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Identifying Australian snakes by color patterns

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Abstract

We investigated if Australian snakes can be identified by using their color, pattern, size and location. We coded these criteria for the 185 terrestrial snake species of Australia (excluding 37 species of sea snakes from our analysis). Uniformly brown snakes are most common, followed by banded and blotched species. Some highly variable species can have dozens of color patterns. For most localities these four criteria are sufficient to narrow down the number of possible species to fewer than 21 species and in most cases accurate identification is possible with a few photos for comparison. Given that most Australian snakes are venomous, accurately identifying snakes is also of medical importance. In addition to identifying snakes, colors and patterns provide useful data for phylogenetic and ecological studies.

Key words

Elapidae, geography, Pythonidae, Typhlopidae.

Introduction

More than 4,600 different snakes are recognized today, including ~3,800 species and ~780 subspecies, distributed over all five continents (Uetz, 2020). These include almost 800 venomous species which cause an estimated 94,000 deaths per year (Chippaux, 1998; Kasturiratne *et al*., 2008), hence it is important that venomous snakes can be identified quickly and easily. However, it has been shown that Australians (and likely people in most other countries) struggle between distinguishing between dangerous and harmless snakes (Wolfe *et al*., 2020).

While the snake body plan is simple (essentially a tube), snakes occur in a great variety of colors, patterns, and sizes. Even with a limited set of pigments (black, red, yellow, plus reflections by iridophores), snakes can be blue, green, brown or purple. These colorations result from variations in quantity and quality and interaction of the basic colors, the various components of the spectrum reflected by the iridophores, and the hemoglobins in the blood supply of the dermis. Snake patterns also show a great diversity, where the most common patterns are longitudinal striping, regular and irregular crossbands, neck rings, rings on the body, chain marking, longitudinal rows of dorsal blotches or saddles, longitudinal rows of diamond-shaped markings, and spots and checkers on the venter (Bechtel, 1978).

We wondered if we can use simple descriptions of color and pattern to identify snakes or at least possible species. In other words: is it possible to identify a snake species by simply recording its color, pattern, and size in a given locality? If not, to how many species can we narrow it down to and what other information do we need for a reliable identification? A sub-problem of this question is whether a particular snake is venomous or not.

Australia has about 220 snake species most of which are either elapids (145 species), blindsnakes (49), or pythons (18). The country has a very high fraction of medically important snakes (34%; Longbottom *et al*., 2018),

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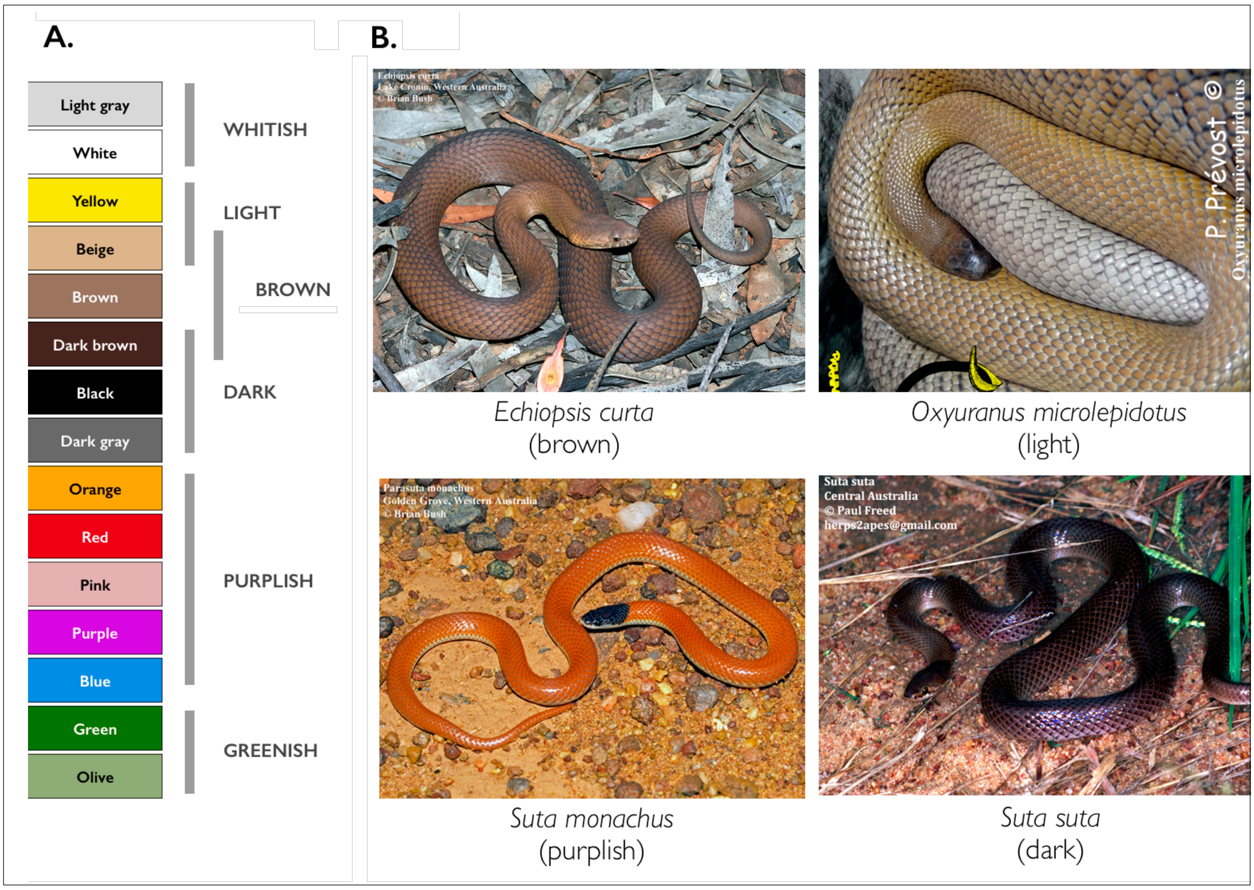


Fig. 1. Color terminology used in this study. A. Original color scheme (left) with 15 colors that were reduced to a simpler scheme with 6 colors (bars and labels on right). B. Examples. Photos courtesy of Paul Freed, Brian Bush, and Patrick Prevost (as indicated).

