ORIGINAL ARTICLE

Asian Herpetological Research 2023, 14(4): 271–279
DOI: 10.3724/ahr.2095-0357.2023.0032

Sexual Dimorphism, Female Reproductive Characteristics and Embryonic Thermosensitivity in the Tonkin Forest Skink (*Sphenomorphus tonkinensis*) from Hainan, South China

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Abstract We collected 75 adult Tonkin forest skinks (*Sphenomorphus tonkinensis*) from Hainan, South China and incubated eggs at four constant temperatures ranging from 22 °C to 28 °C to study sexual dimorphism, female reproductive characteristics and embryonic thermosensitivity. The largest male was 53.4 mm snout-vent length (SVL), and the largest female was 54.3 mm SVL. The mean SVL was slightly greater in adult females (49.9 mm) than in adult males (48.8 mm), but the difference was not significant. Head length, head width, fore-limb length and hind-limb length were longer in adult males and abdomen length was longer in adult females after accounting for SVL. Accordingly, we conclude that *S. tonkinensis* is basically a sexually size-monomorphic species with sexual dimorphism in head size, abdomen (trunk) length and limb size. Females laid up to two clutches of 1–4 eggs each per egg-laying season from February to May. Egg mass, clutch size and clutch mass were independent of female SVL. Embryonic stages at laying varied from Dufaure and Hubert's stage 30 to 31. With female SVL held constant, the negative correlation between egg mass and clutch size was not significant, suggesting that the offspring (egg) size-number trade-off between is not evident or eggs are well optimized for size in *S. tonkinensis*. None of the eggs at 28 °C hatched; hatching success was lower at 22 °C than at 24 °C or 26 °C. The mean incubation length was 52.9 d at 22 °C, 40.4 d at 24 °C and 33.6 d at 26 °C. Hatchlings from eggs incubated at 22 °C, 24 °C and 26 °C did not differ morphologically at hatching, suggesting that temperatures within this range do not differentially affect hatchling morphology in *S. tonkinensis*.

Keywords egg, hatching success, hatchling morphology, incubation length, reproduction, Scincidae, sexual dimorphism

1. Introduction

Asian forest skinks of the genus *Sphenomorphus* Fitzinger, 1843 (Sauria, Scincidae) are either oviparous or viviparous, occurring in South, Southeast and East Asia and on islands of the West Pacific (Uetz *et al*., 2021). Of some 115 currently recognized *Sphenomorphus* species, seven (the Medog Forest Skink *S. courcyanus*, the Earless Forest Skink *S. cryptotis*, the Brown Forest Skink *S. incognitus*, the Indian Forest Skink *S. indicus*, the Spotted Forest Skink *S. maculatus*, the Taiwan Forest Skink *S. taiwanensis* and the Tonkin Forest Skink *S. tonkinensis*) can be found in China (Huang, 1999; Darevsky *et al*., 2004; Nguyen *et al*., 2011, 2012; Qi *et al*., 2022), with *S. taiwanensis* endemic to the country and found only in Taiwan (Chen and Lue, 1987; Huang, 1997). Despite its high species richness, the biology and ecology of the genus *Sphenomorphus* are poorly known. Sexually dimorphic traits and/or female reproductive characteristics have been studied in *S. incognitus* (Huang, 2010; Ma *et al*., 2018), *S. indicus* (Huang 1996; Ji and Du, 2000; Ji *et al*., 2006b), *S. jagori* (Auffenberg and Auffenberg,

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Received: 20 July 2023 Accepted: 7 October 2023
Published Online: 9 October 2023

1989), *S. maculates* (Huang, 1999), *S. taiwanensis* (Huang, 1997, 1998) and *S. tonkinensis* (Wang *et al.*, 2013a). However, relatively detailed information is available only for *S. indicus* and *S. incognitus*. Incidental data on clutch or litter size have been reported for *S. jagori* (Auffenberg and Auffenberg, 1989), *S. taiwanensis* (Chou and Lin, 1992; Huang, 1997) and *S. tonkinensis* (Wang *et al.*, 2013a), but in none of these species have statistically meaningful data on maternal size, offspring (egg or neonate) size (mass), fecundity (clutch or litter size) and reproductive output (clutch or litter mass) already been collected and reported.

