Journal of Ornithology
https://doi.org/10.1007/s10336-024-02160-5

ORIGINAL ARTICLE

Rüppell's Vulture (*Gyps rueppelli*): a new vulture species for Europe?

Alejandro Onrubia[1] · Carlos Torralvo[1] · Virginia Morandini[1] · Miguel Ferrer[2]

Received: 3 January 2023 / Revised: 5 January 2024 / Accepted: 22 February 2024

Abstract

The Rüppell's Vulture, formerly restricted to a strictly African distribution, has recently been classified as a Critically Endangered species worldwide. However, in recent decades, observations of the species in Europe, particularly in the south of Spain, have been on the rise. In this study, we conduct a diagnosis of the situation of this species in southern Europe through the analysis of the Sahel Precipitation Index (SPI) and Griffon Vulture autumn migration counts as quantitative measures, with the aim of identifying possible drivers of these changes and population trends. The analyses demonstrated that a number of Griffon Vultures during autumn passage through the Strait of Gibraltar, together with Sahel precipitation anomalies from the previous year, are the best predictors of the number of Rüppell's Vultures during autumn passage through the same strait in the following year, explaining 68.7% of the variance. The proportion of Griffon Vultures in the Sahel has markedly increased as populations of other vultures have declined. Under these circumstances, it seems more than likely that Rüppell's Vultures would be prone to moving to Europe, following Griffon Vultures. This effect has also been favored by increases in number of raining days and floods in the Sahel due to climate change, which can lead to escapes of Rüppell's Vultures outside their usual ranges. Under these circumstances, it appears likely that the Rüppell's Vulture will soon become a new species among European vultures.

Keywords Griffon Vulture · Migration · Sahel · Distribution areas · Precipitation anomalies · Climate change

Zusammenfassung

Der Sperbergeier (*Gyps rueppelli*): eine neue Geierart in Europa?

Der Sperbergeier, früher ausschließlich in Afrika verbreitet, wurde kürzlich weltweit als vom Aussterben bedrohte Art eingestuft. Dennoch wurde er in den letzten Jahrzehnten immer häufiger in Europa (vor allem in Südspanien) gesichtet. In dieser Studie unternahmen wir eine Situationsanalyse der Art im südlichen Europa anhand des Sahel-Niederschlagsindex (SPI) und der Zählungen der Gänsegeier-Herbstwanderung als quantitative Messgrößen mit dem Ziel, mögliche Treiber dieser Veränderungen und Populationstrends zu identifizieren. Die Analysen zeigten, dass die Anzahl der Gänsegeier während der Herbstpassage über die Straße von Gibraltar zusammen mit den Sahel-Niederschlagsanomalien des Vorjahres die besten Prädiktoren für die Anzahl der Sperbergeier während der Herbstpassage über die Straße von Gibraltar im nächsten Jahr sind und 68,7 % der Abweichungen erklären können. Der Anteil von Gänsegeiern in der Sahelzone hat deutlich zugenommen, während die Populationen anderer Geierarten zurückgegangen sind. Unter diesen Umständen scheint es mehr als wahrscheinlich, dass die Sperbergeier eher dazu neigen, den Gänsegeiern zu folgen und nach Europa zu ziehen. Dieser Trend wird auch durch die vom Klimawandel bedingten Überschwemmungen in der Sahelzone unterstützt, die möglicherweise zu einem Ausweichen der Sperbergeier aus ihren üblichen Verbreitungsgebieten herausführen. Unter den derzeitigen Umständen könnte der Sperbergeier bald eine neue Art unter den europäischen Geiern sein.

Communicated by O. Krüger.

✉ Miguel Ferrer
mferrer@ebd.csic.es

[1] Fundación Migres, CIMA, N-340 Km 85, 11380 Tarifa, Spain

[2] Estación Biológica de Doñana, CSIC, Avd. Américo Vespucio, 26, 41092 Seville, Spain

Introduction

The Rüppell's Vulture (*Gyps rueppelli*) was originally a common species throughout its Sahel range, from south-western Mauritania and Senegal to Sudan, Ethiopia, and Tanzania, with an estimated population in the early 1990s of approximately 30,000 individuals (Mundy et al. 1992).

Published online: 27 March 2024

Since then, there has been a strong decline in most of its distribution range, becoming extinct in large areas and rare in many others, especially outside protected areas (Thiollay 2006 and 2007, Virani et al. 2011). In the savannas of West Africa, transect counts by Thiollay (2006) showed a decline from 61.3 Rüppell 's Vultures/100 km in 1969–1973 to 2.5 birds/100 km in 2003–2004. The causes of this severe decline are common with other African vultures and are related to changes in agropastoral systems, decline in wild ungulate populations (and therefore carrion availability), hunting for trade, direct persecution and poisonings, collisions and electrocution with power lines, and disturbance in breeding areas. Also poisoning problems are especially important (mainly by carbofuran pesticides), the increase in the use of veterinary drugs (nonsteroidal anti-inflammatory drugs such as Diclofenac), capture for local or international trade (fetishes, medicinal uses, and rituals) (Cuthbert et al. 2007; Thiollay 2007; Buij et al. 2015; Smallie and Viran 2010; Ogada et al. 2015).

The Rüppell's Vulture (*Gyps rueppelli)* has recently been classified as Critically Endangered Worldwide, the last category before global extinction. Formerly with a strictly African distribution (Ferguson-Lees and Christie 2001), observations of the species in Europe (particularly in the south of Spain) have increased during the last decades. Recently, the environmental administration of the south of Spain (Andalusia) has decided to include it within the species of scavenger birds in the Andalusian Autonomous Community, being the first territorial entity that declares this species as autochthonous outside of the African continent. In this context, it is necessary to determine if this species may already be reproducing in Andalusia. Specifically, we try to find evidence that supports Rüppell's Vulture, considered a native species in Europe such as the breeding of single individuals and the breeding of couples producing nonhybrid offspring. This allows us to determine how close Rüppell's are to being proven native.

The purpose of this study is to perform a diagnosis of the situation of this species of African vulture in southern Europe through the compilation and analysis of all published and unpublished information available on changes in the distribution area and the population trend (see data collection).

At the same time, we are interested in possible drivers of these changes. According to some authors (Gutierrez 2003; Ramrez et al. 2011), one of the hypotheses explaining the arrival of Rüppell's Vultures on the Iberian Peninsula is based on the seasonal movement of Griffon Vultures and the interspecific attraction between the two species. Another hypothesis explaining the appearance of Rüppell's vultures in Europe highlights the role of climatic changes in the Sahel, suggesting that changes in precipitations would be driving Rüppell's vulture movements.

