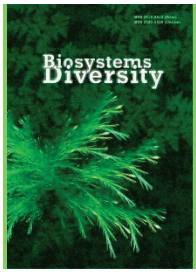
Biosystems
Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.,
2023, 31(4), 493–499
doi: 10.15421/012358

Is there an effect of electromagnetic waves from base stations on the breeding success of *Ciconia ciconia ciconia* in Algeria?

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Article info

Received 17.09.2023
Received in revised form 25.10.2023
Accepted 07.11.2023

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Sakraoui, D., Ziane, N., Ghalem, R., Boukheroufa, M., & Habbachi, W. (2023). Is there an effect of electromagnetic waves from base stations on the breeding success of Ciconia ciconia ciconia in Algeria? Biosystems Diversity, 31(4), 493–499. doi:10.15421/012358

New nest supports used by the white stork *Ciconia ciconia ciconia* (Linnaeus, 1775) are mobile phone network relay antennas, which are not without danger because they emit electromagnetic waves that can have a major, although insidious, impact on the species. The aim of this study is to assess the effects of electromagnetic waves from mobile phone network base stations on white stork reproduction. We monitored the breeding phenology of the storks as a function of the distance of their nests from the base stations over 2 consecutive seasons, 2020 and 2021. The work took place in the North-East of Algeria, in Annaba and El-Tarf provinces. The nests were counted and divided into 3 distinct groups. The first is located on the relay antennae, the second less than 200 m and the third more than 300 m from the antennae. We calculated nest occupancy, number of young in the nest and number of nests without young. The results show that nests located directly on base stations have a reduced clutch size, not exceeding two storks and a low reproductive success since the majority of nests (51.9%) remained without young. The number of young storks tends to increase in nests far from base stations. Broods with 3 and 4 young are generally those located more than 300 m from relay antennas.

Keywords: white stork; mobile phone masts; reproduction; electromagnetic waves.

Introduction

The white stork is a synanthropic species, lacking natural structures for nesting near urban areas, so it is faced with using available artificial structures as nesting sites (Vergara et al., 2006; Benharzallah et al., 2015; Babouri et al., 2020). A number of studies have highlighted the widespread use of electricity poles throughout its range (Lovaszi et al., 2020). This selection of high nest sites responds to an adaptive strategy of defence against potential predators, anthropogenic disturbances and also offers greater stability (Gyalus et al., 2018). In recent years, we have observed the frequent use of mobile phone base stations as nesting sites. These antennae can have an impact on these waders, as they emit electromagnetic waves.

Numerous laboratory studies have highlighted the harmful effects of these waves on physiological processes in humans (Wdowiak et al., 2007; Ghanbari et al., 2013) and on animal health (Bahaodini et al., 2015). Long-term exposure to low-frequency electromagnetic fields (EMFs) in male rats appears to reduce the diameter of seminiferous tubules and increase their number per unit area of the testes. In addition, low-frequency EMF would significantly reduce sperm motility and testosterone levels (Bahaodini et al., 2015).

Also in rats, data showed that exposure to DECT (Digital Enhanced Cordless Telecommunications) base station radiation caused an increase in the heart rate of embryos on the 17th day of pregnancy. In addition, significant changes in the somatometric characteristics of the newborns were observed. Pyramidal cell loss was detected in the CA4 region of the hippocampus of 22-day-old pups that were irradiated either during prenatal life or before and after birth (Stasinopoulou et al., 2016). In 2021, a study showed the effects of radiofrequency electromagnetic radiation emitted by a mobile phone base station on redox homeostasis in various organs of Swiss albino mice (Zosangzuali et al., 2021). Tomruk et al. (2022) have demonstrated the harmful effects of short-term exposure to radiofrequency radiation on the activities of metabolic enzymes during pregnancy and prenatal development in New Zealand white rabbits. All these studies have been carried out in the laboratory, where all the parameters can be controlled, but outdoor work is more complex and involves methodological and technical difficulties. Experiments studying the effects of electromagnetic radiation on living beings are complex, as there are a large number of variables to control. The complexity of this control makes it difficult to achieve the "identical conditions" necessary for duplication (Balmori, 2005, 2009).

