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Local climate conditions impact on breeding performance of house martin (*Delichon urbica*) populations in Algeria

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Abstract

The Mediterranean climate of North Africa encompasses an interesting variety of sub-climates, from humid and sub-humid to semi-arid and arid. Such variability may provide vital insights into mechanisms that drive species distribution and offered us an ideal opportunity to test phenotypic variations along gradients. We aim in this study to investigate the breeding behaviour of house martin *Delichon urbica* (Linnaeus, 1758) populations along regional climatic gradients in north-eastern Algeria. During two consecutive breeding seasons (2016–2017), nine field sites (328 active nests) belonging to three different sub-climates: humid, sub-humid, and semi-arid were surveyed regularly from March to August. We used generalized linear models to test the relevance of local climate and several ecological variables on laying reproductive output. Laying dates were positively correlated with climate condition (GOF = 0.42), the semi-arid climate creating appropriate conditions for advancing the laying process, whereas sub-humid and humid climate delayed it. Clutch-size and number of chicks hatched per nest were affected by local climate conditions; they were greater in humid areas than in sub-humid and semi-arid ones. The other non-climatic variables as brood order, laying date, distance to fields, and distance to water were not significant. The spatial analysis around nest sites of house martins also showed that dense vegetation cover and reduced urbanization levels may be potential predictors of breeding behaviour. Nest sites located in humid areas with dense vegetation cover, and low urbanization levels that characterize the surrounding landscape provide high-breeding success rate to this species if compared to sub-humid and semi-arid areas. These findings can be a useful indicator of environmental change in a country that is already experiencing severe drought stresses, uncontrolled urbanization, and high deforestation rates.

Keywords Climatic gradients · Breeding success · Semi-arid · Vegetation cover · Urbanization

Introduction

The impact of climate change on the population biology of birds has gained the long-term attention of ornithologists on the basis that bird's life history is closely linked to climate (Crick 2004). There is a general consensus that birds can adjust the magnitude and pattern of their breeding effort in relation to climate change (Slagsvold et al. 1984). They can for example advancing their date of laying associated with warmer spring temperature (Dunn 2004), thereby leading to an important influence on several aspects of reproduction (Møller 2002) such as clutch size, hatching success, and recruitment (Verboven et al. 2001; Both and Visser 2005; Cooper et al. 2005; Drent 2006). Moreover, climate change can be more detrimental for breeding birds especially when it operates synergistically with anthropogenic stressors (Laudelout and Paquet 2014).

Mediterranean climate of North Africa is characterized by extreme fluctuations (UNESCO 1963; Ramdani et al. 2009). At basin scale several divergences of meteorological parameters (e.g. ambient temperature, rainfall, evapotraspiration) have been detected (Cody and Mooney 1978; Ramdani et al. 2009). Based on trends of these important climatic parameters this climate encompasses an interesting variety of sub-climates: humid to sub-humid (warm and dry summers and mild and relatively rainy winters), and semi-arid to arid (relatively

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hot temperatures and modest precipitation) (Bagnouls and Gaussen 1957; Stewart 1975; UNESCO 1963; Le Houérou et al. 1977; Torrent 2005). The time and space behaviour of the geographical features (orography, proximity to the ocean (or sea), elevation, water bodies distribution, vegetation cover...etc.) play an important role establishing the climate at local scale (Lionello et al. 2006).

Algeria is the largest country in Africa and has a typical Mediterranean climate. However, there is a distinct regional gradient in the climate, from Mediterranean humid and sub-humid climate in the coastal northeast part of the country to semi-arid in the Hauts Plateaux (high lands) and an arid climate across the Sahara (Meddour 2002; Elafri et al. 2020). The effect of this variability on fauna and flora diversity of the country is perceptible by all. Biodiversity levels, landscapes and ecosystems in humid areas are much higher than for the country overall. Such variability may provide vital insights into mechanisms that drive species distribution and offer us an ideal opportunity to test phenotypic variations along gradients. These can be useful indicators of species-level responses to environmental change in a country that is already experiencing severe drought stresses and has also been subjected to uncontrolled urbanization and a high deforestation rate.

Given this context, our aim was to investigate the breeding behaviour of house martin *Delichon urbica* (Linnaeus, 1758) populations along regional climatic gradients. In pursuance of this goal, reproductive performances (measured as laying dates, clutch size, and hatching success) in house martin populations nesting at three different North African sub-climates (humid, sub-humid and semi-arid) were investigated during two consecutive breeding seasons. Semi-arid zones are the most seriously affected by extreme variability in climatic conditions during breeding season, leading to "ecological crunches" that have profound effects on bird populations (Morrisson 1986) either indirectly, through habitat changes, or directly through heat stress or water restriction (George et al. 1992). Thus, we hypothesized that nests located at semi-arid areas where vegetation is reduced in quantity and quality would provide low breeding success of this Hirundinidae.

