A comprehensive monograph on the ecology and distribution of the House bunting (*Emberiza sahari*) in Algeria

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Abstract

The House bunting (*Emberiza sahari* Levaillant, 1850) is a human commensal passerine bird species, characteristic of urban environments in the Sahara Desert of Algeria. Its distribution in Algeria, with particular emphasis in Ghardaïa, was investigated using two sampling methods: progressive frequency sampling and point abundance index, with ecological field data collected during 2017–2019. Morphological biometric measurements were carried out on free-living individuals for each sex. Reproduction phenology and success were surveyed through the breeding season (February–September) during 2018–2019. Trophic behavior was studied by direct observations of foraging individuals. Results showed that the species range in Algeria is larger than shown by data from the literature, with expansion northwards within the country. At a finer scale, in Saharan cities, the species prefers old and traditional urban environments, where its densities are higher than within modern urban habitats. At a national scale, we found that the species range is not restricted to desert climates, but extends towards the north of Algeria, including the semi-arid steppe rangelands of the Hauts-Plateaux region. Range changes are attributed to changes in building practices and climate change. Adult females were heavier and slightly larger than males, whose head plumage had different coloration patterns compared to females. Nests weighed 82.03 ± 20.77 g (mean ± standard deviation) and consisted of 72% plant materials, 19% animal-origin materials and 9% inert constituents. The nest cups were oval in form, top-lined and stuffed with diverse material. House buntings nest under the roofs of uninhabited houses, in stairwells, traditional water wells, and holes within walls. Nesting height averaged 2.14 ± 0.8 m. In Ghardaïa, courtship and pair formation began mid-February. Females can raise up to three successive broods (March-September), with 31–34 days/brood including 14–15 days for egg incubation. Clutch size is typically 2–3 eggs. The diet of the House bunting included seeds of annual grasses dominated by Poaceae species. The species also fed on anthropogenic food remains, and sometimes on insects, especially during the breeding period.

Highlights

- This study represents a comprehensive monograph on House Bunting ecology in North Africa, which deepens the understanding of distribution and breeding management of the species in dryland urban environments.

- We provide data on several biometric parameters, breeding biology (clutch size, hatchling and reproductive success), nesting timing, and diet composition of adults.

- The study identified and addressed potential gaps in knowledge of the species' ecology in the Sahara Desert and semiarid lands of North Africa, showing an increase in range compared to the current literature (including the IUCN Red List assessment).

- As a synanthropic species of urban environments of the Sahara, *Emberiza sahari* prefers traditional urban designs over modern estates.

- Range adjustments at fine scales appear linked to changing building practices and urbanization.

Introduction

The Sahara, the largest and most extreme of the deserts worldwide, is marked by edapho-climatic conditions that constrain the survival of spontaneous living beings (Chehma 2006). This ecoregion is characterized by low and uneven rainfall and pronounced thermal amplitudes between day and night and between seasons (Doumandji and Doumandji-Mitiche 1994). Regardless of its dryness, emptiness and severe environmental conditions, the Sahara contains a very particular diversity of flora and fauna, where some species have remarkable adaptations (Chehma 2006).

Birds are excellent indicators for studying the effects of urbanization because they react quickly to modifications in the landscape (Marzluff et al. 1998), and the trophic resources available present significant spatio-temporal variations that influence the functioning of populations and the expression of life history traits of individuals (Roff 1992). Among the birds of the Emberizidae family, two Bunting species characterize the Sahara Desert: House bunting (*Emberiza sahari* Levaillant, 1850) in Northwest Africa and Striolated bunting (*Emberiza striolata* Lichtenstein, 1823) in Northeast Africa and Asia. The latter includes three subspecies: *E. s. saturiator*, *E. s. jebelmarrae* and *E. s. striolata* (Kirwan and Shirihai 2007, Svensson et al. 2009, Sangster et al. 2013, Schweizer et al. 2017). Globally, the House bunting is categorized as a species of least concern (LC) on the IUCN Red List of threatened species (BirdLife International 2016).

In Algeria, the House bunting has a narrow distribution range. The northern boundary includes the Saharan limits of the Aurès mountains and its oases (M'Chouneche, El Kantra, Outaya, Biskra, Tolga, Chetma) and the southern aspect of the Saharan Atlas (Bousâada, Messaad, Laghouat, Ain Sefra, Beni Ounif, Bechar). The southern boundary passes through Biskra, Ghardaia, M'Zab, the oasis of Taghit and that of Beni Abbes south of Bechar. The distribution of this species also includes Hoggar, Tassili, Kalaa-Beni-Hammad (Setif), Belhiourt, Oued Abiod and Ghoufi (Aurès mountains) (Heim de Balsac and Mayaud 1962, Chenchouni 2010). The House bunting is considered a noble, sacred, and daring species, and it is a synanthropic species that has lived close to human settlements for a long time. Locally, this species has several appellations in Arabic and Berber such as "*Bou-Oud*", "*Bou-Hommir*" and "*Bou-Bechir*" (Chedad, pers. obs.). Locals protect it and contribute to its conservation through promoting traditional constructions that include suitable features for the species, such as arcades, small windows, walls with lighting, or ventilation holes. Despite these conservation efforts, the species population size is locally decreasing due to modern urbanization sprawl, while its distributional range is expanding towards northern latitudes of Algeria (Chedad, pers. obs.).

The Algerian avifauna have been extensively studied in various Saharan environments (Taibi et al. 2009, Guezoul et al. 2011, 2013, 2017, Ababsa et al. 2011, 2013, Chenchouni 2012, Djilali et al. 2012, Farhi et al. 2012, Bounaceur et al. 2016, Belkacem et al. 2017). However, with regard to the House bunting, no study has been conducted specifically on this species except for records made by Heim de Balsac and Mayaud (1962), Dupuy (1969), Ledant et al. (1981), Isenmann and Moali (2000) and Moulaï (2019). It is in this context that the current study aimed to fill scientific gaps in several aspects of the species' ecology and biogeography, by providing a comprehensive investigation including: (i) mapping and updating its range in Algeria with emphasis on the province of Ghardaia and its neighboring regions in central Algeria; here the study focuses on how cultural shifts in building practices are changing the species' distribution and abundance and assesses distribution shifts and expansion at a national scale. We investigated how urbanization intensity and building structure (considered as different urban habitats ranging from less urbanized and traditional habitats to modern and dense buildings) influence the occurrence and population abundance of this synanthropic species; (ii) determining biometric parameters and their variation between sexes; (iii) examining its breeding biology with analysis of the temporal variations of breeding parameters (clutch size, hatchling and reproductive success) and egg-laying date for different broods, times of nesting and years of study; and (iv) exploring adult diet composition.

Materials and Methods

Study area

The present study was carried out in the region of Ghardaia (32°28'N, 3°42'E), which is located in the central–northern part of the northern Sahara Desert. The City of Ghardaia is located 600 km south of the capital city Algiers (Heim de Balsac and Mayaud 1926) and is described as a UNESCO World Heritage Site (https://whc.unesco.org/en/list/188/). The region has a Saharan bioclimate characterized by mild winters (mean temperature of the coldest month = 11.5° C), very hot summers (mean temperature peaks in July with 35.5 °C) and low annual rainfall (~50–70 mm).

Mapping species distribution in Algeria

In order to establish a distribution map of the House bunting in Algeria, with a particular focus in Ghardaia (central Algeria), species occurrence data during 2017–2019 were collected using the Progressive Frequency Sampling (*Echantillonnage Fréquentiel Progressif "EFP"*) method, which is a point-sampling technique (see details in Blondel 1975, Bendjoudi et al. 2013). Using species occurrence data from the current study, complemented with additional occurrence data derived from eBird (www.ebird.org), we mapped and updated the geographic distribution of the House bunting in new locations detected outside its known range (BirdLife International 2016). Previous studies involving species range or occurrence reporting (Heim de Balsac and Mayaud 1962, Ledant et al. 1981, Isenmann and Moali 2000, Moulaï 2019) were also considered in updating the map of the House bunting range. ArcGIS (version 10.2.2 for Desktop: Esri®) was used to produce species distribution maps.

Population estimation

Population counts of the House bunting were conducted in the region of Ghardaia and surrounding areas using two sampling methods: progressive frequency sampling applied during the non-breeding season (October–early February) and a punctual abundance index (PAI) during the breeding season (mid-February–September), where the number of detected contacts, visual and/or auditory, were counted at four sampling points per habitat type (Blondel et al. 1970, Blondel 1975). Three different study sites were chosen and surveyed as representative of three types of urban environments in Ghardaia, considering construction material and building architecture and density: (i) traditional urban (Fig. 1A), often consisting of one-floor buildings, sparse (density≈4–5 dwellings/ha) and scattered within date palm trees and/or other trees such as pomegranates, orange trees, etc., and featuring traditional elements such as stone walls and floors with wood and clay; (ii) semi-modern urban (Fig. 1B), consisting of one-floor buildings, organized regularly in space (density≈24 dwellings/ha), of the same area, height and distance from the street and/or other houses. While semi-modern urban buildings were constructed of modern materials (i.e. concrete), the architecture of traditional buildings, such as many small windows, arches and triangles, was preserved, but without green-spaces crisscrossing houses, and; (iii) a totally modern urban area (Fig. 1C), in the form of two-story buildings (density ≈ 92 dwellings/ha), with the same height, shape and area, and located adjacent to paved main roads. In each site, four sampling points were monitored in order to study the influence of the urban environment type on the fluctuations in the number of individuals.

