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Photo identification of viperid snakes using pattern recognition software: a case study of *Vipera ammodytes* (Linnaeus, 1758)

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Abstract. Snakes have a unique scale and color patterns that allow for individual identification – however, manual comparison of images is often very time consuming, especially in larger samples. In this study, we tested the capacity of Hotspotter – a specialized pattern recognition software – to recognize individuals of the Nose-horned viper *Vipera ammodytes*. We used data from a five-year study on a viper population near Gara Lakatnik Village in North-Western Bulgaria. A total of 107 vipers were caught, photographed, measured, and released in the period 2013–2017. Hotspotter successfully identified 27 of the 28 recaptured individuals, including 12 multiple matches (vipers recaptured 2–8 times). Our results suggest that the most reliable approach for automated identification in this species is using frontal images of the head (with the shape and scale position of the horn clearly visible), with images of the head and neck color pattern used in cases of uncertain identification.

Keywords: automatic comparison, image similarity, nose-horned viper, recapture study, Serpentes.

Introduction

Capture-mark-recapture (CMR) field methods are widely used in population ecology to estimate parameters such as movement and survival rate, population size, and density. Most traditional CMR methods for amphibians and reptiles are either invasive (e.g., toe and scale clipping) or temporary (e.g., paint markings; Kornilev et al. 2012), and have relatively low efficacy for snakes in particular, as they lack limbs, shed their skin, and clipped scales heal over time (Fitch 1987, Dyugmedzhiev et al. 2018). Newer methods, such as passive integrated transponders (PIT tags), microchips, or visual implant elastomers (VIE tags), are equally invasive (Ferner 2010). Naturally occurring body patterns provide cost-effective and non-invasive alternatives (Drechsler et al. 2015) that have been used successfully in a number of amphibian (e.g., Kenyon et al. 2009, Kim et al. 2017, Naumov & Lukanov 2018, Burgstaller et al. 2021) and reptile species (e.g., Fitch 1987, Sheldon & Bradley 1989, Benson 1999, Knox et al. 2012, Dunbar et al. 2014, 2021, Baker & Allain 2020, Jones et al. 2020). However, manual comparison of images is very time-consuming and decreases efficiency in long-term studies (Arntzen et al. 2004). Various pattern-matching algorithms have been developed for speeding up the recognition process; for example, in their study on the Adder, *Vipera berus* (Linnaeus, 1758), Ray & Timmerman (2018) state that the I3S software they used was "more objective, easier to use and takes less time" compared to manual methods. However, their application could often lead to erroneous identification and decreased accuracy (Elgue et al. 2014). Recent studies with crested newts (Naumov & Lukanov 2018, Lukanov 2022), green toads (Burgstaller et al. 2021), and hawksbill sea turtles (Dunbar et al. 2021) have established that best results in software-assisted identification can be achieved by using the freely available Hotspotter software (Crall et al. 2013). To our knowledge, there have not been attempts to use this software in snakes, and so to test its usefulness, we chose a snake species with a very characteristic appearance – the Nose-horned viper, *Vipera ammodytes* (Linnaeus, 1758). This is a common Eurasian viperid species distributed from Italy in the west to Azerbaijan in the east (Sillero et al. 2014). It is a sedentary species, with individuals holding comparatively small individual home ranges, and until recently, there were no published studies based on CMR data (Dyugmedzhiev et al. 2020). Manual image comparisons of the number, shape, and arrangement of the scales on the frontal part of the horn, as well as the color patterns of the head and the body, have been successfully used for long-term individual identification (Dyugmedzhiev et al. 2018). We hypothesized that Hotspotter would successfully identify all recaptures from a wild population that is part of a recent population study.