Material and methods

The species

The Rüppell's Vulture is a large scavenger (85–105 cm), with a wingspan of 220–250 cm and a weight between 5500 and 9000 g (Clark and Davies 2018; Kemp et al. 2020). Two subspecies are recognized: *G. rueppelli rueppelli*, spread over most of its distribution range, and *G. r. erlangeri*, restricted to the eastern end of its range (Brown et al. 1982; Ferguson-Lees et al. 2001). It is a soaring bird and, in flight, is characterized by a high wing loading that favors a high glide speed but limits the ability to use relatively weak updrafts and increases the cost of beaten flight compared to other soaring birds (Ruxton and Houston 2004; Duriez et al. 2014).

As a breeder, Rüppell's Vulture is widely distributed in open habitats of savannas, arid steppes, and grasslands of the Sahel fringe, from Senegambia to Eritrea, Ethiopia, Somalia, and south to Tanzania, with the presence of large herbivores (Clark and Davies 2018; Kemp et al. 2020). Its distribution is usually associated with the presence of large cliffs, hills, and mountains, for nesting or the location of roosts, although cases of nesting in trees have been recorded in West Africa (Clark and Davies 2018). Its diet consists almost exclusively of carrion, where it feeds mainly on the muscles, viscera, and bone fragments of the corpses of medium and large mammals, usually ungulates (Cramp and Simmons 1980; Kemp et al. 2020).

It is a very gregarious species that forms communal roosts and tends to forage and feed in conspecific groups or in association with other vultures, where the larger species dominate. Different individuals cooperate in foraging, dispersing over great distances from breeding colonies or communal roosts, and exploring wide areas meticulously (Kemp et al. 2020). The Rüppell's Vulture tends to follow other vultures (especially *Gyps africanus* and *Torgos tracheliotos*) after large herds of wild herbivores or domestic herds, to locate their food (Kendall et al. 2012).

Adult birds are residents and do not perform regular movements in most of the areas, although they can perform extensive daily roaming movements, up to 150–200 km away from nesting or roosting areas. Radio-tagged specimens in Kenya and Tanzania moved an average of 65 km per day with a total range area of 71,990 km^2 in a period of 10 months (Virani et al. 2012; Kemp et al. 2020). However, in West Africa, they may move south during the dry season to the edge of the jungle areas of Guinea (Kemp et al. 2020).

On the other hand, juvenile specimens can move far from the breeding colonies and behave as seasonal nomads during the dry season (February-October), reaching areas as far north as Egypt, Israel, or Western Sahara, and even Zambia,

Zimbabwe, or South Africa to the south (Goodman et al. 1989; Riddell 2004; Dowsett et al. 2008; Van den Berg and Haas 2014; Harrison 2015). Since the late 1970s, it has been regularly recorded in southern Morocco (Thevenot et al. 2003) and since 1992 it is a regular and increasing visitor to the Iberian Peninsula, particularly immature individuals (Gutierrez 2003; Forsman 2005; De Juana 2006; Ramirez et al. 2011; Ramirez 2012).

Data collection

In order to make a diagnosis of the situation of Rüppell's Vulture in Europe, we compiled all the published and unpublished information available on this species in the Palearctic, for the period 1978–2021. Specifically, the following collection activities have been carried out: Bibliographic review, review of blogs and portals, consultation of citizen science databases, consultation of experts, consultation of databases of banding centers, and consultation of the information collected during migration in the Strait of Gibraltar.

In the bibliographic review, all possible ornithological atlases, yearbooks, and news bulletins have been consulted, including the "ornithological newsletter" and "rare birds of Spain" sections of the Ardeola journal edited by the Spanish Ornithological Society, ornithological newsletter of "The Gibraltar Ornithological and Natural History Society (GONHS)," reports of the rarity committees of Portugal, France (Fremont and Duquet 2006; Reeber and CHN 2012) and Morocco (published annually in Go South magazine), national ornithological atlases or inventories (Europe, France, Spain, Portugal, Morocco), regional or local ornithological atlases and yearbooks, as well as some monographic works on rare birds (De Juana 2006) or specifically on Rüppell's Vulture (De Juana 1999; Gutierrez 2003). The works in which information or references of species have been found are reported in the bibliography section of this report.

A database on records of the species has been prepared, which included the following fields: Place, Region, Country, Date, Latitude, Longitude, and Number of birds. Age class, considering three categories: young (birds in the first calendar year), immature (birds from the second to the fourth calendar year), and adults (birds over the fourth calendar year), was also recorded. This database was subsequently reviewed and filtered, since many records that appear in yearbooks and ornithological newscasts are also repeated in blogs and citizen science databases. Likewise, in these citizen science databases, there are numerous duplicates when different observers share the same place and activity (observatories); in those cases, the observations made by different observers at the same place, date, and time (up to a difference of half an hour) were withdrawn.

Movements

To try to know the possible movements of Rüppell's Vultures, consultations have been carried out with the banding and recovery databases of the main banding centers, both in markings with an official metal ring (Office of Migratory Species of the Ministry of Ecological Transition of Spain, through the SEO/BirdLife Bird Migration Center, Aranzadi Science Society Banding Office, European Union for Bird Ringing—Euring) as well as with special brands (Doana Biological Station Banding Office). Likewise, platforms with information on individuals tagged with conventional, GPS, or satellite transmitters, such as Movebank.org, were also consulted.

Autumn pass to Africa

The information available on both vulture species on monitoring the migration of soaring birds in the Strait of Gibraltar from the Migres 1997–2021 program, in autumn migration toward Africa, has been reviewed (SEO 2000; Barrios and Doval 2007; Migres Program 2009; De la Cruz et al. 2011). This monitoring program is based on daily censuses from fixed observatories that operate with constant effort protocols following the recommended standards for this type of study (Fuller and Mosher 1981; Bildstein 2001; Bird and Bildstein 2007).

Annual counts of Griffon and Rüppell's Vultures (among other species) over the Strait of Gibraltar have been recorded using standardized protocols since 1999, conducted during postnuptial migration between mid-July and the end of November (De la Cruz et al. 2011). The numbers of individuals were recorded on a daily basis at two different observatories (Algarrobo 36o 05 25 N, 5o 29 02 W and Cazalla 36o 1 58 N, 5o 34 36 W). Counts at both sites were conducted simultaneously. At each observatory, counts were carried out by a minimum of four observers, with at least one of the observers being a trained ornithologist (De la Cruz et al. 2011). All observers were equipped with binoculars. Counts were not carried out on days with persistent rain or when crosswind speeds exceeded Beaufort scale 6. However, under adverse weather conditions in the Strait, such as high-speed winds, rain, or low visibility between Europe and Africa, the crossing of soaring birds is usually delayed and birds are forced to wait until weather conditions improve (Miller et al. 2016).

