Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2018, 8(4), 248-251

ORIGINAL ARTICLE

Adaptive peculiarities of pigmentation in the redbelly rock agama *Paralaudakia erythrogastra* (Nikolsky, 1896) (Agamidae)

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Received: 10.12.2018. Accepted: 20.12.2018

The aim of the study is to show the level of adaptation of reptiles to a natural habitat through skin pigmentation, using definitions of RGB coordinates, which are the main colour characteristics. Here, the coloration of the Redbelly Rock (Khorasan) Agama's skin is compared with the shades of the enclosure simulating the mountain substrate, which is the natural habitat of the lizard. The following average parameters of RGB coordinates have been determined: imitation of the mountain substrate-RGB (170, 139, 128); the agama's skin covering-RGB (177, 136, 100). The data obtained are indicative of the protective coloration in the agama.
Keywords: Redbelly rock (Khorasan) agama; skin; pigmentation; protective coloration; habitat

Introduction

The role of protective skin coloration in the vertebrates' adaptation to the habitat conditions and the successful strategy of the species' survival is well known, as is the morphological basis of pigmentation-a variety of pigment cells of the epidermis and corium (Bagnara et al., 1968; Taylor & Hadley, 1970; Morrison et al., 1996; Saxena R.K. & Saxena S., 2008; Stuart-Fox & Moussalli, 2009; Saenko et al., 2013).
The interest in the natural coloration in animals in the context of adaptation processes has a long history, beginning with the classic book of the English scientist Hugh Cott (1900-1987) "Adaptive Coloration in Animals" (1940). This fundamental monograph significantly contributed to understanding of the role of adaptive coloration in animals (Forsyth, 2014). This book was reissued in Russian in 1950 (Cott, 1950).
Protective skin coloration in reptiles is essential for active and passive protection from enemies. Effective camouflage in a habitat serves as passive protection. It ensures the fusion of the contours and body of an animal with the background of the substrate, making it difficult for predators to recognize it (Cott, 1950; Bannikov et al., 1977). A change in skin coloration can also be a manifestation of temperature regulation in reptiles (Stuart-Fox & Moussalli, 2009). The most interesting research related to the morpho-physiological bases of pigmentation in reptiles was carried out on chameleons Chamaeleonidae, who have an exceptional ability to show rapid and complex skin colour changes, which is linked with manifestation of communicative interaction between individuals in the form of competition between males or courtship behavior during a breeding season (Teyssier et al., 2015). The variability in pigmentation in chameleons is conditioned by the scattering and accumulation of pigment-containing organelles in the chromatophores of the dermis. It has been discovered that chameleons change their colour via the active tuning of a lattice of guanine nanocrystals present in dermal iridophores (Teyssier et al., 2015).
At the same time, despite numerous naturalistic descriptions and serious morphological studies in this field, the criteria for objective assessment of the degree of the adaptive marking ability of the skin require further development and testing on other types of reptiles. In this context, the purpose of this paper is to compare, based on the additive colour model, the skin coloration exemplified by the Redbelly Rock Agama with the colour of the substrate where this species lives, to determine its degree of adaptation to the habitat conditions. The proposed method is based on the principles of bioimage informatics, which is one of the areas of bioinformatics (Miura, 2016).

Material and methods

The objects of the study were three individuals of the Redbelly Rock (Khorasan) Agama *Paralaudakia erythrogastra* (Nikolsky, 1896) kept in the Scientific Terrarium at the Zoological Scientific Research Museum of the Lomonosov Moscow State University. The lizards were photographed against the background of the enclosure, imitating their natural habitat. A typical snapshot was processed using a special program freely available on the Internet at: https://www.imgonline.com.ua/get-dominant-colors.php. (Define the dominant colours of the image online, 2017). Palettes of five colours were obtained for fragments of the images of the agama's skin and the enclosure surfaces with indication of an alphanumeric colour code and its RGB coordinates. Coordinates in an RGB format can vary from black (0, 0, 0) to white (255, 255, 255). To determine the dominant colour of the substrate and the skin, the arithmetic mean values of the RGB coordinates were found. The resulting indicators were expressed in round numbers. Based on the coordinates calculated, the corresponding colours were determined using the search engine www.google.com.

Results and discussion

Figure 1 features the appearance of the agama (Figure 1A), a fragment of the enclosure imitating a mountain relief (Figure 1B), as well as part of the lizard's body (Figure 1C). Figure 1 is also supplemented with a palette of five colours for each fragment of the photo. The quantitative characteristics related to the additive colour model, accompanied by the RGB coordinates of the five colours, are shown in Figure 2.