Material and methods

The "region of interest" (ROI) for Hotspotter was selected as either 1) the color pattern of the head and neck ("back") or 2) the frontal shape and scale position of the horn ("horn"). For both series, the program suggested six possible matches for each image, ordered by similarity score (for details on working with the software, see Naumov & Lukanov 2018, Burgstaller et al. 2021, Dunbar et al. 2021). We used images from a five-year CMR study on a Nose-horned viper population near Gara Lakatnik Village in North-Western Bulgaria (a karst valley with steep rocks and terraces, interspersed with patches of a deciduous forest; N43°5'; E23°23'; 352–733 m a.s.l.; map and photographs of the site are presented in Dyugmedzhiev et al. 2020). There were 155 captures of 107 individuals photographed, measured, and released in 2013–2017. Images from this dataset were already manually verified for recaptures in the published study of Dyugmedzhiev et al. (2020). For this study, all recaptures were manually verified *a priori* by A.D. and subsequently randomized, so during the testing, S.L. did not have knowledge of the snakes' identity and only relied on the images. Each image was compared to all others to maximize the chance of detecting matches.

Results

As a proof-of-concept test, we used 48 images of 13 individuals from five populations across Bulgaria from the same five-year CMR study. Results for the "back" series were inconclusive – while there were some very high-score matches (i.e., the first suggested matches were indeed recaptures), most images were ordered randomly (Fig. 1). However, results for the "horn" series were very clear, with the software successfully identifying all seven recaptured individuals (including two cases of multiple matches with injury-induced changes in the shape of the horn) (Fig. 1). For this reason, for the analysis of actual CMR data from a single population, we chose to use only frontal images of the head with the horn clearly visible.