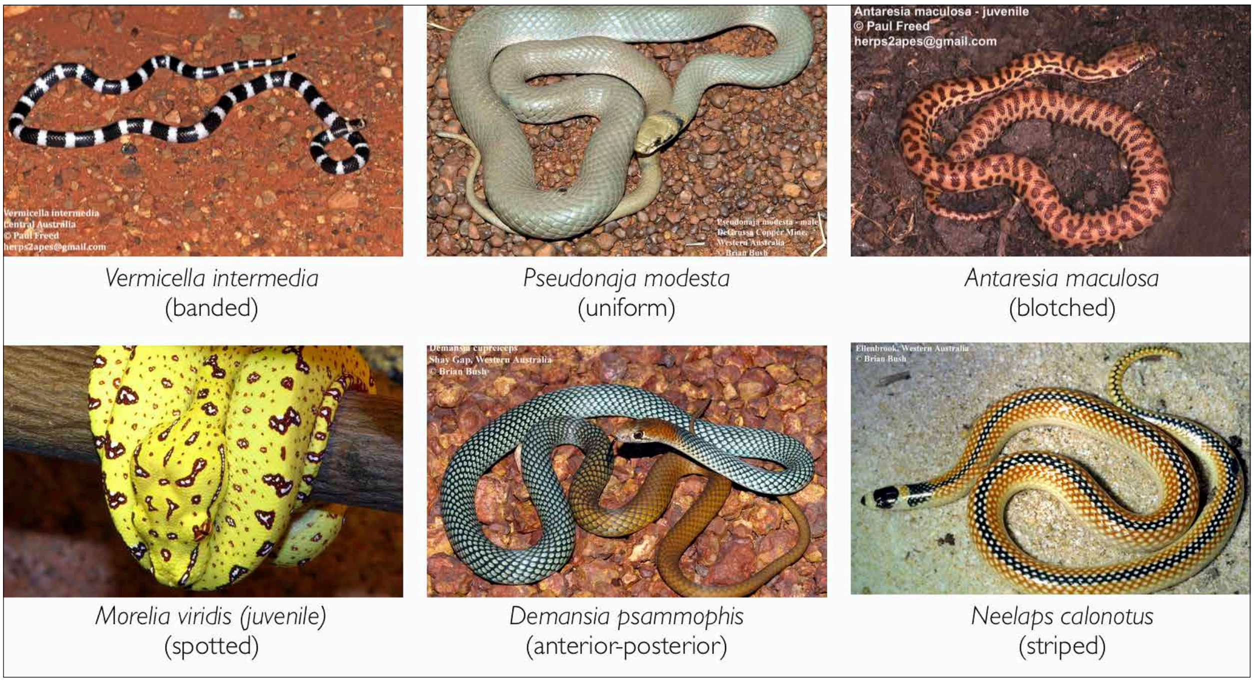


Fig. 2. Snake patterns used in the study. A total of 6 snake patterns were used to differentiate between all snakes. The anterior-posterior pattern represents snakes that have different colors anteriorly and posteriorly. 'Blotches' are large spots and 'spots' are small (less than 3 scales in diameter). Some species like this *Morelia viridis* may show a combination of patterns, such as both blotches and spots. When *all* scales show the same or a very similar pattern, they are classified as *uniform* (except when they have another obvious pattern, like the *Neelaps calonotus* shown here). *Demansia psammophis cupreiceps* (as shown) has been also assigned to *D. reticulata* or treated as a valid species, *D. cupreiceps*, by some authors. Photos courtesy of Paul Freed, Brian Bush (as indicated) and Mike Wesemann / Wikimedia (*M. viridis*).

that account for ~1,200 snakebite envenomation and 2–4 fatalities every year (Currie, 2000).

Although numerous field guides and other snake books have been published, it is often cumbersome to search them. Thus, a goal of this project was to compile data that would allow even inexperienced users to identify a snake or a least narrow down possible species, eventually using a website or mobile app, although this goal is outside the scope of this project.

In order to classify colors and patterns of Australian snakes, we collected > 1000 published photographs of all terrestrial species and coded their color and pattern. We then mapped these color patterns to geographic maps to find the frequency of patterns in each grid cell. This would tell us, for instance, how many uniform brown snakes are expected in one cell and thus which species they likely are. Although we did not expect precise identifications from such a simplified approach, our goal was to provide the data to identify a shortlist of possible species that can then be verified with additional data such as photographs or scalation data.

Materials and Methods

Image and character collection

In order to collect pattern data, we collected 1194 published images from books and papers, with additional images from the Reptile Database (Table 1). This approach was preferred over image searches online, given that such images are often much less reliably identified and often fleeting (web pages can disappear or their URLs change). While we attempted to have at least 2 images of live specimens per species, 11 species are represented by only one photo (e.g., the photo of *Vermicella parsacauda* was taken from Eipper & Eipper, 2019 but is essentially the same as the one in the original description). A complete list of images and their sources is provided in Supplementary Table S1.

The images were then used to code the patterns and colors. We initially used 15 colors (with additional shades, such as olive included in green) but then simplified them to six color codes (whitish, light, brown, dark, purplish and greenish; Fig. 1) and six basic patterns (banded, anterior-posterior, spotted, uniform and striped; Fig. 2). For most patterns this was straightforward but some patterns are intermediate between pattern categories, e.g., many sea snakes are intermediate between blotched and banded. These cases were coded with both patterns, so they can be found when searching a list using either term. For colors, we coded the dominant 1–3 colors, so if a black-and-white banded snake has a few yellow dots somewhere, they were usually ignored unless they are big enough to be easily seen from a distance. Given that brown is the most common color among Australian snakes, we initially differentiated light brown, brown and dark brown, but eventually merged them into a single "brown", given that light conditions or variation among specimens may make it often impossible to pick the "correct" hue. Similarly, rare colors such as purple or orange were subsumed under "purplish" which is found in no more than 50 species, even when applied generously. This approach is still imperfect but simplifies data analysis and utility, and thus should be acceptable for our goals. However, the full dataset is available for further analyses and ID app development.

