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Research Article

Egyptian Vulture in Kazakhstan

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Abstract: Egyptian Vulture *Neophron percnopterus* Linnaeus, 1758 is a breeding migrant in Kazakhstan at the northernmost border of its range. The area is divided into two parts differing significantly in biotope – patches of desert plateaus in the western Aral-Caspian region and semi-desert mountains in the south and southeast. We summarize all available literature on the distribution of Egyptian Vulture in Kazakhstan and analyse information from databases and photo-websites, plotting all data on a map and applying grid mapping to visualise the distribution. We also report a preliminary estimate of Egyptian Vulture abundance in Kazakhstan in 2000 to 2021. We modelled Egyptian Vulture distribution in Google Earth Engine using the image classification method Random Forest. Currently, 163 breeding territories of Egyptian Vultures have been identified in Kazakhstan. The bird's population in Kazakhstan is estimated to range from 332 to 667 pairs, with an average of 502 pairs. The results of repeated visits to Egyptian Vultures breeding territories in Ustyurt and Karatau with intervals of 8–12 years suggest the stability of these populations despite various threats within the breeding range of this species.

Key words: Egyptian Vulture, *Neophron percnopterus*, Kazakhstan, distribution, raptor

Introduction

Egyptian Vulture *Neophron percnopterus* (hereafter EV) is a Palaearctic, Afrotropical and Western Indo-Himalayan species; it is a breeding (summer) migrant in Kazakhstan (Botha et al. 2017). Its number is declining in almost all parts of its range in Europe and Asia. IUCN classifies EV as Endangered, with a global population of 12,400–36,000 adults or 18,600–54,000 including juveniles (BirdLife International 2021). Since 1978, this species has been included in the Red Book of the Republic of Kazakhstan as "rare, found in small numbers" (Category III) (Pfeffer 2010).

EV is found in Kazakhstan at the most northern edge of its range. Its nesting distribution is divided in two parts, significantly different in biotopes and separated from each other by 1,000 km: patches of desert plateaus of the Aral-Caspian region in the west of the country and semi-desert mountains in the south and southeast of the country (Fig. 1).

In Kazakhstan, the species remains rather poorly understood. Review articles on its distribution and range date back to 1950s–1960s only (see Discussion). Since then, the main information source has been scattered data in Russian-language faunistic notes in several references to other bird species.

Modern EV abundance estimates (mainly expert estimates) are also based on these sources. In the 1980s, A.F. Kovshar (unpublished) estimated the EV population at several dozen to several hundred pairs. This estimate was included in Kazakh Red Book editions between 1996 and 2010 (Pfeffer 2010). Later, Sklyarenko & Katzner (2012)

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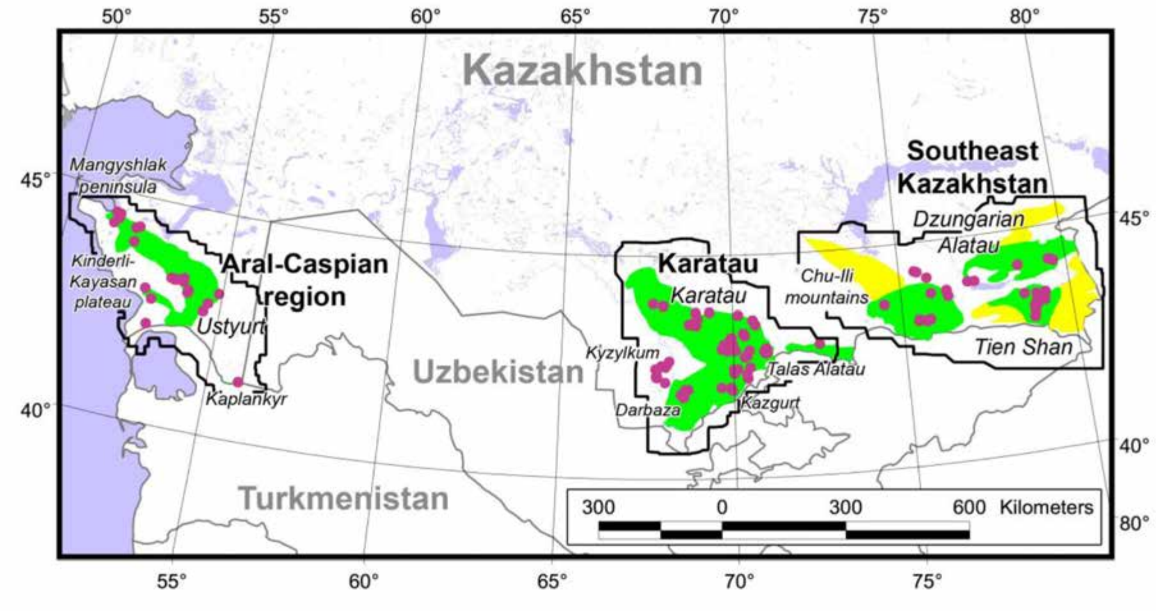

Fig. 1. Distribution of the Egyptian Vulture *Neophron percnopterus* in Kazakhstan. Dots indicate summer records in breeding biotopes and nests of the EV described in the literature. Dark shaded is the breeding range of the EV, in which its breeding has been confirmed since the 1990s. Light shaded is the former nesting range of the EV, within which the breeding of the EV has not been established since the 1990s. The names of countries are given in bold grey font. The names of the regions of the nesting range of the EV are given in bold black font. Natural geographical areas, in which the EV breeding has been described in the literature, are given in italics.

estimated EV population in Kazakhstan at 80–100 pairs. Thus, there is a need for a complete census of EV breeding in Kazakhstan (Kovshar 2019).

A new source of information about bird sightings and nest finds in Kazakhstan has emerged in the past decade – databases compiled by birdwatchers and animal photographers. These data are found in electronic bird registration systems in iNaturalist (https://www.inaturalist.org, accessed 12 January 2023), eBird (https://ebird.org, accessed 12 January 2023) and Web-GIS "Faunistics" (https://wildlifemonitoring.ru, accessed 12 January 2023). Additionally, the website of the Kazakhstan Birdwatching Community (https://birds.kz, accessed 12 January 2023) provides data, which are not included in other sources.

Modern modelling methods provide possibilities to make fairly accurate predictions of the species' nesting distribution and to estimate its abundance with good accuracy. In this study, we aimed to update the contemporary EV breeding status and to model its distribution in Kazakhstan. We set the following objectives of the present work: (1) review and record of the Egyptian Vulture distribution; (2) description of breeding biotopes; (3) modelling species distribution; (4) estimation of the species abundance in country; (5) visualisation of data in the form of grid mapping; descriptions of (6) breeding biology and (7) phenology; (8) evaluation of threats in the country.

Materials and Methods

The work consisted of six stages: (1) Collection and compilation of data from available sources on EV sightings in Kazakhstan since the early 1990s, both printed and electronic. (2) Field counts of the species. (3) Modelling its distribution in a GIS environment. (4) Abundance estimate. (5) Data visualization in the form of grid mapping. (6) Summarizing all collected data on EV phenology, nesting preferences and parameters and threats to the species.

Gathering data from available sources

We reviewed information about EV breeding distribution in Kazakhstan from different referenced and non-referenced sources of information and online databases (see Supplementary Material 1). We collected and summarised data on EV distribution, abundance, nesting biology, phenology and threats to the species from all possible sources. Some nests were visited repeatedly. For the analysis of nesting biology, we sought to exclude repeated descriptions of the same nest. Factors and evaluation methods used by different researchers also vary, so it is not always possible to compare correctly some charac-

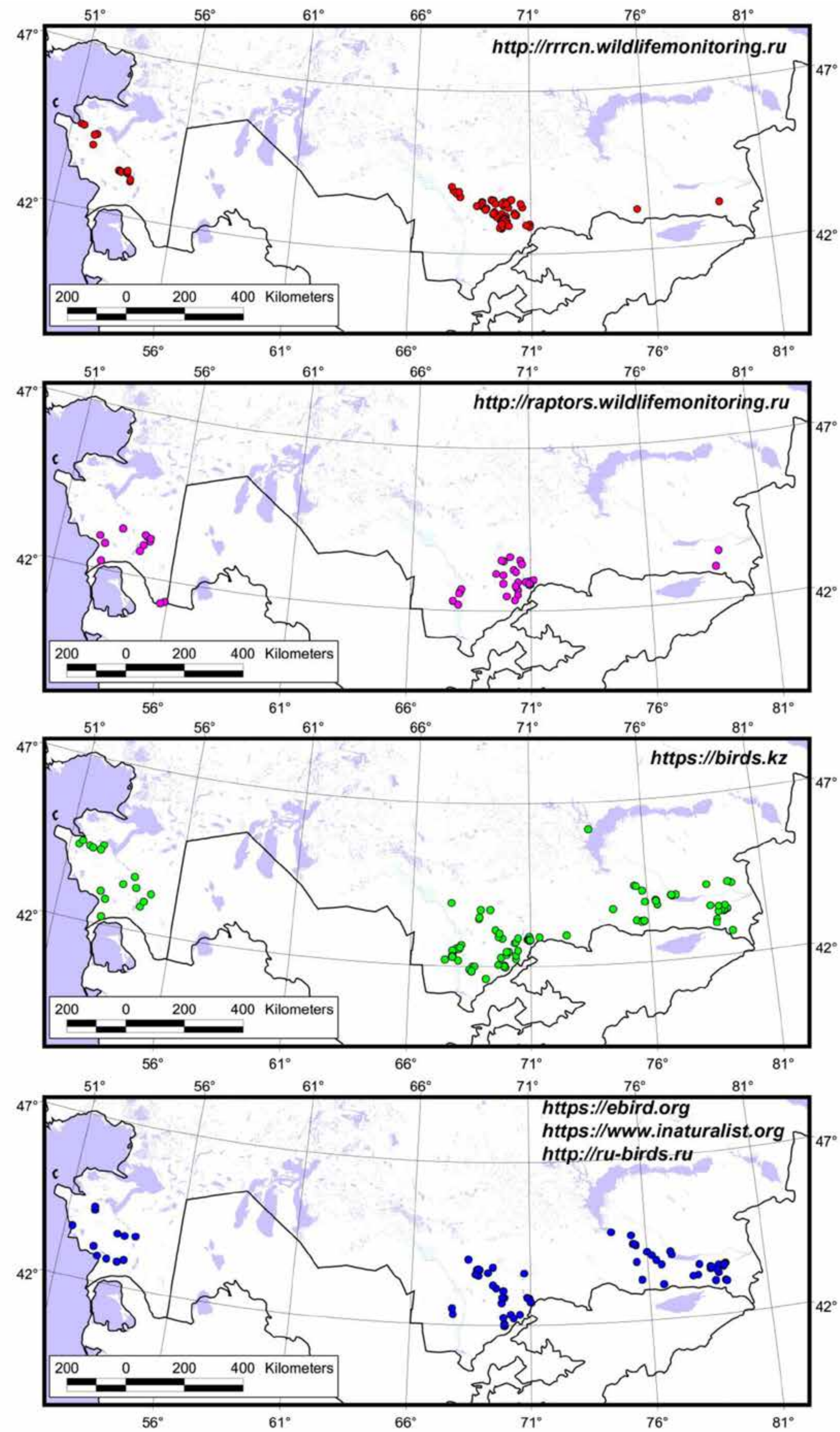

Fig. 2. Egyptian Vulture *Neophron percnopterus* records in Kazakhstan from various databases.

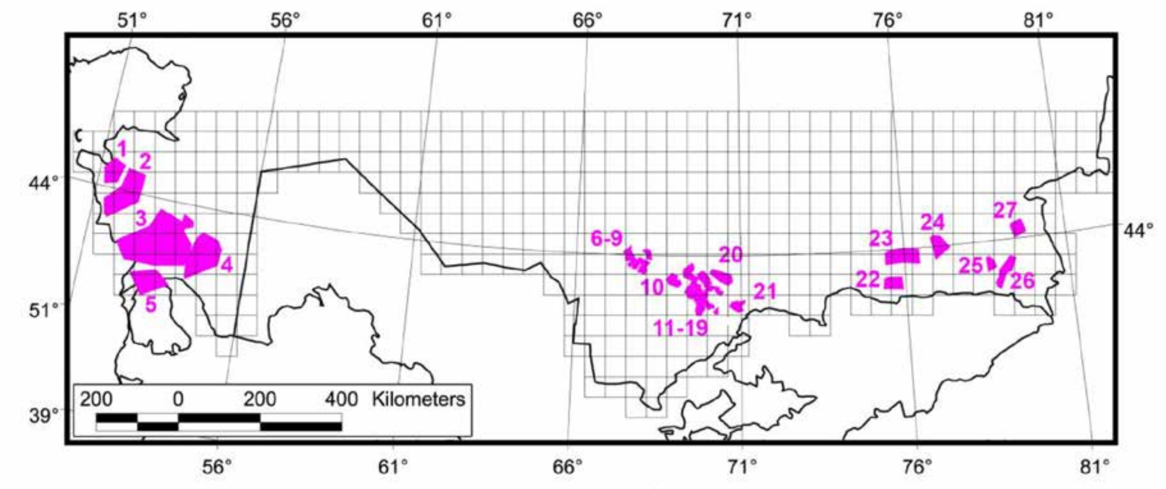

Fig. 3. Surveyed plots where breeding Egyptian Vultures *Neophron percnopterus* were counted. Plot numbering corresponds to that in Table 1.

teristics. Therefore, we have only used those that we could accurately determine in the article. We found 413 breeding records of EV in Kazakhstan in 2000–2022 (Fig. 2). They are concentrated in three large regions: Aral-Caspian, Karatau and Southeast Kazakhstan.

Species field counts

EV abundance surveying was carried out on plots identified based on literature data and our research. When choosing plots, we tried to cover as many types of suitable EV breeding habitats as possible. Territories in the Aral-Caspian region were surveyed as part of targeted projects for other species (Karyakin et al. 2005, 2009, 2011, Levin & Karyakin 2005), where EV data was also collected. In addition to our data for sites in the Aral-Caspian region and Southeast Kazakhstan, data from other researchers were also used (Pestov & Nurmuhambetov 2012, Pestov et al. 2019a, Amirekul et al. 2022). At Karatau, raptor censuses were carried out in 2010, when EV was counted simultaneously with other raptors, followed by targeted EV counts in 2022, the results of which are published (Karyakin et al. 2022). As a result, by 2022, 27 plots were established within the species' breeding range in Kazakhstan (Fig. 3, Table 1), with a total area of 38,682.83 km^2. These included the Aral-Caspian Region (5 plots with an area of 28,860.38 km^2, 74.61%), Karatau (16 plots with an area of 4,191.54 km^2, 10.84%) and Southeast Kazakhstan (6 plots with an area of 5,630.91 km^2, 14.56%). At these plots, EV breeding biotopes were surveyed to identify and count nesting pairs. In the course of the field work, cliffs were examined with binoculars and spotting scopes. Location coordinates were documented for all bird and nest encounters. The authors sought to level possible gaps by tracking the distances between neighbours and specifically checking areas where distances between neighbours exceeded 20 km.