Sphenomorphus tonkinensis is a small oviparous scincid species described by Nguyen *et al.* (2011) based on nine specimens, eight from North Vietnam and one from South China (Hainan), with an unknown sex ratio. The skink occurs in southern China (Guangdong, Guangxi, Hainan and Jiangxi Provinces) and northern Vietnam, using habitats near streams in deep forest (Wang *et al.*, 2013a; Qian *et al.*, 2019; Figure 1). Earlier studies on *S. tonkinensis* only presented very descriptive data on morphology and habitat use from a limited number of individuals (Nguyen *et al.*, 2011; Wang *et al.*, 2013a; Qian *et al.*, 2019). From an earlier study by Wang *et al.* (2013a) on three populations of *S. tonkinensis* in China we know that females lay 2–4 eggs per clutch. Here, we presented data for *S. tonkinensis* from Hainan, South China. Based on morphological measurements taken for adults in the field, clutches laid in the laboratory and eggs incubated at four constant temperatures ranging from 22 °C to 28 °C, we studied sexual dimorphism, female reproductive characteristics and embryonic thermosensitivity. Our aims were to show (1) sexual dimorphism in body size and shape, (2) the relationships among egg size (mass), clutch size, clutch mass and female size (snout-vent length, SVL), (3) the embryonic stage at laying, and (4) the thermal dependence of hatching success, incubation length and hatchling morphology.

2. Materials and Methods

We collected 75 adults (30 females and 45 males larger than 44 mm SVL) of *S. tonkinensis* in 2013 and 2014 from Wuzhishan, Hainan, southern China. We palpated all females and transported 19 reproductive females with enlarged follicles or oviductal eggs to our laboratory in Sanya. The remaining females and all males were released at their point of capture following the collection of morphological data. Skinks were individually weighed on a portable balance (Mettler-Toledo International Inc., China), and measured with electronic digital calipers (Mitutoyo, Japan) for SVL, abdomen length (the distance between the fore-limb and the hind-limb), head length (from the snout to the anterior edge of tympanum), head width (taken at the posterior end of the mandible), fore-limb length (humerus plus ulna) and hind-limb length (femur plus tibia) (Sun *et al.*, 2012).

The 19 reproductive females brought to the laboratory were individually housed in 500 mm × 300 mm × 200 mm plastic terraria placed in a room inside which temperatures varied from 20 °C to 28 °C. Each terrarium had a substrate consisting of moist soil (~60 mm depth) with cobblestones and fallen leaves. Females were able to regulate body temperature by using natural sunlight. Mealworms (larvae of *Tenebrio molitor*), house crickets (*Achetus domesticus*) and water enriched with vitamin and minerals were provided daily.

Females laid eggs from early February to late May. We checked the terraria at least thrice daily for freshly laid eggs after the first female laid eggs, thereby collecting and weighing eggs within 6 h post-laying. Of the 19 females, three laid the second clutch 42–47 d after laying the first clutch. Post-laying



Figure 1 Wet forest microhabitats used by *S. tonkinensis* are rich in dead branches and fallen leaves. The right plot shows an adult male (photo by Yu DU).

females were weighed and measured for SVL. We calculated relative clutch mass (RCM) by dividing clutch mass by the post-laying female mass and used the coefficient of variation [CV = 100 × (standard deviation/mean)] to estimate within-clutch egg size variability (Guo *et al.*, 2022).

We collected 42 fertilized eggs, of which 14 (one from each of 14 clutches) were dissected to identify the Dufaure and Hubert's (1961) embryonic stage at laying. The remaining 28 fertilized eggs were individually placed into covered plastic jars (50 mL), of which each had a substrate of moist vermiculite at −12 kPa (Ma *et al.*, 2018). All eggs were 2/3 buried in the substrate, with the surface near the embryo always kept upward. Eggs were equally assigned to four incubators (Binder, Tuttlingen, Germany), inside which temperatures were set at 22 °C, 24 °C, 26 °C and 28 °C, respectively. Temperatures were confirmed with Tinytalk temperature loggers (Gemini Pty, Australia) placed inside jars for a week. We rotated jars at 4-d intervals, thereby minimizing the influence of thermal gradients. We adjusted substrate water potential by weighing jars at the same time intervals. Incubation length was defined as the time between laying and pipping. Hatchlings were weighed and measured within 6 h post-hatching.