The software R (R Core Team 2020) was employed for statistical analyses. Descriptive statistics, i.e. mean, standard deviation (SD) and range (min–max), were computed to summarize data on House bunting population counts across the different types of urban environments and also for data generated below. Normality was checked using Shapiro-Wilk tests before carrying out one-way ANOVA to test the variation of species count data between urban environments.

Body biometric measurements

Biometric measurements were obtained from free-living individuals captured either with an ornithological net (Japanese net) or by hand at roosting sites. Each captured individual (females = 4 and males = 7) was weighed using an electronic scale with 0.01 g precision, and the following morphometrics were measured using a digital Vernier caliper (precision = 0.01 mm): (i) total length (distance between the beak tip and the longest feathers of the tail), (ii) wingspan (distance between the wingtips with wings held outstretched), (iii) stretched wing (distance from the bend of the wing to the tip of the longest primary feathers), (iv) tail length (distance from the tip of the longest feathers to the base of the tail), (v) bill length (culmen: distance between the tip of the upper mandible and the first feathers of the skull), and (vi) length of tarsometatarsus (distance from the

tibiotarsal articulation to the base of the toes; Eck et al. 2011). All individuals measured were captured from the semi-modern urban site of Ghardaia during the non-breeding season. Each individual was immediately released after obtaining these measurements. The variation of body biometric traits among sexes was tested using one-way ANOVA. Interrelationships between body morphometric variables were investigated using Pearson correlation tests at a significance threshold α = 0.05. Correlations were mapped in an interactive plot displaying the correlation matrix using the package {corrplot} in R (Wei and Simko 2017).
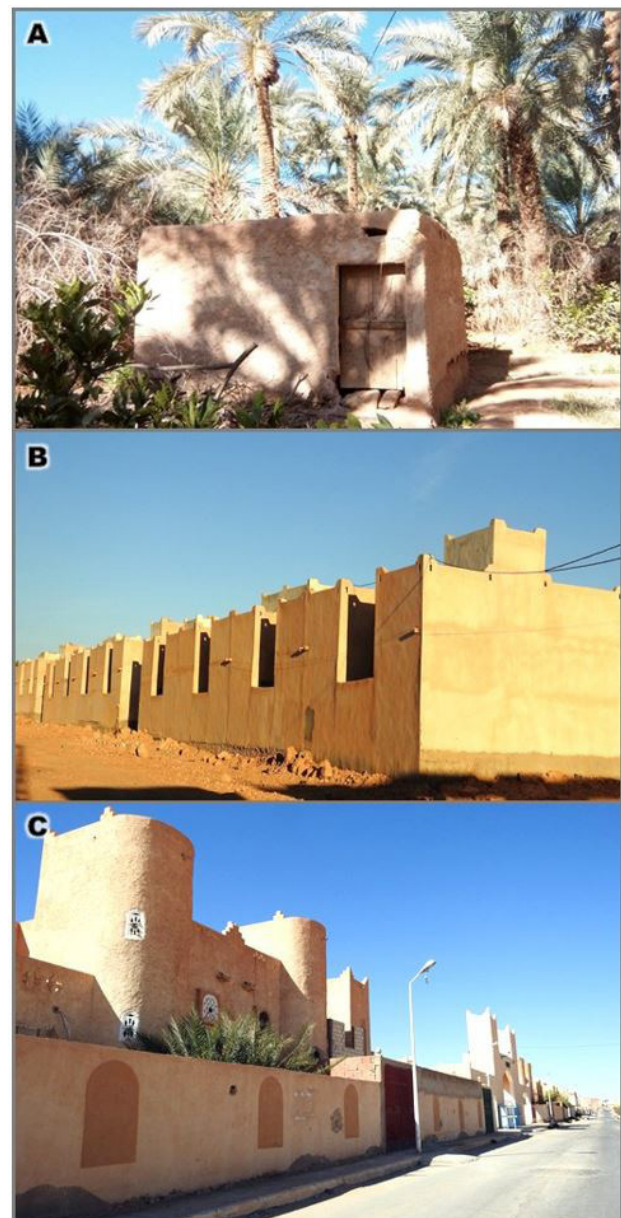

Figure 1. Photos of different urban sites where populations of the House bunting (*Emberiza sahari*) were estimated in the region of Ghardaia (Sahara Desert of Algeria). A) traditional urban site inside an oasis of date palm (*Phoenix dactylifera*) trees; B) semi-modern urban environment; C) modern urban habitat. (Photographs by Abdelwahab Chedad)

Breeding ecology

From 2018 to 2019, nests of the House bunting were examined in all localities where the species' presence was confirmed in the province of Ghardaia. Nesting surveys started at an early stage of the breeding season and before egg laying. Field surveys were carried out regularly every 2–3 days. Once a nest was found, the following parameters were recorded: geographical coordinates, date, nest state (old or new), nesting height above the ground, nest cup orientation, and other nest measurements (cup depth, nest outer and inner diameters).

For active nests, clutch size was recorded, and egg length (EL) and egg breadth (EB) were measured using a Vernier caliper (accuracy 0.01 mm). Egg weight (EW) was determined with an electronic scale (precision 0.01 g) during the first day after egg-laying. The shell index (IC) was subsequently calculated according to the formula of Ramade (1978): IC = EW1/EB, where EW1 is egg weight during the first day of laying. Egg volume (EV) was calculated following the formula of Hoyt (1979): $EV = 0.51 \times EL \times EB^2$. Egg shape index (SI) was computed using the formula: $SI = EB/EL \times 100$ (Panda 1996). Represented as a correlation matrix, Pearson correlation tests were employed to analyze relationships between egg characteristics (EL, EB, EW, IC, EV and SI).

After hatching, the number of surviving hatchlings were monitored regularly every 3–4 days until all chicks fledged. Chicks were tagged with numbered and colored rings. During each nest visit, chicks were weighed to determine body mass, and total length was measured using the same methods described above.

For each nest, the following breeding parameters were obtained in each breeding year (2018–2019), for each brood and for all years and broods combined (Metallaoui et al. 2020): (i) the duration of incubation (from first egg laid to hatching of all eggs), (ii) the duration of brooding (from first egg laid to chick fledging), (iii) hatching success (%; calculated as the number of eggs hatched/clutch size × 100), (iv) fledgling success (%; calculated as the number of fledglings/number of hatchlings × 100), and (v) breeding success (%; calculated as the number of fledglings/clutch size × 100).

The data used in the analysis of breeding biology of the House bunting were observed at the nest level. First, nests observed during the same brood (in total, there were three per year) were classified into two categories, i.e. 'early' and 'late' brood timing, based on the median of dates of egg-laying of the first egg per nest. The effects of breeding attributes (i.e. breeding year '2018-2019', brood timing 'early/late', and number of broods '1-3') on the variation of breeding parameters (i.e. clutch sizes, number of hatchlings and fledglings) were tested using generalized linear models (GLM). The first GLM included breeding year, brood timing, and number of broods as predictor variables of changes observed in clutch sizes. The second model included clutch size in addition to the previously described breeding attributes as explanatory variables of the variation in the number of hatchlings. The third GLM

tested the variation in the number of chicks fledged per nest with the above-mentioned breeding attributes, clutch size and the number of hatchlings as predictor variables. Each GLM was simplified using the 'backward/forward' stepwise selection procedure in order to automatically obtain the model with the best fit, i.e. with the lowest Akaike Information Criterion (AIC) score. Based on the model selected, a likelihood ratio test was performed for each breeding parameter using the function 'Anova()' for GLM in order to determine the effects of each explanatory variable.

At the end of the breeding season in 2018, ten nests were carefully collected in cardboard bags and brought to the lab to analyze the composition of nest building materials. Each nest was weighed using an electronic scale (precision 0.01 g), and the nest building materials were separated and grouped into three categories, plant, animal and inert materials. Plant materials were compared with leaves and twigs of trees, shrubs and herbs in the environment surrounding the nest. Plant species used as nest material were determined using plant guides (e.g. Chehma 2006). ANOVA was used to test the variation of weights of nesting materials between the three material categories.

Diet composition analysis

The trophic behavior of the House bunting was studied using direct observations of birds when foraging (Blagosklonov 1987). Using a Nikon P900 bridge camera (×83), the foraging birds were observed regularly all year round from 2017 to 2019 in several regions of the province of Ghardaia. Observations took place mainly during the morning (07:00–12:00). In case of foraging activity on the ground, the individual (or the flock) was monitored for a while, and just after the bird left the site, the plant and/or animal species consumed were precisely described. Samples and photographs were considered in order to facilitate the identification of plant and insect species consumed. Plant species were determined using a plant guide (Chehma 2006), whereas insects were identified mainly based on Chinery (1988).

