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ORIGINAL ARTICLE

# Using self-organizing maps to investigate environmental factors regulating colony size and breeding success of the White Stork (*Ciconia ciconia*)

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**Abstract** We studied variations in the size of breeding colonies and in breeding performance of White Storks *Ciconia ciconia* in 2006–2008 in north-east Algeria. Each colony site was characterized using 12 environmental variables describing the physical environment, land-cover categories, and human activities, and by three demographic parameters: the number of breeding pairs, the number of pairs with chicks, and the number of fledged chicks per pair. Generalized linear mixed models and the self-organizing map algorithm (SOM, neural network) were used to investigate effects of biotic, abiotic, and anthropogenic factors on demographic parameters and on their relationships. Numbers of breeding pairs and of pairs with chicks were affected by the same environmental factors, mainly anthropogenic, which differed from those affecting the number of fledged chicks per pair. Numbers of fledged chicks per pair was not affected by colony size or by the number of nests with chicks. The categorization of the environmental variables into natural and anthropogenic, in connection with demographic parameters, was relevant to detect factors explaining variation in colony size and breeding parameters. The SOM proved a relevant tool to help determine actual dynamics in White Stork colonies, and thus to support effective conservation decisions at a regional scale.

**Keywords** White Stork · *Ciconia ciconia* · Algeria · Breeding performance · Colony site · Conservation

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**Zusammenfassung**

**Welche Umweltfaktoren regulieren Koloniegröße und Bruterfolg beim Weißstorch *Ciconia ciconia*?—der Einsatz von Selbstorganisierenden Karten**

Untersucht wurden Unterschiede in Brutkoloniestärke und Bruterfolg bei Weißstörchen *Ciconia ciconia* in Nordostalgerien, in den Jahren von 2006–2008. Jede Kolonie wurde anhand von zwölf Umweltvariablen charakterisiert, welche Auskunft über physische Umweltbedingungen, Landbedeckung und menschlichen Einfluss gaben, sowie anhand von drei demografischen Parametern: der Anzahl der Brutpaare, der Anzahl von Paaren mit Küken und der Anzahl flügger Junge pro Paar. Es wurden Generalisierte Lineare Gemischte Modelle und der Selbstorganisierende Karten-Algorithmus (Self-Organising Map, SOM, ein neuronales Netz) angewendet, um die Wirkung biotischer, abiotischer und anthropogener Faktoren auf die demografischen Parameter und die Beziehungen zwischen diesen zu untersuchen. Die Anzahl der Brutpaare und die der Paare mit Küken wurden von denselben (hauptsächlich anthropogenen) Umweltfaktoren beeinflusst. Dagegen wurde die

Anzahl flügger Küken pro Paar von anderen Faktoren bestimmt: Weder die Koloniegröße noch die Anzahl von Nestern mit Küken hatten hier einen Einfluss. Die Einteilung der Umweltvariablen in natürliche und anthropogen bedingte half in Verbindung mit demografischen Parametern dabei, die Faktoren zu identifizieren, welche die Variation in Koloniegröße und den Brutparametern erklären. Die SOM-Methode erwies sich als geeignetes Werkzeug zur Beschreibung der tatsächlichen Dynamik in Weißstorch-Kolonien und stellt somit eine Hilfe bei der Festlegung effektiver Schutzmaßnahmen auf regionaler Ebene dar.

## Introduction

Many studies have investigated biological and socio-economic factors affecting threatened species in order to understand the current biodiversity crisis (Scott et al. 1995). In birds, studies on habitat selection are of growing importance for conservation policy and planning because they deal with quantitative information affecting the dynamics of bird populations (Caughley 1994). Environmental conditions are significant determinants in breeding habitats, and may influence the breeding success of birds and contribute to the variability of breeding populations (Lack 1968). The determination of the factors (natural or anthropogenic) affecting breeding success is the main target of many bird conservation studies, since breeding success can often be more easily managed than other demographic parameters (Pedrini and Sergio 2002; Gil-Sánchez et al. 2004; Manning et al. 2004).