Methods

Study areas

The study was conducted in Mila Province (9375 km^2) situated in the high plateau in the northeast of Algeria between the coast and Sahara at 464 m of altitude and 33 km from the Mediterranean Sea (Fig. 1). It is governed by three microclimates: humid in northern mountain reliefs and median part, semi-dry to sub-humid in the median part of the Wilaya, and semi-dry in the high plains (Fig. 2) (Ouelbani et al. 2016; Laala and Alatou 2017; Bramki et al. 2018). On the territory of this Wilaya, there is an important area of forests that covers 9.68% of the total surface area. These two forest heritages contain varied species: pines of Aleppo (*Pinus halepensis* Mill.*),* eucalyptus (*Eucalyptus* sp.), cork oak (*Quercus suber* L.), and holm oak (*Quercus ilex* L.) as well as the introduced species such as *Pinus nigra*, *Eucalyptus globulus*, and *Cupressus arizonica*. The rest of the vegetation cover is partitioned between cereal culture, dried vegetables, and arboriculture (Ouelbani et al. 2016).

Data collection

During two consecutive breeding seasons (2016–2017), nine nest sites belonging to three different sub-climates: humid, sub-humid, and semi-arid (Fig. 1) were surveyed regularly from March to August to determine the start of eggs laying, clutch size, and hatching success (proportion of the eggs hatched to the total number of the eggs laid) of the house martin *D. urbica*.

In total, we recorded 328 active nests; all of them were found on concrete buildings (schools and houses). The contents of each nest were checked at least once a week during the two nesting seasons. In Algeria, the house martins produced two broods (Lahlah et al. 2006); after the success of the first breeding (chicks fledged) they often attempt to produce a second clutch.

Once all clutches had either hatched or failed and all birds had left their nests, I measured for each nest, the shortest distance to water (including all water bodies: streams, rivers, ponds...etc.), and the distance to the closest field (crop fields). To calculate distances, the location (using a hand-held GPS receiver) of each nest was mapped using Esri map open (source: https://satellites.pro/carte_de_l-Algerie).

Based on landscape elements observed from aerial photographs (Esri map open source: https://satellites.pro/carte_de_l-Algerie), we determined the composition of the surrounding landscape areas at each nest site at spatial scale consisting of circular buffers with radii of 1000 m. This is the average distance at which Hirundinidae family commonly moves around their nests during the breeding period (Osawa 2015).

We categorized three landscape classes: urbanized areas, vegetated area, and non-vegetated area. For assessing our classification accuracy, we have collected ground truth data using a hand-held GPS receiver. We went to the field (in March 2016 and 2017) to see what the land covers are and record their coordinates (x, y). In total, 308 ground truth points have been collected in the field (Table 1). The class accuracies determined by comparing test pixels with the corresponding location in the classified image. We used field verified ground references locations for the test pixels. Results are expressed in an error matrix (Rwanga and Ndambuki 2017) which

