

## Ecology and Reproductive Patterns of the Littoral Skink *Emoia atrocostata* on an East Asian Tropical Rainforest Island

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**Wen-San Huang (2011)** Ecology and reproductive patterns of the littoral skink *Emoia atrocostata* on an East Asian tropical rainforest island. *Zoological Studies* 50(4): 506-512. I describe the habitat use, diet, and male and female reproductive cycles of *Emoia atrocostata*, an oviparous skink inhabiting Orchid I., a tropical island off the southeastern coast of Taiwan. All *E. atrocostata* individuals were observed on a rocky beach near the ocean edge. The diet of *E. atrocostata* consisted of Homoptera (Aphrophoridae), Hymenoptera (Formicidae), and crabs. The mean snout-vent length (SVL) of adult males was 76.6 mm, and that of females was 74.5 mm. Males had a significantly larger SVL than females. Females exhibited spring and summer vitellogenesis, with oviposition occurring from Mar. to Aug. There was no correlation between the onset of vitellogenesis and the mass of female fat bodies. Females produced 1-3 eggs per clutch, in contrast to 2 eggs per clutch in a Philippine population of *E. atrocostata*. The clutch size was not correlated with SVL. Two clutches were recorded during a single year in some individuals. Male fat bodies exhibited the lowest mass from Mar. to Sept., coincident with the period of reproductive activity. Reproductive characteristics of other sympatric lizards on Orchid I. and conspecifics in other regions were compared to those of *E. atrocostata*. <http://zoolstud.sinica.edu.tw/Journals/50.4/506.pdf>

**Key words:** Clutch size, Reproduction, Sexual dimorphism, Lizard.

Over the past several decades, there has been widespread interest in the ecology of tropical lizards, such as spatial, temporal, feeding, and reproductive patterns (Fitch 1981, Vitt and de Carvalho 1995, Vitt and Zani 1996a b). However, most studies of tropical lizards were mainly focused on the Amazon region (Vrcibradic and Rocha 1996, Vitt et al. 1997 2000) and Mexico (Benabib 1994, Ramirez-Bautista and Vitt 1998, Jimenez-Cruz et al. 2005, Ramirez-Bautista et al. 2006 2008, Ramirez-Sandoval et al. 2006), and little is known about other lowland rainforest lizards (but see Benabib 1994, Ramirez-Bautista et al. 2006), especially on tropical islands of East Asia (but see Mori and Hikida 1993, Mori et al. 1995, Huang 2010).

The genus *Emoia* (Squamata: Scincidae)

occurs in rocky-beach and mangrove-forest habitats of Southeast Asia, Australia, and the Pacific islands (Alcala and Brown 1967, Ota 1991, Huang 2004). In Taiwan, the littoral skink *E. atrocostata* is a poorly known species distributed in the southern part of the main island, and on Orchid I. and Green I. (Ota 1991, Zhao and Adler 1993). Attempts to understand the biology of the littoral skink are difficult on the main island of Taiwan, because most areas in its range have been destroyed or degraded by pollution. Consequently, even the most-basic ecological data are unavailable. Fortunately, the natural environment of Orchid I. (Lanyu in Chinese) located off the southeastern coast of Taiwan, is still largely intact due to the relative difficulty of approach by ship and preservation of the Ami aboriginal culture by

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the Japanese during their occupation. Therefore, Orchid I. provides a rare opportunity to collect ecological data about and develop ecological hypotheses for *E. atrocostata* and other lizards (Huang 2004).

