NEW DATA ON BREEDING BIO-ECOLOGY OF THE RED-KNOBBED COOT (*FULICA CRISTATA* GMELIN) IN NORTH AFRICA

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Abstract. This study attempts to document the breeding bio-ecology of the Red-knobbed Coot (*Fulica cristata*) in two North-African mountainous wetlands. Data were collected weekly in the Zerrouka and Hachlaf lakes in Morocco during the breading seasons of 2018 and 2019. Field visits were carried out between February and August. The obtained results showed that important breeding populations colonized the two sites. Nesting sites were selected on the emerging vegetation at the Zerrouka site, while at Lake Hachlaf nests were located in open waters. During the two years, the breeding season was different in the two sites and from year to year: in 2018, it was from mid-March to the end of July in Zerrouka and between April and mid-August in Hachlaf. In 2019, the breeding activity took place between January and mid-July in Zerrouka and between the end of February and the end of August at Hachlaf. Nests and eggs were relatively larger in Zerrouka than in Hachlaf, while the breeding success was much lower in Zerrouka (around 33.3% in 2018 and 39.8% in 2019) than in Hachlaf (56.1% in 2018 and 54.7% in 2019). In summary, this study provides the first significant results on the breeding bio-ecology of the vulnerable North African populations of the Red-knobbed Coot and allows formulating some measures for its conservation. Furthermore, the obtained results will allow future comparative studies in the Western Mediterranean basin.

INTRODUCTION

Investigating breeding bio-ecology patterns of birds is essential for understanding their biology, ecology, and evolution, as well as for their conservation. In Northwest Africa including Morocco and Algeria, many or most of these patterns remain insufficiently investigated in terms of species and geographical distribution. Patterns of breeding bio-ecology were studied within a few species, mostly in farmlands, such as the globally threatened Turtle Dove (*Streptopelia turtur*) (Mansouri et al. 2020, 2021, 2022), while within most species, mainly water birds, data are limited to simple descriptions of nests and eggs (Hanane 2010; Hanane et al. 2011; Es Salai et al. 2021; Squalli et al. 2021). However, changes in population sizes (Kamp et al. 2021), the decline of many species due to increased human impacts, and natural factors (Bernat-Ponce et al. 2020; Traba and Morales 2019) need more attention, at least for the threatened species.

The Red-knobbed Coot (*Fulica cristata*) is one of the less investigated species in North Africa (Es Salai et al. 2021). The population of this Rallidae is limited to two regions; Southern and Eastern Africa, mainly Madagascar (Del Hoyo et al. 1996; Taylor and Van Perlo 1998) and the west of the Mediterranean basin (Varo 2008). The species is mainly observed in natural and artificial wetlands where it finds the required food and breeding resources. The estimated global population of *Fulica cristata* varies between 107,000 and 1,011,000 individuals and is classified as Least Concern on the World Red List of Threatened Species (IUCN 2017). The Morocco-Spanish population is estimated to consist of only 2,500–5,000 individuals (Dakki et al. 1989; El Agbani and Dakki 1992; Dodman 2014.). Consequently, the European population was considered to be in danger of extinction (Tucker and Heath 1994), particularly on the Spain Red List (Madrono et al. 2004). It is also listed in the Annex I of the EU ‘Wild Birds’ Directive and Annex II of the Bern Convention. In parallel, in

Morocco, awaiting the publication of the national red list, the Red-knobbed Coot is considered vulnerable (El Agbani et al. 2011).

The breeding bio-ecology of *Fulica cristata* is widely studied on the European side, counting breeding habitats, phenology, and reproductive success (Amat and Raya 2004; Rebassa 2005; Varo 2008). Equally, the impact of human activities and biotic factors including parasites and competitors are studied (Amat and Green 2010; Rubio et al. 2014). On the contrary, Northwest African populations were only mentioned and estimated in natural and artificial wetlands (Amat and Green 2010; Green et al. 2002; Martínez-Abraín et al. 2016). In Morocco, the species is classified as a sedentary breeding bird with 600 to 1000 pairs overall (El Agbani et al. 2011; El Hamoumi et al. 2014) and it is widely documented in different habitats from coastal (Amezian et al. 2007; El Hamoumi et al. 2000; El Agbani et al. 2009; Thevenot et al. 2003) to mountainous wetlands (Chillasse 2004). The breeding bio-ecology is limited to the breeding chronology (Salai et al. 2021) and the approximation of breeding pairs (El Agbani et al. 2011; El Hamoumi et al. 2014).

In this study, to help fill this data gap, we described several aspects of the breeding bio-ecology of the *Fulica cristata* from the Middle Atlas region, including the estimation of the breeding population, the mapping of nesting sites, the description of the breeding chronology, clutch size, and reproductive success. By putting this threatened bird in the context of the life history theory and knowledge about its breeding bio-ecology, we hope to pay more attention to the studied population and the monitored areas since they offer breeding and foraging resources. Equally, this study is suggested to help in understanding the breeding performances of this species which is of great interest in the assessment of its population regeneration in Morocco and entire Northwest Africa.

MATERIALS AND METHODS

Study area

Based on the water bird census conducted in Morocco since 1983 (Dakki et al. 2003; Ouassou et al. 2018, 2021), we carried out this study in Ramsar wetlands located in the Middle Atlas Mountains (Figure 1). This area is located at an altitude ranging from 1400 m to 2000 m above sea level and dominated by woodlands of Holm Oak (*Quercus ilex*), Atlas cedar (*Cedrus atlantica*), and Aleppo pine (*Pinus halepensis*), farmlands of apple orchards, plum trees, and cereals, and natural wetlands (rivers and lakes) (Ouassou et al. 2021), which are suggested to offer breeding resources (nesting supports and materials) and foraging resources (seeds, leaves, insects, and small aquatic invertebrates). Moreover, the area is dominated by a humid climate, with annual precipitation of 843 mm and an average temperature of 11.3 °C.

