental Impact Assessment System (SEIA). Now, companies must thoroughly assess the implications of their projects on climate change, specifically under the RCP8.5 scenario (SEA, 2023).

To facilitate this process, a methodological guide was published for incorporating climate change into the SEIA (SEA, 2023). This guide recommends using a climate projection tool, ARClim, developed by the Ministry of the Environment in 2020 as a reference for assessing the impacts of climate change (MMA, 2020).

Overall, incorporating climate change considerations has become crucial in state regulations worldwide, reflecting the recognition of the need to safeguard ecosystems and biodiversity in the face of a constantly changing climate.

BACKGROUND

Global cases of biodiversity conservation in the face of climate change projections are highly valuable case studies. They help understand the complex interaction between climatic variables, habitat dynamics, and human factors.

Biodiversity, which encompasses all the variety of life on Earth and is crucial for our food, water, medicine, and climate, is at risk due to various threats. Climate change, characterized by long-term alterations in temperatures and weather patterns, has led to issues such as droughts, water scarcity, wildfires, rising sea levels, floods, polar ice melting, storms, and a decrease in biodiversity. These changes, significantly attributed to human actions, have placed around one million of the estimated eight million plant and animal species on our planet at risk of extinction (UN, 2024b; WWF, 2024).

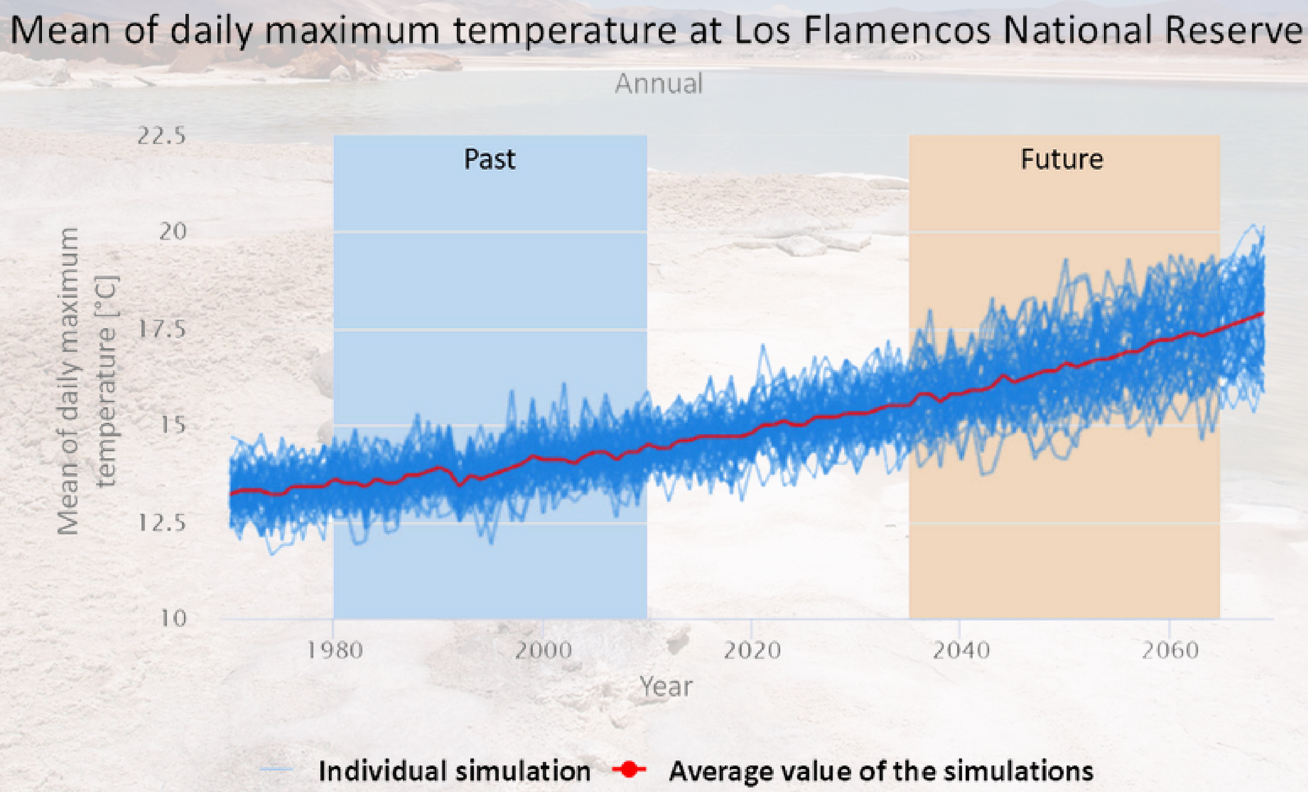
As part of this broad context, the study focuses on the abundance of flamingos in the Salar de Atacama in Chile, a region renowned for its pristine lagoons and distinctive species of Chilean flamingos (*Phoenicopterus chilensis*), Andean flamingos (*Phoenicopterus andinus*), and James's flamingos (*Phoenicopterus james*). These are migratory birds that prefer to live in warm plains with abundant water resources. Temperature changes play a significant role in the distribution of flamingos (Liang et al., 2021).

The migratory patterns of flamingos can vary depending on their species and the specific geographic region in which they live. For example, some populations of flamingos undertake seasonal migrations between breeding and feeding areas, while others move in response to changes in water levels or climatic conditions.