Climatic data

We used a generalized climatic indicator such as the Sahel precipitation index (SPI). SPI is based on data representing deviations in rainfall from the long-term mean for a set of

meteorological stations (Janowiak 1988). The anomalies are calculated as an average for each calendar month for the Sahel meteorological stations. For our analyses, we chose SPI values for August and September, since most rainfall occurs during these months (Buontempo 2010). We used data available from the Joint Institute for the Study of Atmosphere and Oceans for 1978–2017 (http://research.jisao.washington.edu/data_sets/sahel/). For the last four years (2018–2021), we used data published by Eligib et al. (2021).

Statistical analyses

We used GLM models with Poisson error distribution and log link to analyze the number of observations of Rüppell's Vultures over the years, using as explanatory variables the number of Griffon Vultures in migratory passages to Africa and the Sahel precipitation index (SPI) for the previous year. We tested the correlation between the variables used in the model: Griffon and Rüppell's Vultures counts during fall migration, Rüppell´s observation in Europe, and the Sahel precipitation index (SPI). After Graham (2003), if covariates included in the models were correlated with $r > 0.50$ with a Spearman correlation, we did not include both parameters in the same model. That was the case with Rüppell's Vultures autumn passage counts and annual Rüppell's observations in Europe ($r = 0.8883$), so we selected the former as an independent variable because it is potentially more standardized than annual observations of Rüppell's Vultures, which is the result of a mixture of observations carried out by different methods with an enormous potential for error.

As there are no data of spring migration from Africa to Europe in the Gibraltar Strait, we have to use the count of autumn passages for the species of both vultures, to analyze possible correlations. However, Rüppell's Vultures that go south from Europe to Africa must necessarily have arrived earlier in the spring of the same year in the opposite direction because most individuals probably do not stay over winter. Therefore, we used the autumn passage counts of Griffon Vultures of the previous year as the response variable in the analyses, in order to test the hypothesis of Rüppell's Vultures following Griffon Vultures during spring migration to Europe, because it is again a good proxy of spring migration next year. We conducted analyses using SPI values of the previous year as explanatory variables (SPI (t-1)) because precipitation would have effects in Rüppell´s populations on the Sahel area, if any, after the summer of each year, so we expected changes in bird numbers migrating to Europe the following year. In summary, we analyze the relationship between the autumn counts of Rüppell's Vultures $_{(t)}$ versus Griffon Vultures $_{(t-1)}$ and SPI $_{(t-1)}$.

We used an information-theoretic approach to develop a priori model sets and ranked models using Akaike's information criterion corrected for small sample sizes (AIC_c), ΔAIC_c (the difference in AIC_c between each candidate model and the model with the lowest AIC_c value). Models within 2 ΔAIC_c values of the top model were considered competitive. A model that included only the intercept was included before to rank the models. The degree to which the 95% confidence intervals for the slope coefficients (β) overlapped zero was also used to evaluate the strength of the evidence for competing models within the set of models (Arnold 2010; Dugger et al. 2016). We used the STATISTICA 13.3 package (Statsoft Inc., Tulsa, USA).

Results

As a result of the search process, the following records of Rüppell's Vultures were obtained: (i) Bibliographic and consultation of citizen science databases: 1668 total records of Rüppell's Vultures corresponding to 2254 individuals. (ii) Consultation of ringing databases: 11 records of ringed Rüppell's Vultures that have produced 3 recoveries. (iii) Consultation of data from the Migres Program: 452 records in passage through the Strait of Gibraltar during the autumn migration have been obtained.

Historical trends in observations

The first record of the species in the Iberian Peninsula refers to a subadult in the Sierra de San Pedro (Cáceres) in April 1990, which remained in the area until 1992. Later specimens were recorded in 1992 and 1993 in Extremadura (reservoir de Cedillo, Sierra de San Pedro), Andalusia (Doana), and Portugal (Portalegre). Since then, the number of records of the species has increased significantly.

Most of the observations occurred on the Iberian Peninsula, which accumulates 95% of the records (Fig. 1). In the Iberian Peninsula it has been cited throughout its geography, although most observations tend to be concentrated in the south-west quadrant of the peninsula, in western Andalusia, Extremadura, Algarve, Alentejo, Beira, and especially in the surroundings of the Strait of Gibraltar, which constitutes a "hot spot" for the species. The number of records remains relatively low between 1990 and 2007 (average of 6.5 records/year), but by 2008 the number of annual records has increased exponentially, especially from 2014 to the present ($r = 0.778$, $p < 0.0001$; Fig. 2).

Age classes and seasonality of observations

Out of a sample of 445 individuals whose age was identified, 17% corresponded to one-year-old birds, 70% were immature

