Rapid color change to blue in metamorphic *Discoglossus scovazzi* (Camerano, 1878)

The presence of brilliant colors such as the primary colors red, yellow and blue has been widely studied and documented among animals, from invertebrates to higher vertebrates. Particularly, individual color variation is a main subject for research in areas as diverse as ecology, ethology, physiology, evolutionary biology or ecotoxicology (e.g., Fujii et al. 1989; Camargo et al. 1999; Martin & Forsman 1999; Chaplen et al. 2002; Frentiu et al. 2007; Heflin et al. 2009; López et al. 2009; Sköld et al. 2012). In vertebrates, skin color is mostly determined by the disposition of chromatophores, specialized dermal cells (Mills & Patterson 2009). In some species, coloration can change at the individual level, with these changes classified as either morphological or physiological (Bagnara 1976). The former is a slow process associated with variations of pigment content in the integument. The latter is a much faster (from minutes to hours) process based on intracellular movement of the organelles containing the pigments. Physiological color changes may be caused by a multitude of internal and external factors (Sköld et al. 2012), but the cytological mechanisms involved are still unclear (Bagnara 2005).

Bluish coloration is common among vertebrates, in spite of the generalized absence of blue pigments, with only a few

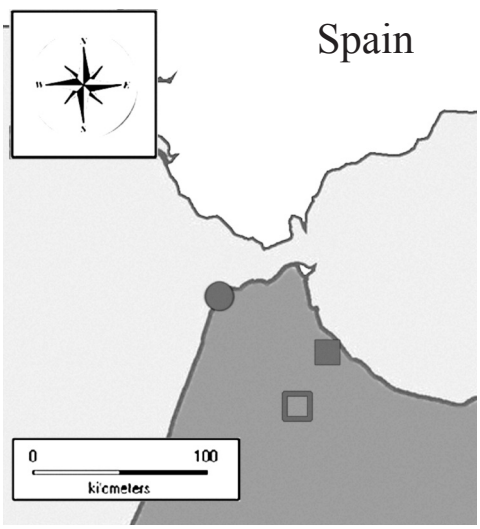

Fig. 1: Map showing the locations in Morocco where the metamorphic, rapidly color-changing *Discoglossus scovazzi* (Camerano, 1878) were found. Cap Spartel (circle), Oued Laou (solid square) and Derdara (open square).

fish species having real cyanophores (GODA & FUJII 1995). Thus, most of the times blue is a structural color caused by light scattering (BAGNARA et al. 2007). Several studies have revealed a functional role of blue (UMBERS 2013) in different life history traits as mate choice (MARTIN & LÓPEZ 1999; CUADRADO 2000), crypsis (MACEDONIA et al. 2009) or antipredator strategies (SAPORITO et al. 2007; HAWLENA 2009).

In amphibians, blue is produced in the absence of xantophores (or at least of some of their pigments) by the light scattered in the iridophores (DUELLMAN & TRUEB 1986). Although generally uncommon, blue is present in the regular color pattern of several amphibian species (BAGNARA 2007; TOLEDO & HADDAD 2009) or as low frequency individual variants, as in several species of Anura (see for example NISHIOKA & UEDA 1985, RIVERA et al. 2001 and references therein). Even scarcer are the cases of individual color change from regular coloration into blue. A striking example is the temporal color dimorphism observed in *Rana arvalis* NILSSON, 1842, with males changing from regular coloration to blue during the breeding season (HETTYEY et al. 2009). Jörn KÖHLER (Hessisches Landesmuseum, Darmstadt) suggested (pers. comm.) that dehydration produced by prolonged handling of juvenile frogs can drive change of the color, providing observations of froglets turning blue in some species of the genera *Stumpffia* and *Adenomera*, among others.