Strictly or usually colonial bird species exhibit wide variation in colony size, with the smallest and largest colonies within a species often varying by several orders of magnitude. Numerous studies used natural variation in colony size to measure fitness consequences of breeding with different numbers of conspecifics (van Vessem and Draulans 1986; Møller 1987; Brown and Brown 2001). In addition, environmental factors or ecological situations surrounding breeding sites of birds have critical impacts on breeding success in either direct or indirect manners (Burger and Shisler 1980; Cody 1985; Yorio et al. 1995).

In its breeding range, the White Stork (*Ciconia ciconia*) nests either solitarily or colonially (Cramp and Simmons 1977). Although several studies investigated the factors affecting White Stork colony size and fitness parameters, such as breeding success, independently (van Vessem and Draulans 1986; Carrascal et al. 1993; Barbraud et al. 1999; Moritzi et al. 2001; Jovani and Tella 2004; Tryjanowski et al. 2005a, 2005b; Denac 2006), variations in colony size and fitness may be due to different environmental factors, and few studies have aimed at disentangling these factors. In fact, the effect of one environmental factor (e.g., ambient temperature) may become evident, sometimes with lagged effects, only when other environmental factors (e.g., food availability) affecting reproduction are taken into account (Tryjanowski and Sparks 2008).

Therefore, the aim of this paper was to investigate the main environmental factors affecting the distribution and size of breeding colonies and breeding parameters of the White Stork in an ecotone area located between the arid and semi-arid bioclimatic stages. Most demographic studies on this species have been conducted in temperate areas, mainly in Europe, where environmental conditions and life history traits (e.g., clutch size, colonial or solitary nesting) differ from those encountered in northern Africa. This species is of high conservation interest and its populations have experienced considerable changes during the last decades (Thomsen and Hötker 2006). Our approach is based on artificial neural network analyses that enhance our ability to determine the actual dynamics in colony sizes and breeding performance, and to investigate how these demographic parameters are associated to broad-type natural as well as anthropogenic information.

## Methods

### Study area

The study was conducted in the Wilaya (department) of Batna, north-east Algeria, in an area of 12,192 km$^2$ located between 6° and 7°E and 35° and 36°N (Fig. 1). The general climate is typically Mediterranean with a continental influence (semi-arid area with cool winters), but ranges from the arid to the humid category according to Emberger's (1955) classification. This wilaya is characterized by predominance of high montane vegetation forests including tree species such as Holm Oak (*Quercus ilex* L.), Atlas Cedar (*Cedrus atlantica* M.), and Aleppo Pine (*Pinus halepensis* Miller.). Plains are mostly used for cereal crops (mainly Durum Wheat *Triticum durum* L. and Barley *Hordeum vulgare* L.) and livestock. Livestock mainly includes extensive sheep grazing and intensive poultry farming.

### Survey method

Colonies of White Storks were censused during 3 years (2006–2008) from early January to early July. We defined a colony of storks as a breeding site with at least two nests built on the same support or on two supports separated by a few meters (<10 m). Based on dates of first hatched eggs (2006: March 10; 2007: March 24; 2008: March 20), colonies censuses were carried out from May 20 to June 8 2006, from June 2 to July 2 2007 and from June 14 to 30 2008, in order to ensure that when the counts were made no chick had already fledged. These dates were dictated