Birds have been extensively used to analyse the environmental significance of exposure to non-ionising radiation. Their ability to detect magnetic stimuli has been widely documented (Keeton, 1971; Gudmundsson & Sandberg, 2000; Wiltschko & Wiltschko 2001; Wiltschko et al., 2002; Thalau et al., 2006).

In this area, storks appear to be an interesting species to study in order to demonstrate the effects that electromagnetic waves from relay antennae can have, because in the study region, along with house sparrows, they are the only species to build their nests on electricity and telephone poles and other high supports, which results in a high level of electromagnetic contamination. They also nest directly on base stations, where electromagnetic contamination is even higher, and spend a lot of time in the nest. For these reasons, the reduction in the number of broods can be a good biological indicator for detecting the effects of this radiation (Balmori, 2005, 2009). In Algeria, the white stork *C. ciconia* nests commonly in the Mediterranean part, from the coastal plains to the steppe high plateaux (Moali-Grine et al., 2013). It has been the subject of numerous studies, particularly on density parameters (Moali-Grine et al., 2004), diet and trophic niche (Cheriak et al., 2014; Chenchouni et al., 2015), reproduction (Bouriach et al., 2015), parasitism (Touati et al., 2022) and the effects of climate change (Mammeria et al., 2019); but in Algeria no study has yet focused on the effect of base stations on the species' reproduction. Our aim is to analyse the data available for the first time in Algeria to determine whether there is a correlation between exposure to the electromagnetic waves emitted by mobile phone base stations and the reproduction rate of white storks. This research could contribute to a better understanding of the impact of wireless technologies on the environment and help develop strategies to preserve this species.

Materials and methods

Our work was carried out from December 2019 to August 2021 in three localities belonging to two different provinces, namely Dréan and Ben M'hidi in El-Tarf province and Berrahal in Annaba province (Fig. 1).

The commune of Ben M'hidi, between 36°46′19″ N 7°54′19″ E (Fig. 2), is a semi-urban area covering 150.65 km^2, close to the Mekhada marsh, considered to be an excellent stork feeding area. The commune of Dréan is located between 36°41′00″ N 7°45′00″ E (Fig. 2), a semi-urban area of 48 km², mainly agricultural. The commune of Berrahal lies between 36°50′00″ N 7°27′00″ E (Fig. 2), covers an area of 180.15 km^2 and is bounded to the south by the depression of Lake Fetzara. The two main sectors of activity in this industrial zone are agri-food and public works.