The RCP8.5 scenario, characterized by its pessimistic projection of greenhouse gas concentrations and global temperature increase, shows significant variation in the prediction of various climatic factors affecting biodiversity. Understanding the implications of this scenario is crucial, as these fluctuations can have profound repercussions on ecosystems, species distribution, and overall ecological health. **Figure 3** illustrates the projected variation in maximum temperature by 2069 in the Los Flamencos National Reserve within the Salar de Atacama.

The data reveal a substantial increase of 8.5 [°F] in maximum temperature for the study area when considering the period from 1970 to 2069, which is the latest year of ARClim data available to date. However, this study focused on the more immediate timeframe from 2024 to 2069, during which the temperature is projected to rise by 5.2 [°F], reaching an average maximum temperature of 64.2 [°F].

FIGURE 3. PROJECTION OF THE DAILY MAXIMUM TEMPERATURE UNDER RCP8.5 SCENARIO AT LOS FLAMENCOS NATIONAL RESERVE



Source: own elaboration based on ARClim1 (2024)

Recognizing the critical need to monitor and address the impacts of climate change at the state level, the RCP8.5 scenario is examined up to 2069 to thoroughly understand the anticipated effects of changing climatic conditions on flamingo populations. Additionally, the influences of the mining industry are explored, acknowledging its potential impact on the delicate ecosystem. Through statistical analysis of historical data, direct and indirect factors affecting bird populations were identified. The patterns derived from this analysis serve as a basis for projecting future scenarios, providing valuable insights for informed decision-making and conservation strategies in a changing environment.

[1] ARClim (Climate Risk Atlas) is a project developed by the Chilean Ministry of the Environment. This platform currently has different risk maps and projections of climate variables under the RCP8.5 scenario, which are necessary for the development of environmental instruments under current Chilean regulations.