We used linear regression analysis to examine the relationship between a selected pair of dependent and independent variables and partial correlation analysis to examine the relationship between egg mass and clutch size while holding female SVL constant. We used ANCOVA to test for slope homogeneity of regression lines. We used unequal (for abdomen length using one-way ANOVA on regression residuals of the variable against SVL) or equal (for body mass, head length, head width, fore-limb length and hind-limb length using one-way ANCOVA with SVL as the covariate) slopes model to examine if an examined variable differed between the sexes. We used one-way ANOVA to examine if male and female adults differed in mean SVL and if mean values for mass at laying and incubation length differed among eggs incubated at different temperatures. We used one-way ANCOVA with egg mass at laying as the covariate to examine if hatchlings from eggs incubated at different temperatures differed morphologically at hatching. Prior to parametric analyses, all data were tested for normality using the Kolmogorov-Smirnov test, and for homogeneity of variances using Bartlett's test. All statistical analyses were performed in Statistica 8.0 (StatSoft; Tulsa, OK, USA). Descriptive statistics are expressed as mean ± standard error (SE) and range, and the significance level is set at 0.05.

3. Results and Discussion

3.1. Body size and sexual dimorphism The largest male was 53.4 mm SVL, and the largest female was 54.3 mm SVL. Both values are greater than the maximal sizes reported previously for *S. tonkinensis* from Hainan (48.8 mm; Qian *et al.*, 2019), Chinese mainland (52.5 mm; Wang *et al.*, 2013a) and North Vietnam (47.5 mm; Nguyen *et al.*, 2011). The mean SVL was slightly greater in adult females (49.9 mm) than in adult males (48.8 mm), but the difference was not significant (Table 1). Accordingly, we come to a conclusion that *S. tonkinensis* is among lizard species with sexual size monomorphism (SSM). SSM is one of three patterns of sexual size dimorphism (SSD), and the other two are male-biased (male-larger) SSD and

Table 1 Descriptive statistics, expressed as mean ± SE and range, for snout-vent length, abdomen length, head length, head width, fore-limb length and hind-limb length of adult *S. tonkinensis* from Hainan, South China, and results of one-way ANOVA (for snout-vent length and abdomen length, with the latter analyzed by using unequal slopes model) and ANCOVA (for the remaining variables) using SVL as the covariate.

	Females	Males	Results of one-way ANOVA or ANCOVA
N	30	45	
Snout-vent length (mm)	49.9 ± 0.6 44.1–54.3	48.8 ± 0.4 44.1–53.4	$F_{1, 73} = 3.21$, $P = 0.077$
Body mass (g)	1.87 ± 0.07 1.25–2.59	1.86 ± 0.05 1.33–2.62	$F_{1, 72} = 2.52$, $P = 0.117$
Abdomen length (mm)	27.5 ± 0.4 22.1–31.7	25.9 ± 0.3 22.3–29.1	$F_{1, 73} = 16.95$, $P < 0.0001$; F > M
Head length (mm)	8.9 ± 0.07 7.9–9.4	9.0 ± 0.06 8.2–9.8	$F_{1, 72} = 18.98$, $P < 0.0001$; F < M
Head width (mm)	5.4 ± 0.05 4.9–6.0	5.4 ± 0.03 4.9–5.9	$F_{1, 72} = 4.24$, $P = 0.043$; F < M
Fore-limb length (mm)	4.3 ± 0.06 3.9–4.9	4.4 ± 0.05 3.9–5.3	$F_{1, 72} = 19.79$, $P < 0.0001$; F < M
Hind-limb length (mm)	9.0 ± 0.09 7.9–9.9	9.3 ± 0.08 8.3–11.0	$F_{1, 72} = 5.87$, $P = 0.018$; F < M