Distribution modelling in a GIS environment

We modelled EV breeding biotopes in a GIS environment by determining the relationship of a set of environmental variables with information about the species' presence (Evans et al. 2011) using methodology already proven on baseline data on Karatau (Karyakin et al. 2022). Data preparation, raster import/export, calculation of areas and conversion to shapefiles or kml-files were carried out in ArcView GIS 3.3 (ESRI 2002).

We evaluated the distribution model for this species' global range based on bioclimatic, topographic, vegetation and anthropogenic variables (Panthi et al. 2021), analysed the parameters and results and adjusted our distribution modelling for Kazakhstan. In view that there is a positive relationship between the species' range size and the breadth of its ecological niche (Moore et al. 2018), it is recommended to avoid modelling the species' distribution over its entire range where the range is large and contains population and (or) subspecies aggregations. It has been shown that aggregation in a particular part of the species' range can lead to smoothed response curves to environmental gradients (Pearman et al. 2010), which, in turn, leads to an increase in the niche width and an overestimation of the predicted distribution of this species (or, conversely, to a narrowing). Therefore, we modelled EV distribution separately for the three regions – Aral-Caspian, Karatau (with adjacent territories) and Southeast Kazakhstan.

Table 1. Surveyed plots where breeding Egyptian Vultures *Neophron percnopterus* were counted. Plot numbering corresponds to that in Fig. 2. Abbreviations: R – region; ACR – Aral-Caspian region; SE KZ – Southeast Kazakhstan; No – number of plot; PA – area of the plot (km^2); PBB – area of breeding biotopes on the plot (km^2); Last Year – year of last examination; n – number of occupied breeding territories (OBT); DP – density of OBT on the plot (pairs/100 km^2); DBB – density of OBT in breeding biotopes on the plot (pairs/100 km^2).

R	No	PA	PBB	Last year	n	DP	DBB
ACR	1	2630.35	57.44	2019	1	0.04	1.74
	2	1513.03	203.51	2019	4	0.26	1.97
	3	4895.63	706.33	2019	5	0.10	0.71
	4	14687.84	571.40	2019	16	0.11	2.80
	5	5133.53	365.08	2019	6	0.12	1.64
Total /Average in ACR		**28860.38**	**1903.76**		32	**0.11**	**1.68**
Karatau	6	218.05	42.71	2022	2	0.92	4.68
	7	184.61	71.30	2022	1	0.54	1.40
	8	192.41	66.88	2022	1	0.52	1.50
	9	84.18	62.88	2022	0	0	0
	10	359.67	249.78	2022	4	1.11	1.60
	11	488.84	81.24	2022	3	0.61	3.69
	12	654.85	237.92	2022	7	1.07	2.94
	13	321.39	172.46	2022	0	0	0
	14	110.46	98.28	2022	1	0.91	1.02
	15	68.97	51.91	2022	2	2.90	3.85
	16	9.22	6.54	2022	0	0	0
	17	317.40	64.66	2022	2	0.63	3.09
	18	41.06	14.79	2022	1	2.44	6.76
	19	71.31	33.36	2022	0	0	0
	20	357.25	146.28	2022	6	1.68	4.10
	21	711.88	5.36	2022	1	0.14	18.67
Total/Average in Karatau		**4191.54**	**1406.35**		**31**	**0.74**	**2.20**
SE Kazakhstan	22	823.73	314.62	2018	12	1.46	3.81
	23	261.73	100.25	2018	4	1.53	3.99
	24	2068.63	67.11	2018	5	0.24	7.45
	25	839.15	77.01	2018	4	0.48	5.19
	26	1005.51	82.35	2018	3	0.30	3.64
	27	632.16	66.13	2018	3	0.47	4.54
Total /Average in SE KZ		**5630.91**	**707.47**		31	0.55	4.38
Total/Average		38682.83	4017.57		94	0.24	2.34

To begin, we created a research extent field, which covered the entire historical breeding range of the EV in the south of Kazakhstan. For this extent, using a Random Point Generator (RPG) (Jenness 2005), we created a system of 244 random points and selected 244 locations (35 Aral-Caspian region, 151 Karatau and 58 mountains of Southeast Kazakhstan) of EV nests or sightings in breeding habitats in summer within Kazakhstan.

In total, 68 explanatory variables obtained from remote sensing products were used to describe the features of breeding biotopes:

NASADEM (NASA JPL. NASADEM Merged DEM Global 1 arc second V001 [Data set]. 2020. NASA EOSDIS Land Processes DAAC. DOI:10.5067/MEaSUREs/NASADEM/NASADEM_HGT.001 Available from https://developers.google.com/earth-engine/datasets/catalog/NASA_NASADEM_HGT_001 [Accessed 22 February 2023]);

MOD13A1.061 Terra Vegetation Indices 16-Day Global 500m (Didan 2021);

Geomorpho90m (Amatulli et al. 2020), Global Habitat Heterogeneity (Tuanmu & Jetz 2015), Global Wind Atlas (Badger et al. 2021), World Clim (Fick & Hijmans 2017) and ESA WorldCover 10m v100 (Zanaga et al. 2021). The variables were tested for statistical normality using the Lilliefors test.

We needed to understand which variables contribute the most to the difference between EV presence points and random points and to select variables in different sets to model the EV distribution. For this purpose, mean values for EV presence points and random points were compared using a t-test.

To model the EV distribution, we chose from 36 (southeast Kazakhstan) to 40 (Karatau) variables, the values of which differed most significantly for EV points of presence and random points.

After studying the relationships of variables using the Spearman correlation coefficient (r) to eliminate multicollinearity, we discarded the least significant variables, the correlation coefficient (r) in pairs of which was > 0.75 (Eliseeva 2022). As a result, for the most accurate model, we selected a minimum set of 19–21 variables.

To verify whether the predicted model values depend on the geographical distance between locations and to exclude spatial autocorrelation, the Moran test was used (R-function “moran.test” in the “spdep” package) (Griffith & Peres-Neto 2006, Dormann et al. 2007).

Random Forest method (Breiman 2001) was used for image classification (for advances of this method, see Radchenko 2017 and Lingjun et al. 2018). We used probability and regression options. In accordance with previously published recommendations (Brotons et al. 2004), we prepared EV absence points and imported them into Google Earth Engine (GEE) along with their presence data.

The raster set was fitted and classified via GEE according to the previously proposed species distribution model fitting workflow algorithm (Crego et al. 2022) but without pseudo-absence or background points, as we used actual EV absence points that are more prioritised in distribution modelling species (Brotons et al. 2004). We divided EV presence data into training (80%) and testing (20%) sets and implemented a spatial block cross-validation method to split the data for training and model validation (Roberts et al. 2017, Valavi et al. 2019, Crego et al. 2022). During analysis, 25 iterations were run using a random division of blocks. Model accuracy was assessed on the basis of validation for each iteration of model fitting using AUC-ROC (Fielding & Bell 1997, Fawcett 2006) controlled by R^2 and Kappa (Brownlee 2016, Zhang et al. 2021). Because of the GEE operation, a map of breeding biotopes was built and then exported in Geotiff format as a raster with pixels ranked by the probability of presence. The raster is vectorised in ArcView in shapefile format. Pixels with a probability of the presence of the species of greater than 50% are classified as breeding biotopes.

Abundance estimate

Two methods were used to calculate EV population:

(1) Direct recalculation of the density of occupied breeding territories in breeding biotopes on census plots to the total area of species breeding biotopes in the region (Karyakin 2004) with the calculation of an asymmetric confidence interval (Ravkin & Chelincev 1990).

(2) Generating random points (further RPG) over a given range of distances between nearest neighbours based on a regular network (Karyakin et al. 2022).

The algorithm was as follows: random points were sequentially generated so that the distance from a new point to all previous ones fell within a given interval. The distance interval was determined by distances between observed species presence points. In order to optimize the algorithm, points were selected from a predetermined finite set of points obtained by dividing the region of interest into squares of a given size not exceeding the minimum distance between the detected nests.

To check how well the algorithm estimates species abundance, it was tested as follows: plots studied at the observation stage were randomly divided into two sets (training and test). Distances between nests were calculated based on the training set, and a set of random points in the region of interest was built using the algorithm described above. After that, the number of random points that fell into the plots from the test set was counted and compared with the number of real nests on these plots. This operation was carried out 100 times, and the results were used to calculate the minimum, maximum, mean number ± standard deviation, mean error, and confidence interval. For completeness, the check was carried out two times, using different principles for dividing sections into test and training sets.

Based on ESA WorldCover 10m v100 (Zanaga 2021) and Sentinel satellite images, layers of buildings, oil and gas production facilities and mining enterprises as well as farms were created. The best layer was chosen from 100 sets of random points obtained at the algorithm’s testing stage. It was further corrected by excluding points that fell within a three-kilometre radius around oil and gas production facilities and mining enterprises, reducing the number of points located far from farms as well as by approximating the number of points that fell into surveyed plots to the actual number of nests on these plots. The corrected layer of points was considered the result of the abundance estimate and was used to visualize the data in the form of grid mapping.

Data visualisation as grid mapping

In order to facilitate visualization of all EV records in Kazakhstan, we have created a map based on a regular grid with a cell size of 50 × 50 km. Subsequently, we attached the following indicators to each cell of the grid:

(1) Area of EV breeding biotopes obtained as a result of Google Earth Engine modelling using the Random Forest method.

(2) Extent of knowledge in a given cell: presence or absence of birds of prey studies in a given cell. We used information from the database of survey routes available in the "Raptors of the World" section of Web-GIS "Faunistics" (http://rrrcn.wildlifemonitoring.ru) and a selection of ornithological publications as well as from electronic databases containing any mention of systematic records of large raptors expected to be present in the EV study area (between 1 April and 20 September).

(3) Points of EV presence, ranked by status:

– breeding territory, determined by the presence of an active nest or this year's fledglings in a breeding habitat;

– summer record of an adult bird in a breeding territory (< 10 km from a breeding biotope),

– summer record of birds of any age away from breeding habitats, record during migration.

(4) Points of possible EV breeding territories generated using RPG method.

Summarizing EV phenology, nesting preferences and parameters and threats based on all collected data

Rephrase to we found 64 EV nests in Kazakhstan in 2021 in publications, photo-sites and in Faunistics web-GIS. This includes 15 nests in the Aral-Caspian region, 27 nests in Karatau and adjacent territories and 22 nests in the mountains of Southeast Kazakhstan. In 2022, a report on Karatau was published, summarising information on 44 nests (Karyakin et al. 2022).

We analysed threats to EV published in various literature sources. We also sent a request to the Committee for Veterinary Control and Supervision under the Ministry of Agriculture of the Republic of Kazakhstan regarding the use of non-steroid anti-inflammatory drugs (NSAIDs) in veterinary medicine in EV range. We attempted to perform a expert assessment of the severity of the threat of EV poisoning in Kazakhstan based on the received information.

Results

Egyptian Vulture distribution

Before the 1990s, EV distribution in Kazakhstan was described in eight literary sources (Dementiev 1951, Shnitnikov 1949, Korelov 1962, Kapitonov 1969, Przhevalsky 1878, Alferaki 1891, Kozlov 1963, Pfeffer 1990; for details, see Supplementary Material 2). These data were used as a basis for creating a breeding range map (Fig. 1).

Peculiarities of EV breeding biotopes

Currently, 185 sites with confirmed records of Egyptian Vulture in breeding biotopes have been identified in Kazakhstan, including 163 occupied breeding territories. Of these, 33 breeding territories are reliably known in the Aral-Caspian region, 91 are in Karatau and adjacent territories, and 39 in Southeast Kazakhstan.

In accordance with the division of count plots into Thiessen polygons, one EV breeding territory occupies an area ranging from 18.24 to 2,630.35 km^2, on average (n = 122) 325.33 ± 487.24 km^2. In the Aral-Caspian region, this indicator averages (n = 33) 901.89 ± 649.87 km^2 (from 103.25 to 2,630.35 km^2), in Karatau (for 2010 and 243.13 km^2), and in Southeast Kazakhstan (n = 31) 181.64 ± 166.78 km^2 (from 36.89 to 588.27 km^2).

In the Aral-Caspian region, distances between nearest neighbours ranges from 4.24 to 29.58 km, averaging (n = 19) 15.01 ± 8.51 km (median = 10.57 km). Where the chink wall stretches for more than 10 km, pairs of vultures nest 5–10 km apart (47.37% of pairs).

All known EV nests in this area were situated on high sheer, mostly chalk or shell rock, walls of chinks on the Mangyshlak Peninsula, Ustyurt Plateau, Kinderli-Kayasan Plateau and Kaplankyr on the border with Turkmenistan.

In the Karatau Mountains and on chinks in the foothills, distances between the closest EV neighbours range from 2.10 to 15.96 km, averaging (n = 44) 8.15 ± 3.91 km.

In Southeast Kazakhstan, distances between nearest neighbours vary from 2.8 to 13.74 km, averaging (n = 19) 6.67 ± 2.97 km (median = 6.34 km).

Modelling distribution

EV points of presence during the nesting phase in all three parts of its nesting range in Kazakhstan (Aral-

Caspian region, Karatau and Southeast Kazakhstan) had significantly distinct habitat features relative to random points. EV were present on steeper slopes, in more rugged terrain, in areas with greater wind pressure at altitudes of 10–100 m than random points (Table S1 in Supplementary Material). Of the climatic variables, Mean diurnal range (bio02), Temperature seasonality (bio04), Temperature annual range (bio07), wettest month Precipitation (bio13), wettest quarter Precipitation (bio16), coldest quarter Precipitation (bio19) were the most important for the difference between EV points of presence and random points for all three regions.

From the set of variables, we selected three sets for modelling species distribution, reflected in Table S2 in Supplementary Material. The set for Model 1 contained all variables important for this region according to the t-test and elevation. The set for Model 2 contained variables important for this region according to the t-test without multicollinear variables and the same set of variables for all regions from ESA WorldCover 10m v100. The set for Model 3 contained important variables common to all regions and elevation.