METHODOLOGY

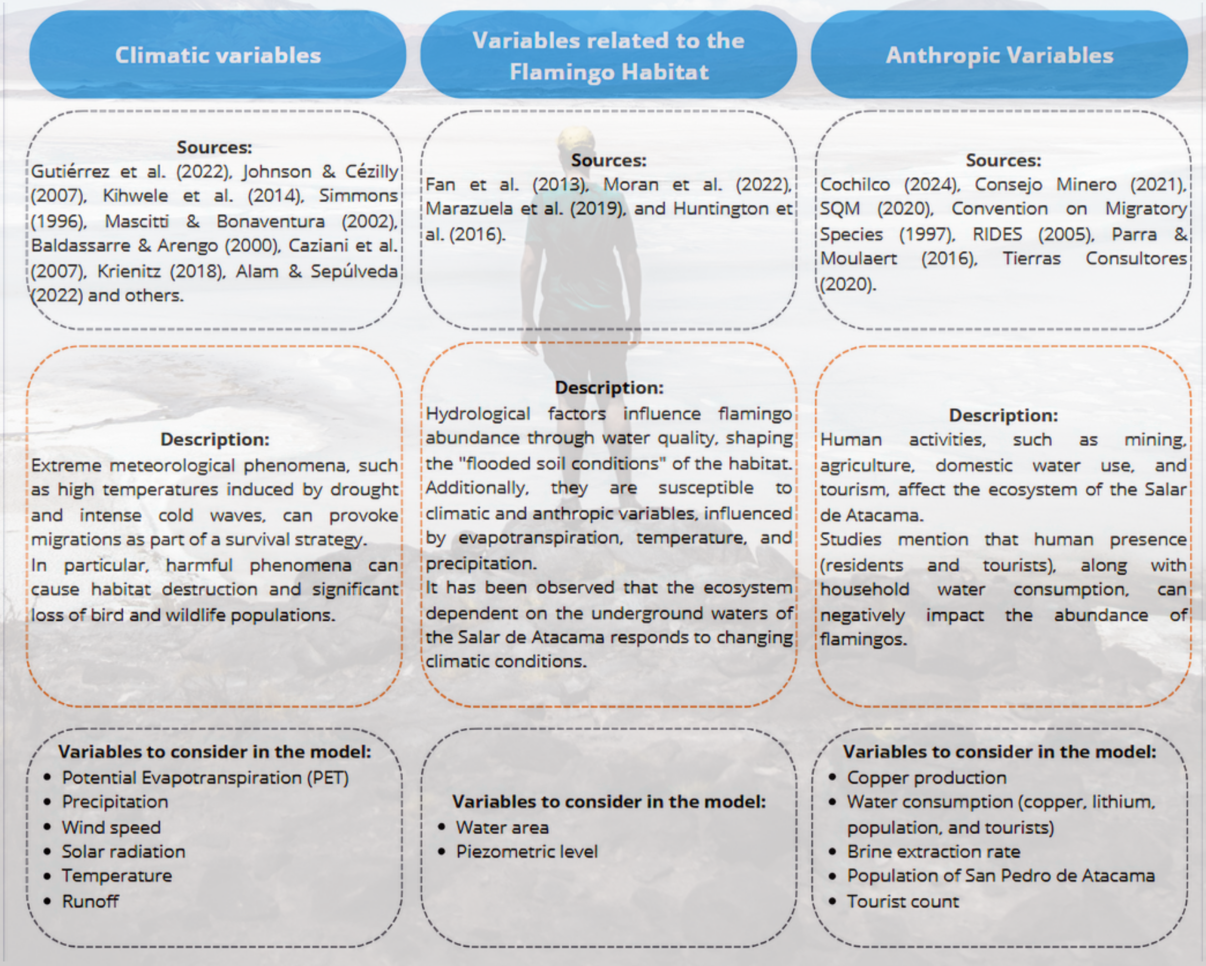
The database construction

This study analyzes the flamingo species inhabiting the lagoons of the Salar de Atacama in Chile. Specifically, it examines the three distinct species mentioned earlier: the Chilean flamingo, the Andean flamingo, and James's flamingo. Data on these species were obtained from the Ministry of the Environment (MMA, 2018a; MMA, 2014; & MMA, 2018b). The study period covers the years from 2002 to 2021 according to the data from the original source, with data collection conducted quarterly. The research focuses on five specific lagoons within the Salar de Atacama region: (i) Canal Burro Muerto, (ii) Laguna Barros Negros, (iii) Laguna Chaxa, (iv) Laguna Puilar, and (v) Lagunas Interna, Saladita, and Salada, collectively observed as a single area.

To predict the behavior of flamingo populations within the context of the RCP8.5 scenario up to 2069, it is essential to identify the factors influencing these species.

The approach involves leveraging expert knowledge and an extensive literature review to generate a comprehensive database of factors that potentially affect flamingo abundance. In addition to flamingo count values, historical data on the other analyzed variables were collected for the period 2002-2021. Data for the period 2022-2069 were obtained from ARClim or estimated using previous data. Finally, the variables subjected to testing were classified into the following three categories.

FIGURA 4. RELEVANT ASPECTS



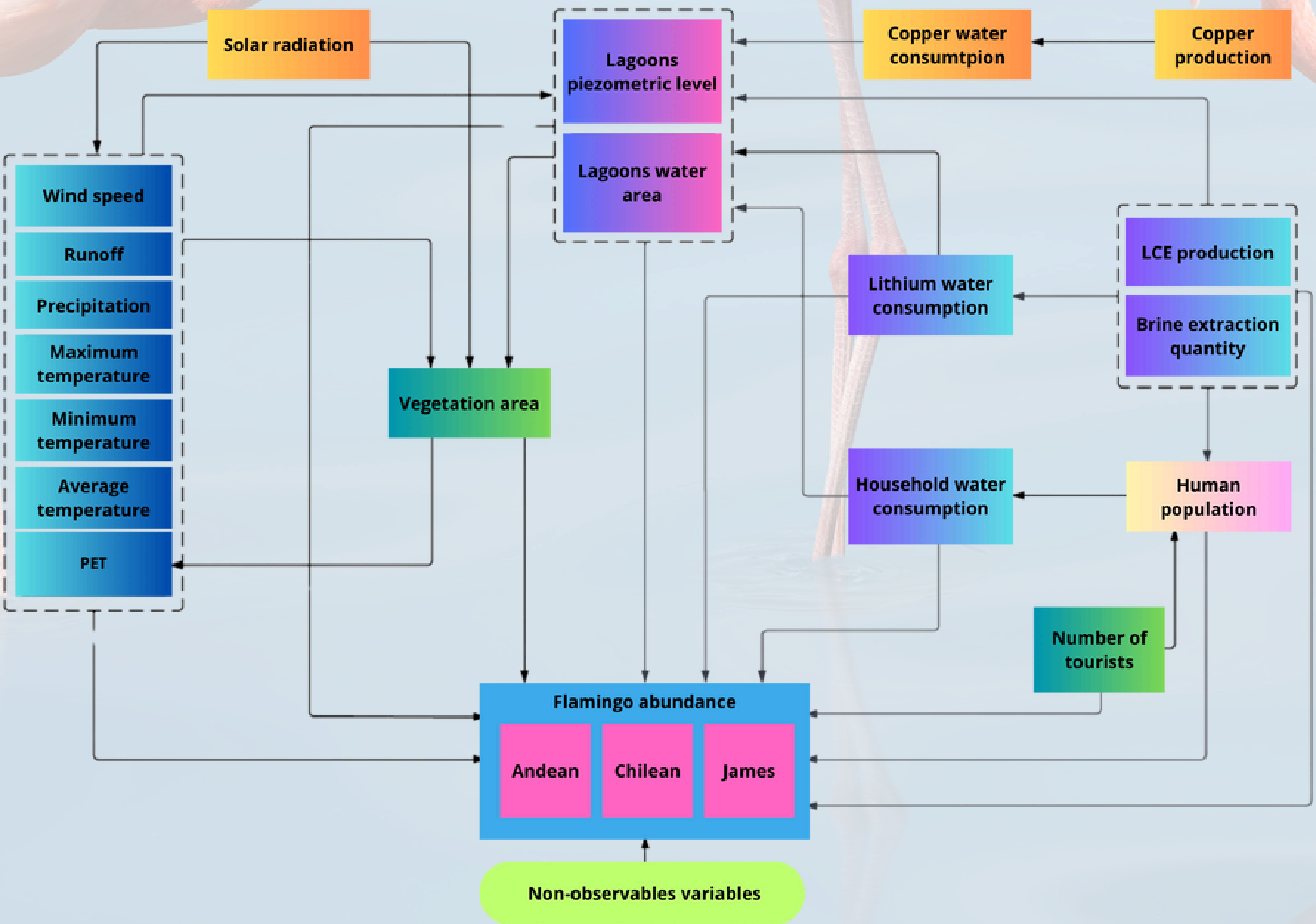
Source: own elaboration

Note: It is important to understand that many of the factors mentioned in various studies can influence the number of flamingos in several ways, either directly or indirectly. Some of these factors were difficult to assess or were not available during the study period, such as: extreme weather events, anthropogenic climate change factors, cyanobacteria blooms, availability of other food sources for flamingos, physico-chemical properties of water that may affect bird habitats, threats from predators and scavengers, water consumption related to agricultural activities and other human activities, such as egg collection, dog hunting, pollution from transportation, road construction, port infrastructure, etc.