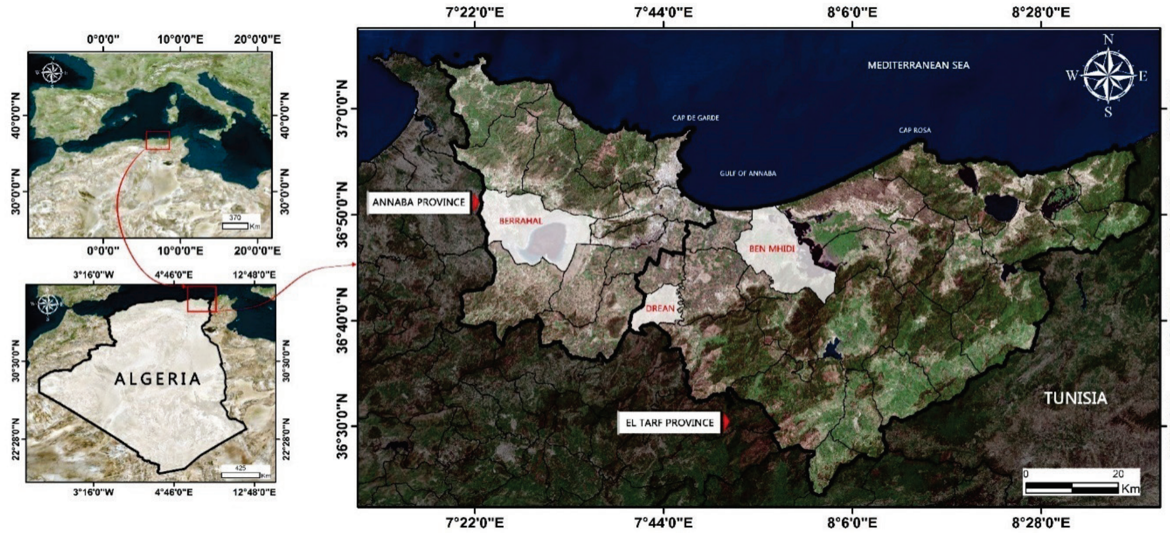

Fig. 1. Study area with the 3 sampling study districts

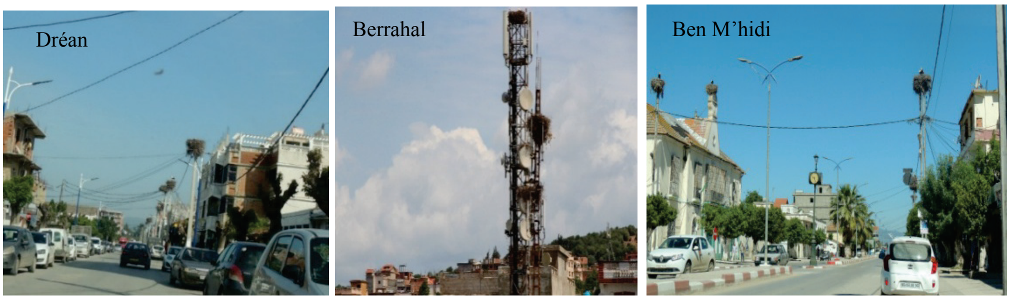

Fig. 2. Different nesting sites (Poles, roofs, relay antennas) (Photo by D. Sakraoui)

It is important to note that the 3 localities are close to wetlands, so food is abundant for the storks. We can therefore assume that the environment of the three populations is close to the species' preference.

The work was spread over two successive years, 2020 and 2021. We monitored the breeding phenology of the species, two times a week, using binoculars (Breaker optical, model 7×50, 119m/1000m, JL = 99888) and a camera (Nikon P500). The nests located in the three districts (Ben M'hidi, Dréan, Berrahal) were counted in order to estimate the white stork population in each locality. Observations began with the arrival of the storks, and covered the period of nest construction and maintenance, and the period from egg-laying to the fledging of the young. We selected the nests according to their proximity to the base stations (taking into account the homogeneity of the age of the storks to avoid any bias).

The distances were calculated by the geolocation of the nests and antennae (GPS 72 GARMIN). We followed the protocol proposed by Balmori (2004) to define the distances at which individuals are more exposed (–200 m) or less exposed (+300 m) to the radiation emitted by base stations. We considered the nests located directly on the base stations (0 m away) as a separate group.

A total of 140 nests were selected (Table 1) and divided into three groups:

– the 1st group G1 is made up of nests located 0 m from relay antennae, i.e. placed on the electromagnetic wave transmitters.

– the 2nd group G2 is made up of nests less than 200 m from relay antennae.

– the 3rd group G3, is made up of nests at least 300 m away from any relay antennae.

Table 1
Number and distance of nests from mobile phone base stations mobile phone masts

Groups	Distance of nests/antennae, m	Number of studied nests
G1	0 (on transmitters)	27
G2	2–164 (– 200)	43
G3	315–548 (+ 300)	70

By taking these distances into account, we were able to assess the potential impact of exposure to the electromagnetic waves emitted by mobile phone base stations on the reproduction of white storks in the areas studied. The main parameter studied in this research is reproduction success, more specifically fledging success, as the inaccessibility of the nests, especially on the antennae, makes it impossible to verify hatching success.