In the present note, the authors report the observation of color change from brown to blue in metamorphic *Discoglossus scovazzi* (CAMERANO, 1878) in different localities from Morocco. During fieldwork carried out in May 2013 on three distant areas belonging to the Tanger-Tetouan region (Achakkar, near Cap Spartel, 35°45.9'N, 5°55.9'W; Oued Laou, 35°26.2'N, 5°04.9' W; Derdara, 35°06.1'N, 5°18.1'W; Fig. 1), three metamorphic *D. scovazzi* were found that, when handled, quickly changed their

Fig. 2: *Discoglossus scovazzi* (CAMERANO, 1878).
A - normal coloration of metamorphic specimen;
B - bluish coloration after manipulation;
C - almost normalized coloration
approximately 10 minutes after manipulation.

original cryptic coloration to bluish tones (Fig. 2). Maximum blue intensity was achieved after less than a minute of being manipulated. Once the coloration had changed, the specimens were released and observed. The animals regained their original color at a slower rate, taking from 10 to 15 minutes to become fully brown. Given the structure of the dermal cromatophore unit described for *Discoglossus* (D'ANNA & LA SPINA 1975) and the rapidity of the changes, they are most likely explained by the mobilization of pigment-containing organelles in the xantophores.

Most species of the genus *Discoglossus* feature a range of variation for intraspecific patterns and colour shades (LANTZ 1947; MARTÍNEZ-SOLANO 2009). D'ANNA & LA SPINA (1975) also indicated that *D. pictus* can rapidly become darker or lighter in response to the particular background color. The authors did not detect any descriptions of a drastic colorpattern change from cryptic to blue in the genus *Discoglossus* such as reported here. Apart from a thorough literature search, interviews with several experienced researchers working for years with species of *Discoglossus*, did not result in observations of similar changes.

Physiological color changes in amphibians may be considered as functional traits of adaptive value, with implications in prey-predator interactions (KING & KING 1991), thermoregulation and water balance (HUTCHINSON & DUPRÉ 1992; KING et al. 1994; STEGEN et al. 2004) or intraspecific communication (WELLS 1980). But they may also occur as hormonally induced responses to stress (NIELSEN 1978). In the present case, the observed color change occurred within seconds, suggesting that the stress can be derived directly from the fact of being captured and grabbed, rather than changes in environmental factors such as hydration, temperature, or light intensity (NIELSEN 1987; DUELLMAN & TRUEB 1986; KING et al. 1994). Handling was shown to be a strong stress source in several vertebrate species (see BALCOMBE et al. 2004 and references therein). Turning blue, instead, could have additional implications, for example, a possible anti-predator response (UMBERS 2013), as brilliant, conspicuous colors are typically associated both with camouflaging and aposematic patterns (TOLEDO & HADDAD 2009). If the changes described are limited to just a single species within *Discoglossus*, or even localized populations within *D. scovazzi*, as suggested by the lack of further observations, it could even be possible that blue color change developed under some type of selective pressure in this region. However, all these open hypotheses are in need of experimental testing before the actual causes of this behavior are understood.

ACKNOWLEDGMENTS: This work was partially funded by the project cgl2010-15786 of Ministerio de Ciencia e Innovación of Spain. The second author (ER) is supported by a DGAPA-UNAM (Dirección General Asuntos del Personal Académico - Universidad Nacional Autónoma de México) Post-Doctoral fellowship. The authors thank Iñigo MARTÍNEZ SOLANO and José MARTÍN for their review and comments of the manuscript.