Causal Map Concept

As previously stated, the central goal of this research is to combine GEM's expertise in mining with available information to explore how various factors can affect flamingo abundance, both directly and indirectly. Based on Shipley's (2016) causal mapping approach, the aim is to reveal the complex network of connections that influence flamingo population dynamics. This approach allows for the exploration of multifaceted influences, ranging from mining operations to ecological variables, and provides a holistic understanding of the complex ecological landscape of the Salar de Atacama. For a better understanding, see **Figure 5.**

FIGURE 5. PROPOSED CAUSAL MAP OF FACTORS POTENTIALLY AFFECTING FLAMINGO ABUNDANCE AT THE SALAR DE ATACAMA



Source: own elaboration

This map contains all the variables measured in the boxes to assess whether they potentially have a direct or indirect impact on flamingo abundance over time. Boxes with dashed borders combine groups of interrelated variables. Unmeasured variables (in circles) are grouped into a single object on the map as "Unobservable Variables."

Statistical analysis

A statistical study was conducted using the R programming language[1] to determine which variables impact flamingo abundance.

The fundamental premise is that each bird species may respond differently to the investigated factors. Regression techniques were used to model both flamingos and other important variables, such as the piezometric level of the lagoons, lagoon area, vegetation cover, water consumption related to lithium and copper mining, human water consumption, and population density.

Future projections

After calculating the parameters and establishing relationships between the variables, predictions were generated regarding the variables that affect flamingo numbers. This process was carried out for the years 2022 to 2069, with the goal of informing how flamingo population trajectories might change under the projected climatic conditions.

RESULTS

Historical data analysis

The modeling conducted allowed for thorough testing and exploration of various combinations of variables that may affect flamingo abundance in the Salar de Atacama. Utilizing the obtained database, literature review on bird behavior, and mining expertise, significant relationships were identified. These results were incorporated into 9 equations that outline fluctuations in (1-3) the count of flamingos specific to each species, (4) the piezometric level of the lagoons, (5) the lagoon water area, (6) vegetation cover, (7) lithium water consumption, (8) household water consumption, and (9) the population number in the basin. Independent variables for each equation were selected using a 90% confidence interval. Additionally, to account for potential unforeseen factors, a measurement error variable was included in the estimates. This means that some flexibility was allowed to address other possible factors that could affect the study results. Therefore, there are three separate equations for Andean, Chilean, and James's flamingos, and seven additional equations involving variables unrelated to flamingo abundance, which are identical across all bird species and lagoons.

(1-3) Flamingo abundance

When examining the factors influencing Andean flamingo species, the derived equation provided the following insights: (1) The count of Andean flamingos is directly related to potential evapotranspiration, average temperature, and tourist flow in the area. Additionally, there is competitive interaction with the Chilean flamingo population and a cooperative relationship with James's flamingos. On the other hand, (2) the number of Chilean flamingos is primarily affected by maximum temperature, the amount of vegetation in the area, and competition with the James's flamingo population. Finally, (3) the count of James's flamingos is influenced by: minimum temperature, the presence of other Andean bird species that collaborate with flamingos, and competition with the abundance of Chilean flamingos in the area.

(4) Lagoons' Piezometric level

The piezometric level of the lagoons appears to be negatively affected by maximum temperature and positively influenced by lagoon water area, vegetation cover, and household water consumption associated with increased numbers of residents and tourists.

(5) Lagoons' water area

The water surface area of the lagoons is negatively affected by climatic variables such as precipitation, minimum temperature, and runoff. Significant factors associated with anthropogenic activities include those related to lithium extraction and household water consumption.

(6) Vegetation area

The anticipated results suggested that climatic variables would have a significant direct influence on vegetation cover, which, in turn, proved to be a significant factor positively affecting the abundance of Chilean flamingos. Precipitation showed a positive impact, while maximum temperature had a negative contribution, as expected.

(7) Lithium water consumption

Changes in water consumption associated with lithium extraction operations by major producing companies were observed. The production of lithium carbonate equivalent (LCE) was examined but did not show any significant relationship with the study variables. The results revealed that the main factor influencing lithium water consumption is the brine extraction rate. The analysis evaluated the seasonality of brine extraction variables from the two leading lithium companies. To remove trends, the first difference of the series was taken, reflecting variations in extraction rates over time. The results indicated a negative correlation, to varying degrees, between the variables of Company X (with 95% confidence) and Company Y (with 80% confidence) and the total water consumption in the lithium industry.

