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# Fieldwork campaigns and citizen science data increase the distributional range of the elusive *Vipera monticola* in Morocco

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Morocco comprises most of the geographic range extent of *Vipera monticola* and the three subspecies described within this taxon. However, the distribution of this species is likely underestimated due to its low detectability. In this note, we use data collected through recent fieldwork campaigns and citizen science to update the distribution of *V. monticola* in Morocco, considering the distribution of the three described subspecies. We provide records for 45 vipers corresponding to 15 UTM 10x10 km cells (six new UTM 10x10 km cells), increasing by 8.8% the range of *V. monticola* in the country. Remarkable range increases occur for the subspecies *V. monticola atlantica* and *V. monticola monticola*, the latter confirmed by genetic assessment, as well as for *V. monticola saintgironsi* with a new record in Jbel Bou Naceur. We note the occurrence of habitat degradation across the species range, likely promoted by anthropogenic factors as deforestation, aridification and overgrazing. We also indicate Jbel Oukaimeden as a potential area to develop population-monitoring studies.

***Key words***: Atlas; habitat degradation; Maghreb; Mediterranean relict; range extensions; Rif; Viperidae.

The recent taxonomic scenario proposed for Lataste's viper (Martínez-Freiría *et al.*, 2021) recognises the North African Mountain Viper, *Vipera monticola* Saint Girons, 1953, as the single representative of the European vipers (genus *Vipera*; Freitas *et al.*, 2020) in Africa. This small-sized venomous snake inhabits areas with humid and subhumid Mediterranean climates of the Maghreb, with populations scattered across some of the main mountain ranges of Morocco, Algeria, and probably Tunisia (Freitas *et al.*, 2018; Martínez-Freiría *et al.*, 2021). Three subspe-

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cies, allopatrically distributed, are currently recognised within this species (MARTÍNEZ-FREIRÍA *et al.*, 2021): *V. monticola monticola* in the Central High Atlas; *V. monticola atlantica* in the Western High Atlas; and *V. monticola saintgironsi* in the Eastern High Atlas, Middle Atlas, Rif and Tellian Atlas. *Vipera monticola* is listed as Near Threatened by the IUCN (MIRAS *et al.*, 2006; PLEGUEZUELOS *et al.*, 2010). However, this category must be updated in accordance with the recent taxonomic changes hereafter referred.

Morocco has been recognised as the centre of diversification of *V. monticola* (FREITAS *et al.*, 2018; MARTÍNEZ-FREIRÍA *et al.*, 2020). The country comprises most of the genetic diversity described within the species, which translates into the occurrence of all three subspecies, two of which are endemic (MARTÍNEZ-FREIRÍA *et al.*, 2020, 2021). Morocco also encompasses most of the species' geographic range extent, with about 80% of the records compiled in previous works having been reported from this country (e.g., FREITAS *et al.*, 2018; BOUAM *et al.*, 2019). Although the herpetofauna of Morocco is the best investigated of all Maghreb countries (see MARTÍNEZ DEL MÁRMOL *et al.*, 2019; BOUAZZA *et al.*, 2021), information on the distribution of montane species like *V. monticola* is believed to be incomplete. The large extent of suitable areas reported for the species' occurrence in the Moroccan mountains (e.g., BRITO *et al.*, 2011a,b; FREITAS *et al.*, 2018) contrasts with its actual restricted occurrence, resulting from low detectability during fieldwork campaigns (e.g., FAHD *et al.*, 2005, 2007; MARTÍNEZ-FREIRÍA *et al.*, 2017). The elusiveness of *V. monticola* limits the assessment of historical records and/or the discovery of new populations (see MARTÍNEZ-FREIRÍA & VELO-ANTÓN,, 2023), as well as the acquisition of knowledge on life history and ecological traits of this species (MARTÍNEZ-FREIRÍA *et al.*, 2021).