female-biased (female-larger) SSD (Fairbairn *et al*., 2007; Dunham and Rudolf, 2009; Corl *et al*., 2010). It is worth noting that patterns of SSD may vary even among populations of the same species. For example, adult *S. incognitus* displays male-biased SSD in Taiwan (Huang, 2010) but SSM in Chinese mainland (Ma *et al*., 2018). The evolution and maintenance of a SSD pattern often result from sexual differences in reproductive success relating to adult size (Cox *et al*., 2003). Within the family Scincidae, sexual selection via male contest competition is the key factor for male-biased SSD in the Chinese Skink *Plestiodon* (*Eumeces*) *chinensis* (Lin and Ji, 2000), the Blue-tailed Skink *Plestiodon elegans* (Zhang and Ji, 2004) and the Many-lined Sun Skink *Eutropis* (*Mabuya*) *multifasciata* (Ji *et al*., 2006a), and fecundity selection is the main factor for female-biased SSD in *S. indicus* (Ji and Du, 2000), the Slender Forest Skink *Scincella modesta* and the Reeves' Smooth Skink *Scincella reevesii* (Yang *et al*., 2012). SSM occurs in a diverse array of lizard taxa including species of the families Agamidae (Ji *et al*., 2002a; Lin, 2004; Qu *et al*., 2011), Lacertidae (Li *et al*., 2006; Lu *et al*., 2023), Sincidae (Lin, 2005) and Shinisauridae (He *et al*., 2011) where these two selective forces cancel each other out or male contest competition and physical constraints from maternal body size on reproductive output are both less evident. Here we add a scincid species to the list of lizards with SSM.

Abdomen length increased more rapidly with SVL for females than for males (ANCOVA for slope homogeneity, $F_{1, 71} = 6.13$, $P = 0.015$), whereas the rates at which body mass, head length, head width, fore-limb length and hind-limb length increased with SVL did not differ between the two sexes (ANCOVA for slope homogeneity; all $P > 0.215$) (Figure 2). For a given SVL, body mass did not differ between the two sexes, abdomen length was greater in females than in males, and head length, head width, fore-limb length and hind-limb length were greater in males than in females (Table 1). These findings suggest that, as in nearly all lizard species studied thus far (Huang, 1996; Olsson *et al*., 2002; Cox *et al*., 2003; Kratochvíl *et al*., 2003; Lin, 2005; Pincheira-Donoso and Tregenza, 2011), adult males have larger heads and shorter abdomen (trunk) length than females of the same SVL in *S. tonkinensis*. Head and abdomen sizes are sexually dimorphic often because they are directly linked to the reproductive role of each sex (Bulté *et al*., 2008), although in some species the greater relative head size in males may have a secondary role in reducing resource competition between the sexes (Zhang and Ji, 2004). Sexual dimorphism in appendage size is less commonly reported in comparisons of female and male lizards (Lin, 2005). As in *Anolis* lizards (Powell and Russell, 1992; Malhotra and Thorpe, 1997; Butler and Losos, 2002), the Tropical Thornytail Iguana *Uracentron* (*Tropidurus*) *flaviceps* (Vitt and Zani, 1996), the Eastern Water Skink *Eulamprus quoyii* (Lin, 2005), *S. incognitus* (Huang, 2010; Ma *et al*., 2018) and the Przewalski's toad-headed lizard *Phrynocephalus przewalskii* (Zhao and Liu, 2014), males have longer fore- and hind-limbs than females of the same SVL in *S. tonkinensis* (Table 1). Data from the aforementioned species including *S. tonkinensis* support the conclusion that there is selection directly on limb length in lizards.