(8) Household water consumption

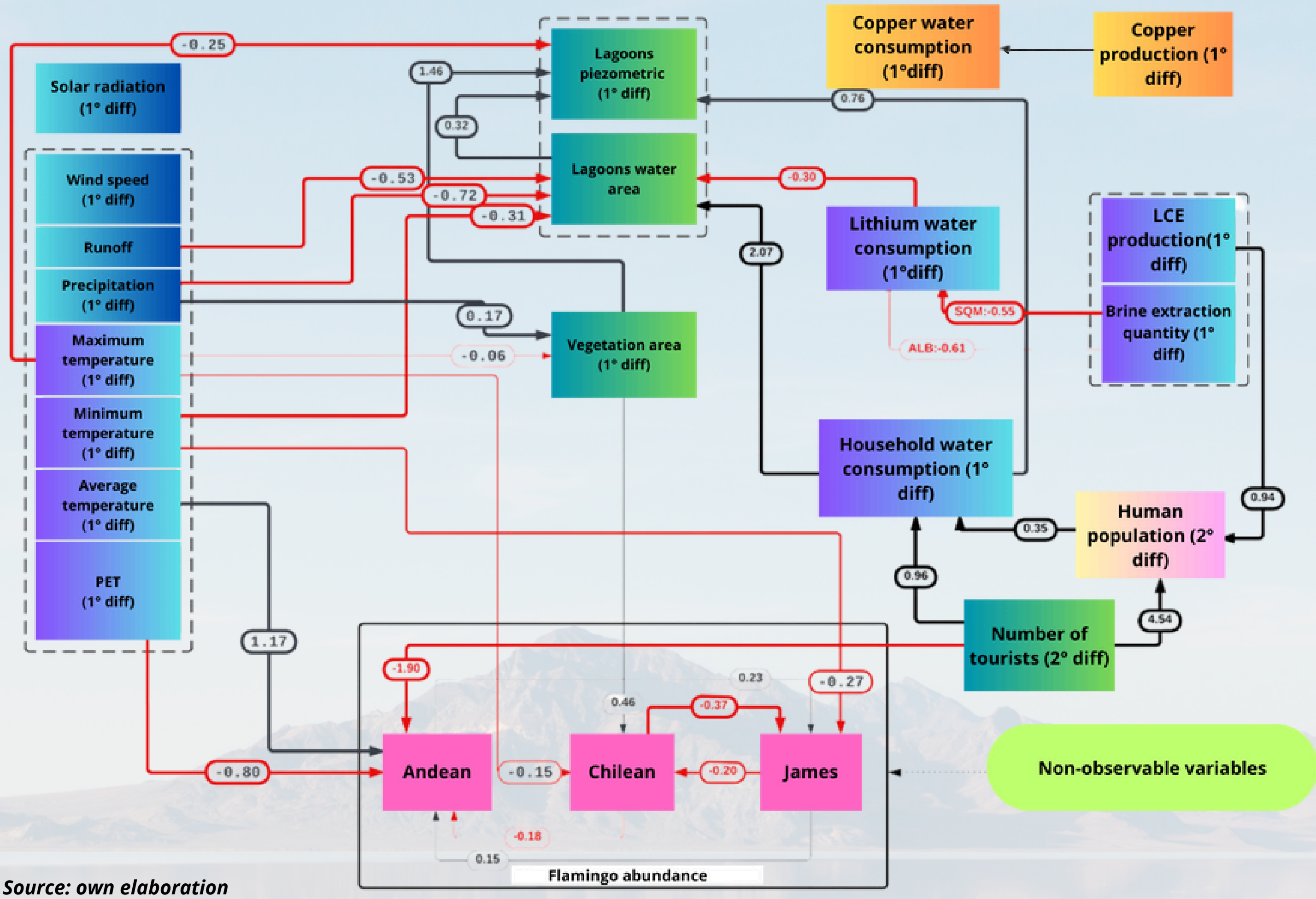
As anticipated, there is a direct positive correlation between household water consumption and both the number of residents and tourists. The expected link between these variables highlights the influence of demographic factors on household water demand, underscoring the importance of considering population growth and tourism dynamics when assessing water consumption patterns.

(9) Population number

The final observation illustrates that the population of San Pedro de Atacama is positively influenced by the number of tourists. Evidently, the continued influx of tourists to one of the most unique places not only in South America but also in the world has played a favorable role in the region's demographic growth. Consequently, the increasing number of residents and visitors has significantly contributed to overall water consumption rates. Another key factor appears to be lithium carbonate equivalent (LCE) production. As a vital economic driver for the region, lithium production and its subsequent expansion attract people to the area, whether in search of employment opportunities or due to the burgeoning industrial development infrastructure.

Therefore, understanding the complex relationships between independent and dependent variables is crucial for determining how climatic, anthropogenic, and habitat-related factors affect the dynamics of flamingo populations in the studied region. Based on the statistical results and the proposed causal map shown in **Figure 4**, a detailed causal map has been developed and is presented below **(Figure 6).**

FIGURE 6. COMPREHENSIVE CAUSAL MAP OF THE FACTORS INFLUENCING FLAMINGO ABUNDANCE IN THE SALAR DE ATACAMA (2002-2021)