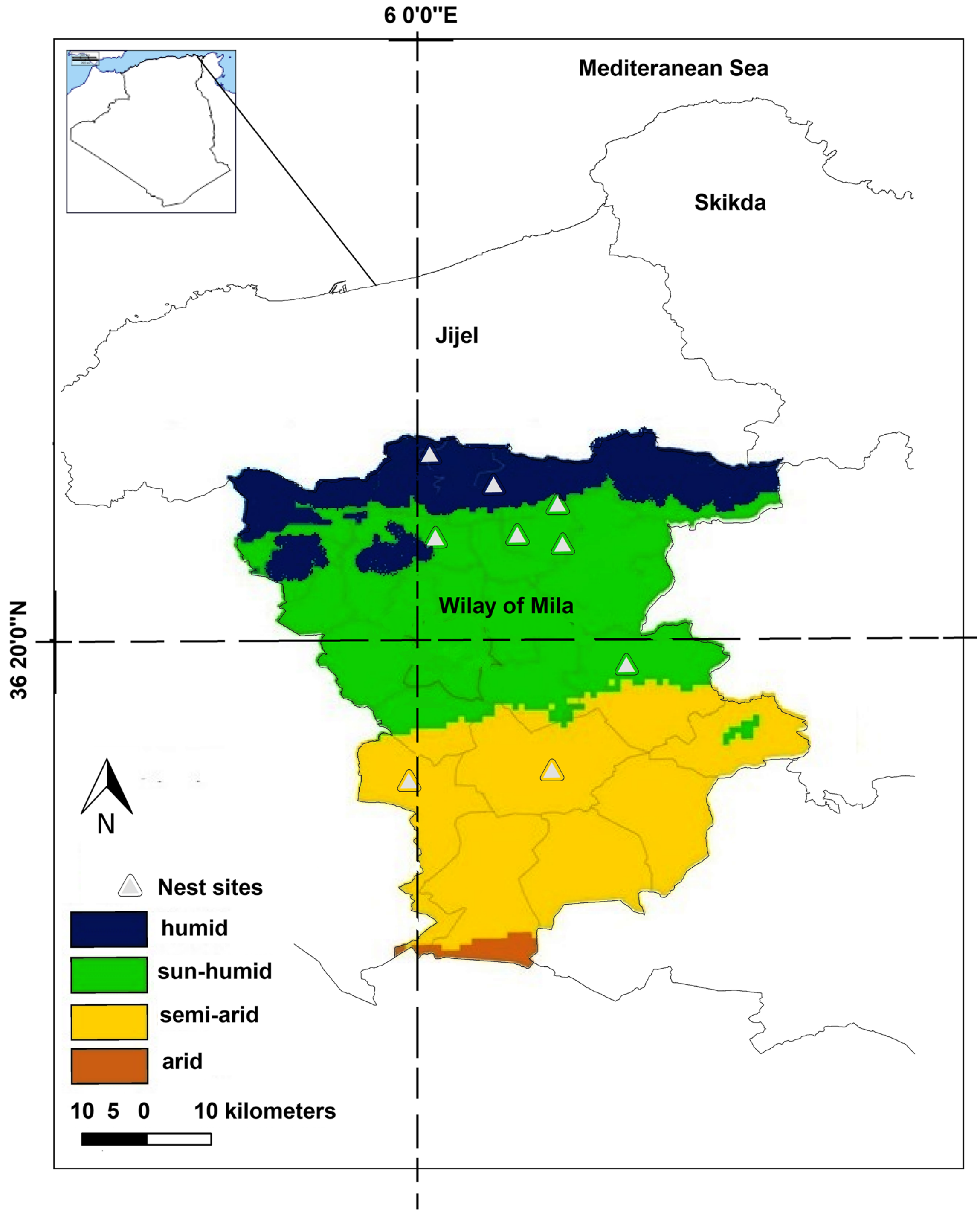

Fig. 1 Location of nest sites in Mila Province, north-eastern Algeria (source: Laala and Alatou 2017)

shows the overall and class accuracy and amount of ground truth points within each class (Table 1). We use ArcGIS geoprocessing tools to accomplish this assessment.

Data analysis

Possible correlations among variables were checked using variance inflation factors (VIFs). To prevent multicolinearity, the variables were tested with VIF Analysis (Quinn and Keough 2002). Variables with a VIF > 5 were removed as recommended by Zuur et al. (2009). To test the effect of the covariates on house martin laying date, clutch size and hatching success (i) we used Generalized Linear Models (GLM) with the negative binomial distribution to test the influence of local climate as a categorical variable of three climate types (humid, sub-humid, and semi-arid) on laying date (local

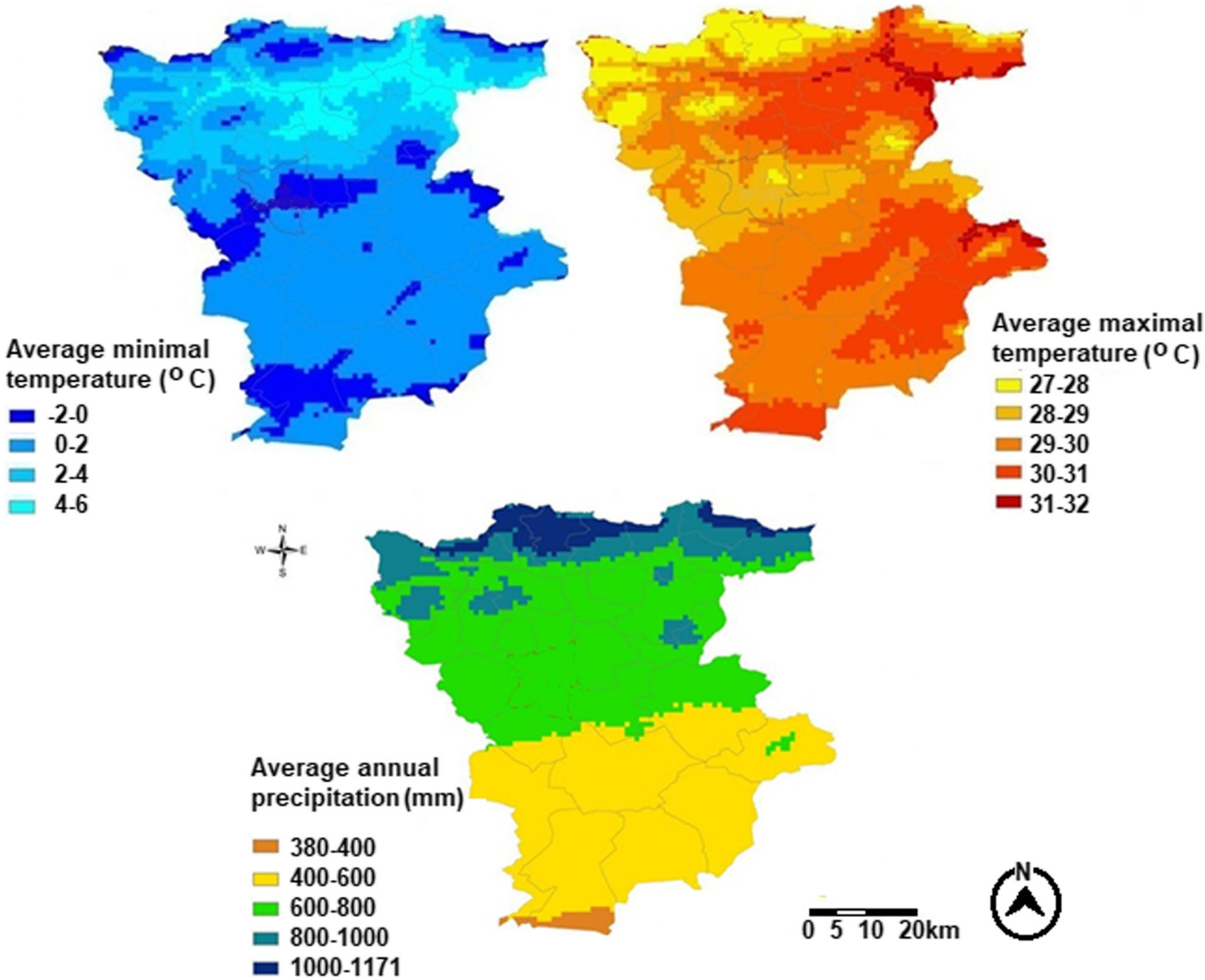

Fig. 2 Summary stats for each region on temperature and precipitation (an average of 30 years including the two years of the study, from 1988 to 2018) (ArcGIS 10.5 Owner ESRI, Redlands, California, USA)