Results

Nest counting. The number of occupied nests recorded at the 3 localities is 140 nests/year, giving an overall white stork population estimated at 280 individuals. The Berrahal population is the largest, with 70 nests per year, or 140 individuals. It is followed by Ben M'hidi, with 44 nests per year, i.e. 88 individuals, and Dréan, with 26 nests per year, i.e. 52 individuals (Fig. 3). The white stork populations of the 3 localities are therefore stable, since there is no annual variation in the number of nests for the years 2020 and 2021 (Fig. 3).

In relation to relay antennae, the number of nests on antennae (distance = 0 m) is 8 nests/year in the region of Ben M'hidi, 4 nests/year in

Dréan and 15 nests/year in the region of Berrahal (Fig. 4). Concerning the nests located at –200 m from the base stations, we recorded 14 nests/year in the region of Ben M'hidi, 9 nests/year in Dréan and 20 nests/year in the Berrahal district (Fig. 3). For the group of nests located at + 300 m, we counted 22 nests/year in Ben M'hidi district, 13 nests/year in Dréan and 35 nests/year in Berrahal district. There was no annual variation in the distance of the nests from the base stations, and the number of nests was identical for the two years 2020 and 2021 (Fig. 3).

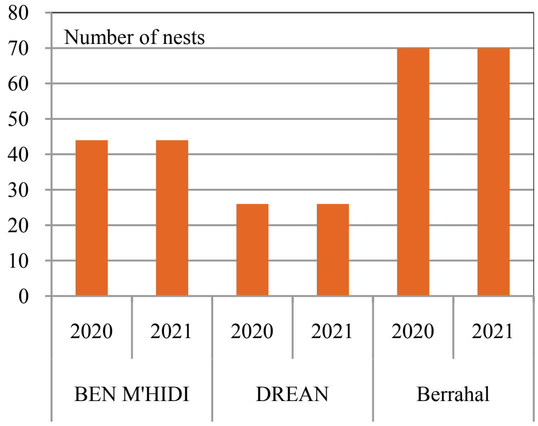

Fig. 3. Number of nests by location and year

Number of nestlings. The number of young storks in the nest varied from 0 to 4 per nest in the three sites. Nests with no young were exclusively found on the relay antennae (G1), while nests with 4 young were most common in nests located more than 300 meters from the antennae (Table 2). Nests with only one young stork are common in G1 and G2 broods, and are absent or poorly represented in G3. Nests with two young storks are poorly represented in group G1 nests, but are almost equally represented in groups G2 and G3. Finally, broods with 3 and 4 young are absent from group G1. Those with 3 young are slightly more numerous in group G3 and those with 4 young are virtually absent from group G2 (Table 2).

Young storks in the nests. For the group of nests located on the relay antennae (G1), the average number of young in the locality of Ben M'hidi was 0. 62 in 2020 and 0.75 in 2021. For G1, the average number of young in the nests in Dréan was 0.25 in 2020 and 1.25 in 2021, and the average number of young in the nests in Berrahal was 0.66 in 2020 and 0.73 in 2021 (Table 3). The group of nests located at –200 m from the antennas (G2) in the site of Ben M'hidi had an average number of young of 2 in 2020 and 2.11 in 2021. For G2, the nests in Dréan had an average number of young of 1.77 in 2020 and 2.11 in 2021, and the nests in Berrahal had an average number of young of 2.2 in 2020 and 2.11 in 2021 (Table 3). The last group of nests located at +300 m from the antennae (G3) in the site of Ben M'hidi had an average number of young of 2.95 in 2020 and 2.86 in 2021. For G, the nests in Dréan had an average number of young of 2.76 in 2020 and 2.84 in 2021 and the nests in Berrahal had an average number of young of 2.76 in 2020 and 2.88 in 2021 (Table 3).