Two wetlands were selected and monitored in the Middle Atlas Mountains (Figure 1). The Zerrouka reservoir is a small artificial reservoir located at the north-east exit of Ifrane city towards Imouzzar-Kandar. It is permanently fed by the spring of Zerrouka wadi, a small tributary of the Tizguite stream (Figure 1). It is a sport fishing lake of 3.5 hectares and a maximum 3 m depth located between 1400 m and 1600 m altitude above sea level. This lake is bounded by an artificial wall and is often invaded by submerging and emergent plants that are used by the Red-knobbed Coot during the nesting season (Salai et al. 2021). The Hachlaf artificial reservoir is located at 1660 m altitude at about 10 km from the northeast of Ifrane city. It is installed downstream of the spillway of a large shallow marshland of Hachlaf (14 ha, with a maximum depth of 1–4 m), which occupies a large flat-bottomed karst depression (Figure 1). This marshland, fed by small springs, dries out during the summer period, giving rise to a large meadow densely occupied by sheep and cattle. Following heavy snowfall, the excess water of the marshland flows into a small stream, on which a small dam was installed much further downstream from the marshland, creating an elongated shallow reservoir that offers an alternative environment to water birds when the marshland dries up.

Description and mapping of the breeding sites

In this study, we identified vegetation cover around and inside the reservoirs. The vegetation was collected and identified in the laboratory using the following identification guides (Benabid 1982; Benabid and Fennane 1994; Valdés 2002). We delimited the water bodies and vegetation cover around the study reservoirs using field visits and Geotracker software (a mobile software with which we recorded the limits of reservoirs during field visits). First, the study reservoir maps and dominant habitats (based on dominant vegetation) were generated with QGIS (https://www.qgis.org/fr/site/forusers/download.html). Second, the maps were generated according to data from the last five years (2015–2022) in order to present precisely the real picture of land occupation in the studied sites. The spectral data sources of the Landsat Enhanced Thematic Mapper Plus (ETM1) images from January 2015 to December 2021 were used in the classification procedure (delineation of habitats' boundaries). The Landsat (ETM1) and MNT of Esir (Copyright: c. 2014) with 30 m resolution beam records and distinct groups of spectral data in the infrared and visible ranges of the electromagnetic spectrum. Multi-date images

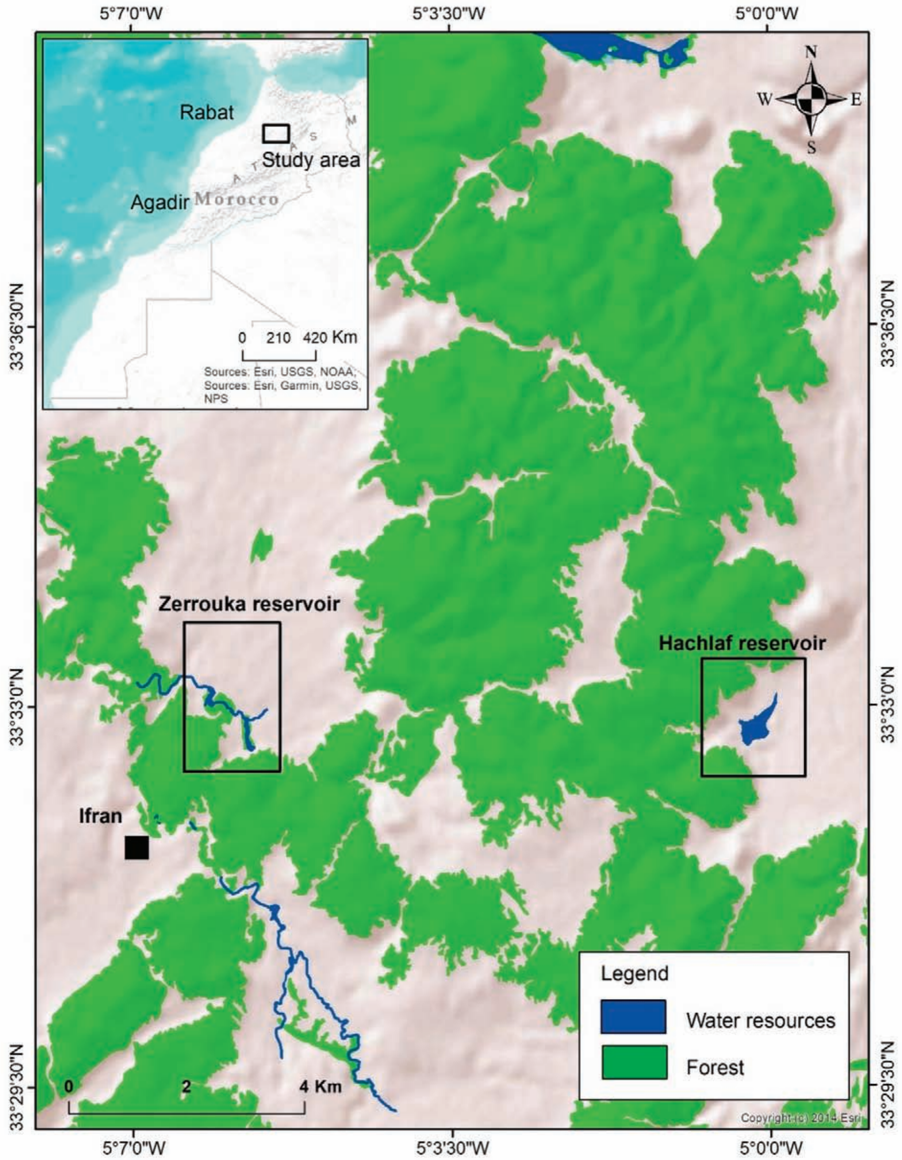

Figure 1. Location of reservoir study areas in the Middle Atlas Mountains (Morocco).

