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10 authors, including:

Wed Abdellatif Ibrahim Abdou
Egyptian Ministry of State For Environmental Affairs

Hichem Azafzaf
Association "Les Amis des Oiseaux" (AAO/BirdLife in Tunisia)

Arnaud Béchet
Tour du Valat

Mohamed Dakki
Mohammed V University in Rabat - Institut Scientifique

BREEDING AND WINTERING POPULATION TRENDS OF THE GREATER FLAMINGO IN THE MEDITERRANEAN OVER A 30-YEAR PERIOD (1990-2021).

Laura Dami[1], Wed Abdou[2], Antoine Arnaud[1], Hichem Azafzaf [3], Arnaud Béchet [2], Nadjiba Bendjedda[4], Khalil Baddour[1], Mohamed Dakki[5], Ugoline Godeau[1], Khaled Etayeb [6]

[1] Tour du Valat, Institut de recherche pour la conservation des zones humides méditerranéennes, Le Sambuc, 13200 Arles, France, dami@tourduvalat.org
[2] Egyptian Environmental Affairs Agency, 30 Misr/Helwan Road, PO 11728, El Maadi Helwan, Egypt
[3] Association "Les Amis des Oiseaux" (AAO/BirdLife en Tunisie), 14, Rue Ibn El Heni, 2ème étage – Bureau N° 4, 2080 Ariana, Tunisia
[4] Direction Générale des Forêts, Ben Aknoun, Alger, Algeria
[5] Scientific Institute, Mohammed V University of Rabat, Av. Ibn Battota, 10106 Rabat-Agdal, Morocco
[6] Zoology Department, Faculty of Science, The University of Tripoli, Alfornaj, P.o.Box: 13227, Tripoli, Libya

Abstract

The Greater Flamingo (Phoenicopterus roseus) is listed in the appendices of several international conservation agreements including the Barcelona Convention. We combined 30 years of data from the International Waterbird Censuses (IWC) across North Africa, coordinated by the Mediterranean Waterbirds Network (MWN), with over 30 years of monitoring by the "The Network for the study and conservation of the Greater Flamingos in the Mediterranean and West Africa" to assess trends of the species in the Mediterranean basin. Wintering bird count data were analysed using a new statistical approach called LORI, while breeding data were summarized through descriptive analyses. The number of breeding pairs in the Camargue, as well as across the broader Mediterranean region, has generally increased over the past few decades. A similar trend has been observed for wintering flamingos in North Africa. In the last five years, both breeding and wintering populations appear to stabilize despite important fluctuations from year to year. Strengthening the link between breeding and wintering monitoring networks could provide critical insights into emerging trends and underlying causes of these changes.

Key-words: Greater Flamingo, Mediterranean region, trends, breeding populations

Introduction

The Greater Flamingo *Phoenicopterus roseus* is listed in the appendices of several international conservation agreements including the Bern Convention (1979), the Bonn Convention (1983), the EU Birds Directive (79/409/EEC), and the Barcelona Convention (1976). It exhibits a widespread distribution with an estimated population exceeding half a million individuals worldwide. This population is distributed across various regions, including West Africa (estimated at 45,000–90,000 individuals), South Africa (around 50,000), East Africa (approximately 35,000), the Mediterranean (around 200,000), and the Middle East and Southeast Asia (around 200,000) (Béchet *et al.* 2017).

In the Mediterranean, flamingos are partial migrants, with individuals flying southward from European sites to winter in North African wetlands, while others remain in Europe, particularly in countries where winter is mild (Sanz-Aguilar *et al.* 2012). Mediterranean and West African flamingos constitute a single metapopulation because of substantial rates of natal and breeding dispersal among colonies of the region (Balkız *et al.* 2007; Diawara *et al.* 2007; Johnson and Cezilly 2007).

Despite this widespread population, the Greater Flamingo remains a fragile and vulnerable species, with few breeding sites in the Mediterranean (<20) and highly variable breeding success. The Greater flamingo does not tolerate any disturbance during incubation and until the chick leaves the nest, otherwise the adults will abandon the colony. Numerous cases of human or animal disturbance have been documented (Johnson and Cézilly 2007). Nesting sites remain threatened by urbanization and water management practices, such as the diversion of water for irrigation (Béchet 2017). If climate change would contribute, as some models predict, to a rise in the level of the Mediterranean Sea, this would expose some of these sites to submersion with unpredictable effects on the dynamics of this population (Verniest *et al.* 2023).