weather was the only explanatory variable examined for lay date), (ii) we used Generalized Linear Models (GLM) with Poisson's error distribution, to test the effect of years, local climate, the brood order, laying date, distance to fields and distance to water on the clutch size and hatching success separately. For each set of predictors, we developed an all-inclusive design (all possible combination models) by using multimodal inference. Models were then ordered by

Table 1 Error matrix shows the overall and class accuracy and number of ground truth points within each class

	Ground truth (count points)				
Predicted (class name)	Urbanized area	Vegetated area	Non-vegetated area	Percent	Predictions
1) Urbanized area	90	0	20	81.81%	110
2) Vegetated area	0	80	4	95.23%	84
3) Non-vegetated area	10	4	100	87.71%	114
Percent	90%	95.23%	80.64%	87.66%	
Total	100	84	124		**308**

increasing AICc (Burnham and Anderson 2002). We considered all models with ΔAICc lower than 2 as equally good (Burnham and Anderson 2002). Model weights were used to define the relative importance of each explanatory variable across the full set of models evaluated by summing weight values of all models that included the explanatory variable of interest. We tested the model performance by the Hosmer–Lemeshow Goodness of Fit Test (Hosmer and Lemeshow 2000).When significant effects were found we used One-way ANOVA with pairwise comparisons (Tukey multiple comparisons of means 95% family-wise confidence level) to determine which pairs differences (three pairs: humid vs. sub-humid, humid vs. semi-arid, sub-humid vs. semi-arid) are statistically significant.

All statistical analyses were performed in R-3.0.2 software (R Development Core Team 2013). We used the package 'MASS' to apply Generalized Linear Models (GLM) with the negative binomial distribution, the package 'car' (Fox and Weisberg 2011) to calculate Variance Inflation Factor (VIF), the package 'MuMIn' to calculate AICc (Bartoń 2015), and the package 'Resource Selection' to test the best model performance.

Results

Breeding ecology

Under the three different local climate conditions of the study area, means laying date of Algerian common house martin varied significantly (Fig. 3a). Going from most humid to least humid the negative Binomial GLMs analysis indicated that laying date was significantly correlated with local climate condition (GOF = 0.42), demonstrating thereby potential importance of this predictor. The semiarid climate creating the appropriate conditions for advancing the laying process (ß = −034, z = −4.17 $p < 0.001$) while the humid climate delaying it (ß = 3.08, z = 69.09, $p < 0.001$). Generally, the onset of egg laying was advanced from 20 and 25 April at humid and sub-humid environments, respectively, to 7 April at the semi-arid ones (Table 2).

Clutch size for the three localities all study areas combined ($n = 328$ nests) ranged from 3 to 7 eggs. Maximum habitat difference in mean clutch size for the populations was 1.08 eggs (Table 2) comparing humid and sub-humid habitats. Clutches of seven eggs were recorded exclusively at the humid habitat (14 nests) (Fig. 3b). Results of a Poisson GLM with clutch size showed that the model including local climate was the only top model(Δ AICc <2, GOF = 0.99).From least humid to most humid, the top model indicating that clutch size was positively associated with local climate conditions (semi-arid: ß = −0.14, z-value = −2.27, $p = 0.02$; subhumid: ß = −0.22, z-value = −3.62, $p = 0.05$; and humid: ß = 1.66, z = 48.38, $p < 0.001$). On other words, clutch size was lower in arid areas (least humid) and increased slightly when local climate conditions became more humid (Tukey multiple comparisons of the three pairs: humid vs. sub-humid, humid vs. semi-arid, sub-humid vs. semi-arid are statistically significant (all $p < 0.05$) (Fig. 4). Whereas, the other non-climatic variables (years, brood order, laying date, distance to fields, and

