RESEARCH ARTICLES
ОРИГИНАЛЬНЫЕ СТАТЬИ

PHENOLOGY OF THE REGIONALLY CRITICALLY ENDANGERED DRAGONFLY *UROTHEMIS EDWARDSII* IN THE NATIONAL PARK OF EL KALA, NORTHEAST OF ALGERIA

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In the Mediterranean, *Urothemis edwardsii* is one of the most threatened dragonfly species with a relict population restricted to the northeast of Algeria. Despite the recent subtle local expansion in the geographic distribution of the species during the past decade, studies on the life history of the species are still lacking. We carried out a study on the phenology of emergence and flight season on Lake Bleu, Northeast-Algeria. Using repeated sampling of exuviae and marking of adults during two seasons (2018 and 2019), we estimated the population size, sex ratio, and the temporal pattern of emergence and flight season. The first year (2018) was considerably drier than the second year (2019). We collected a total of 576 and 887 exuviae and 711 and 655 adults in 2018 and 2019, respectively. The sex ratio at emergence was slightly female-biased with 57.1% in the first year and equal to unity (50.5%) in the second year, respectively. The species started its emergence earlier in the dry year (2018). The emergence of the species was quite asynchronous where 50% of the population emerged after 11 days and 16 days in 2018 and 2019, respectively. The difference in population size (based on exuviae) and the temporal pattern of emergence and flight season were likely due to differences in weather between the two years. The current study provides useful information on the life history and plasticity of *U. edwardsii*, which could be used for the management of this locally Critically Endangered dragonfly.

Key words: adult, exuvia, life history, North Africa, Numidia, Odonata, Protected Area, threatened

Introduction

Biodiversity loss of insects has sparked a debate across the world (Wagner, 2020; Jähnig et al., 2021). Scientists agree that climate change, habitat loss, and other anthropogenic stressors have driven extirpations of insect populations and potentially the extinction of multiple species (Hallmann et al., 2021; Raven & Wagner, 2021). Currently, there are several populations at the brink of extinction at local or global scale, which warrants particular attention to protect them in order to maintain global biodiversity and ecosystem services (Schowalter et al., 2018; Samways et al., 2020). However, the conservation of species requires an understanding of habitat requirements, behaviour, and life history to establish an effective conservation plan (Samways et al., 2010).

The conservation of relict populations (distant populations from the core geographic range) is crucial because they bear a wealth of ecological and evolutionary information to scientists (Habel & Assmann, 2010; Habel et al., 2010). For example, they represent living examples of the impact of major geological and climatic events on biodiversity (Hampe & Petit, 2005). They also explain a lot of the phenotypic and genetic variation, and represent good models to study allopatric speciation (Cronk, 1997; Joger et al., 2010; Spikkeland et al., 2016). However, relict populations are very sensitive and their conservation is challenging because of the typically small population size, absence of immigration, and low potential of geographic shift.

Odonates are a relatively diverse group of aquatic insects with about 7000 species worldwide (Kalkman et al., 2008). Although they have good dispersal abilities, many species have relict populations that are distant from the core geographic range (Riservato et al., 2009). In Africa, a few examples exist in the North where small populations of dragonflies (*Acisoma inflatum* Selys, 1882 and *Urothemis edwardsii* (Selys, 1849)) and damselflies (*Pseudagrion sublacteum* (Karsch, 1893)) exist far from the core African populations (Khelifa et al., 2021a). *Urothemis edwardsii*, in particular, is restricted to the northeast of Algeria. A decade ago, the distribution of the species was limited to a single location, but more recently, the species was recorded in different locations locally (Khelifa et al., 2016, 2018). Although some aspects of the behaviour and ecology of *U. edwardsii* have been studied (Khelifa et al., 2013a,b), studies on its emergence are still very limited (Baaloudj, 2019).

In this study, we have assessed the temporal pattern (phenology) of emergence and flight season of *Urothemis edwardsii* for two years (2018–2019) on Lake Bleu, Northeast-Algeria. We specifically conducted regular collections of exuviae and marking of adults during the emergence and flight season of 2018 and 2019; then we estimated the population size, sex ratio, and temporal patterns. The study is crucial for the establishment of a conservation plan for the species in Northeast-Algeria.