Results

Range of the House bunting in Algeria and Ghardaia

During November 2017–December 2019, the presence of the House bunting was confirmed in several regions in Algeria (Fig. 2A), i.e. Bechar (Beni Ounif and Taghit), El Bayadh (El Abiod Sidi Cheikh and Ain Larak), Laghouat (Laghouat city, Aflou, Sidi Makhlouf and El Hadjeb), Djelfa city, Biskra (Biskra city and El Kantara), M'sila (Bousâada), Batna (Ghoufi, T'kout, Ghassira, Arris and M'doukal), Ouargla (Touggourt and Megarine), northern Ghardaia, southern Tissemsilt, and the extreme south of the Algerian Sahara, Illizi (Djanet). The number of confirmed occurrence points used in updating and mapping species distribution was 425 (Fig. 2A), with 94% observed in 2017– 2019 and 6% retrieved from ebird.org. In Ghardaia, the
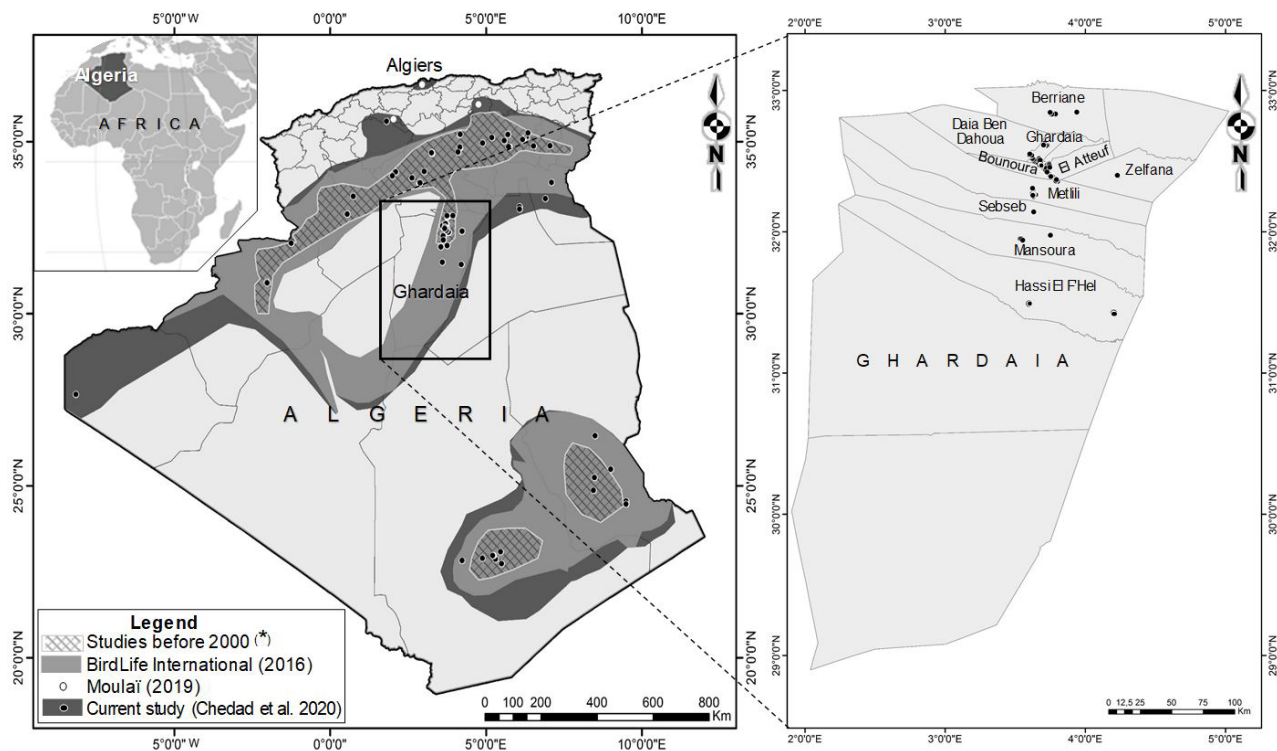
Figure 2. Maps showing previous and updated distributions of the House bunting (*Emberiza sahari*) in Algeria (left) and confirmed occurrences in different locations of Ghardaia 'Saharan region in central Algeria' during the period 2017–2019 (right). *: previous studies before 2000 included Heim de Balsac and Mayaud (1962), Ledant et al. (1981) and Isenmann and Moali (2000). Solid black circles indicate confirmed areas of species occurrence data for the current study.

House bunting was mainly located in the M'Zab valley (Beni-Isguen, El Atteuf, Bounoura, Melika and Daya Ben Dahoua) and in the regions of Zelfana, Berriane, Metlili, Sebseb and Mansoura (Fig. 2B).

The distribution of *Emberiza sahari* densities among different urban environment types showed a significant difference (one-way ANOVA: $F_{(2, 9)}$ = 34.03, $P<0.0001$). The traditional urban habitat had 18 pairs with a mean of 4.50 ± 0.41 pairs/ha for each sampling point, which was significantly greater than pair density in the semi-modern urban zone (mean = 3.0 ± 0.41 pairs/ha, total = 12 pairs) and the modern urban environment (mean = 1.63 ± 0.63 pairs/ha) (Table 1). During the breeding season, the density of pairs varied between 1 and 2 pairs/ha in the three urban sites.

Body biometrics for both sexes

In male House buntings, mass varied between 15.74 and 17.81 g, with a mean of 16.64 ± 0.72 g. The total length ranged between 13.1 and 13.3 cm (13.21 ± 0.09 cm). The wingspan was 20.7 ± 0.82 cm (range: 19.6–21.9 cm). The length of the tail fluctuated between 5.1 and 5.7 cm (5.39 ± 0.22 cm). The tarsometatarsus was between 1.5 and 1.7 cm (1.61 ± 0.06 cm). The stretched wing fluctuated between 8.3 and 9.6 cm (9.11 ± 0.48 cm). The beak was 0.9–1.1 cm long (0.98 ± 0.06 cm). In females, mass varied between 17.81 and 18.07 g (17.98 ± 0.12 g). The total length ranged between 13.2 and 13.3 cm (13.23 ± 0.05 cm). The wingspan was 21.15 ± 0.13 cm (range: 21–21.3 cm). The length of the

tail fluctuated between 5.2 and 5.4 cm (5.3 ± 0.08 cm). The tarsometatarsus had a length of 1.68 ± 0.03 cm (range: 1.65–1.7 cm). The stretched wing fluctuated between 9.2 and 10.7 cm (10.08 ± 0.63 cm), whereas the length of the bill varied between 0.9 and 1.05 cm (0.98 ± 0.06 cm) (Table 2). The variation of body traits between sexes was not significant except for body mass (ANOVA: $F_{(1, 9)}$ = 12.83, $P = 0.006$) and the length of the stretched wing (ANOVA: $F_{(1, 9)}$ = 8.083, $P = 0.019$).

The Pearson correlation matrix (Supplementary Material - Figure S1) showed that out of 20 correlation tests between morphometric traits, none were significant ($|r| <0.58$, $P >0.05$). Length of wing was correlated positively with all morphometric traits except bill length, which was negatively correlated with all other traits, excluding body mass. The latter was negatively correlated with total length, tail length and wingspan, but correlated positively with length of the tarsometatarsus. This uneven pattern of correlations may be related to species-specific allometry or to the sample size analyzed.

Sexual dimorphism in morphology and plumage

With regard to the morphological description of the House bunting, the head, neck and chest are gray in color speckled with white. For both sexes, the bill is dark grayish for the upper mandible and yellowish for the lower mandible. The lower parts of the body are slightly brown. The wings have a rusty color with dark black wingtips. The tail is black with a heart-shaped

Table 1. Numbers of the House bunting (*Emberiza sahari*) counted in different types of urban environments and counting-points during non-breeding season (using progressive frequency sampling technique) and breeding season (using punctual abundance index method) in the region of Ghardaia, Sahara Desert of Algeria.

Variables	Urban environments											
	Traditional				Semi-modern				Modern			
	Site characteristics											
Latitude (North)	32°30′17.75″				32°23′58.68″				32°21′49.84″			
Longitude (East)	03°38′51.58″				03°45′39.29″				03°47′49.95″			
Elevation (m a.s.l.)	515				491				440			
Counting points	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
	Counts during non-breeding season											
Point-counts (pairs/ha)	4.5	5	4	4.5	3	3.5	2.5	3	1.5	1	1.5	2.5
Total	18				12				6.5			
Mean ± SD	4.50 ± 0.41				3.00 ± 0.41				1.63 ± 0.63			
	Counts during breeding season											
Point-counts (pairs/ha)	1.5	2.5	2	2.5	1	1.5	1	2	1	1.5	1	1
Total	8.5				5.5				4.5			
Mean ± SD	2.16 ± 0.48				1.38 ± 0.48				1.13 ± 0.25			

tip. Males are defined by more marked patterns on the head, with a more obvious dissimilarity between light and dark areas compared to females. On the other hand, females are characterized by a gray-brown color, and the patterns are less clear. The tibia and tarsus are russet with dark gray legs and black toes for both sexes (Fig. 3).

