

Short-term trends, trend drivers and conservation status of *Onychogomphus boudoti*.

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Abstract

Onychogomphus boudoti is the only dragonfly species strictly endemic to Morocco and simultaneously listed as Critically Endangered on the IUCN Red List. Its entire known global population is confined to rheocene springs and headwater streams of the Oum Er Rabia (= Oum Errabiâ = Um Er Bia) catchment in the tabular Middle Atlas of Khenifra Province. Systematic field surveys conducted in May and June 2024 across 25 previously or newly identified localities revealed a substantial decrease in occupancy compared to 2022 surveys, with confirmed autochthony dropping from 20 to 9 localities — a statistically significant drop of approximately 53–55% in two years. Four additional localities were identified during the 2024 campaign. A composite Spring Disturbance Index (SDI), combining five field-measurable metrics related to hydrological status, pastoral pressure, pastoral infrastructure, crenophilous vegetation cover, and downstream aquatic vegetation, was developed to quantify habitat disturbance across occupied sites. SDI values showed a significant negative correlation with altitude, with the highest disturbance levels concentrated below 1,300 m a.s.l. The observed population decline is driven by two interacting pressure factors, namely 1) an extended structural drought affecting Morocco during the 2019–2025 period, resulting in the complete drying out of seven spring localities, and 2) a too strong intensive livestock grazing degrading aquatic and riparian habitats quality across all known sites. These findings emphasize the strong need for an integrated monitoring and conservation program addressing both hydrological protection and pastoral management to secure the long-term viability of this critically endangered endemic species.

Introduction

Onychogomphus boudoti is one of eight dragonfly species of the family Gomphidae recorded in the Maghreb region, and until now the only strict and firmly established endemic gomphid species to Morocco (status of *G. maroccanus* needs further confirmation) (Dumont et al 2021). Following its description (Ferreira et al. 2014 ; Dumont et al. 2021, *O. boudoti* was listed as "Critically Endangered" on the IUCN Red List (Ferreira 2016), owing to its rarity (a single known locality at the time of its description, with a small population size), its narrow ecological requirements, and documented degradation of its habitat quality. Twenty-one additional localities were recorded between 2016 and 2022 (Van der Meer 2017; Durand 2023), all situated in the upper catchment of the Oum Er Rabia (= Oum Errabiâ = Um Er Bia) river basin (Khenifra Province, Moroccan Middle Atlas) and in comparable habitat types. In 2024, an experimental conservation program aimed at protecting rheocene springs in this region secured funding from the Critical Ecosystem Partnership Fund (CEPF), in partnership with the Donors' Initiative for Mediterranean Freshwater Ecosystems (DIMFE). Within this framework, field surveys were conducted at previously occupied localities as well as at new sites not previously surveyed. The results of this inventory provide information on short-term trends in the conservation status of *O. boudoti* and on the main pressure factors acting upon its sole known global population.

Material and Methods

Two survey sessions were conducted from 19 to 26 May 2024 and from 9 to 16 June 2024, corresponding to the optimal flight period of the species and maximizing detection probability at breeding habitats. Surveys targeted indicators of autochthony, including the presence of exuviae and freshly emerged imagines, as well as reproductive behaviors and evidence of breeding (oviposition, tandem pairs), across the 21 occupied localities recorded in June 2022, of which 20 with confirmed autochthony (Durand 2023). Two visits per session were carried out at each locality to confirm the local status of the species.

These surveys also targeted approximately thirty previously unsurveyed sites presenting potentially suitable biotopes for the species. Newly occupied localities were georeferenced, their elevation recorded, and their biological status was determined (autochthony and breeding status).

The 2024 survey results are compared with the 2022 baseline records to assess short term occupancy trends in terms of range extent and localities with confirmed autochthony.