Material and Methods

Study site

The study was conducted on Lake Bleu, located in the National Park of El Kala, Northeast-Algeria (Fig. 1). Lake Bleu is an integral reserve of 0.02 km^2 large. Overall, the climate is typically Mediterranean with a wet season from October to March and a dry season from April to August/September. The average temperature varies between 8°C and 29.7°C and the annual rainfall is 717–944 mm. The wetland is surrounded by stands of *Schoenoplectus lacustris* (L.) Palla, *Typha angustifolia* L., *Lythrum salicaria* L., *Phragmites australis* (Cav.) Trin. ex Steud., and *Cladium mariscus* (L.) Pohl. About 20% of the wetland area is covered with a belt of floating *Nymphaea alba* L. The wetland harbours a diverse odonate fauna (13 dragonflies and five damselflies).

Sampling protocol of exuviae

Prior to the start of the emergence season, we performed weekly visits to the site in May to determine whether the emergence/flight season had started. We selected the southern part of the wetland which was previously shown to host the emerging population (Khelifa et al., 2018). We chose a 15 × 2 m^2 stretch that was carefully checked for exuviae at each visit. To avoid trampling effects on the wetland, only one person performed exuviae sampling and used the same walking path on every sampling occasion. Sampling took place during the emergence season of 2018 (from 31 May to 05 August) and 2019 (from 14 June to 16 August), performing a total of 22 and 19 sampling days in 2018 and 2019, respectively. Sampling was done daily during the peak of emergence, but only weekly afterward when the frequency of exuviae had declined drastically. Although it is likely that we missed some exuviae due to non-detection (DuBois, 2015) or exuviae loss due to weather conditions (e.g. wind, rain) (Lubertazzi & Ginsberg, 2009), these partial losses should not have changed the temporal pattern of emergence of the species. During each visit, all detected exuviae were collected and put in a box for sex identification in the laboratory. Using counts of exuviae collected across the season, we were able to determine the temporal pattern (phenology) of emergence and calculate some emergence metrics. EM10, EM50, and EM90 were calculated as the total number of days when 10%, 50%, and 90% of the collected exuviae were recorded. We used the identification key of Khelifa et al. (2013b) to identify exuviae of *U. edwardsii*.

Sampling protocol of adults

We carried out regular captures of adult odonates across a transect of 100 m near the bank of the southern part of the wetland from 31 May to 03 August in 2018 (25 sampling days) and 14 June to 23 August in 2019 (19 sampling days). Adults were captured with a hand net, measured with an electronic caliper (adult size data are not included here), marked with a permanent marker, and released at the same location. Because the number of recaptures was very low, the temporal pattern of flight season was derived from the total number of captures. Similarly to EM (EM10, EM50, EM90), we calculated AD10, AD50, and AD90 as the total numbers of days when 10%, 50%, and 90% of the marked individuals were recorded.