Breeding and nesting biology

Nest building materials

Nests of House buntings weighed on average 82.03 ± 20.77 g. They were constructed in three fractions, i.e. 72% plant materials (59.14 ± 14.25 g), 19% materials of animal origin (15.95 ± 3.82 g), and 9% inert materials (6.93 ± 6.62 g). The variation of nesting material weights among these three categories was highly significant (one-way ANOVA: $F_{(2, 27)} = 86.7$, $P < 0.0001$). The plant part was composed of 21 species belonging to 12 plant families. The Poaceae family was best represented with seven species: *Bromus* spp., *Cynodon dactylon*, *Setaria viridis*, *Polypogon monspeliensis*, *Hordeum murinum*, *Triticum* spp. and *Hordeum vulgare* (Table 3). The animal material fraction was composed of feathers, sheep wool, goat hair and human hair. The inert part was composed of several elements, including stone, mud, and small pieces of timber, tissue, foil, plastic fibers, fabric and soap. In the middle of the nests, several specimens of insects were found, including *Larinioides* spp., *Lepisma* spp., Myrmeleontidae spp. unidentified and larvae of Dermestidae.

Nests of the House bunting were built mainly from annual plants and dry medium-size branches (twigs) of trees (*Punica granatum*, *Citrus sinensis*, *Citrus limon*, *Ficus carica* and *Phoenix dactylifera*) collected from the environment surrounding the nesting site. Nests were garnished with stones, mud, seeds, tree barks and fruits. The cup of the nest, of oval shape, was composed of fine plant elements (small branches and blades of dry grass, roots, straws, etc.). Inside, it was lined and stuffed with palm hair, fibers, and feathers, and it was essentially characterized by the presence of sheep wool, human hair and goat hair.

Characteristics of nests and nest sites

In general, House buntings install their nests under a house roof or inside holes. The nests are always sheltered from direct sunlight. They build their nests above the shelves within houses (usually uninhabited), in stairwells (Fig. 4A), in holes of walls of traditional water wells, on bases of house windows, or in holes and cracks in fencing walls. The nesting height varied between 0.9 and 4.15 m (2.14 ± 0.795 m). The inner diameter averaged 5.8 ± 0.56 cm (range: 4.9–6.5 cm). The cup depth ranged between 5.01 and 6.2 cm (5.71 ± 0.39 cm). The outer diameter varied between 29 and 44 cm (34.77 ± 4 cm). Usually both partners participated in nest building (Fig. 4B, 4C), which lasted between 5 and 22 days. Nests were mainly installed with the cup oriented to the East, sometimes Northeast or Southeast.

Breeding chronology, egg traits and chick growth

The courtship and pair formation in the House bunting began in mid-February. The female can have three successive broods on the same nest over a period of seven months (March–September). Each brood lasted 31–34 days with 14–15 days spent in egg incubation. The first brood began in mid-March (mean laying date of the first egg = 5th April ± 14 days), the second occurred in mid-May (mean egg-laying date = 10th May ± 13 days) and the third brood was observed in early July (mean egg-laying date = 13th July ± 22 days).

Table 2. Descriptive statistics of body morphometric traits for males (n = 7) and females (n = 4) of House buntings (*Emberiza sahari*) from the Sahara Desert of Algeria.

Variables	Mean	SD	IQR	CV	Min	25%	50%	75%	Max	Skewness	Kurtosis	$F_{(1,9)}$	P-value
Body weight [g]												12.83	0.006
Female	17.98	0.12	0.09	0.006	17.8	18.0	18.0	18.0	18.1	−1.63	2.88		
Male	16.64	0.72	0.91	0.043	15.7	16.1	16.8	17.0	17.8	0.43	−0.62		
Overall	17.13	0.88	1.47	0.051	15.7	16.4	17.2	17.9	18.1	−0.38	−1.54		
Total length [cm]												0.047	0.833
Female	13.23	0.05	0.03	0.004	13.2	13.2	13.2	13.2	13.3	2.00	4.00		
Male	13.21	0.09	0.15	0.007	13.1	13.2	13.2	13.3	13.3	−0.35	−1.82		
Overall	13.22	0.08	0.10	0.006	13.1	13.2	13.2	13.3	13.3	−0.33	−0.88		
Wingspan [cm]												1.134	0.315
Female	21.15	0.13	0.15	0.006	21.0	21.1	21.2	21.2	21	0.00	−1.20		
Male	20.70	0.82	1.15	0.040	19.6	20.1	20.9	21.2	22	0.04	−1.25		
Overall	20.86	0.68	0.70	0.033	19.6	20.5	21.1	21.2	21.9	−0.70	−0.12		
Stretched wing [cm]												8.083	0.019
Female	10.08	0.63	0.53	0.063	9.2	9.9	10.2	10.4	10.7	−1.08	1.75		
Male	9.11	0.48	0.55	0.053	8.3	8.9	9.2	9.5	9.6	−0.98	−0.37		
Overall	9.46	0.70	0.65	0.074	8.3	9.2	9.4	9.9	10.7	0.16	−0.16		
Tail length [cm]												0.545	0.479
Female	5.30	0.08	0.05	0.015	5.2	5.3	5.3	5.3	5.4	0.00	1.50		
Male	5.39	0.22	0.30	0.041	5.1	5.3	5.3	5.6	5.7	0.25	−1.37		
Overall	5.35	0.18	0.20	0.034	5.1	5.3	5.3	5.5	5.7	0.72	−0.11		
Bill length [cm]												0.008	0.931
Female	0.98	0.06	0.08	0.066	0.9	0.9	1.0	1.0	1.1	0.00	−1.20		
Male	0.98	0.06	0.05	0.065	0.9	1.0	1.0	1.0	1.1	1.14	1.95		
Overall	0.98	0.06	0.05	0.062	0.9	1.0	1.0	1.0	1.1	0.69	0.29		
Length of tarsometatarsus [cm]												3.239	0.105
Female	1.68	0.03	0.05	0.017	1.7	1.7	1.7	1.7	1.7	0.00	−6.00		
Male	1.61	0.06	0.05	0.039	1.5	1.6	1.6	1.7	1.7	−0.74	1.49		
Overall	1.64	0.06	0.08	0.036	1.5	1.6	1.7	1.7	1.7	−1.10	1.67		

(SD: standard deviation, IQR: interquartile range, CV: coefficient of variation, *F* (*F*-statistics with degrees of freedom between groups and within groups in round brackets) and *P*-value are summary results of one-way ANOVA).

Clutch size varied between 2 and 3 eggs. Eggs were ivory–whitish colored, spotted with brown, and these spots were very dense at the end of the egg on the side of the air chamber. The weight of the eggs varied between 1.70 and 2.26 g (1.97 ± 0.15 g). Their length varied between 1.8–2.0 cm (1.87 ± 0.7 cm), and their breadth ranged between 1.3 and 1.5 cm (1.39 ± 0.05 cm). The values of the shell index fluctuated from one nest to another and from one egg to another (range: 0.13–0.16 g/cm, mean ± SD: 0.14 ± 0.008 g/cm). The mean of egg volume was 1.84 ± 0.19 cm³ and that of shape index was 74.33 ± 2.72% (Table 4).

Once hatched, 2-day–old chicks weighed 2.52 ± 0.41 g with a total length of 3.40 ± 0.20 cm. At the age of 7 days old, their average weight reached 9.4 ± 0.9 g and they measured 5.33 ± 0.89 cm long. Just before fledging, after 14 days, their average weight reached 14.94 ± 0.04 g, with a total length of 9.25 ± 0.07 cm.

The correlation matrix (Supplementary Material - Figure S2) showed that out of 15 Pearson correlation tests between egg characteristics, five were significant (*P* <0.05). These correlations were all positive and observed between egg weight—breadth (*r* = 0.75, *P* = 0.001), weight—volume (*r* = 0.59, *P* = 0.021), weight—shell index (*r* = 0.90, *P* <0.001), volume—length (*r* = 0.87, *P* <0.001) and volume—breadth (*r* = 0.87, *P* <0.001).