Pressure factors associated with all sites occupied in 2022 and/or 2024 are also presented. Their characterization was based on five simple, easily measurable field metrics (Table 1). In the absence of a standardized disturbance index applicable to small headwater streams lacking woody riparian vegetation, we developed a composite Spring Disturbance Index (SDI) tailored to the specific constraints of our study system. This SDI integrated five field-measurable metrics selected for their ecological relevance to pastoral and hydrological disturbances in crenic environments. Each metric was recorded in situ during both survey sessions (May and June 2024) and reflects disturbance conditions solely during the emergence period and the early oviposition period. The SDI was calculated as the sum of five scores divided by the theoretical maximum (13), yielding a continuous index ranging from 0 (undisturbed habitat) to 1 (severely disturbed habitat). Although not externally validated, this approach is consistent with the methodological framework recommended for poorly documented spring ecosystems for which no transferable index currently exists (Gerecke et al. 2011 ; Cantonati et al. 2022), and draws on disturbance metrics documented in the literature for headwater habitats and springs (Hinterlang & Lischewski 1993 ; Stubbington et al. 2017).

The correlation between the SDI and occupancy status (ψ) was assessed using a Mann-Whitney test. A Spearman correlation was used to test the relationship between the SDI and the altitude of each locality. A Mann-Whitney test combined with a biserial correlation was applied to test the relationship between SDI values and the autochthony status of *O. boudoti*.

Results

Distribution and occupancy

The 2024 survey campaign recorded *O. boudoti* at 14 localities, all located within the tabular Middle Atlas zone of Khenifra, defining an Extent of Occurrence (EOO) of 13,342 ha (Figure 1). Four additional localities were identified during surveys conducted in 2024 at previously unsurveyed sites.

Between 2022 and 2024 a substantial deterioration in hydrological conditions was recorded at seven localities (1, 4, 5, 6, 8, 11, 14, 16), all of spring type, which shifted from permanent or low-flow regimes to complete drying out. The remaining 18 localities retained permanent flow over the study period, although reduced discharge was noted at localities 3 and 19. Localities 1, 4, 5, 6, 8 and 16 – all of which had dried up by 2024 – consequently lost their autochthonous populations (Table 2).

In 2024, the occupancy rate showed a marked decline, with 8/18 localities exhibiting confirmed autochthony ($\psi = 0.44$ [95% CI: 24.6–66.3%]) and 8/19 localities with confirmed breeding ($\psi = 0.42$ [95% CI: 23.1–63.7%]), respectively. This decline, on the order of 56 to 58% over two years, is statistically significant for both metrics (McNemar test: autochthony, $\chi^2 = 8.10$, $p = 0.004$; breeding, $\chi^2 = 9.09$, $p = 0.003$).

Pressure factors

The assessment of the 5 pressure factors was conducted at 24 of the 25 localities occupied by the species. Locality 9 was excluded, as the single observation made in 2022 most likely corresponds to a vagrant individual recorded near an aquatic habitat incompatible with the known ecological requirements of the species (Table 3).

For the period covered by the field surveys, the index value ranged from 0.15 to 0.77 (mean: 0.55; standard deviation: 0.19).

A significant negative correlation was found between the SDI and altitude (Spearman's $\rho = -0.694$, $p = 0.0002$, $n = 24$), with altitude alone explaining 49% of SDI variance ($R^2 = 0.49$). This relationship reflects a decrease in pastoral pressure with increasing elevation, with localities below 1,300 m a.s.l. recording the highest SDI values ($SDI \geq 0.62$), while localities above 1,400 m a.s.l. consistently displayed the lowest scores ($SDI \leq 0.23$).

The disturbance index differed significantly between localities with confirmed autochthony and those without (Mann-Whitney test: $U = 13.5$, $p = 0.019$, $r = 0.555$, $n = 18$). Occupied sites had a median SDI of 0.50, substantially lower than unoccupied sites ($Md = 0.70$ [95% CI: 0.54–0.77]). The point-biserial correlation confirmed this negative relationship ($r_{pb} = -0.584$, $p = 0.011$), with the SDI accounting for 34.2% of the variance in autochthony status. These results indicate that spring habitat disturbance, as quantified by the SDI, represents a significant determinant of autochthonous populations persistence across the locality network.

Discussion

The systematic comparison of the population status of *O. boudoti* detected in 2022 revealed that, within a two-year period, nearly 50% of localities had undergone local extinction, alongside a slight contraction of the species' extent of occurrence. These short-term temporal trends are unprecedented for the species given its recent description and the absence of any protocol-based population monitoring.