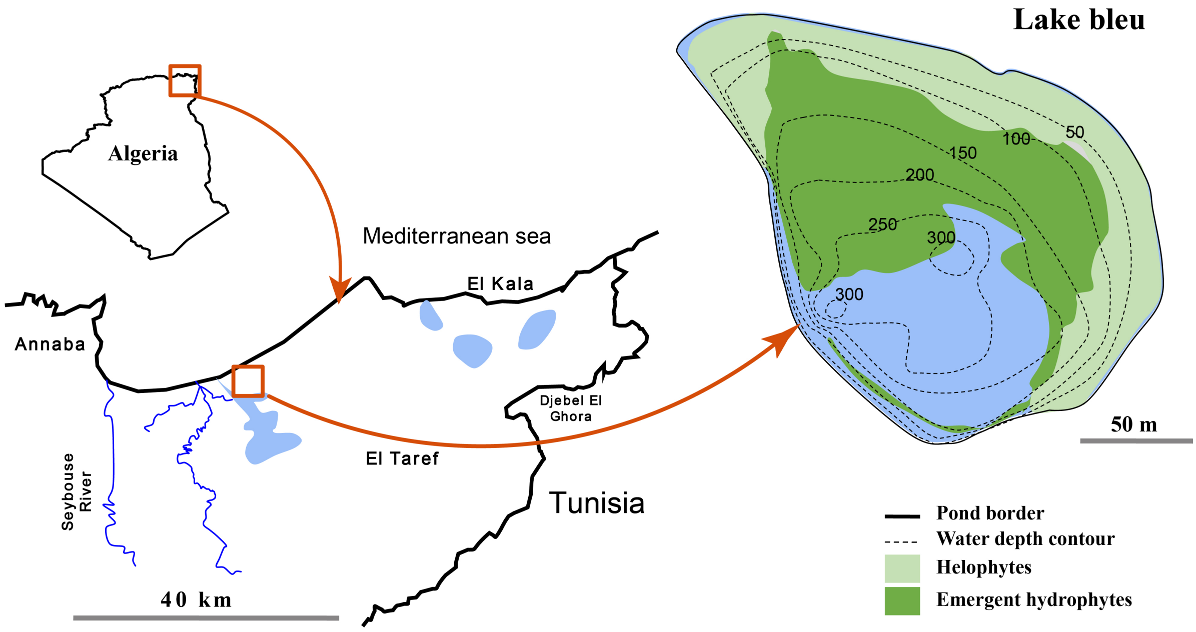

Fig. 1. Map showing the geographic location of Lake Bleu in Northeast-Algeria. The closeup of Lake Bleu shows the bathymetry of the wetland in cm.

Statistical analyses

Our statistical analyses were conducted using R 4.0.2 (R Development Core Team, 2021). We tested whether daily average temperatures were significantly different between the two years using a t-test. We compared the temporal pattern of the phenological distribution of emergence among sexes and years using a Two-sample Kolmogorov-Smirnov test. We also tested if the sex ratio at emergence deviated significantly from 1:1 using chi-square tests. Values are mean ± SD.

Results

Weather conditions

The two studied years had different weather conditions. Although the daily average temperature was not significantly different in the two years (t-test: t = -1.029, df = 709.8, p-value = 0.30), the cumulative daily average temperature was higher during 2019 compared to 2018 (Fig. 2a). During autumn (from 01 September to 30 November), the cumulative average temperature was 6.8% higher in 2019 (1728°C vs. 1854°C). During autumn – winter (from 01 September to 28 February), it was 3.7% higher in 2019 (2827°C vs. 2926°C). Combining autumn, winter, and spring (from 01 September to 31 May), both years showed similar cumulative average temperatures (4345°C vs. 4331°C). Precipitations were more frequent in 2019 than 2018 (Fig. 2b). In autumn (01 September to 30 November), the cumulative precipitation was higher by 37.6% in 2019, and combining autumn, winter, and spring (from 01 September to 31 May), the cumulative precipitation was 13.1% higher in 2019 than in 2018.

Temporal pattern of emergence

A total of 576 and 887 exuviae were collected during the emergence season of 2018 and 2019, respectively. Sex ratio at emergence was slightly female-biased in 2018 (57.1%, $X^2 = 11.6$, $p = 0.0006$) but did not deviate from unity in 2019 (50.5%, $X^2 = 0.9$, $p = 0.76$). The phenology (temporal disribution) of emergence was significantly different between the two years (Two-sample Kolmogorov-Smirnov test: $D = 0.64$, $p < 0.0001$). EM10, EM50, and EM90 were five days, 11 days, and 39 days in 2018, and four days, 18 days, and 36 days in 2019 (Fig. 3).

Temporal pattern of adults

A total of 711 and 655 adults were captured during the emergence season of 2018 and 2019, respectively. The sex ratio at the flight season was highly male-biased in both 2018 (83.5%, $X^2 = 320$, $p < 0.0001$) and 2019 (80.3%, $X^2 = 240.6$, $p < 0.0001$). The phenology (temporal distribution) of the flight season was significantly different between the two years (Two-sample Kolmogorov-Smirnov test: $D = 0.29$, $p < 0.0001$). AD10, AD50, and AD90 were nine days, 23 days, and 67 days in 2018, and five days, 16 days, and 43 days in 2019 (Fig. 4).