In recent years, citizen science has become an important source of scientific information (de SHERBININ *et al.*, 2021), particularly in the case of elusive species (e.g., ADAMÍK *et al.*, 2019; Loso & Roos, 2019). The use of tools commonly integrated in smartphones and usable for data acquisition, such as cameras and GPS, and the transfer of information to online platforms and social networks have made data collected by people often inexperienced in wildlife research available for different purposes (e.g., mapping distributions, ADAMÍK *et al.*, 2019; assessing population trends, SANTOS *et al.*, 2022). In this note, recently collected fieldwork (FW) and citizen science (CS) data are used to update the distribution of *V. monticola* in Morocco, also considering the ranges of the three described subspecies.

## Material and Methods

Fieldwork was conducted by the authors over 31 days, divided into three study periods carried out in September 2021, May 2022 and September-October 2022. In each campaign, field sampling was carried out by four team members, and was based on visual encounter surveys developed in habitats deemed favourable for the species. Sampling campaigns focused on the areas where the species was already recorded or was predicted to occur according to ecological niche-

**Table 1:** List of sequences considered in this study depicting codes, subspecies and lineage (*sensu* Martínez-Freiría *et al.*, 2021), geographic information including locality, region, country, latitude (lat) and longitude (lon), source (GB- GenBank, TS- this study) and GenBank accession numbers.

| code | subspecies | lineage | locality | region | country | lat | lon | source | accession |
|---|---|---|---|---|---|---|---|---|---|
| M017 | *saintgironsi* | Rif-E.Atl-Alg | Jbel Aalam | Rif | Morocco | 35.35 | -5.58 | GB | MG875543 |
| 13VL018 | *saintgironsi* | Rif-E.Atl-Alg | Jbel Taria | Rif | Morocco | 35 | -5.2 | GB | MG875537 |
| P182 | *saintgironsi* | Rif-E.Atl-Alg | Aguelmane Sidi Ali | Middle Atlas | Morocco | 33.09 | -4.96 | GB | MG875545 |
| BEV11978 | *saintgironsi* | Rif-E.Atl-Alg | Tislit lake | Eastern High Atlas | Morocco | 32.2 | -5.64 | GB | MG875542 |
| 11VM002 | *saintgironsi* | Rif-E.Atl-Alg | Jbel Azourki | Eastern High Atlas | Morocco | 31.76 | -6.29 | GB | MG875535 |
| P184 | *saintgironsi* | Rif-E.Atl-Alg | Akfadu | Tell Atlas | Algeria | 36.63 | 4.63 | GB | MG875546 |
| P186 | *saintgironsi* | Rif-E.Atl-Alg | Djurjurá Mts | Tell Atlas | Algeria | 36.49 | 4.27 | GB | MG875547 |
| MNCN50497 | *saintgironsi* | Rif-E.Atl-Alg | Jbel Chélia | Aurès Mts | Algeria | 35.32 | 6.63 | GB | MZ712102 |
| MNCN50498 | *saintgironsi* | Rif-E.Atl-Alg | Djurjurá Mts | Tell Atlas | Algeria | 36.45 | 4.23 | GB | MZ712101 |
| 15VM073 | *atlantica* | WH-Atlas | Tichka plateau | Western High Atlas | Morocco | 30.9 | -8.62 | GB | MG875539 |
| 15VM074 | *atlantica* | WH-Atlas | Tichka plateau | Western High Atlas | Morocco | 30.9 | -8.62 | GB | MG875540 |
| M195 | *monticola* | CH-Atlas | Oukaimedem | Central High Atlas | Morocco | 31.22 | -7.84 | GB | MG875544 |
| 11VM003 | *monticola* | CH-Atlas | Jbel Toubkal | Central High Atlas | Morocco | 31.08 | -7.93 | GB | MG875536 |
| 14VM016 | *monticola* | CH-Atlas | Jbel Tichka | Central High Atlas | Morocco | 31.3 | -7.4 | GB | MG875538 |
| 16VM003 | *monticola* | CH-Atlas | Jbel Sirwa | Anti-Atlas | Morocco | 30.71 | -7.62 | GB | MG875548 |
| 22VM133 | *saintgironsi* | Rif-E.Atl-Alg | Talassentame NP | Rif | Morocco | 35.11 | -5.13 | TS | OQ589709 |
| 22VM134 | *saintgironsi* | Rif-E.Atl-Alg | Izoughar lake | Eastern High Atlas | Morocco | 31.70 | -6.26 | TS | OQ589710 |
| 22VM216 | *monticola* | CH-Atlas | Tamda n'Oughmar | Central High Atlas | Morocco | 31.32 | -7.00 | TS | OQ589711 |