The following models showed the best results for predicting EV distribution and cross-validation in Random Forest (Table S3 in Supplementary Material):

Model 2 for the Aral-Caspian region (OOB error for 20 trees = 0.19, AUC = 0.997, training R2 = 0.922, validation R2 = 0.853, Kappa = 0.968, cc r= 0.986 for regression);

Model 3 for Karatau (OOB error for 20 trees = 0.17, AUC = 0.988, training R2 = 0.942, validation R2 = 0.87, Kappa = 0.949, ccr = 0.977 for regression) and Southeast Kazakhstan (OOB error for 20 trees = 0.09, AUC = 0.997, training R2 = 0.904, validation R2 = 0.827, Kappa = 0.973, ccr = 0.989 for probability).

According to Random Forest results for Ustyurt, variables that determined EV distribution were topographic variables: Vector ruggedness measure (vrm), Terrain slope (slope) and bioclimatic variable: bio07 for probability and regression, and Stream power index (spi), Mean temperature of wettest quarter (bio08) and Mean temperature of coldest quarter (bio11) only for regression.

For mountainous areas of Southern (Karatau) and Southeast Kazakhstan, in addition to topographic variables (vrm, slope, Terrain ruggedness index (tri), roughness and elevation), it turned out that a range of bioclimatic variables determined distribution. These included the Annual mean temperature (bio01), bio02, bio04, Min temperature of coldest month (bio06), bio08, bio11, Annual precipitation (bio12), Precipitation of driest month (bio14) and Precipitation of wettest quarter (bio16) characterize the natural area, in which EVs nest more than they affect Egyptian Vulture. Diagrams of important variables in the best Random Forest models for probability and regression are shown in Fig. S1 in Supplementary Material. The AUC-ROC plots for these models are shown in Fig. S2 in Supplementary Material.

As a result, the area of breeding biotopes for nesting EV in Kazakhstan (using modelling results by the Random Forest method using the average parameters for probability and regression), was determined to be 16,430.89 km^2, of which the Aral-Caspian region contains 2,809.52 km^2 (17.10%), Karatau and its environs contain 10,378.85 km^2 (63.17%), and Southeast Kazakhstan mountains contain 3,242.52 km^2 (19.73%) (Fig. 4).

Abundance estimate

Our study represents the first attempt to estimate Egyptian Vulture abundance throughout its breeding range in Kazakhstan, using data from targeted surveys of this species at specific sites and on modelling its distribution by analysing topographic and bioclimatic variables.

Results of censuses on plots: The results of counts on plots are shown in Table 1. The distribution density of occupied EV breeding territories (hereinafter OBT) on plots, while taking into account plots where the species was not found, averaged (n = 27) 0.24/100 km^2 (0–2.9/100 km^2), including in breeding biotopes on plots – 2.34/100 km^2 (0–18.67/100 km^2). The minimum density indicators were found in the Aral-Caspian region (from 0.71 to 2.8, on average, 1.68 ± 0.36/100 km^2, n = 5), the maximum – in Southeast Kazakhstan (from 3.64 to 7.45, on average 4.38 ± 0.11/100 km^2, n = 6). In Southeast Kazakhstan, with its high density of EV OBT in breeding biotopes and the density of the total census area (0.55/100 km^2) turned out to be less than in Karatau (0.74/100 km^2), a fact associated with strong fragmentation and a small area of breeding biotopes. Moreover, here the ratio of breeding biotopes suitable for EV to unsuitable biotopes reflects the situation across all of Southeast Kazakhstan, despite few census plots. In Karatau on the contrary, plots were established in areas with the maximum number of EV breeding biotopes.

Abundance estimation according to censuses on plots: Result of direct recalculation of the density of EV OBT in breeding biotopes on plots (taking into account "null" plots) to the total area

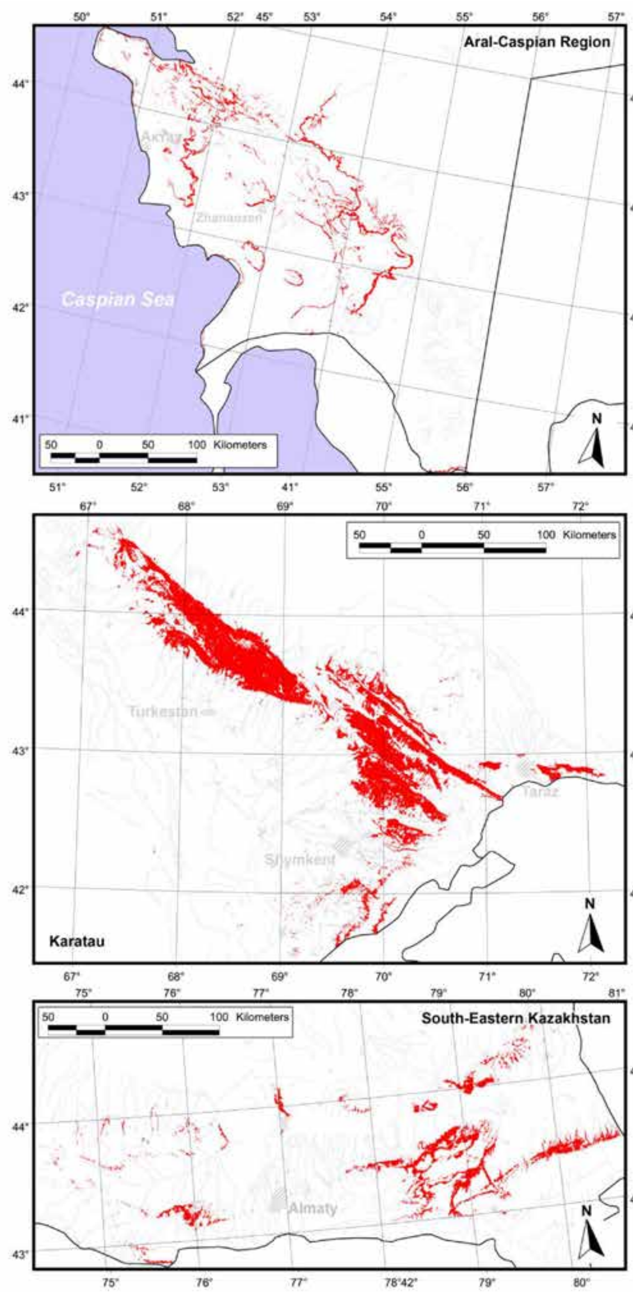

Fig. 4. Breeding biotopes of Egyptian Vulture *Neophron percnopterus* identified from Random Forest simulations of species distribution in Google Earth Engine: Aral-Caspian Region (at the upper), Karatau (in the centre) and Southeast Kazakhstan (at the bottom).

of breeding biotopes in the regions of the species breeding range in Kazakhstan are shown in Table 2. As a result of this extrapolation, the EV abundance estimate in Kazakhstan is assumed to range from 321 to 549, an average of 418 breeding pairs, including 30–75 in the Aral-Caspian region (average 47 pairs), 171–306 in Karatau (average 229 pairs) and 120–168 in Southeast Kazakhstan (average 142 pairs). However, this is a rather rough calculation that does not consider fragmentation of breeding biotopes and differentiation of the pattern of EV breeding biotopes both in single clusters (area > 100 $km^{2)}$ and in isolated clusters (area of 0.1 km^2). In addition, for Ustyurt the lower limit of the confidence interval turned out to be even less than the absolute number of counted EV breeding territories.

Abundance estimation using the RPG method: Using RPG for the entire array of breeding biotopes (taking into account validation errors), gives the following indicators: 466–894 throughout Kazakhstan (average 608 points). In the Aral-Caspian region this includes 68–144 (average 92 points), 250–397 in Karatau (average 307 points), and 148–353 in Southeast Kazakhstan (averaging 209 points) (Table 3). The large confidence interval for Southeast Kazakhstan is associated with regular validation errors due to highly fragmented coverage from breeding biotopes, despite a more even EV distribution, unlike in Karatau or the Aral-Caspian region. Detail results of Egyptian Vulture abundance estimation for Kazakhstan by the method of generating random points over a given range of distances between the nearest neighbours based on a regular network is shown in Table S4 in Supplementary Material.

After filtering generated points that fall within the buffer zones of human settlements and mining sites, as well as after thinning the pattern of points in areas with low EV density and outside the buffer zones around farms, we obtain the final abundance estimate during nesting in Kazakhstan: 332–667 (average of 502 pairs). Included in this are the Aral-Caspian region (58–124 pairs, average of 79 pairs) Karatau (171–298, average 278 pairs), and in Southeast Kazakhstan (103–245, average 145 pairs) (Table 4).

Verification of generated and corrected points showed that 32.47% of the points from the entire created pattern were confirmed as EV breeding territories. In other words, this coincides with actual nests or locations of repeated summer registrations of birds demonstrating nesting behavior in breeding biotopes. Another 12.67% of points lie in the zone of summer EV observations by birdwatchers. To date, the pattern of points requiring primary verification is 54.86%, almost half of the estimated number of nesting EV in Kazakhstan.

Data visualization in the form of grid mapping

Visualization of the degree of inspection of EV breeding range and abundance estimates for its breeding population in Kazakhstan are presented in Fig. 5. The entire area of potential EV breeding is

Table 2. Estimation of abundance of Egyptian Vulture in Kazakhstan based on census in surveyed plots. Abbreviations: ACR – Aral-Caspian region; SE KZ – Southeast Kazakhstan; PBB – area of breeding biotopes on surveyed plots (km²); BB – area of breeding biotopes in the region (km²); n – number of occupied breeding territories.

Region	PBB, km²	n	Density of breeding territories, pair/100 km² M±SE (confidence interval)	BB, km²	Abundance estimate, breeding pairs, average (min–max)
ACR	1,903.76	32	1.68±0.36 (1.06–2.68)	2,809.52	47 (30–75)
Karatau	1,406.35	31	2.20±0.21 (1.65–2.95)	10,378.85	229 (171–306)
SE KZ	707.47	31	4.38±0.11 (3.72–5.17)	3,242.52	142 (120–168)
Kazakhstan	4,017.57	94		16,430.89	418 (321–549)

Table 3. Results of RPG for breeding biotopes in Kazakhstan (without filtering points). Abbreviations: ACR – Aral-Caspian region; SE KZ – Southeast Kazakhstan; NND – nearest neighbor distances (km); PT – area of the Thiessen polygons built around points of presence for Egyptian Vulture, identified as breeding territories, at surveyed plots (km²); BB – area of breeding biotopes in the region (km²); n – number of occupied breeding territories.

Region	n	NND, km	PT, km²	BB, km²	Number of generated random points best validation value (min-max)	Number of generated random points with validation error logging; M±SD (confidence interval)
ACR	32	(n=19) 15.01±8.51 (4.24–29.58)	(n=33) 901.89±649.87 (103.25–2,630.35)	2,809.52	86 (58–153)	92±15.0 (68–144)
Karatau	31	(n=44) 8.15±3.91 (2.10–15.96)	(n=59) 88.12±58.94 (18.24–243.13)	10,378.85	370 (232–395)	307±33.6 (250–397)
SE KZ	31	(n=19) 6.67±2.97 (2.8–13.74)	(n=31) 181.64±166.78 (36.89–588.27)	3,242.52	192 (143–291)	209±34.5 (148–353)
Kazakhstan	**94**			16,430.89	648 (433–839)	608 (466–894)

Table 4. Estimation of abundance of Egyptian Vulture abundance estimation for Kazakhstan using RPG with correction. Abbreviations: ACR – Aral-Caspian region; SE KZ – Southeast Kazakhstan; BB – area of breeding biotopes in the region (km²); n – number of occupied breeding territories; PV – number of points confirmed as breeding territories; PVS – share of verified points corresponding to breeding territories, out of the total number of generated points (%); PP – number of points simulating potential breeding territories.

Region	BB, km²	n	Abundance estimate, breeding pairs average (min–max)	Result of points verification based on real breeding territories (for the average covered)		
				PV	PVSh, %	PP
ACR	2,809.52	32	79 (58–124)	33	41.77	46
Karatau	10,378.85	31	278 (171–298)	91	32.73	187
SE KZ	3,242.52	31	145 (103–245)	39	26.90	106
Kazakhstan	16,430.89	94	502 (332–667)	163	32.47	339

divided into 451 cells over an area of 2,500 km². Breeding biotopes were identified in 109 cells of the network based on the results of modelling. EV nesting was established in 53 cells of the network, including for four cells (7.55%) containing more than ten pairs, for eight cells (15.09%) containing from five to nine pairs, for 25 cells (47.17%) containing two to four pairs, and for 16 cells (30.19%) containing a single pair each. For 96 cells (88.07% of the number of cells with breeding biotopes), EV abundance was calculated using the RPG method. For 14 cells (14.58%), the abundance estimate ranged from 10 to 23 pairs per cell. For 25 cells (26.04%), it ranged from five to nine pairs. For 38 cells (39.58%), there are an estimated two to four pairs, and for 19 cells (19.79%) – just one pair each.

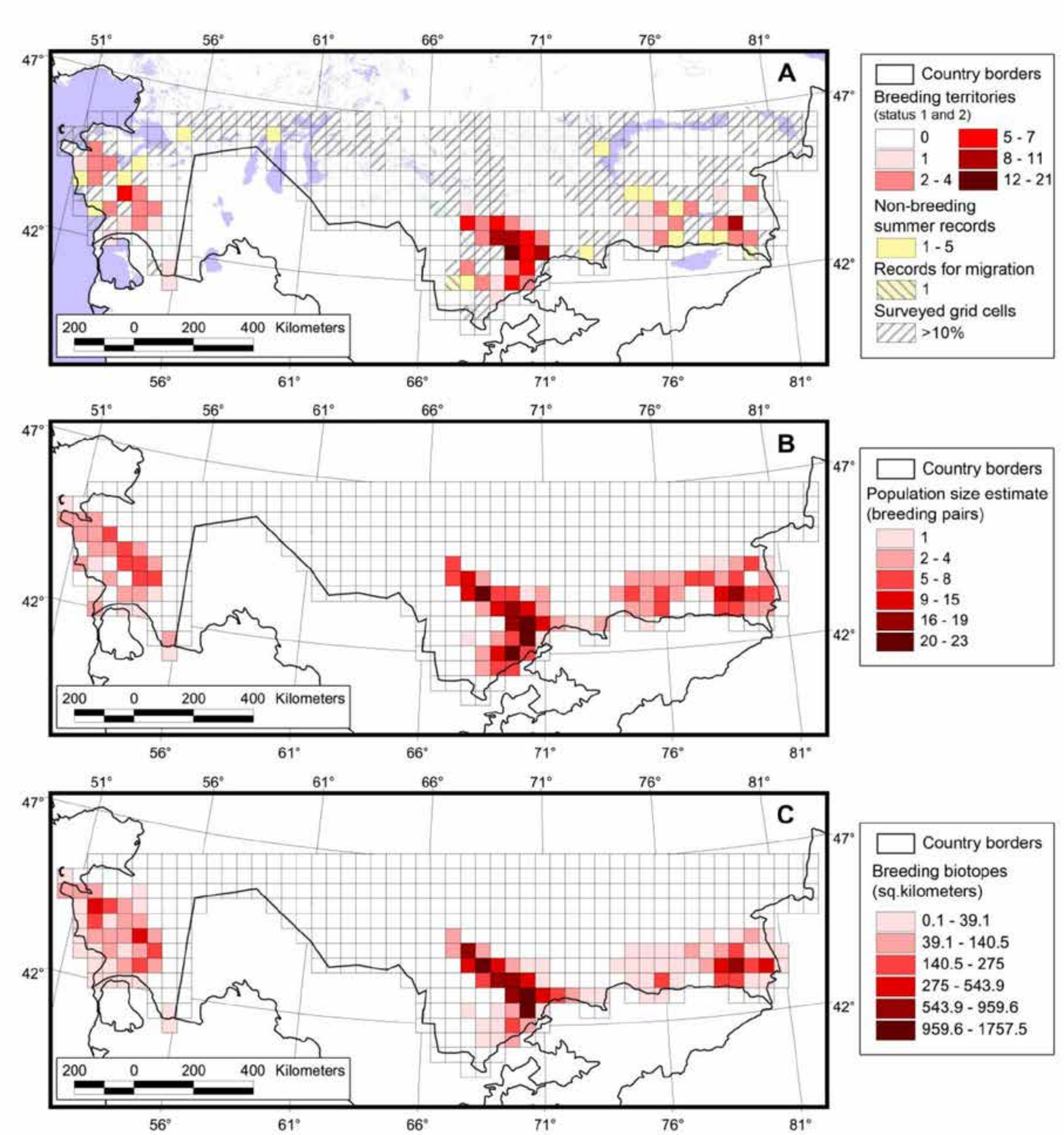

Fig. 5. Grid mapping of the distribution of Egyptian Vulture in Kazakhstan (cell size 50x50 km): degree of study of cells on the grid, known breeding territories and summer records – A, abundance estimate – B, area of breeding biotopes based on the results of modeling – C.