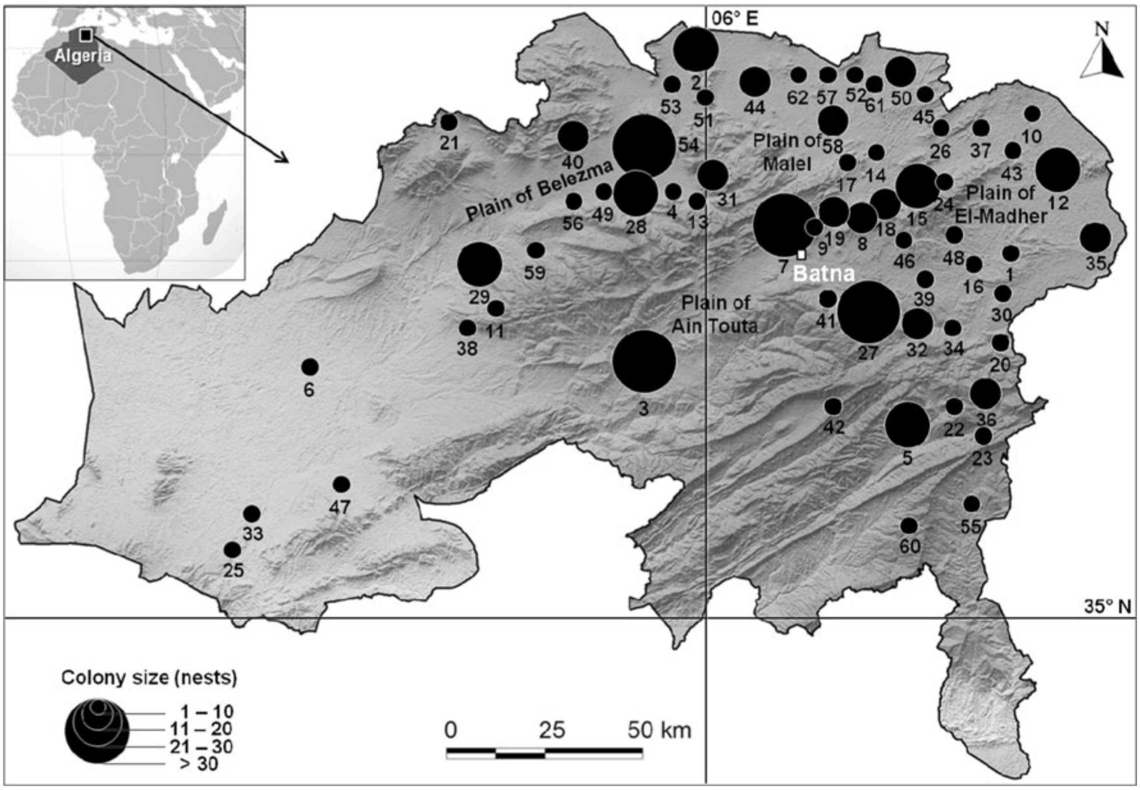


**Fig. 1** The wilaya (department) of Batna, Algeria, with locations of the 62 colonies and densities of breeding pairs of White Storks (*Ciconia ciconia*) per colony (census 2008). *Numbers* refer to colony codes

according to arrival dates of White Storks on one hand and dates of the first hatched chick on the other hand. During the survey period, the color of chicks' beak and legs was still black, thereby facilitating their detection in the nest without confusion with the parents. According to Schüz (1936), Arnhem (1980), and Whitfield and Walker (1999), at 6 weeks the black feathers on the wings appear, and in the seventh week standing is regular and the chicks perform wing beats that prepares the muscles to fly. After the ninth or tenth week, young chicks perform their first flight.

Censuses were carried out in all administrative units of the wilaya of Batna with assistance from the local staff of the Forests Conservation Direction, who directed us towards nesting sites of storks. Chick counts were often made during the morning when chicks are fed more frequently and are upright in the nest facilitating their count. The number of chicks was estimated by eye or with binoculars.

For each colony, the following parameters were recorded:

(1) Site description: name of the site, exact location (longitude, latitude), census dates.
(2) The number of breeding pairs (HPa), defined as a male and female holding a nest with or without chicks.
(3) The number of pairs with chicks (HPm), defined as a male and female holding a nest with chicks, the presence of chicks indicates the presence of a breeding pair with chicks.
(4) The number of fledged chicks per nest (JZG). Fledged chicks were defined as nestlings older than 7 weeks which are still on the nest and about to fledge. At this age, chicks are supposed to survive until fledging since there is no or very slight mortality between the census period and their fledging (Djerdali et al. 2008b). In computation, JZG was entered as the average number of fledged chicks per breeding pair in the colony.