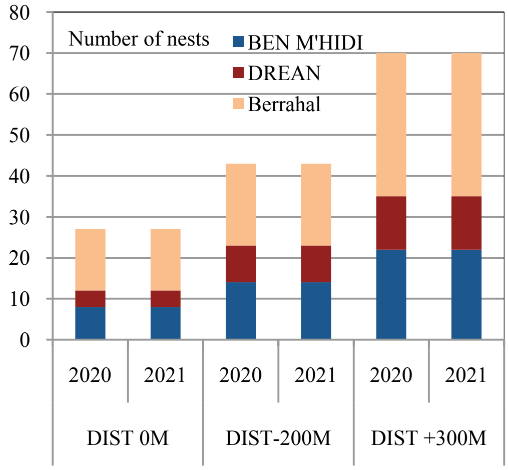

Fig. 4. Distance between nests and base stations

The number of young storks differs a little from one year to the next, but it does significantly vary depending on the distance from the base stations. The number of young tends to increase in nests that are further away from base stations. Statistical analysis shows a positive and significant correlation in Ben M'hidi in 2020 ($r = 0.61$, $P < 0.05$) and 2021 ($r = 0.51$, $P < 0.05$), in Dréan in 2020 ($r = 0.69$, $P < 0.05$) et 2021 ($r = 0.60$, $P = 0.05$) and in Berrahal in 2020 ($r = 0.53$, $P < 0.05$) and 2021($r = 0.65$, $P < 0.05$).

Table 2
Number of nestlings (%) of the white stork *Ciconia ciconia ciconia*

Years	2020			2021		
Parameters	Ben M'hidi G1–G2–G3	Dréan G1–G2–G3	Berrahal G1–G2–G3	Ben M'hidi G1–G2–G3	Dréan G1–G2–G3	Berrahal G1–G2–G3
Share of nests with 0 young, %	50.0–0.0–0.0	75.0–0.0–0.0	46.7–0.0–0.0	50.0–0.0–0.0	25.0–0.0–0.0	46.7–0.0–0.0
Share of nests with 1 young, %	37.0–35.7–4.5	25.0–33.3–0.0	40.0–20.0–5.7	25.0–7.1–4.5	25.0–11.1–0.0	33.3–20.0–0.0
Share of nests with 2 young, %	12.5–28.6–27.3	0.0–55.6–36.5	13.3–45.0–40.0	25.0–57.1–27.3	0.0–66.7–30.8	20.0–50.0–37.1
Share of nests with 3 young, %	0.0–35.7–36.4	0.0–11.1–46.2	0.0–30.0–31.4	0.0–28.6–45.5	0.0–33.3–53.8	0.0–30.0–37.1
Share of nests with 4 young, %	0.0–0.0–31.8	0.0–0.0–15.4	0.0–20.0–22.9	0.0–7.1–22.7	0.0–0.0–15.5	0.0–0.0–25.7

Table 3
Variation in the number of nestlings in relation to base stations (2020–2021)

2020	Ben M'hidi x ± SD (n)	Dréan x ± SD (n)	Berrahal x ± SD (n)	2021	Ben M'hidi x ± SD (n)	Dréan x ± SD (n)	Berrahal x ± SD (n)
G1	0.62 ± 0.74 (8)	0.25 ± 0.50 (4)	0.66 ± 0.72 (15)	G1	0.75 ± 0.88 (8)	1.25 ± 0.95 (4)	0.73 ± 0.79 (15)
G2	2.00 ± 0.87 (14)	1.77 ± 0.66 (9)	2.20 ± 0.83 (20)	G2	2.35 ± 0.74 (14)	2.11 ± 0.60 (9)	2.11 ± 0.79 (20)
G3	2.95 ± 0.89 (22)	2.76 ± 0.72 (13)	2.71 ± 0.89 (35)	G3	2.86 ± 0.83 (22)	2.84 ± 0.68 (13)	2.88 ± 0.79 (35)