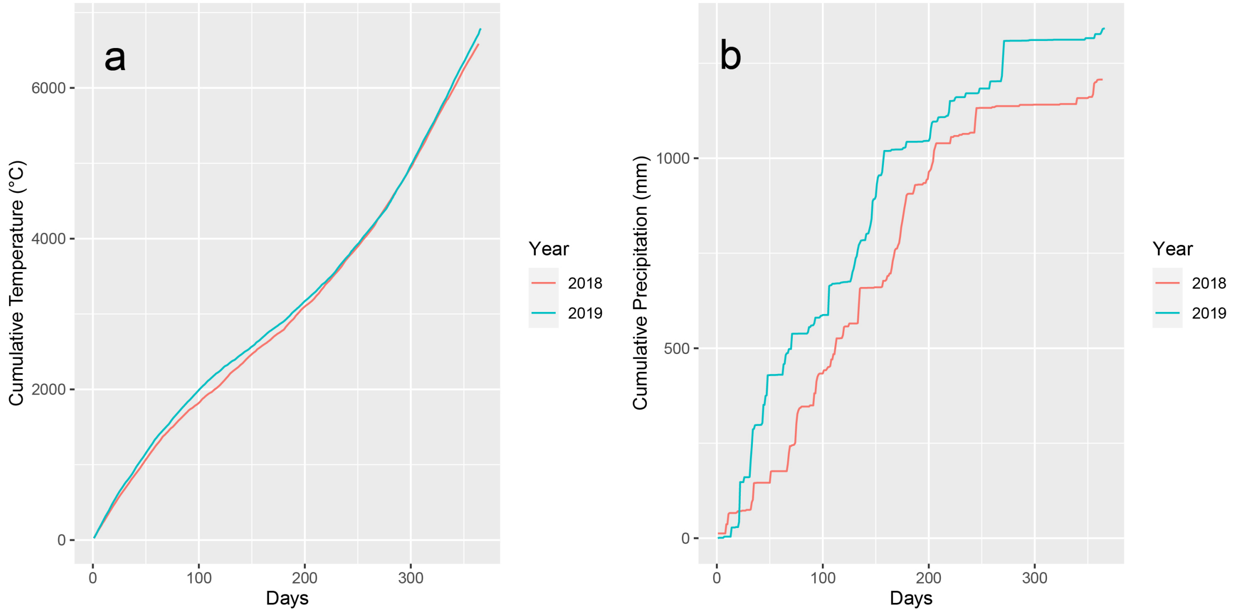

Fig. 2. Cumulative daily average temperature (a) and precipitation (b) in the study region in 2018 and 2019. Data were obtained from a weather station 35 km from the study site (Tebarka, Tunisia). The first day is 01 September, which is relevant to the life history of dragonflies.