## Environmental variables

For each colony site we collected the following environmental variables:

(1) Altitude in meters above sea level measured by an altimeter (±1 m).
(2) Annual precipitation (mm).
(3) Cumulated precipitation (mm) recorded during November, December, and January (winter rainfall) corresponding to the pre-breeding period.

(4) Cumulated precipitation (mm) recorded during March, April, and May (spring rainfall) corresponding to the early nesting period.
(5) Annual mean of minimum temperatures (°C).
(6) Annual mean of maximum temperatures (°C).
(7) Approximate flight distance between the colony and the closest urban area (in m, ±10 m).
(8) Approximate flight distance between the colony and the nearest refuse (rubbish dump) (in km, ±0.1 km).
(9) Total useful agricultural surface (UAS in ha). The term 'useful agricultural surface' is adopted by official statistics and covers all areas available to all types of agricultural activities (forage, arable or cultivable areas).
(10) Irrigated useful agricultural surface (irrigated UAS in hectares).
(11) Inhabitant's density (number of individuals per $km^2$).
(12) Type of colony [monospecific for the colonies occupied only by White Storks; plurispecific for the colonies occupied by storks and Cattle Egrets (*Ardea ibis*)]. Most new colonies of Cattle Egret, which is invasive in Algeria, are built in mixed colonies with or close to the colonies of White Storks (Si Bachir et al. 2011). This has given rise to a multitude of plurispecific colonies of the two species.

Environmental variables were extracted in a 1.5-km radius from the center of the colony, which represents the distance covered by the majority of foraging flights (Alonso et al. 1991; Nowakowski 2003). Annual data dealing with the agricultural surfaces (UAS and irrigated) and inhabitant density were provided by the planning and territory management direction of Batna City (DPAT, Direction de Planification et d'Aménagement du Territoire). To this end, data for each municipality in which a colony was established and for each census year were taken into account.

Climatic data mainly originated from the meteorological station of Batna. In addition, altitudinal extrapolations of precipitation and temperature were carried out to characterize the climate of some areas (11 colonies out of a total of 61). According to Seltzer (1946), the minimum and maximum temperatures decrease within altitude gradient is respectively 0.3 and 0.7 °C for 100 m, while precipitation increases by 40 mm for each 100 m of altitude. The error in extrapolated values is ≈10 % (Seltzer 1946).

## Data analysis and modeling procedure

Data from a set of 61 colonies representing a cumulative total of 1,547 nests was analyzed by artificial neural network (ANN) over three consecutive breeding seasons (2006–2008). Specifically, we used the self-organizing map algorithm (SOM, unsupervised neural network) to sort bird colonies according to environmental variables and to highlight relationships between environmental and surveyed breeding parameters (HPa, HPm and JZG). The SOM Toolbox (version 2) for Matlab® developed by the Laboratory of Information and Computer Science at the Helsinki University of Technology was used (http://www.cis.hut.fi/projects/somtoolbox/). With its ability to combine ordination and gradient analysis functions, the SOM is convenient to visualize high-dimensional ecological data in a readily interpretable manner without prior transformation. The SOM algorithm is an unsupervised learning procedure that transforms multi-dimensional input data into a two-dimensional map subject to a topological (neighborhood preserving) constraint (details in Kohonen 2001). The SOM thus plots the similarities of the data by grouping similar data items together using an iterative learning process that was further detailed in Park et al. (2003). The SOM algorithm is specifically relevant for analyzing sets of breeding parameters that vary and covary in a non-linear fashion, and/or that have skewed distributions.

Additionally, the SOM algorithm averages the input dataset using weight vectors through the learning process and thus removes noise (Lek and Guégan 2000). Moreover, with the SOM algorithm, there is no effect of outliers on the overall scatter plot distributions, because outliers are displayed in a part of the scatter plot without affecting other parts. A detailed description of the modelling procedure (training, map size selection, number of iterations, map quality measurements) was given in Park et al. (2003).