Impact of base stations on the success of breeding. We have grouped the data from three sites (Ben M'hidi, Dréan and Berrahal) in order to analyse the impact of relay antennae on the breeding success of white storks. In 2020, Group G1 (27 nests located directly on the base stations) had an average of 0.592 young per nest, with a percentage of 51.9% of nests without young. Group G2 (43 nests at a distance of less than 200 m from the antennae) had an average of 2.046 young per nest, and no nests without young. Group G3 (70 nests at a distance of more than 300 m from the antennae) had an average of 2.8 young per nest, and no nests without young (Table 4). In 2021, the tendencies remain similar. Group G1 had an average of 0.814 young per nest, with a percentage of 40.7% of nests without young. Group G2 had an average of 2.186 young per nest, with no nests without young. Group G3 had an average of 2.87 young per nest, with no nests without young (Table 4).

The results of the paired T-test show no significant difference ($P = 0.162$) between the years 2020 and 2021. Concerning the average number of young per nest, the analysis of variance (ANOVA) revealed a very highly significant difference between the groups (G1, G2, G3) ($F = 122.21$, $P < 0.001$) for 2020, 2021. Tukey's multiple comparisons showed significant differences between group means, with G2 and G3 having higher means than G1. In addition, linear regression analysis between distance from base stations (DIST) and average number of young per nest (NJ) shows a very highly significant relationship ($P < 0.0001$). The regression equation is $DIST = –68.8 + 141$ (Fig. 5).

Table 4
Global variation in reproductive success

Year	Group	Total number of nests	Total number of young storks	Average number of young per nest	Share of nests without young storks, %
2020	G1	27	16	0.59	51.9
	G2	43	88	2.04	0.0
	G3	70	196	2.80	0.0
2021	G1	27	22	0.81	40.7
	G2	43	94	2.18	0.0
	G3	70	201	2.87	0.0

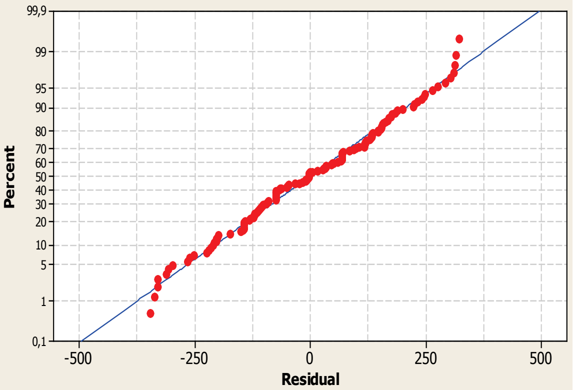

Fig. 5. Regression line (number of young – nest distance): normal probability plot of the residuals (response is DIST)

These results suggest that the proximity of nests to mobile phone masts affects stork reproduction. Nests located directly on the antennae have a very low reproductive success. The further away from the antennae, the greater the reproductive success, with nests located more than 300 m from the antennae having a higher rate.

Discussion

The overall population of white storks studied is estimated at 280 individuals. The Berrahal population is the largest, with 140 individuals, followed by Ben M'hidi with 88 and Dréan with 52. The white stork populations in the three localities are therefore stable, since there is no annual variation in the number of nests between 2020 and 2021. Concerning the location of the nests, we counted a total of 27 nests on the base stations at the three sites, some of which housed two or even three nests.

Several authors have studied the impact of electromagnetic (EM) radiation on flora and fauna. Waldmann-Selsam et al. (2016), for example, measured all the trees and found significant differences between the damaged side facing a telephone mast and the opposite side, as well as differences between the exposed side of the damaged trees and all the other groups of trees away from the base stations and those on both sides. Also, according to Upadhyaya et al. (2021), the antimicrobial potential of the plants *Oscimum sanctum* and *Bacopa monnieri* was significantly damaged by high-frequency electromagnetic waves after exposure for 72 to 144 h.

