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Update on the geographic distribution of the critically endangered *Urothemis edwardsii* (Selys, 1849) (Odonata: Libellulidae) in northeastern Algeria

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Summary. Assessing temporal changes of the distribution of threatened species is paramount for effective management. Threatened species are sensitive to environmental changes and can be extirpated rapidly due to climatic and anthropogenic effects. Here, we monitor the distribution of the locally critically endangered *Urothemis edwardsii* in northeastern Algeria where the species has been recovering during the last decade after being restricted to a single locality since the 1990s. During the flight seasons in 2018, 2019, and 2021, we conducted field surveys recording the number of males, females, and breeding pairs across 15 sites in northeast Algeria (El Taref province). We found the species at seven sites; reproduction was confirmed at four. In two of the sites, the species was newly recorded but showed no signs of reproduction. We confirmed the maintenance of the reproductive populations that were recently discovered. While the local conservation status of the species is better than that in the 1990s, there are still different threats that need to be addressed and conservation measures that should be implemented or reinforced to ensure maintenance as well as future expansion of the species.

Résumé. Mise à jour de la répartition d'*Urothemis edwardsii* (Selys, 1849) (Odonata : Libellulidae), en danger critique d'extinction dans le nord-est de l'Algérie. Évaluer les changements temporels de la répartition des espèces menacées est primordiale pour une gestion efficace de leur conservation. Les espèces menacées sont sensibles aux modifications de l'environnement et pourraient disparaître rapidement en raison des effets climatiques et anthropiques. Dans ce travail, nous étudions la répartition d'*Urothemis edwardsii*, localement en danger critique d'extinction dans le nord-est de l'Algérie, où l'espèce s'est rétablie au cours de la dernière décennie après avoir été confinée à une seule localité depuis les années 1990. Au cours des saisons de vol de 2018, 2019 et 2021, nous avons mené des observations sur le terrain, enregistrant le nombre de mâles, de femelles et de couples reproducteurs sur 15 sites dans le parc national d'El Kala au nord-est de l'Algérie (province d'El Taref). Nous avons trouvé l'espèce dans sept sites ; sa reproduction a été confirmée dans quatre. Dans deux des sites, l'espèce a été nouvellement enregistrée mais n'a montré aucun signe de reproduction. Nous avons confirmé le maintien des populations reproductrices récemment découvertes. Bien que l'état de conservation local de l'espèce soit meilleur que dans les années 90, il existe encore différentes menaces qui doivent être prises en compte et des mesures de conservation doivent être mises en œuvre ou renforcées pour assurer le maintien ainsi que l'expansion future de l'espèce.

Keywords: distribution range; dragonfly; El Kala; Odonata; protected area; threatened

The geographic distribution of species is governed by historical, extrinsic, and intrinsic factors (Gaston 2009). Habitat availability is a crucial determinant of species' geographic ranges as they can live and persist in habitats where their niches are fulfilled. In addition, some species have attributes that confer to them a greater ability to occupy a larger space such as greater tolerance for the abiotic environmental conditions and higher dispersal ability (Calosi et al. 2010; Angert et al. 2011). At its margins, the geographical range of a species is typically

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fragmented into different spatial entities (Pironon et al. 2015). However, sometimes some species can have isolated populations far from their main geographic range (Habel & Assmann 2014). Understanding the range and population dynamics of these relict populations is important in the management and maintenance of them.

In North Africa, ecological barriers such as the Mediterranean Sea and Sahara Desert have isolated populations of various taxa from their core geographic range (Khelifa et al. 2021b). In odonates, for instance, three afrotropical species, *Pseudagrion sublacteum* (Karsch, 1893), *Acisoma inflatum* (Selys, 1889), and *Urothemis edwardsii* (Selys, 1849) that have large geographic ranges in central and southern Africa have only a few isolated populations either in Algeria or Morocco (Boudot et al. 2009). *Urothemis edwardsii* is a good example of a local relict species that has witnessed a severe population decline during the last century (Riservato et al. 2009). The species used to occur in separate localities in North Africa with some populations showing phenotypic variation from the core population (Riservato et al. 2009). However, almost all of these populations have been extirpated, most likely due to anthropogenic factors (e.g. drainage of wetlands). Until the early 1990s, the species was restricted to a single location in northeastern Algeria in the National Park of El Kala. More recently, a restoration scheme resulted in a rapid increase in the geographic distribution of the species. It successfully reproduced in different locations (Khelifa et al. 2016, 2018).