Table 1. Image sources for this project. A complete list of photos and their sources is provided in Supplementary Table S1.

Source	Number of photos
Eipper & Eipper (2019)	260
Wilson & Swan (2013)	247
Cogger (2014)	193
Storr *et al*. (2002)	122
Uetz (2020)/Reptile Database	217
34 other sources (< 24 photos each)	155
Total	**1194**

Mapping colors and patterns

All categorical traits were classified in binary terms, by presence or absence of each trait, although traits could adopt multiple values, e.g., black and white for color (Supplementary Table S1). The size was the maximum published value for each species. Small species were arbitrarily considered to be smaller than 1 m and large were considered to be of 1 m or more of length.

We refer to each combination of traits as "morphotype". Several species may share the same morphotype, for example, *Anilios ammodytes*, *A. aspinus* and *A. australis* can all be uniform brown. On the other hand, one species may also have numerous morphotypes, such as the coastal taipan (*Oxyuranus scutellatus*) which can be gray or brown and have stripes or be uniform. Hence, the number of morphotypes in a particular cell refers to the number of different combinations of colors, patterns and size thresholds. A grid cell with low species richness may therefore still have a high number of morphotypes, and a cell with high richness may have a low number of morphotypes.

Distribution maps and spatial analysis

To map the colors and patterns of the 227 Australian snake species, we intersected the species ranges obtained either from IUCN or by digitizing the distribution maps from Cogger (2014) to a 50 by 50 km grid. The georeferencing of the distribution maps was done in qgis 3.6 and the remaining analysis were conducted in R 3.5.1 (R Core Team, 2018), using the packages sf 0.7-1 (Pebesma, 2018), raster 3.0-7 (Hijmans *et al*., 2015),

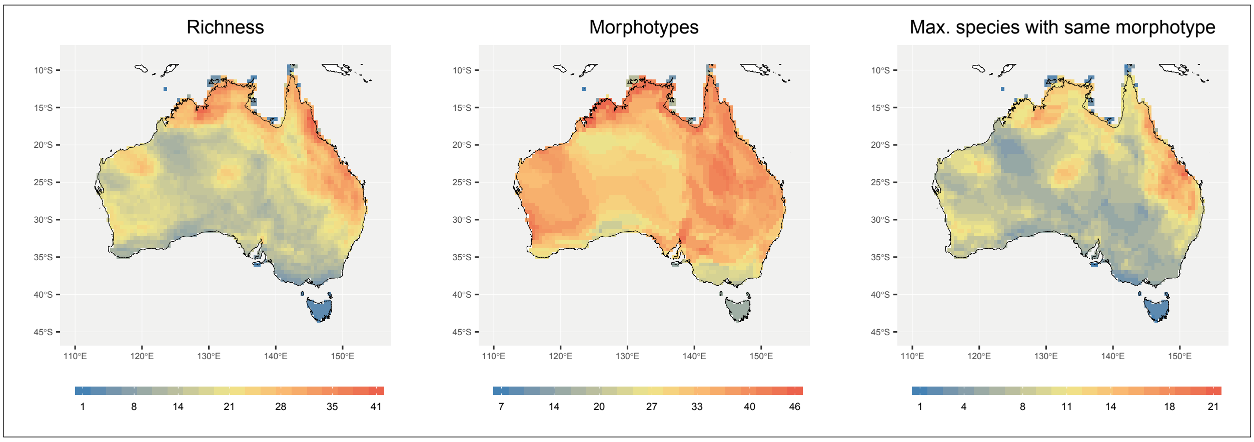


Fig. 3. Species richness (left), morphotype richness (middle) and maximum number of species with the same morphotype across Australian snakes. The maximum number of species in a grid cell was 41, while some grid cells have up to 46 different morphotypes. The maximum number of species with the same morphotype in a cell was 21, namely small brown uniform snakes in cell in Queensland.

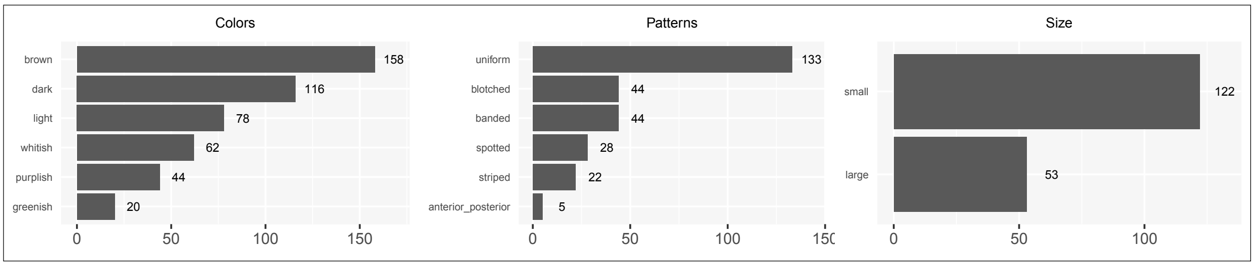


Fig. 4. Number of species by trait. Left panel – color, middle panel – pattern, right panel – size.

ggplot2 3.1.0 (Wickham, 2016), and rnaturalearth 0.1.0 (South, 2017).

Due to the lack of distribution maps of Australian sea snakes in the IUCN database, we excluded the sea snakes from our spatial analysis. A total of 37 marine species were excluded, belonging to the following genera: *Aipysurus*, *Emydocephalus*, *Ephalophis*, *Hydrelaps*, *Hydrophis*, *Laticauda*, *Parahydrophis*, and *Microcephalophis*.