In most tropical oviparous lizards, both males and females seem to exhibit year-round gonadogenesis, with subsequent courtship, mating, and oviposition (Fitch 1970, Duvall et al. 1982, Mendez-de la Cruz et al. 1999), but lizards in some seasonal tropics are known to show seasonal reproductive cycles in reproduction (i.e., Auffenberg and Auffenberg 1989). Likewise, the tropical skink *E. atrocostata* was also reported to exhibit year-round reproduction in the Philippines (Alcala and Brown 1967). Although Taiwan is generally categorized as a subtropical area, it does have tropical areas in the southern part of the main island, as well as on Orchid I. (Huang 2004). Climatic patterns on this island are similar to those of tropical regions. Huang (1997a b 1998) demonstrated that annual reproductive patterns of 3 high-elevation Taiwanese lizards, *Takydromus hsuehshanensis*, *Eumeces elegans*, and *Sphenomorphus taiwanensis*, resemble those of seasonal temperate lizards. Huang (2006a b 2007) also showed that 3 lizards on Orchid I., *T. sauteri*, *Mabuya longicaudata*, and *Japalura swinhonis* exhibit annual reproductive patterns similar to those of temperate lizards. The reproductive biology of low-elevation subtropical lizards of Taiwan was examined (Cheng 1987), but that of lizards of tropical areas such as those on Orchid I. has not been well studied (but see Huang 2006a b).

It is generally thought that reproduction of a given lizard reflects adaptations to the environmental regimes of its habitats (e.g., ambient temperature, resource dynamics, and predators; Avery 1976, Ota 1994), a simple phenotypic response to its environment (Huang 2004), effects of phylogenetic constraints (James and Shine 1985, Vitt 1986, Ota 1994), or a combination of these factors. Comparative studies of reproductive patterns in lizards often attempted to identify the underlying causes responsible for the observed reproductive patterns (Fitch 1981 1982, Vitt 1986).

In this paper, I studied the ecology of *E. atrocostata*, including its morphology and the reproductive cycles of males and females. I also compared the ecological characteristics of populations of *E. atrocostata* from other localities for which data are available.

## MATERIAL AND METHODS

This study was conducted on tropical Orchid I. (22°02'N, 121°33'E) about 60 km off the coast of Taitung County, southeastern Taiwan, from Apr. 1997 to July 2001, at about 10 m in elevation. The mean maximum air temperature from June to Aug. ranged 25.75-26.11°C, and the minimum air temperature ranged 18.58-19.69°C from Dec. to Feb. The mean maximum monthly precipitation for 11 yr of data was about 408 mm in Sept., most of which was brought by typhoons. The wettest month was June, and the driest month was Dec. (data from the Orchid I. Weather Station, Central Weather Bureau, Taipei, Taiwan). The environmental conditions of Orchid I. are well described elsewhere (Huang 2010).

Skinks were hand-collected each month. For each sampling period, I attempted to collect 5 males and 5 females, but some monthly samples were smaller due to the difficulty of finding skinks in rainy weather. Following capture, I weighed each specimen to the nearest 0.01 g; measured the snout-vent length (SVL) to the nearest 0.1 mm; and dissected out the liver, fat bodies, gonads, and associated organs, all of which were weighed wet to the nearest 0.01 g. The stage of maturity of males was assessed by spermatogenic activity. The appearance of sperm bundles and/or free sperm in the seminiferous tubules was regarded as indicative of maturity.

The reproductive state of adult females was determined on the basis of the presence or absence of oviductal eggs (Huang 2006a b). Females with eggs were considered to be reproductively active, and those without eggs were considered inactive. Clutch size was estimated using the number of oviductal eggs. The time necessary to produce a clutch of eggs was estimated from the period between the date when the 1st females with larger vitellogenic follicles were collected and the date when the 1st females with oviductal eggs were collected. The annual clutch frequency was calculated based on the oviposition period (from the laying date of the 1st clutch to that of the last clutch), and the estimated time necessary to produce a clutch. Females with regressed ovaries which contained follicles of < 3 mm in diameter were considered to be post-parturient. Voucher specimens were deposited at the National Museum of Natural Science, Taichung, Taiwan (NMNS catalog nos. 3061, 3261, 3265, 3271, 3274, 3277, 3279, 3282, 3285, 3289, 3293, 3297, 3304, 3307, 3313, and 3320).