While a large number of studies on the odonates of the region have been carried out (Razkallah & Houhamdi 2018; Hadjadji et al. 2019; Halassi et al. 2021), including those on threatened species (Zebsa et al. 2014; Mahdjoub et al. 2015; Zebsa et al. 2015; Chelli et al. 2019; Baaloudj 2020), less attention has been paid to *U. edwardsii* despite it being the most threatened odonate in the area. Although we currently have more information on the habitat preferences, taxonomy, reproductive behavior and conservation status of the species (Khelifa et al. 2013a, 2013b, 2016; Baaloudj 2019), we still urgently need an update on the local geographic range of this relict species. In this study, we carried out surveys on the geographic distribution of the species based on three years of data collection (2018, 2019, and 2021) across a set of sites that have previously been visited (presence/absence data available). We discuss the historical change in the geographic range of the species in northeastern Algeria during the last 32 years (1989–2021) and attempt to explain the causes of the restricted distribution.

Material and methods

Study area

The study focuses on the extreme northeastern Algeria (El Taref province) which includes the National Park of El Kala (36.64°N 8.28°E). The climate is one of the wettest in North Africa. It is typically Mediterranean with an annual rainfall of 710–910 mm. The wet season lasts from October to March and the dry season from April to September. The National Park has a large spectrum of wetlands of international importance; a large number of waterbirds breed and overwinter there. It also hosts many threatened odonates, including *Urothemis edwardsii*, *Acisoma inflatum*, and *Lindenia tetraphylla* (Vander Linden, 1825) (Khelifa & Zebsa 2018; Baaloudj 2020).

Sampling methods

We analyzed the 15 previously surveyed sites by Khelifa et al. (2016). In addition to these data, we performed field surveys of the occurrence of *Urothemis edwardsii* in all sites during the summer (June, July, and August) of 2018, 2019, and 2021 (Table S1 in the online supplemental material); each site was visited at least twice by two persons. We sampled each site from 10:00 to 16:00. At each site and on each visit, we recorded the total number of individuals (males and females) across a 100 m transect near the banks of the wetland. We also recorded whether reproduction occurred at each site by noting the presence of exuviae, tenerals, copulation, and oviposition.

Statistical analyses

Our spatial calculations and mapping were conducted using R 4.0.2 (R Development Core Team 2021). We used climate data from WorldClim v2 for 1980–2018 (2.5-minute spatial resolution) (Fick & Hijmans 2017). Based on all localities where the species was found, we extracted the average annual temperature and precipitation across sites. To estimate the area within which the species exists, we used the geographic locations of all sites where the species currently exists, drew a polygon across sites, and estimated the area of the polygon. To produce maps, we used the raster (Hijmans et al. 2015), sf (Pebesma 2018), and sp (Pebesma et al. 2012) packages.

Results

Climate of the coastal region

The average annual temperature of the sites was 18.4°C, which is relatively low compared to the national thermal landscape (Figure 1A, B). The average annual precipitation was 890.4 mm, which is a very high value compared to the national geographic distribution of precipitations (Figure 1C, D). Wet areas are restricted to the northern part of the country, and the species is restricted to the northeastern section, particularly in El Taref province (Figure 2).