Results

Australia has a relatively low number of snakes for a country of its size and climate (smaller countries such as Mexico or India have many more). Hence the number of different species in any particular area is also moderate with about 1 to 41 species per area unit (here: ~ 50 × 50 km, Fig. 3 – left panel). All possible combinations of color, patterns and size result in 72 unique possible morphotypes (6 × 6 × 2), of which 51 actually exist (to our knowledge) in Australia. The range of possible snake morphotypes per grid cell observed across the country was between 7 and 46 (Fig. 3 – middle panel).

We wondered how many different morphotypes can be found in any particular grid cell. More importantly, how does the number of species relate to the number of morphotypes in a grid cell? The latter number would give the number of species that share a particular morphotype and thus indicate how difficult it is to identify a species. We find that no grid cell had more than 21 species of the same morphotype (i.e. when all color, pattern, and sizes are combined, Fig. 3).

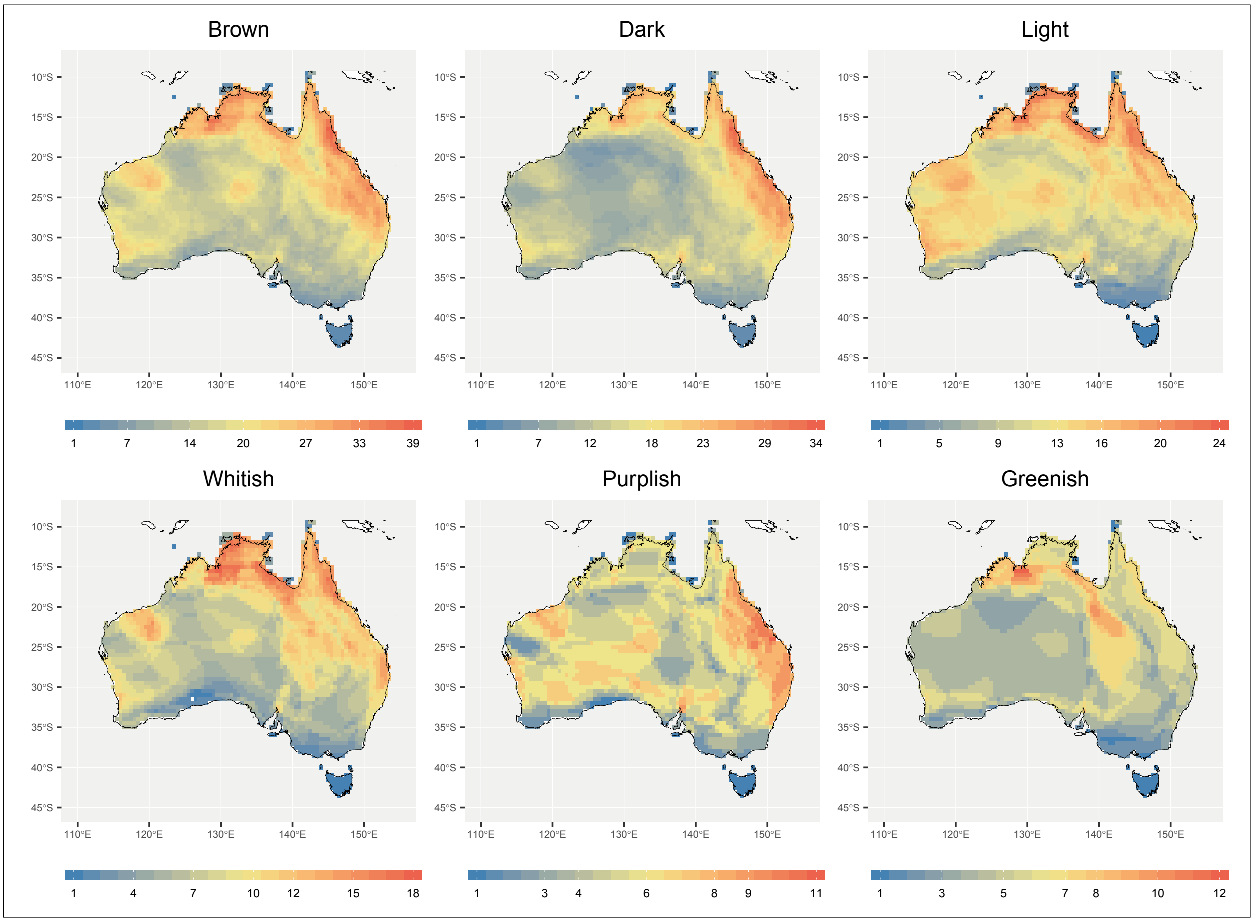
Despite hundreds of snake species, the morphological diversity in Australia is also moderate. For instance, > 2/3 of all snakes are uniformly colored (Fig. 4 – middle panel), > 85% (Fig. 4 – left panel) are brown.

