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CONSERVATION AND NATURAL HISTORY

The Valley of Four Viper Species and a Highland of Dwarfs: Fieldwork on Threatened Vipers in Northeastern Turkey

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Turkey is well known for its high diversity of Palearctic viper species, which include vipers originating from Europe, Asia, and northern Africa. In the northeastern part of the country, at least eight species occur within a radius of 200 km from the point where the three provinces of Erzurum, Artvin, and Ardahan meet (Nilson and Andren 1986; Joger et al. 1997, 2005, 2007; Avci et al. 2010; pers. data). Although these vipers occasionally gain positive public attention, due to the potential medical applications of their venom and the role they serve in preventing overpopulation by mice carrying infectious diseases, we have only minimal ecological knowledge with which to safeguard their existence in nature. Unfortunately, vipers usually have a negative reputation in our society and are becoming increasingly threatened by anthropogenic actions that include habitat degradation and intentional or accidental killing. For example, in northeastern Turkey, increasing development of monocultures, such as for tea and hazelnut plantations along the Black Sea versant and intensive agricultural practices in vast semi-arid Central Anatolia, have drastically decreased the natural habitat and the associated microstructure so important for the survival of vipers. The construction of dams and massive livestock herding (sheep, goats, and cattle) have also dramatically and negatively altered the availability of living space for small animals such as vipers. Hence, viper species often are characterized by declining populations and are listed in the IUCN Red List of Threatened Species with a conservation status either requiring action or in need of evaluation (Aghasyan et al. 2009; Behrooz et al. 2015; Ettling et al. 2015; IUCN 2015; Mebert et al. 2015).

Historically, interest in Turkish vipers has focused on distributional data in a biogeographic context or exploitation for the illegal international pet trade, for which many of these rather attractively colored vipers are highly sought (e.g., Baran and Atatür 1998; Baran et al. 2004; Nilson et al. 2009). Although Turkish authorities have established strict conservation laws to protect these species against illegal collection for the pet trade, chaotic and unresolved systematics and a shortage of ecological information for most species render current conservation efforts ineffective. Consequently, identifying key environmental factors relevant to habitats and elucidating which taxa actually represent independent evolutionary lineages that deserve intensive conservation efforts are paramount. These goals can best be achieved by studying habitat selection in the field as well as the genetics and morphology of populations in contact zones of two or more species. For this reason, we have initiated a long-term project to study geographic and genetic species delimitations of as many as eight taxa of the genera *Vipera*, *Montivipera*, and *Macrovipera* in northeastern Turkey. We began by identifying characteristics of habitats in contact zones between closely related species with the intent of providing relevant biological information necessary for the conservation of rare and threatened vipers in northeastern Turkey.

Results from expeditions in 2013 and 2014 have been published (Göçmen et al. 2014; Mebert et al. 2015). Herein we focus on results gathered during the 2015 expedition, which concentrated on two contact zones and involved four species listed here with their current IUCN Red List status: **(1) *Montivipera wagneri* (Wagner's Mountain Viper):** Critically Endangered; a Turkish endemic known from only seven areas and highly sought in the pet trade (Baran and Atatür 1998); **(2) *Montivipera raddei* (Radde's Mountain Viper):** Near Threatened; known from at least 13 areas in Turkey alone and a few more in Armenia, but overexploited in the pet trade in both countries (Nilson et al. 2009; Ettling et al. 2015); **(3) *Vipera darevskii* (Darevsky's Viper):** Critically Endangered; known from approximately 20 wild adult specimens, with an extent of occurrence probably less

Fig. 1. Interviewing local residents about the occurrence, threat, and biology of vipers inhabiting an area using a questionnaire with images of regional species.

than 100 km^2 and habitat of <10 km^2 in Armenia alone, with a similar situation in Turkey (Aghasyan et al. 2009; Tuniyev et al. 2009a; Mebert et al. 2015); **(4)** ***Vipera eriwanensis*** **(Armenian Steppe Viper):** Vulnerable; known from approximately 14 areas in Turkey and a few more in Georgia and Armenia (e.g., Tuniyev et al. 2009b; Mebert et al. 2015).