Firstly, we identified relationships between environmental variables and the distribution of colonies. The structure of the SOM for this analysis consisted of two layers of neurons connected by weights (or connection intensities): the input layer was composed of 12 neurons (1 per environmental variable) connected to the 146 samples (44, 43, and 59 colonies in 2006, 2007, and 2008, respectively), and the output layer was composed of 66 neurons (see below) visualized as hexagonal cells organized on an array with 11 rows and 6 columns. With the exception of "Altitude", all variables showed variations over the 3 years. The number of output neurons retained for this study (after testing quantization and topographic errors) fitted the heuristic rule suggested by Vesanto et al. (2000), who reported that the optimal number of map units is close to $5\sqrt{n}$, where $n$ is the number of samples. At the end of the training, each sample is set in a hexagon of the SOM map. Neighboring samples on the grid are expected to represent adjacent clusters of samples. Consequently, samples appearing distant in the modeling space (according to the variables used during the training) represent expected differences among samples for actual environmental characteristics. Ward's algorithm was applied to the weight vectors of the neurons in order to divide the SOM units (hexagons) into clusters.

Secondly, we aimed to emphasize the relationships between environmental variables and the three breeding parameters recorded for each colony (the number of breeding pairs "HPa", the number of pairs with chicks "HPm", and the number of fledged chicks "JZG"). During the aforesaid training, we used a "mask" function to assign a null weight to the breeding parameters, whereas environmental variables were assigned a weight of 1 so that the ordination process was based on the environmental variables only. In addition, setting the mask value to zero for a given component removes the effect of that component on organization (Vesanto et al. 2000; Vesanto and Hollmen 2003; Sirola et al. 2004; Raivio 2006). The values for breeding parameters were thus visualized on the SOM previously trained with environmental variables only.

Finally, we tested for factors affecting HPa, HPm, and JZG with generalized linear mixed models using PROC GLIMMIX in SAS (2002). Factors entered in the model were the year for HPa, year and HPa for HPm, and year, HPa, or HPm for JZG. Colony was entered as a random effect.

## Results

Breeding parameters and numbers of nests found each year are shown in Table 1. The number of breeding pairs per colony did not vary significantly between years ($F = 0.71$, $p = 0.49$) (Table 2) and was in average 10.6 ± 10.3 (SD). The number of pairs with chicks per colony increased with colony size and varied significantly between years (being higher in 2006 than in other years; Table 2). The mean number of fledged chicks per nest varied between years (being higher in 2006 than in

**Table 1** Annual variation (±SD) of the breeding parameters of White Storks (*Ciconia ciconia*) in the area of Batna, Algeria

| | 2006 | 2007 | 2008 | All survey period |
|---|---|---|---|---|
| Breeding pairs per colony (HPa) | 10.5 ± 9.6 | 12.2 ± 11.4 | 9.7 ± 10.1 | 10.6 ± 10.3 |
| | $n = 44$ | $n = 43$ | $n = 58$ | $n = 145$ |
| Pairs with chicks per colony (HPm) | 13.4 ± 10.1 | 10.2 ± 10.5 | 7.5 ± 8.1 | 9.2 ± 9.4 |
| | $n = 15$ | $n = 43$ | $n = 59$ | $n = 117$ |
| Fledged chicks per nest (JZG) | 1.9 ± 0.6 | 1.6 ± 0.8 | 1.4 ± 0.7 | 1.5 ± 0.6 |
| | $n = 18$ | $n = 42$ | $n = 61$ | $n = 121$ |