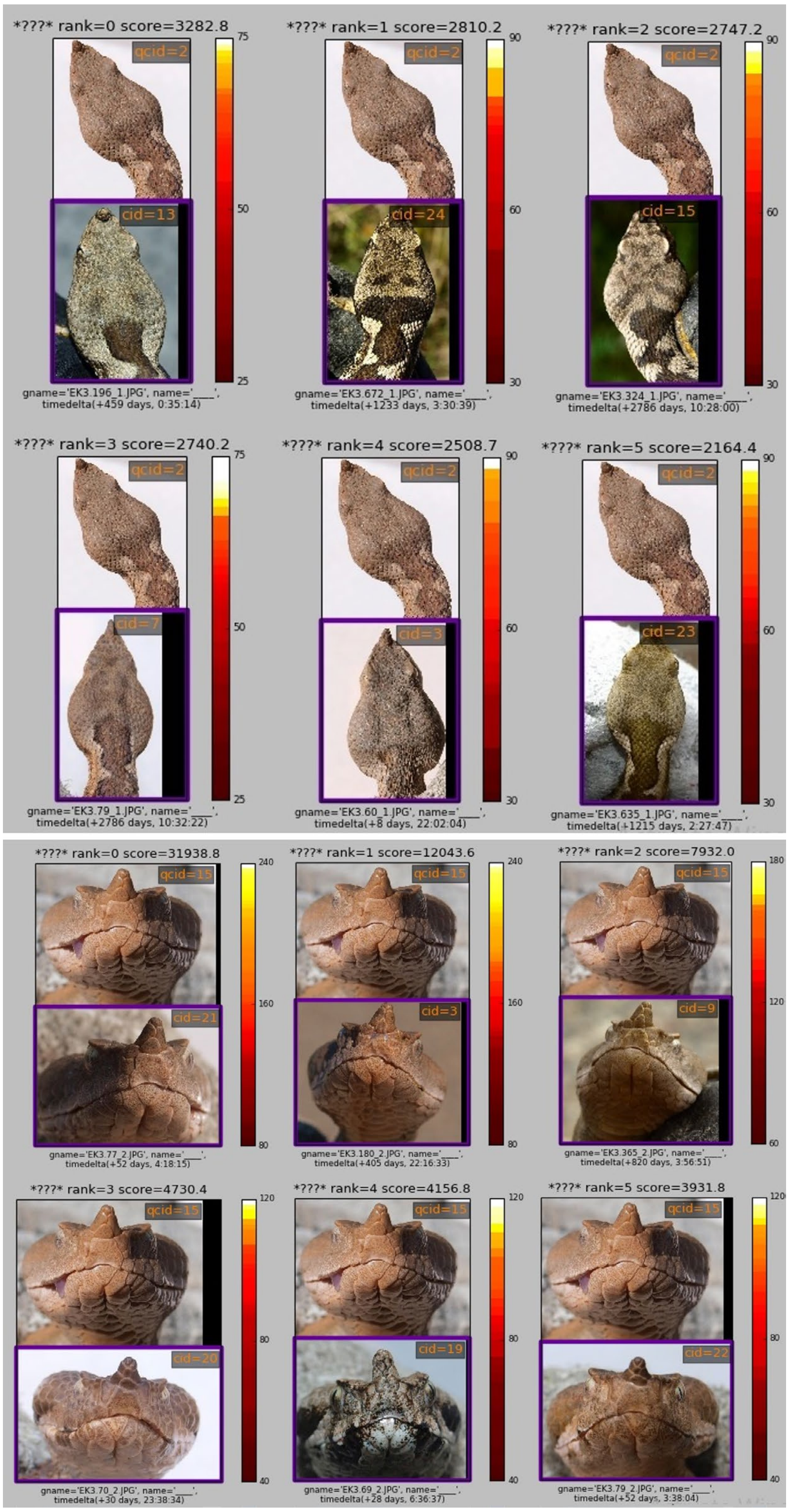

Figure 1. Top: dorsal view of a viper that was manually verified to have three recaptures over a period of three years. All the suggested matches by the software (bottom photograph in each pair) were false positives, with the real matches not present in the first six suggestions.
Bottom: frontal view of the same viper. Despite the considerable amount of time between recaptures and the injury sustained between the first and the second recapture, the software was successful in identifying all three matches in consecutive order (photographs on upper row).

Results for the "horn" series were very clear, with the software successfully identifying 27 out of the 28 recaptured individuals – including 12 cases of multiple recaptures (i.e., individuals captured three times or more). Two of these 12 multiple recaptures were captured four and nine times, respectively. In all cases, matches were ordered consecutively by similarity score from first to last (i.e., there were no false positive matches between them). As we had kept the default setting for the maximum number of suggested matches (six), in the case of the snake captured nine times, Hotspotter could not list all nine matches at the same time. Nevertheless, the suggested matches for each image complemented each other very well (for eight images, all six suggested matches were verified recaptures, and only in one the last suggested match was not a recapture). Thus, in the end, it was evident that the overall number of recaptures for this particular individual was nine. It should be noted that during the blind testing, on one occasion, the software failed to identify a manually verified recapture (i.e., the recapture was not among the six suggested matches). However, after a change of the query image that was used for this individual (still a frontal image, but with slightly better focus), the verified recapture was suggested as the first match (Fig. 2). The distribution of the matching traits used by Hotspotter was mainly across the frontal part of the mouth and the lower part of the horn (Fig. 3), suggesting that this area is of the greatest value for the automatic identification.

