The Green Toad Example: A Comparison of Pattern Recognition Software

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Short report

Keywords: Amphibia, picture comparison, population statistics, recapture study

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The green toad example: a comparison of pattern recognition software

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Abstract

Background

Individual identification of animals is important for assessing the size and status of populations. Photo-based approaches, where animals are recognized by naturally occurring and visually identifiable features, such as color patterns, are cost-effective methods for this purpose. We compared five available programs for their power to semi-automatically identify dorsal patterns of the European green toad (*Bufotes viridis*).

Method

We created a data set of 200 pictures of known identity, two pictures for each individual, and analyzed the percentage of correctly identified animals for each software. Furthermore, we employed a generalized linear mixed model to identify important factors contributing to correct identifications. We used these results to estimate the population size of our hypothetical population.

Conclusions

The freely available HotSpotter application was the software which performed by far the best for our green toad example, identifying close to 100% of the photos correctly. The animals' sex highly significantly influenced detection probability, presumably because of sex-specific differences in the pattern contrast. Population estimates were close to the expected 100 for HotSpotter, but for the other applications population size was highly overestimated. Given the clarity of our results we strongly recommend the HotSpotter software, which is a highly efficient tool for individual pattern recognition.

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Background

One of the most basic but also most important tasks in conservation biology is to assess size and status of animal populations. Therefore, mark-recapture techniques in combination with population statistics are used to estimate demographic parameters. In many cases such data are collected in long-term studies and allow prediction of population trajectories. Certain mark-recapture techniques require to tag animals with more or less invasive methods ranging from toe clipping in amphibians (1), inserting PIT tags (2) to adding visual markings (3). Alternatively, genetic identification can be used as a non-invasive method (4).

The most cost-effective method, however, is to make use of naturally occurring body patterns (5–7). Unfortunately, visually matching pictures of such patterns can be very time consuming and, especially for long-term studies, decreases efficiency (8). Therefore, a number of pattern-matching algorithms have been developed which can cut time of photo comparisons, but in many instances, they can also lead to decreased accuracy (5,9,10). Decreased accuracy, in turn, can cause considerable errors when estimating demographic parameters (11,12). Consequently, deciding on the right algorithm to use for the respective data set is crucial.

Differences between data sets could include distance to the animals (e.g. photos of giraffes from the distance (13) and close-up pictures of tree frogs (14)), background of photos and quality of cameras used. In long-term data sets picture quality and attributes might vary drastically, therefore, in many instances, scientists prepare the photos before comparing the patterns, for example by cropping the pictures to only show the region of interest (ROI). This can be a quite elaborate task, although it is arguably less time consuming than comparing pictures visually. Matthé et al. (15) compared the performance of four pattern recognition programs with various amphibian species with high contrast patterns. In our case study we extended the selection of software packages and used different picture preparations, where applicable. Furthermore, we chose the green toad as an example of the programs' effectiveness on species with patterns of highly variable and changing contrast. We compared five different pattern recognition programs, which are freely available to researchers, with the exception of AmphIdent. Our results can help population ecologists to gain efficiency when comparing a variety of animal patterns for individual identification.

Methods

We used pictures from a long-term capture-recapture study of green toads (*Bufotes viridis*) at the Rudolf-Bednar-Park in Vienna (48° 13′ 35″ N, 16° 23′ 47″ E). Green toads are suitable for automated pattern matching as they have striking dorsal patterns, although the contrast of this pattern can change over time (16). Pictures of the dorsal patterns of green toads were taken in the field with a variety of cameras. The photo background was mostly uniformly white or grey (sheet, cup etc.). A few photos were taken on patchy background (e.g. gravel) or contain parts of a researcher's hand. We classified each camera as one of three types: smart phone cameras, compact cameras and reflex cameras. For the purpose of this study we selected 200 pictures of known animal IDs (two per ID, 100 'reference' and 100 'unknown') of varying quality and different sexes (females: 18, males: 58, unidentifiable: 24, this resembles naturally occurring ratios). We used five different software applications (Wild-ID (13), HotSpotter (17), AmphIdent (application for fire bellied toads) (18), I3S Pattern+ (19) and APHIS (20)) to compare the pictures. Furthermore, for Wild-ID and HotSpotter we chose three different ways to pre-process the pictures, where we used different cropping extents. The cropping types are called a, b and c in this paper, and refer to 'whole animal', 'head', 'ROI on head', respectively (Figure S1). In AmphIdent, APHIS and I3SP+ it is required to define a region of interest for every image after loading. For I3SP+ we defined a ROI similar to the shape of cropping type c. For AmphIdent and APHIS we had to adhere to the ROI selection of the respective software. These are squares and rectangles, respectively, which we placed in the same part of the head as in cropping type c. (see Figure S2 for details).