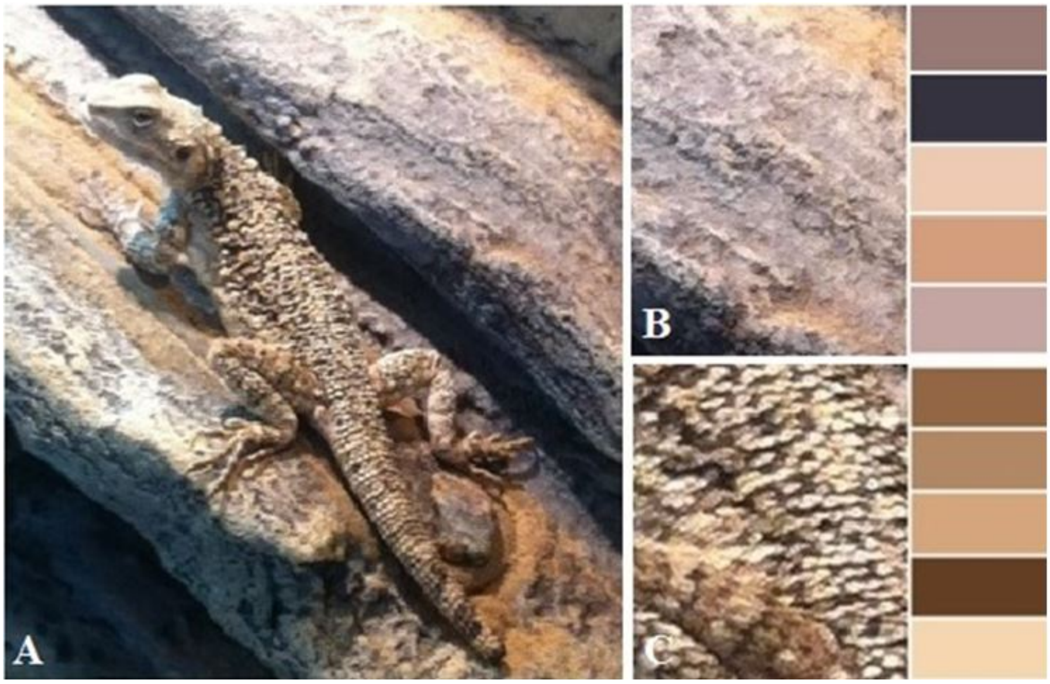

Figure 1. Colour characteristics of the habitat and skin covering of the Redbelly Rock Agama *Paralaudakia erythrogastra*: A-the appearance of the agama with a lost tail. Agamas do not regenerate their tails. Photo by A.B. Kiladze; B-a fragment of the substrate and its colour palette; C-a fragment of the skin covering of the agama and its colour palette.

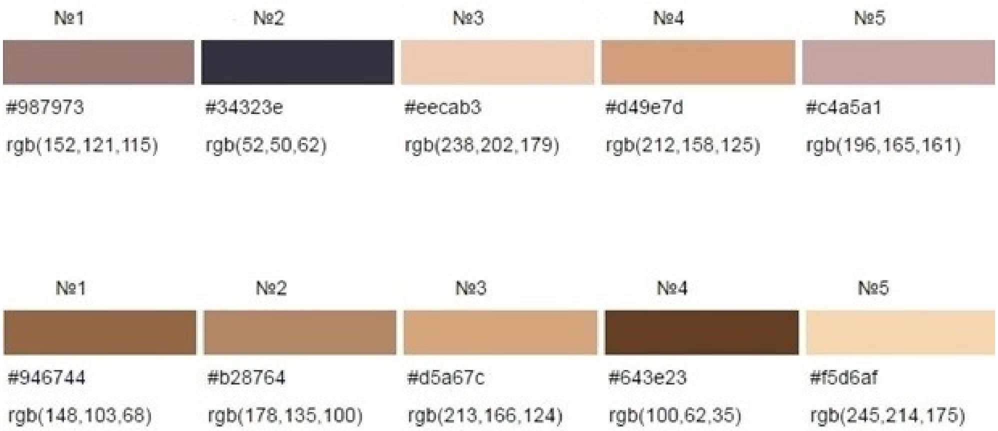

Figure 2. Quantitative parameters of RGB coordinates: at the top-the colour palette of the substrate simulating mountain relief; on the bottom-the colour palette of the Redbelly Rock Agama's *Paralaudakia erythrogastra* skin.