Threats

Electrocution: Targeted surveys of power lines for EV deaths in the nesting area with the greatest density in Karatau in 2022 (386.17 km mapped power lines, 386.2 km examined in detail) showed that mainly corvids perish on power lines (3.53 ind./km in the most dangerous area); dead EVs were not found (Karyakin et al. 2022). Out of 117 EV registrations, high-voltage power lines, where deaths from electric shock are not possible, only account for three deaths.

Mining: Only two publications on the Aral-Caspian region (Pestov et al. 2019a) and Karatau (Karyakin et al. 2022) contain information about threats to EV from mining. For Karatau, Egyptian Vultures abandoned three breeding territories because of expanded mining operations by Kazphosphate Corporation. Out of 41 breeding territories occupied in 2022, geological exploration was carried out on eight of them (19.5%), involving construction of temporary roads and destruction of cliffs, resulting in the displacement of half of the pairs, the old nests of which fell within the geologists' working zone. Expansion of mining operations planned over the next few years risk at least 12 more known EV nesting sites. The same can be said for Ustyurt, where 70% of all EV breeding territories lie within licensed areas for oil and gas production (see Pestov et al. 2019a). At the same time, EV is completely absent here on the chink depressions related to ongoing oil production, indicating that expansion of the exploitation zone by gas workers and oil workers will entail a decrease in the number of the EVs. However, the scale of this reduction is still difficult to assess, since we cannot predict how quickly licensed areas will be developed.

Wind farms: Thirteen V breeding territories fell into the zone of influence of the already-built Zhanatas and Koktal wind farms in Karatau; two were abandoned (Karyakin et al. 2022). Roughly 20 territories fall within the design zone of planned wind farms in Ustyurt and Karatau. The effect of wind farms on migratory vultures has not been studied, and they may lead to the death of some birds. The Zhanatas and Koktal wind farms are located in the Western Circum-Himalayan migration corridor (Karyakin et al. 2021), through which vultures fly the same route as eagles in a fairly narrow range of both latitude and altitude.

Poisoning: Of 59 examined EV breeding territories in Karatau, farmers at 11 (18.64%) sites gave oral testimonies that they poison wolves. Wolf control is typical for mountain areas, but what happens outside the mountains remains unknown. The impact of NSAIDS on EV is unknown. In response to a request from Biodiversity Research & Conservation Centre about medicines used in veterinary practice, the Committee for Veterinary Control and Supervision under the Ministry of Agriculture of the Republic of Kazakhstan provided a list of drugs whose negative impact on scavengers has been proven in different countries of the World. These included diclofenac, ketoprofen and flunixin (http://rrrcn.ru/wp-content/uploads/2023/02/drugs-BRCC2023.pdf). Many of these drugs are banned in a number of Asian countries. In Kazakhstan, they continue to be used without any restrictions. However, the volume of their use, especially in private households, is not known.

Nest loss: Of 19 nests checked three times in 2010 and 2022, only 57.89% were successful. The overall survival rate, taking into account dead nests checked once per season, was only 25.32%. In one nest, the nestlings died immediately after hatching following a nest visit by birdwatchers to photograph birds (https://macaulaylibrary.org/asset/468293081). However, it is impossible to say whether the photographers were the cause of concern, since in several other nests, clearly undisturbed by photographers and located at a distance from highways, death of offspring occurred in the same period. Of 13 successful nests found in early July 2022 in Karatau, only ten successful nestlings remained by the time the nestlings fledged, and in three nests, broods died because of predation by Golden Eagle. In addition, two nestlings (older and middle) were killed by predators in a brood of three nestlings was noted (Karyakin et al. 2022). There are no results of nest re-checks for the remaining regions.

Discussion

Egyptian Vulture distribution

Comparison of literature data shows that EV breeding distribution in Kazakhstan remained roughly the same throughout the entire period of its study (Pfeffer 1990, 2010, Gavrilov 1999, Gavrilov & Gavrilov 2005). Range boundaries have been clarified in the recent years. The species nested on the right bank of the Ili River from Dzharkent to Kapchagay Canyon (Kovshar 2019) but was not found in the Kazakhstani part of the Central Tien Shan (Korelov 1962, Berezovikov et al. 2004, Kovshar 2019).

Peculiarities of EV breeding biotopes

EV breeding biotopes in the Aral-Caspian region are chinks – cliffs formed by marine abrasion during the retreat of the Caspian Sea. EV nests are situated on high sheer, mostly chalk or shell rock, walls of chinks. In these biotopes, almost half of pairs (47.37%) nest within 5–10 km from each other. Distances between pairs of more than 11 km are associated with fragmentation of chinks suitable for this species. Distances greater than 30 km are definitely associated with overlooked nesting pairs.

Typical EV breeding biotopes in Karatau are rocky outcrops along permanent or temporary watercourses in the foothills and low mountains at altitudes up to 1,600 m. Moreover, the height of cliffs and the surface area of rock masses do not play a role. EVs definitely avoid developed areas with fields, even if there are rock outcrops present. In the Karatau Mountains until 2017, EV were more or less evenly distributed but, in 2022, the birds began to nest closer to farms and distance themselves from Golden Eagles (*Aquila chrysaetos*). In connection with this, the number of distances between nearest neighbours ranging from 6–8 km decreased and some nesting groups became denser (Karyakin et al. 2022).

In Southeast Kazakhstan, due to the region's specifics, this species is distributed in isolated groups across different mountain massifs, gravitating mainly to riverside rock faces. It nests only rarely on cliff rocks, which are not connected with streams and along the periphery of wide valleys (e. g, in Syugatinskaya Valley).

Modelling distribution

For the Aral-Caspian region, results of modelling show that the northernmost EV breeding biotopes turned out to be fragments of the western Chink of Ustyurt up to a latitude of 44.76º. The Aral chink did not even reach 30% of the probability of EV nesting. Considering that the northernmost nest of the Egyptian Vulture in the Aral-Caspian region is currently found on Cretaceous chink on Mangyshlak at a latitude of 44.50º and not a single occurrence of documented EV nesting further north (only a few summer records of solitary birds are known), it can be concluded that the distribution model is good.

For Karatau and Southeast Kazakhstan, all selected breeding biotopes lay within the contour of EV records for the last 20 years, so for that reason we also consider the modelling to be successful.

The best model of the EV's global range in MaxEnt (Panthi et al. 2021) included bioclimatic, topographic, vegetation and anthropogenic variables. The most important variables that have the main contribution to the model turned out to be livestock density, temperature seasonality and precipitation of the coldest quarter and slope. Our modelling of EV breeding biotopes in Kazakhstan in general terms coincided with these distribution-modelling results but with better accuracy in identifying breeding biotopes, especially in the flat part of the range.

Our results showed that the suitability of EV habitat determines several topographical and climatic factors. The topographical variables turned out to be common for lowland and mountainous areas: Vector ruggedness measure (vrm), Terrain slope (slope) and bioclimatic variables: Mean temperature of wettest quarter (bio08) and Mean temperature of coldest quarter (bio11). For mountains, elevations above sea level also played a decisive role in EV distribution models in the Aral-Caspian region, average annual temperature amplitude (bio07). Similar variables (elevation – about 54% of the overall model performance, slope and bio7 together gave 34% of the overall model performance) were determining when modelling the distribution of EV breeding individuals in Iraqi Kurdistan in MaxEnt (Khwarahm et al. 2021). Elevation and aspect were GLM-determining in Turkish EV nesting site selection, and Random Forest added distances between nearest neighbours, settlements and roads to an ensemble of important variables (Şen 2012). Standard deviation of elevation and spring-summer NDVI indicators were also determining the summer distribution of the Egyptian vulture in Iran according to MaxEnt modelling data in one article (Farashi & Alizadeh-Noughani 2019) and livestock density (31.82%), the presence of wild ungulates (15.36%), remoteness from landfills (14.77%), vegetation (12.46%) and elevation (11.85%) – in another (Ashrafzadeh et al. 2020).

Abundance estimate

To our knowledge, the global estimation of the EV population (BirdLife International 2021) cannot be considered reliable given that EV breeding populations on the vast extents of the Asian range were never routinely counted. Taking into account the supposed decline in the numbers of the Turkish population (Terraube et al. 2022) and the scale of apparent population decline in the Balkans (Velevski et al. 2015) and in India (Cuthbert et al. 2006), we can suppose that the negative trend in EV's populations is widespread through Asia. To compose a conservation action plan for EV, we need reliable estimations of its population number and regular inspections of breeding colonies. In contrast to densely-populated and birdwatcher-filled Europe, Asia has vast unpopulated areas, very few bird observers and even fewer professional ornithologists. As a result, reliable estimations and regular observations are problematic. This matter is applies fully to Kazakhstan.

In the IUCN Red List and some other sources (Botha et al. 2020, Orta et al. 2020, BirdLife International 2021), estimation of the breeding population of EV in Kazakhstan is only 100 pairs (Sklyarenko 2002, Sklyarenko & Katzner 2012). In 2010, it already became clear that this estimation needs a review since the number of known breeding territories and EV observations in summer doubled the previous assessments. However, to obtain the actual counts in Kazakhstan, new adapted survey protocols and correct estimates of the suitable breeding habitats and possibly inhabited biotopes are needed. The first step in this direction was made in 2022.

In 2022, in order to create protocols for counting and monitoring populations of EV in Kazakhstan and in model areas in Karatau, we planned census work on census routes and EV sites, as well as various methods for extrapolating obtained nesting density of the species to the area of nesting biotopes and habitats (Karyakin et al. 2022). Census surveys with further calculation of species abundance on the contour of breeding biotopes using the RPG method with correction of the pattern of points in the GIS showed the best result, in our opinion. We extended the abundance estimate using this method across the entire range of Egyptian Vulture in Kazakhstan, taking as a basis census surveys in previous years and obtained a good estimate of abundance.

For the entire generated pattern of points, simulating a pattern of potential breeding sites for EV in Kazakhstan, 45.14% were confirmed as breeding or likely nesting from both our data and records by bird watchers or ornithologists. Moreover, by estimating abundance using this method, it was possible to achieve a minimum scatter of the confidence interval both for fragmented habitats in Southeast Kazakhstan and for chinks in the Aral-Caspian region, which, in fact, are a system of linear and point objects. The pattern of dots that we created imitating potential EV nesting sites will serve as the basis for moving forward to plan further surveys in Kazakhstan.

Repeated counts in Karatau 12 years later showed the stability of EV populations despite various negative factors affecting the species in this region. Three pairs of EVs have stably reproduced in Ustyurt State Nature Reserve since 1986 (Onufriev & Dyakin 1991, Pestov & Nurmukhambetov 2012; new unpublished data). The phenomenon of EV well-being relative to other declining scavenger species in Kazakhstan is a promising topic for future study.

The abundance estimate using two differing methods (plots and RPG) totalled 418 (321–549) and 502 (348–639) breeding pairs, respectively. The resulting difference in estimates by the two methods is insignificant and confirms correctness of the estimates. The actual species abundance most likely lies in a range between these estimates.

Phenology, nesting preferences and parameters based on all collected data

Height of nests

According to our data for 2010–2022, nest height in Karatau and its foothills varied from 2.5 to 200 m, averaging (n = 43) 28.4 ± 41.18 m; in 55.81% of cases, nests were located in the upper third of the cliff, in 30.23% – in the middle, and in 13.95% – in the lower third (Karyakin et al. 2022). There are published data about the location of three nests: on the upper quarter of a conglomerate cliff (Chalikova 2004, 2008), at one-third the height of an eight-metre cliff (Gubin 2018) and in the middle of a sheer eight-metre cliff (Gubin 2020).

In the Aral-Caspian region, of 15 known nesting structures (Karyakin et al. 2004, Levin & Karyakin 2005, Pestov et al. 2017, 2019b, Onufriev & Dyakin 1991; unpublished data of the present authors). Only one (7.14%) was located at the lower part of the cliff (at a height of 10 m and at 30 m from the top), three nests (21.42%) were the middle (at a height of 25–50 m) and 71.43% (n = 14) nests were located in the upper third, at a height of 30–80 m.

In the mountains of Southeast Kazakhstan, one nest was located 10 m above the base of a 20-metre cliff, while another nest was located 15 m high on a 30-metre cliff (Gubin 2008). There are also mentions of a nest 1.5–2 m from the top (Korelov 1962). Pfeffer (1990) provided the most comprehensive description of the height of Egyptian Vulture nests: nests were located at 5–80 m, on average 22 m from the base, while the height of nesting rocks and cliffs varied from 10 to 150 m, averaging (n = 15) 45 m.