were applied to delineate the water bodies and surrounding vegetation for each reservoir. Nests recorded with GPS were plotted on the map to show the nesting sites in both open waters and emerged vegetation.

Breeding parameters

During 2018 and 2019, we carried out a total of 65 visits to both reservoirs between January and August, with an almost weekly frequency. During each field visit, we counted adults and chicks, using binoculars (10 × 50 mm) and a telescope (20–40 × 60 mm) when needed.

To tackle the chick growth, we distinguished three size (age) classes that can be estimated without catching birds: (i) *small-size chicks*, indicating chicks younger than 6 days (Cordonnier 1984), distinguished by a coloured feathering (black duvet and orange redhead); (ii) *medium-size chicks*, assigned to individuals that have lost their nestling plumage but whose size is much smaller than that of adults; and (iii) *large-size chicks*, assigned to individuals whose plumage has not yet turned black but the size of which is quite similar to that of adults.

Breeding phenology (from the first nest to the last one, from the first egg to the last one, and from the first chicks to the last ones) and clutch size were detailed only in Zerrouka, where nests were relatively close to the reservoir borders. We also estimated hatching rates (hatched eggs/total laid eggs) and fledging success (adult chicks/total hatched chicks). In parallel, for all nests we took several measurements such as height above the water level, inner (small axis) and outer diameters (large axis), as well as egg dimensions by counting their polar (L) and equatorial (B) diameters using a calliper with 0.1 mm precision. To estimate the volume of the eggs

(V), we used the formula V = Kv × LB², recommended by Hoyt (1979). Eggs were weighed using a portable electronic scale with a precision of 0.1 g. In the absence of a Kv value (volume coefficient) specific to *F. cristata*, we used the one estimated for *F. americana* (0.499) by Governali et al. (2012).

In the Hachlaf site, it was neither possible to ensure daily monitoring nor to manipulate nests or eggs. Indeed, all the nests were on open water (as the emergent vegetation was not dense enough and was even close to the banks). To avoid disturbing the breeding birds, they were observed weekly from the reservoir bank. This rhythm allowed determining the first egg-laying date in each nest only by extrapolation, using the hatching date and assuming that the incubation period lasts 22 days (due to the estimated average of the studied sample at the Zerrouka site). The presence of chicks in or near the nest indicates that the egg-hatching was successful, while it is considered unsuccessful when eggs are abandoned in the nest or crushed (often a sign of predation). Finally, when a nest showed no sign of occupancy during a given visit, we supposed that it had undergone predation or egg harvesting (i.e. by the local population).

In both sites, the breeding success, limited to the fledging success (emancipated chicks), was estimated by the proportion of the total number of fledged chicks out of the total number of hatched chicks. To calculate this success, nests were monitored from laying to emancipation phase (or to the loss of the nest).

Statistical analysis

Results were presented as a sample size and mean ± SD. Before executing statistical analyses, we checked for normality and variance homogeneity for all the variables.

We calculated the nests breeding success rates (occupied nests/built nests) and fledging (survived chicks/hatched eggs) during two seasons. Breeding dates counting nest construction (first nest per season), laying (first eggs per season), and hatching (date of the first chick per season) were compared between both sites using the simple t-test, considering two breeding seasons. We analysed the correlation between nest (n = 18) and egg (n = 42) dimensions separately via Pearson correlation. A generalized linear model (GLM) was used to test the relationship between hatching rates (dependent variable), incubation period, and clutch size (fixed factors), as well as between the incubation period (dependent variable) and clutch size (independent variable). Statistical analyses were completed in Statgraphics Centurion software, version XVI.I.

RESULTS

Characterization of breeding habitats and nesting sites

The vegetation cover of the studied sites is summarized in Table 1. In the Zerrouka reservoir, 11 species of emergent and shore plants were identified; the most abundant ones were *Potamogeton pectinatus* and *Ranunculus aquatilis*, while the lake was surrounded by *Populus alba*. On the contrary, only five plant species were identified in the Hachlaf reservoir.

In total, 200 pairs and 81 nests were documented in the study area between 2018 and 2019. In Zerrouka, 100 breeding pairs and 31 nests were recorded. This population selected nesting sites in islets of emergent vegetation. In bulrush islets, nests were made with *Typha* leaves and bulrush stems, while in the *Typha* islets, the breeding birds used mainly *Typha* stems, leaves, and milfoil fragments (Figure 2). In Hachlaf, 60 breeding pairs and 50 nests were recorded. Nests were built in open waters far from reservoir borders. Nests were made with poplar twigs and leaves and other *Polygonum*, *Ceratophylls*, *Milfoils,* and *Ranunculus* fragments.

Nesting dates

The chronology of nest construction was significantly variable between the two sites (n = 4 (two years and two

Table 1. Plants species recorded in both studied reservoirs between 2018 and 2019.