Insects are not spared by the phenomenon, Lazaro et al. (2016) studied the effects of EMR (Electromagnetic Radiation) from telecommunication antennae on the main groups of wild pollinators (wild bees, hoverflies, bee flies, rest flies, beetles, butterflies and wasps) on the islands of Limnos and Lesvos, Greece. The results showed that all groups of pollinators, with the exception of butterflies, were affected by the EMR. On both islands, the abundance of beetles, wasps and hoverflies decreased with the EMR, while the abundance of wild bees and ground-nesting bee flies unexpectedly increased with the EMR.

In studies dealing with the effects of telephony radiation on birds, the high mobility of birds, the variation in exposure times and the physical properties of radiant waves, such as resonance, reflections or attenuation by certain structures, can complicate the study (Balmori, 2005). It is also possible that each species, or even each individual, shows a different sensitivity to radiation, since vulnerability depends on genetic predisposition and the physiological and neurological state of the living being subject to irradiation (Hyland, 2000; Otto & Von Mühlendahl, 2007).

In the United Kingdom, due to the installation of mobile phone base stations in several regions, a considerable decline has been recorded in bird populations in urban areas, including the sparrow, where numbers have fallen by 41% in thirty years (Choudhary et al., 2020). In Spain, Balmori & Hallberg (2007) report that in the 10 years from 1997 to 2007, three out of fourteen bird species completely disappeared, and a decline in the population of four species was observed. According to Ali & Daniel (2012), continuous exposure to EM radiation affects the behaviour, immune system, growth, reproductive success and development of birds. It also appears that when birds fly through an area close to a mobile phone base station, the EM radiation affects the birds' navigational abilities, causing them to become disorientated from their path and fly in the wrong direction (Everaert & Bauwens, 2007).

In their summary of several works analysing the ecological effects of radio frequency electromagnetic fields (RF-EMF), Cucurachi et al. (2013) found that for the experiments carried out in laboratories, the results concluded an effect of RF-EMF on embryo mortality and development at both high and low doses. For the five field studies, the results showed a significant effect of RF-EMF on breeding pair density, reproduction or species composition.

In our study, the results show that nests located near one or more base stations have lower fecundity than nests located more than 300 m from all antennae. In 2020, 14 nests out of a total of 70 located less than 200 m from a base station had no stork chicks, i.e. 20% of the nests. In 2021, the trend was confirmed, with 11 nests without young out of a total of 70, or 16%. Furthermore, in both 2020 and 2021, no nests without young were recorded among those located more than 300 m from a relay antenna. In contrast, nests with 4 young are only found at this distance. One-chick broods are frequent at –200 m from antennae, while two-chick broods are found in both G2 and G3 groups, but particularly the one at +300 m. Several hypotheses can be put forward to explain this result, including the position of the nest in the main beam of the relay antenna, increased temperature, sterile eggs, dead embryos.

Another hypothesis is that the metal structures on which storks nest better transmit, or even amplify, electromagnetic radiations. In addition, the open structure of the stork's nest means that it is directly exposed to the waves, as it is not located in cavities or sheltered in any way, and its elevated position means that it is more exposed to the electromagnetic waves (Balmori, 2005). It can also be argued that storks, being birds that nest mainly in villages or semi-urban environments, are more exposed to waves than birds living directly in large cities, because the radiation emitted by relay antennae in rural environments is higher than in urban environments due to the greater density of built structures in cities.

In Algeria, the Post and Telecommunications Regulatory Authority (ARPT) has set the maximum thresholds for public exposure to electromagnetic fields for the 900 MHz band at 41 volts/metre, for the 1800 MHz band at 58 V/m and for the 2.1 GHz band and above at 61 V/m, according to the ARPT, which limits the radiation from radio electric installations, in this case relay antennaes located near sensitive areas, to 28 V/m. This decision applies to all fixed and mobile telephone operators.