Applied Field Methods

The expeditions in 2013 and 2014 included searches for as many as eight species of vipers in northeastern Turkey, whereas the expedition in May/June 2015 focused on contact zones between the mountain vipers *Montivipera wagneri* and *M. raddei* in the Aras Valley, Kars Province (17–28 May), and between the highland dwarf vipers *Vipera darevskii* and *V. eriwanensis* on the plateau in eastern Ardahan Province (30 May–4 June). As in the previous expeditions, our goal was to find new sites to reduce the gap between potentially parapatric (i.e., species with ranges that do not significantly overlap but are immediately adjacent to each other and co-occurring only in a narrow contact zone) and closely related pairs of viper species. We employed visual encounter surveys of sites with complex rock structures that could potentially serve as both shelter and hunting grounds for vipers. Such microhabitats include rocky outcrops and cliffs, rock slides, and dry stone walls, usually including an area facing south and exposed to intense solar radiation. Variously exposed slopes are subject to different angles of solar radiation and surfaces are warmed to varying degrees, resulting in distinct differences in microclimate and vegetation. In the northern hemisphere, south-facing slopes become warmer than other slopes, making them more suitable for meeting the physiological needs of ectothermic species, such as vipers. In addition, whenever possible, we interviewed local residents about the vipers present in their area by showing them photos of regional species (Fig. 1) from which they correctly identified approximately 90% of local species.

For each viper observed, we recorded the exact locality with a Global Positioning System (GPS) device and noted macro- and microhabitat structures within 25 m and 5.5 m, respectively, of where the viper was discovered. We determined the sex of each snake and photographed every individual to assess variation in color patterns. We also measured some body proportions and counted scales either in the field or later the same day (Fig. 2). We acquired tissue samples for molecular analysis by clipping the dead edge of 3–4 ventral scales complemented by mouth swabs in order to identify any hybridization or evaluate interspecific gene flow in contact zones between proximate populations. All snakes were released at their respective sites of capture.

Results and Discussion

1. Contact zone between the mountain vipers, *Montivipera wagneri* and *M. raddei*. Both mountain viper species occur in the Aras Valley, but only allopatric populations (i.e., no contact or overlap between them) have been reported to date. *Montivipera wagneri* occupies the region around Kağizman and to the west, whereas *M. raddei* occurs farther east (Nilson et al. 1988; Schätti et al. 1991; Mulder 1995; Stümpel 2012). In the 2014 expedition, we had located a potential contact zone in the Günindi Valley east of Kağizman, where both species occupy virtually identical habitat along slopes with southern exposures (Mebert et al. 2015). The ranges appear to be parapatric (next to each other) and we had not found a zone of contact where the two species occur sufficiently close to each other (i.e., within a few kilometers) to potentially interact during their annual activity.

Fig. 2. Processing vipers and data acquisition in hotel rooms and in the field on cold and windy or hot, sunny days.

During the 2015 expedition, we continued to explore the Günindi Valley and detected four different species of vipers within a 1.2-km radius, and subsequently termed this area "the Valley of Four Viper Species" (Fig. 3). We added 10 new records from this valley and adjacent areas for *M. raddei* (captures, shed, and observations) and four for *M. wagneri* (captures and observations). Accordingly, we reduced the surface distance between both mountain vipers from 6.7 km to 2.4 km. No clear barrier or obstacle has been found between the nearest localities for the two species, and several intervening rock piles or formations could serve as stepping-stone habitats. The stream on the valley floor is only 2–7 m wide and rarely more than 50 cm deep and thus unlikely to pose an effective barrier between adjacent *M. wagneri* and *M. raddei* populations. However, as Mebert et al. (2015) indicated, the predominantly mineral soils, mostly sand or fine-grained, dried organic particles in this particular transition area, reduce the stability of subterranean living space for vipers, as such soils do not firmly support burrows that are necessary for vipers (for hibernation, shelter, protection from predators, temperature regulation, and prevention of dehydration) and their prey. Indeed, all mountain vipers were found on humus (organic soil), in some instances only a few meters away from large patches of mineral soils (Fig. 4).

The slopes with predominantly mineral soils stretch approximately 9 km in a straight line between what appear to be relatively stable populations of *M. wagneri* on one side and *M. raddei* on the other (Figs. 3, 5, and 6). In this zone, rock slides are much less abundant than in adjacent areas, where the terrain occupied by snakes is dominated by more stable