	Hachlaf	Zerrouka
Aquatic vegetation	*Potamogeton pectinatus*	*Potamogeton pectinatus*
	Ranunculus aquatilis	*Ranunculus aquatilis*
	Myriophyllum spicatum	*Myriophyllum spicatum*
	Ceratophyllum spp.	*Polygonum amphibium*
	Polygonum amphibium	*Elodea* spp.
		Ceratophyllum spp.
Emergent vegetation		*Typha latifolia*
		Scirpus lacustris
		Juncus bufonius
		Carex spp.
Vegetation surrounding the lake	*Populus alba*	*Populus alba*

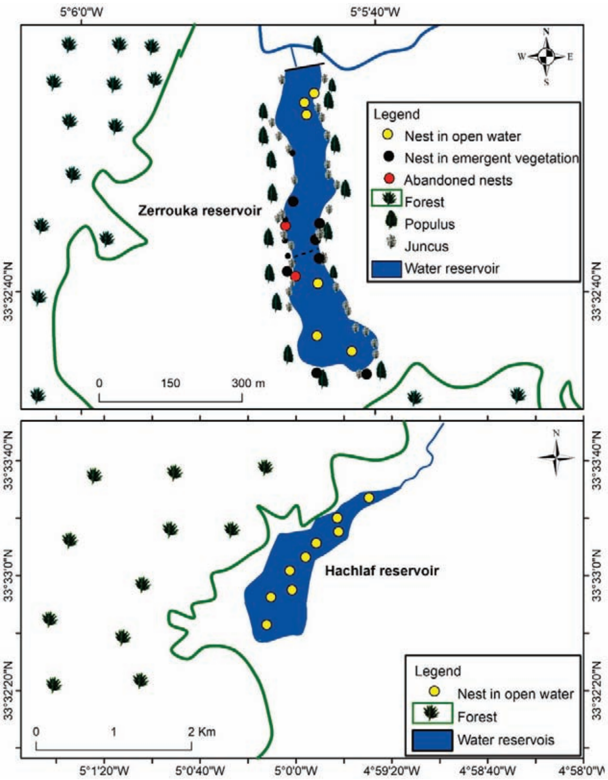

Figure 2. Nesting sites selected by the Red-knobbed Coot in Zerrouka and Hachlaf reservoirs.

sites), t = 1.021, $p < 0.001$). At the Zerrouka reservoir, the first nests' construction started during the fourth week of March in 2018, while in 2019 it started during the last week of January (Figure 3). The last nest was constructed during the fourth week of May in 2018 and in mid-May in 2019. At the Hachlaf reservoir, in 2018, we observed the construction activity between the third week of April and the second week of June. In 2019, the nest building started earlier than in the Zerrouka site, precisely in the fourth week of February, and the last ones were built during the fourth week of June.

Laying and hatching dates

The chronology of laying and hatching activities is summarized in Figure 4. At Zerrouka, egg-laying activity occurred for two months in 2018 beginning from the third week of March until the end of May, while hatching activity was observed between the third week of April and the second week of June, with maximum intensity in the fourth week of April. Similarly, in 2019, this activity also covered two months, from the beginning of February to the second week of May, while hatching was noted between the fourth week of February and the end of May, with a maximum peak during the second week of April.