3.2. Female reproductive characteristics Table 2 shows female reproductive characteristics of *S. tonkinensis* from Hainan, South China. Females laid up to two clutches of 1–4 eggs each per egg-laying season from early February to late May. Clutch size was independent of female SVL ($r^2 = 0.06$, $F_{1, 20} = 1.34$, $P = 0.260$). This finding suggests that, as in *S. incognitus* from Taiwan (Huang, 2010), maternal size is not an important source of variation in fecundity (clutch size) in *S. tonkinensis* from Hainan. The mean clutch size was smaller in *S. tonkinensis* (2.5 in the first clutch, and 2.0 in the second clutch; Table 2) than in *S. incognitus* [5.2 in Chinese mainland (Ma *et al*., 2018); ~4.0 in Taiwan (Huang, 2010)], *S. indicus* (7.2; Ji and Du, 2000) and *S. taiwanensis* (5.0; Chou and Lin, 1992; Huang, 1997). The differences in fecundity between *S. tonkinensis* and the other three congeneric species could be partly due to the fact that adult females on average are smaller in *S. tonkinensis* (51 mm SVL; Table 1) than in *S. incognitus* (86 mm SVL; Huang, 2010; Ma *et al*., 2018), *S. indicus* (mean SVL = 81 mm SVL; Ji and Du, 2000) and *S. taiwanensis* (56 mm SVL; Huang, 1998), because larger female skinks are generally more fecund than smaller ones and this is especially true in comparisons of congeneric species (Lin and Ji, 2000; Du and Ji, 2001; Sun *et al*., 2012). Data on egg mass and clutch mass have never been reported for *S. tonkinensis*. Here we found that neither clutch mass ($r^2 = 0.02$, $F_{1, 20} = 0.51$, $P = 0.485$) nor egg mass ($r^2 = 0.01$, $F_{1, 20} = 0.17$, $P = 0.688$) was related to female SVL. From these findings we may come to a conclusion that, as in *S. incognitus* (Ma *et al*., 2018), female size is not an important source of variation in reproductive output or investment per offspring in *S. tonkinensis*. With female SVL held constant, egg mass was found to show no significant negative correlation with clutch size ($r = -0.26$, $t = 1.19$, $df = 19$, $P = 0.249$). This finding suggests that, as in other oviparous sincid lizards such as the Long-tailed Sun Skink *Eutropis longicaudata* (Sun *et al*., 2012), *S. modesta* (Yang *et al*., 2012) and *S. incognitus* (Ma *et al*., 2018), the egg size-number trade-off is not evident or eggs are well optimized for size in *S. tonkinensis*.

The mean RCM was smaller in *S. tonkinensis* (0.21; Table 1) than in other sincid species so far studied in China: 0.25 in *S. incognitus* (Ma *et al*., 2018), 0.31 in *P. elegans* (Du and Ji, 2001), 0.33 in *P. chinensis* (Lin and Ji, 2000), 0.34 in *E. longicaudata*