To determine the diet, the stomach of each skink was removed, usually within 5 h following preservation, and prey items were identified to family level or the lowest taxonomic category possible, and measured for length and width with Mytutoyo digital calipers (Mytutoyo, Kawasaki, Japan).

The relationship between clutch size and female body size was examined using Pearson's correlation analysis. I used a *t*-test to examine sexual differences in SVL between adult males and females. The other variables used to test for sexual differences were body mass (BM), diameter of the waist (WD); diameter of the waist between the hind limb and abdomen), head length (HL), head width (HW), head depth (HD), tail length (TL), forelimb length (FLL), hind limb length (HLL), 3rd toe length (TTL), and 4th toe length (FTL). Because the organ variables usually varied with SVL, I calculated a regression of all log<sub>10</sub>-transformed organ data against log<sub>10</sub>-SVL. Monthly differences in the log<sub>10</sub>-transformed liver mass (LM) and fat body mass (FBM) in each sex, and testis mass (TM) in males were assessed with an analysis of covariance (ANCOVA) using log<sub>10</sub>-SVL as the covariate (SAS 8.2, SAS Institute, Cary, NC, USA). I accepted the analyses if the interactions between the log<sub>10</sub> SVL and test variables were non-significant (homogeneity of slopes), and the data were confirmed to be normally distributed and had homogeneous variances before all of the tests. I adopted a type I error level of 0.05 for all statistical tests.

**RESULTS**

**Diet**

Based on samples collected from individual lizards, eight of 139 (5.8%) skinks had food items in their stomachs. All lizards contained only 1 type of prey item. The diet of *E. atrocostata* on Orchid I. consisted of Homoptera (Aphrophoridae; 4/8), Hymenoptera (Formicidae; 2/8), and crabs (2/8).

**Morphology**

Mean SVLs of adult males and females were 76.60 (*n* = 84) and 74.46 (*n* = 55) mm, respectively, and the sexual difference in SVL was significant (*p* = 0.004, *t*-test; Table 1). The mean body mass of adult males (8.35 g, *n* = 70; range: 5.11-12.66 g) was significantly greater than that of adult females (7.06 g, *n* = 47; range: 4.88-10.24 g; *p* < 0.001; ANCOVA; Table 1). Males had longer, deeper, and wider heads, longer limbs, and wider waistlines than females when the effect of SVL was removed (Table 1). Adult males had TLs of 68.31-148.57 mm, whereas those of adult females ranged 57.64-122.26 mm; a significant sexual difference in TL at maturity was detected (*p* = 0.04, ANCOVA; Table 1).

**Female reproductive cycle**

The smallest reproductively active female *E. atrocostata* measured 68.59 mm in SVL; therefore,

**Table 1.** Morphology of 84 sexually mature male and 55 female *Emoia atrocostata*. BM, body mass; FLL, forelimb length; FTL, 4th toe length; HD, head depth; HL, head length; HLL, hind limb length; HW, head width; SVL, snout-vent length; TL, tail length; TTL, 3rd toe length; WL, waist length

	Males		Females		<i>p</i> value
	Mean ± S.E.	Range	Mean ± S.E.	Range	
SVL (mm)	76.60 ± 0.49	67.01- 84.32	74.46 ± 0.51	68.59- 82.69	0.005
BM <sup>a</sup> (g)	8.35 ± 0.21	5.11- 12.66	7.06 ± 0.19	4.88- 10.24	< 0.001
WL (mm)	9.82 ± 0.10	7.77- 12.32	9.24 ± 0.11	7.76- 11.59	0.008
TL <sup>a</sup> (mm)	105.64 ± 1.92	68.31-148.57	99.02 ± 2.18	57.64-122.26	0.049
FLL (mm)	24.77 ± 0.18	19.66- 29.17	22.35 ± 0.14	19.50- 24.68	< 0.001
HLL (mm)	37.12 ± 0.24	30.58- 41.00	33.19 ± 0.25	32.09- 48.27	< 0.001
TTL (mm)	6.52 ± 0.06	4.02- 7.66	5.92 ± 0.06	4.62- 6.62	< 0.001
FTL (mm)	7.12 ± 0.10	5.02- 8.60	6.64 ± 0.06	5.63- 7.87	< 0.001
HL (mm)	17.66 ± 0.12	15.31- 19.76	16.21 ± 0.11	14.34- 18.24	< 0.001
HW (mm)	10.03 ± 0.10	7.78- 12.25	9.13 ± 0.08	7.78- 10.87	< 0.001
HD (mm)	6.51 ± 0.09	5.20- 11.38	5.84 ± 0.06	4.98- 6.96	< 0.001