Pictures were always compared in the same order. The picture comparisons followed the applications' manuals; however, the general procedure was the same throughout. We first added 100 'reference' pictures for each of the used individuals to the application's database, which simulates that we already encountered each of the individuals (once) before. We did this to ensure that each of the new pictures could find a match in the previous record. We then compared 100 pictures of 'unknown' ID to the application database. Usually the user decides whether one of the first few automatically selected pictures is a match or not, but for the purpose of this analysis we only considered the picture ranked first. If this picture was a true match, we recorded a true detection (1), otherwise a false detection (0). AmphIdent and I3SP+ have functions for manual input to improve the performance, we used them to the following extent. In I3SP+ pixels can be chosen to discern the pattern's fore- and background. Our time effort to discern fore- from background did never exceed three minutes. AmphIdent has the option to only compare subareas of the ROI. If comparing the whole ROI did not yield a true detection, this function was used up to two times. We bootstrapped a 95% confidence interval for the mean detection success for each software using the function boot.ci in the package boot (21) in R (22).

To statistically analyze the performance of the different software we used a generalized linear mixed model (GLMM) with a binomial error distribution employing the function glmmTMB from the package glmmTMB (23). As the response variable we used the level of detection (0/1) and predictors were the software application, sex of the animals, camera type of the first picture and the second picture as well as interaction between the camera types. In addition, we used individual as a random factor in the model.

We used the Petersen index (24) to estimate abundance assuming that we compared two sampling occasions (the first occasion was the set of the first 100 pictures of 100 individuals, the second occasion was the second set of 100 pictures). The true 'population size' therefore was 100. Raw data and R code to reproduce our analysis are available in the supplementary information.

Results

From the evaluated applications HotSpotter performed the best with detection rates close to 100%, there was only little variation accounted for by image cropping for this software (Figure 1). AmphIdent, Wild-ID (c), and APHIS identified just over 60% of the images correctly. Wild-ID (b), Wild-ID (a) and I3SP+ all identified less than 60% of the images correctly. Cropping was important for Wild-ID, but not for HotSpotter, presumably because this application contains a well-developed background subtraction algorithm incorporated in the software. It should be noted that in all cases results would have been substantially better, if we had included more than just the first hit for an image.