REFERENCES: BAGNARA, J. T. (1976): Color change. pp. 1-52. In: LOFTS, B. (Ed.): The physiology of the Amphibia. Vol. III. New York (Academic Press). BAGNARA, J. T. (2005): The hormonal regulation of colour change in amphibians. Endocrinology. pp. 2377-2391. In: HEATWOLE, H. (Ed.): Amphibian biology, Vol. 6. Chipping Norton, Australia (Surrey Beatty and Sons). BAGNARA, J. T. & FERNÁNDEZ P. J. & FUJII, R. (2007): On the blue coloration of vertebrates.- Pigment Cell Research, Oxford; 20: 14-26. BALCOMBE, J. P. & BARNARD, N. D. & SANDUSKY, C. (2004): Laboratory routines cause animal stress.- Contemporary Topics in Laboratory Animal Science, Cordova, Tennessee; 43: 42-51. CAMARGO, C. R. & VISCONTI, M. A. & CASTRUCCI, A. M. (1999): Physiological color change in the bullfrog, *Rana catesbeiana*.- Journal of Experimental Zoology, Hoboken, New York; 283: 160-169. CHAPLEN, F. W. R. & UPSON, R. H. & MCFADDEN, P. N. & KOLODZIEJ, W. (2002): Fish chromatophores as cytosensors in a microscale device: detection of environmental toxins and bacterial pathogens.- Pigment Cell Research, Oxford; 15: 19-26. CUADRADO, M. (2000): Body colors indicate the reproductive status of female Common chameleons: experimental evidence for the inter-sex communication function.- Ethology, Berlin; 106: 79-91. D'ANNA, T. & LA SPINA, R. (1975): Interrelations of dermal chromatophores in *Discoglossus pictus pictus*.- Bolletino di Zoologia, Padova; 42: 33-38. DUELLMAN, W. E. & TRUEB, L. (1986): Biology of amphibians. Baltimore & London (Johns Hopkins University Press). FRENTIU, F. D. & BERNARD, G. D. & CUEVAS, C. I. & SISON-MANGUS, M. P. & PRUDIC, K. L. & BRISCOE, A. D. (2007): Adaptive evolution of color vision as seen through the eyes of butterflies.- Proceedings of the National Academy of Sciences, Washington, D. C.; 104: 8634-8640. FUJII, R. & KASUKAWA, H. & MIYAJI, K. (1989): Mechanisms of skin coloration and its changes in the blue-green damselfish, *Chromis viridis*.- Zoological Science, Tokyo; 6: 477-486. GODA, M. F & FUJII, R. (1995): Blue chromatophores in two species of callionymid fish.- Zoological Science, Tokyo; 12: 811-813. HAWLENA, D. (2009): Colorful tails fade when lizards adopt less risky