Breeding parameters

House bunting reproduction in Ghardaia during 2018–2019 was monitored based on a total of 25 nests and 62 eggs, with 10 nests and 23 eggs surveyed in 2018 and 15 nests with 39 eggs monitored in 2019 (Table 5). The clutch size averaged overall 2.48±0.51 eggs/nest (mean ± SD), with 2.30 ± 0.48 eggs/nest in 2018 and 2.60 ± 0.51 eggs/nest in 2019 (Fig. 5). GLM indicated that clutch size increased significantly in 2019 compared to 2018 (GLM: χ^2 = 7.35, *P* = 0.007) (Table 6). Clutch size was
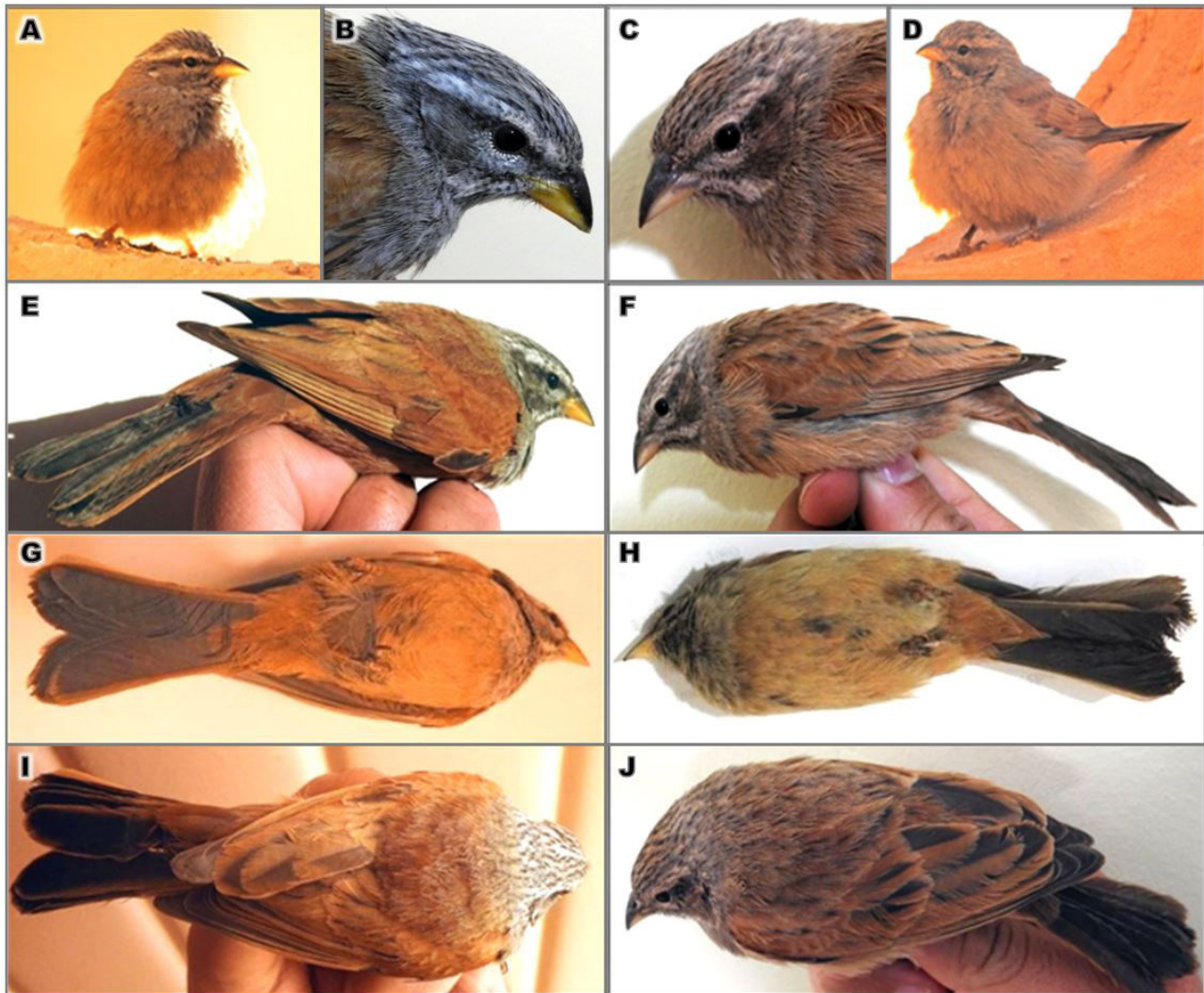
Figure 3. Photographs of males (left column photos) and females (right column photos) of House buntings (*Emberiza sahari*) showing (from top to bottom): general view (A, D); lateral view of the head (B, C); side view (E, F); ventral view (G, H); and dorsal view (I, J). (Photographs by Abdelwahab Chedad)

larger for the first brood in 2018 (2.67 ± 0.58 eggs/nest) compared to 2019 (2.60 ± 0.51 eggs/nest) and for the second and third broods in 2019 with 2.50 ± 0.58 and 3.00 ± 0.00 eggs/nest, respectively, compared with 2018, when we recorded 2.00 ± 0.00 and 2.33 ± 0.58 eggs/nest, respectively (Fig. 5). Statistically, the model did not reveal any significant difference between the three broods ($P = 0.186$), nor for brood timing for each brood ($P = 0.099$) (Table 6).

Hatchlings totaled 48 individuals, with an overall hatching success of 77.4%. Hatching success reached 100% (23 hatchlings) in 2018 and 64.1% (25 hatchlings) in 2019 (Table 5). Two-egg nests had higher hatching success (88.5%) than three-egg nests (69.4%). Fledglings totaled 43 individuals with a total fledging success of 89.6%, where 20 fledged in 2018 (fledging success = 87%) and 23 fledged in 2019 (fledging success = 92%). Nests with three eggs had a fledging success of 92%, higher than that in two-egg nests (87%). The overall reproductive success was 69.4% (87% in

2018 and 59% in 2019). Breeding success in two-egg nests (76.9%) was greater than that in three-egg nests (63.9%). In two-egg nests, reproductive success increased with the increase in the number of broods per year (72.2%, 83.3% and 100% for the first, second and third brood, respectively), but it decreased with the increase in the number of broods in three-egg nests (70.4%, 50.0% and 33.3% for the first, second and third brood, respectively).

Statistical analysis showed that the number of hatchlings varied significantly between the two breeding years (GLM: $\chi^2 = 5.61$, $P = 0.018$). The number of hatchlings either in earlier or late broods did not vary significantly ($P > 0.05$) with brood timing, number of broods or brood order. However, the number of hatchlings increased significantly (GLM: $\chi^2 = 4.21$, $P = 0.040$) with the increase in clutch size, but with a difference between years. Although hatchling success was deemed to increase significantly with the increase in clutch size ($\chi^2 = 8.42$, $P = 0.004$), no significant effects

Table 3. Nest building materials of the House bunting (*Emberiza sahari*) breeding in the Sahara Desert of Algeria.

Type of material	Family	Species	Weight (g)/nest (n = 10)	
			Mean ± SD	Range
Plant material	Punicaceae	*Punica granatum*	59.14 ± 14.25	30.80–78.61
	Rutaceae	*Citrus sinensis, Citrus limon*		
	Rosaceae	*Malus domestica*		
	Moraceae	*Ficus carica*		
	Vitaceae	*Vitis* spp.		
	Arecaceae	*Phoenix dactylifera*		
	Casuarinaceae	*Casuarina equisetifolia*		
	Cucurbitaceae	*Cucumis melo*		
	Fabaceae	*Arachis* spp., *Vicia faba*		
	Poaceae	*Bromus* spp., *Cynodon dactylon, Setaria viridis, Polypogon monspeliensis, Hordeum murinum, Triticum* spp., *Hordeum vulgare*		
	Liliaceae	*Allium sativum, Allium cepa*		
	Anacardiaceae	*Pistacia atlantica*		
Animal material	Feathers, sheep wool, goat hair, human hair		15.95 ± 3.82	11.24–21.30
Inert material	Stone, dry mud, small piece of construction wood, tissue paper, aluminum foil, plastic fibers, cloth, pieces of soap		6.93 ± 6.62	1.97–21.77
Overall (n = 10)			82.03 ± 20.77	46.24–108.5
One-way ANOVA		$F_{(2,27)}$ =	86.706	
		P-value =	<0.0001	

Figure 4. Photographs showing: (A) an overview of an active two-egg-nest of the House bunting *Emberiza sahari* built in an indoor stairwell of a house in Ghardaia region, Algeria. The nest is mainly built of plant materials, with the top of the nest lined with whitish-grey goat hair. Photographs of a (B) female and (C) male collecting nesting plant materials from the yard of a house in July 2018. The female is holding a dry branch of *Cynodon dactylon* in her bill, whereas the male is holding fresh uprooted twigs of *Cynodon dactylon*. (Photographs by Abdelwahab Chedad)

Table 4. Measurements of eggs and duration of breeding period in the House bunting (*Emberiza sahari*) nesting in the Sahara Desert of Algeria. Values are expressed as mean ± SD and range (min–max)

Variables	Mean ± SD	Range
Egg traits (n = 25)		
Weight [g]	1.97 ± 0.15	1.70–2.26
Length [cm]	1.87 ± 0.70	1.80–2.00
Breadth [cm]	1.39 ± 0.05	1.30–1.50
Volume [cm³]	1.84 ± 0.19	1.55–2.30
Shell index [g/mm]	0.14 ± 0.008	0.13–0.16
Shape index [%]	74.33 ± 2.72	69.23–77.78
Breeding parameters (n = 25)		
Brooding time [days]	31.61 ± 1.20	31–34
Incubation duration [days]	14.26 ± 0.45	14–15

Table 5. Breeding parameters of the House bunting breeding at urban environments of the region of Ghardaia in the Sahara Desert of Algeria. Data were grouped for each clutch size per two breeding seasons (2018 and 2019) and number of brood.