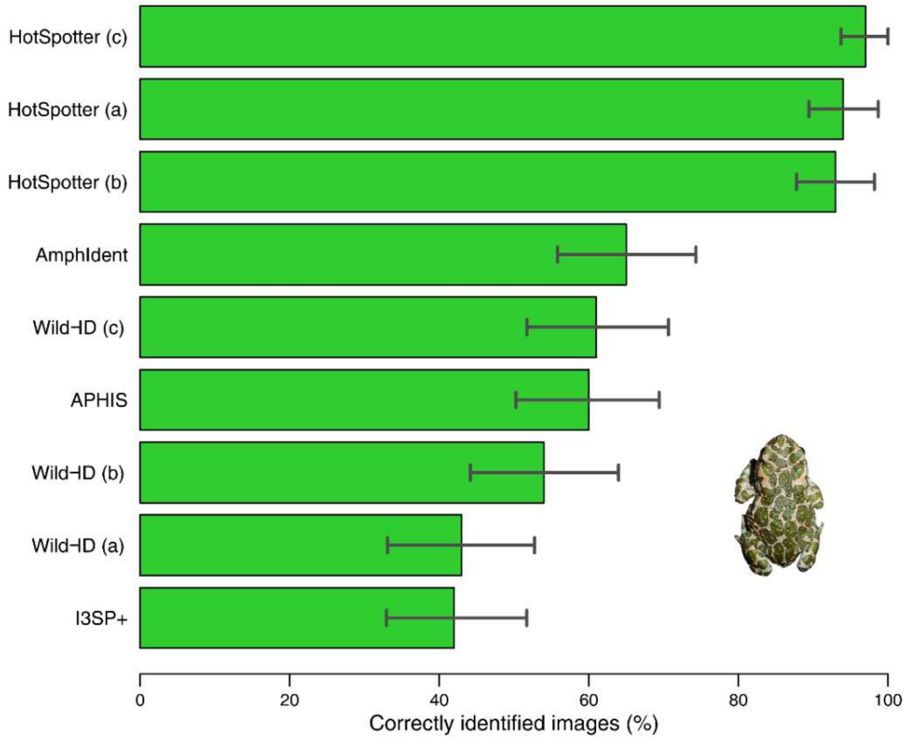

Figure 1: Results of comparison showing the percentage of correctly identified pictures in our data set.

Apart of the highly significant effect of the software also the sex of the animals influenced probability of correct identification (Table 1). This might be expected as the patterns of females have higher contrasts between the green and white patches than the male patterns (16). Nonetheless, it highlights potential confounding factors when performing capture-recapture analyses based on pattern recognition. The camera type used for the pictures only showed weakly significant effects or no effects at all, we did not find any interaction effect between the camera used for the first and the second photo. Switching cameras from one to another occasion might not be an important factor for successful identification.

Table 1: ANOVA table showing the results for the GLMM

	Chisq	*df*	*p*
Sex	28.38	2	<0.01
Software	124.62	8	<0.01
Cam 1	6.02	2	0.049
Cam 2	2.30	1	0.129
Cam 1 : Cam 2	4.17	2	0.124

If we used solely the first hit from the respective software application and no additional manual comparison, the population sizes would be overestimated to different extent (Table 2). For the HotSpotter software, the estimated numbers are still close to the actual N, and only a few animals would be added. However, for I3SP+ the estimated size would be more than doubled, in comparison to the real population size.

Table 2: Population size estimates for the different applications

Software	*Petersen index estimate*
AmphIdent	153.85
APHIS	166.67
HotSpotter (a)	106.38
HotSpotter (b)	107.53
HotSpotter (c)	103.09
I3SP+	238.10
Wild-ID (a)	232.56
Wild-ID (b)	185.19
Wild-ID (c)	163.93

Discussion

We show that using automatic pattern recognition applications can be a highly efficient tool to identify individual animals. The software which worked best for our example was the freely available HotSpotter (17). Using this software, we identified the majority of the individuals correctly, and this even with our stringent detection criterium. Applying the same criteria for all other tested applications yielded detection rates around 60% and below. HotSpotter also allows to process the pictures without any time-consuming pre-processing, i.e. cropping the pictures did not significantly change the detection probability. Note that for animals lacking well-defined color patterns these applications might not be an efficient solution for individual identification (10). Focusing on other distinct features (e.g. arrangement of warts or the pores of the parotoid gland) might be a viable alternative in these cases, possibly demanding different cropping techniques. Furthermore, we showed that differences in the detection probability between individuals and sexes could bias population estimations. Knowing such potential biases (e.g. detection probability for a certain group) and/or error rates could be used to inform and improve population analyses (25).

Recently, it has been shown that HotSpotter can be used for identification of animals that were photographed from the distance (26). Therefore, apart from the general use in traditional population analyses, matching individuals from photos could also be used in citizen science projects. In cases where citizens are asked to take pictures of certain animals in a specific area, scientists might be able to determine the individual identity from such photos (27).

In conclusion, at least for our green toad example and possibly species with similar patterns the freely available HotSpotter software constitutes a major improvement to other more widely used pattern recognition software, such as APHIS and Wild-ID.

Declarations

Ethics approval

Toad pictures are taken from an ongoing effort in monitoring green toad populations in Vienna. All pictures were taken under a permit issued by the municipal department for environmental protection (MA 22 – 984143-2015-5).

Consent for publication

All authors consent for publication of this manuscript.

Availability of data and materials

Raw data are available in the supplementary of this manuscript.

Competing interests

The authors declare to have no competing interests.

Funding

The authors received no funding for this study.