**Table 2** Testing for factors affecting breeding parameters of White Storks in the area of Batna (Algeria) between 2006 and 2008

| Effect | *F* | *df* | *p* | Variance | SE |
|---|---|---|---|---|---|
| Number of pairs per colony ($\chi^2/df = 1.00$ with a negative binomial distribution and log link) | | | | | |
| Year | 0.71 | 2, 93.52 | 0.49 | | |
| Colony | | | | 0.378 | 0.133 |
| Number of pairs with chicks ($\chi^2/df = 1.06$ with a Poisson distribution and log link) | | | | | |
| Year | 4.09 | 2, 111 | 0.019 | | |
| HPa | 576.69 | 1, 70.45 | <0.001 | | |
| Colony | | | | 0.037 | 0.019 |
| Number of chicks per nest ($\chi^2/df = 0.52$ with a normal distribution and identity link) | | | | | |
| Year | 3.77 | 2, 84.93 | 0.027 | | |
| HPa | 0.24 | 1, 91.07 | 0.629 | | |
| Colony | | | | 0.013 | 0.036 |
| Number of chicks per nest ($\chi^2/df = 0.46$ with a normal distribution and identity link) | | | | | |
| Year | 4.45 | 2, 82.61 | 0.015 | | |
| HPm | 1.57 | 1, 88.15 | 0.213 | | |
| Colony | | | | 0.015 | 0.032 |

Test statistics (*F* and *P* values) are Type III, and *df* (numerator, denominator) for fixed effects were estimated using the Satterthwaite approximation. Variance components plus their SE are shown for random effects (Colony). See "Methods" for the definition of variables other years), but was not affected by the number of pairs in the colony or the number of pairs with chicks (Table 2).

The majority of Stork colonies were distributed in the north-eastern part of the wilaya, particularly on the plains of El Madher, Malel, Belezma and Ain Touta. These areas host the most populated colonies, while in the southern part of the country, the colonies are very sparse and little populated (Fig. 1).

After training the SOM with the 12 environmental variables, colonies were separated into five subsets (clusters A–E) according to the quantitative structure of the colonies assemblages (Fig. 2a). Cluster A included colonies built at low altitudes, subjected to low precipitation and high temperature (both maximum and minimum), low inhabitant density, moderate irrigation, and located far from urban areas but close to refuse. These colonies corresponded roughly to those located in the arid and sparsely populated region.

Cluster B and C included colonies located in areas with low inhabitant density, relatively close to urban areas and refuse tips, and intermediate altitude, temperature and precipitation. Compared to cluster C, cluster B included colonies located in areas with large irrigated agricultural areas. These areas corresponded to the regions where intense farming uses irrigation. Cluster D included colonies established at high altitude with high precipitation (annual, winter and spring) and low temperature, located close to urban areas, and with high useful agricultural surface. These characteristics are typical of mountainous areas with small villages surrounded by agricultural lands. Cluster E included colonies situated in areas with low useful agricultural surface, far from refuse, but close to the cities with high inhabitant density. These colonies were located in, or near, the largest urban areas and were also occupied by Cattle Egrets (Fig. 2b).

When explaining breeding parameters, the ordinate on the SOM revealed a similar gradient for both number of breeding pairs per colony and number of pairs with chicks (Fig. 2c). Compared with the distribution of environmental variables on the SOM, this indicated that high numbers of breeding pairs per colony, as well as high numbers of pairs with chicks, were in the areas located close to urban areas with high population density, far from refuse, and these colonies were also occupied by Cattle Egrets (Fig. 2c). However, the gradient for the mean number of fledged chicks per nest showed a different pattern (Fig. 2c). The mean number of chicks fledged per nest was higher in relatively small monospecific colonies at high altitude, with high precipitation (annual, winter and spring), relatively close to urban areas and refuse, and with low population density (Fig. 2c).

## Discussion

Our results suggest that the largest colonies were established close to urban areas and refuse, and consequently in the most human-populated zones. Most of these colonies were also shared with the Cattle Egret. The smallest colonies were situated at high altitudes where precipitation was most important. Although the SOM suggested the classification of breeding colonies into five groups, these could be gathered into two super-sets based on the nature of the environmental factors characterizing the habitats: (1) White Storks breeding close to urban areas where they exploit food resources mainly on refuse (Djerdali et al. 2008a, 2008b) and are not demanding in terms of weather, and (2) pairs breeding in colonies situated in suburban or natural areas where environmental conditions foster the abundance of prey species (mainly Orthoptera and terrestrial Coleoptera). In this case, the Storks feed both in natural habitats and in irrigated farmland (Boukhemza et al. 2006).