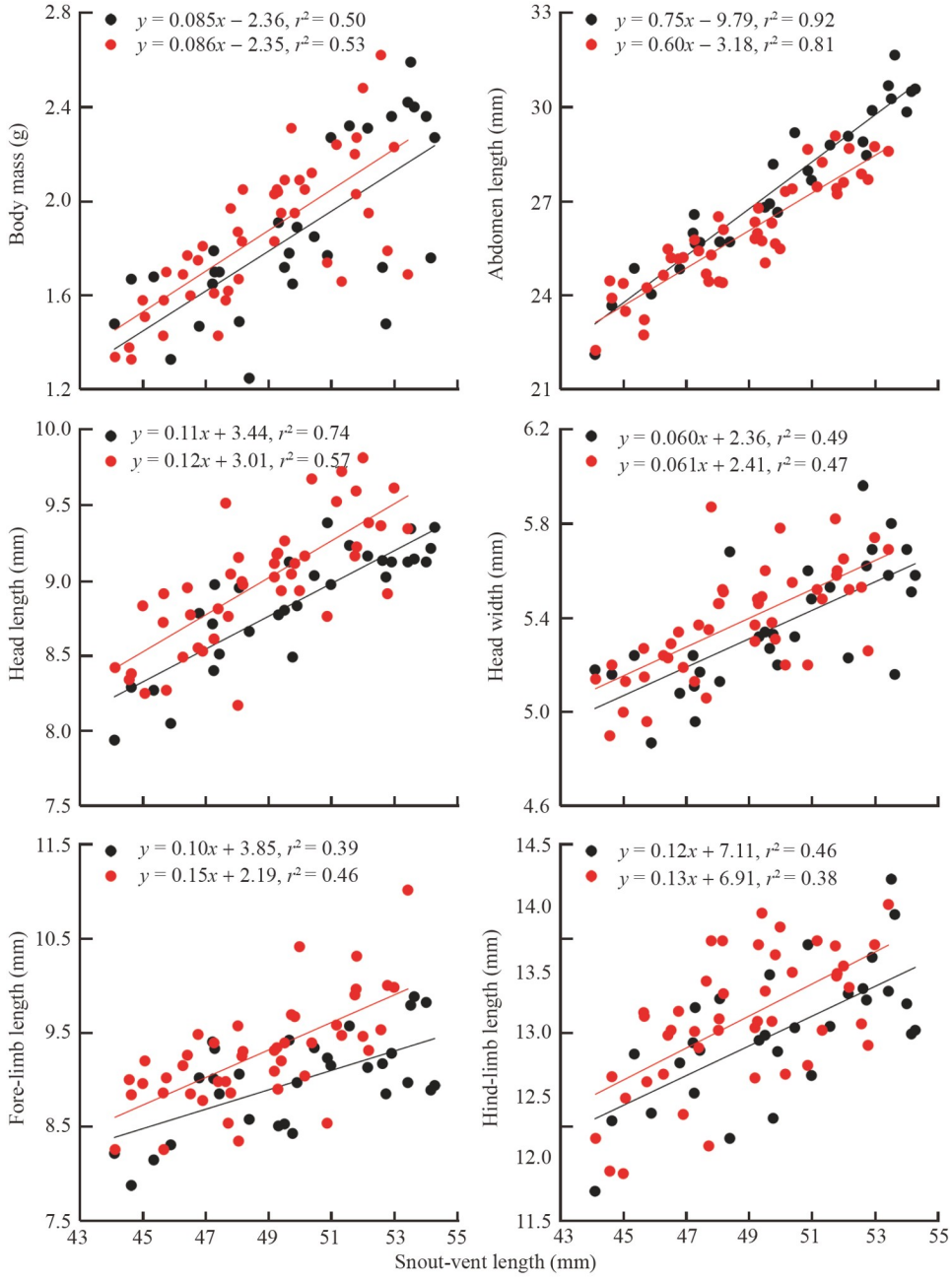


Figure 2 Linear regressions of body mass, abdomen length, head length, head width, fore-limb length and hind-limb length on SVL in *S. tonkinensis*. Black dots and lines represent adult females; red dots and lines represent adult males.

Table 2 Descriptive statistics, expressed as mean ± SE and range, for post-laying female size and mass, egg mass, within-clutch variability [CV = 100 × (standard deviation/mean)] in egg mass, clutch size, clutch mass, and relative clutch mass in *S. tonkinensis* from Hainan, South China. *N* = the number of females laying eggs.

	N	Post-laying female size and mass		Egg mass and within-clutch variability		Clutch size	Clutch mass (g)	Relative clutch mass
		SVL (mm)	Body mass (g)	Egg mass (g)	CV of egg mass			
First clutch	19	50.6 ± 0.6 44.1–54.3	2.0 ± 0.09 1.3–2.6	0.17 ± 0.01 0.14–0.28	7.4 ± 1.8 0.34–29.6	2.5 ± 0.2 1–4	0.42 ± 0.03 0.19–0.60	0.22 ± 0.02 0.08–0.36
Second clutch	3	51.6 ± 0.3 51.0–52.2	2.1 ± 0.09 2.0–2.3	0.16 ± 0.02 0.15–0.20	14.6 ± 8.7 4.0–31.8	2	0.33 ± 0.03 0.29–0.39	0.15 ± 0.02 0.13–0.19

(Sun *et al*., 2012) and 0.72 in *S. modesta* (Yang *et al*., 2012). The proportion of variation in clutch mass explained by female SVL was much lower in *S. tonkinensis* (2%) than in *S. incognitus* (12%; Ma *et al*., 2018), *S. modesta* (37%; Yang *et al*., 2012), *E. longicaudata* (42%; Sun *et al*., 2012), *P. elegans* (46%; Du and Ji, 2001) and *P. chinensis* (51%; Lin and Ji, 2000), and the proportion of variation in clutch size explained by female SVL was much lower in *S. tonkinensis* (6%) than in the Ixbaac Brown Forest Skink *Scincella* (*Sphenomorphus*) *cherriei* (12%; Goldberg, 2008), *S. incognitus* (18%; Ma *et al*., 2018), *E. longicaudata* (35%; Sun *et al*., 2012), *P. elegans* (37%; Du and Ji, 2001), *S. modesta* (40%; Yang *et al*., 2012), *P. chinensis* (52%; Lin and Ji, 2000) and *S. taiwanensis* (86%; Huang, 1997). The above comparisons allow a conclusion that selection on increased maternal body size and thus increased body volume available to hold eggs is comparatively weak in *S. tonkinensis*.