Breeding parameters	Breeding season and Number of broods	2	3	Overall
Number of nests	Year 2018	7	3	10
	Year 2019	6	9	15
	1st brood	9	9	18
	2nd brood	3	2	5
	3rd brood	1	1	2
	Overall	13	12	25
Sum of clutch sizes [eggs]	Year 2018	14	9	23
	Year 2019	12	27	39
	1st brood	18	27	45
	2nd brood	6	6	12
	3rd brood	2	3	5
	Overall	26	36	62
Number of hatchlings	Year 2018	14	9	23
	Year 2019	9	16	25
	1st brood	15	20	35
	2nd brood	6	4	10
	3rd brood	2	1	3
	Overall	23	25	48
Number of fledglings	Year 2018	11	9	20
	Year 2019	9	14	23
	1st brood	13	19	32
	2nd brood	5	3	8
	3rd brood	2	1	3
	Overall	20	23	43
Hatching success [%]	Year 2018	100	100	100
	Year 2019	75	59.3	64.1
	1st brood	83.3	74.1	77.8
	2nd brood	100	66.7	83.3
	3rd brood	100	33.3	60
	Overall	88.5	69.4	77.4

     10

Table 5. Continued...

Breeding parameters	Breeding season and Number of broods	Clutch size		
		2	3	Overall
Fledging success [%]	Year 2018	78.6	100	87.0
	Year 2019	100	87.5	92
	1st brood	86.7	95	91.4
	2nd brood	83.3	75	80
	3rd brood	100	100	100
	Overall	87.0	92	89.6
Breeding success [%]	Year 2018	78.6	100.0	87.0
	Year 2019	75.0	51.9	59.0
	1st brood	72.2	70.4	71.1
	2nd brood	83.3	50.0	66.7
	3rd brood	100.0	33.3	60.0
	Overall	76.9	63.9	69.4
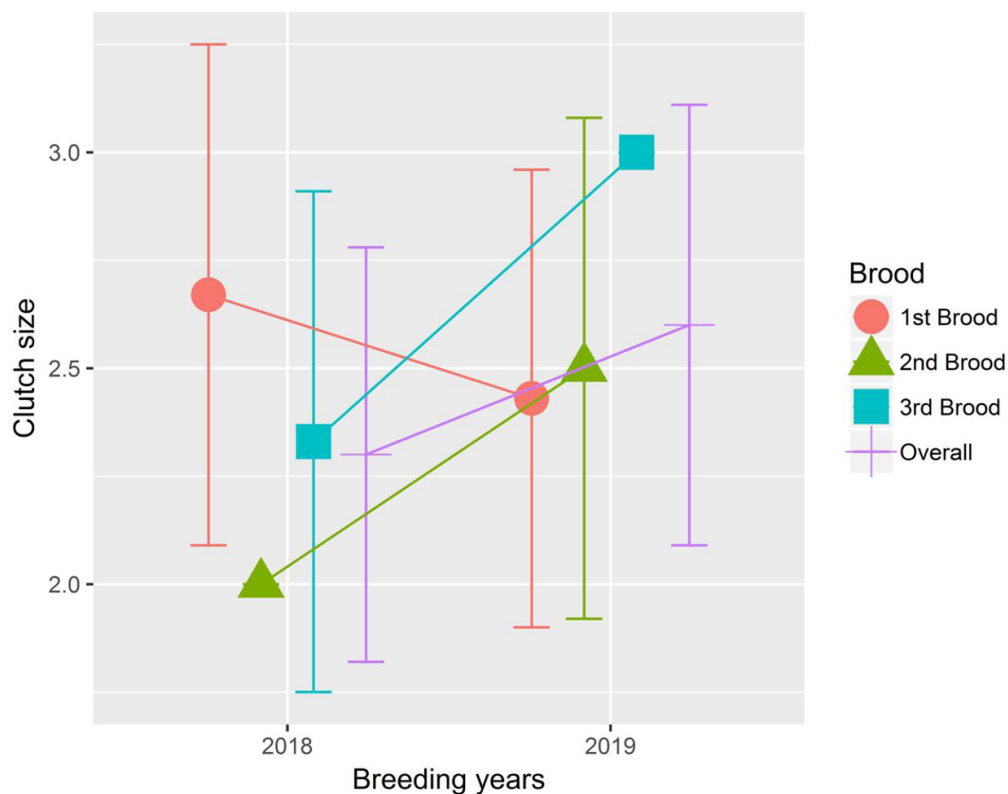
Figure 5. Plots of means displaying the distribution of clutch size for 1st (n = 18 nests), 2nd (n = 5 nests) and 3rd (n = 2 nests) broods of House buntings (*Emberiza sahari*) nesting in the region of Ghardaia (Sahara Desert of Algeria) during the breeding years 2018 (n = 10 nests) and 2019 (n = 15 nests). Shape and color of points (means) are set to the number of the brood. Vertical bars are ± standard deviations.

were observed for the number of eggs laid in terms of the number of hatchlings when combined with different brood timings (χ^2<0.01, P = 0.976), number of broods (χ^2 = 2.79, P = 0.248) and their interaction 'clutch size × brood timing × number of broods' (χ^2 = 3.26, P = 0.196) (Table 6). The relationship of 'clutch size—number of hatchlings' was positive for the first brood. However, it was not significant for the second and third broods regardless of brood timing (Fig. 6). The third GLM (Table 6) demonstrated that the number of hatchlings (χ^2 = 54.87, P <0.001), but not clutch size (χ^2 = 2.82, P = 0.093), influenced significantly the variation of chicks fledged per nest. Additionally, the number of fledglings varied significantly (χ^2 = 11.99, P = 0.002)

Table 6. Generalized linear models analyzing the effects of breeding attributes (i.e. breeding year, brood timing, and number of broods) on the variation of clutch sizes (GLM #1), breeding attributes and clutch size on the variation of number of hatchlings (GLM #2), and breeding attributes, clutch size and number of hatchlings on the variation of the number of fledglings (GLM #3) of House buntings (*Emberiza sahari*) nesting in the region of Ghardaia (Sahara Desert of Algeria). Selection of model with best fit (lowest AIC score) was carried using the 'backward/forward' stepwise procedure. Sample size = 25 nests, 62 eggs, 48 hatchlings, and 43 fledglings.

Variables	χ^2	*P*-value	Sig.
GLM #1: Clutch size (AIC = 43.292, ΔAIC = 5.306)			
Breed timing	2.71	0.100	NS
Number of broods	3.36	0.186	NS
Year	7.35	0.007	**
Brood timing × Number of broods	4.63	0.099	NS
GLM #2: Number of hatchlings (AIC = 41.657, ΔAIC = 0)			
Clutch size	8.42	0.004	**
Brood timing	0.06	0.807	NS
Number of broods	4.63	0.099	NS
Year	5.61	0.018	*
Clutch size × Brood timing	0.00	0.976	NS
Clutch size × Number of broods	2.79	0.248	NS
Brood timing × Number of broods	1.05	0.593	NS
Clutch size × Year	4.21	0.040	*
Clutch size × Brood timing × Number of broods	3.26	0.196	NS
GLM #3: Number of fledglings (AIC = 15.856, ΔAIC = 72.643)			
Hatchlings	54.87	<0.001	***
Brood timing	1.65	0.199	NS
Clutch size	2.82	0.093	NS
Number of broods	11.99	0.002	**
Year	1.10	0.294	NS
Hatchlings × Brood timing	0.05	0.830	NS
Hatchlings × Number of broods	4.72	0.095	NS

(χ^2: Chi-square value of the likelihood ratio test, AIC = Akaike information criterion of the current selected GLM, ΔAIC = AIC difference between the initial GLM and the simplified one with the lowest AIC, Sig.: probability significance codes, ***: *P*<0.001, **: *P*<0.01, *: *P*≤0.05, NS: *P*>0.05)

between broods of the same breeding year. Although the number of fledglings was associated positively with the number of hatchlings, the effects of the number of hatchlings was the same when interrelated with brood timing, i.e. early/late brood (*P* = 0.830), or with number of broods (*P* = 0.095), which displayed the same variation patterns (Fig. 6). In addition, the GLM showed that the number of fledglings had no significant variation between years (*P* = 0.294) or brood timings (*P* = 0.199) (Table 6).

Diet composition

Using the visual method, it was possible to determine the diet of House buntings, which consisted mainly of annual weed seeds belonging to 13 species and 5 families. The Poaceae family was best represented with eight species, including *Cynodon dactylon*, *Polypogon monspeliensis* and *Phalaris paradoxa*. The House bunting also fed on food remains of plant origin, especially breadcrumbs, and sometimes on

insects, including *Sarcophaga carnaria*, *Cadra* spp. and *Messor* spp. (Table 7).

Discussion

Species distribution and population size estimates

The presence of the House bunting was confirmed in the majority of the areas already mentioned in the literature (Heim de Balsac and Mayaud 1962, Ledant et al. 1981, Isenmann and Moali 2000), including El Kantra, Biskra, Bousâada, Beni Ounif, Ghardaia, M'Zab, Taghit, Tassili, Ghoufi, and Laghouat. We have reported the presence of the species in new sites such as El Abiodh Sidi Cheikh and Ain Larak (El Bayadh), Aflou, El Hadjeb and Sidi Makhlouf (Laghouat), M'doukal, T'kout, Ghassira and Arris (Batna), Touggourt and Megarine (Ouargla), Djelfa city and Tissemsilt. In the present work, the expansion of House bunting distribution was observed more towards the North of Algeria. In

2017, the species was already observed in northern Algeria, at the capital city Algiers, Tissemsilt and Bordj Bou-Arreridj (Moulaï 2019). In Morocco, the same expansion trend in species range was reported northward, but also southward (Amezian et al. 2006, Azaouaghe et al. 2020).