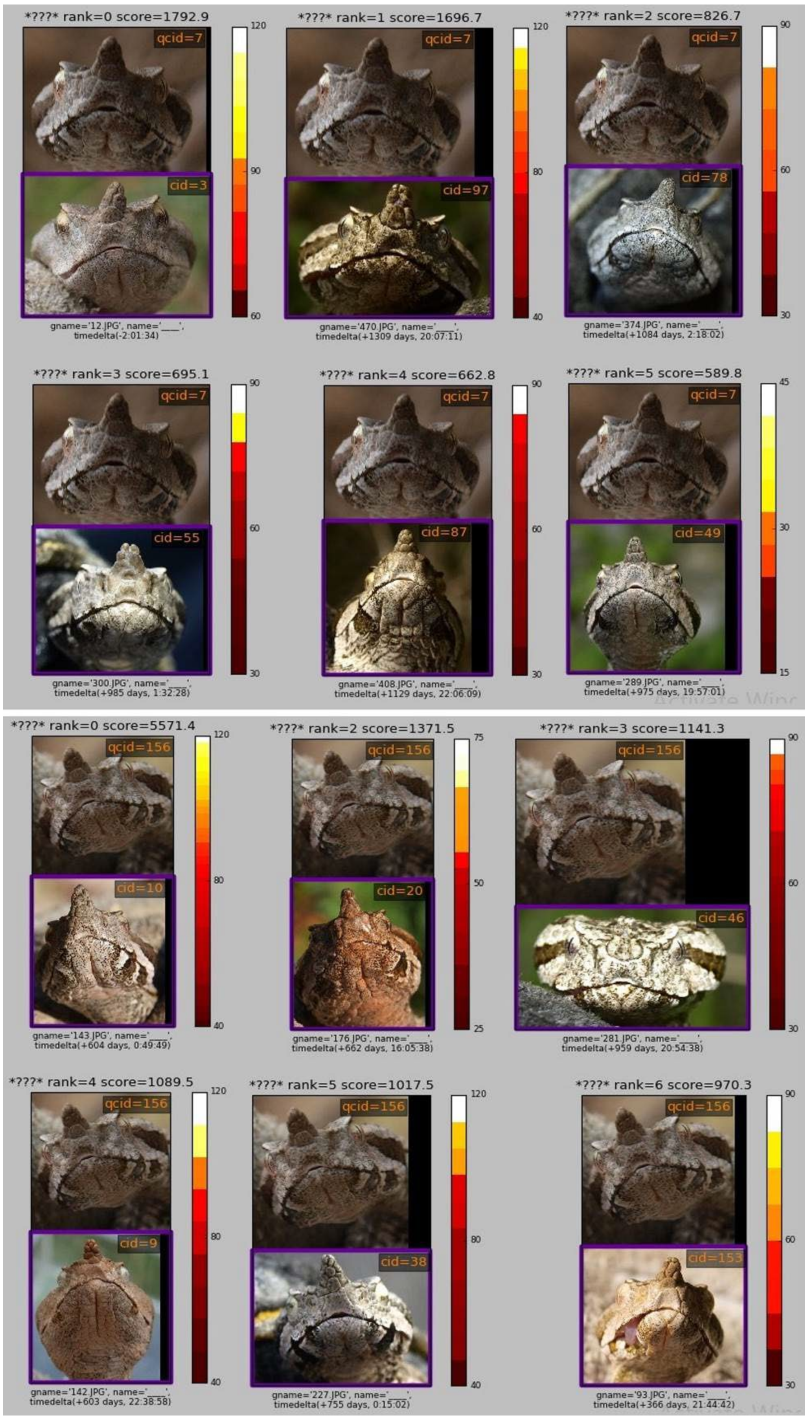

Figure 2. Original (top) and replacement photograph (bottom) for a viper with a verified recapture that was not initially detected by the Hotspotter software. Originally, all suggested matches by the software (bottom photograph in each pair) were different images, but after replacement, the verified match was the first suggested.

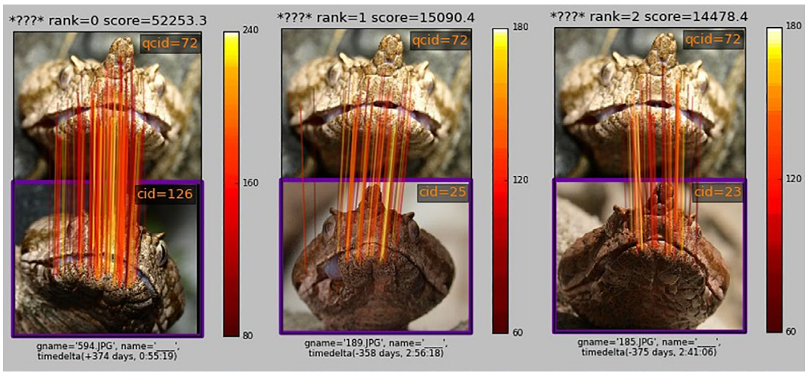

Figure 3. Distribution of the matching traits in three confirmed matches - most are distributed across the jaws and the frontal part of the head.

The similarity score varied within an exceptionally broad range, but only four verified matches had a score below 2600, which was the average for the non-matches, and similarity scores above 5200 produced correct results in 86% of the cases (Table 1). The time between the first and last capture varied between 1126 and 11 days, with an average of 436 days. On six occasions, the similarity score for a first match was rather low (below 3000); SL could not definitively verify a recapture from the "horn" image and so manually checked the "back" images as well to be certain of successful automatic identification. On all six occasions, the suggested low-score matches were indeed recaptures. There were no "false positives", i.e., images accepted by SL as matches that, in reality, were not.

Table 1. Similarity scores for the whole dataset, summarized into groups. First match – score of the first suggested match for verified matches; Last match – aggregate score for all verified matches after the first suggested match (in cases with more than one verified match); No match – score of the first suggested match for individuals without verified recapture. Values are presented as Mean (Max–Min).