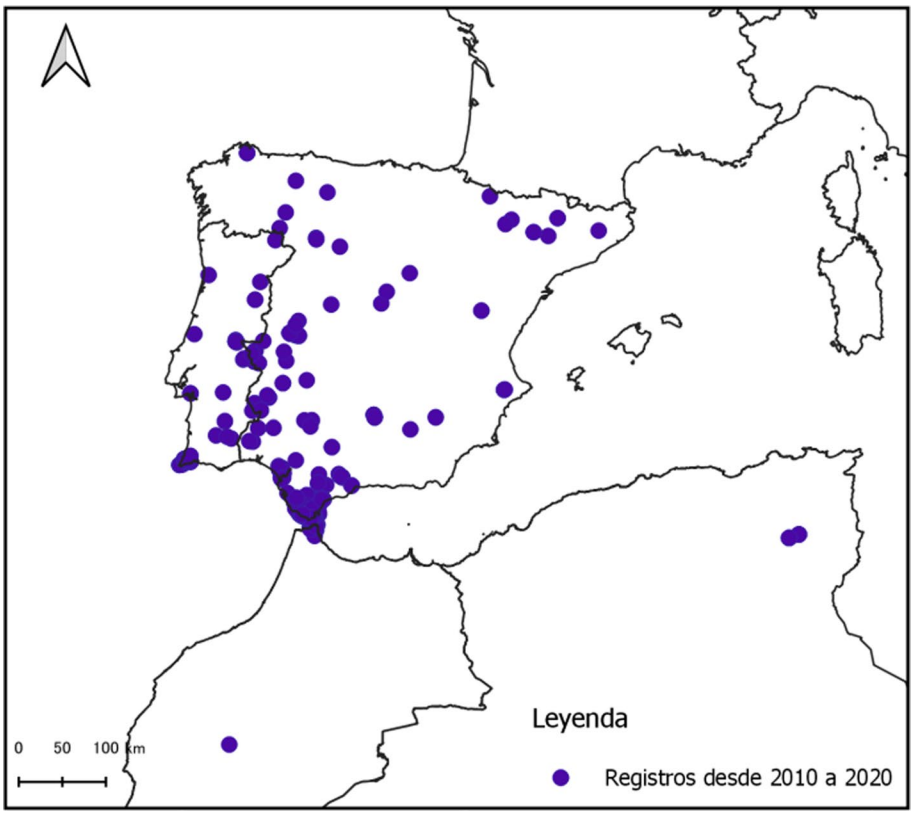

Fig. 1 Observations of Rüppell´s Vultures in Europe since 1990

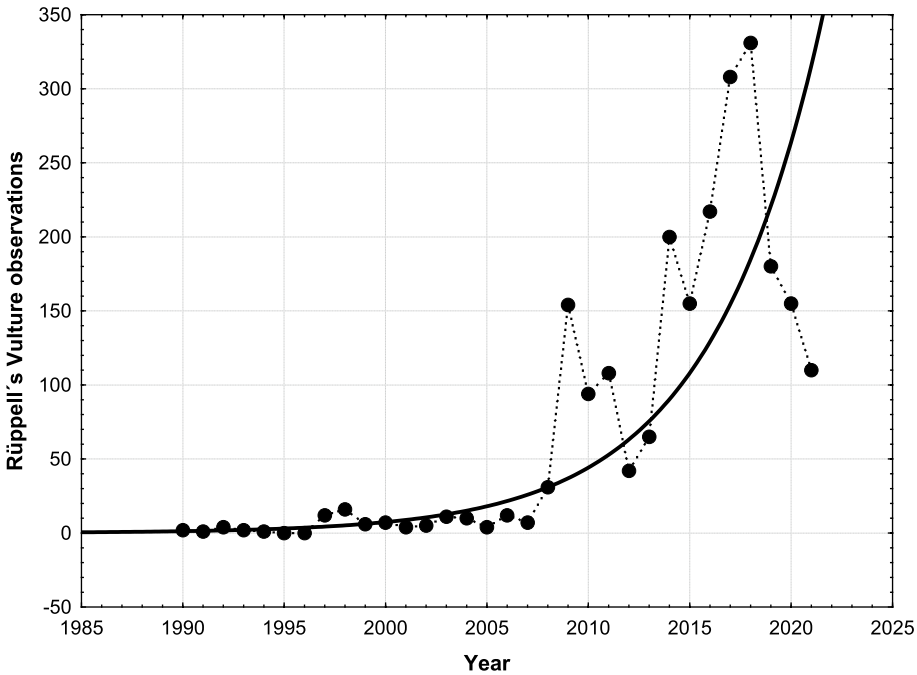

Fig. 2 Significant exponential increase of Rüppell´s Vultures sighted in Europe (r = 0.778, $p < 0.0001$) since 1990

and 13% adults. Young and immature made up most of the records (> 85%).

There were observations of Rüppell's Vultures in the Iberian Peninsula throughout all months of the year, although there was a significant concentration of records from August to November. This circumstance could be explained by the high concentration of records in the Strait of Gibraltar and the Algarve, coinciding with the migration period of

immature Griffon Vultures to Africa, and due to the special circumstances, that occur there for the crossing of the sea (Bernis 1980; Bildstein et al. 2009; Miller et al. 2016).

Despite the fact that most of the Rüppell's Vultures records correspond to young and immature specimens, there are 13% of the observations corresponding to adult individuals, which indicates that at least some of them could potentially settle in the Iberian Peninsula and try to breed.

Movements

Very limited information on Rüppell's Vultures tagged in the Palearctic context is available. In the Iberian Peninsula, barely a dozen specimens have been ringed with metal rings (and some with special markings), which have produced three recoveries, all within the Iberian Peninsula: a young individual marked in February 2006 in Ronda (Málaga) recovered sick a month later 306 km away in Fuente lamo (Murcia), to be released later. A subadult specimen marked in October 2008 in Tarifa is recovered dead collided with a power line in February 2009, very close to the ringing location. Finally, a young specimen from a recovery center is tagged and released in October 2018 in the Sierra Pelada Natural Park (Huelva) and is recovered dead, electrocuted a week later in Mérida (Badajoz, 115 km). However, information on a Rüppell's Vulture captured and marked with a GPS-GSM transmitter on 5 October 2017 in Sierra Mariola (Alcoi, Alicante) is available and its movements throughout the south of the peninsula could be followed, until crossing the Strait of Gibraltar into Africa on 22 October after traveling more than 1300 km in 16 days (Godino et al. 2018).

The information available on recoveries of ringed Griffon Vultures in Africa shows movements to the Maghreb and the western Sahel, mainly in Senegal and to a lesser extent in Mali, Mauritania, Gambia, and Niger. On the other hand, an adult Griffon Vulture tagged with a GPS device in Cádiz is followed through a complete migration cycle until it reaches Senegambia in November and returns to the Iberian Peninsula the following spring (Muoz et al. 2016).

Distribution and estimate population

The autumnal passage of Rüppell's Vultures through the Strait of Gibraltar extended from July 20 to December 5, with the peak of passage toward September 18, although 80% of the specimens were concentrated between August 23 and October 8, with duration of passage of 47 days. In autumn passages, from 0 to 67 Rüppell's Vultures were counted crossing into Africa annually, with an average of 4.7 individuals per year for the period 1999–2009, and an average of 33.33 individuals per year in 2010–2021.

With the information currently available, it is not possible to offer an exact figure for the number of Rüppell's Vultures present in Europe. The records collected in this study accumulate an average of 176,3 individuals observed throughout Europe per year, from 2010 to the present, although this number may include not only many double counts but also many undetected specimens. However, the number of passages in the Strait of Gibraltar amounts to an average of 36,3 individuals per year in the autumn passage to Africa in the last decade. Based on these results, an attempt can be made to estimate 36 to 176 specimens of Rüppell's Vultures in Spain. However, approximately 87% of these specimens are young and immature individuals in the dispersal phase, while adults only account for 13% of the total. This means that the current adult population visiting Europe probably does not exceed 14 adult individuals.

Rüppell's and griffon vultures passes and climate conditions in the Sahel

Regarding their gregariousness, most of the records of Rüppell's Vultures in passage involve single specimens and, to a lesser extent, associations of 2–4 individuals. In most cases (65.2%) they were integrated into groups of Griffon Vultures whose sizes ranged between 2 and 120 specimens (average size 19.2 ± 3.19). The passage patterns of both species of vultures in the strait occur within the same dates.

The data obtained with standardized protocols in the Strait of Gibraltar allow us to infer the trend of Rüppell's Vultures. Censuses in the Strait show a significant increase in the number of individuals in the passage (autumn) in the period 1999–2021 ($r = 0.764$, $p < 0.0001$; Fig. 3). It was a sporadic or absent species in the first years, but its presence has been regular since 2007, progressively increasing its numbers in subsequent years, reaching a maximum number of individuals in 2015 (67 individuals). For its part, the passage of Griffon Vultures follows a similar trend, although the numbers are several magnitudes higher than those of the Rüppell's Vulture ($r = 0.679$, $p = 0.007$; Fig. 4). A highly significant correlation was found between the number of Rüppell´s Vultures crossing to Africa and the number of observations of individuals in Europe each year (Spearman correlation $= 0.8033$, $p < 0.0001$) was found.

