

New high-elevation records of *Malpolon monspessulanus* and *Hemorrhois hippocrepis* from the High Atlas Mountains (Morocco)

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RESUMEN: El cambio climático está afectando drásticamente a los patrones de distribución de las especies en todo el mundo. En Marruecos, las montañas del Alto Atlas albergan varias especies de reptiles especialistas, adaptadas a climas fríos, muchas de ellas endémicas, y localizadas en las zonas elevadas, así como especies generalistas, localizadas a media o baja altitud. En esta nota documentamos el hallazgo de cuatro ejemplares y una muda de dos especies de serpientes mediterráneas generalistas, *Malpolon monspessulanus* y *Hemorrhois hippocrepis*, en las zonas elevadas del Oukaimeden (Alto Atlas central) y páramo del Tichka (Alto Atlas occidental). Discutimos el posible conflicto que puede ocasionar el establecimiento de estas especies en las zonas elevadas de estas montañas en relación a la fauna de reptiles endémicos.

Climate change is critically affecting biodiversity worldwide (Habibullah *et al.*, 2021). An expected and already documented effect of such disturbance is the displacement of the distributional ranges of animal species towards more climatically suitable areas (Parmesan, 2006; Roberts *et al.*, 2019). The magnitude of these distributional shifts depends on life-history and eco-physiological traits of the species in question (Hill *et al.*, 2002; Pacifici *et al.*, 2020). In temperate regions, for instance, generalist, warm-adapted species might extend their distributions towards formerly colder regions, as higher altitudinal ranges (Hill *et al.* 2002; Davey *et al.*, 2012; Pacifici *et al.*, 2020). However, specialist, cold-adapted montane species could undergo a reduction of their distributions, when they move upwards (Hill *et al.*, 2002; Pacifici *et al.*, 2020).

Morocco is one of the richest Mediterranean countries in terms of herpetological diversity (Martínez del Marmol *et al.*, 2019; Bouazza *et al.*, 2021), with mountain ranges representing regional hotspots of biodiversity (Martínez-Freiría *et al.*, 2013). The High Atlas Mountain range, located in central-western Morocco, is characterized by some of the most humid, freshest climates of the country (Born *et al.*, 2008). Its reptile fauna includes both endemic mountain specialists, restricted to high elevations (e.g. *Atlantolacerta andreanskyi*, *Chalcides montanus*, *Quedenfeldtia trachyblepharus*, *Vipera monticola monticola*, *V. m. atlantica*), and many generalists, located at medium and low elevation levels (e.g. *Tarentola mauritanica*, *Psammodromus algirus*, *Agama impalearis*, *Hemorrhois hippocrepis*) (e.g. Martínez-Freiría



et al., 2017, 2021; Avella *et al.*, 2019). The rise in temperatures and the decrease in rainfall caused by climate change are currently altering ecosystems in the High Atlas (as in the rest of the Mediterranean region; Lionello & Scarscia, 2018), consequently inducing shifts in the distributional ranges of cold-adapted and warm-adapted reptile species (see Martínez-Freiria *et al.*, 2013, 2017).

In this note, we report five observations of two species of generalist, warm-adapted snakes, namely the Montpellier snake *Malpolon monspesulanus* (Hermann, 1804) and the horseshoe whip snake *Hemorrhois hippocrepis* (Linnaeus, 1758), from two localities in the central and western High Atlas of Morocco. Specifically, four observations occurred in Oukaïmeden (Marrakesh-Tensift-El Haouz region; Figure 1a, b), and correspond to: (1) two adult males of *M. monspesulanus* observed at about 2670 m of altitude in the same area (31.2026, -7.8675; WGS 1980 datum), one in May 2012, escaped immediately upon detection, and the other in August 2014, found dead (killed by local people; Figure 2a); and (2) two specimens of *Hemorrhois hippocrepis* found between 2600 and 2700 m of

altitude, consisting of one juvenile observed in spring 2012, escaped upon being detected (31.203773, -7.869354), and one adult male found dead on road in May 2019 (31.2105, -7.8512; Figure 2b). In addition, we report one shed skin of *H. hippocrepis* (Figure 2c, d, e) found at 2650 m of altitude in the Tichka Plateau (30.9004, -8.6223; Figure 1a, c), in September 2021.