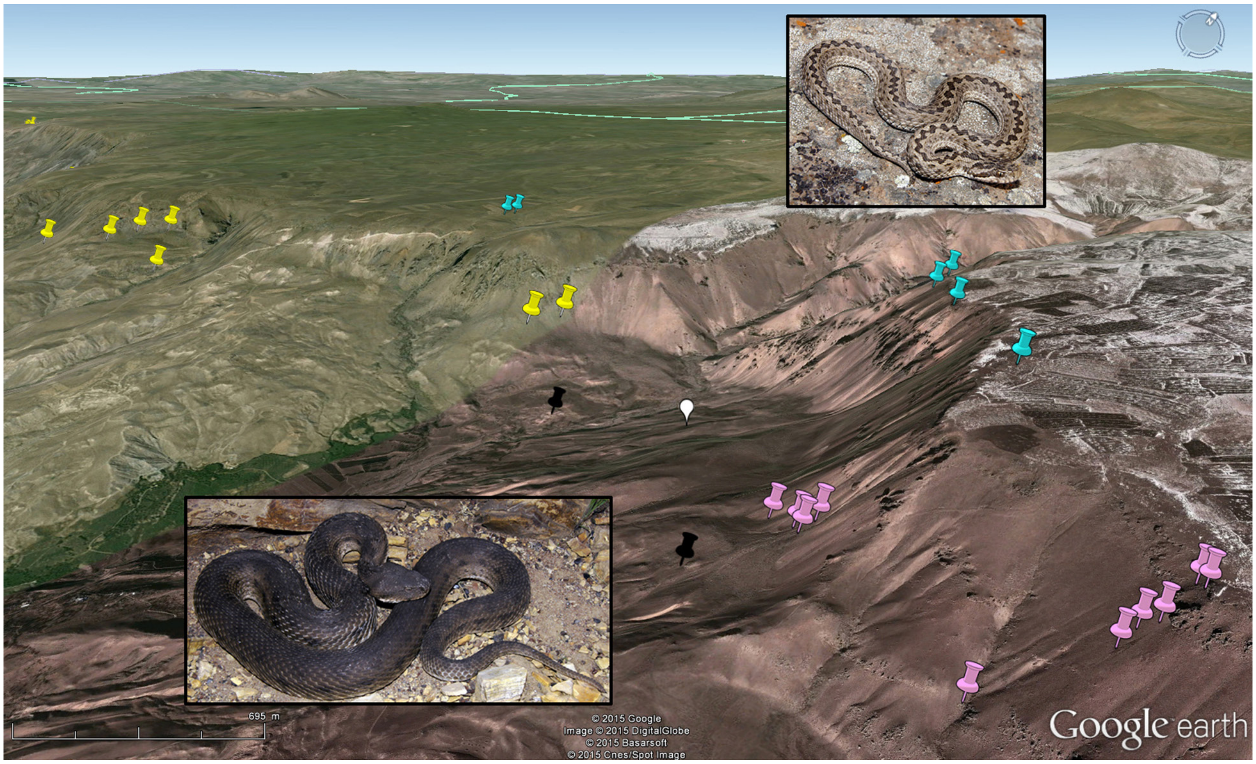

Fig. 3. Google© image showing "The Valley of Four Viper Species" and the transition zone between known localities of Wagner's Mountain Viper (*Montivipera wagneri*) and Radde's Mountain Viper (*M. raddei*) with a contact zone likely occurring along the stream in the valley. The yellow markers represent *M. wagneri* records and the pink markers *M. raddei* (photographs of both species from this area are depicted in Fig. 5). Also indicated are records of *Vipera eriwanensis* (light blue markers and upper inset) and *Macrovipera lebetina* (black markers and lower inset) with all four species found within <1.2 km of the white marker.

Fig. 4. Adjacent patches of mineral soils (left on the gloves and in the background image) versus dark organic soils (right side) appear to influence the habitat quality in the transition zone between Wagner's Mountain Viper (*Montivipera wagneri*) and Radde's Mountain Viper (*M. raddei*). Vipers were found only in areas with organic soils, as evident in front of the bush visible on the right.

Fig. 5. Mountain vipers from the transition zone near Günindi, Kağızman, Kars: Wagner's Mountain Viper (*Montivipera wagneri*; upper image) and Radde's Mountain Viper (*M. raddei*; lower image). The distance between these two snakes was ca. 6 km, but we found individuals of the two species as close as ca. 2 km (see also Figs. 3 and 6).