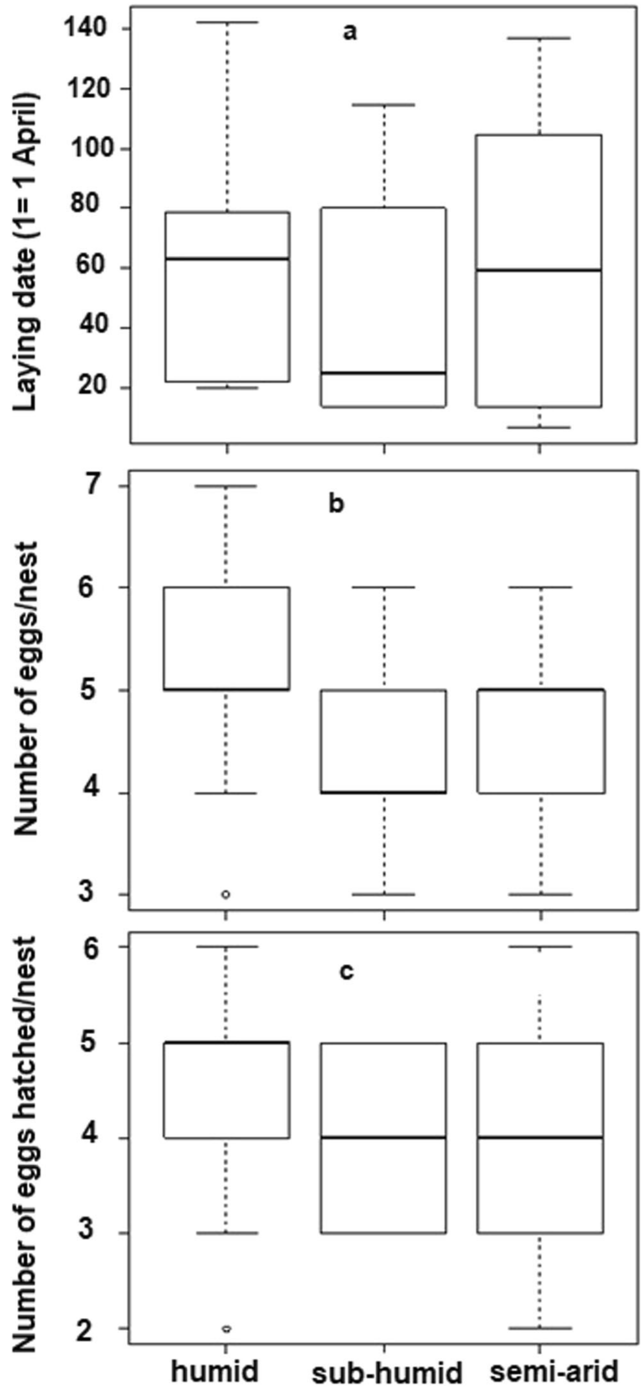

Fig. 3 Laying date (**a**), the number of eggs per nest (**b**), and number of eggs hatched (**c**) in response to climatic variables in the Algerian common house martin. Median and interquartile range are shown

Table 2 Mean clutch size and laying date for an Algerian common house martin nesting at three local climate conditions

	Clutch size[a]		First-egg dates[b]	N (number of nests)
Humid	5.26 ± 1.07	20 April	(20 April - 18 June)	161
Sub-humid	4.18 ± 0.77	25 April	(25 April - 20 June)	85
Semi-arid	4.57 ± 1.03	7 April	(7 April - 30 May)	82

[a] Mean ± SD

[b] Median range

distance to water) were not significant (Δ AICc >2, was not retained after model selection) (Table 3).

Among the 328 clutches monitored (1597 eggs), 88.47% were successfully hatching. Average hatched success was 4.25 (± 1.01) hatchlings per nest, ranging from 2 to 6 nestlings (Fig. 2c). The most parsimonious model (Poisson GLM) of hatching success includes only local climate conditions (Δ AICc <2, GOF = 0.99) (Table 2). The number of eggs hatched per nest was greater in humid conditions (ß = 1.51, z = 41.16, $p < 0.001$) than in sub-humid and semi-arid ones (respectively: ß = −0.14, z = −2.27, $p = 0.02$; ß = −0.13, z = −1.99; $p = 0.04$) (Fig. 2c). The remaining variables (years, brood order, laying date, distance to fields, distance to water) poorly explained (Δ AICc >2, was not retained after model selection) the variation in the hatching success of Algerian common house martin.

Landscape characteristics around each nest site

According to the obtained overall accuracy (87.66%) (Table 1), our landscape categorization of aerial photos is very appropriate. The spatial analysis around each nest sites of house martin shows that the surrounding landscape in the humid areas is characterized by dense vegetation cover and reduced urbanization levels (Fig. 5c), while the vegetation cover is reduced in quantity and quality when local climate conditions became more arid (Fig. 5a).

Discussion

This study contributes considerably to our understanding of the importance of local climate conditions as a determinant factor on laying dates, clutch size variation, and hatching success, in a long-distance migratory species (common house martin) across the southern part of their breeding range. Studies on North African populations of this Hirundinidae species are very interesting; Garcia and Arroyo (2001) expected that different environmental factors influencing life histories may reach their extreme values at the southern edge of the species breeding range. This fact has already been confirmed by Sakraoui et al. (2005) regarding the breeding ecology of a similar aerial insectivore, the barn swallow *Hirundo rustica* (Linnaeus, 1758) when clutch sizes were larger than expected. Furthermore, the hot and dry period of the breeding season, typical of North Africa, is a heavily limiting factor for breeding phenology (Blondel and Aronson 1999).