The Sahel precipitation index showed a significant trend toward increasing positive anomalies throughout the years, that is, more precipitations than expected ($r = 0.606$; $p < 0.0001$; $R^2 = 0.36$) over time, after the severe drought during the 1980s (Fig. 5). Nevertheless, fluctuations among years are still very important, with several years showing a negative SPI.

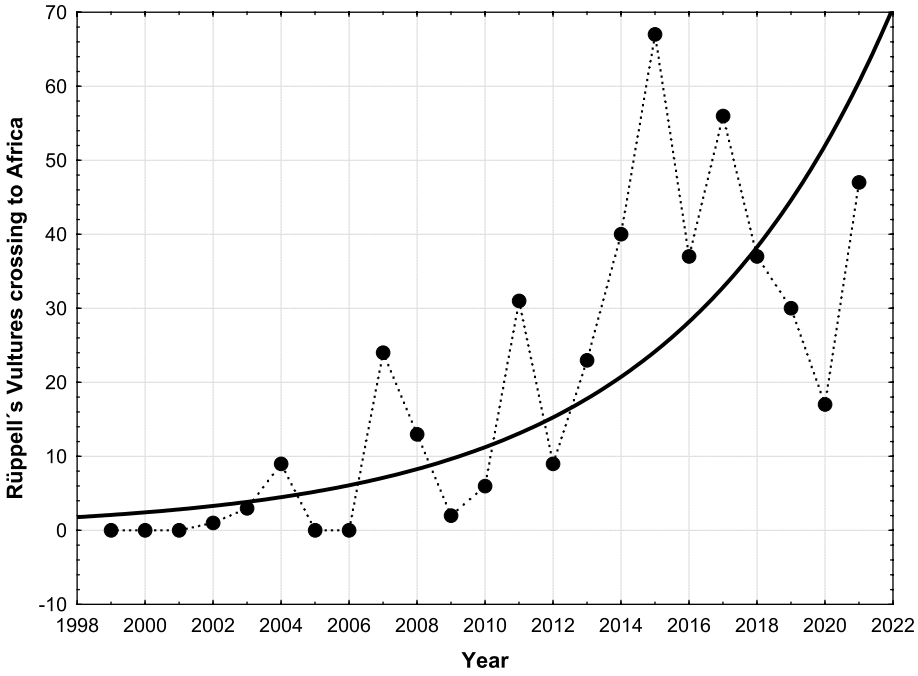

Fig. 3 Significant exponential increase of Rüppell´s Vultures passing from Europe toward Africa in autumn (r = 0.764, $p < 0.0001$) since 1999

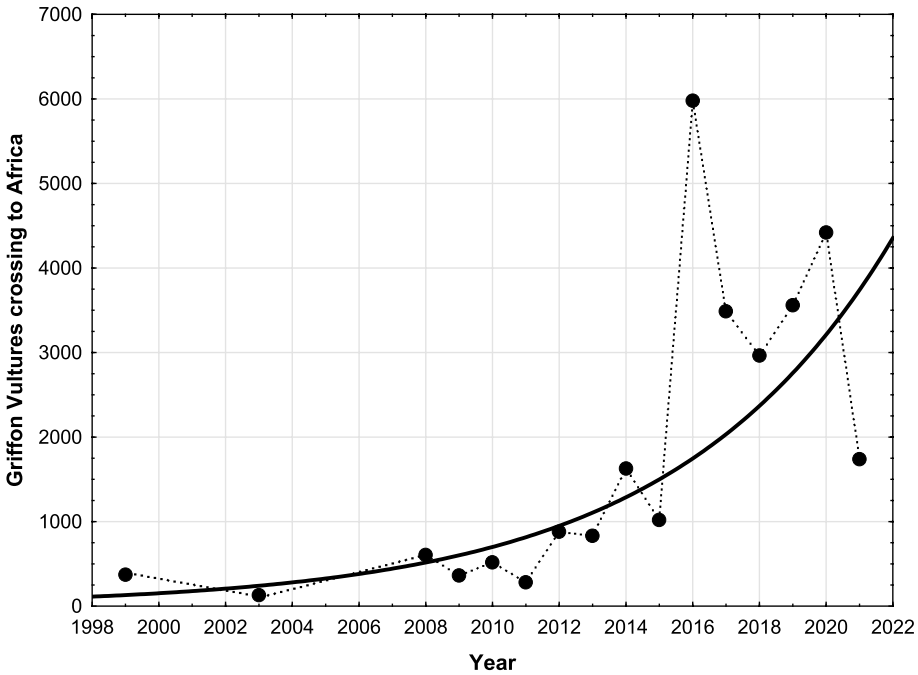

Fig. 4 Significant exponential increase of Griffon Vultures passing from Europe toward Africa in autumn (r = 0.679, $p = 0.007$) since 1999

Modeling the Rüppell's Vultures $_{(t)}$ passage counts as a dependent variable and Griffon Vultures $_{(t-1)}$ in the autumn passage and SPI $_{(t-1)}$ as explanatory variables, the results showed that the most competitive model was the one that included both variables (Table 1). The number of Griffon Vultures each fall passage showed a positive coefficient, indicating a positive relationship with the observations of Rüppell. SPI $_{(t-1),\ also}$ showed a positive relationship with the observations of Rüppell's Vultures, suggesting more observations in Europe after a year with precipitations in the Sahel over average. Spearmen correlation between both variables was < 0.5. The selected model (Griffon Vultures in Autumn Pass $_{(t-1)}$ + SPI $_{(t-1)}$) showed high precision in predictions, with no estimates overlapping zero, and explaining 68.7% of the variance in Rüppell's Vultures observations in Europe.