Thus, in Kazakhstan (including our data) (n = 63), Egyptian Vulture prefers to nest on steep cliffs, mainly in the upper third (57.14%) and in the middle (30.16%) of the cliff, and only 12.70% were located in the bottom third. The height of nest location varies from 2.5 to 200 m, averaging (n = 58) 30.5 ± 37.6 m.

Location of nests

The elevation range above which EV do not nest in Kazakhstan is 1675 m a.s.l. (average 679.89 ± 218.11 m). EVs nest in Himalayan foothills in Central-West Nepal (Gurung et al. 2023) in the same elevation range (523–1644 m a.s.l.). It is likely that these heights are optimal for the species' breeding when it comes to nesting in mountainous parts of Asia.

The average distances between nearest neighbours in Kazakhstan vary from 6.67 ± 2.97 km in Southeast Kazakhstan to 15.01 ± 8.51 km in the west, reaching some optimal values in Karatau – an average of 8.15 ± 3.91 km. This corresponds to the distribution parameters of the species in Nepal (8.8 ± 6.1 km) (Gurung et al. 2023), which seems to be typical for Asian EV populations.

According to literature data for the Karatau mountains and adjacent territories (n = 8), 75% of nests are located on rocks and 25% on chinks, while 96.15% of EV nests are located in niches (n = 26) (Ivashchenko 1991, Chalikova 2004, 2008, Kolbintsev 2004a, 2004b, Gubin & Belyalov 2017, Gubin 2018, 2020, Korelov 2012, Amirekul et al. 2022). According to our data in 2010–2022 in Karatau (n = 44), 88.64% of nests were built in niches and 11.36% on shelves; nests on shelves were identified in 2022. Apparently, this is a new phenomenon associated with the displacement of nesting pairs to lower cliffs closer to farms (Karyakin et al. 2022).

In the Aral-Caspian region, all 15 known nesting structures are located on the chalky cliffs of the Ustyurt Plateau chinks, 13 (86.67%) of which were located in niches, two on a shelf (13.33%), one of which was under an overhang (half-niche) (Karyakin et al. 2004, Levin & Karyakin 2005, Pestov et al. 2017, 2019b, Onufriev & Dyakin 1991; present authors' unpublished data).

In the mountains of Southeast Kazakhstan (*n* = 21), 71.43% of nests were located on rocks and 28.57% on loess cliffs while 33.33% were in niches and 66.67% on shelves and ledges (Korelov 1962, Gubin 2008, Pfeffer 1990, Amirekul et al. 2022).

In general for Kazakhstan, 70.45% of all described nests are located in rock massifs, 22.73% in chinks and 6.82% on loess cliffs (*n* = 88). In 79.25% of cases, EV prefers to nest in niches (*n* = 106).

Breeding outcome

In publications and on photo sites, we found ten references to the number of eggs in EV clutches in 2017 and 2018. One nest contained one egg (Gubin & Belyalov 2017, Gubin 2018, 2020). In Southeast Kazakhstan, Pfeffer (1990) described one clutch of three eggs and, in other cases, clutches of one to two eggs are described. On average, according to ten observations, clutch consisted of 1.9 ± 0.57 eggs (from one three eggs). According to our data for 2010 and 2022, in Karatau, the number of eggs in a clutch (*n* = 19) was 1.32 ± 0.58 (from 1 to 3) (Karyakin et al. 2022).

The number of EV nestlings in nests is mentioned in 11 publications and posts on the birds.kz website. In three cases, two nestlings per nest are described (Ivashchenko 1991, Gubin 2020). In the remaining cases, one nestling per nest was found (Gubin 2018, 2020, Kovalenko 2008, Korelov 2012, Onufriev & Dyakin 1991). The number of nestlings per nest (*n* = 11) averaged 1.27 ± 0.47 (from 1 to 2). If we add data to this sample, Kolbintsev (2004b) documented an EV nest in the Karasai Canyon (Small Karatau Mountains), resulting in obtaining an average (*n* = 30) of 1.42 ± 0.5 nestlings (from 1 to 2) per nest. According to our data in 2022, in Karatau, the number of nestlings per successful nest at the beginning of July (*n* = 17) was 1.29 ± 0.59 (from 1 to 3), at the end of July (*n* = 11) – 1.27 ± 0.47 (from 1 to 2). The number of nestlings per active nest at the end of July (*n* = 19) was 0.74 ± 0.73 (from 0 to 2) (Karyakin et al. 2022).

There is no reliable data in the literature that can be used to assess EV breeding success in Kazakhstan. Only Kolbintsev (2004b) reports an EV nest in Karasai Canyon that has never once been empty over the course of 21 years (since 1983); on average, every second year EVs were able to successfully rear two nestlings in this nest. However, such breeding efficiency is not the norm for EV in Kazakhstan.

Of the 19 nests with breeding in Karatau, the contents of which were checked at least three times per season (1 nest in 2010 and 18 nests in 2022), 11 nests were successful (57.89%) (Karyakin et al. 2022). Given the loss of clutches and broods at early stages, nests were checked once after offspring death, the survival rate of the EV nests in 2022 was only 25.32%. Nestling loss at ages older than 50 days was mainly due to predation by Golden Eagles but we do not know what causes the majority of nestling to die at an earlier age.

It is likely that the early mortality in EV nests was mainly caused by starvation, given that an analysis of nest survival reveals that the main variable associated with EV survival of nests is grazing pressure and, thus, the mortality rate of livestock (Karyakin et al. 2022).

Phenology

In Kazakhstan, Egyptian Vulture are a migratory species, arriving at breeding areas in the second half of March and early April and departing for the winter in September. The earliest encounter took place on the Ustyurt Plateau (Mangyshlak Peninsula) at 17 March 1986 (Onufriev & Dyakin 1991, Gubin 2015).

According to our observations in Karatau, egg-laying began in EV nests from 13–25 April, on average (*n* = 19) on 20 April ± 3 days. The nestlings began to hatch from 25 May to 6 June, on average (*n* = 17) on 1 June ± 4 days. The nestlings left nests in the period from 18 to 30 August; however, with intensive feeding, fledging is possible in the range of 70 to 80 days, which means that the earliest fledglings may appear at nests from 3 to 15 August but this is hardly the norm (Karyakin et al. 2022). All finds of clutches and nestlings described in publications are within the described terms.

The latest autumn encounter of EVs in Kazakhstan is described at Chokpak Pass on 28 September 1971 (Gavrilov & Gistsov 1985, Gubin & Belyalov 2017). The latest record of an adult EV in the Karatau Mountains was noted by us on 21 September 2022 (Karyakin et al. 2022). On Ustyurt, the last autumn vulture was encountered on 11 September 1996 (Belyalov 2014, Gubin 2015). In Southeast Kazakhstan, birds were observed on 5 September 2015 (Amirekul et al. 2022). Further details are presented in Supplement Material 3.

Threats

Unfortunately, we know almost nothing about the threats to EV in Kazakhstan except for such factors as death on power lines and habitat destruction. It is necessary to identify threats in order to understand in which direction efforts should be made in the first place to preserve this species.

There is no regular monitoring of EV nests in Kazakhstan. There are no centralised sources of information on bird deaths. Even when EV deaths are detected by official employees of oversight agencies, they are not recorded and data are not being collected anywhere. This complicates the threat assessment. We can only discuss a fairly good study of the issue of negative impacts on EV caused by bird-hazardous power lines (10–35 kW with reinforced concrete poles, metal traverses and pin insulators) conducted by the scientific community and a database of bird death cases linked to power lines maintained by RRRCN.

Low numbers of EV electrocution on power lines have been detected during field studies, noting only one case in more than 1,000 recorded raptor deaths throughout Kazakhstan (Dwyer et al. 2023). This case was in 2013 in the Aral-Caspian region (Mangistau region), reporting one electrocuted EV recorded during surveys of power lines dangerous for birds, which amounted to 0.8% of all found electrocuted birds (Levin & Kurkin 2013).

Due to the fact that in Kazakhstan EV do not gather at landfills and do not tolerate the presence of humans, thus avoiding short poles used for bird-hazardous power lines as perches, avoiding death on them even where these power lines pass close enough to nests (within a 5-kilometer zone from the nests).

Habitat destruction is not as critical for EV in Europe, although it is indicated as a threat in Greece (Kret et al. 2016). However, for Kazakhstan, this can become one of the serious limiting factors since most of the country's mining is carried out in the core of EV population in the south and southeast of Kazakhstan, including in Karatau (Sonter et al. 2020). We already see one-fifth of the known EV nests pool in the area of active exploration work and the same number lying within the licensed areas allocated for mining. If mining plans for all licensed areas are fully implemented, the Karatau EV population may lose up to a third of breeding pairs (Karyakin et al. 2022) and the same number in the Aral-Caspian region.

Human disturbance poses significant threats in local areas. E.g., Zuberogoitia et al. (2008) reported that out of 100 breeding attempts of 15 EV pairs they observed, 42 attempts were unsuccessful due to human intervention. In Karatau, we observe a huge nest loss at the stage of laying and small downy nestlings, which can also be caused primarily by human disturbance. In recent years, this has been exacerbated by the location of EV nests closer and closer to farms and places of human presence. If the feeding situation in Karatau does not improve, EV will continue to huddle near the farms and suffer reproductive losses. Eventually, this will have a negative impact on its population due to a reduction in the pool of free individuals and the inability to compensate for the loss of adult birds in nesting pairs (Karyakin et al. 2022). The situation may be similar in southeastern Kazakhstan but we have no knowledge of it because no publications on this topic. Aral-Caspian region could be better since it is relatively deserted but, in recent years, the number of tourists has begun to increase there. However, tourists hardly pose a significant disturbance to EV in their nests on high cliff walls.

We know absolutely nothing about the influence of the poisons used by individuals to kill wolves, a widespread issue in Karatau but less developed in the Aral-Caspian region. This is also valid for poisons used for pest-management by the sanitary public health service (probably a main factor in Southeast Kazakhstan). In addition, nothing is known about the impact of veterinary NSAIDs on the Kazakh EV populations. These issues require urgent clarification, especially in light of the response received from Ministry of Agriculture of the Republic of Kazakhstan regarding the use of diclofenac and other NSAIDs in veterinary practice.

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Data availability statement: EV points of presence, VERIFIED as breeding territories, used to model species distribution and abundance are available to editor-level registered users in the "Faunistics" web-GIS (http://rrrcn.wildlifemonitoring.ru). Breeding biotopes in shapefile format (http://rrrcn.ru/wp-content/uploads/2023/02/BBKZ-NP2023.zip), grid mapping results in shapefile format (http://rrrcn.ru/wp-content/uploads/2023/02/GridMap-NP2023.zip) and MS Excel table with cell centroid coordinates (http://rrrcn.ru/wp-content/uploads/2023/02/GridMap-NP2023.xls) are available on the RRRCN website (WGS84, geographic projection, decimal degrees). The code used in this article is available on GitHub (https://github.com/kiri-rin/rrrcn-ee-nodejs).

Supplementary materials: *https://www.acta-zoologica-bulgarica.eu/2023/Suppl_17_09_Supplementary*

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Supplementary Materials

Supplementary Material 1

Information sources

We used five sources of information, which we searched for articles relevant to our study and sightings of the vulture from open databases:

(1) We searched the Russian Science Citation Index, Web of Science, Scopus, and Google Scholar databases for articles containing the keywords “Egyptian Vulture” in Russian and English, “Neophron percnopterus” + “Kazakhstan” in Russian and English;

(2) We reviewed all accessible articles retrieved from this search to identify those that were relevant to our study. Secondly, we looked at available articles in open electronic libraries, including Electronic Biological Library (https://zoomet.ru), Fundamental Electronic Library “Flora and Fauna” by A. Shipunov (http://herba.msu.ru/shipunov/school/sch-ru.htm), in the “Publications” section on the website of the Institute of Zoology of the Ministry of Education and Science of the Republic of Kazakhstan (https://zool.kz/eng/main-page), in the archive of the Kazakhstan Ornithological Bulletin (http://rrrcn.ru/ru/archives/10171), as well as in the archive of Russian Raptor Research and Conservation Network publications (http://rrrcn.ru/ru/library);

(3) We downloaded available datasets from electronic bird registration systems, such as GBIF (https://www.gbif.org), iNaturalist (https://www.inaturalist.org), eBird (https://ebird.org), web-GIS “Faunistics” (https://wildlifemonitoring.ru), and the closed section “Raptors of the World” web-GIS “Faunistics” (http://rrrcn.wildlifemonitoring.ru);

(4) We wrote a script with which we created a dataset from the Kazakhstan Birdwatching Community website (https://birds.kz) in MS Excel format (http://rrrcn.ru/wp-content/uploads/2022/12/birds-kz-2sheets.xls) and selected all EV records from that site;

(5) We referenced all materials in the personal libraries of each of the co-authors.

All observations from the literature and databases were mapped according to a single structure: observation number, observation date, observation author, observation status, number of birds. Among them, we launched a search for duplicates according to attributes, comparing them by the author and date of observation, and the identified duplicates were removed from our sample.

Supplementary Material 2

Article review of the distribution of the Egyptian vulture in Kazakhstan

While its presence was only presumed in Ustyurt until the 1950s, in Kazakhstan's south and southeast it was considered confirmed north to Karatau and the central Tien Shan (Dementiev 1951).

Shnitnikov (1949) recorded the vulture during its nesting period on northern spurs of Dzungarian Alatau, but did not find nests here. Instead, breeding was only presumed in Santash Mountains, between Karabulak and Dzhangyz-Agach, in the Altyn-Emel Mountains, on the Bora-Khoro ridge north of Dzharkent, in the vicinity of Kutemalda, in the Semizbelsky Mountains and in the Kabaksky Mountains near the Chamandy River valley. Moreover, Shnitnikov (1949) (with reference to E.P. Spangenberg) wrongly suggested the presence of EV on Kyrgyz (then Aleksandrovsky) Ridge. Similarly, A.A. Kuznetsov (1962a; 1962b) observed 96 EVs in the Kyrgyzsky Ridge highlands (above 2000 m) and noted that this species occurs no less in winter than in summer, which points to an obviously incorrect species definition.

The EV's nesting range was clearly marked by M.N. Korelov (1962), according to which this species inhabited low desert mountains, cliffs of chinks, outer spurs of mountain systems. EV was common in Mangyshlak, and southern Ustyurt chink. It was rare across the entire Karatau massif including Boroldai, Lakes Akkol, Ashikol and Kazgurt (Talas Alatau). The species was rare in Kyrgyz Alatau, Chu-Ili Mountains, western Zailiysky Alatau, Kendyktas, in the eastern spurs of the Zailiysky Alatau (Syugaty and Boguty), common in southern Dzungarian Alatau, but probably no longer breeding in Ili River in Kapchagay Gorge. EV was considered abundant on Karzhantau Ridge (Kapitonov 1969). The EV was completely absent from nesting in the mountains of Zailiysky, Kungei and Terskey Alatau (Korelov 1962) and in the Eastern Tien-Shan range adjacent to Kazakhstan in the upper reaches of the Ili River (in the Kunges and Greater and Lesser Yuddus river basins) (Przhevalsky 1978; Alferaki 1891; Kozlov 1963).