Source: own elaboration

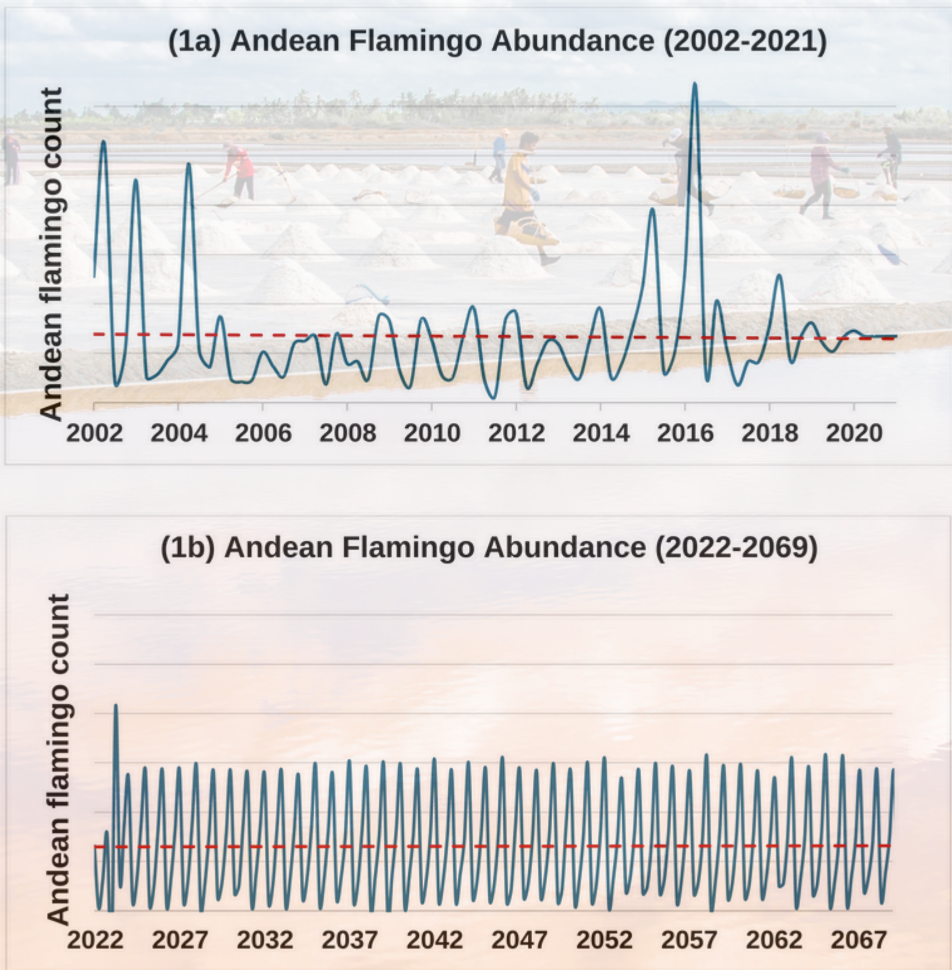
The comprehensive causal map consolidates the variables influencing flamingo abundance in the Salar de Atacama from 2002 to 2021. Dashed boxes group interrelated variables, while black and red trajectories denote positive and negative influences, respectively. The numerical values represent the magnitude of each variable's impact on flamingo abundance.

Flamingo abundance projection

The statistical analysis of historical data, as previously explained, was used to predict how flamingo abundance might respond to the projected RCP8.5 scenario. This analysis considered the dynamics of cooperation and competition among the different species, providing valuable insights for understanding and strategically planning under varying environmental conditions.

During the specified period (2022-2069), it is projected that the population of Andean flamingos will decrease by 1.9%. Similarly, the Chilean flamingo population is expected to decline by 5.6%, while James's flamingos are anticipated to experience a modest increase of 1.1%, as illustrated in Figure 7.

FIGURE 7. COMPARISON OF THE ABUNDANCE OF THE FLAMINGO SPECIES INHABITING THE SALAR DE ATACAMA OVER THE 2002-2021 PERIOD VS. 2022-2060 PROJECTIONS UNDER CLIMATE CHANGE IMPACT



Source: own elaboration

IHistorical trend (2002-2021) and future projection (2022-2069) of flamingo abundance. Historical abundance of (1a) Andean, (2a) Chilean and (3a) James' flamingo species inhabiting the Salar de Atacama. And projected abundance of (1b) Andean, (2b) Chilean and (3b) James' flamingo species with climate change impact.