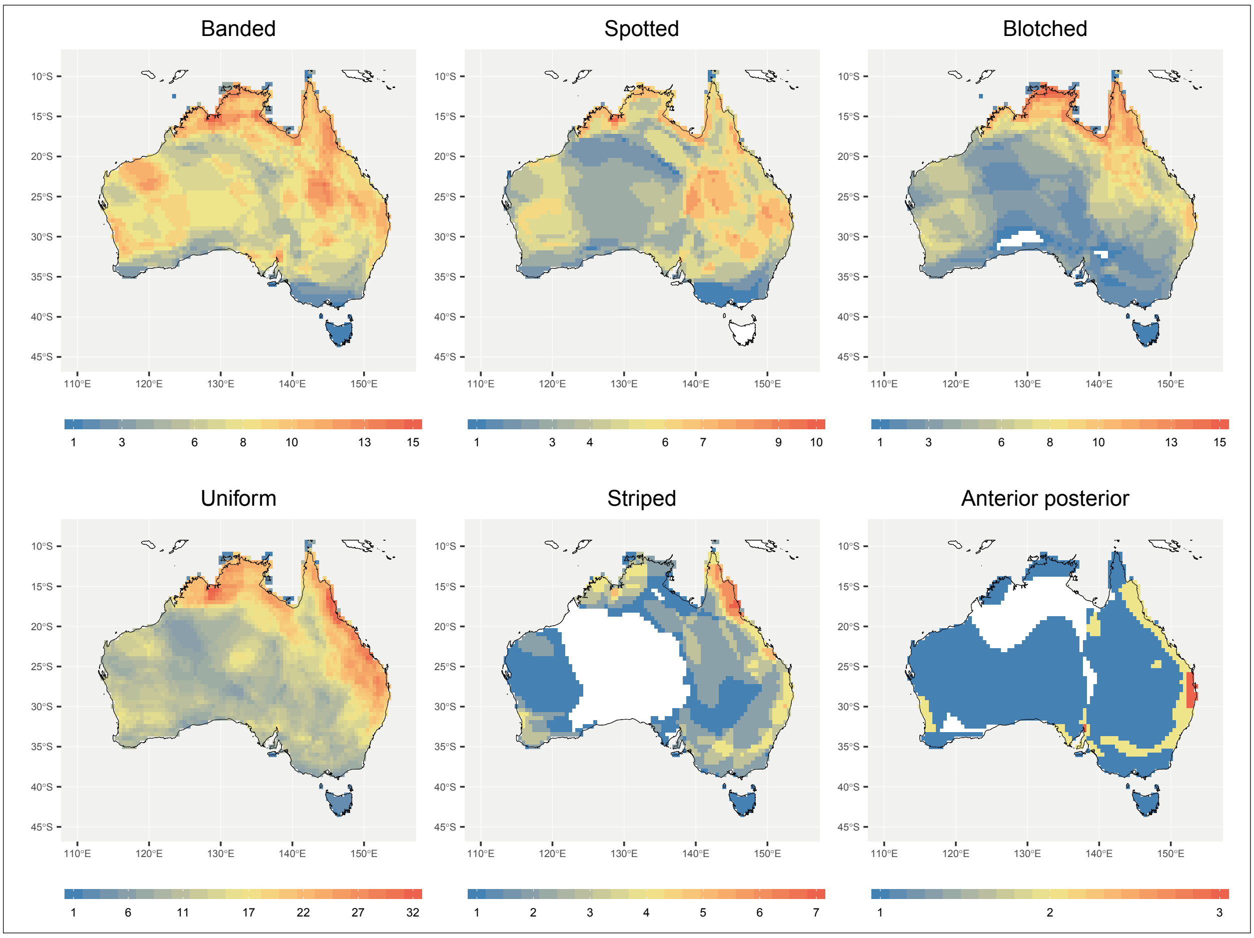
Overall, the morphotype richness reflects the species richness (Figs 3, 5). However, there are also surprising geographic patterns, such as the enrichment of greenish snakes in a "northern arc", especially in north-eastern Western Australia (Fig. 5).

Even with ~ 130 uniformly colored snakes, there is no grid cell that has more than 39 brown species or more than 32 uniformly colored species (Figs 5 and 6).

→ **Fig. 5 – top.** Number of species per color trait across Australia. See Fig. 1 for explanation of colors.

→ **Fig. 6 – bottom.** Number of species per pattern across Australia. See Fig. 2 for explanation of patterns.


Brown
Dark
Light
Whitish
Purplish
Greenish
10°S
15°S
20°S
25°S
30°S
35°S
40°S
45°S
110°E
120°E
130°E
140°E
150°E
1 7 14 20 27 33 39
1 7 12 18 23 29 34
1 5 9 13 16 20 24
1 4 7 10 12 15 18
1 3 4 6 8 9 11
1 3 5 7 8 10 12


Banded
Spotted
Blotched
Uniform
Striped
Anterior posterior
10°S
15°S
20°S
25°S
30°S
35°S
40°S
45°S
110°E
120°E
130°E
140°E
150°E
1 3 6 8 10 13 15
1 3 4 6 7 9 10
1 3 6 8 10 13 15
1 6 11 17 22 27 32
1 2 3 4 5 6 7
1 2 3