3.3. Egg incubation and hatchling phenotype Embryonic stages at laying ranged from Dufaure and Hubert's (1961) stage 30 to 31, with a mean of 30.1. Embryonic stage at laying is an important source of variation in incubation length in lizards (Wang *et al*., 2013b). However, incubation length at any given temperature may vary among species that differ in phylogeny, egg size, distribution and/or habitat use (Lu *et al*., 2006; Lin *et al*., 2010; Li *et al*., 2012, 2013; Sun *et al*., 2013). For example, the mean incubation length at 22 °C is longest in *S. incognitus* (~76 d; Ma *et al*., 2018) and shortest in *S. modesta* (~31 d; Li *et al*., 2012), with *S. tonkinensis* (~53 d; Table 3) in between. It is worth noting that the mean embryonic stage at laying does not differ between *S. incognitus* (31.3; Ma *et al*., 2018) and *S. modesta* (31.1; Lu *et al*., 2006) and is only about one stage earlier in *S. tonkinensis* than in the other two species. The finding that incubation length can be longer in congeneric species with more advanced embryos at laying suggests that factor(s) other than embryonic stage at laying can affect the rate of embryonic development.

None of the eggs at 28 °C hatched, suggesting that the upper thermal threshold for embryonic development is lower in *S. tonkinensis* than in *S. incognitus* and *S. modesta* of which eggs can be successfully incubated at 28 °C (Lu *et al*., 2006; Li *et al*., 2012; Ma *et al*., 2018). The upper thermal threshold for egg incubation is lower in lizards using shaded habitats than in those using opened habitats. For example, temperatures higher than 28 °C adversely affect egg incubation in *S. incognitus* and *S. modesta* using habitats along forest edges (Lu *et al*., 2006; Li *et al*., 2012; Ma *et al*., 2018), whereas temperatures slightly higher than 30 °C do not dramatically reduce hatching success in the Oriental Garden Lizard *Calotes versicolor* (Ji *et al*., 2002b) and the White-striped Grass Lizard *Takydromus wolteri* (Pan and Ji, 2001) using more open habitats. Hatching success was much lower at 22 °C (25%) than at 24 °C (62.5%) and 26 °C (62.5%),

Table 3 *F* values and significance levels of one-way ANOVA (egg mass and incubation length) and ANCOVA (hatchling mass, snout-vent length, abdomen length, tail length, head length, head width, fore-limb length, and hind-limb length) with temperature the fixed factors and egg mass at laying as the covariate.

	22 °C	24 °C	26 °C	
N	2	5	5	
Egg mass (mg)	163.0 ± 0.5 162.5–163.4	193.2 ± 14.3 151.5–238.5	184.3 ± 26.8 144.7–189.2	$F_{2, 9} = 0.32$, $P = 0.734$
Incubation length (d)	52.9 ± 2.0 50.9–55.0	40.4 ± 1.8 35.8–44.9	33.4 ± 0.8 30.9–35.1	$F_{2, 9} = 28.93$, $P < 0.001$
Hatchling mass (mg)	97.4 ± 29.5 67.9–126.9	136.0 ± 12.3 105.2–167.2	143.9 ± 19.3 110.9–214.2	$F_{2, 8} = 1.07$, $P = 0.387$
Snout-vent length (mm)	18.2 ± 0.3 17.9–18.5	18.2 ± 0.7 16.5–19.5	18.0 ± 0.6 16.3–20.0	$F_{2, 8} = 0.23$, $P = 0.798$
Abdomen length (mm)	8.4 ± 0.4 8.1–8.8	8.0 ± 0.2 7.1–8.5	8.2 ± 0.4 7.0–9.2	$F_{2, 8} = 1.25$, $P = 0.336$
Tail length (mm)	20.2 ± 1.2 19.0–21.5	19.1 ± 1.3 15.5–22.5	19.7 ± 1.6 15.4–24.9	$F_{2, 8} = 0.85$, $P = 0.464$
Head length (mm)	4.7 ± 0.1 4.6–4.9	4.8 ± 0.2 4.3–5.1	4.7 ± 0.2 4.4–5.3	$F_{2, 8} = 0.23$, $P = 0.803$
Head width (mm)	3.5 ± 0.2 3.3–3.6	3.5 ± 0.2 3.0–4.0	3.2 ± 0.2 2.8–4.0	$F_{2, 8} = 1.67$, $P = 0.248$
Fore-limb length (mm)	3.1 ± 0.2 2.9–3.2	2.9 ± 0.2 2.2–3.5	3.1 ± 0.05 2.9–3.2	$F_{2, 8} = 0.24$, $P = 0.794$
Hind-limb length (mm)	4.2 ± 0.2 4.0–4.4	4.0 ± 0.2 3.4–4.5	4.3 ± 0.2 3.9–5.0	$F_{2, 8} = 0.62$, $P = 0.561$