Nevertheless, they are consistent with the broader context of regional decline among lotic odonate species. Indeed, many dragonfly species associated with running waters in the Mediterranean biome are characterized by restricted ranges, a low overall number of occupied localities, and unfavorable conservation status (Riservato et al. 2009 ; Kalkman et al. 2018). Ferreira et al. (2015) estimated that nearly 45% of Moroccan populations of *Coenagrion mercuriale* have gone extinct in recent decades, whereas Boudot (2020) assessed this decline at 38% across the Maghreb as a whole. A similar situation has been documented in another lotic dragonfly species endemic to the Maghreb. Khelifa & Mellal (2017) demonstrated the disappearance of 77% of *Calopteryx exul* subpopulations within a single decade in the Seybouse River catchment, north-eastern Algeria. An identical extinction trajectory has also been documented in *Gomphus lucasii*, one of the two Gomphidae endemic to the Maghreb alongside *O. boudoti*. In this species, 90% of Tunisian populations are reported to have disappeared within a decade, and only 23% of historically known localities in Algeria are still occupied (Boudot 2010).

The results of the diachronic monitoring call for a critical assessment of the interpretive framework. Indeed, absence at a given locality may result from several distinct processes: definitive local extinction, a temporary demographic collapse linked to a drought episode, or imperfect detection (a potentially important source of bias for rare, low-abundance species). In the present case, intrinsic detection probability cannot be considered a significant source of bias, given the repeated visits conducted during the key activity periods of the species.

These trends must, however, be interpreted in the context of a shifting drought regime, marked by the onset of a phase of structural aridification in Morocco characterized by a simultaneous increase in the frequency, intensity, and spatial extent of droughts (Driouch 2010 ; Gumus et al. 2024). The 2019–2025 period was marked by a prolonged drought affecting the entire national territory, including high and mid-mountain zones (the High Atlas and Middle Atlas, respectively), which supply a substantial proportion of Morocco's water resources (Toreti et al. 2025). In these areas, the drought was reflected not only in a substantial deficit in rainfall but also in snowfall (snow cover extent and snowpack depth), consistent with trends observed over the 1961–2019 period in the neighboring province of Ifrane (Aboubi et al. 2025). In the province of Khenifra, field observations and numerous exchanges with shepherds and/or residents of this rural area attest the recent drying up of many snowmelt-fed springs. This climatic situation exerts considerable pressure on local communities and partly explains the unprecedented rural exodus currently underway in the country (Haut Commissariat au Plan, 2024).

The current rural population of the Khenifra region is predominantly relying on agriculture and livestock farming. As observed across Moroccan agricultural areas more broadly, the drying up of surface flows has driven large-scale groundwater exploitation since the early 1980s (Del Vecchio & Kuper 2021). While the mountain zones of the Moroccan Middle Atlas had until recently been relatively spared by this phenomenon, the proliferation of wells and the use of petrol-powered water pumps are likely to be contributing to an acceleration of the drying of small watercourses in the region (Fig. 2).

Furthermore, the reduction in surface water availability creates conditions conducive to overgrazing of these habitats. Grazing was recorded at all known localities of *O. boudoti*, with varying modalities on a case-by-case basis (intensity, livestock type, etc.), and with proportionally more pronounced impacts among lower-altitude populations (< 1,300 m a.s.l.). Through degradation of water quality and of aquatic and terrestrial habitats, overgrazing affects *O. boudoti* across the main stages of its life cycle (larvae, emergence, oviposition) (Fig. 3).

The critical situation calls for the establishment of a monitoring and integrated management program for *O. boudoti* populations to confirm the trends described. The spring conservation project implemented in the Oum Er Rabia region between 2023 and 2025 (AESVT coord. 2025) led to the protection of two springs through consultation with local users. This initial program also highlighted the remarkable ecological value of these habitats (high endemism of crenobiontic fauna), the importance of stakeholder engagement, and the need for involvement from both political actors and public institutions to implement management actions integrated with existing land uses.

Declarations

Author Contribution

E. D authored this manuscript

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Tables

Tables 1 to 3 are available in the supplementary files section.