Historical change in geographic range

Across the entire period from 1989 to 2021, *Urothemis edwardsii* was recorded at seven out of the 15 sites. In 1989, it was found at Lake Bleu and Lake Noir. After severe degradation of Lake Noir due to drainage and fire, the species was restricted to a single location in 1991

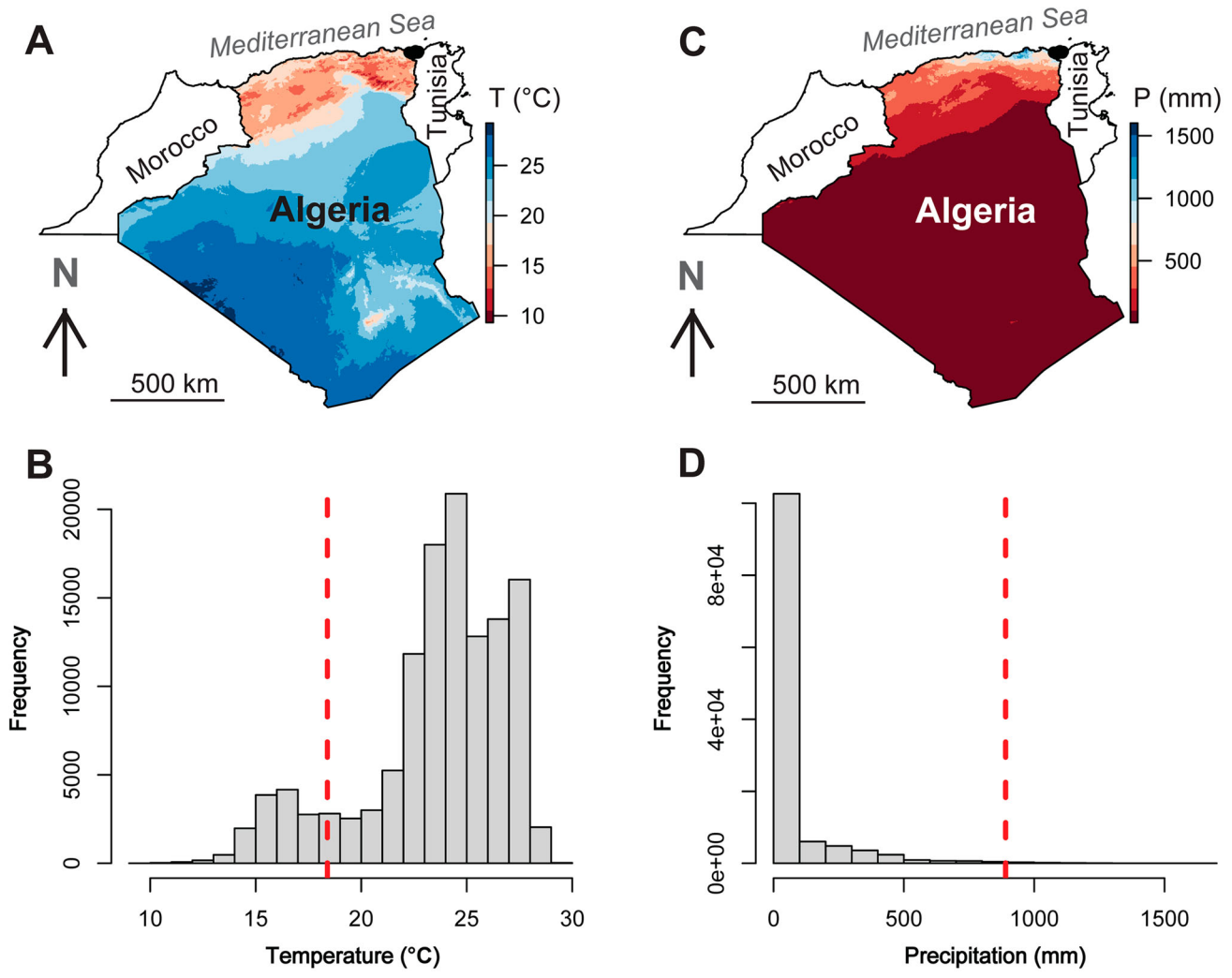

Figure 1. Climatic conditions in Algeria with the distribution of *Urothemis edwardsii* at the national scale. **A,** Map of the annual average temperature; **B,** frequency distribution of annual average temperature in Algeria indicating the average temperature across the sites of *U. edwardsii* as a vertical dashed line; **C,** map of the annual precipitation; **D,** frequency distribution of annual precipitation in Algeria indicating the average annual precipitation across the sites of *U. edwardsii* as a vertical dashed line.