	First match (n = 75)	Last match (n = 76)	No match (n = 80)
Score range	94 863 (666 800 – 2640)	30 888 (101 938 – 2027)	2598 (6749 – 812)
Below 2 600	0	4	41
Above 5 200	65	69	5
2 600 – 5 200	10	3	34

Discussion

Our results indicate that automatic pattern recognition software is a highly efficient tool for identifying individual Nose-horned vipers. The manual verification of matches for all 155 animals took five days of working 3–4 hours each day; with Hotspotter, the same result was achieved within a single day of a 4-hour work period. This is in accordance with results from other studies, which also established the merits of Hotspotter compared to similar software (Naumov & Lukanov 2018, Burgstaller et al. 2021, Dunbar et al. 2021). Dunbar et al. (2021) point out that Hotspotter was able to identify even out-of-focus images of Hawksbill sea turtles (*Eretmochelys imbricata*), and Patel & Das (2020) have successfully used it with Assam sucker frogs (*Amolops formosus*) photographed from up to 6 m away. However, we must stress that in our case, image quality was shown to be particularly important. The single case when the algorithm initially failed to recognize a recapture was when the horn in the photo was partially shaded (although with discernable scales on the head and horn). When the image was replaced with another with brighter ROI, the program worked markedly better, providing the only recapture as the first suggested match. Dunbar et al. (2021) used similarity scores to calculate a cut-off value for their first-choice match, above which there was an 84% chance that the first choice was a true match. Although similarity scores vary with sample size, smaller samples tend to produce higher scores (Crall et al. 2013), and despite the exceptionally wide variation in the scores for our verified matches, our results suggest a comparable conclusion. Still, in our view, the order of the confirmed matches was more important, as it was always consecutive (with no false matches between verified ones) – a good indicator of the algorithm's accuracy. This accuracy was also confirmed in our proof-of-concept test, where the software could identify the three matches of a viper by images before and after a wound on the horn, with 430 days between the images of the first and last capture. In the population of the present study, the software recognized a recapture after more than three years. A valuable feature in this regard is the ability of Hotspotter to read the photographs' metadata and calculate days between the compared images, which allows for rapid assessment of the time between recaptures. The software could also be useful in other viperid species with clearly differentiated and individually specific scales, such as *Vipera berus, V. ursinii*, or *V. seoanei*. It should be noted that for larger samples (over 900–1000 images), Hotspotter tends to crash and disrupt the workflow (S. Lukanov, pers. obs.; S. Burgstaller, pers. comm. 2022) – however, no problems of this kind were reported by Dunbar et al. (2021), who used 2136 images of Hawksbill turtles. Regarding alternative pattern recognition software, Ray & Timmerman (2018) were positively impressed by the ability of I3S to identify individual *V. berus* by the scale and color pattern of the back of the head but stated that photos should be taken perpendicularly (no more than 30° offset), without light reflections on the scales; otherwise, analyses were hindered. Their database was comparable to ours and consisted of 153 images of 73 vipers, although they did not use alternative images (i.e., as the frontal images in our study). While Hotspotter failed with the "back" series, the "horn" images provided reliable results, depending only on focus. Several studies that used I3S for other species have indicated a high probability of decreased matching accuracy with increased variability in photo angle, light, and distance (Calmanovici et al. 2018, Chaves et al. 2016, Dunbar et al. 2014, Sacchi et al. 2010), as well as an increased necessity for manual verification (Dunbar et al. 2014, 2021). For this reason, we encourage additional testing of various software for image recognition in snakes, as they can only benefit CMR studies in this reptile group.

In conclusion, the main advantage of this method is that it significantly reduces time spent on identification compared to manual verification of the images while maintaining the same reliability. Still, it is advisable to have images of both the back and the horn, which can be compared in case of inconclusive identification by the algorithm. Especially important for the "horn" comparison is that the scales on the head and the horn itself should be in focus and clearly visible, as even a slight blur in the ROI can lead to a lower probability of correct matching. Regarding usefulness for other reptile species, our results suggest that this method could be successful in any species with well-defined and characteristic scales, but additional data are needed before any definitive conclusions may be made.

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