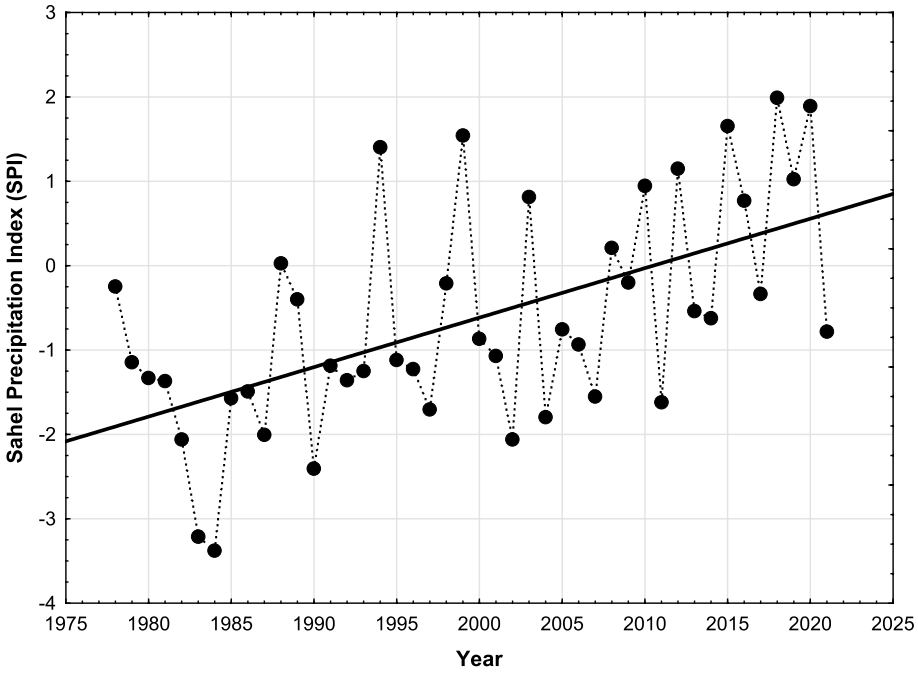

Fig. 5 Historical trends of Sahel Precipitation Index (SPI), showing anomalies well above or below mean values in August–September period. Sahel precipitation index showed a significant trend to increasing positive anomalies along the years, that is, more precipitations than expected over time ($r = 0.606$; $p < 0.0001$; $R^2 = 0.36$), after the severe drought during the 1980s

Table 1 Results of GLM analyses showing Griffon Vultures passage and Sahel Precipitation Index as the best predictors for number of observations of Rüppell´s Vultures in Europe

Rüppell´s Observ—distribution: poisson, link function: Log						
Var.—1		Var.—2	df	AIC_c	L.Ratio—Chi^2	R^2
G. Vulture passage $_{(t-1)}$		SPI $_{(t-1)}$	2	266.88	322.31	0.687
G. Vulture passage $_{(t-1)}$			1	329.03	258.16	0.402
SPI $_{(t-1)}$			1	364.16	223.03	0.327
	Estimate	SE	Wald Stat	Lower CL—95, %	Upper CL—95, %	*P*
Intercept	2.2371	0.08475	696.8284	2.0710	2.4032	< 0.0001
G. Vulture passage $_{(t-1)}$	0.0002	0.00002	102.6395	0.0002	0.0003	< 0.0001
SPI $_{(t-1)}$	0.4027	0.05043	63.708	0.3038	0.5015	< 0.0001
Scale	1.0000	0.00000				

Discussion

Until the middle of the twentieth century, there were no records of the Rüppell's Vulture in the western Palearctic. However, since the late 1970s it has been sporadically recorded in southern Morocco, including a record of a group of 43 immature individuals in 1978 (Thevenot et al. 2003), and since May 1992 it has been a rare but regular nonbreeding visitor, in the Iberian Peninsula, generally of young or immature birds (Gutierrez 2003). Until 2010, there are 45 citations (60 individuals) accepted for Spain, 13 for Portugal, and 1 for Gibraltar (De Juana 2006; De Juana and Garca 2015). In France, an adult was recorded at a supplementary feeding point located in the south-east (Drome) between the autumn of 2003 and the spring of 2004, and again in February–March 2011 in Drome and in the Alpes de Haute Provence (Fremont et al. 2006; Reeber et al. 2012). Likewise, several individuals are recorded passing through the Strait of Gibraltar, both on the Iberian side (Ramirez et al. 2011) and on the Moroccan side (Ramirez 2012).

The first records of the Rüppell's Vulture in Spain occurred in the early 1990s, around the Strait of Gibraltar. Since then and up to the present, the numbers of Rüppell's Vultures have increased significantly, reaching their maximum between 2015 and 2020. Being originally a species of sub-Saharan African descent, distributed throughout the Sahel strip, the "drag" effect produced by Griffon Vultures of mainly Iberian origin that visit this area of the Sahel has

been postulated as the origin of these individuals during the juvenile dispersal period (Gutierrez 2003; Ramirez et al. 2011). These young and immature Griffon Vultures from the Iberian colonies reach the Sahelian strip during their dispersal and after a period of stay of one or more years in the African savannas, they return to the Iberian Peninsula where they will establish themselves as breeders (Ramirez et al. 2011). In the Sahel, these Griffon Vultures coincide in the carrion of wild and domestic ungulates with other scavengers such as Lappet-faced Vultures (*Torgos tracheliotus*), White-backed Vultures (*Gyps africanus*), Rüppell's Vultures, White-headed Vultures (*Trigonoceps occipitalis*), Egyptian Vultures (*Neophron percnopterus*), Hooded Vultures (Necrosyrtes monachus), and Palm-nut Vultures (*Gypohierax angolensis*), establishing complex interactions in the scavenger guild, where it is common for the largest or most numerous species to establish dominance relationships with the others (Kendall et al. 2012). In this context, it is common for Rüppell's Vultures (a medium-sized species) to follow other species during the search and location of carcasses (Kendall et al. 2012). It so happens that these Griffon Vultures groups in the Sahel return to the Iberian Peninsula at the end of the dry season (March–June), coinciding with the period of flight, independence, and dispersal of the young Rüppell's Vultures, and it is common for them to form mixed groups (Kemp et al. 2020). In this way, some young or immature Rüppell's Vultures reach the Iberian Peninsula integrated in groups of Griffon Vultures. However, this simple fact alone would not explain the increase in records of Rüppell's vultures in the Iberian Peninsula.

From 1979 to the present, the population of the Iberian Griffon Vulture has increased notably, from 2283 pairs in 1979 to 7,519 in 1989, 17,337 in 1999, 24,609 in 2008, and 30,946 pairs in 2018, as a result of the conservation policies developed in recent decades in Europe. In the same way, the number of young Griffon Vultures has increased in parallel, and consequently, the number of Griffon Vultures dispersing toward Africa has also increased. According to migration monitoring of soaring birds through the Strait of Gibraltar, conducted by the Migres Foundation, about 1000–2000 Griffon Vultures crossed the Strait in 1979, which amounted to about 2600 in 1999, 8218 in 2008 and reached 12,057 in 2019 (Bernis 1980; Migres Program 2009). However, in the same period, scavenger populations in the Sahel have suffered a very strong decline produced by profound changes in savanna habitats and agropastoral uses, direct persecution, or a higher incidence of poisons and drugs for veterinary use (Smallie and Virani 2010; Ogada et al. 2015).