based models (e.g., BRITO *et al.*, 2011a,b; FREITAS *et al.*, 2018). These areas (and the number of sampling days in each region) are the following: (1) Jbel Aalam, Jbel Bouhachem, Jbel Taria, Talassemtane National Park and Jbel Tighighine in the Rif (7 days); (2) Aguelmane Sidi Ali in the Middle Atlas (2 days); (3) Tislit and Isli lakes, Jbel Azourki and Izoughar lake in the Eastern High Atlas (6 days); (4) Tamda'n Oughmar and Jbel Oukaimeden in the Central High Atlas (8 days); and (5) Jbel Tabgourt and Tichka plateau in the Western High Atlas (8 days).

Vipers were captured by hand and placed in cotton bags before being processed, in order to reduce stress. Each specimen was then measured and photographed, and buccal swabs were collected for genetic analyses. Finally, vipers were released at the same place where they were captured. Fieldwork was carried out with permits from the Haut Commisariat aux Eaux and Forets of Morocco (refs. 26/2021 and 12/2022 DEF/DLCDPN/DPRN/CFF).

To phylogenetically assign some of the sampled vipers to the already described subspecies (see MARTÍNEZ-FREIRÍA *et al.* 2021), DNA from the buccal swabs collected from three individuals was sequenced for one mtDNA fragment (cytochrome *b*, *cytb*). Lab procedures of DNA extraction, amplification and sequencing followed the protocols previously used for this species (see FREITAS *et al.*, 2018; MARTÍNEZ-FREIRÍA *et al.* 2020, 2021). A total of 18 sequences (three resulting from this study and 15 available from previous studies; Table 1) were aligned and cleaned in Geneious ver. 4.8.5 (KEARSE *et al.*, 2012). The resulting alignment of 488 bp length was imported to POPART (LEIGH & BRYANT, 2015) and used to generate a TCS haplotype network.

Citizen science data consisted of photos of *V. monticola* specimens (species identification confirmed by A. BOUAZZA and F. MARTÍNEZ-FREIRÍA) with acquisition dates and toponyms or records precise enough to derive the geographic coordinates of where the photo was taken with an accuracy of up to 2 km, as well as some additional information about the animal and/or the encounter. CS was collected by A. BOUAZZA for the period 2017 – 2022 through search on two Facebook groups focused on Moroccan herpetofauna and wildlife in general (i.e., Al-Zawahif Mag, https://www.facebook.com/groups/1477515485736569; Wildlife in Morocco, https://www.facebook.com/groups/451213405828604). Then, collectors were interviewed to confirm the observation and provide additional information if necessary. CS are provided under permission of the collectors.

## RESULTS

Records for 45 vipers corresponding to 15 UTM 10x10 km cells, six of them new, were obtained (Table S1; Fig. 1A). These records and the genetic assignment of three individuals are commented below, by mountain region:

1) Rif Mountains - six records corresponding to six UTM 10x10 km cells. Five of these records were gathered with CS (Fig. 2, Table S1) and three of them represent new UTM 10x10 km cells (in the western Jbel Bouhachem, Beni Bchir and Tarya; Fig 1). FW conducted in this area allowed