By examining the breeding strategy of common house martin nesting across north-eastern Algeria, it appears that the magnitude of local weather conditions drives the timing of breeding and reproductive investment. We provide evidence of the negative effect of semi-arid and sub-humid conditions on laying dates, clutch size variation, and hatching success. At a local scale, our results revealed that laying dates were advanced in semi-arid areas where warm and dry spring is most pronounced compared to humid areas. This is logical since, the initiation of egg laying is known to be more affected by

Table 3 Most supported models on the effect of climatic and non-climatic variables on clutch size and hatching success in the Algerian common house martin

Model		logLik	AICc	ΔAICc	Wi	GOF (*p*)
Clutch size	Local climate	−594.74	1195.6	0	0.99	0.99
	Null model	−602.18	1206.4	10.84	0.004	
Hatching success	Local climate	−577.92	1161.9	0	0.81	0.99
	Null model	−581.43	1164.9	2.95	0.187	

Models are ranked according to AICc and only models within an interval of ΔAICc<2 and the null models are shown. The difference in AICc from the best-supported model (ΔAICc), Akaike's weights (wi), −2 log-likelihood values(logLik), and Hosmer–Lemeshow Goodness of Fit Test (GOF) are also given.".. ." Refers to additional models examined, but not listed in detail to avoid overlong table, as they were not informative (all models that were ran for each response variable are shown in Online resource 1). N = 328. Local climate: humid, sub-humid, and semi-arid

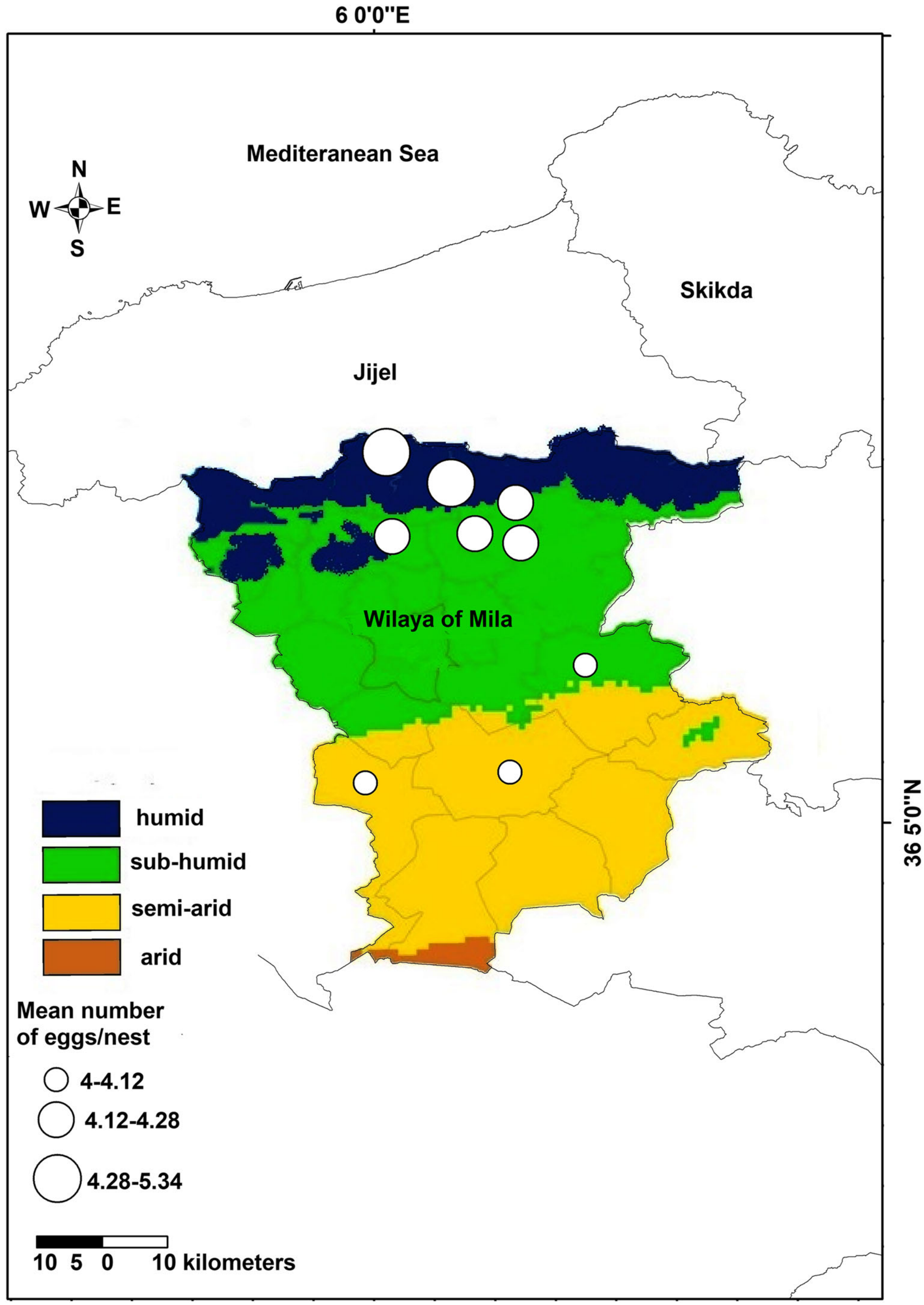

Fig. 4 Spatial variation of mean clutch size at the three climatic levels (humid, sub-humid, and semi-arid) of the Algerian common house martin (ArcGIS 10.5 Owner ESRI, Redlands, California, USA)

local conditions than by overall climate changes (Green 2010), and species breeding at different localities can attain a higher intraspecific variation (Visser et al. 2003). Also, in similar species such as barn swallows (Møller 2008), there is considerable variation among study sites related to local temperature differences. This phenomenon is very common and is mostly likely caused by geographic differences in the extent and timing of warming (Dunn and Winkler 2010). In addition to temperature per se, variation in the time of egg-laying is often associated with precipitation (Newton 1998). In the semi-arid region such as our study area, precipitation is strongly seasonal and often concentrated in one portion of the year. Thus, rainfall deficiency certainly has a negative effect on ground vegetation and associated insects (Wolda 1978) that female martin rely on to produce clutches (Aslan and Yavuz 2010). Furthermore, by testing some metabolic mechanisms in passerines, it was shown that the beginning of some specific physiological processes could be triggered by rainfall (Leitner et al. 2003; Hau et al. 2004; Fulgione et al. 2005). Indeed, birds cannot anticipate and prepare for a