In Africa, populations of Rüppell's Vulture have declined by at least a third in the last 30 years, and in West Africa they may now be a fifth of what they were in the 1970s (Thiollay 2006 and 2007; Virani et al. 2011). In contrast, Griffon Vulture populations have been able to escape, at least partially, from this profound decline, since the adult reproductive fraction has been placed in another geographical context of more favorable protection. The result has been that the proportion of Griffon Vultures in the Sahel has increased markedly as populations of other vultures have declined, and under these circumstances, it is more than likely that young and immature Rüppell's Vultures were more prone to move to Europe, following Griffon Vultures in the last two decades. This effect has also been favored or magnified by floods in the Sahel due to climate change, which can cause escapes or extensive movements of Rüppell's Vultures outside their usual ranges (Kemp et al. 2020). In fact, both factors together (an increase of wintering Griffon Vultures in the Sahel and an increase in Sahel precipitations) were selected as the most competitive model explaining the increase in Rüppell's Vultures passage counts. These circumstances could also explain recent records of white-backed vultures and hooded vultures in the Iberian Peninsula (De Juana 2006; De Juana and Garcia 2015). Considering that Rüppell's Vulture is a soaring bird, depending on thermal currents to move, an increase in rainfall and flooding events would force them to abandon their usual area.

These young and immature Rüppell's Vultures reach the Iberian Peninsula through the Strait of Gibraltar, integrated into flocks of Griffon Vultures, and begin a dispersive stage linked to the breeding nuclei of Iberian Griffon Vultures. From there, some specimens of the Rüppell's Vulture reach sexual maturity in the Iberian Peninsula, and some individuals establish themselves as potential associated breeders in colonies of Griffon Vulture. A similar process could be taking place in North Africa, where the incipient recovery of vulture populations, that is taking place in some areas (the case of the Saharan Atlas in Algeria), could be behind the breeding attempts or the establishment of small colonies of Rüppell's Vultures from 2012 to the present (Dr. Amina Fellous, personal communication).

To date, there are very few references that indicate the possibility of breeding in the Iberian Peninsula. In February 1999, an adult specimen of a Rüppell's Vulture was detected incubating in a nest located in the International Tagus, on the border of Castelo Branco (Portugal) and Cáceres (Spain), although it is unknown if it successfully reared chicks, and it is possible that they were a hybrid pair with Griffon Vultures (Berliner et al. 2001). Later, an adult was observed in a breeding colony of Griffon Vultures in Portas de Rodao (Portugal) in 2004, although its reproduction could not be confirmed either (Equipa Atlas 2008). In this area, Rüppell's vulture adults have continued to be observed until 2007, although breeding has not been verified. More recently, in 2020, evidence of reproductive behavior has been detected in two adult specimens of Rüppell's Vulture in two parts of Andalusia (Sierra de la Plata—Cadiz, Desfiladero de los Gaitanes—Malaga). Both specimens were settled in important colonies of Griffon Vulture

and were observed carrying material for the nest, and in the case of Cádiz, copulating with a male Griffon Vulture (Elorriaga et al. 2020). Interestingly, these few breeding attempts are associated with Griffon Vulture colonies and appear to involve mixed pairs of Rüppell's and Griffon Vultures. In this regard, it is worth noting the record of an adult specimen in January 2009 in the Sierra de San Pedro (Cáceres), exhibiting hybrid traits of the Rüppell's and Griffon Vultures.

In a context of sharp decline in sub-Saharan Rüppell's Vulture populations, this potential colonization of the Maghreb or the European continent through the Iberian Peninsula opens up new and interesting scenarios for the conservation of the species on a global scale. The presence of a population of Rüppell's vultures in Andalusia raises an extremely interesting conservation debate. During the last three decades, its presence in the Iberian territory has been related to the arrival of young or immature specimens of African origin during their period of juvenile dispersal, integrated into groups of Griffon Vultures. As a result, there is a stable and regular presence of Rüppell's Vultures in the south of Europe, which in recent years has resulted in a low but stable number of adults and some breeding attempts. There is thus an extraordinary circumstance in which a population threatened worldwide, with populations in deep decline in its original range, may be rescued by natural (assisted?) colonization that would end in the establishment of new populations in a different geographic context. However, this new population is not fully established yet and runs the risk that the severely and rapidly declining African source populations will cease to contribute a high enough number of individuals to this incipient Iberian population before it vanishes.

If no important changes in European populations of Griffon Vulture happen and the trend of Sahel Precipitation Index does not change, it seems likely that the Rüppell's Vulture would soon be a new species among European vultures.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Data availability Data will available by authors upon request.

References

Arnold TW (2010) Uninformative parameters and model selection using Akaike's information criterion. J Wildl Manag 74:1175–1178

Equipa Atlas (2008) Atlas das Aves Nidificantes em Portugal (1999–2005). Instituto da Conservacao da Natureza e da Biodiversidade, Sociedade Portuguesa para o Estudo das Aves, Parque Natural da Madeira e Secretaria do Ambiente e do Mar. Assirio and Alvim, Lisboa.

Barrios L, Doval G (2007) El programa migres de aves planeadoras. Almoraima 35:77–85

Berliner A, Pacheco C, Monteiro A (2001) III Censo portugués de Grifo. In: del Moral JC, Martí R (eds) El buitre leonado en la península Ibérica. I Censo Ibérico coordinado 1999. SEO/BirdLife Monografía 7, Madrid, pp 25–39

Bernis F (1980) La migración de las aves en el estrecho de Gibraltar. Aves Planeadoras, vol I. Universidad Complutense, Madrid

Bildstein KL (2001) Why migratory birds of prey make great biological indicators. In: Bildstein KL, Klem D Jr (eds) Hawkwatching in the Americas. Hawk Migration Association of America, North Wales, pp 169–179

Bildstein KL, Bechard M, Farmer C, Newcomb L (2009) Narrow sea crossings present major obstacles to migrating Griffon Vultures. Ibis 151:382–391

Bird DM, Bildstein KL (2007) Raptor research and management techniques. Hancock House Publishers, Surrey, British Columbia

Brown LH, Urban EK, Newman K (1982) The Birds of Africa, vol 1. Academic Press, London, New York

Buij R, Nikolaus G, Whytock R, Ingram DJ, Ogada D (2015) Trade of threatened vultures and other raptors for fetish and bushmeat in West and Central Africa. Oryx 50:606–616. https://doi.org/10.1017/S0030605315000514

Buontempo C (2010) Sahelian climate: past, current, projections. In: Buontempo C (ed) Met office. Hadlez Centre, Exeter

Clark WS, Davies R (2018) African Raptors. Helm, Bloomsbury, London

Cramp S, Simmons KEL (1980) The birds of the western Palearctic. Hawks to bustards, vol 2. Oxford University Press, Oxford

Cuthbert R, Parry-Jones J, Green RE, Pain DJ (2007) NSAIDs and scavenging birds: potential impacts beyond Asia's critically endangered vultures. Biol Lett 3:90–93