In the north of the Mediterranean, the Greater Flamingo has benefited from several conservation efforts which have consisted in building and securing breeding islands, either in France (Johnson 1982) or in Spain (Rendón-Martos *et al.* 1996). Even if this has resulted in increasing breeding frequency and productivity of the species in the last 40 years locally (Béchet *et al.* 2012), the effect on the overall trend of the species' population in the Mediterranean has remained undocumented.

Since 2002, coordinated monitoring of nesting colonies across the Mediterranean has been conducted through the Network for the study and conservation of the Greater Flamingo (Béchet *et al.* 2006). This initiative involves recording breeding pairs and chicks fledged at ten to 20 key sites to track trends in the breeding success of the species in the Mediterranean region. Flamingos have also been counted in North Africa during the International Waterbird Census (IWC). This monitoring program, which covers more than 140 countries, collects crucial data on waterbird populations in wetlands, helping to identify trends and inform national management policies and international agreements such as AEWA and Ramsar Convention (Delany 2005; van Roomen *et al.* 2011; Wetlands International 2014; Nagy and Langendoen 2020). Here, we present trends in Greater Flamingo breeding numbers in the Mediterranean region over a 30-year period (1990-2021) together with wintering trends in North Africa over the same period.

Materials and methods

Breeding numbers in the Mediterranean and West Africa

Each year from 1990 to 2002, the Flamingo Specialist Group encouraged thorough efforts across the Mediterranean to identify all possible flamingo breeding sites. In 2002, the initiation of the Network for the study and conservation of the Greater Flamingo in the Mediterranean and West Africa, allowed to consolidate historical data and members of the network were committed to send breeding surveys of their site to Tour du Valat as the coordinator of the network. Once a breeding site was found, the number of breeding pairs and the number of chicks fledged were recorded using either estimate from the ground or count on pictures made from a plane or a drone depending on the sites. Counts of breeding pairs were generally made in May, when peak numbers (as suggested by field observations) were incubating and the crèches were counted ~15 days before the first chicks fledged when they are no longer vulnerable to predation (Béchet and Johnson 2008). Here, we make the assumption that no major breeding site were missed over the Mediterranean basin during the 30 years of the survey (1990-2021) so that no particular correction was necessary for computing trends.

Wintering numbers in the Mediterranean

The IWC in North Africa experienced low participation prior to 2012. In response, the Mediterranean Waterbird Network (MWN) was established to enhance both the quantity and quality of waterbird monitoring across the region. This collaborative network, involving the five North African countries, the Tour du Valat (serving as the network coordinator), and the Office Français de la Biodiversité (French Biodiversity Office), facilitated the development of training tools, secured funding to support fieldwork, and promoted research efforts across North Africa (Nagy *et al.* 2015; Mediterranean Waterbirds Network 2024).

Limited human and technical resources have for long constrained national networks to perform regular and comprehensive censuses, particularly in remote wetlands spanning thousands of kilometres (Dakki *et al.* 2001; Sayoud *et al.* 2017). As a result, the IWC database for North Africa contains significant gaps in data (62% of missing data), hampering simple assessment of species trends using conventional methods. To address this issue, a novel statistical approach was developed to yield reliable results despite the high rate of missing data. This method called the Low-Rank Interaction (LORI) model, is based on penalized Poisson models to impute and analyse incomplete monitoring data in a large-scale framework. Taking advantage of the Lasso penalty, the LORI method has the capacity to integrate many environmental covariates, as well as time-space interactions. This brings improvement over standard approaches by incorporating more information, reducing autocorrelation, as well as estimating outliers, including for reasonably over-dispersed or zero-inflated count distributions (Dakki *et al.* 2021; Robin *et al.* 2019). This allows parameterization of (a) space and time factors, (b) the main effects of predictor covariates, as well as (c) space-time interactions. In a missing data imputation perspective, incorporating additional covariates provides an opportunity to improve the prediction of missing entries, as these could be good predictors of species counts (Amano *et al.* 2018). We used this method to analyze data from the IWC in North Africa to assess population trends of the Greater Flamingo between 1990 and 2021. We modelled the time-trend and spatial distribution of the Greater Flamingo in North Africa using 21 covariates. We performed multiple imputations (with the 'mi.lori' function of LORI package in R, Robin *et al.* 2019), to obtain 100 imputed values for each site and year as well as 100 estimates of covariance effects. Based on the outputs of the multiple imputation, we plotted the estimated population sizes over time using boxplots to represent the 100 posterior draws. These were accompanied by a Generalized Additive Model (GAM) smooth line (fitted with the ggplot2 package, Wickham 2016) to highlight overall temporal trends. Additionally, the estimated effects of covariates were also represented as boxplots, summarizing the distribution of the 100 draws for each effect.