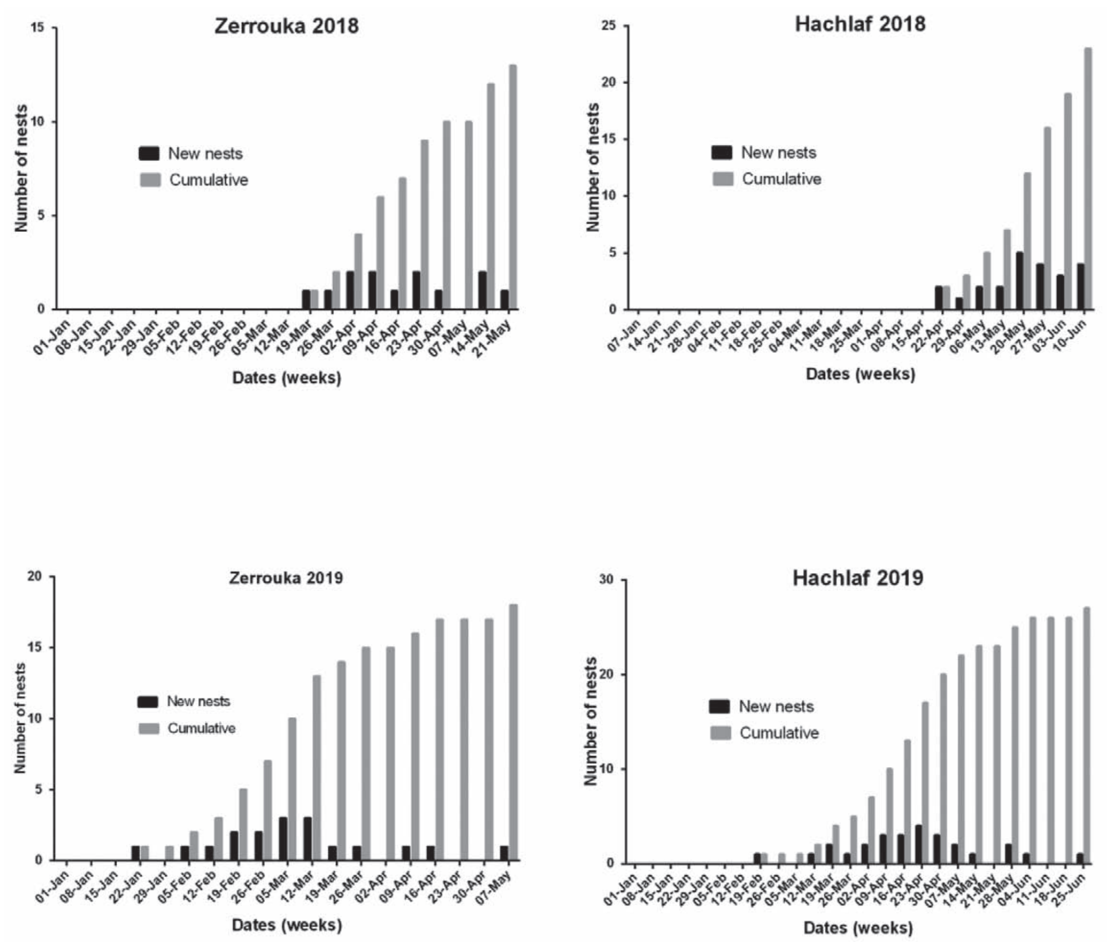

Figure 3. Chronology of nest construction in Hachlaf and Zerrouka reservoirs during 2018 and 2019.

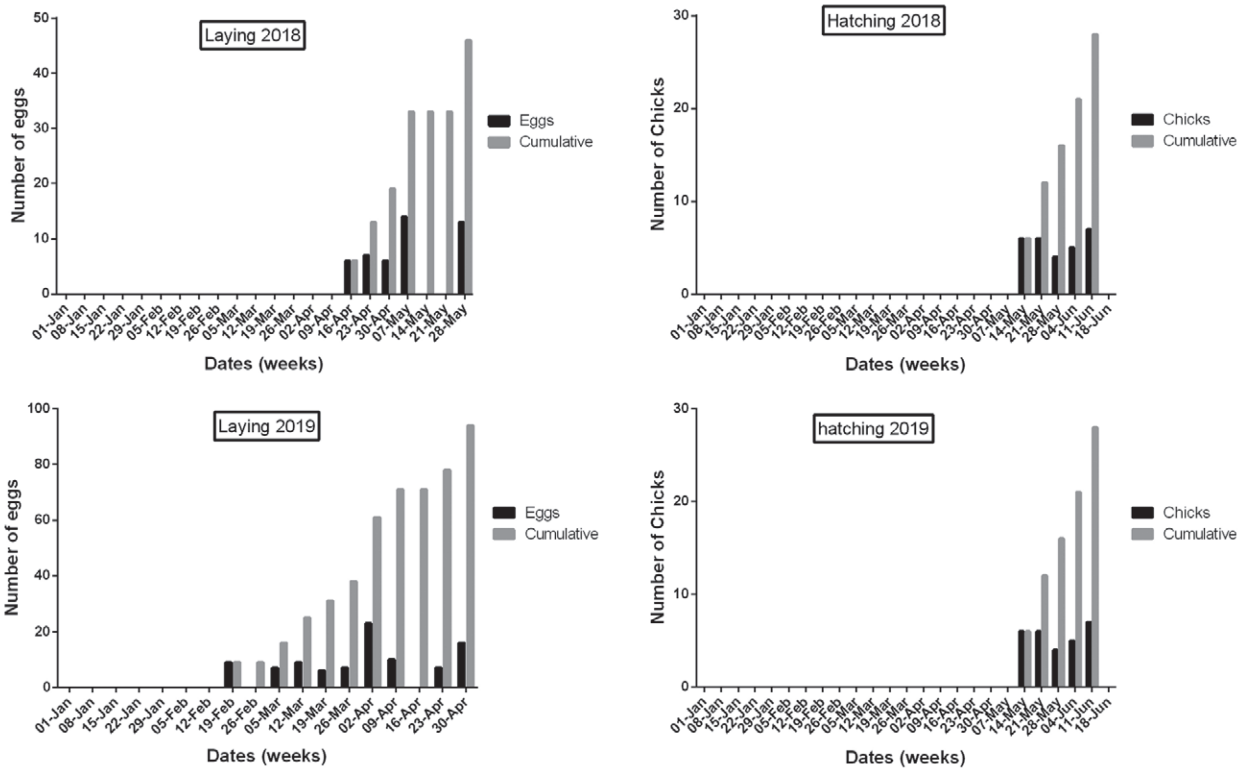

Figure 4. Chronology of egg-laying and egg-hatching of the Red-knobbed Coot at Zerrouka (2018–2019).

Table 2. Relationship (generalized linear model) between incubation period (dependent variable) and clutch size (factor) (R^2 = 0.666 (adjusted R^2 = 0.484)).

Source	Sum of squares	df	Mean square	F	*p*-value
Corrected model	790.994	6	131.832	3.662	0.030
Intercept	2274.865	1	2274.865	63.199	0.000
Clutch size	790.994	6	131.832	3.662	0.030
Error	395.950	11	35.995		
Total	7055.000	18			
Corrected total	1186.944	17			

Clutch size and incubation period

The clutch size was documented for 18 nests located only in the Zerrouka reservoir during the period from 2018 to 2019. The number of laid eggs varied from five to fourteen with an average of 8.11 ± 2.42 eggs/nest. The clutches of 13 and 14 eggs were those of nests colonized by two breeding pairs with two laying attempts (the second pair laid their eggs over the firsts pair's eggs) which led to the desertion of the nests. In addition, clutch size was significantly different between the two breeding seasons (t = 6.37, df = 5, p = 0.001). On the other hand, the incubation period varied from 20 to 23 days with an average of (n = 16 eggs) 21.66 ± 0.89 days. Equally, the incubation period was significantly variable between the two breeding seasons (t = 54.5, df = 5, $p < 0.001$) and depended on the clutch size (Table 2).