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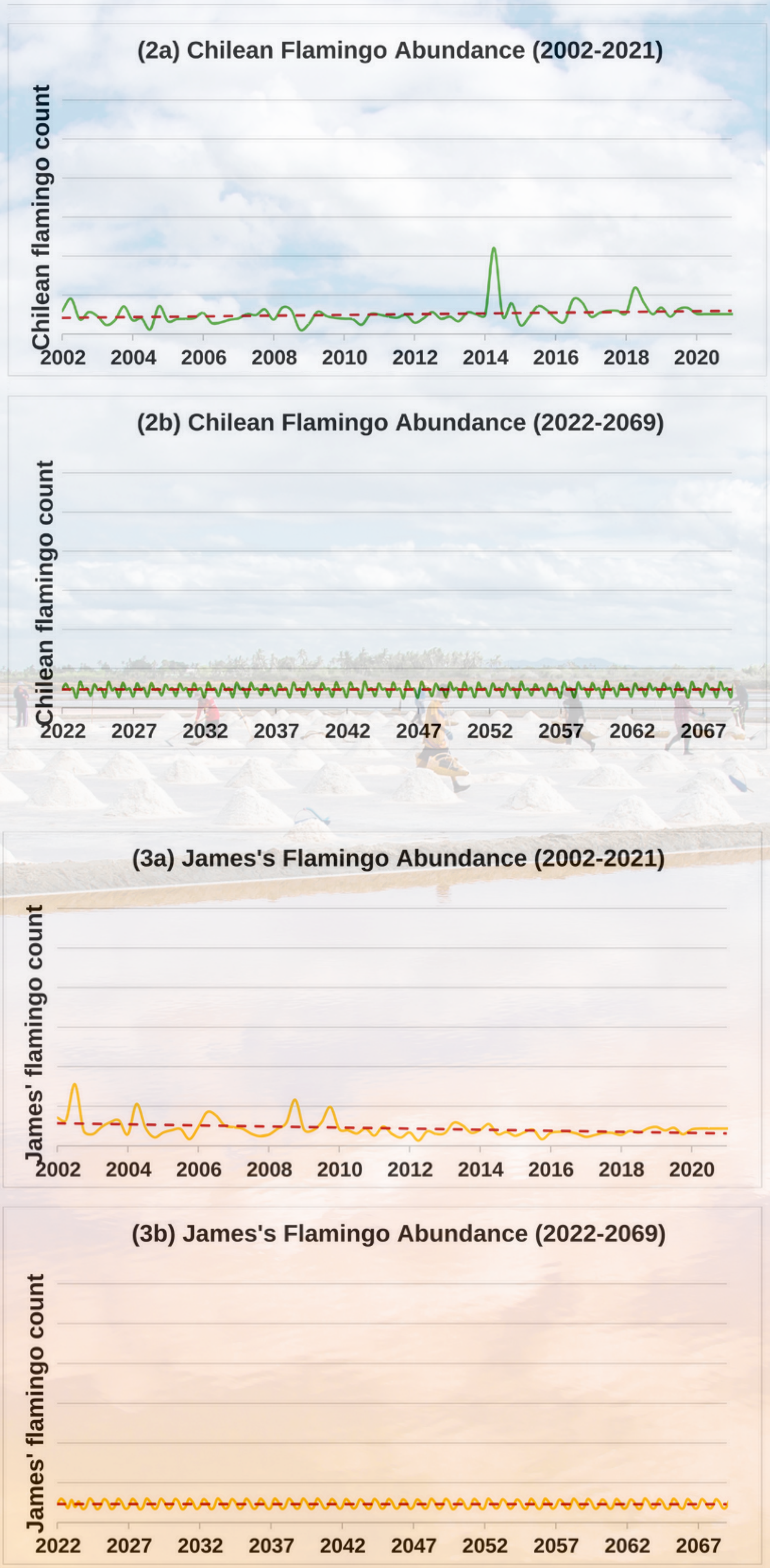
FIGURE 7. COMPARISON OF THE ABUNDANCE OF THE FLAMINGO SPECIES INHABITING THE SALAR DE ATACAMA OVER THE 2002-2021 PERIOD VS. 2022-2060 PROJECTIONS UNDER CLIMATE CHANGE IMPACT (CONT.)



Source: own elaboration

DISCUSSION

Evaluation of climate change impact on the flamingo abundance

The three species appear to be exposed to the temperature regime of their habitat, as shown in **Figure 5**. Additionally, while Andean flamingos may also be negatively affected by potential evapotranspiration, Chilean flamingos depend on vegetation cover, which in turn is influenced by variations in precipitation and maximum temperature, and thus is included in the discussion. As expected, the Andean flamingo species proved to be vulnerable to expanding anthropogenic activity, such as tourism, reacting negatively to the number of visitors to the Reserva Nacional Los Flamencos.

This research also highlights a complex interaction between the flamingo species. Specifically, a competitive dynamic is observed between Andean and Chilean flamingos, indicating that these two species may be competing for similar resources or habitats. In contrast, the Andean flamingo appears to engage in a cooperative relationship with James's flamingo, suggesting a mutually beneficial interaction, possibly in terms of shared habitats or complementary resource use. Additionally, a competitive relationship persists between Chilean and James's flamingos, implying potential competition for resources. Each equation individually supports these interspecific relationships.

The flamingo species interact based on their dietary preferences. Andean flamingos prefer larger algae, while James's flamingos favor smaller algae. This difference promotes cooperation between them. However, they compete with Chilean flamingos, which share similar dietary preferences, creating a competitive dynamic (Jamali et al., 2012; Brown & King, 2005; Rodríguez et al., 2005). **These intricate relationships highlight the need for a comprehensive understanding of the ecological dynamics to support conservation strategies and habitat management for these unique bird species.**

After a thorough evaluation, it is evident that under the RCP8.5 scenario, variations in mean temperature significantly impact Andean flamingos, accounting for approximately 51% of the population reduction from 2022 to 2069. For Chilean flamingos, vegetation area plays a substantial role, contributing around 44% to the impact on population reduction during the same period. This implies that precipitation and maximum temperature affect the abundance of this flamingo species. However, maximum temperature alone accounts for 22% of the population impact for the observed period. Lastly, for James's flamingos, minimum temperature has a considerable impact, constituting 33% of the population reduction during 2022-2069. **Essentially, climate change has pronounced effects on each flamingo species, particularly through temperature fluctuations, highlighting the importance of addressing these variations in conservation efforts.**

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Evaluation of mining related activities impact on the flamingo abundance

So far, the results indicate that current mining activities, including copper and lithium production, brine extraction, and water consumption, are not statistically significant factors influencing the abundance of flamingos inhabiting the lagoons of the Salar de Atacama, either through direct or indirect relationships.