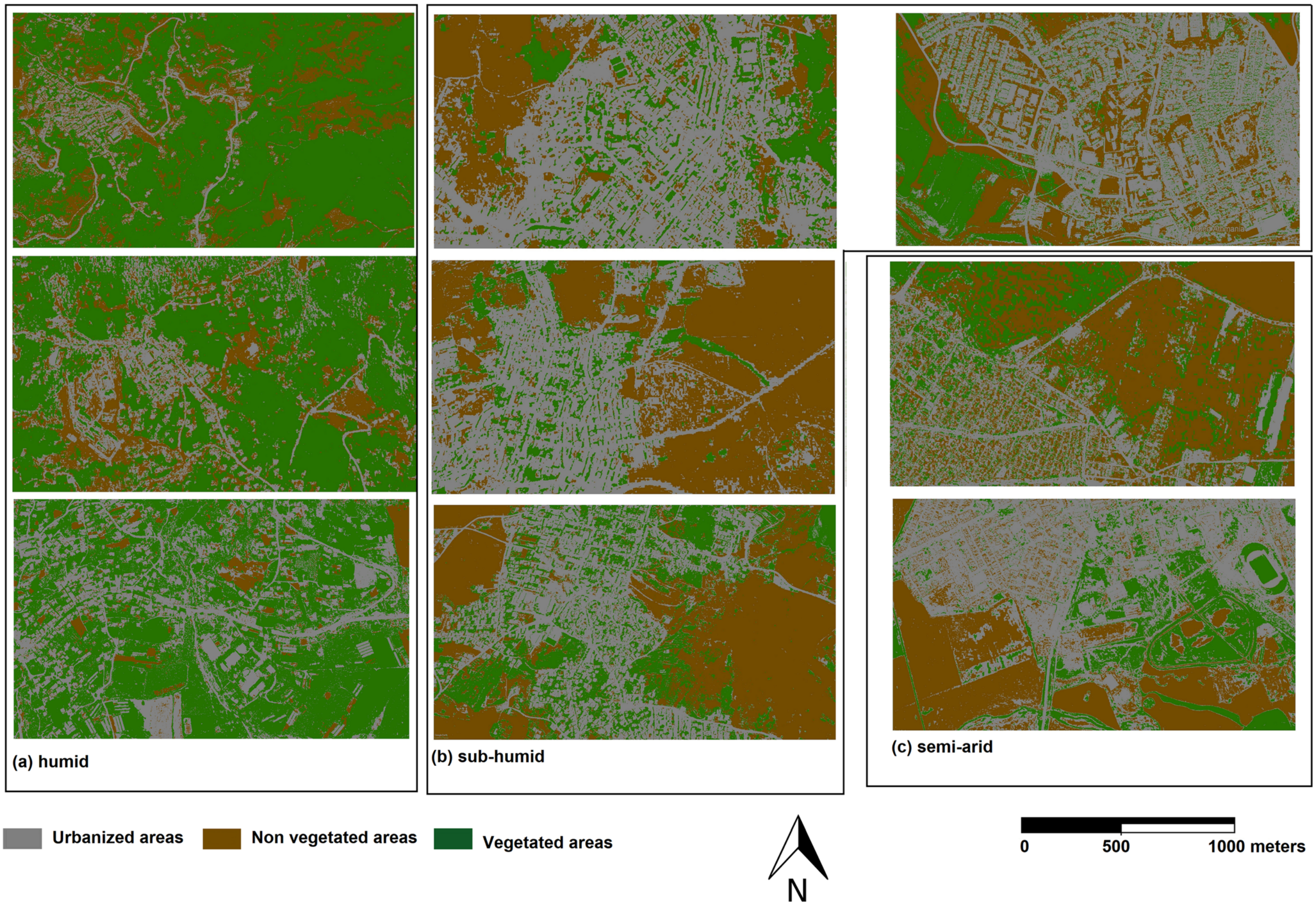

Fig. 5 Composition of the surrounding landscape areas within circular buffers of radius 1000 m for eight (8) house martin nest sites located in the humid (2 sites) (**a**), sub-humid (4 sites) (**b**) and semi-arid areas (2 sites) (**c**) (ArcGIS 10.5 Owner ESRI, Redlands, California, USA)

regular reproductive period in such seasonally unpredictable habitats (Hau et al. 2004); they will start therefore egg laying opportunistically at any time during the breeding season.

At the regional scale, our findings are consistent with the typical pattern shown by house martin in the other parts of the country: April 6th recorded by Lahlah et al. (2006), and April 18th by Hamlaoui et al. (2016). The overall laying dates were relatively advanced in comparison to more northerly regions, such as central and north Europe (Pikula and Beklova 1987; Kamiński and Wołosiuk 1995; Górska 2001), excepting the Town of Extremadura, West Spain where the first eggs were laid in March (Pajuelo et al. 1992; de Lope et al. 1993). It is well known that climatic factors such as temperature and precipitation are amongst the most important factors affecting breeding ecology of birds (Slobodník et al. 2013). There is a general consensus that lay dates within bird species varied by population and local climatic conditions (Visser et al. 2003).Warming in the spring certainly induces most species to advance their laying dates (Dunn 2004).