Nest and egg dimensions

The analysis of 31 nests (only at the Zerrouka site where nests were accessible) indicates that the Crested Coot builds large-sized nests to support its clutches and nestling; the average outer and inner diameters of the Zerrouka nests were 36.30 ± 2.12 cm and 19.31 ± 2.59 cm, respectively, and their height was around 13.01 ± 2.40 cm. On the other hand, a significant correlation was revealed among all nests' dimensions counting the outer axis, inner diameter, and nest height (Table 3).

The eggs' dimensions were variable; the polar diameter fluctuated between 46 and 61 mm, with an average of 54.2 ± 4.06 mm, while the equatorial diameter fluctuated between 27 and 41 mm, with an average of 33.5 ± 3.71 mm. Equally, the volume of the eggs was widely variable between 32.2 and 71.9 cm^3, with an average of 50.26 ± 12.47 cm^3, as well as their weight was between

Table 3. Pearson correlation between nest (n = 18) and egg (n = 52) dimensions of the Red-knobbed Coot.

Nests					Eggs			
	Large axis	Depth	Height above water	Small axis		Polar diameter	Equatorial diameter	Volume
Large axis		0.821	0.547	0.938	Polar diameter		0.949	0.983
N		18	18	18	N		52	52
p-value		0.000	0.019	0.000	*p*-value		0.000	0.000
Depth	0.821		0.470	0.820	Equatorial diameter	0.949		0.987
N	18		18	18	N	52		52
p-value	0.000		0.049	0.000	*p*-value	0.000		0.000
Height above water level	0.547	0.470		0.364	Volume	0.983	0.987	
N	18	18		18	N	52	52	
p-value	0.019	0.050		0.138	*p*-value	0.000	0.000	
Small axis	0.939	0.820	0.364					
N	18	18	18					
p-value	0.000	0.000	0.138					

Table 4. Eggs' characteristics at Zerrouka site.

Parameter	Average	Minimum	Maximum
Polar diameter (mm): B	54.200	46.000	61.000
Equatorial diameter (mm): L	33.500	27.000	41.000
Volume (cm^3) ($V = Kv \times LB^2$)	50.300	32.200	71.900
Weight (g) (N = 42)	42.100	27.000	53.400

Kv: specific constant for each Coot species, Kv = 0.499 (Hoyt 1979).

Table 5. Relationship (generalized linear model) between the hatching rates (dependent variable) and clutch size, incubation period (factors) ($R^2 = 0.965$ (adjusted $R^2 = 0.902$)).

Source	Sum of squares	Df	Mean square	F	*p*-value
Corrected model	95.528	11	8.684	15.251	0.002
Intercept	206.524	1	206.524	362.677	0.000
Clutch size	5.570	6	0.928	1.630	0.284
Incubation period	29.976	4	7.494	13.160	0.004
Clutch size * Incubation period	0.033	1	0.033	0.059	0.817
Error	3.417	6	0.569		
Total	539.000	18			
Corrected total	98.944	17			

27 and 53.4 grams, with an average of 42.06 ± 10.82 grams (Table 4). On the other hand, eggs dimensions were closely correlated (Table 3).

Breeding success

The number of active nests was variable between the reservoirs and the monitoring years (n = 4 (two years and two sites), t = 1.02, $p < 0.001$). At the Hachlaf reservoir, the number of occupied nests was 23 in 2018 and 27 in 2019, while at the Zerrouka site, 13 nests were active in 2018 compared to 18 nests in 2019. In addition, the hatching rate was different between sites and years. At Zerrouka, 84.85% of nests hatched in 2018 compared to 79.5% in 2019. In Hachlaf, the hatching rate was 60.87% in 2018 and 66.67% in 2019. On the other hand, hatching rates were dependent only on the incubation periods (Table 5).

The fledging success is summarized in Figure 5. In the Zerrouka site, 33.3% of chicks reached the fledgling stage in 2018, while this proportion increased to 39.8% in 2019. In the Hachlaf reservoir, the fledging success was much higher with 56.1% in 2018 and 54.7% in 2019.

DISCUSSION

This research provides the first consistent data on the breeding bio-ecology of the Red-knobbed Coot in the southern slope of the Mediterranean basin (Es Salai et al. 2021). Similarly, breeding habitats and nesting sites were investigated and mapped deeply with satellite images and field visits. The obtained results combined breeding features and habitats characteristics which are of great importance for the conservation efforts of this threatened species and its remarkable breeding ecosystems in Morocco, already registered as Ramsar sites.