Since the 1960s, *Emberiza sahari*, which was mainly observed in the south of the country at that time (Heim de Balsac and Mayaud 1962), has spread progressively to the north. We consider it likely that the species will continue to increase its range in the north of Algeria, first in the Northwest of the country and then in the highlands of both the East and West regions that are characterized by arid and semi-arid climates (Fatmi et al. 2020). The range of the House bunting in Ghardaia includes mainly the northern regions where the species occupies urban habitats and the surrounding areas, in particular the regions
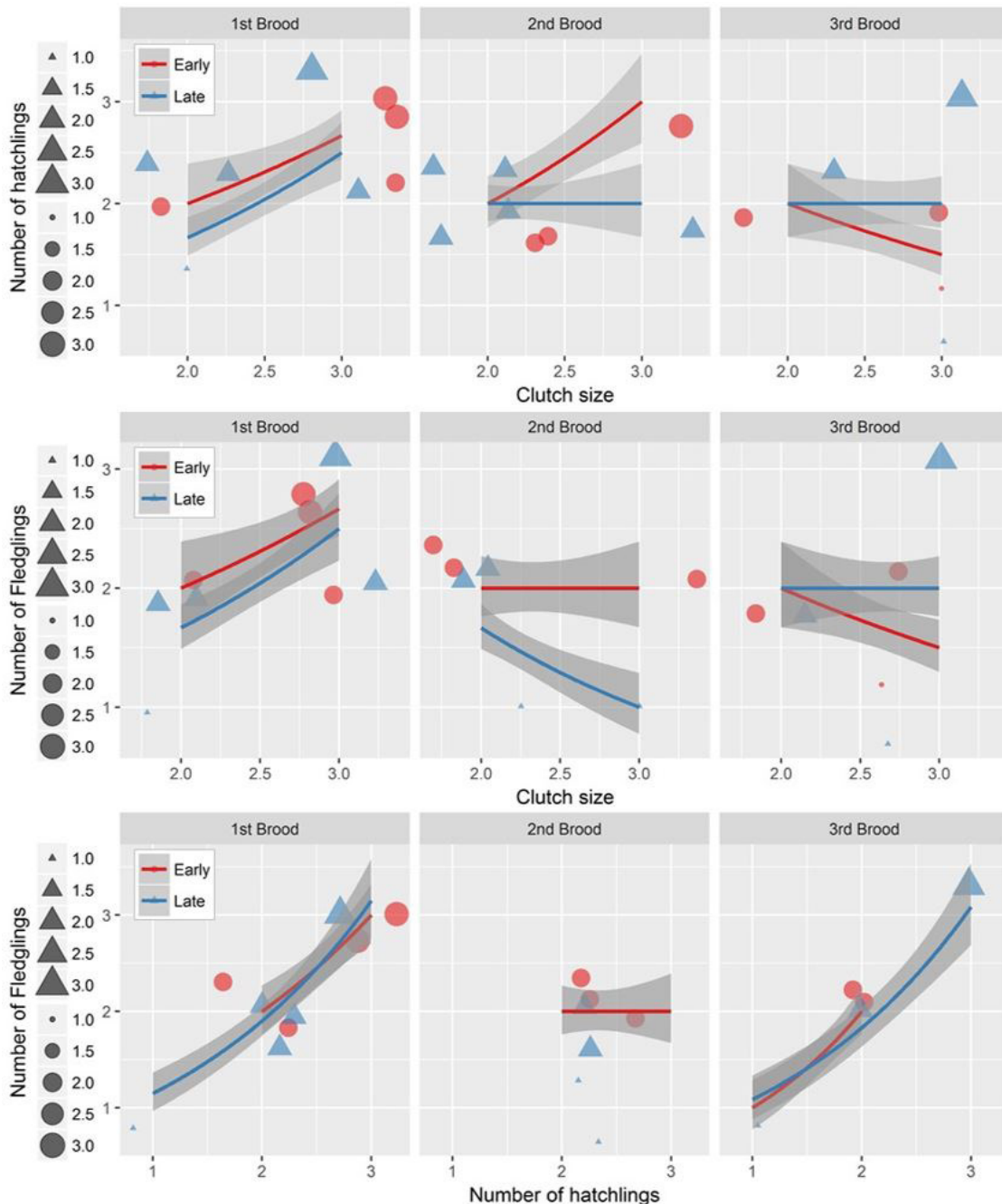

Figure 6. Scatterplots showing relationships between clutch size—number of hatchlings (top plots), clutch size—number of fledglings (middle plots) and number of hatchlings—number of fledglings (bottom plots) during early (symbol: red circles) and late (symbol: blue triangles) brooding timing for the 1st, 2nd and 3rd broods of House buntings (*Emberiza sahari*) nesting in the region of Ghardaia (Sahara Desert of Algeria). The solid lines represent linear regressions obtained by Poisson GLM fit with confidence intervals in dark grey.

Table 7. Diet composition of the House bunting (*Emberiza sahari*) in the region of Ghardaia (Sahara Desert of Algeria). Total number of foraging activities = 323 observations based on which plant and/or animal species consumed were determined.

Type	Family	Species
Vegetal	Asteraceae	*Aster squamatus*
	Poaceae	*Schismus barbatus*, *Cynodon dactylon*, *Setaria viridis*, *Polypogon monspeliensis*, *Phalaris paradoxa*, *Stipa* spp., *Hordeum* spp., *Lolium* spp.
	Amaranthaceae	*Bassia muricata*, *Chenopodiatrum murale*
	Geraniaceae	*Monsonia nivea*
	Brassicaceae	*Sisymbrium* spp.
Animal (Insects)	Sarcophagidae	*Sarcophaga carnaria*
	Crambidae	*Cadra* spp.
	Formicidae	*Messor* spp.
Other	Food remains of plant origin, fine gravels	

of the M'Zab Valley, Zelfana, Berriane, Metlili, Sebseb and Mansoura. The species was absent in the rest of the region of Ghardaia, such as in Guerrara, Hassi El F'Hel, Hassi El Gara and El Menea.

The change in building practices combined with the expansion of modern urban environments in hot drylands have a negative influence on species distribution and populations dynamics of the House bunting. For this synanthropic species, traditional dwellings offer more favorable conditions, such as roosting and nesting sites, as this type of urban habitat is characterized by arcades, small windows, ventilation and lighting holes within walls that facilitate entry and exit. In addition, traditional dwellings are distinguished by the abundance of food resources (weeds) around orchards and palm groves and characterized by less disturbance to their behavior (low human density and less light, sound and soil pollution). This is supported by several studies that investigated the harmful impact of urbanization on biodiversity, demography and stress physiology of passerines and other bird species (Bonier 2012, Meillère 2015, Ferland 2015, Chenchouni 2017a, Marzluff 2017). Yet, urban habitats present some advantages to birds, including more food resources, good nesting sites, and stable and high-quality foraging habitats. Thus, they allow species to settle in areas close to favorable foraging and breeding habitats, and sometimes offer secure nests against natural predators (Møller 2010, Seress and Liker 2015, Marzluff 2017).

During the non-breeding season, the number of pairs recorded in traditional urban habitats of Ghardaia was 4.5 pairs/ha, whereas it was 3 pairs/ha in semi-modern urban environments and 1.5–2 pairs/ha in modern urban environments. During the breeding season, the density of breeding pairs varied between 1 and 2 pairs/ha in the three urban habitats. Abundance of the House bunting varied from one region to another and from one period to another. House bunting density was higher in traditional urban habitats and during the non-breeding period compared to modern urban environments and during the breeding season. This decrease during the breeding season was due to the territoriality of this species, which is reflected by its

conspecific antagonism and intra-specific competition between pairs (Roux et al. 1990). Guezoul et al. (2013) reported 0.75 pairs/ha in Biskra oasis and 0.25 pairs/ha in Ghardaia oasis during the breeding season, whereas the density of breeding pairs in Marrakech (Morocco) was 2 pairs/ha (Roux et al. 1990).

Morphological sexual dimorphism

According to Kirwan and Shirihai (2007), *Emberiza sahari* and *E. striolata* are similar to each other in terms of plumage patterns, the structure of the bird's silhouette and behaviors (foraging, flying, etc.). We found that adult males of *E. sahari* differed partially from adult females in the plumage pattern and coloring of their eyebrows. Although only body mass and stretched wing were significantly different, females were slightly larger than males, based on body mass, tarsometatarsus length, total length, stretched wing and wingspan. In *E. striolata*, Ali and Ripley (1974) reported that males were larger than females. When comparing the biometric measurements of *E. sahari* obtained in the current study with those of Ali and Ripley (1974), the House bunting's biometrics were larger than those of the Striolated bunting, especially the total length and length of the tarsometatarsus. These findings agree with the data obtained by Kirwan and Shirihai (2007).