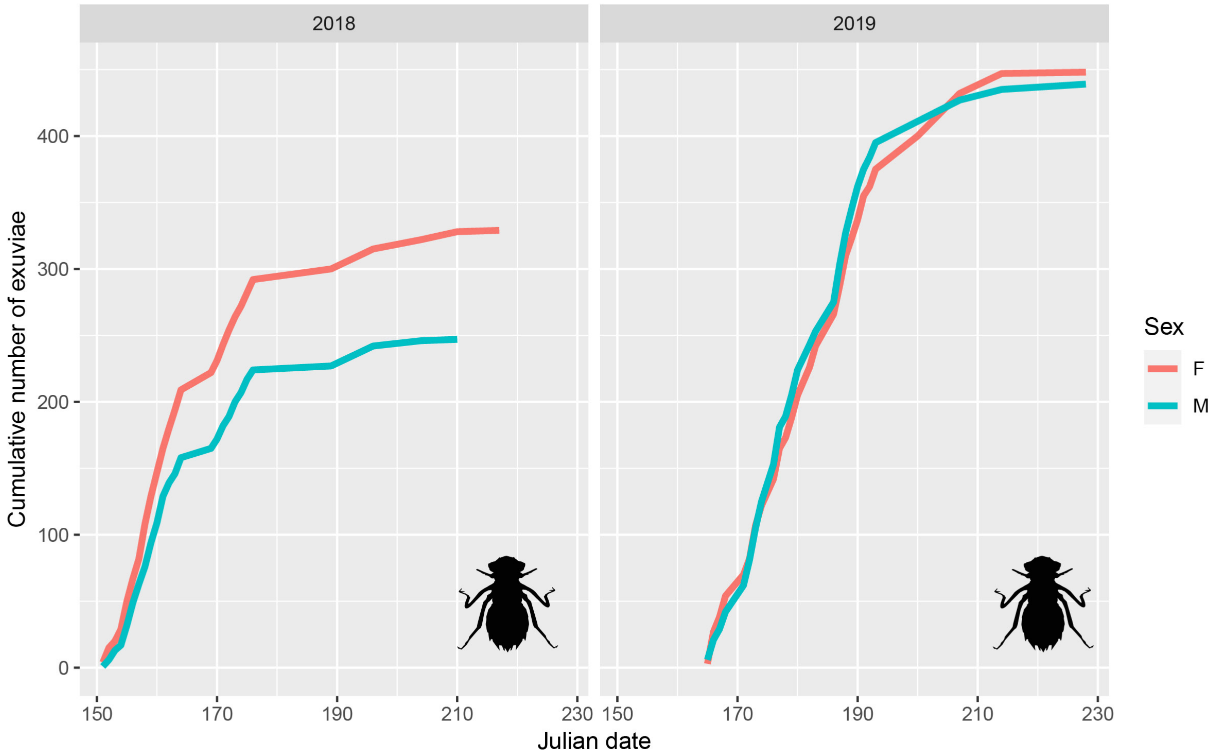

Fig. 3. Cumulative number of exuviae of *Urothemis edwardsii* on Lake Bleu in 2018 and 2019.

Discussion

The current study has investigated the phenology of emergence and flight season of *U. edwardsii* in Northeast-Algeria, particularly in the type population (Lake Bleu). Our data show that the species has an asynchronous and relatively long emergence and flight season. The sex ratio at emergence was equal with a slight bias towards females, particularly in the dry year. The sex ratio at the adult stage was highly male-biased. Based on the estimates obtained from exuviae collections during 2018–2019, we recorded a larger populations size in the wetter year (2019). This is the first study using extended data collections on the emergence of *U. edwardsii* on Lake Bleu.