suggesting that the lower thermal threshold for egg incubation is higher in *S. tonkinensis* than in *S. incognitus* and *S. modesta* of which eggs can be successfully incubated at 22 °C (Li *et al.*, 2012; Ma *et al.*, 2018). From the above comparisons we may come to a conclusion that the range of suitable incubation temperatures is narrower in forest skinks such as *S. tonkinensis* using habitats in the deep forest than in other closely related species using habitats along forest edges where the mean and amplitude of thermal fluctuations are relatively great.

We found that in *S. tonkinensis* the mean incubation length was shortened by 12.5 d at the changeover from 22 °C to 24 °C, and by 7.0 d at changeover from 24 °C to 26 °C (Table 3). Such a thermal dependence of incubation length has been repeatedly reported in a diverse array of reptilian taxa including turtles (Ji *et al.*, 2003, Du *et al.*, 2010), lizards (Wang *et al.*, 2013b; Shen *et al.*, 2017), snakes (Ji and Du, 2001; Lin *et al.*, 2010) and crocodilians (Charruau, 2012; Liu *et al.*, 2023). Hatchlings from eggs incubated at 22 °C, 24 °C and 26 °C did not differ morphologically (Table 3), suggesting that incubation temperatures within a certain range do not differentially affect hatchling morphology in *S. tonkinensis*. A similar result has been reported for crocodilians (Liu *et al.*, 2023), turtles (Du and Ji, 2003; Ji *et al.*, 2003), lizards (Chen *et al.*, 2003; Andrewartha *et al.*, 2010; Li *et al.*, 2013) and snakes (Chen and Ji, 2002; Lin and Ji, 2004; Lin *et al.*, 2008; Lu *et al.*, 2009). In nearly all reptilian species studied thus far, incubation temperature has no role in modifying hatchling traits as long as eggs or embryos are not exposed to extreme temperatures for prolonged periods of time. A certain degree of thermal insensitivity of hatchling phenotype is important for ectothermic animals including reptiles where embryos are unlike to complete development under constant-temperature conditions.

4. Conclusions

Sphenomorphus tonkinensis is a sparsely studied species. Here we used adults collected from Hainan, South China to study sexual dimorphism, female reproduction and egg incubation in this species. From this study we may come to the following conclusions about *S. tonkinensis*. First, the skink is basically a sexually size-monomorphic species with sexual dimorphism in head size, abdomen length and limb size. Second, females larger than 44 mm SVL lay up to two clutches of 1–4 eggs each per egg-laying season from early February to late May. Third, egg mass, clutch size and clutch mass are independent of female SVL and, with female SVL held constant, the negative correlation between egg size (mass) and clutch size is not significant. Fourth, embryonic stages at laying range from Dufaure and Hubert's stage 30 to 31, and the mean incubation length at a given temperature is much shorter in *S. tonkinensis* compared to *S. incognitus*, a congeneric species with a slightly more advanced embryonic stage at laying. Last, incubation temperatures across the range from 22 °C to 26 °C do not differentially affect hatchling morphology.

Acknowledgements Our experimental procedures complied with the current laws on animal welfare and research in China. We thank Zhongyin CHEN, Xiangmo LI and Qize LIU for assistance during the research. This work was supported by grants from the Special Foundation for Basic Work of the Science and Technology Ministry of China (2022FY100500-2), Hainan Key Program of Science and Technology (ZDXM20110008) and Hainan Specially Supporting Discipline of Zoology.

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Scientific Editor: Jianguo CUI

How to cite this article:

Du Y., Lin C. X., Zhu X. M., Yao Y. T., Ji X. Sexual Dimorphism, Female Reproductive Characteristics and Embryonic Thermosensitivity in the Tonkin Forest Skink (*Sphenomorphus tonkinensis*) from Hainan, South China. Asian Herpetol Res, 2023, 14(4): 271–279. DOI: 10.3724/ahr.2095-0357.2023.0032