(De Belair & Samraoui 1994). From 1991 to 2006, there were no other records, but only a false negative (i.e. undetected during surveys despite its presence) that suggested that the species was probably extinct. There were no records until 2011 when the adults of Lake Bleu were found again, confirming the existence of the species. The restoration scheme initiated during that year, aiming at expanding the species range with translocations in Lake Tonga and Lake Noir, led to the subsequent discovery of the species there in 2012. In 2015, the species was recorded at a new site, El Graeate 2, which is 2.5 km from Lake Noir. This was the first confirmed natural dispersal of the species in northeastern Algeria. Therefore, until 2015, only three populations were still existing.

Between 2018 and 2021, we recorded the species at seven localities in six distinct wetlands (Table 1) but confirmed reproduction in only four of these (El Graeate 2, Lake Bleu, Lake Tonga NE, and Lake Tonga SW). In the rest of the sites, we found it only as single adults. We recorded two new localities, El Graeate 4 and Ruppia, where only adults were recorded (Figure 3). The largest distance between the localities was 26 km. The area of the sites varied between 0.21 ha (Ruppia pond) and 2700 ha (Tonga Lake). We found that the estimated area of the polygon drawn on species observed localities was 186 km² (Figure 2).

Discussion

We presented here the first comprehensive, up-to-date, historical dynamics of the geographic range of *Urothemis*

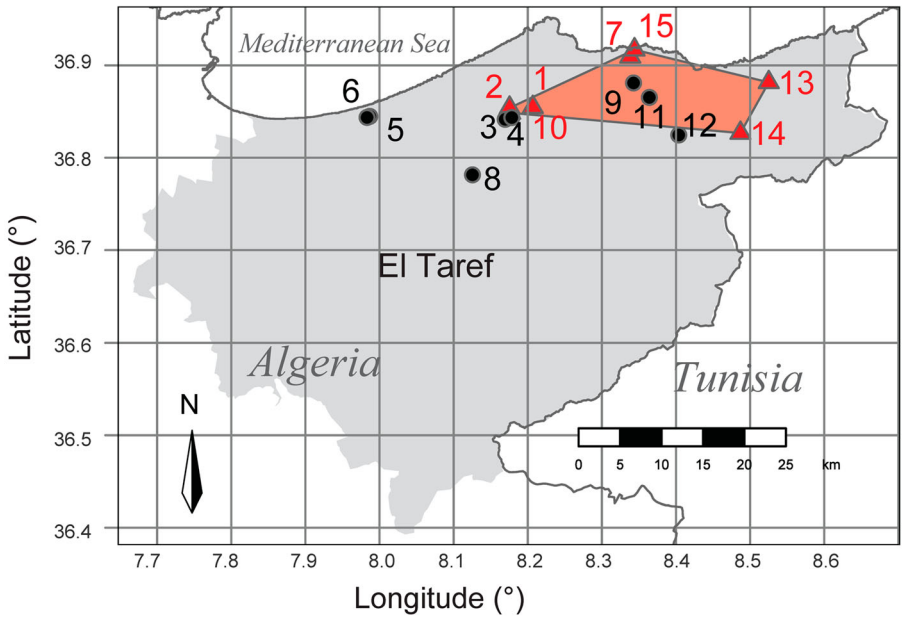

Figure 2. Study sites and the geographic distribution of *Urothemis edwardsii* within El Taref province (northeastern Algeria). Triangles are sites where the species was recorded; black points are sites where it was not. The polygon is the area surrounding the sites where the species was recorded, indicating its local range.

Table 1. Historical records and geographic coordinates of the study sites.