The analysis of the colour palette allows for assessment of the level of the colour matching, which can be considered quite sufficient, as evidenced by the uniform and general nature of the palette obtained, displaying close values of the RGB coordinates, at least for three colour pairs out of five. So, according to Figure 2, the following three pairs of similar colours can be singled out, namely: (1) colour No. 3 in the upper row and colour No. 5 in the lower row; (2) colour No. 4 in the upper row and colour No. 3 in the lower row; (3) colour No. 1 in the upper row and colour No. 2 in the lower row. To assess the dominant colour characteristic for the natural substrate and the skin covering, the arithmetic mean of the RGB coordinates was found.

The results are given in Figure 3. As is seen from the data obtained, the values of the RGB coordinates are quite close to each other, namely: the colour shade of the enclosure is RGB (170, 139, 128) (Figure 3A); pigmentation of the agama's skin-RGB (177, 136, 100) (Figure 3B).

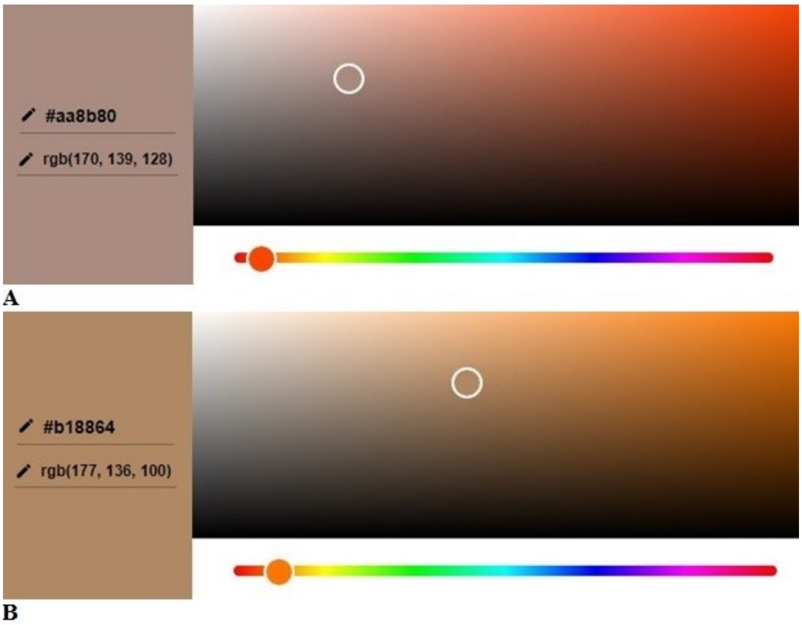

Figure 3. The dominant colour shade, characteristic of the habitat (A) and the skin covering (B) of the Redbelly Rock Agama *Paralaudakia erythrogastra*.

Only the last coordinate has a more significant deviation, which leads to some discrepancy between the colour shades of the substrate and the agama's skin. We believe that this may be due to the presence of the colour black (Figure 2, at the top, colour No. 2) which is accounted for by the cleft of the enclosure caught in the photo.

In general, the results presented show the necessary level ensuring the effectiveness of the protective coloration in the agama living on this substrate. They are consistent with the nature of the colour variations of the most typical habitats of this lizard. So, the habitat of the agama is limited by the territories of Afghanistan, Iran and Turkmenistan (Ananjeva et al., 2006; Baig et al., 2012; Panov & Zykova, 2016). The natural habitat of the species covers individual mountain ranges, while the preferred height where the lizards are dispersed is limited to 900-2500 m above sea level (Papenfuss et al., 2010; Baig et al., 2012; Panov & Zykova, 2016). Other agama species' colorations also have a high level of similarity with the ambient environment. For example, the characteristic pattern of the natural coloration of the Black-necked Agama *Acanthocercus atricollis* (Smith, 1849), whose natural habitat is boughs and trunks of trees, is brown and brownish-black spots that resemble bark of trees and a moss carpet (Cott, 1950).

Conclusion

Thus, the use of modern bioinformational approaches related to the assessment of colour adaptation in vertebrates allows us to construct the most objective system of indices necessary for understanding the mechanisms of the adaptation of vertebrates to their habitat conditions. The results obtained also have a general biological significance, quantitatively proving the morpho-functional adaptations of the animal skin covering to the nature of the ambient environment, which previously were described by zoologists in a verbal form. Obviously, the content of the paper can be used not only in herpetology, but also in other sections of zoology by the example of other taxonomic groups of animals living in a variety of environmental conditions.

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Citation: Kiladze, A.B., Chernova, O.F. (2018). Adaptive peculiarities of pigmentation in the redbelly rock agama *Paralaudakia erythrogastra* (Nikolsky, 1896) (Agamidae). Ukrainian Journal of Ecology, 8(4), 248-251.