De Juana E (1999) Atención Al Buitre Moteado. La Garcilla 106:29–31

De Juana E (2006) Aves raras de España. Lynx Edicions, Barcelona

De Juana E, Garcia E (2015) The birds of the Iberian Peninsula. Christopher Helm, London

De la Cruz A, Arroyo GM, Onrubia A, Barrios L, Muñoz AR (2011) Migración primaveral de aves planeadoras en el Estrecho de Gibraltar. Diseño de un programa de seguimiento a largo plazo. Migres Revista De Ecología 2:65–72

Dowsett RJ, Dowsett-Lemaire F, Hester A (2008) The avifauna of Ghana: additions and corrections. Bull African Bird Club 15:191–200

Dugger BD, Coluccy JM, Dugger KM et al (2016) Population dynamics of mallards breeding in eastern Washington. J Wildl Manag 80:500–509

Duriez O, Kato A, Tromp C, Dell'Omo G, Vyssotski AL, Sarrazin F, Ropert-Coudert Y (2014) How cheap is soaring flight in raptors? A preliminary investigation in freely-flying vultures. PLoS ONE 9:e84887

Elagib NA, Al Zayed IS, Saad SAG, Mahmood MI, Basheer M, Fink AH (2021) Debilitating floods in the Sahel are becoming frequent. J Hydrol 599:126362

Elorriaga J, Ramirez J, Gonzalez M, Herrera D, Benjumea R, Hohental N (2020) Nuevas evidencias de reproducción e hibridación del buitre moteado en España y el Paleártico. Quercus 409:47–48
Ferguson-Lees J, Christie DA (2001) Raptors of the World. Christopher Helm, London
Forsman D (2005) Rüppell ´s Vulture in Spain. Birding World 18:435–438
Frémont JY, Duquet M (2006) Les oiseaux rares en France en 2004. Ornithos 13:73–113
Fuller MR, Mosher JA (1981) Methods of detecting and counting raptors: a review. Estimating numbers of terrestrial birds. Stud Avian Biol 6:235–246
Godino A, Machado C, Seguí A, Bildstein KL, Bartoszuk K, Elorriaga J, Guerrero A (2018) Primer seguimiento con GPS del buitre moteado en Europa. Quercus 386:40–41
Goodman SM, Meininger PL, Baha el Din SM, Hobbs JJ, Mullié WC (1989) The Birds of Egypt. Oxford University Press, Oxford, New York
Graham MH (2003) Confronting multicollinearity in ecological multiple regression. Ecology 84:2809–2815. https://doi.org/10.1890/02-3114
Gutiérrez R (2003) Occurrence of Rüppell's Griffon Vulture in Europe. Dutch Birding 25:289–303
Harrison I (2015) From the Rarities Committees. Sandgrouse 37:203–210
Janowiak JE (1988) An investigation of interannual rainfall variability in Africa. J Clim 1:240–255. https://doi.org/10.1175/1520-0442(1988)001b0240:AIOIRVN2.0.CO%3B2
Kemp AC, Christie DA, Kirwan GM, Sharpe CJ (2020) Rüppell's Griffon (Gyps rueppelli), version 1.0. In: del Hoyo J, Elliott A, Sargatal J, Christie DA, de Juana E (eds) Birds of the World. Cornell Lab of Ornithology, Ithaca
Kendall C, Virani MZ, Kirui P, Thomsett S, Githiru M (2012) Mechanisms of coexistence in vultures: understanding the patterns of vulture abundance at carcasses in Masai Mara National Reserve, Kenya. Condor 114:523–531
Migres P (2009) Seguimiento de la migración de las avesen el Estrecho de Gibraltar. Migres Revista De Ecologia 1:3–21
Miller RA, Onrubia A, Martín B, Kaltenecker GS, Carlisle JD, Bechard M, Ferrer M (2016) Local and regional weather patterns influencing post-breeding migration counts of soaring birds at the Strait of Gibraltar, Spain. Ibis 158:106–115
Mundy PJ, Butchart D, Ledger J, Piper S (1992) The Vultures of Africa. Academic Press, London
Muñoz AR, Chamorro D Toxopeus AG, Venus V, Bouten W, Skidmore AK (2016) One complete migration cycle of an adult Griffon Vulture: from southern Spain to Senegambia as revealed by high-resolution GPS tracking technology. Proceedings African Congress for Conservation Biology. El Jadida, Morocco
Ogada D, Shaw P, Beyers RL, Buij R, Murn C, Thiollay JM, Beale CM, Holdo RM, Pomeroy D, Baker N, Krüger SC, Botha A, Virani MZ, Monadjem A, Sinclair AR (2015) Another continental vulture crisis: Africa's vultures collapsing toward extinction. Conserv Lett 9:89–97. https://doi.org/10.1111/conl.12182
Ramírez J (2012) First record of Rüppell's Vulture *Gyps rueppellii* arriving in Morocco from Spain. Go-South Bull 9:44–45
Ramírez J, Muñoz AR, Onrubia A, de la Cruz A, Cuenca D, González JM, Arroyo GM (2011) Spring movements of Rüppell's Vulture Gyps rueppellii across the Strait of Gibraltar. Ostrich 82:71–73
Reeber S (2012) Les oiseaux rares en France en 2011. Ornithos 19:353–395
Riddell IC (2004) Eighth report of the BirdLife Zimbabwe rarities committee. Honeyguide 50:230–232
Ruxton GD, Houston DC (2004) Obligate vertebrate scavengers must be large soaring fliers. J Theor Biol 228:431–436
SEO/BirdLife (2000) Programa Migres. Seguimiento de la migraciónen el Estrecho Año. SEO/BirdLife: Madrid
Smallie J, Virani MZ (2010) A preliminary assessment of the potential risks from electrical infrastructure to large birds in Kenya. Scopus 30:32–39
Thévenot M, Vernon R, Bergier P (2003) The Birds of Morocco. An annotated check-list. British Ornithologists' Union, Tring
Thiollay JM (2006) The decline of raptors in West Africa: long-term assessment and the role of protected areas. Ibis 148:240–254
Thiollay JM (2007) Raptor population decline in West Africa. Ostrich 78:405–413
Van den Berg AB, Haas M (2014) WP Reports. Dutch Birding 36:195–208
Virani MZ, Kendall C, Njoroge P, Thomsett S (2011) Major declines in the abundance of vultures and other scavenging raptors in and around the Masai Mara ecosystem, Kenya. Biol Conserv 144:746–752
Virani MZ, Monadjem A, Thomsett S, Kendall C (2012) Seasonal variation in breeding Rüppell's Vultures *Gyps rueppellii* at Kwenia, southern Kenya and implications for conservation. Bird Conserv Internat 22:260–269