Figures

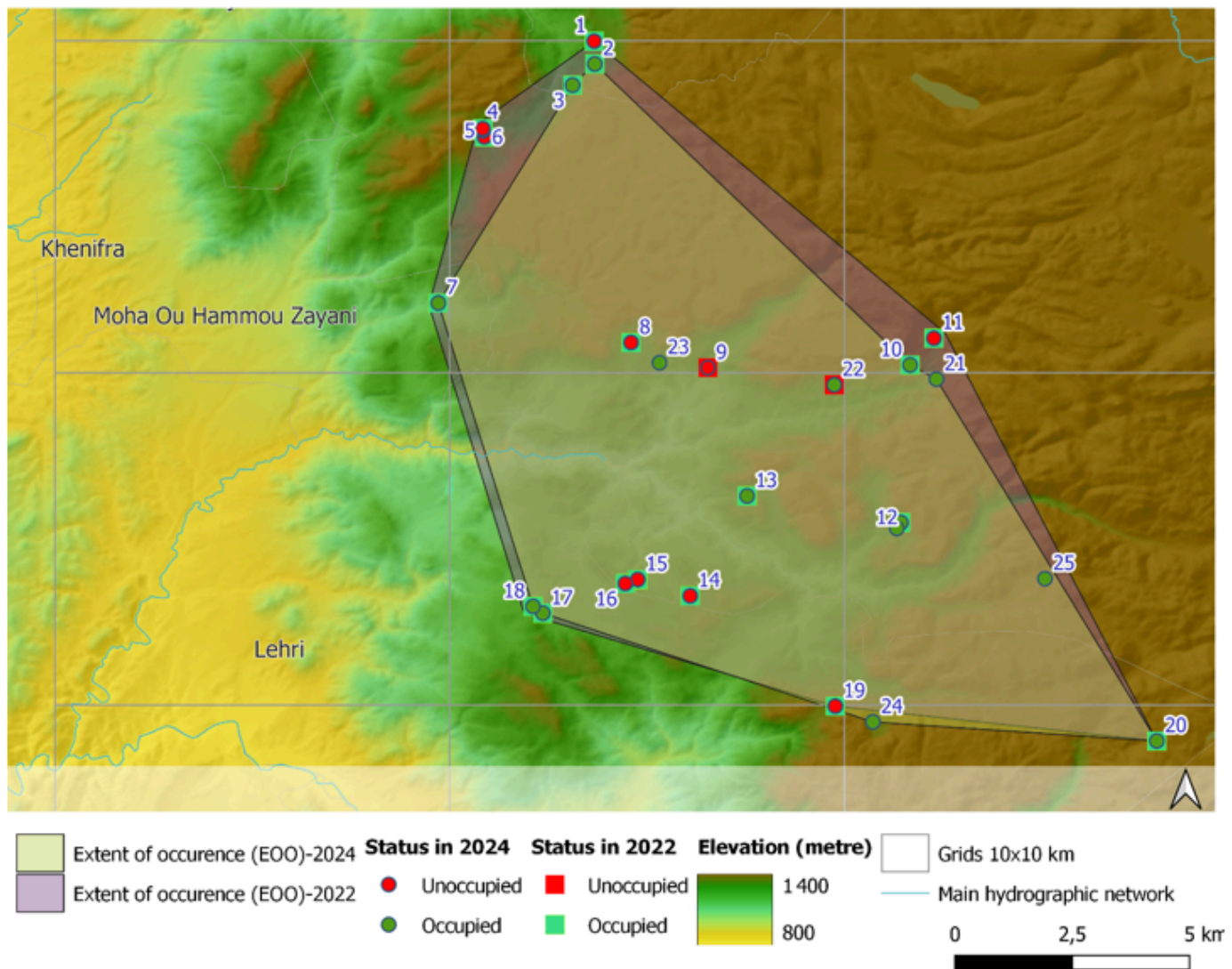


Figure 1

Location of sites occupied by *Onychogomphus boudoti* in 2022 and/or 2024 and changes in EOO over the two periods.



Figure 2

Combined effects of pressure factors (drought, grazing and mechanized pumping).



Figure 3

Failed emergence of a male *O. boudoti*

Supplementary Files

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