Our investigation revealed an important breeding population of the Red-knobbed Coot. Indeed, 200 breeding pairs and 81 nests were documented in Hachlaf and Zerrouka reservoirs during 2018 and 201, as reported by Es Salai et al. (2021). In our case, the abundance of foraging and breeding resources, represented by the diversity of vegetation cover in and around both reservoirs, is suggested to support the nesting success of

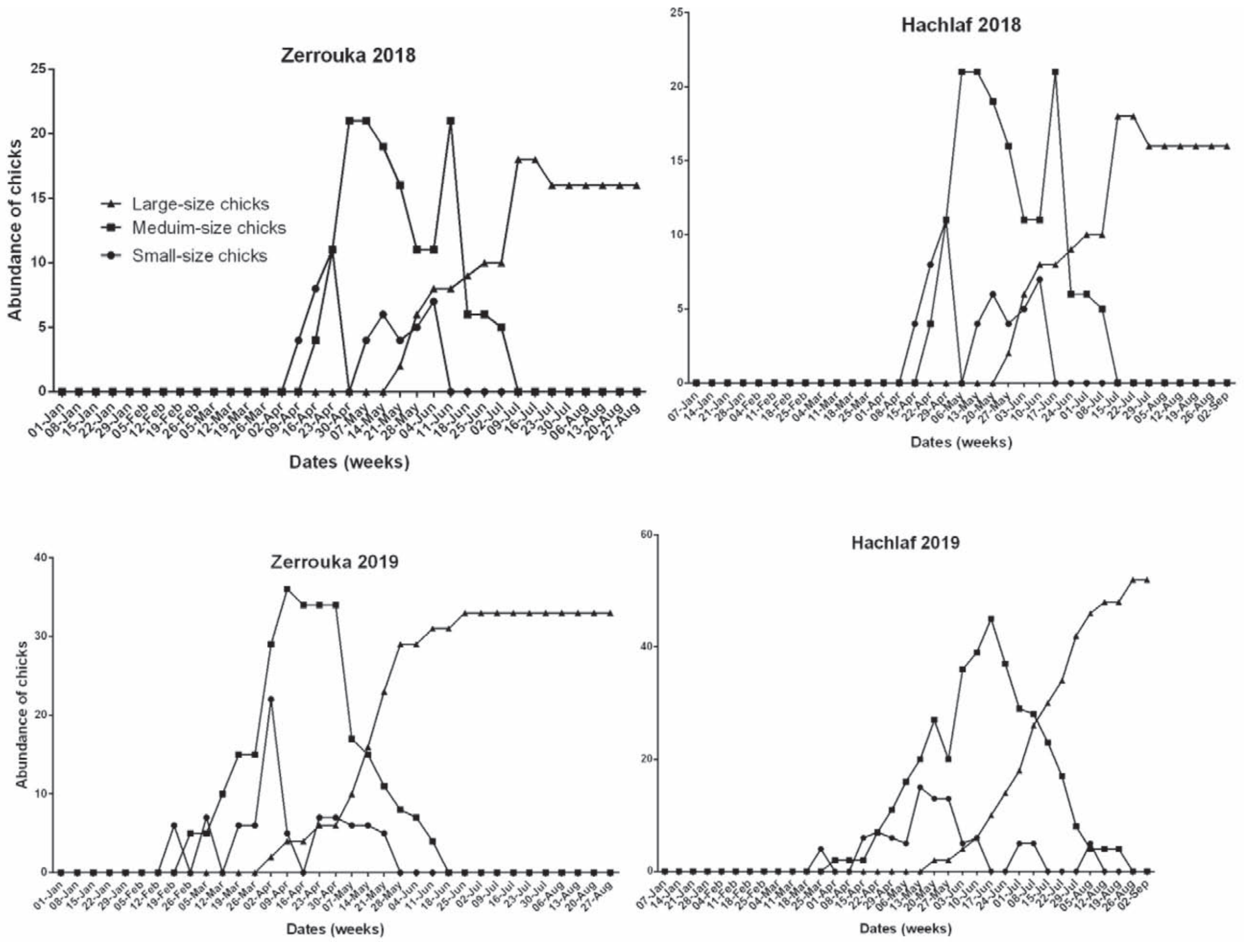

Figure 5. Evolution of the Red-knobbed Coot chick numbers in the Zerrouka and Hachlaf reservoirs between 2018 and 2019.

the species. Similar results were recorded in the Oued Fez River (100 km north-west to Hachlaf and Zerrouka sites), in which emerging and submerged plants attract the species in both wintering and breeding seasons (Squalli et al. 2020). Moreover, the Red-knobbed Coot selected nesting sites on islets of emergent vegetation in Zerrouka but directly on open waters in Hachlaf. Despite the absence of statistical evidence, this difference seems to be governed by two parameters: the abundance of emerged vegetation and the reservoir depth, which were higher in Zerrouka (11 plant species and 3 m depth) compared to Hachlaf (6 submerged plants and 1–4 m depth). Similarly, the Common Coot (*Fulica atra*) selects its nesting sites in relatively deep habitats in emergent plants, mainly in the wetlands' periphery, suggesting that vegetation biomass offers a greater breeding success (Nieoczym and Kloskowski 2018). Indeed, this vegetation is used by the Red-knobbed Coot both as nest materials (Hayes et al. 2018) and protective cover against predators (Ritenour et al. 2021). In open waters (case of Hachalf reservoir), nests are far from the wetland border, to ensure better protection against terrestrial enemies (dogs and cattle) and people disturbances. This is confirmed by the fact that during summer, the lowering of the water depth in this wetland puts the marginal nests within predators' reach.

