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Sexual dimorphism in *Heosemys spinosa* (Testudines: Geoemydidae) in Sarawak, Borneo

Siti Nor Baizurah[1] and Indraneil Das[1,*]

Sexual dimorphism in turtles, comprising secondary sexual characteristics of morphology, has previously been reviewed by Berry and Shine (1980) and Gibbons and Lovich (1990). Colour differences (sexual dichromatism) have been discussed less often (but see Moll et al., 1981; Ennen et al., 2015), perhaps because of challenges associated with colour standardisation and loss of pigmentation details upon preservation (Coon, 1949).

Heosemys spinosa (Gray, 1831) is a mid-sized (maximum straight carapace length 275 mm; Goetz, 2007) tropical terrestrial turtle, currently listed as 'Endangered' in the IUCN Red List. The known distribution of the species extends from southern Myanmar, south into the Malay Peninsula, in addition to the islands of Sumatra, Borneo, and the southern Philippines (Bonin et al., 2006; Platt et al., 2014). The unusual morphology of the juvenile carapace gave rise to its common name of "walking pincushion" (Mardiastuti, 2008), and ontogenetic changes in its shell, particularly the relative flattening of the posterior marginal, that are lost with age appear in the taxonomic literature (e.g., Boulenger, 1889; de Rooij, 1915; Smith, 1931; Lim and Das, 1999). The strongly keeled spine present in juveniles is assumed to serve as a means to prevent being swallowed by predators. However, little has been published on sexual dimorphism and dichromatism in the species. Zug and Mulcahy (2019) were the first to report on the topic, describing carapace shape as "elongate, oblong, moderately domed and dorsally flattened in males" and "broad oblong and moderately domed in females." Further, a report by Spinks et al. (2012) indicated the presence of cryptic variation in *H. spinosa* based on the distinct genetic and phenotypic variation observed in large, confiscated specimens in Hong Kong and China. This included variation in size, iris colour, and shell colouration among the observed specimens. However, a lack of reliable geographic provenance limited further systematic evaluation.

Materials and Methods

The following observations were made as part of a larger study on a population of *H. spinosa* at Kubah National Park, Sarawak, Borneo, East Malaysia (Park Headquarters at 01.6124°N, 110.1966°E; WGS 84; elevation 141 m; Fig. 1), that emphasised the spatial, trophic, and thermal biology of the species (Baizurah, 2021). This note addresses variation between sexes in colouration observed in 11 wild individuals and of morphology in six tagged specimens (two males, four females) fitted with radiotransmitters and iButtons. These six individuals remained tagged from April 2017–January 2019, and their straight carapace length (SCL) and straight carapace width (SCW) were measured periodically over the 22-month period. Sexual size dimorphism was assessed by comparing the allometric relationship of SCL and SCW between sexes. All measurements were log-transformed to achieve linearity in regression analyses. X-rays were taken using a Model E7239X Sedecal Apr-Vet radiographic unit with settings of 78 kVp / 25 mAs / 320 mA / 0.08 s. The Xscan radiology application (Version 2.10) was used to edit the images obtained. Measurements were taken with Mitutoyo CD-CSX vernier callipers. Photographic images were obtained using a Nikon D600 camera and a 105 mm MicroNikkor lens in a Lastolyte lightbox. A total of 11 individuals were examined for colouration, which was described using the standard colour swatches in Smithe (1975).

Results and Discussion

Size. The six individuals used in this study ranged in size from 125.2–240.3 mm, with males the larger of the sexes (mean SCL in males 210.8 ± 7.5 mm, in females 167.0 ± 25.3 mm). A significant difference (Pearson correlation, $P < 0.05$) was found between measurements (SCW = 1.204 ± 0.4266 SCL in males, SCW = 1.434 ± 0.3209 SCL in females), demonstrating that shell proportions in adult *H. spinosa* are sexually dimorphic (Fig. 2).

[1] Institute for Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.

[*] Corresponding author. E-mail: idas@unimas.my