Nests and nesting characteristics

The nest of the House bunting was built mainly from dry plant material such as twigs, barks, fibers and roots, which are collected around the nesting site. The top layer of the nest was covered with animal materials, especially goat hair and sheep wool. Pande et al. (2006) indicated that sometimes nests are lined with inflorescences of soft herbs and one or two feathers. We observed the presence of small stone, dry mud blocks, tissue paper, aluminum foil, plastic fibers, and cloth tissues. In some nests, we found insects such as *Larinioides* spp. (Araneae), *Lepisma* spp. (Zygentoma), Myrmeleontidae spp. (Neuroptera) and larvae of Dermestidae (Coleoptera). These inquilinic

species likely use *E. sahari* nests either to feed on plant building materials and/or nestling food scraps, or to lay their eggs.

According to Joshi and Bhatnagar (2016), *E. striolata* nests in southern Rajasthan are placed at 120 cm height, facing north where direct sunlight never reaches. The same observation was made in Ghardaia in the present study concerning the installation of House bunting nests, but with the nest cup oriented toward the East (sometimes Northeast or Southeast) and nesting height on average 214 cm above the ground. Pande et al. (2006) indicated that Striolated bunting nests measured 12 cm × 9 cm (outer diameter × inner diameter) in Maharashtra, India, and were 2.3 cm deep. However, in this study, we found larger nest sizes, where outer diameter of the nest averaged 34.77 cm, inner diameter was 5.8 cm, and the cup depth was 5.71 cm. These dimensions varied depending on the nest location where they were installed. During nest construction, we observed that both partners participated in collecting nesting materials (Fig. 4B–4C) and the construction of the nest, similar to observations of Pande et al. (2006), but different from Roux et al. (1990) who stated that only the female was responsible for building the nest.

Breeding biology

Our findings indicated that the courtship and pair bond formation in the House bunting begins in mid-February. According to Chakir (1986), copulation behavior is often associated with antagonistic contacts between parents, while during mating, parents rapidly vibrate their half-stretched wings with the female beneath the male. This is a common courtship behavior in many sparrow species (Guezoul et al. 2011). Roux et al. (1990) noted that the courtship period lasts approximately 5–10 days prior to nest construction. In addition, we demonstrated in the present study that the female House bunting can produce up to three broods between March and September, with an incubation of 14–15 days/brood, which is consistent with incubation periods documented in previous studies, i.e. 14–16 days in Morocco (Roux et al. 1990) and 14 days in Maharashtra, India (Pande et al. 2006). The brooding time (from first egg laid to chick fledging) of the house bunting in Ghardaia lasts 31–34 days, including 14–15 days of egg incubation and 17–19 days of chick rearing. Roux et al. (1990) reported observing parents feeding their fledglings for an additional week outside the nest after rearing them for 17–18 days.

According to Heim de Balsac and Mayaud (1962), two successful broods per reproduction season are common in *E. sahari* in the Tassili n'Ajjer (Sahara Desert of Algeria). Exceptionally, some pairs can rear four broods during the same season (Robin 1971). The number of broods per year is species-specific and depends on (i) extrinsic factors: ecological conditions of the region and the quality of climatic conditions during the breeding season (especially precipitation which influences food resources), quality of the nesting site, etc., and (ii) intrinsic factors: age and breeding experience of parents, fertility of the female, etc. (Reynolds et al. 2019, Metallaoui et al. 2020).

According to Behidj-Benyounes et al. (2013), the synchronization of reproduction depends on climatic conditions, which influence the abundance, quality and availability of food and thus affect breeding success and population demographics (Bendjoudi et al. 2015, Chenchouni et al. 2015). Subsequently, Bradai et al. (2015) indicated that both the amount of rainfall and its temporal distribution have an important influence on habitat productivity. Precipitation exerts many effects at different levels of the biology of animal species, influencing fertility, longevity and thus population dynamics (Idder-Ighili et al. 2015, Bezzalla et al. 2019).

Slight differences exist between the different egg measurements of the House bunting and the Striolated bunting. In Ghardaia, House bunting eggs weighed on average 1.97 g and were 1.87 cm in length and 1.39 cm in width. These egg measurements are similar to those reported in Ali and Ripley (1974) (length = 2 cm, width = 1.5 cm), Pande et al. (2006) (weight = 2 g, length = 1.8 cm, width = 1.35 cm), and Roux et al. (1990) (length = 1.985 cm, width = 1.41 cm).

According to Pande et al. (2006), only the female Striolated bunting incubated eggs. This is also what we observed with female House buntings in Ghardaia. The male was often observed standing next to the nest while the female incubated the eggs, but when she was absent for short feeding periods, the male turned the eggs. In general, hatching of eggs in the same nest was relatively synchronized, with just a few hours between the first and the last hatchling of the House bunting (Roux et al. 1990). In the present study, 2-day–old chicks weighed on average 2.52 g, they increased 2-fold on the fifth day, 4-fold on the seventh day, 5-fold on the tenth day and then 6-fold on the fifteenth day, which denotes a weight gain of about 0.996 g/day during the first 15 days. Pande et al. (2006) stated that 4-day-old chicks of the Striolated bunting weighed 2.5 g, reached only 4 g at the eighth day, 11.83 g on the twelfth day and 12.5 g on the fourteenth day. Growth curves in bird chicks indicate a rapid increase at an early age, then a plateau at the premature stage or fledging. This trend of body growth, in both length and body mass of offspring of most vertebrate species, follows a non-linear regression most often fitted to a three- or four-parameter logistic function, such as Richards, Gompertz, Von Bertalanffy, Weibull and Baranyi models (Chenchouni 2017b).

Feeding ecology

The method of direct visual observation used to study the trophic behavior of birds is a very flexible and efficient practice that provides a rapid qualitative assessment of the diet of the observed species (Blagosklonov 1987). This technique facilitates the identification of consumed species/matter/items when studying diet composition compared to other diet analysis methods, such as the analysis of fecal sacs, droppings and/or regurgitate pellets. The House bunting usually competes for food with other grain-eating species such as House Sparrows (*Passer domesticus* Linnaeus, 1758), Spanish sparrows (*Passer hispaniolensis* (Temminck, 1820)) and their hybrids (*Passer domesticus* × *P. hispaniolensis*), Rock Doves

(*Columba livia* Gmelin, 1789) and Trumpeter Finches (*Bucanetes githagineus* (Lichtenstein, 1823)) (Chedad, pers. obs.). The House bunting is a granivorous species, feeding mainly on seeds of annual weeds found near its roosting or nesting site (Pasteur 1956, Pande et al. 2006). According to Grzegorz and Czarnecka (2007), the diet of the House bunting resembles that of the Common Reed bunting (*Emberiza schoeniclus*). Our study indicated that the House bunting preferred feeding on certain plant species such as *Chenopodium murale*, *Cynodon dactylon* and *Schismus barbatus*. The species often picks up the remains of food of plant origin (crumbs of dried bread, seeds) inside houses (Pasteur 1956). Sometimes it feeds on insects (*Sarcophaga carnaria*, *Cadra* spp., *Messor* spp.), especially when rearing and feeding chicks. In Ghardaia, we observed that it ingests fine stones and grains of sand, probably to facilitate food processing, especially in chicks.

Conclusion

The House bunting is a human commensal bird that characterizes the desertic regions of Algeria where it frequents, breeds and forages in urban and anthropogenic environments. It cohabits with humans and has lived alongside them for a long time. The House bunting range in Algeria is larger than described in previous works. Locally, it is distributed mainly in northern Ghardaia. This study showed that the species range has extended towards the north of Algeria through the semi-arid steppe rangelands of the Hauts-Plateaux region. The present study provides a baseline for future comparisons, as climate and building practices continue to change across the Saharan landscape. The individuals examined showed a slight morphological difference between the two sexes. The species prefers nesting indoors in traditional urban habitats, at an average height of 2.14 m, on different structures, which influences nest dimensions and construction materials used. Accordingly, the duration of nest building, involving both parents, varies from 5 to 22 days. In Ghardaia, courtship and pair-formation displays begin in mid-February. Females can raise up to three successive broods of 2–3 eggs/clutch (31–34 days from egg-laying to chicks fledging) over seven months (March-September), with 14–15 days for egg incubation. Being a granivore, the species feeds on annual weeds, mainly Poaceae, exploits other resources in human buildings such as leftover food and sometimes eats insects. Due to the widespread range of *Emberiza sahari* in Algeria, which is distinct from the range of *Emberiza striolata*, it is recommended to investigate the spatial genetic variability of both species through phylogenetic analysis based on 16S rRNA mitochondrial DNA sequences involving populations from northern regions of the Maghreb countries (including Algeria) and from the Sahara.

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Author Contributions

OG and AC conceived the study. AC and BB conducted fieldwork and collected data. AC and OG carried out laboratory work and compiled data. AC, DB, and HC analyzed data. AC, DB, OG and HC wrote the original manuscript. AC, DB, OG and HC revised the final article. All authors read and approved the final paper.

Data Accessibility

The datasets used and/or analyzed during the study are available from the first author on reasonable request.

Supplementary Materials

The following materials are available as part of the online article from https://escholarship.org/uc/fb
Figure S1. Correlations between morphometric variables measured on House bunting (Emberiza sahari) adults from the region of Ghardaia in the Sahara Desert of Algeria.
Figure S2. Correlations between egg characteristics of House buntings (Emberiza sahari) breeding in the region of Ghardaia (Sahara Desert of Algeria).

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