The impact of climate on breeding dates may require additional information about the availability of food, physiological condition as well as patterns of adult mortality throughout the breeding season. Despite that, and since the obtained laying dates were notably associated with local climate fluctuations, we may conclude that local climate is the most likely explanation for the breeding phenology in the studied house martin populations.

The present study also highlights the effect of local climatic conditions on clutch size variation. We observed that mean clutch size was higher in humid areas and decreased slightly when local weather conditions became more arid. This finding is in concordance with clutch size patterns for many bird species when number of eggs per nest was negatively affected by critical level of temperature and positively correlated with rainfall rates (Aslan and Yavuz 2010). As well as direct effects of temperature increase, clutch size can also be affected indirectly by other constraints of aridity. The most crucial one of these, is food availability and more important is nutrient availability (fat, protein, water, and calcium) that egg formation requires (Patten and Rotenberry 1999). In the investigated semi-arid areas, water resources such as small rivers, streams, and other water bodies are temporary and tend to dry up and disappear early during the breeding season (Smadhi et al. 2017). Also, these areas belong to the Algerian steppe where vegetation is reduced in quantity and quality, and the main vegetation cover remains exclusively cereals and rangelands (Bouazza et al. 2012). The effect of host plants on insect herbivore population is well known, higher plant richness leads to higher abundances and diversity of most insect species (Masters et al. 1998) which are the primary source and the typical diet in the house martin and many other passerine species, especially when nesting (Johnston 1993; New 2015). Thus, clutch size should be constrained during oogenesis because of reduced availability of these preferred food items (Johnston 1993; Seress and Liker 2015; Seress et al. 2018). On the other hand, the spatial analysis around each nest sites of house martin showed that the surrounding landscape in the humid areas is characterized by dense vegetation cover and reduced urbanization levels. This may result in greater clutch sizes thanks to food availability for egg-laying females and reduced human disturbances (Seress et al. 2018).

It is important here to mention that in all populations of house martin studied (Lahlah et al. 2006) the average clutch size of 5.26 found in this study is among the greatest one. Although, these differences in clutch sizes are driven by changes in a range of environmental conditions, we demonstrate that large clutches were recorded at nest sites under humid local weather, dense vegetation cover, and low urbanization levels that characterize the surrounding landscape. Such results may provide insights into mechanisms that drive breeding strategies in urban insectivorous birds that still remain unclear (Gil and Brumm 2014).

Regarding the hatching success, we found that numbers of hatchlings are higher in nest sites located in humid areas than in semi-arid area. This finding could be related to the environmental conditions during the breeding season that might directly influence incubation in aerial insectivores (Magrath 1990). Changes in incubation costs can have fitness consequences (Bryan and Bryant 1999). Breeding females that have experienced reduced incubation demands due to changes in environmental conditions (temperature, food availability, air pollution...etc.) may be in poor body condition and thus unable to build up sufficient body reserves necessary for successful incubation (Daunt et al. 1999). Yet again, we demonstrate the suitability of nest sites located in humid as opposed to the semi-arid area as a determinant factor of breeding success in house martin populations of north-eastern Algeria.

Numbers of hatchlings are much higher than those reported for hose martin populations nesting in neighbouring regions, such as Annaba in extreme north-eastern Algerian (Lahlah et al. 2006). An inspection of environmental conditions concerning Mila (study area) and Annaba shows that although both the cities face similar climatic conditions, they differ in urbanization level. Annaba is a more urbanized city and has also been subjected to severe anthropogenic problems (water and air pollution) (Ounissi et al. 2016). This difference is probably the reason why nest sites in our study area (Wilaya of Mila) provide more safe places for nesting house martin. Furthermore, the values of hatching success (4.25 hatchlings per nest and rates of 88.47%) are much higher than most of those reported for other house martin populations (for example: Cramp 1988; Pajuelo et al. 1992; Christe et al. 2001; Lahlah et al. 2006; Zhou et al. 2012).

Variability in local climate conditions among regions that characterized our study area offered us an ideal opportunity to test phenotypic variations along gradients. Such variability may provide insights into mechanisms that drive species distribution, and thus can be a useful indicator of environmental change. We found that local climate conditions and vegetation cover as well as urbanization levels are the main environmental variables that determine laying dates, clutch size variation, and hatching success in an Algerian house martin population. Nest sites located in humid areas with dense vegetation cover, and low urbanization levels that characterize the surrounding landscape, provide high-breeding success rate to this Hirundinidae. We believe that these findings strongly inform predictions of species-level responses to environmental change in a country that is already experiencing severe drought stresses and subject to uncontrolled urbanization and a high deforestation rate.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.2478/s11756-020-00666-w.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article a sa supplementary material.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval All procedures followed by this study were in accordance with international ethical standards and were approved by the Algerian Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (M.E.S.R.S.). The research involved no human participant.

Consent for publication Authors accept all publication rights.

Code availability Software used in this paper will be available upon reasonable request.

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