Our choice of each covariate was governed by a priori hypothesis listed below (Tab. 1):

Table 1. List of hypotheses guiding covariate selection for the LORI model using winter counts data of greater flamingos

HYPOTHESES
* The field experience of a country's team of ornithologists, site accessibility, road infrastructure and/or the political situation and governance in the country could affect sampling and detection processes and, as a result, the abundance estimates on a national level (Amano *et al.* 2018). (i.e.: country's counts, distance from the nearest city).
* Gross Domestic Product growth rate per country and per year (i.e. performance of the economy) was used as a proxy for governance, which has been shown to be a major driver of waterbird conservation (Amano *et al.* 2018).
* Wetland surface area is a primary predictor of waterbird abundance, a proxy of which was provided by the maximum water extent extracted from the Global Surface Water dataset (De Goeij *et al.* 1992; Pekel *et al.* 2016).
* Site-specific flooding is a primary predictor of habitat availability and hence abundance of waterbirds. The sum of autumn/winter precipitation per site and per year (rainfall) was used as a proxy of yearly hydroperiod.

HYPOTHESES
* Agriculture is one of the major drivers impacting bird communities at a large scale: for example, through habitat loss and reclamation. Percentage of farmland per year and per country was used to index this impact (Gaston *et al.* 2003; Teyssèdre and Couvet 2007; Vickery *et al.* 2014).
* Altitude and distance from the coast covariates were used to compare low-altitude coastal lagoons and inland wetlands (e.g. chotts, sabkhas or reservoirs) and mountainous areas or plateaus. The combination of low altitude and proximity to the coast was used as a proxy for the threatened ecosystems of Mediterranean lagoons, a preferred habitat for several wading species (Dakki *et al.* 2001; Qninba *et al.* 2007; Ayache *et al.* 2009; Hüttich *et al.* 2012).
* Distance from the nearest urban agglomeration was used as a proxy both for wetland monitoring accessibility and potential impact of disturbance and/or pollution. Hence, this covariate could potentially negatively or positively impact the detection of waterbirds.
* As for any living organism, habitat is a primary influence on abundance and was thus indexed under 3 ecosystem macro groups ('Temperate & Boreal Forest', 'Shrubland & Grassland', 'Desert & Semi-Desert').
* Dams can positively or negatively affect waterbird abundance through habitat modification; some dams were created in the course of the time-series of counts we used, with a likely ecological impact on the waterbird community (El Agbani *et al.* 1996; Bergkamp *et al.* 2000; Dakki *et al.* 2011).
* Spring temperature and precipitation anomalies in breeding areas can affect reproduction and thus the abundance of birds subsequently migrating from northern Europe to North Africa (Forcey *et al.* 2011; Pavón Jordán *et al.* 2017).
* Winter temperature anomalies in wintering areas of southern Europe, especially lower-than-average temperatures, could influence migration numbers to North Africa, notably in the case of cold spells.
* The North Atlantic Oscillation (NAO) was used as a synthetic proxy for the yearly weather conditions affecting waterbirds in their wintering range and annual displacements between Europe and North Africa (Pavón Jordán *et al.* 2019).

Results

In the Camargue the main breeding colony in the Fangassier lagoon (Salin-de-Giraud) shows an increasing trend in the number of breeding pairs of greater flamingos from 1990 to 2000 and a stabilization afterward (Fig. 1). There is a notable peak in 2000 when flamingos used both their historical breeding site in the Fangassier lagoon and a nearby artificial island built for terns. In 2007 and 2014 there was complete failure of breeding and in 2015 flamingos moved to a new breeding site in the saltpans of Aigues-Mortes. The number of fledglings follows a similar trend to breeding pairs but has experienced a slight decline in recent years (Fig. 1).

At the Mediterranean level, the total number of breeding pairs and chicks gradually increased over the year, likely driven at least in the first decade by the increase in the number of breeding colonies used regularly (Fig. 2).