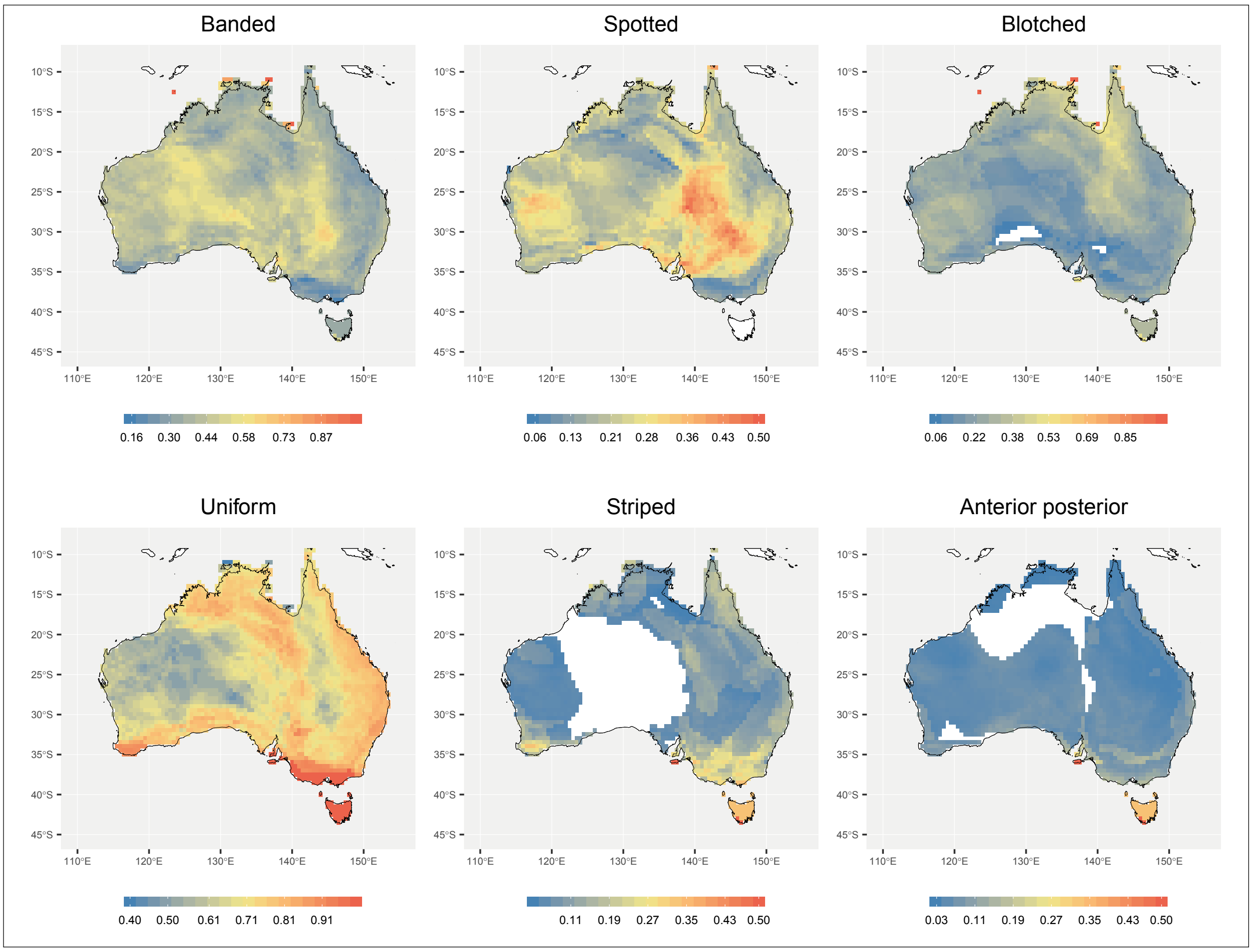


Fig. 7. Fraction of morphotypes relative to all snake species. Only uniform species make up a majority of all snakes in any particular area, including species that occur in both uniform and other patterns (e.g., *Notechis scutatus* which is notoriously variable)."

When color and pattern combinations are taken into account, this reduces the number of possible combinations per grid cell even further (Fig. 7). For instance, the most common color/pattern combination are uniformly brown snakes, but only 13.4% of all Australian grid cells have this combination for more than 20 species (Fig. 7). All other combinations are much rarer (e.g., Fig. 8 top right, bottom left). For instance, green spotted snakes do not occur in most grid cells at all, and if they occur, no more than 2 such species are found in any grid cell (Fig. 8 bottom right). Note, however, that "greenish spotted" includes obvious species such as *Morelia viridis* but also species that may only remotely look greenish and spotted, e.g., *Tropidonophis mairii*, which can have an olive tint.

Overall, no grid cell has more than about 20 species of the same pattern / color combination, even when all known variants of a species are considered (Figs 4, 9). This suggests that we can narrow down possible species by simply recording their color, pattern, size and locality. The correct species can usually be identified by comparing our specimen with photos of the candidate species with the same characters (Fig. 10), even though in some cases additional data such scalation will be required for an unambiguous ID.

Discussion

Photos as data source

We have used an average of 3–4 photos per snake species to extract color and pattern information. Photos have many limitations, including variable lighting, color distortion during image processing and the often-subjective interpretation of colors by the person who codes a color. For instance, dark brown snake may easily appear as black in a photo if the photo was taken under poor light conditions, making it look like black. We have tried to address this by using multiple photos, although the ideal number of photos per species is likely to be greater than an average of 3–4, especially considering the morphological and ontogenetic variation within some species (see below).

Natural variation

Another source for errors is natural variation. Many rare species are known from only a few specimens and many publications illustrate only one specimen, thus ignor-

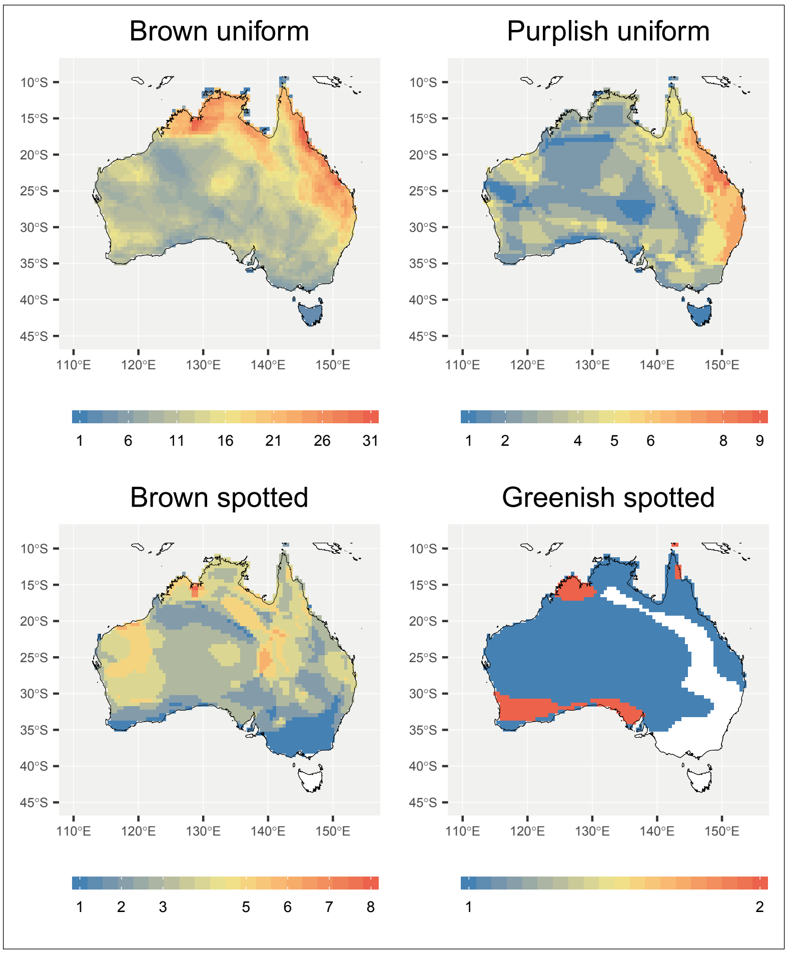


Fig. 8. Species richness of particular color patterns. Top left. Brown and uniform species. Top right: purplish and uniform species. Bottom left: brown and spotted species, and bottom right: greenish and spotted species.