organic soil. Nonetheless, the suboptimal transition zone likely provides sufficient habitat for survival and corridors for migration between the two viper species, as numerous rock slides and piles lie in close proximity (<500 m) to each other and to horizontal rocky outcrops or cliffs along the upper margin of this zone. As Ettling et al. (2013) indicated, *M. raddei* in a steppe/cropland habitat in Armenia moved seasonally between sites that were 1–3 km apart. Consequently, even though the transition zone at our study site (<10 km) appears comparatively less favorable, it likely is sufficient for migration or movement of individuals of either species. However, any potential gene flow might be countered by competition from the other species, either by genetic swamping via hybridization, higher fitness by the locally dominant species, or both. For example, an individual *M. raddei* migrating a few km into a population of *M. wagneri* is unlikely to find a conspecific mate. If it were to hybridize and resulting F1-hybrids were fertile, they would encounter only a *M. wagneri* gene pool, thus further diluting the impact of that individual *M. raddei*. This scenario would work the other way as well (if an individual *M. wagneri* migrated into *M. raddei* habitat) and assumes that both species survive equally well in this valley and on adjacent slopes with no substantive competitive advantage for either species over the other.

The entire transition zone of mineral soils might represent a population density trough (i.e., an area into which individuals of either species could migrate and live in sympatry or even syntopy), while the density of both remains too low to have a relevant impact on the neighboring populations of either species. As one continues deeper into the Günindi Valley, the canyon becomes narrower and the cliffs and slopes occupied by *M. raddei* angle increasingly more to the north, and are thus cooler due to the reduction in direct solar radiation. The canyon extends approximately 3 km to the village of Keşişkıran, where the cliffs end and are replaced by more gradual slopes, plateauing at >2,200 m above sea level (asl), a habitat less suitable for either species of *Montivipera*. Additional on-site research is needed to evaluate whether the perceived correlation of soil types with viper presence is

Fig. 6. Upper image: View from a site where we found several Radde's Mountain Vipers (*M. raddei*; foreground) to ca. 2 km straight distance across the Günindi Valley, Kars Province, to the slope where we found Wagner's Mountain Vipers (*Montivipera wagneri*; black arrow). Lower image: Counterview from the *M. wagneri* site (rocks in the foreground, bottom of image) across the valley to where *M. raddei* was found (black arrow). The black arrows point also to the location from where each of the photographs was taken. Elliptical markers indicate rock formations that are sufficiently complex and have at least a partial southern exposure that could function as stepping-stone sites between the populations of the two mountain viper species.

important, and whether the mineral soils pose an incomplete barrier for migration between the apparently parapatric populations of these two species.

2. Contact zone between the highland dwarf vipers, *Vipera eriwanensis* and *V. darevskii*. The second potential contact zone investigated in 2015 occurs between two species of externally similar dwarf vipers (Fig. 7). Although they are assigned to different species complexes (Zinenko et al. 2015), both species occupy high-elevation rocky grasslands.

Recent studies demonstrated that the two dwarf viper species occur at sites around Posof in eastern Ardahan Province, Turkey, and across the border in Georgia (Avci et al. 2010; Tuniyev et al. 2012, 2014). After discovering several new populations of *V. darevskii* a little farther south in eastern Hanak District, Ardahan Province (Göcmen et al. 2014; Mebert et al. 2015), we focused our search in 2015 on a potential contact zone between the two species near the neighboring villages of Oğuzyolu, Börk, and Binbaşak. We found an individual *V. darevskii* southeast of Oğuzyolu (Fig. 8) and, more importantly, a *V. eriwanensis* north of Binbaşak. The two new discoveries reduced the straight-line distance between the ranges of these species from 8 km (Mebert et al. 2015) to 4.5 km. The zone of transition or contact between the two vipers probably occurs where the rolling hills are replaced with the larger and higher mountain slopes about 1 km south of Oğuzyolu.

Fig. 7. Darevsky's Viper (*Vipera darevskii*; upper left image) in its natural habitat, a large rock slide in eastern Hanak District, Ardahan Province; in the background, rolling hills where the Armenian Steppe Viper (*V. eriwanensis*; upper right image) was found north of Binbaşak. The lower image shows the potential contact zone between these two highland dwarf vipers; arrows point to where the *V. darevskii* from the upper left image (violet) and the *V. eriwanensis* (700 m in the direction of the black arrow) were found in 2015.