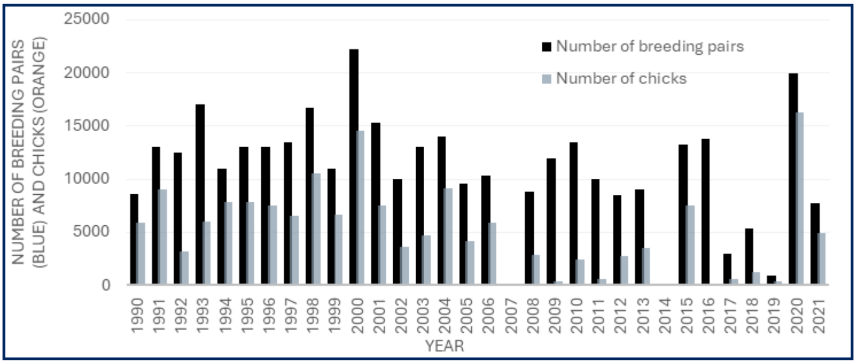

Figure 1. Number of breeding pairs and number of chicks of the Greater Flamingo in the Camargue, south of France, from 1990 to 2021.

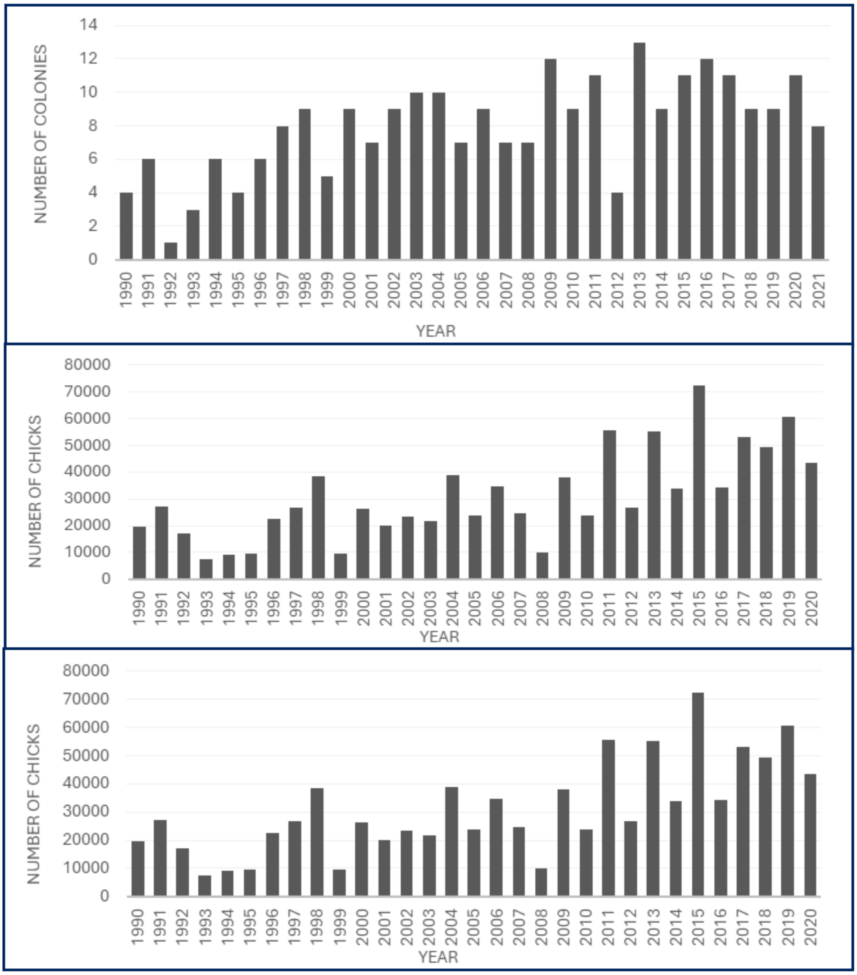

Figure 2. Number of Greater Flamingo colonies, breeding pairs, and fledglings in the Mediterranean region from 1990 to 2021.