Both Oukaïmeden and the Tichka Plateau are dominated by sparse shrubby vegetation, grasslands and rocky outcrops, and are characterized by a montane Mediterranean climate, with very cold winters and a snow cover lasting from four to five months (Haroni *et al.*, 2009). While human influence in the Tichka Plateau is limited to traditional shepherding, the anthropogenic pressure in Oukaïmeden, winter tourist destination and popular ski resort since the 1960s, is intense (Haroni *et al.*, 2009).

Malpolon monspesulanus and *H. hippocrepis* are widespread in the Mediterranean region of Morocco (Martínez del Mármol *et al.*, 2019). The records of *M. monspesulanus* we report here set a new altitudinal range limit for the species, which was previously reported to occur up to 2100 masl in Morocco (Martínez del Mármol *et al.*

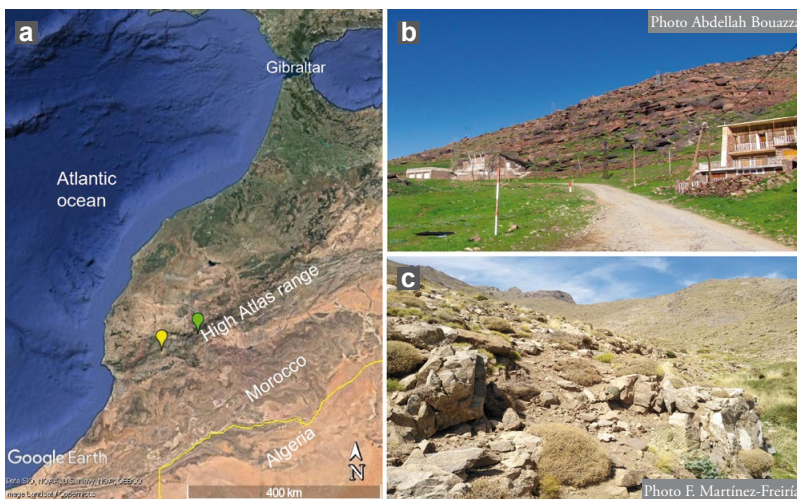
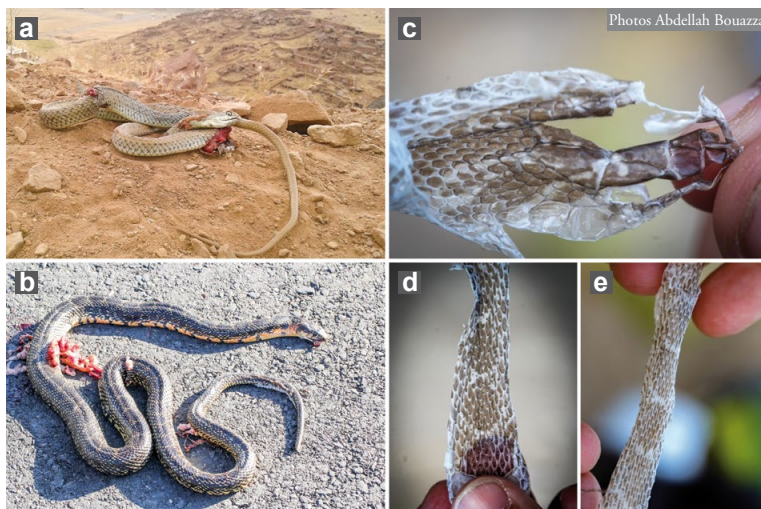


Figure 1: a) Geographic location of Oukaïmeden (green) and Tichka Plateau (yellow) in Morocco; b) landscape view of Oukaïmeden; c) landscape view of the Tichka Plateau from the site of collection of the *H. hippocrepis* shed skin.