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Table S1. Comparison (means and standard deviations) between 56 variables quantifying the nesting biotopes for 244 breeding records of the Egyptian Vulture and 84 random sites for 3 regions of Kazakhstan.

Variables	Karatau				South-Eastern Kazakhstan				Aral-Caspian region			
	Mean NP	Mean Random	t-value (df=307)	p	Mean NP	Mean Randm	t-value (df=114)	p	Mean NP	Mean Random	t-value (df=68)	p
cti	**-0.71±3.07**	**-0.08±1.97**	**-2.15**	**0.032**					**-1.64±1.50**	**1.36±1.76**	**-7.68**	**0.00000**
tri	**21.1±14.8**	**6.5±12.1**	**9.51**	**0.00000**	**15.64±9.2**	**7.6±12.8**	**3.86**	**0.00019**	**19.45±10.49**	**0.68±0.85**	**10.55**	**0.00000**
slope	**13.0±9.0**	**4.2±7.7**	**9.32**	**0.00000**	**9.66±6.1**	**5.1±8.6**	**3.30**	**0.00127**	**13.50±7.0**	**0.45±0.60**	**10.99**	**0.00000**
aspect	**195.6±98.2**	**140.6±105.6**	**4.74**	**0.00000**	**212.39±92.9**	**165.1±118.0**	**2.40**	**0.018**	**226.5±106.0**	**144.7±115.41**	**3.09**	**0.0029**
vrm	**0.0093±0.0121**	**0.0024±0.0074**	**6.03**	**0.00000**	**0.0066±0.0107**	**0.0030±0.0071**	**2.16**	**0.033**	**0.006±0.004**	**0.00002±0.00004**	**7.63**	**0.00000**
roughness	**64.9±45.9**	**20.7±39.1**	**9.12**	**0.00000**	**48.11±29.0**	**24.8±41.7**	**3.50**	**0.00068**	**61.58±31.62**	**2.18±2.72**	**11.07**	**0.00000**
spi					37.72±96.2	2.0±12.0	2.80	0.0059				
geom	**6.2±1.9**	**3.1±2.6**	**11.99**	**0.00000**	**6.66±1.9**	**3.5±2.9**	**6.78**	**0.00000**	**5.91±1.2**	**1.46±1.60**	**13.21**	**0.00000**
cov	1029.6±465.2	811.1±558.1	3.73	0.00023					1042.0±469.9	501.2±497.7	4.67	0.00001
corr									2708.2±1405.8	1794.4±2281.9	2.02	0.048
contrast	150372.3±142328.4	113037.6±166334.1	2.12	0.035								
dissimilarity	27013.2±13337.7	19981.8±16820.7	4.06	0.00006								
entropy	**26201.2±2960.2**	**21827.1±7722.7**	**6.52**	**0.00000**	**22536.64±5453.5**	**18322.1±10079.4**	**2.80**	**0.0060**	**21539.9±4406.2**	**13585.4±8469.8**	**4.93**	**0.00001**
homogeneity	3589.8±1399.3	5033.8±2447.9	-6.33	0.00000								
maximum	1460.6±686.7	2733.4±2320.8	-6.47	0.00000					2603.5±1296.8	4140.8±2755.7	-2.99	0.0039
mean	2966.1±851.2	2564.7±1239.7	3.30	0.00107								
pielou	**9277.5±357.3**	**8630.9±1523.8**	**5.08**	**0.00000**	**8820.41±943.5**	**7582.7±3210.4**	**2.82**	**0.0057**	**8861.3±580.2**	**6304.6±3400.3**	**4.39**	**0.00004**
range	1039.5±510.0	803.2±668.8	3.48	0.00057								
shannon	**19011.6±3200.9**	**15298.5±6471.2**	**6.35**	**0.00000**	**15452.48±4775.1**	**12786.8±8028.7**	**2.17**	**0.032**	**14144.1±3538.6**	**8070.5±6402.1**	**4.91**	**0.00001**
simpson	**8192.5±648.8**	**6961.6±2096.6**	**6.90**	**0.00000**	**7196.26±1455.3**	**5872.7±3020.2**	**3.01**	**0.0033**	**7026.4±1058.6**	**4222.9±2821.3**	**5.50**	**0.00000**
sd	302.6±151.9	229.5±197.0	3.64	0.00031								
uniformity	883.3±376.1	1966.6±2047.1	-6.40	0.00000					1617.9±934.7	3223.0±2507.8	-3.55	0.00071
wind_speed_50	5.7±1.8	4.8±1.3	4.90	0.00000	3.81±1.0	4.7±1.6	-3.73	0.00029				
wind_speed_100	6.5±1.8	5.7±1.5	4.29	0.00002	4.55±1.1	5.6±1.8	-3.73	0.00030				
wind_speed_10	4.3±1.9	3.4±1.0	5.37	0.00000	2.71±0.9	3.4±1.2	-3.58	0.00051				
air_density_50									1.208±0.008	1.213±0.010	-2.24	0.029
air_density_100									1.202±0.008	1.207±0.010	-2.23	0.029
air_density_10									1.213±0.008	1.218±0.010	-2.24	0.028

Table S1. Continuation.

Variables	Karatau				South-Eastern Kazakhstan				Aral-Caspian region			
	Mean NP	Mean Random	t-value (df=307)	p	Mean NP	Mean Randm	t-value (df=114)	p	Mean NP	Mean Random	t-value (df=68)	p
power_density_50	**474.9±410.9**	**212.5±140.9**	**7.58**	**0.00000**	**135.07±89.9**	**204.8±134.8**	**-3.28**	**0.0014**	**491.5±228.1**	**354.0±118.0**	**3.17**	**0.0023**
power_ density_100	**579.2±423.2**	**287.0±182.7**	**7.94**	**0.00000**	**179.94±111.4**	**274.9±177.2**	**-3.45**	**0.00078**	**653.6±245.7**	**503.3±139.7**	**3.15**	**0.0024**
power_density_10	**322.0±428.4**	**103.5±84.4**	**6.29**	**0.00000**	**70.11±62.9**	**105.4±83.7**	**-2.57**	**0.012**	**290.1±198.9**	**176.0±82.9**	**3.13**	**0.0026**
RIX									0.021±0.027	0.00006±0.0004	4.47	0.00003
bio01					74.55±14.7	55.5±44.5	3.10	0.00245	120.4±6.5	109.8±16.3	3.55	0.00070
bio02	**128.1±3.0**	**126.9±6.3**	**2.13**	**0.034**	**118.55±7.4**	**115.0±8.2**	**2.47**	**0.0150**	**103.89±3.72**	**113.17±7.38**	**-6.65**	**0.00000**
bio03	29.7±0.8	29.1±1.5	4.21	0.00003	27.50±1.3	25.5±2.1	6.16	0.00000				
bio04	**10455.3±443.6**	**10673.0±830.4**	**-2.86**	**0.0046**	**10756.34±217.2**	**11610.2±931.7**	**-6.80**	**0.00000**	**10773.5±336.0**	**11714.3±955.4**	**-5.50**	**0.00000**
bio05									335.74±9.97	343.20±9.83	-3.15	0.0024
bio06					-140.83±15.3	-167.7±44.5	4.34	0.00003	-66.91±9.38	-97.97±31.79	5.54	0.00000
bio07	**424.5±12.8**	**429.1±23.0**	**-2.13**	**0.0338**	**423.97±9.0**	**443.2±24.2**	**-5.67**	**0.00000**	**402.66±12.97**	**441.17±32.54**	**-6.51**	**0.00000**
bio08	95.7±20.4	86.1±33.7	2.99	0.0030	144.59±23.5	92.7±65.9	5.66	0.00000				
bio11					-71.43±13.5	-101.9±44.2	5.02	0.00000	-16.91±8.23	-41.23±29.02	4.77	0.00001
bio12	378.3±131.0	321.2±181.4	3.16	0.0018	370.53±36.7	288.8±106.7	5.51	0.00000				
bio13	**60.0±19.3**	**50.1±27.3**	**3.68**	**0.00027**	**53.66±7.9**	**41.6±20.1**	**4.25**	**0.00004**	**15.71±0.93**	**18.00±1.89**	**-6.41**	**0.00000**
bio14					15.86±1.6	9.0±4.6	10.77	0.00000	5.00±1.63	3.80±1.78	2.94	0.0044
bio15									31.74±6.76	40.66±11.69	-3.91	0.00022
bio16	**155.8±55.3**	**132.6±78.1**	**2.99**	**0.00301**	**146.86±18.0**	**113.6±56.8**	**4.25**	**0.00004**	**44.06±2.01**	**47.63±3.03**	**-5.81**	**0.00000**
bio17					52.78±4.7	35.3±13.8	9.14	0.00000	19.60±5.49	15.29±6.22	3.08	0.0030
bio18									21.69±6.01	17.26±7.15	2.81	0.0066
bio19	**118.0±36.8**	**99.7±47.4**	**3.78**	**0.00019**	**56.69±7.7**	**48.0±15.6**	**3.81**	**0.00023**	**26.74±1.38**	**31.14±3.47**	**-6.96**	**0.00000**
NDVI_april_2022	0.42±0.11	0.31±0.17	7.01	0.00000	0.32±0.2	0.3±0.2	2.32	0.022				
NDVI_may_2022	0.35±0.14	0.28±0.18	3.56	0.00043								
WC_Shrubland	0.003±0.013	0.12±0.25	-5.81	0.00000								
WC_Grassland	0.89±0.17	0.68±0.38	6.31	0.00000					0.04±0.11	0.36±0.43	-4.30	0.00006
WC_Cropland	0.007±0.036	0.10±0.26	-4.13	0.00005	0.002±0.016	0.064±0.231	-2.03	0.044				
WC_Bare					0.182±0.279	0.051±0.178	3.02	0.0031	0.96±0.13	0.50±0.45	5.71	0.00000
WC_Water					0.014±0.066	0.138±0.348	-2.66	0.0088				

Explanation of variable abbreviations:

NASADEM https://developers.google.com/earth-engine/datasets/catalog/NASA_NASADEM_HGT_001

Name	Min	Max	Description	Units
elevation	-512*	8768*	Integer heights in the merged void-free DEM files are relative to the EGM96 geoid (whereas the floating-point heights in the SRTM-only DEM files are relative to the WGS84 ellipsoid).	m

Geomorpho90m Geomorphometric Layers (https://www.nature.com/articles/s41597-020-0479-6/tables/2) https://portal.opentopography.org/dataspace/dataset?opentopoID=OTDS.012020.4326.1

Name	Geomorphometric variable name	Description
slope	Slope	Terrain slope (slope), as mentioned above, is the rate of change of elevation in the direction of the water flow line. It is considered one of the most important terrain parameters and is often calculated first. It can be expressed in degrees or percentages, where for example, 5% means 5m of vertical displacement over 100m. It is especially important for the quantification of soil erosion, water flow velocity, or agricultural suitability https://www.nature.com/articles/s41597-020-0479-6#ref-CR29
aspect	Aspect	Aspect (aspect) is the angular direction that a slope faces. It is expressed in degrees and therefore defined as a circular variable.
cti	Compound topographic index	The compound topographic index (cti), also known as topographic wetness index, is computed as the logarithm of the cumulative upstream catchment area divided by the tangent of the local slope angle. This index is a proxy of the long-term soil moisture availability. It is has been often used in applications that include species distribution modelling, species richness and composition, landslide susceptibility and soil carbon assessment https://www.nature.com/articles/s41597-020-0479-6#ref-CR21
spi	Stream power index	The stream power index (spi) is computed as the product between the upstream catchment area and the tangent of the local slope angle. The stream power index reflects the erosive power associated with flow and the tendency of gravitational forces to move water downstream. It is commonly used in soil erosion models, landslide susceptibility and groundwater estimation. https://www.nature.com/articles/s41597-020-0479-6#ref-CR8
tri	Terrain ruggedness index	The terrain ruggedness index (tri) is a mean of the absolute differences in elevation between a focal cell and its 8 surrounding cells. It is a type of statistical variance of elevation change across the 3×3 cells. Flat areas have a value close to zero, while mountainous areas have positive values that can be greater than 500 m. https://www.nature.com/articles/s41597-020-0479-6#ref-CR49
roughness	Roughness	Roughness (roughness) is expressed as the largest inter-cell absolute difference of a focal cell and its 8 surrounding cells. It is expressed in unit length, in our case metres, and is always positive, ranging from zero values in flat areas to progressively larger positive values in mountain areas. This variable is a measure based on a maxima, therefore it is more sensitive to the artefacts that remain in the MERIT-DEM. https://www.nature.com/articles/s41597-020-0479-6#ref-CR50
vrm	Vector ruggedness measure	The vector ruggedness measure (vrm) quantifies terrain ruggedness by measuring the variation by means of sine and cosine of the slope in the three-dimensional orientation of grid cells, within a moving window. Slope and aspect are decomposed into 3-dimensional vector components (in the x, y, and z directions) using standard vector analysis in a user-specified moving window size (3×3). In other words, it captures variability of slope and aspect in a single measure. The vector ruggedness measure quantifies local variation of slope in the terrain more independently than the topographic position index and terrain ruggedness index methods. It is dimensionless because of sine-cosine derivation, and values range from 0 to 1 in flat to rugged regions, respectively. https://www.nature.com/articles/s41597-020-0479-6#ref-CR51
tpi	Topographic position index	The topographic position index (tpi) is the difference between the elevation of a focal cell and the mean of its 8 surrounding cells. It ranges from positive to negative values and they correspond to ridges and valleys, respectively. Zero values correspond to flat areas. https://www.nature.com/articles/s41597-020-0479-6#ref-CR29 https://www.nature.com/articles/s41597-020-0479-6#ref-CR52
geom	Geomorphon	The geomorphological forms (geom) consist of 10 classes that can be extracted from DEMs using morphometry techniques. This technique identifies geomorphological phonotypes also known as geomorphons. It is based on pattern recognition rather than differential geometry and thus has high computational efficiency. It classifies the terrain in terms of the following features: flat, peak or summit, ridge, shoulder, spur, slope, hollow, footslope, valley, and pit or depression (class label-number for each geomorphon are respectively: 1,2,3,4,5,6,7,8,9,10 These geomorphon classes have been used in a wide range of studies such as landslide susceptibility mapping, human mobility, and ecosystem service assessments. https://www.nature.com/articles/s41597-020-0479-6#ref-CR56