Authors' contributions

SB and LL conceived the study. SB performed the picture comparisons. SB and LL did the statistical analyses. SB, LL, and GG interpreted the data and wrote the paper.

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Supplementary figure

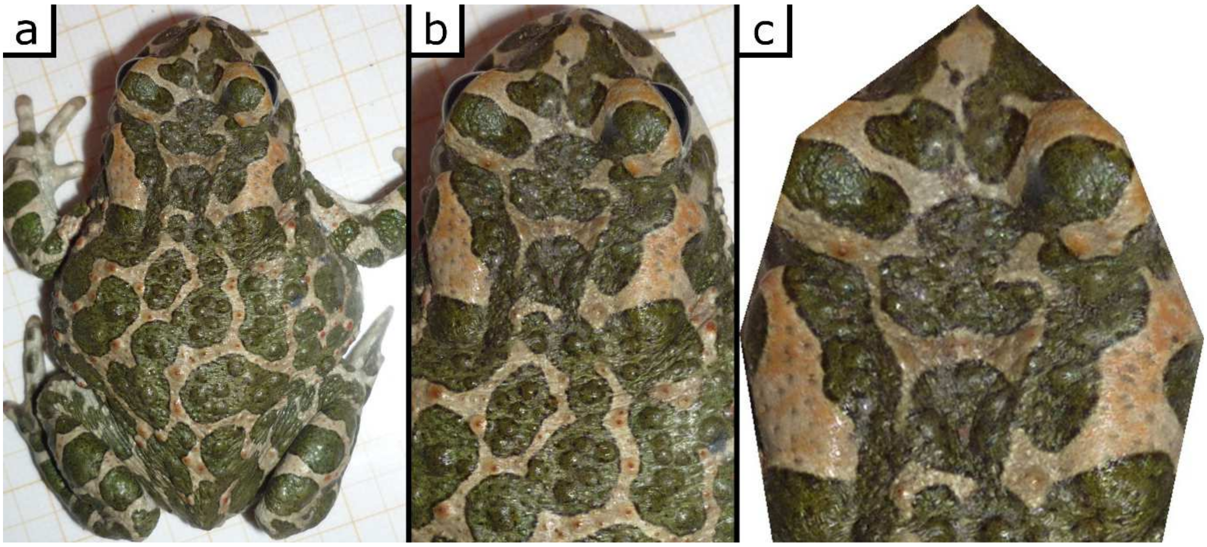

Figure S1: The three different cropping types used in the study for HotSpotter and Wild-ID: whole animal (a), head (b), region of interest (c).

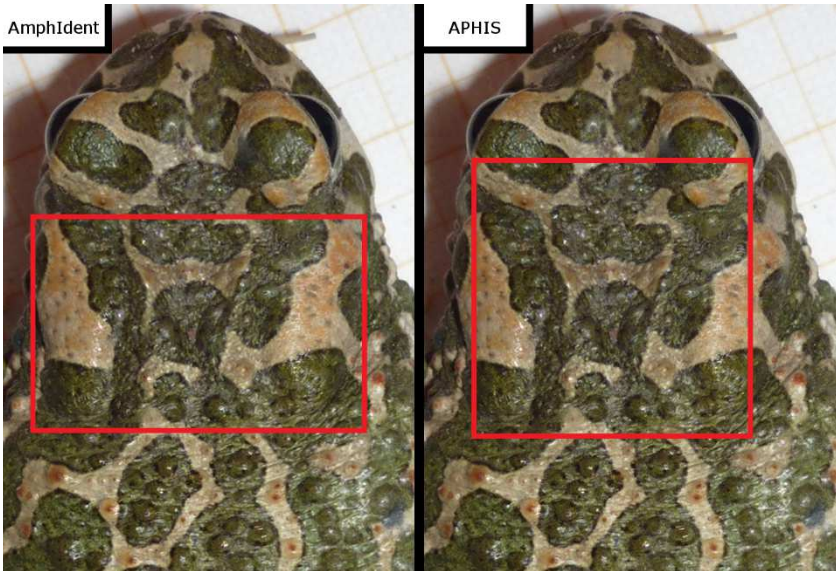

Figure S2: The shapes of the ROI for AmphIdent (left) and APHIS (right). The width to height ratio for APHIS is fixed at 1:1. We chose to locate the upper two corners of the ROI at the lower end of the visible eyeballs. For AmphIdent the ROI ratio can be freely chosen but the selected area will be stretched to a 10:7 ratio, so in order not to distort the original picture too much we selected an area with this approximate ratio. The ROI extends from the upper to the lower, as well as from the left to the right edges of the parotoid glands.