Technological advancements in the Chilean mining sector could be a potential factor explaining the lack of correlation between mining variables and flamingo abundance. For example, in the case of lithium production, some companies have adopted innovative approaches. Company Y's agreement with CRAMSA involves using desalinated seawater, relinquishing water rights in the Salar de Atacama by 2027 (CRAMSA, 2023). Similarly, Company X's new project is committed to implementing various changes to achieve a positive water balance by 2030.

Additionally, regulatory restrictions on brine extraction ensure that Companies Y and X adhere to the maximum extraction limits prescribed. Company X has voluntarily committed to exceeding these regulatory requirements by significantly reducing brine extraction compared to legal limits. In the context of copper production, some mining companies in the Salar de Atacama have transitioned to using seawater since 2020. This shift has effectively eliminated the use of lagoon water inhabited by flamingo species (Brion, 2020).

In recent years, mining operations in the Salar de Atacama have faced numerous criticisms, particularly regarding their potential negative impact on the unique biodiversity of the region, with a particular focus on concerns about flamingo species. For example, CONAF's report indicated a decline in the number of Andean flamingo eggs during 2017-2019, along with a substantial decrease in the total flamingo population.

The negative effects are attributed to factors such as salinity, alteration of water levels, and changes in flora and fauna (Carrere, 2020). Some argue that climate change, unregulated tourism, and lithium extraction operations in the area pose a threat to rare flamingo species (Circular País, 2023). However, mining operators argue that environmental monitoring demonstrates the ecosystem's integrity (Livingstone, 2019). Contradictory opinions persist regarding the extent of the direct impact caused by lithium mining on flamingo abundance, with some studies highlighting minimal influence compared to other factors mentioned earlier (Gutiérrez et al., 2022).

Despite these concerns, various publications also highlight positive outcomes, such as the record of over 800 Andean and Chilean flamingo chicks born in the Atacama Region, marking a notable population increase (Barrera Campos, 2023).
A press release from CONAF dated April 1, 2024, indicates that the annual summer census in the high Andean salt flats of the Reserva Nacional Los Flamencos in the Antofagasta region recorded a total of 18,078 flamingos, with a high presence of young flamingos. Of the counted flamingos, 50% are concentrated in the Salar de Pujsa, with 7,573, and the Salar de Tara, with 5,392.

A recent article references conservation specialist Enrique Derlindati, whose meticulous observations of Andean flamingo nesting in the Puna region of Argentina provide valuable guidelines for directing future exploration and exploitation activities in the corresponding areas (Jemio, 2024). The researcher suggests that mining could be conducted with less environmental impact, citing examples from Chile where mining companies avoid operating during nesting periods and consider alternative extraction techniques.

Therefore, this comprehensive review reveals the complexity of the causal system of variables affecting the flamingo population in the Salar de Atacama and how various factors must be investigated to determine their potential impact on the region's biodiversity. **In particular, climatic factors and temperature variations emerge as predominant influences, along with the human impact of tourism. Conversely, the impact of industrial development has not been conclusively demonstrated to date**. In the Lithium Triangle, the number of flamingos in recent years has remained stable. Future research should delve deeper into this aspect, covering a prolonged period, to unravel its potential implications for the local ecosystem.

CONCLUSION

This study concludes that **current mining activities, including copper and lithium production, brine extraction, and water consumption, do not exert a direct impact on flamingo abundance.** Technological advances in the mining industry, such as the use of seawater and desalination, along with stricter regulations, contribute to this seemingly less intrusive relationship. However, delving into the potential consequences of the RCP8.5 scenario up to 2069, **climate change does pose a significant threat to these iconic bird species.**

Through the analysis of historical data and future projections under the RCP8.5 scenario, identifying the relationships between climatic, habitat, and anthropogenic variables, it was possible to reveal the dynamics influencing the abundance of Andean, Chilean, and James's flamingo populations. In particular, **temperature variations caused by climate change emerge as a dominant factor affecting flamingo abundance, predominantly harming Andean and James's flamingos.** The study indicates that flamingo species will respond differently to future climate conditions. While Andean and Chilean flamingos compete with each other, the Andean species exhibits a cooperative relationship with James's flamingos. These complex interspecies relationships highlight the importance of comprehensive ecological management and conservation strategies.

The Salar de Atacama is at a crossroads between ecological sensitivity and industrial progress, facing growing challenges due to the increasing impacts of climate change. Given the urgent need to implement adaptive conservation measures, the new regulations under Law N°19.300 on the General Environmental Framework, which establish the SEIA regulations, provide a timely and effective framework to address the complex environmental dynamics of the region. This pioneering EIA standard offers a comprehensive tool for evaluating and mitigating the environmental consequences of industrial activities, perfectly aligning with the methodology of this study to assess the interaction between climate variables, habitat-related factors, and anthropogenic influences on flamingo abundance. The study also suggests a methodology and a climate projection database (ARClim), which was utilized in this research. Therefore, the proactive application of the new EIA approach is encouraged, urging companies to adopt this robust framework as a fundamental step towards achieving sustainable development.

By implementing the methodology presented in the study, companies operating in the Salar de Atacama region can proactively assess and manage the impact of climate change on biodiversity. This approach will enable them not only to meet regulatory requirements but also to foster a genuine and proactive commitment to environmental management.

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