The results of our study show also that the reproductive success of storks varies according to their distance from mobile phone base stations. Nests located directly on the antennae have the lowest rate, with an average of 0.59 young per nest in 2020 and 0.81 young per nest in 2022, corresponding to a rate of nests without young of 51.9% in 2020 and 40.7% in 2021.Those located less than 200 metres from the antennae did not have good reproductive success in 2020 and 2021, indicating that these stocks were probably more exposed to the electromagnetic waves. On the other hand, nests located more than 300 m from the antennae had significant reproductive success, with an average of 2.8 young per nest in 2020 and 2.87 young per nest in 2021.

These results suggest that the electromagnetic waves emitted by mobile phone base stations can adversely affect stork reproduction. Nests located on antennae appear to be the most affected, with very low reproductive success. Many nests remained without young despite the presence of adult pairs. This result is linked either to a lack of egg-laying or to a clutch with sterile eggs. Experiments conducted in the laboratory on hens exposed directly (< or = 25 cm) to EM radiation showed that they suffered a higher percentage of embryonic mortality than those exposed at 1.5 m (Batellier et al., 2008). Finally, nests located more than 300 metres from antennae appear to be less affected, with a higher reproductive success rate.

These results concur with those of Balmori (2005) who worked on 60 white stork nests. According to the author, 40% of the 30 nests located less than 200 m from a telephone mast failed to produce chicks, whereas in another colony of 30 nests located more than 300 m away, only 3.3% failed to produce chicks.

Another interesting result for storks is that the results obtained did not show a cumulative effect. In fact, contrary to many studies, such as that conducted by Magras & Xeno (1997), which indicates a progressive reduction in the number of births, mice exposed to 0.168 W/cm^2 became sterile after 5 generations, while those exposed to 1.053 W/cm^2 became sterile after only 3 generations. The interaction seems to take place via the central nervous system rather than directly on the reproductive glands. But in our study, even the irradiated storks had a slight increase in natality between 2020 and 2021.

The low reproductive success rate in 2020 may also be linked to the impact of the COVID-19 pandemic. In fact, the period of confinement during which mobile phone use reached record levels throughout the world (Clipper, 2020; Chin & Rajermani, 2021), coincided with the storks' breeding season, so it can be assumed that the increased use of mobile phones and the Internet during this period led to overuse of mobile phone base stations, many of which included 3G and 4G, which may have led to greater stork radiation in 2020 than in 2021.

It is extremely difficult to establish a cause-and-effect relationship with certainty in laboratory studies, due to the complexity and multiplicity of environmental parameters to be taken into account. However, our *in situ* study made it possible to study radiation conditions almost *in vitro*, because the storks' nests were built directly on electromagnetic wave transmitters. This continuous, full-power radiation cannot be ignored in terms of its impact on reducing the brood size of the storks concerned. This finding suggests that electromagnetic waves have an effect on stork reproduction. However, this hypothesis needs to be examined in greater depth and requires a broader study of the subject.

Conclusion

Electromagnetic waves generated by man-made sources are increasingly present in our environment and we are beginning to become aware of their potential impact on human and animal health. Storks are migratory birds that are exposed to these electromagnetic waves when they nest, which can potentially lead to a reduction in their broods. The results of our *in situ* study suggest an association between a reduction in stork broods and exposure to electromagnetic waves. However, it is important to note that field studies are limited by the complexity and variability of the environmental parameters, and it is therefore difficult to conclude definitively on a cause-and-effect relationship. Nevertheless, our results highlight the need for mobile phone operators to consider the potential impact of their emissions on avian wildlife, and to put in place precautionary measures to minimise the risks to animal and human health. Future research is needed to further our understanding of the effects of electromagnetic waves on wildlife and to help develop appropriate management policies to protect avian wildlife and their environment.

We would like to thank all those who participated in this work. This study was funded by the Ministry of Higher Education and Scientific Research of Algeria (MESRS) and the General Directorate for Scientific Research and Technological Development (DGRSDT: PRFU project Code: D00L02UN230120220003).

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