Figures

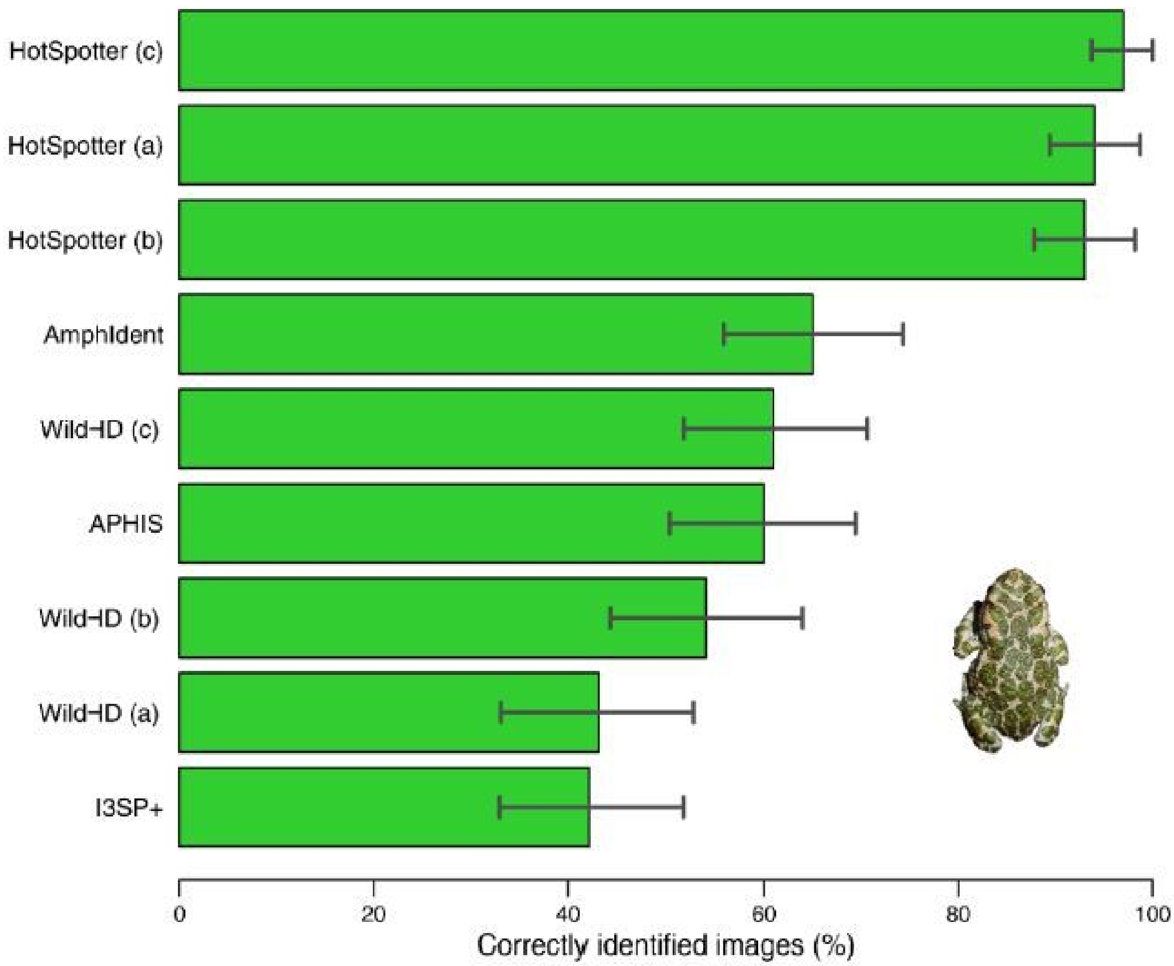

Figure 1

Results of comparison showing the percentage of correctly identified pictures in our data set.

Supplementary Files

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- FigS1.JPG
- FigS2.JPG