Figura 1: a) Localización geográfica de Oukaïmeden (verde) y el páramo del Tichka en Marruecos (amarillo); b) vista del paisaje en Oukaïmeden; c) vista del paisaje en el páramo del Tichka desde el lugar donde fue colectada la muda de *H. hippocrepis*.

Figure 2: a) Killed specimen of *M. monspessulanus* found in Oukaimeden in August 2014; b) specimen of *H. hippocrepis* found dead on the road in Oukaimeden in May 2019; c-, d,e) Details of the shed skin of *H. hippocrepis* found in the Tichka Plateau in September 2021. **Figura 2:** a) Especímen de *M. monspessulanus* encontrado muerto en Oukaimeden en agosto de 2014; b) Especímen de *H. hippocrepis* encontrado muerto en la carretera en Oukaimeden en mayo de 2019; c,d,e) detalles de la muda de *H. hippocrepis* encontrada en el páramo del Tichka en septiembre de 2021.



al., 2019). The three observations of *H. hippocrepis* reported here represent new distribution records for the species, which mirror its highest altitudinal range, recently reported in Morocco (Martínez-Freiría *et al.*, 2017).

Distinct reasons can explain the new distributional records presented here for *M. monspessulanus* and *H. hippocrepis*. First of all, regarding the Tichka Plateau, since the sampling effort in this area was scarce until very recent times (see Avella *et al.*, 2019), the possibility that these new observations might refer to specimens belonging to undetected populations cannot be excluded a priori. This possibility is, nevertheless, very unlikely for Oukaimeden, which is one of the most accessible areas of the High Atlas, and where intense fieldwork campaigns have been developed since long time ago (e.g. Dubois, 1982; Perera *et al.*, 2006; Barata & Harris, 2015; Bouazza *et al.*, 2016).

For the Oukaimeden area, the possibility of human-mediated introduction cannot be excluded, since these species could be displaced inside cargo (e.g. construction materials), as similarly reported in other isolated systems (e.g. islands, Silva-Rocha *et al.*, 2015).

Finally, it could also be that these new records are the result of a recent natural colonization of these two areas by *M. monspessulanus* and *H. hippocrepis*. Given the distribution of the two species in question, flanking or rounding the sampled localities (Martínez del Mármol *et al.*, 2019), a natural dispersal likely mediated by the ongoing climate change could be the reason behind these observations (see Martínez-Freiría *et al.*, 2013). The generalist character of these relatively high dispersal, warm-adapted species could make them able to reach the warm habitats that the surroundings of villages and other human settlements provide. Additionally, large prey items for them (e.g. rodents; see Feriche, 2017; Pleguezuelos, 2017) tend to be abundant in human-inhabited areas (e.g. Capizzi *et al.*, 2014). The combination of new suitable thermal conditions and abundant prey could very likely grant the establishment of the two snake species in question. Nevertheless, both *M. monspessulanus* and *H. hippocrepis* present characteristics typically counter-selected in cold environments, namely oviparity and spring spermatogenesis (Valera *et al.*, 2011; Ma *et al.*, 2018), which could hamper their establishment in these areas.

The consequences of the occurrence of these two species on the high-elevation fauna endemic to the High Atlas, and especially on the species they could potentially prey upon, would be unpredictable and worthy of special attention for conservation purposes. *Malpolon monspessulanus*, for instance, has been observed preying on *Vipera latastei* (Meijide, 2017), sister species of the North African *V. monticola*, which includes two subspecies restricted to the High Atlas Mountains (Martínez-Freiria *et al.*, 2021). Given that *H. hippocrepis* and particularly *M. monspessulanus* feed on a high variety of vertebrates (Ferliche, 2017; Pleguezuelos, 2017), it is thus realistic to consider them able to prey also on other local endemics (e.g. *Q. trachyblepharus*, *A. andreanskyi*, *C. montanus*).

A future increase in the sampling effort would help detect potential new populations of these two snake species and understand their current status in our target localities. Ecological studies about interspecific interactions would also be needed to clarify their role in the community, especially in the perspective of preserving the High Atlas endemics.

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