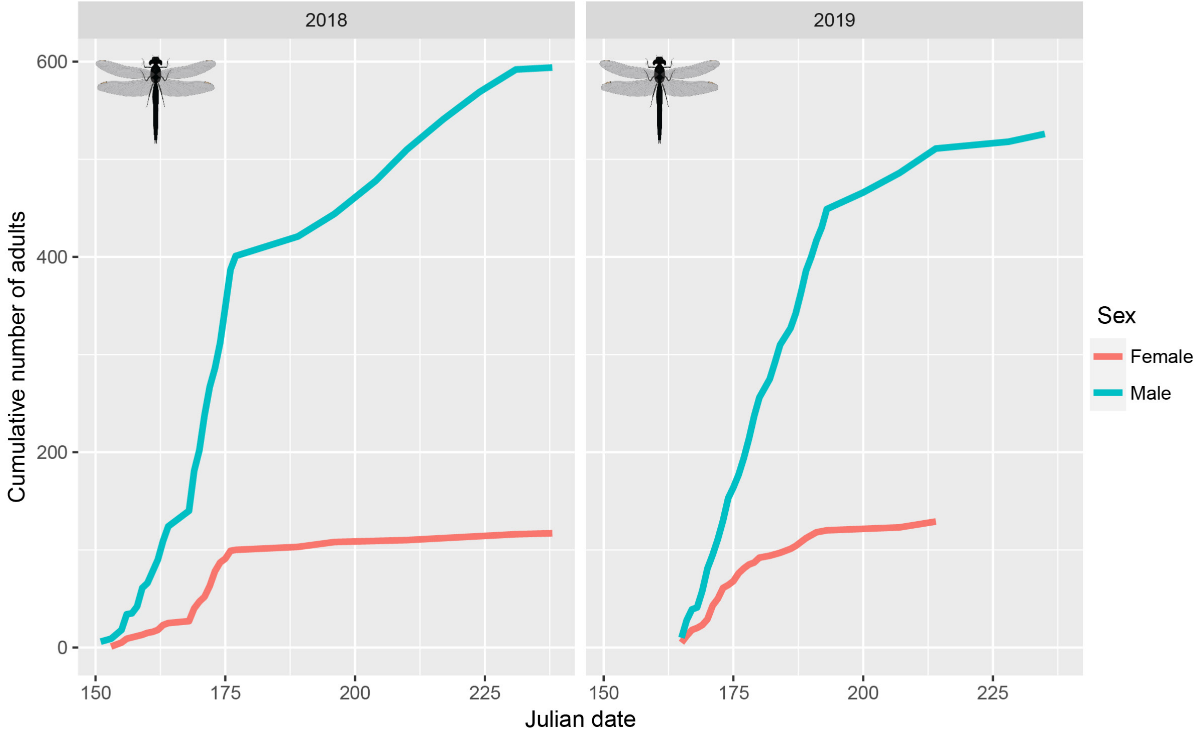

Fig. 4. Cumulative number of male and female adults of *Urothemis edwardsii* on Lake Bleu in 2018 and 2019.

The studied two years had different weather conditions, which allowed us (to a certain extent) to assess how weather affects the phenological distribution of the species. The year 2018 was drier but slightly cooler than 2019. The weather has an important influence on the life history of odonates (Hassall & Thompson, 2008; Frances et al., 2017; McCauley et al., 2018). Studies have shown experimentally that odonate larvae grow faster and emerge earlier under warmer conditions (Lutz, 1974; Pickup & Thompson, 1990), which explains the phenological shift that has been recorded during the past decades (Hassall et al., 2007; Dingemanse & Kalkman, 2008). While a lot of studies have worked on the impact of temperature on life history of odonates, drought has received less attention. There are empirical studies showing that a decline in water level pushes aquatic species to emerge earlier (Leips et al., 2000). Although our study was based only on two years, the observed earlier emergence and flight season of adults which was recorded under dry conditions based on the start (EM10) and the median (EM50) of the phenological distribution goes in line with empirical evidence. Another non-mutually exclusive hypothesis is that the changes in weather conditions might yield changes in not only the biotic interactions (e.g. predation, competition), but also the anthropogenic impacts (e.g. pollutants concentrations), inducing a life history response that contributes to the timing of emergence (Stoks et al., 2008).

Yearly variation in the temporal pattern of emergence is common in dragonflies (Cham, 2012). The recorded EM50 in *U. edwardsii* (11–18 days) was shorter than the one observed for the same species in El Graeate in 2016 (23 days), 15 km away (Baaloudj, 2019). This difference in EM50 might be due to weather differences between years as well as other abiotic and biotic conditions (predation and competition). The El Graeate pond is 15 times larger than Lake Bleu, which suggests that the local community composition is different (Doi et al., 2009). In addition, the El Graeate site is also thought to host a larger population of *U. edwardsii* (Khelifa et al., 2018), suggesting distinct intraspecific competition. EM50 of *U. edwardsii* was quite different than those estimated for other Libellulidae studied in Northeast-Algeria, namely *Sympetrum meridionale* (Selys, 1841) (16 days) (Hadjadji et al., 2019), the Afrotropical *Acisoma inflatum* (25 days) (Baaloudj, 2020), and *Orthetrum cancellatum* (Linnaeus, 1758) (20 days) (Hadjoudj et al., 2014). The overall asynchronous emergence pattern was typical of a «summer species» (Corbet, 1954).

There was a difference in the sex ratio at emergence between the two years. The sex ratio was female-biased in the drier year and equal in the wetter year. A female-biased sex ratio in dragonflies is common (Corbet & Hoess, 1998; Cordero-Rivera & Stoks, 2008), but it might change from one year to another. The recorded female bias was similar to that observed in the same species in El Graeate (54.1%) (Baaloudj, 2019). It is likely that males have experienced a higher mortality due to differences in behaviour. At the adult stage, the sex ratio was highly male-biased in both years, which is typical for dragonflies in North Africa (Khelifa et al., 2012; Zebsa et al., 2015), and elsewhere (Corbet, 1999; Cordero-Rivera & Stoks, 2008). This difference in sex ratio is due to sexual habitat segregation where females stay away from the water whereas males stay near the water, guarding territories and waiting for mates (Foster & Soluk, 2006; Khelifa et al., 2013a).