By simultaneously investigating the effects of the same environmental variables on colony size and breeding parameters, the trained models revealed that the environmental factors positively affecting the number of breeding pairs and the number of pairs with chicks are not necessarily beneficial for the number of fledged chicks per nest. Artificial neural networks suggested that factors explaining the establishment of large colonies were mainly anthropogenic variables (e.g., distance to urban areas, distance to refuse, population density). However, the trained models showed that the pairs breeding at altitude with high precipitation rates and near to slightly anthropogenic habitats were mainly those that fledged more chicks.

Our results differ from those obtained on other colonial species, where breeding success has been found to be positively related to colony size (Young 1994; Barbosa et al. 1997; Brunton 1999). Given the large body size of White Storks and the very small number of its nest predators, colony size probably does not play a role against predation. On the other hand, reproductive success in White Storks is known to be affected by climatic conditions (Sasvári and Hegyi 2001; Jovani and Tella 2004), food availability and accessibility (Alonso et al. 1991; Pinowski et al. 1991), proximity of food abundant feeding sites (Barbraud et al. 1999; Tortosa et al. 2002; Nowakowski 2003), and the presence of livestock where the birds have better access to food resources (Tryjanowski et al. 2005c). The additional presence of food emanating from household refuse also enhances breeding success (Tortosa et al. 2002; Aguirre 2006; Djerdali et al. 2008b). In our study, the higher number of fledged chicks per nest in colonies situated in areas with relatively high precipitation may reflect an indirect effect of precipitation on food abundance, as