Global Habitat Heterogeneity (https://gee-community-catalog.org/projects/ghh/) https://www.earthenv.org/texture

Metric	Value Range	Measure
Coefficient of variation	>=0	Normalized dispersion of EVI
Evenness	>=0; <=1	Evenness of EVI
Range	>=0	Range of EVI
Shannon	>=0; <=ln(max # of different EVI)	Diversity of EVI
Simpson	>=0; <=1-1/(max # of different EVI)	Diversity of EVI
Standard deviation	>=0	Dispersion of EVI
Contrast	>=0	Exponentially weighted difference in EVI between adjacent pixels
Correlation	>=-1; <=1	Linear dependency of EVI on adjacent pixels
Dissimilarity	>=0	Difference in EVI between adjacent pixels
Entropy	>=0	Disorderliness of EVI
Homogeneity	>=0; <=1	Similarity of EVI between adjacent pixels
Maximum	>=0; <=1	Dominance of EVI combinations between adjacent pixels
Uniformity	>=0; <=1	Orderliness of EVI
Variance	>=0	Dispersion of EVI combinations between adjacent pixels

NDVI + EVI MODIS https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD13A1#bands

Name	Min	Max	Scale	Description
NDVI	-2000	10000	0.0001	Normalized Difference Vegetation Index
EVI	-2000	10000	0.0001	Enhanced Vegetation Index

WorldClim (https://www.worldclim.org/) WorldClim BIO V1 https://developers.google.com/earth-engine/datasets/catalog/WORLDCLIM_V1_BIO

Name	Min	Max	Scale	Description	Units
bio01	-290	320	0.1	Annual mean temperature	°C
bio02	9	214	0.1	Mean diurnal range (mean of monthly (max temp - min temp))	°C
bio03	7	96		Isothermality (bio02/bio07)	%
bio04	62	22721	0.01	Temperature seasonality (Standard deviation * 100)	°C
bio05	-96	490	0.1	Max temperature of warmest month	°C
bio06	-573	258	0.1	Min temperature of coldest month	°C
bio07	53	725	0.1	Temperature annual range (bio05-bio06)	°C
bio08	-285	378	0.1	Mean temperature of wettest quarter	°C

bio09	-521	366	0.1	Mean temperature of driest quarter	°C		
bio10	-143	383	0.1	Mean temperature of warmest quarter	°C		
bio11	-521	289	0.1	Mean temperature of coldest quarter	°C		
bio12	0	11401		Annual precipitation	mm		
bio13	0	2949		Precipitation of wettest month	mm		
bio14	0	752		Precipitation of driest month	mm		
bio15	0	265		Precipitation seasonality	Coefficient of Variation		
bio16	0	8019		Precipitation of wettest quarter	mm		
bio17	0	2495		Precipitation of driest quarter	mm		
bio18	0	6090		Precipitation of warmest quarter	mm		
bio19	0	5162		Precipitation of coldest quarter	mm		

Global Wind Atlas Datasets (https://gee-community-catalog.org/projects/gwa/) https://data.dtu.dk/articles/dataset/Global_Wind_Atlas_v3/9420803 https://globalwindatlas.info/ru

Name	Heights (m)	Description	Units
Wind Speed	10,50,100,150,200	wind-speed - The mean wind speed at the location for the 10 year period	m/s
Power Density	10,50,100,150,200	power-density - The mean power density of the wind, which is related to the cube of the wind speed, and can provide additional information about the strength of the wind not found in the mean wind speed alone.	W/m²
Air Density	10,50,100,150,200	air-density - The air density is found by interpolating the air density from the CFSR reanalysis to the elevation used in the global wind atlas following the approach described in WAsP 12.	W/m²
RIX		RIX - The RIX (Ruggedness IndeX) is a measure of how complex the terrain is. It provides the percent of the area within 10 km of the position that have slopes over 30-degrees. A RIX value greater than 5 suggests that you should use caution when interpreting the results.	

ESA WorldCover 10m v100 (https://gee-community-catalog.org/projects/esa_iq/?h=esa+worldcover+v100) https://developers.google.com/earth-engine/datasets/catalog/ESA_WorldCover_v100

Value	Description
10	Tree cover
20	Shrubland
30	Grassland
40	Cropland
50	Built-up
60	Bare / sparse vegetation
70	Snow and ice
80	Permanent water bodies
90	Herbaceous wetland
95	Mangroves
100	Moss and lichen

Table S2. Lists of variables for different models for Random Forest.

Variables	Karatau			South-Eastern Kazakhstan			Ustyurt		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
elevation	1		1	1		1	1		1
cti	1	1	1		1	1	1	1	1
tri	1		1	1		1	1		1
slope	1	1	1	1	1	1	1	1	1
aspect	1	1	1	1	1	1	1	1	1
vrm	1	1	1	1	1	1	1	1	1
roughness	1		1	1		1	1		1
spi		1		1	1			1	
geom	1	1	1	1	1	1	1	1	1
cov	1	1			1		1	1	
corr		1			1		1	1	
contrast	1								
dissimilarity	1								
entropy	1	1	1	1	1	1	1	1	1
homogeneity	1								
maximum	1						1		
mean	1								
pielou	1	1	1	1	1	1	1	1	1
range	1								
shannon	1		1	1		1	1		1
simpson	1		1	1		1	1		1
sd	1								
uniformity	1						1		
wind_speed_50	1			1					
wind_speed_100	1			1					
wind_speed_10	1			1					
air_density_50							1		
air_density_100							1		
air_density_10							1		
power_density_50	1	1	1	1	1	1	1	1	1
power_density_100	1			1		1	1		1
power_density_10	1			1		1	1		1
RIX							1		
bio01				1			1		
bio02	1	1	1	1	1	1	1	1	1
bio03	1	1		1	1			1	
bio04	1	1	1	1	1	1	1	1	1
bio05							1		
bio06				1			1		
bio07	1	1	1	1	1	1	1	1	1
bio08	1	1		1	1			1	
bio11		1		1	1		1	1	
bio12	1			1					
bio13	1		1	1		1	1		1
bio14				1			1		
bio15							1		
bio16	1		1	1		1	1		1
bio17				1			1		
bio18							1		
bio19	1		1	1		1	1		1
NDVI_april_2022	1	1		1	1			1	
NDVI_may_2022									
WC_Shrubland	1	1			1			1	
WC_Grassland	1	1			1		1	1	
WC_Cropland	1	1		1	1			1	
WC_Bare		1		1	1		1	1	
WC_Water		1		1	1			1	
All var. in model	**40**	**23**	**19**	**36**	**23**	**21**	**39**	**23**	**21**

Table S3. Results of models cross-validation. Bold indicates the best models for probability and regression.

Region	Method of RF	Code of model	AUC	Training regression r2	Validation regression r2	Max Kappa	Max Kappa cutoff	Max CCR	Max CCR cutoff
Usturt	Probability	1	0.989	0.916	0.835	0.948	20.833	0.976	20.833
Usturt	**Probability**	**2**	**0.996**	**0.900**	**0.821**	**0.970**	**38.750**	**0.985**	**33.333**
Usturt	Probability	3	0.995	0.915	0.840	0.960	32.083	0.982	32.083
Usturt	Regression	1	0.994	0.925	0.853	0.960	31.667	0.981	27.500
Usturt	**Regression**	**2**	**0.997**	**0.922**	**0.853**	**0.968**	**39.167**	**0.986**	**39.167**
Usturt	Regression	3	0.994	0.932	0.859	0.959	30.417	0.982	30.417
Karatau	Probability	1	0.978	0.926	0.847	0.943	40.417	0.974	40.417
Karatau	Probability	2	0.987	0.928	0.838	0.929	39.167	0.967	37.083
Karatau	**Probability**	**3**	**0.990**	**0.934**	**0.864**	**0.947**	**39.167**	**0.976**	**38.750**
Karatau	Regression	1	0.981	0.938	0.857	0.944	39.167	0.975	39.167
Karatau	Regression	2	0.985	0.938	0.842	0.934	35.833	0.970	32.917
Karatau	**Regression**	**3**	**0.988**	**0.942**	**0.870**	**0.949**	**44.167**	**0.977**	**44.167**
SE Kazakhstan	Probability	1	0.990	0.891	0.785	0.932	39.583	0.971	35.417
SE Kazakhstan	Probability	2	0.988	0.862	0.731	0.936	37.917	0.973	37.917
SE Kazakhstan	**Probability**	**3**	**0.997**	**0.904**	**0.827**	**0.973**	**32.917**	**0.989**	**32.917**
SE Kazakhstan	Regression	1	0.990	0.916	0.812	0.934	33.750	0.971	30.000
SE Kazakhstan	Regression	2	0.986	0.895	0.740	0.906	32.083	0.958	30.833
SE Kazakhstan	**Regression**	**3**	**0.997**	**0.923**	**0.839**	**0.968**	**32.083**	**0.986**	**32.083**

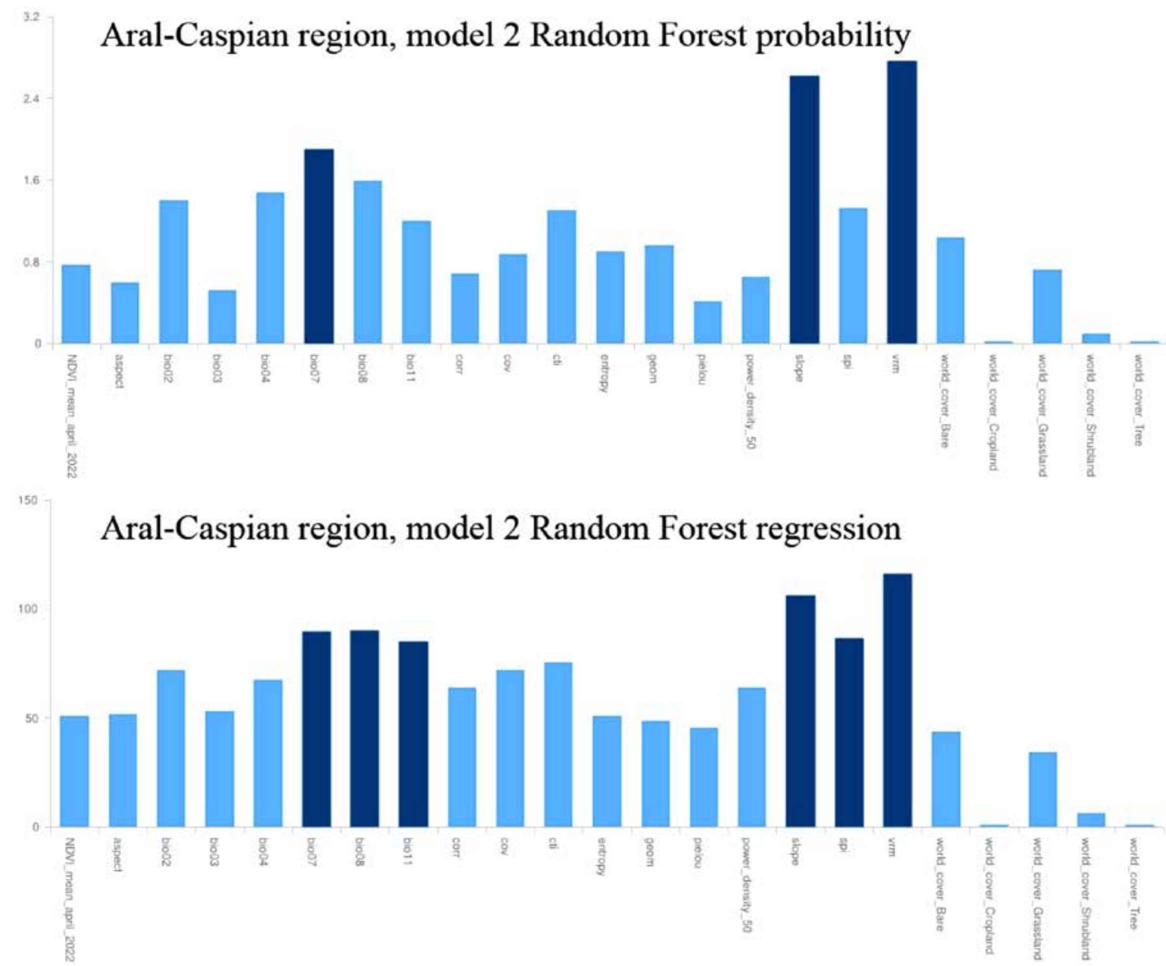

Fig. S1-A. Diagrams of important variables in Random Forest best models for Aral-Caspian region.

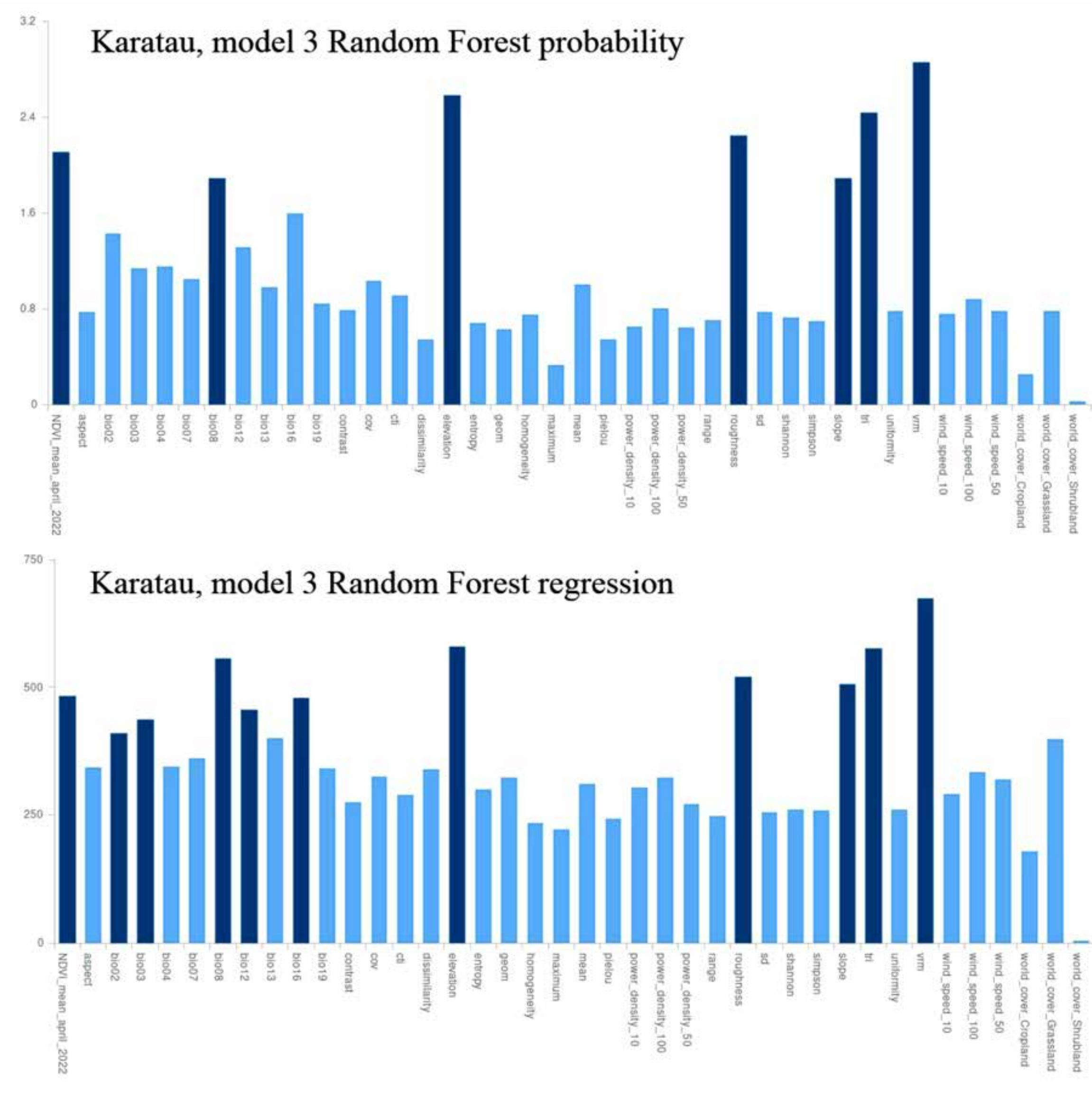

Fig. S1-B. Diagrams of important variables in Random Forest best models for Karatau region.