behaviors.- Behavioral Ecology and Sociobiology, Berlin; 64: 205-213. HEFLIN, B. & YOUNG, L. & LONDRAVILLE, R. L. (2009): Short-term cycling of skin colouration in the blackspotted rockskipper *Entomacrodus striatus*.- Journal of Fish Biology, London; 74: 1635-1641. HETTYEY, A. & HERCZEG, G. & LAURILA, A. & CROCHET, P-A. & MERILA, J. (2009): Body temperature, size, nuptial colouration and mating success in male moor frogs (*Rana arvalis*).- Amphibia-Reptilia, Leiden; 30: 37-43. HUTCHINSON, V. H. & DUPRÉ, R. K. (1992): Thermoregulation. pp. 206-249. In: FEDER, M. E. & BURGGREN, W. W. (Eds): Environmental Physiology of the Amphibians. Chicago (University of Chicago Press). KING, R. B. & KING, B. (1991): Sexual differences in color and color change in woodfrogs.- Canadian Journal of Zoology, Ottawa; 69: 1963-1968. KING, R. B. & HAUFF, S. & PHILLIPS, J. B. (1994): Physiological color change in the Green Treefrog: responses to background brightness and temperature.- Copeia, Washington; 1994: 422-432. LANTZ, L. A. (1947): Note on *Discoglossus* in captivity.- Proceedings of the Royal Society, London; (B) 134: 52-56. LÓPEZ, P. & GABIROT, M. & MARTÍN, J. (2009): Immune challenge affects sexual coloration of male Iberian wall lizards.- Journal of Experimental Zoology, New York; (A) 311: 96-104. MACEDONIA, J. M. & LAPPIN, A. K. & LOEW, E. R. & MCGUIRE, J. A. & HAMILTON, P. S. & PLASMAN, M. & BRANDT, Y. & LEMOS-ESPINAL, J. A. & KEMP, D. J. (2009): Conspicuousness of Dickerson's collared lizard (*Crotaphytus dickersonae*) through the eyes of conspecifics and predators.- Biological Journal of the Linnean Society, London; 97: 749-765. MARTÍN, J. & FORSMAN, A. (1999): Social costs and development of nuptial coloration in male *Psammodromus algirus* lizards: an experiment.- Behavioral Ecology, Oxford; 10: 396-400. MARTÍN, J.& LÓPEZ, P. (1999): Nuptial coloration and mate guarding affect escape decisions of male lizards *Psammodromus algirus*.- Ethology, Berlin; 105: 439-447. MARTÍNEZ-SOLANO, I. (2009): Sapillo pintojo mediterráneo – *Discoglossus pictus*. pp. 1-13. In: SALVADOR, A. & MARTÍNEZ-SOLANO, I. (Eds.): Enciclopedia virtual de los vertebrados Españoles. Madrid (Museo Nacional de Ciencias Naturales). MILLS, M. G. & PATTERSON, L. B. (2009): Not just black and white: Pigment pattern development and evolution in vertebrates.- Seminars in Cell & Developmental Biology, London; 20: 72-81. NIELSEN, H. I. (1978): The effect of stress and adrenaline on the color of *Hyla cinerea* and *Hyla arborea*.- General and Comparative Endocrinology, Orlando; 36: 543-552. NISHIOKA, M. & UEDA, H. (1985): Blue variants in *Hyla arborea japonica*.- Scientific Report of the Laboratory for Amphibian Biology, Hiroshima; 7: 181-197. RIVERA, X. & ARRIBAS, O. & MARTI, F. (2001): Revisión de anomalías pigmentarias en los anfibios de la Península Ibérica y de Europa.- Butlletí de la Societat Catalana d'Herpetologia, Barcelona; 15: 59-75. SAPORITO, R. A. & ZUERCHER, R. & ROBERTS, M.& GEROW, K. G. & DONNELLY, M. A. (2007): Experimental evidence for aposematism in the Dendrobatid poison frog *Oophaga pumilio*.- Copeia, Washington; 2007 (4): 1006-1011. SKÖLD, H. N. & ASPENGREN, S. & WALLIN, M. (2012): Rapid color change in fish and amphibians – function, regulation, and emerging applications.- Pigment Cell & Melanoma Research, København; 26: 29-38. STEGEN, J. C. & GIENGER, C. M. & SUN, L. (2004): The control of color change in the Pacific tree frog, *Hyla regilla*.- Canadian Journal of Zoology, Ottawa; 82: 889-896. TOLEDO, L. F. & HADDAD, C. F. B. (2009): Colors and some morphological traits as defensive mechanisms in anurans.- International Journal of Zoology, New York; 2009: 1-12. UMBERS, K. D. L. (2013): On the perception, production and function of blue colouration in animals.- Journal of Zoology, London; 289: 229–242. WELLS, K. D. (1980): Social behavior and communication of a dendrobatid frog (*Colostethus trinitatus*).- Herpetologica, Lawrence; 36:189-199.

KEYWORDS: Amphibia: Anura: Alytidae, *Discoglossus scovazzi*, blue coloration, rapid color change, stress-induced color change, physiology, behaviour, Morocco

SUBMITTED: February 11, 2014

AUTHORS: Roberto GARCÍA-ROA (Corresponding author < r.garcia-roa@mncn.csic.es >) [1)]; Ernesto RECUERO [2)]; Paloma MAS-PEINADO [3, 4)]

[1)] Department of Evolutionary Ecology. National Museum of Natural Science – Spanish Resarch Council (MNCN-CSIC). José Gutiérrez Abascal, 2, 28006, Madrid, Spain.

[2)] Departamento de Ecología de la Biodiversidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Ap. Postal 70-275, Ciudad Universitaria, México DF, 04510, Mexico.

[3)] Department of Biodiversity and Evolutive Ecology. National Museum of Natural Science – Spanish Resarch Council (MNCN-CSIC). José Gutiérrez Abascal, 2, 28006, Madrid, Spain.

[4)] Instituto de Estudios Ceutíes. Paseo del Revellín, 30. Apartado de correos 593, 51080 Ceuta, Spain.