One of our important conclusions concerns the breeding season of the species. Despite its high variation between both studied wetlands, this season extends from February to August, being then globally similar to that observed at lower altitudes, both in southern Spain (Varo 2008) and north-western Morocco (Amezian et al. 2007). However, the sub-Saharan population generally lays all year round (Taylor and Van Perlo 1998). This comparison revealed, at least in 2019, a precocity of the life cycle in the mountainous Ifrane region located at 1600 m altitude where the species is supposed to breed much later than in the lower plains. Indeed, the nest-building period during both seasons of 2018 and 2019 showed a time lag of five weeks between the two sites and a time lag of about two months between 2018 and 2019 seasons in each site. The weather conditions characterized by a drop in temperatures and heavy snowfall in 2018, compared with 2019, can explain the precocity of the breeding activity in 2019. According to previous studies (Bensouilah et al. 2014), the breeding season can vary with both weather and altitude; in particular, very low temperatures lead to a shorter breeding season (Bears et al. 2009; Mansouri, Squalli et al. 2021; Martin et al. 2009). However, in 2018, both sites were under the same weather conditions, but the breeding activity started much earlier in the Zerrouka site than in that of Hachlaf. We explain this precocity by the winter temperature of the water, which is much lower in the Hachlaf reservoir than in that of Zerrouka. Indeed, this latter receives lukewarm water (permanently around 18°C) from a great spring, which confers to the lake waters a winter temperature over 10°C (and up to 12°C close to the spring) even during snowing weather, while the Hachlaf waters are under the direct effect of cold weather (this issue needs deep research and statistical confirmation). It seems also that the Red-knobbed Coot has a breeding calendar as long as that of the Eurasian Coot, knowing that the latter breeds generally over four months, from the last week of March to the end of July (Zitouni 2014). Nevertheless, to be significant, such a comparison needs simultaneous close monitoring of both species.

Regarding the clutch size, this study revealed high variation between clutches (5 to 10 eggs per nest pairs), with an average value of 7.47 ± 1.50. These values are higher than those recorded in southern Spain (5.9 ± 1.39) by Varo (2008) and in sub-Saharan Africa (5 to 7 eggs per nest) according to Lack (1967) and Taylor and Van Perlo (1998). It's worth mentioning that for *Fulica atra*, the clutch size is larger, as it varies between 4 and 15 eggs, with an average value of 9.13 ± 2.06 (Zitouni 2014). Some authors attest that the clutch size can increase with the availability of food resources before and during egg-laying (Figuerola and Green 2006; Lack 1967). In the shallow reservoir of Zerrouka, where it was possible to estimate the clutch size, the aquatic vegetation, as the main food resource for coots, is very dense, making this wetland an ideal breeding site for them (Nieoczym and Kloskowski 2018). However, the breeding space available in the Zerrouka site seems insufficient, which probably obliges some females to use the same nest, as is confirmed by two monitored nests that contained 13 and 14 eggs, both of them being finally abandoned by adults. In Hachlaf, the number of chicks per female was low, which could confirm the food availability role on the clutch size, since the vegetation was less dense in this site than in Zerrouka. Concerning the egg dimensions, our measurements show that the Middle Atlas eggs have a much greater volume (50.3 cm^3) than those measured in southern Spain (37.97 cm^3). As suggested by Decker at al. (2011), we can link this great difference to a large food availability in Zerrouka. The nest dimensions are slightly larger than those of the Eurasian Coot, for which measurements carried out in Morocco (Squalli et al. 2020) showed an outer diameter of 33.9 cm and a height of 11.6 cm, while in northern Algeria, these dimensions are of 31.56 cm and 13.84 cm, respectively. It seems that in the Zerrouka site, this great size is due to frequent nest expanding at each season by adding additional materials for nests reuse.

Throughout this study, we provided the first data on the breeding success of the Red-knobbed Coot in Morocco and Northwest Africa (Es Salai et al. 2021; Varo 2008). The success rate was much higher in Hachlaf (57.1% in 2018 and 54.7% in 2019) than that in Zerrouka (33.3% in 2018 and 39.8% in 2019). This large difference is not consistent with the small variations within each wetland; however, in southern Spain, Varo (2008) recorded large inter-annual variations in the same sites (36% in 2002 and 55% in 2003). The main factor that is thought to reduce the breeding success in Zerrouka is predation of both chicks and eggs, since we have regularly observed dogs inside the lake and Marsh Harriers flying over it, in addition to abundant viperine snakes.

CONCLUSION

This study identified several characteristics of breeding bio-ecology of the vulnerable population of the Red-knobbed Coot in Northern Africa. Gained results clarify the selection of breeding sites, nesting materials, and define the breeding chronology and reproductive success of this aquatic bird in two small Middle Atlas reservoirs located at high altitudes. These wetlands, belonging to two Ramsar sites, offer necessary breeding and foraging resources for important breeding populations and their broods, especially with the frequent drying out of large wetlands within this region, such as Aoua, Hachlaf and Ifrah lakes (dry out from 2017 to date). The breeding success remains relatively low in the intermittently flooded wetland of Hachlaf. In addition to our hypothetic explanations provided in this work, the understanding of the potential factors that could ensure the survival of the species in this site, as well as in the Zerrouyka reservoir, needs a planned long-term monitoring. In the same context, additional comparative monitoring of the species' life cycle in other wetlands of both the Middle Atlas, the Saïs plain and the Rharb-Loukkos region (located at different altitudes) can significantly improve our knowledge of the spatiotemporal trends of this species and its survival influencing factors in Morocco. These studies would be very useful for implementing management and conservation measures to improve the local breeding conditions of this species. Indeed, these two lakes were integrated into two Middle Atlas Ramsar sites and belong to the National Park of Ifrane, whereas Lake Zerrouka was classified as a prior Site of Biological and Ecological Interest.

ETHICAL STATEMENT:

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

Availability of data
All necessary data are included within the article with clarity careful statement. The full data are available from the corresponding author upon reasonable request for any future studies.

Ethical approval:
Our experimental procedures complied with the current laws and regulations on animal welfare and research in Morocco and had the approval of the animal research ethics committee of Moulay Ismail University and Birdlife Morocco. In addition, all procedures followed standard protocols.

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