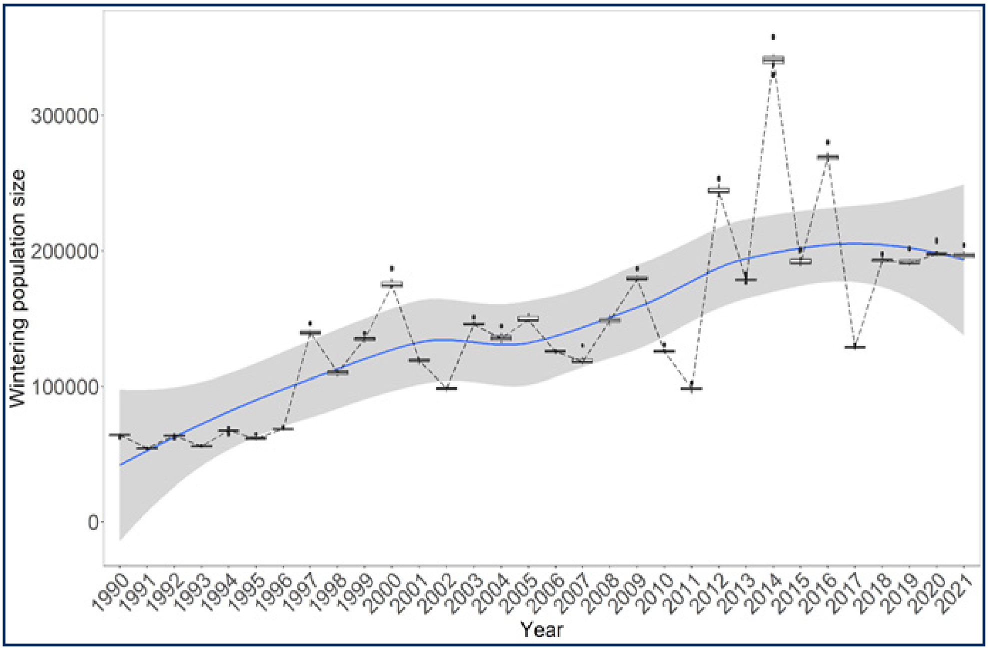

Figure 3. Winter population size of the Greater Flamingo in the Mediterranean (1990-2021). Boxplots based on 100 draws resulting from multiple imputations. The blue line is the smooth curve (with 95% Cis in grey) from a Generalized Additive Model fitting the observed data.

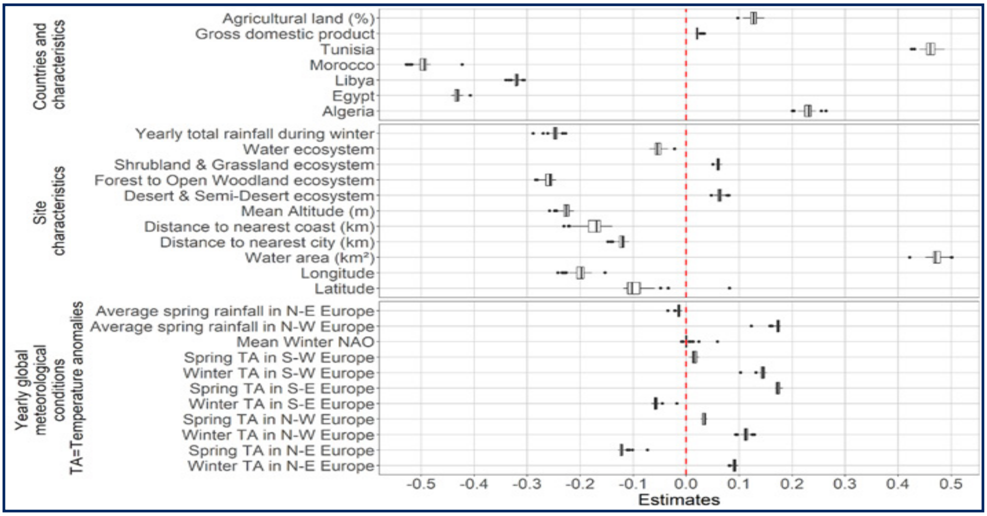

Figure 4. Effects of covariates on spatial and temporal variations in Greater Flamingo winter population size using IWC data as multi-imputed by the LORI method. Boxplots based on 100 draws resulting from multiple imputations.

Using the LORI method to impute count matrices for the Greater Flamingo's wintering numbers, we estimated the long-term trends for the wintering population of the species at the North African scale (Fig. 3).

This imputation-based statistical method also allowed the identification of covariates that may significantly influence species trends (Fig. 4).

IWC showed that Greater Flamingo populations in North Africa increased steadily until 2017, after which a slight decline was observed (Fig. 3). This imputation-based statistical method also allowed the identification of covariates that may significantly influence species trends (Fig. 4). These population trends are primarily influenced by the availability of water surface area and census data from Tunisia, with moderate contributions from Algeria's census data and the extent of agricultural land (Fig. 4).