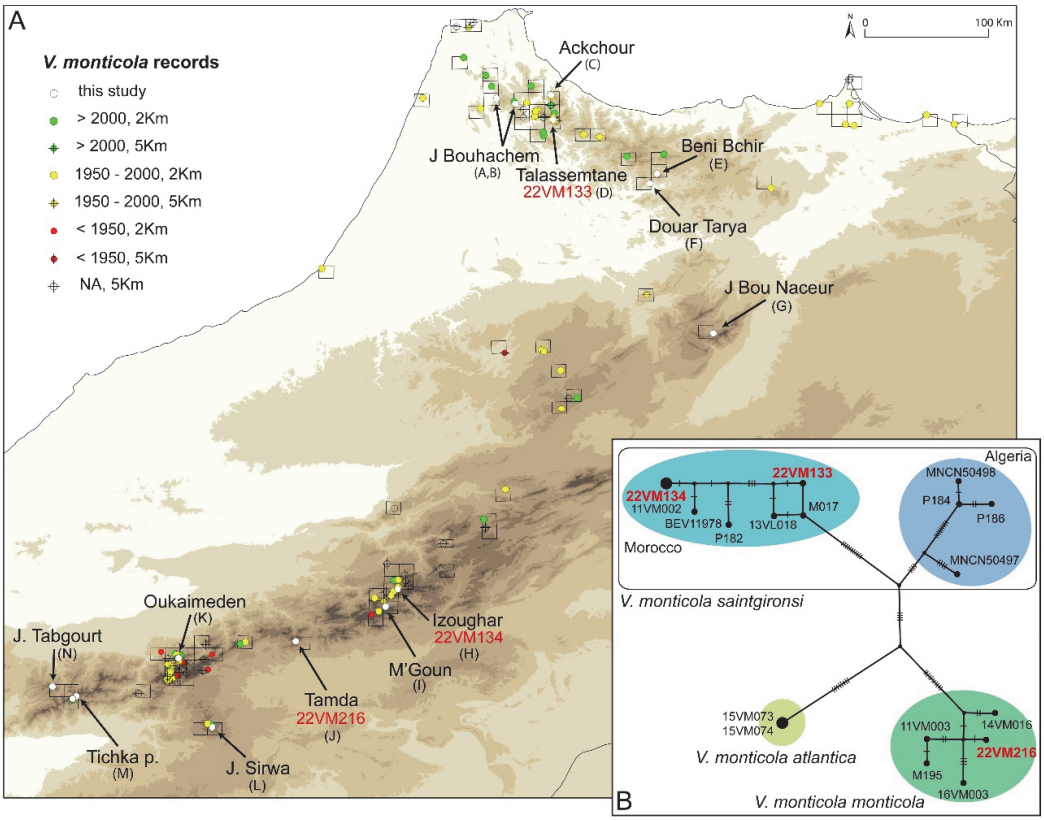


**Figure 1**: **A**. Map of north and central Morocco depicting the distribution of *V. monticola*. Currently available records represented according to time-period and geographic accuracy (from FREITAS *et al.* 2018), the new records provided in this work, and the corresponding UTM 10x10 km cells are included. Toponyms of the localities of the new records are provided, and letters in between parentheses correspond to the pictures in Figure 2; **B**. *cytb* haplotype network depicting the phylogenetic relationships between the 15 sequences already available for *V. monticola* (gathered from GenBank) and the three new ones provided in this study (see Table 1), organised according to the three described subspecies. Codes in red in both the map and the haplotype network correspond to the three new samples sequenced in this study.

to capture one reproductive female in Talassemtane N.P. (Fig. 2D). The *cytb* sequence obtained from this viper corresponds to a new haplotype within the RIF-E.Atlas sublineage and the subspecies *V. m. saintgironsi* (Fig 1B).

2) Middle Atlas – one record in the northern side of Jbel Bou Naceur corresponding to a new UTM 10x10 km cell (Fig. 1A), gathered by CS (Table S1, Fig. 2G). FW in Aguelmane Sidi Ali resulted in the detection of no vipers.

3) Eastern High Atlas – two records corresponding to two already known UTM 10x10 km cells (Table S1, Fig. 2H ,I). CS reported one individual in the M'Goun mountain range (Fig. 2I). FW conducted in the surroundings of Tislit and Isli lakes