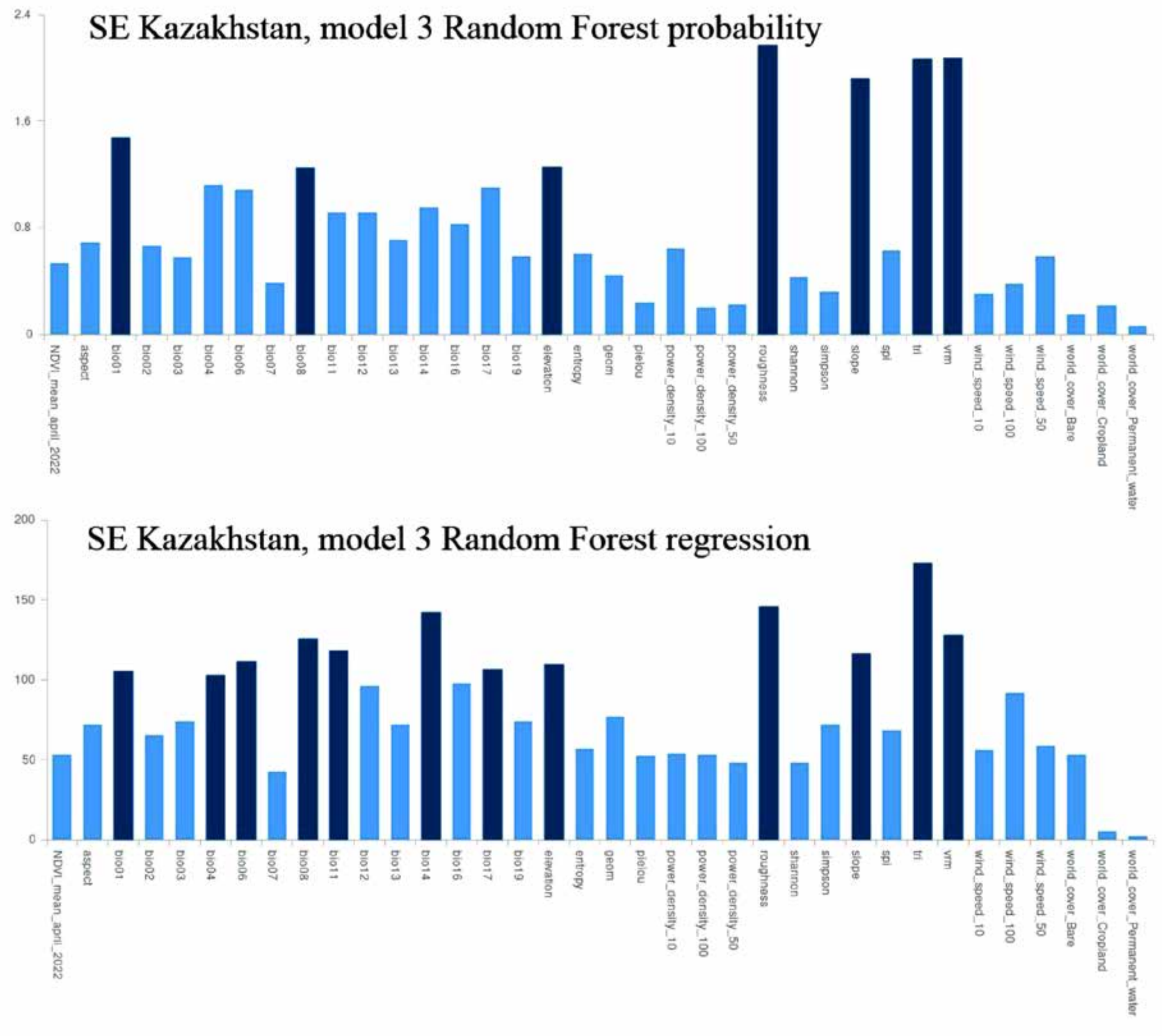

Fig. S1-C. Diagrams of important variables in Random Forest best models for South-Eastern Kazakhstan.

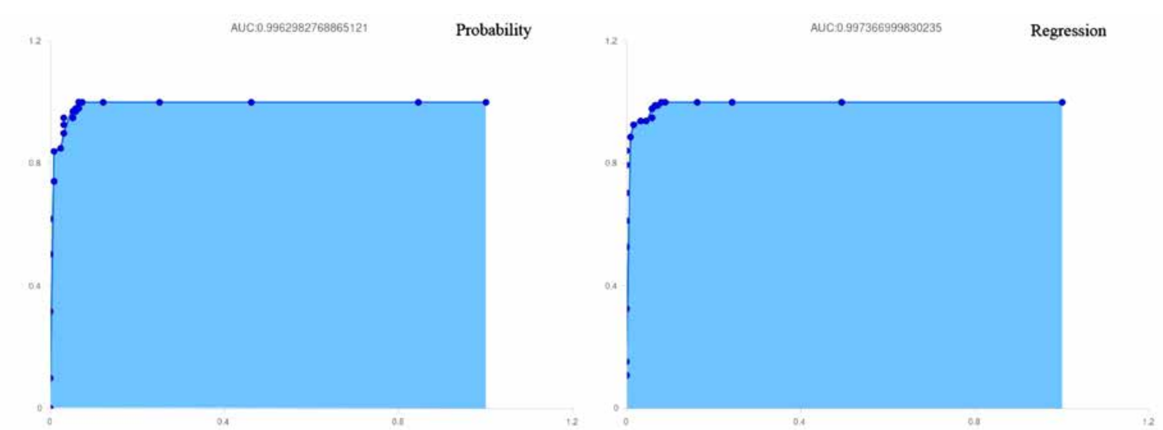

Fig. S2-A. Graphs of estimates of model accuracy by AUC-ROC for best probability and best regression of Random Forest for Aral-Caspian region.

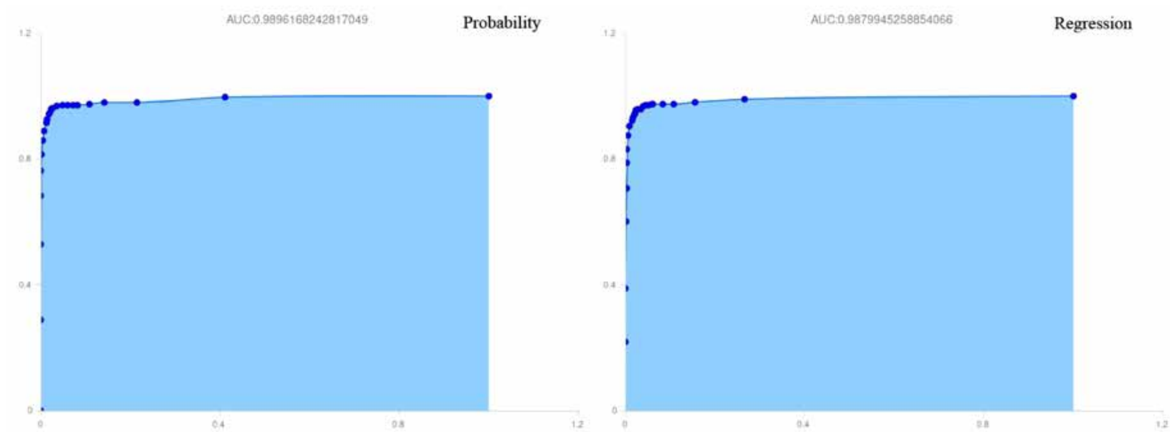

Fig. S2-B. Graphs of estimates of model accuracy by AUC-ROC for best probability and best regression of Random Forest for Karatau region.

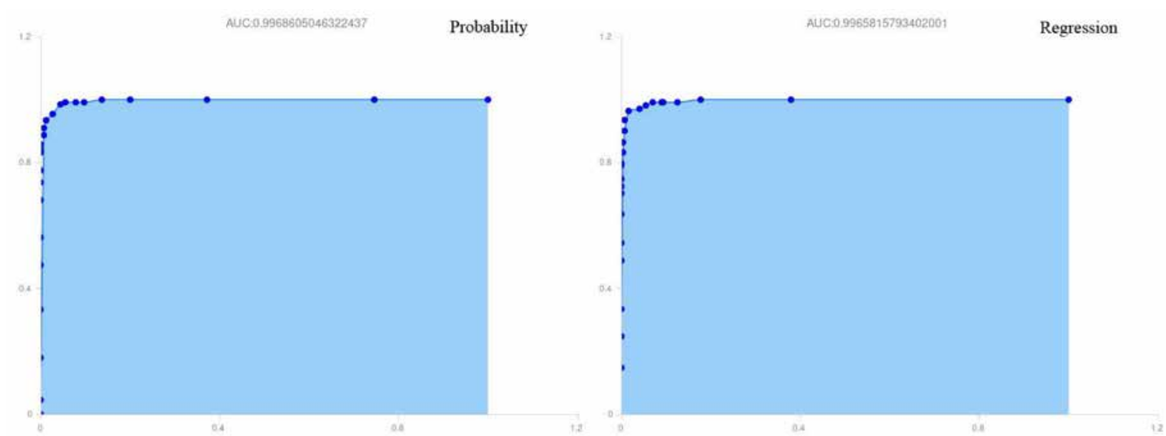

Fig. S2-C. Graphs of estimates of model accuracy by AUC-ROC for best probability and best regression of Random Forest for South-Eastern Kazakhstan.

Table S4. Results of the Egyptian Vulture abundance estimation for the Kazakhstan by the method of generating random points over a given range of distances between the nearest neighbors based on a regular network.

Region	Name	Min Total	Max Total	Average Total	Total SD	Min Estimate	Max Estimate	Average Validation Deviation	Average Validation Abs Deviation	Average Training Deviation	Average Training Abs Deviation
ACR	Thiessen	58	153	92.0	15.0	67.6	144.1	0.0	0.4	0.1	0.2
ACR	Plots	66	155	103.3	11.1	74.4	169.3	0.2	0.4	0.2	0.3
Karatau	Thiessen	232	395	306.5	33.6	249.5	397.3	-0.1	0.2	-0.2	0.2
Karatau	Plots	265	469	344.4	53.1	241.7	598.6	0.1	0.4	0.0	0.1
SE KZ	Thiessen	143	291	208.7	34.5	148.1	353.3	0.2	0.4	0.1	0.2
SE KZ	Plots	168	353	245.4	44.5	150.9	656.8	0.4	0.6	0.3	0.3

Supplementary Material 3

Phenology

In Kazakhstan, Egyptian Vulture are a migratory species, arriving at breeding areas in the second half of March and early April and departing for the winter in September. The earliest encounter took place at Mangyshlak on 17 March 1986 within the boundaries of Ustyurt State Reserve, near Kendirli River (Onufriev, Dyakin, 1991; Gubin, 2015). On 22 March 2021, an EV was photographed in Kyzylkum (Turkestan region) by A. Isabekov (Amirekul *et al.*, 2022). In Southeast Kazakhstan, individual birds were seen in Dzungarian Alatau, Chulak mountains, and in the Kyzylaus Gorge from March 21 to April 30, 1949 (Kuzmina, 2008). And on 25 March 2010, an EV was seen in Karachingil at the mouth of the Turgen River, the middle reach of Ili River (Bevza, 2011). The earliest sighting was recorded on 30 March, 1971 (Gavrilov and Gistsov, 1985; Gubin and Belyalov, 2017).

Clutches were observed in five cases from 27 April (1981) (Ivashchenko, 1991) to 20 May (1909) (Shnitnikov, 1949). Non-flying broods were observed in seven nests between 12 May (2007) (Kovalenko, 2008; Gubin, 2015) and 13 August (1981) (Ivashchenko, 1991). According to observations in Karatau, egg-laying began in EV nests from 13–25 April, on average (n = 19) on 20 April ± 3 days, the nestlings began to hatch from 25 May to 6 June, on average (n = 17) on 1 June ± 4 days; the nestlings left nests in the period from 18 to 30 August, however, with intensive feeding, fledging is possible in the range of 70 to 80 days, which means that the earliest fledglings may appear at nests from 3 to 15 August, but this is hardly the norm (Karyakin *et al.*, 2022).

The latest autumn encounter of EVs in Kazakhstan is described at Chokpak Pass on 28 September 1971 (Gavrilov, Gistsov, 1985; Gubin, Belyalov, 2017). On Ustyurt, the last autumn vulture was encountered on 11 September 1996, at Mangyshlak, in Northern Aktau (Belyalov, 2014; Gubin, 2015). The latest record of an adult vulture in the Karatau mountains was noted by us on 21 September 2022 near Zhanatas (Karyakin *et al.* 2022). In Southeast Kazakhstan, birds were observed near Kurtinsky Reservoir (Almaty region) on 3 September 2011 (Amirekul *et al.* 2022), in the territory of the Altyn-Emel National Park, in the Koiby Gorge on 5 September, 2015 (Amirekul *et al.* 2022), as well as near the Tekes Waterfall on 3 September 2022 – this record is the southernmost one in southeast Kazakhstan (Amirekul *et al.* 2022).

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