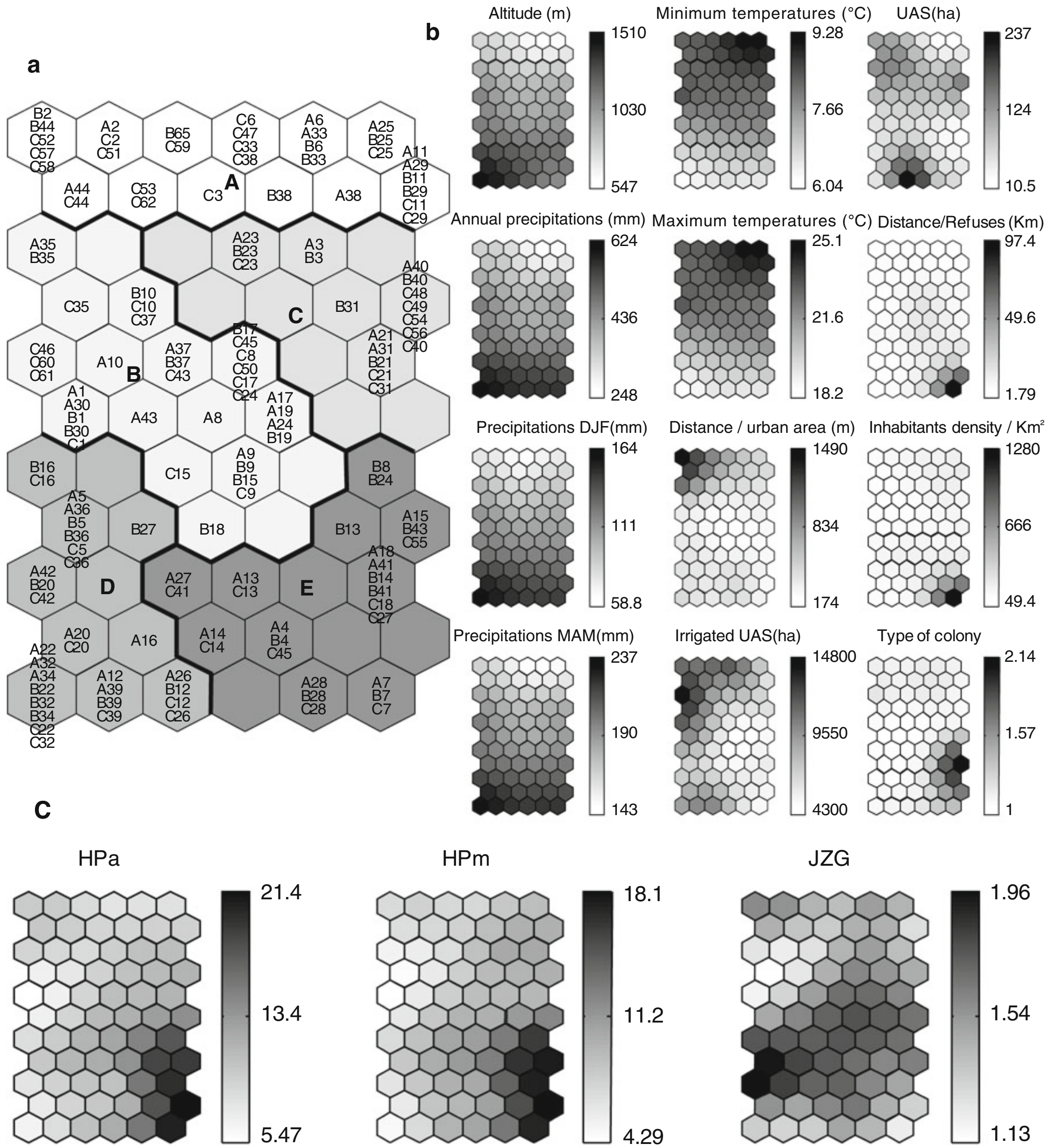


**Fig. 2** **a** Distribution and clustering of colonies on the self-organizing map (SOM) according to the 12 environmental variables. Codes within each hexagon (e.g., *A1*, *B37* and *C62*) correspond to colonies (sampling units). Colonies are numbered from *A1* to *A44* for the 44 colonies listed in 2006; the letter *B* precedes the number of the 43 colonies of 2007 and the letter *C* for the 59 colonies of 2008. The geographical location and the average colony size of these 62 colonies are reported in Fig 1. **b** Gradient analysis of the value for each habitat variable on the trained SOM represented by a *shaded scale* (*light* low value, *dark* high value). Each *small map* represents one parameter that follows similar patterns can be compared to (or superimposed on) the map representing the distribution of colonies presented in panel (**a**), thus showing the distribution patterns of the various environmental variables (in *shade* and *gray*) within each sub-area of the SOM. **c** The three demographic parameters that characterize the colonies in *shades of gray* (*HPa* number of breeding pairs, *HPm* number of pairs with chicks, *JZG* number of fledged chicks per nest). The mean value for each variable was calculated in each output neuron of the SOM previously trained with environmental variables data

suggested by other studies on this species (Denac 2006; Nevoux et al. 2008).

In North Africa, White Storks benefit directly from the use of agricultural habitats, since the creation of irrigated habitats enables multiple opportunistic species such as Storks and Cattle Egrets to benefit from it (Boukhemza et al. 2006; Si Bachir et al. 2011), contrary to what is observed in Europe (Senra and Alés 1992; Carrascal et al. 1993).

One may thus hypothesise that the increase in White Stork populations in North Africa has been partly due to an increase in the surface areas of irrigated agriculture (Anonym 2006), although other factors such as wintering climatic conditions may also have played a role (Kanyamibwa et al. 1990; Barbraud et al. 1999; Schaub et al. 2005; Saether et al. 2006). In the region of Batna, the increase in local breeding populations of the White Stork is in agreement with the results of the sixth international census (2004–2005) which highlighted an increase of about 39 % since 1994–1995 over the entire breeding area (NABU 2006). Our study thus supports the idea that identifying the variables which significantly affect the breeding parameters of White Storks should be a research priority for conservationists and environmental policy makers.

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