**Figure 2:** Photos of *V. monticola* specimens from some of the records reported in this study (toponym, region, author): **A** – Jbel Bouhachem, Rif, A. Ouardi; **B** – Jbel Bouhachem, Rif, Y. Sehli; **C** – Ackchour, Rif, A. Elamri; **D** – Talassemtane N.P., Rif, F. Martínez-Freiría; **E**- Beni Bchir, Rif, A. Yassine; **F** – Tarya, Rif, Y. Nassi; **G** – Jbel Bou Naceur, Middle Atlas, M. Bourmdane; **H**– Lake Izoughar, Eastern High Atlas, F. Martínez-Freiría; **I** – M'Goun, Eastern High Atlas, H. Lemasra; **J** – Tamda m'Oughmar, Central High Atlas, J. Buldain; **K** – Jbel Oukaimeden, Central High Atlas, F. Martínez-Freiría; **L** – Jbel Sirwa, Anti-Atlas, S. Belhajali; **M** –Tichka plateau, Western High Atlas, F. Martínez-Freiría; **N** – Jbel Tabgourt, Western High Atlas, A. Azahrou. See Fig. 1 and Table S1 for the geographic location and additional data of each viper.

resulted in no vipers, while FW in Izoughar lake allowed to collect one juvenile (Fig. 2H). The *cytb* sequence derived from this viper corresponds to the same haplotype as the one obtained for the viper with code 11VM002 from Jbel Azourki (Table 1), falling within the RIF-E.Atlas sublineage and the subspecies *V. m. saintgironsi* (Fig 1B).

4) Central High Atlas – records of 22 vipers corresponding to two already known UTM 10x10 km cells. FW allowed to collect one adult female in Tamda'n Oughmar (Fig. 2J) and 20 live vipers in the surroundings of Jbel Oukaimeden (Fig. 2K). CS reported one viper in the latter area as well. The DNA sequence derived from the adult female found in Tamda'n Oughmar corresponds to a new haplotype within the CH-Atlas lineage and the subspecies *V. m. monticola* (Fig 1B).

5) Western High Atlas – records of 13 vipers corresponding to three UTM 10x10 km cells, two of them new (Fig. 1A). FW developed in the Tichka plateau allowed to find 11 vipers, two of them in a new UTM 10x10 km cell (Fig 1A, Table S1). Fieldwork developed in the surroundings of Jbel Tabgourt reported no vipers. However, a shepherd interviewed by our team later provided photos of two vipers found at the same location (Fig. 2N). This record corresponds to a new UTM 10x10 km cell (Fig 1A).

6) Anti-Atlas – one record corresponding to one already known UTM 10x10 km cell (Fig. 1A), provided by CS in the south face of Jbel Sirwa (Fig 2L).

## Discussion

Overall, this study increases by 8.8 % the range of *V. monticola* in Morocco, currently summing up 74 UTM 10x10 km cells (Fig. 1). This is an even greater range increase (25 %) if we consider the contemporary distribution of the species in Morocco, represented by the records gathered after the year 2000, and currently corresponding to 30 UTM 10x10 km cells (Fig. 1).

A notable range increase occurs for the subspecies *V. m. atlantica*, which passes from one to three UTM 10x10 km cells (Fig. 1). Additional sampling in the Western High Atlas, a region with several mountain areas located at high altitude, with apparently suitable habitat for *V. monticola*, would likely lead to the detection of new populations, potentially belonging to the subspecies *V. m. atlantica*. Assessing the genetic structure and diversity of these populations is, therefore, key to a greater understanding of the biogeography and conservation of the species (e.g., Freitas *et al.*, 2018). Indeed, the basic genetic assessment performed in this study allowed to assign the viper found in Tamda'n Oughmar to the *V. m. monticola* subspecies (Fig. 1B). The presence of *V. monticola* in this area was previously reported by F. Cruzin (observation collected by P. Geniez; in Brito *et al.*, 2011a), and trekking field guides also warned about the presence of "adders" at the campsites (Brown, 2012). Other than this information, there was no detailed information about whether this population belonged to the central (*V. m. monticola*) or eastern lineage (*V. m. saintgironsi*). Our genetic assessment, therefore, expands the range of *V. m. monticola* about 30 km eastwards, reducing in extension the potential area of contact with the subspecies *V. m. saintgironsi*.