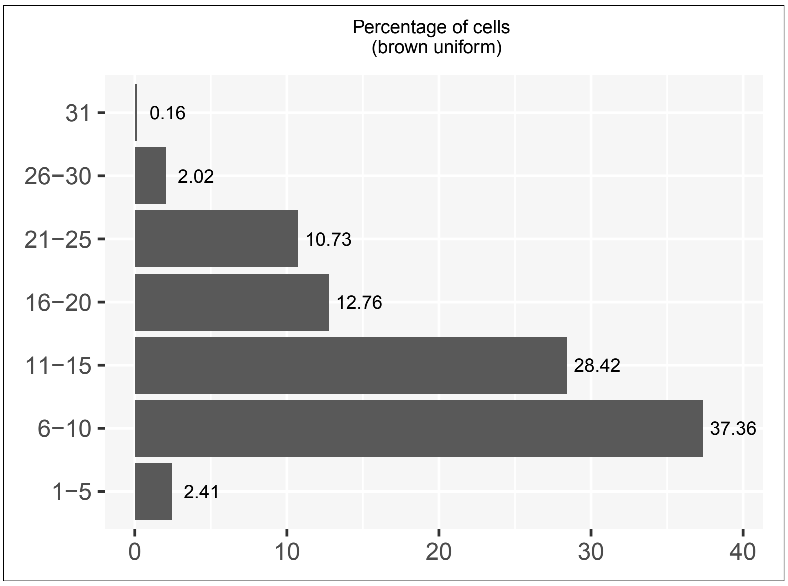


Fig. 9. Percentage of cells per number of species that have the brown and uniform morphotype. Y-axis shows number of species per cell and the X-axis show the percentage of cells per cell value intervals. Only 12.9% have more than 20 species in a single cell.

ing sexual dimorphism or ontogenetic variation. In fact, many juveniles are strikingly different from the adults, e.g., juvenile *Pseudonaja textilis* are typically banded while adults are usually uniform. In addition to that, some species are highly variable by nature (e.g., *Pseudonaja mengdeni*) and may have unknown color variants or mutations. Hence it is practically impossible to describe every single variant and thus to identify every single snake using our approach. Snakes can also show combinations of pattern types such as some whipsnakes (*Demansia*) that may be greenish anteriorly and brown posteriorly or show seasonal coloration changes such as *Oxyuranus*