Continued searches for either species in rock formations in the area between the two new localities did not yield any further vipers. The weather during this expedition was unusually dry for May, with only two short rainfalls in two weeks. However, after investigating the entire area between the closest *V. eriwanensis* and *V. darevskii* localities (depicted in Figs. 7 and 8), we perceived that the heavy grazing of local livestock drastically reduced habitat quality in the putative contact zone. All open grassland and herbaceous stands, even those near rocky structures that would be suitable for vipers, is short or of reduced density, and only sites between or immediately adjacent to the rocks supported tall tufts of grass and stands of herbaceous plants (Fig. 9). The lack of such vegetation probably decreases suitable habitat for invertebrates, in particular grasshoppers and crickets, an important food source for both species (Höggren et al. 1993; Aghasyan et al. 2009). Dense and tall grass and herbaceous plants also provide microclimates with increased humidity, moderate temperatures for thermoregulation, and cover shielding the snakes from detection by the abundant birds of prey in the region (pers. obs.). Consequently, overgrazing has almost completely removed an entire habitat component, and the subsequent open landscape leads to visibly drier soil, which in turn reduces habitat quality for both prey and predators. The overgrazing threat is greater for *V. eriwanensis* than for *V. darevskii*, as the former inhabits the grassy hillsides below 2,200 m asl where few scattered rock formations are sufficiently complex to serve as shelter. In contrast, *V. darevskii* inhabits the same general region, but occupies steeper slopes above 2,000 m asl, which feature a patchwork of grassland and rock slides. Although the grassland at the higher elevations is heavily grazed, the rock slides are comparatively more complex and provide more shelter and thus protection against the effects of grazing when compared to the scattered rock formations in *V. eriwanensis* habitat. Local farmers indicated that *V. darevskii* occurs at many rocky sites in these mountains.

Conclusion

During a few intensive field expeditions focusing on two potential contact zones between *Montivipera wagneri* and *M. raddei* in the Günindi Valley (The Valley of Four Viper Species) and between the highland dwarf vipers, *Vipera darevskii* and *V. eriwanensis*, we were able to substantially reduce the known distances between closely related viper species to approximately 2–4 km. In both areas, we identified natural and anthropogenic elements of reduced habitat quality that could be responsible for segregating each of the two species groups. In subsequent seasons, we intend to further characterize the potential contact zones to evaluate the extent of habitat segregation and identify any potential interspecific gene flow.