Estimating the population size for the species and understanding habitat segregation between sexes have important conservation implications given the critically threatened status of the species (Foster & Soluk, 2004, 2006). Based on our exuviae and adult sampling within a restricted area during the two years, we collected a total of 576–887 exuviae and 655–711 adults. Population estimates based on exuviae reflect the real number of individuals that actually emerged from the site (Raebel et al., 2010). The larger population size recorded in 2019 was probably due to the wetter conditions all along the development season. The collected number of exuviae remains a subset of the real population size of the species on Lake Bleu. We carried out capture-mark-recapture (not presented here) and found a low recapture rate, similar to Khelifa et al. (2016), suggesting a large population size and a low tendency of remaining at the same location. Earlier estimations of the population size of the species on Lake Bleu yielded a total of about 3200 exuviae (Khelifa et al., 2018), which is reasonable, based on our exuviae sampling and observation of adults.

Conclusions

While *U. edwardsii* has shown a promising population expansion during the past decade (Khelifa et al., 2016; Baaloudj, 2019), close attention to its status and geographic range dynamics should be paid. Climate change in North Africa is a major threat for the species in the next few decades (Khelifa et al., 2021a), particularly because the species seems to exist in permanent wetlands. The projected decline in precipitation and increase in temperature extremes will likely change the hydroperiod of wetlands and alter the ecological integrity of freshwater ecosystems (Khelifa et al., 2021b; Xi et al., 2021). Our lack of understanding of why the species seems to struggle to disperse and establish new populations similar to populations in the core range of the species and other Afrotropical species is a crucial knowledge gap and an important research avenue to tackle in the next years. Also, identifying the terrestrial habitats where the females spend most of their time is urgent (Foster & Soluk, 2006). Unfortunately, there is a lack of funding to perform the essential steps to develop management plans to restore habitats and expand species distribution (Samways et al., 2010), including establishing longterm monitoring schemes for the species to estimate the geographic range at the fine scale, estimating population size in Northeast-Algeria, and understanding habitat preferences.

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ФЕНОЛОГИЯ *UROTHEMIS EDWARDSII*, НАХОДЯЩЕГОСЯ НА ГРАНИ ИСЧЕЗНОВЕНИЯ В РЕГИОНЕ, В НАЦИОНАЛЬНОМ ПАРКЕ ЭЛЬ КАЛА, СЕВЕРО-ВОСТОК АЛЖИРА

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В Средиземноморском регионе *Urothemis edwardsii* является одним из наиболее угрожаемых видов стрекоз, ареал реликтовой популяции которого ограничен северо-востоком Алжира. Несмотря на недавнее незначительное локальное расширение ареала этого вида в течение последнего десятилетия, исследований онтогенеза *U. edwardsii* все еще недостаточно. Мы провели исследование фенологии вылета и сезона лёта на озере Блю (Северо-Восточный Алжир). Используя повторный сбор образцов экзувиев и маркировку взрослых особей в течение двух сезонов (2018 и 2019 гг.), мы оценили размер популяции, соотношение полов и временную структуру вылета и сезона лёта. Первый год (2018) был значительно суше, чем второй (2019). Всего мы собрали 576 и 887 экзувиев и 711 и 655 имаго в 2018 и 2019 гг. соответственно. Соотношение полов на момент вылупления было слегка смещено в сторону самок: 57.1% в первый год и примерно было равным (50.5%) во второй год исследования, соответственно. Лёт вида начинался раньше в засушливый год (2018), и был довольно асинхронным: 50% популяции появилось через 11 и 16 дней в 2018 г. и 2019 г. соответственно. Разница в размере популяции (на основе изучения экзувиев), характере времени вылета и сезона лёта, вероятно, была связана с различиями в климатических условиях между двумя годами. Настоящее исследование содержит полезную информацию об онтогенезе и пластичности *U. edwardsii*, что может быть использовано для управления популяцией этой стрекозы, находящейся в регионе на грани исчезновения.

Ключевые слова: Odonata, имаго, Нумидия, онтогенез, особо охраняемая природная территория, Северная Африка, угрожаемый вид, экзувий