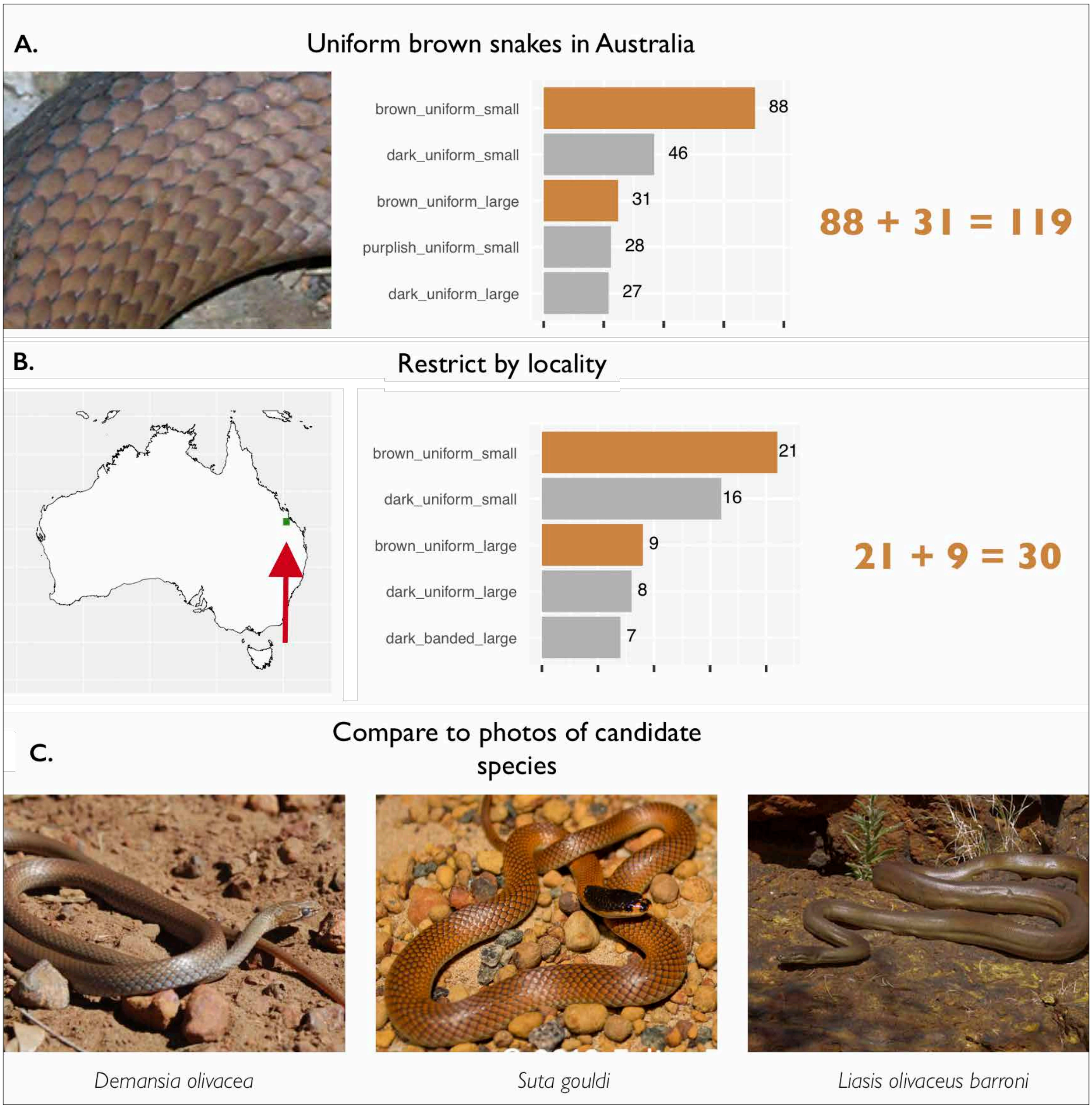


Fig. 10. Species identification using color, pattern, and geography (example). Three examples are shown at the bottom (*Demansia olivacea*, *Liasis olivaceus barroni*, *Suta gouldi*), showing that most morphotypes in any grid cell are sufficiently different to exclude most of them. By adding the size variable to our traits we are able to narrow down from a total of 30 brown uniform snakes to 21 small and 9 large snakes (Figs 10, 11). Photos in *C. courtesy* of Raz Martin, Julien Fonteneau, and Ryan J. Ellis.

microlepidotus (MIRTSCHIN *et al*., 2017). In this analysis we only considered *documented morphotypes*, thus excluding combinations not in our photo library. If a species was observed to be green spotted in one specimen and brown uniform in another, we excluded the option of it being brown spotted or green uniform. This approach is likely to cause an underestimation of possible morphotypes but will avoid an overestimation caused by inferring random trait combinations that do not actually exist. The analysis with all possible combinations can be found in the supplementary materials.

The size factor was added to species that had a high number of species per grid cell with the same morphotype. These include the brown and grey to black species. By adding the size factor we able to reduce the number of options from 30 species per grid cell in the case of uniform brown snakes to 9 species (for snakes greater than 1 m) and 21 species (for snakes smaller than a meter; Fig. 10). Although size is able to exclude smaller species it will not exclude larger ones, given that all snakes are smaller than 1 m when hatching. Our size categories are somewhat arbitrary and more subdivisions (e.g., in groups of 33, 66, 99 cm etc.) may increase the precision of searches, although the ability of observers to accurately estimate the size of a snake from an observation or photograph is also limited.

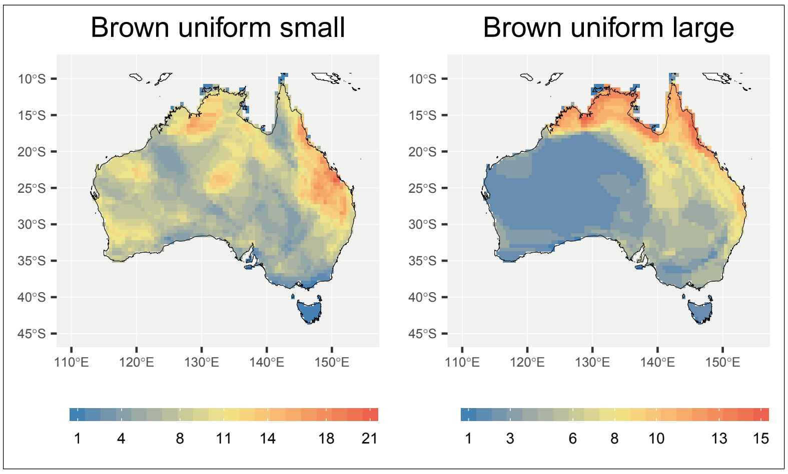


Fig. 11. Spatial distribution of species numbers with the morphotypes brown uniform. Smaller species (< 1 m, left panel) are significantly more common in Western and Central Australia than larger species (> 1 m, right panel).

Geographic localities

Using range maps is often critical to identify species and dramatically narrows down the number of species when combined with colors and patterns. However, polygons are incomplete descriptions of ranges, often ignoring habitat, elevation, or abundance data. While such data can be integrated in niche models (Elith & Leathwick, 2009), this is rarely done with polygons. In addition, ranges are often incompletely known as shown by the numerous range extensions that are published regularly. Projects such as citizen science programs can improve this situation to some extent although they have their own limitations such as erroneous identifications (Bird *et al.*, 2014). Most importantly, polygons are impossible to search by simple text searches, requiring more sophisticated search algorithms. Hence we included a list of (200 × 200 km) grid cells and the species occurring in each cell in Supplementary Table S2. We are also working on an implementation of an online search tool for our data but this was beyond the scope of this study.

Taxonomic considerations

Some snakes are harder to identify than others. For instance, blindsnakes are very similar to each other and are also relatively diverse with 49 species in Australia. Blindsnakes have the advantage that they are often restricted geographically, but on the other hand their ranges are often poorly understood and they may be found outside their known ranges. Given these limitations, our approach is probably not ideal for the identification of blindsnakes.

Outlook: other applications of color pattern data

Our data should be useful for many other applications, such as phylogenetic or ecological studies. In particular, color and pattern data have a strong phylogenetic signal (data not shown), that is, given that similar species are typically related. Good examples are the species of *Vermicella* or *Acanthophis* which are all banded. However, while there are some studies illuminating the role of color patterns in ecology (e.g., Allen *et al.*, 2013) it often remains unclear what the selective pressures and adaptations are that certain color pattern combinations provide in nature. More studies are required to expand these insights to a larger number of species and to geographic regions where snake diversity and snakebite risk may be even greater than in Australia.

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Electronic Supplement Files

at http://www.senckenberg.de/vertebrate-zoology

VZ_70-3_Farooq_Electronic_Supplements.zip (Download)

Fig. S1. 200 × 200 km grid cells used in Table S2.

Table S1. List of all images used in this study, together with their source, species, color and pattern coding.

Table S2. Snake species and their traits mapped to grid cells (Fig. S1).