Located more than 50 km away from

the closest record, the record in Jbel Bou Naceur represents another important range increase for *V. monticola* (Fig. 1). The Eastern Middle Atlas is known for hosting populations of Mediterranean relicts (e.g., *Salamandra algira*, in Jbel Bou Iblane; *Natrix astreptophora*, in Jbel Tazzeka) that can be found in sympatry with *V. m. saintgironsi* across its range in the Rif and Middle Atlas (MARTÍNEZ DEL MÁRMOL *et al.*, 2019). However, information on herpetofauna from the southern ranges of the Eastern Middle Atlas, as Jbel Bou Naceur, is anecdotal, as evident from the gaps in the distribution of common Mediterranean species (e.g., *Pelophylax saharicus*, *Timon tangitanus*, *Coronella girondica*; MARTÍNEZ DEL MÁRMOL *et al.*, 2019). Remarkably, the potential presence of *V. monticola* in the Jbel Bou Naceur was suspected due to its predicted high habitat suitability as reported in several ecological modelling studies (BRITO *et al.*, 2011a,b; FREITAS *et al.*, 2018). This suggests that the area requires to be explored more thoroughly. Predictions derived from ecological modelling studies were already recognised as an important tool to guide fieldwork campaigns directed to find elusive species (e.g., *Vipera graeca*; MIZSEI *et al.*, 2016) and should be kept in use to support future fieldwork campaigns focusing on *V. monticola*.

During our sampling sessions, we did not find *V. monticola* in areas where the species was recently recorded, such as Jbel Taria in the Rif (in 2013, FREITAS *et al.*, 2018), Aguelmane Sidi Ali in the Middle Atlas (in 2006, BRITO *et al.*, 2006), or the surroundings of Tislit Lake in the Eastern High Atlas (in 2012, FREITAS *et al.*, 2018). In these areas, we noticed high levels of habitat degradation, apparently caused by the following anthropogenic factors: (1) deforestation, produced by wood extraction and wildfires in the Rif; (2) aridification, mediated by the extraction of water from small rivers, used to irrigate cannabis plantations in the Rif, and by overexploitation of water bodies by domestic sheep and goats in the Middle and High Atlas; and (3) overgrazing, produced by an increase in the number of herds per area and in the frequency of grazing in the Middle and High Atlas. These factors were already referred as relevant threats to the survival of *V. monticola* in previous publications (see MARTÍNEZ-FREIRÍA *et al.*, 2017; FREITAS *et al.*, 2018). Our personal observations and recent conversations with local shepherds pointed on an increase in the magnitude of these factors over the years, which is likely determined by the strong temperature increases and droughts that the Mediterranean region is currently experiencing (see MedECC, 2020).

Conversely, we found two areas with a relatively high number of individuals of *V. monticola* (Table S1), namely Jbel Oukaimeden and Tichka plateau. Accessing Tichka plateau requires several hours of hiking, but Jbel Oukaimeden is easily reachable by car from Marrakech. Because of such high accessibility and taking into account the considerable number of individuals detected in Jbel Oukaimeden, we think that population-monitoring studies could be developed relatively easily in this area. These studies are crucial to increase knowledge on life history and ecological traits of *V. monticola* (e.g., HODGES & SEABROOK, 2016), and thus to promote detailed conservation assessments. In addition,

long-term monitoring could provide information about the demographic trends of this population and help us develop conservation actions that could guarantee the viability of this and other *V. monticola* populations (e.g., LUISELLI *et al.*, 2018).

Despite the considerable sampling effort conducted over the last 18 years (e.g., FAHD *et al.*, 2005, 2007; MARTÍNEZ-FREIRÍA *et al.*, 2017; AVELLA *et al.*, 2019), the distribution of *V. monticola* in Morocco remains likely underestimated. Our study supports the importance of CS in increasing knowledge on the distribution of elusive species like *V. monticola*. Although fieldwork is still needed, particularly to collect samples to assess genetic diversity of populations, we recommend the development and implementation of initiatives and tools relying on CS (e.g., iNaturalist mapping projects, https://www.inaturalist.org; S.I.A.R.E. in Spain, https://siare.herpetologica.es) as a way to improve the current knowledge on the distribution of elusive wildlife species in Morocco.

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