Discussion and conclusion

Our results suggest that after 25 years of population growth there seems to be a stabilization of the population size of the Greater Flamingo across the Mediterranean, both in terms of wintering and breeding pair numbers. This apparent stabilization should be interpreted cautiously in light of site-specific variability. For example, in the Camargue, since 2015, the main flamingo colony has moved a few kilometres away from the traditional breeding site of the Fangassier. This relocation has resulted from changes in the Salin-de-Giraud saltpan ownership leading to more fluctuating hydrological conditions in spring. The result is a highly fluctuating number of breeding pairs and chicks fledged in the last 10 years.

Comparing figures from the two monitoring networks reveal both consistent and inconsistent patterns. The total number of greater flamingos wintering in North Africa is estimated between 100,000 and 200,000 individuals with a peak over 350,000 in 2014. These figures are coherent with an estimated 40,000 to 80,000 breeding pairs across the Mediterranean, corresponding to 80,000 to 160,000 breeding adult greater flamingos. Because flamingos have delayed recruitment and do not breed every year once having recruited, a significant proportion of flamingos do not participate to breeding every year so that the number of breeding pairs is expected to be lower than the number of wintering birds. Compiling wintering numbers in the north of the Mediterranean (from Portugal to Turkey) would be a useful perspective to better assess variation of reproduction effort of the whole Mediterranean population.

Pronounced peaks in the number of wintering birds appear in the trends (Fig. 3). These peaks could be related to successful breeding seasons in the previous year. Indeed, peaks observed in 2012, 2014, and 2016 correspond with high chick production during the breeding seasons of 2011, 2013, and 2015. Given that approximately 34% of first-year chicks migrate to North Africa for their first winter (Sanz-Aguilar *et al.* 2012), these juveniles are added to the existing wintering population from previous years. Some negative peaks in North-African trends appear to coincide with years of poor reproductive success, such as 2011, 2017, and the period from 1993 to 1996.

However, winters following poor breeding years do not consistently show a marked decline in wintering numbers in North Africa. For example, the winters of 2000 and 2009, following notably poor breeding years, did not result in significant drops in the number of wintering individuals. This apparent inconsistency may be explained by additional factors influencing migration toward North Africa, such as European weather conditions, which might drive more individuals to migrate. More detailed analyses integrating all available data and covariates could help clarify these contrasting patterns.

Analyses of the wintering data in North Africa also highlight the strong influence of certain environmental covariates in explaining both spatial and temporal variations of population size. In particular, the extent of available water surfaces, the proportion of agricultural land, and spring rainfall in northwestern Mediterranean countries show a positive effect. Additionally, spring temperature anomalies in southwestern Europe and winter temperature anomalies in southeastern Europe appear to influence migratory decisions. These findings suggest that climatic conditions potentially unfavourable for breeding or wintering may influence flamingos to migrate to North Africa (and perhaps even affect the subsequent breeding season).

Finally, data from two countries, Tunisia and Algeria, have a particularly strong impact on the observed trends. This is largely due to the presence of key sites such as Lake Ichkeul in Tunisia (which in the past was a very important site for flamingos and other waterbirds), and emerging important habitats in Algeria, which have gained significance for the species over time.

Our results highlight the critical need for enhanced regional cooperation in monitoring and data interpretation. The Mediterranean Waterbird Network, which coordinates and compiles wintering data across the region, and the International Network for the study and conservation of the Greater Flamingo, which focuses on breeding data operate largely in parallel. However, cross-referencing their data sets would offer a more holistic understanding of population dynamics and would improve the detection of significant ecological events, such as breeding failures or shifts in migratory patterns.

Greater integration between these networks would strengthen the region's capacity to respond to emerging threats. In particular, shared data platforms, harmonized methodologies, and joint reporting would enable more timely and targeted conservation actions. Moreover, consistent and comprehensive data submissions from all participating countries are vital to ensure accuracy and facilitate effective decision-making. Finally, the conservation of Mediterranean wetlands and the flamingos that depend on them is a shared international responsibility. No single colony operates in isolation; rather, each breeding and wintering site contributes to the resilience of the entire population. Regional cooperation is therefore not just beneficial — it is essential to sustaining flamingo populations in the face of climate variability, habitat change, and human pressures.

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