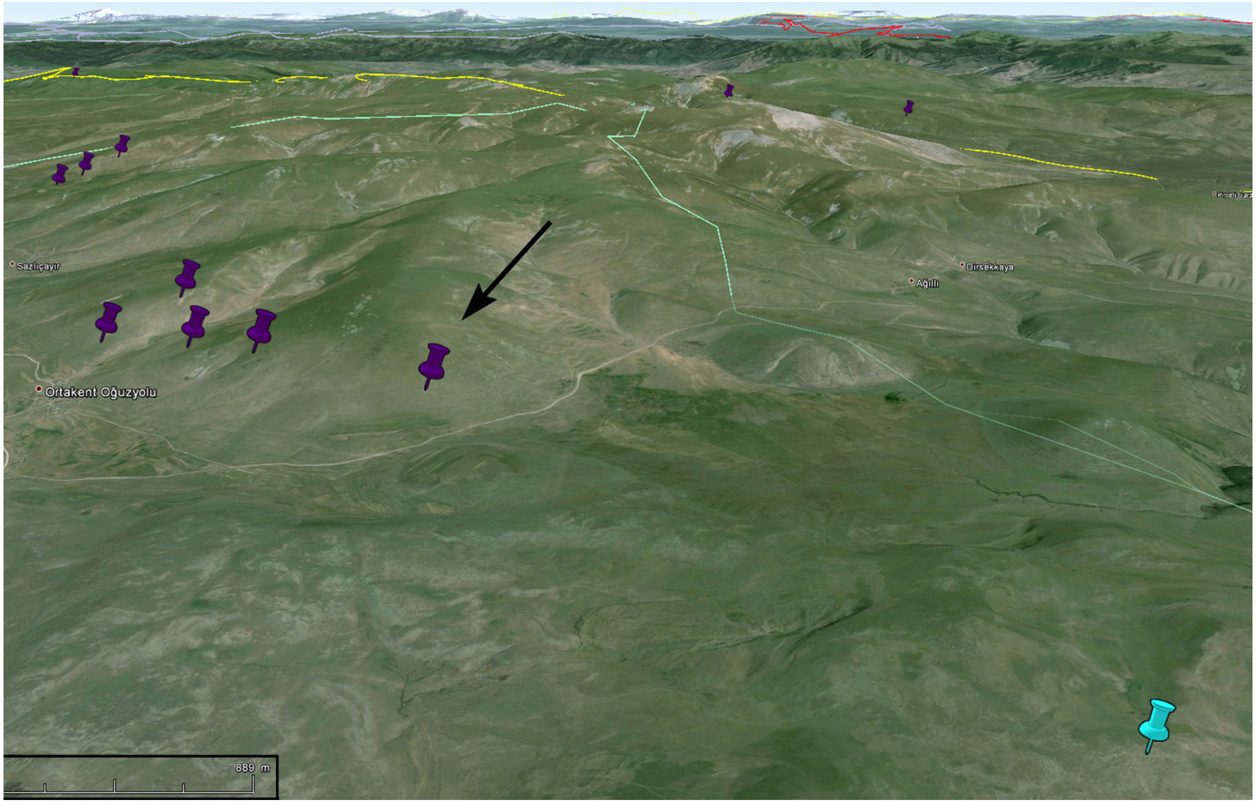

Fig. 8. Google© image showing the transition zone between the ranges of Darevsky's Viper (*Vipera darevskii*; violet markers) and Armenian Steppe Viper (*V. eriwanensis*; light blue markers), including our 2015 discovery of *V. darevskii* (marker with arrow) and data from Göçmen et al. (2014), Tuniyev et al. (2014), and Mebert et al. (2015).

Fig. 9. One of the few extensive rock formations in the rolling-hills habitat of the Armenian Steppe Viper (*V. eriwanensis*) at Binbaşak, Ardahan Province; the individual in Fig. 7 was found in the middle of this formation. The meadows around such rock formations are heavily grazed with only the less accessible sites between the rocks maintaining some higher tufts of grass and herbaceous vegetation.

Heavy grazing and its potential detrimental effects likely pose a severe threat for the local flora and fauna, including the mountain vipers and the insectivorous dwarf vipers that occupy these highlands. During future expeditions, we hope to acquire sufficient data to develop conservation management plans for all four species, including the definition of range limits and critical habitats, information regarding population sizes and densities, and a better understanding of which taxa constitute clearly independent lineages for conservation assessment.

Conservation Statement

The publication of new viper locations in Turkey has been a contentious issue, as such information not only attracts benign wildlife tourism (mainly photographs to be shared on social media) but could also facilitate the search for vipers by potential animal smugglers and dealers in order to supply the illegal pet trade, both of which supposedly have been increasing for the last three decades. However, in our experience, tourism has had a negligible impact on locally stable populations in Turkey, and the rarity of the species in other areas prevents them from becoming detrimentally exploited for commercial and private husbandry purposes. In this context, during the "The 4th Biology of the Vipers" conference organized by the Viper Specialist Group of the SSC-IUCN in Athens, Greece in October 2014 and other viper-related conferences in 2015 and 2016, we suggested that the threat status for Turkish vipers, as stated in the current IUCN Red Lists, is exaggerated and requires a complete re-evaluation. Indeed, our recent studies indicated that most viper species are significantly more common and widespread in Turkey than indicated in the Red List assessments. After several years of research on vipers in Turkey, combined with our extensive field research and knowledge of the biology of vipers in other countries, we have no reason to consider the densities of Turkish vipers to be any different than other "healthy" viper populations in comparable mountain ranges (e.g., Alps, Balkan Peninsula). Numerous requests for information from persons with extensive knowledge of Turkish vipers in the pet trade have not uncovered an explicit commercial trade of wild-caught vipers from Turkey, and essentially all Turkish vipers in the market originated from breeding captive specimens. The occasional reports of vipers being smuggled out of Turkey are either erroneous or apply to very few individuals and are, in both instances, largely irrelevant for the conservation of Turkish populations. Nonetheless, we wish to promote respect for Turkey's natural assets and state clearly that collecting Turkish vipers is strictly forbidden and such illegal action should and will be prosecuted. Consequently, we do not perceive the publication of new localities in this article as problematic, since illegal sampling at these sites with relatively low viper densities is not profitable (large search effort for little success), which should serve as a sufficient deterrent for illegal collectors. On the other hand, sites with extensive habitats and large populations of vipers are robust enough to sustain limited human impact.

Based on our experience in Turkey and studies of vipers in Western and Central Europe, we conclude that the greatest threat for Turkish vipers results from anthropogenic habitat degradation, including dam construction, overgrazing, and intensive agriculture. We therefore suggest conducting, publishing, and promoting studies of wild Turkish viper populations, which should result in relevant information on the habitat requirements of the various species. In so doing, we hope that our studies will provide the essential knowledge for public education and the development of species-specific conservation plans for Turkish vipers.

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