Code	Site	Geographic coordinates	Historical records	Area (ha)
1	El Graeate 1	36.8485°N, 8.1762°E	0	10
2	El Graeate 2	36.8539°N, 8.1754°E	1	35
3	El Graeate 3	36.8415°N, 8.1695°E	0	1.3
4	El Graeate 4	36.8434°N, 8.1785°E	1	3.2
5	G. Dakhla	36.8448°N, 7.9868°E	0	6.2
6	G. Estah	36.8436°N, 7.9831°E	0	3.6
7	Lake Bleu	36.9092°N, 8.3382°E	1	2
8	Lake des oiseaux	36.7814°N, 8.1254°E	0	70
9	Lake Mellah	36.8809°N, 8.3427°E	0	873
10	Lake Noir	36.8547°N, 8.2068°E	1	2.2
11	Lake Oubeira 1	36.8652°N, 8.3640°E	0	2198
12	Lake Oubeira 2	36.8245°N, 8.4037°E	0	2198
13	Lake Tonga NE	36.8816°N, 8.5251°E	1	2700
14	Lake Tonga SW	36.8266°N, 8.4869°E	1	2700
15	Ruppia	36.9169°N, 8.3440°E	1	0.21

edwardsii in northeastern Algeria. We show that the dragonfly has recently expanded its local geographic distribution considerably in this region and that the recently discovered populations were being maintained. We add new localities but no new reproducing populations in addition to El Graeate 2, Lake Bleu, Lake Noir and Lake Tonga. We discuss the implications of our historical account and present useful information about the geographic distribution for the management of this threatened population.

The species shows clear dispersal limitations that might be explained by at least two hypotheses. First, it is likely that *U. edwardsii* has limited movement mobility. Previous reports pointed out that the adults at Lake Bleu stray up to 1.2 km (Khelifa et al. 2016); distances exceeding this magnitude were not reported. The same study assessing the likelihood of dispersal between Lake Bleu and Lake Noir (13 km apart) based on the marking of 102 individuals at the former site and 49 at the latter site found no evidence of movement from one site to another. The second hypothesis is that there is a lack of nearby wetlands that provide the ecological requirements of the species. This hypothesis is strengthened by the presence of an array of small ponds in the area to which the species could potentially disperse, but where it has never been recorded (Khelifa et al. 2018).

Figure 3. Male adult *Urothemis edwardsii* in Graeate 4, National Park of El Kala, Algeria.

Some of the largest sites that could have hosted a large population are Lake Oubeira (2200 ha), which unfortunately has been severely degraded after the introduction of Eurasian carp (*Cyprinus carpio* Linnaeus, 1758) (Stevenson et al. 1988). Both hypotheses stated above are plausible and present serious problems for the long-term maintenance of the species in scenarios where extreme climatic conditions and anthropogenic perturbation lead to drought and potentially the extinction of populations.

There is a strong likelihood that the long isolation of *U. edwardsii* in North Africa distant from its main home range led to genetic changes that shaped both its dispersal ability and habitat preferences. In southern Africa, the species can colonize artificial ponds, establish large populations and seems to tolerate anthropogenic pressure (Suhling et al. 2003). Future genetic studies on different populations will reveal potential genetic differentiation similar to that recorded between Northern African and European populations of Palearctic species, e.g. *Pyrrhosoma nymphula* (Sulzer, 1776), *Coenagrion mercuriale* (Charpentier, 1840) and *Aeshna cyanea* (Müller, 1764) (Guan et al. 2013; Froufe et al. 2014; Swaegers et al. 2014; Ferreira et al. 2016; Simonsen et al. 2020).

Understanding species' habitat suitability using methods such as niche modeling or occupancy modeling is necessary to plan management plans that potentially increase population resilience (e.g. artificial sites) or translocation schemes into suitable areas of western Algeria. The central east coastal region near Jijel has a wet climate similar to that of the National Park of El Kala. Some wetlands there already host populations of the Afrotropical *Acisoma inflatum*, which often coexists with *U. edwardsii*, suggesting that the ecological niche for the latter could be available. Careful planning for the success of such transplants will increase the resilience of the species to climate change and anthropogenic pressure that are expected to increase in lotic and lentic areas in the coming decades (Khelifa et al. 2021a, 2021b).

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No potential conflict of interest was reported by the author(s).

Supplemental data

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