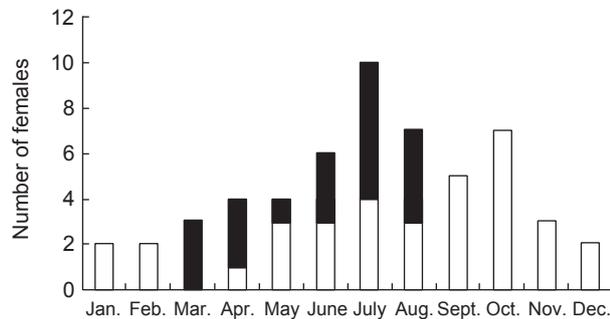
<sup>a</sup>Some individuals lost their tails while being caught; thus only 70 males and 47 females were analyzed for TL and BM.

only females with an SVL of  $\geq 68.59$  mm were considered to be adults. All adult females were reproductively active in Mar., 75% in Apr., 25% in May, 50% in June, 60% in July, and 57% in Aug. (Fig. 1). All adult females were reproductively inactive from Sept. to the following Feb. (Fig. 1).

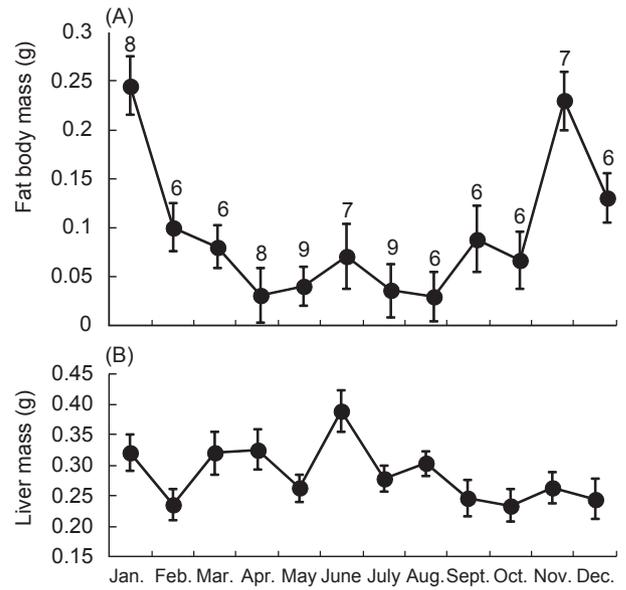
The 1st vitellogenic females were found on 22 Mar., and the 1st females with oviductal eggs was seen on 24 Apr. The interval between these was 33 d. Three of the 20 females collected in May and June 1998 still had enlarged vitellogenic follicles after having laid eggs. Clutch size averaged  $2.00 \pm 0.32$  ( $X \pm S.D.$ ; range 1-3) and was not correlated with female SVL ( $Y = 0.019X + 0.5319$ ;  $r = 0.236$ ;  $n = 20$ ;  $p = 0.317$ ). Female fat body and liver masses showed monthly variations ( $F_{11,43} = 4$ ,  $p = 0.0002$  in fat body mass; ANCOVA, Fig. 2A;  $F_{11,43} = 1.21$ ,  $p = 7.7$  in liver mass; ANCOVA, Fig. 2B). The fat body mass was smaller during the reproductive season from Mar. to Aug. but increased before the dormant season from Oct. to Jan.

**Male reproductive cycle**

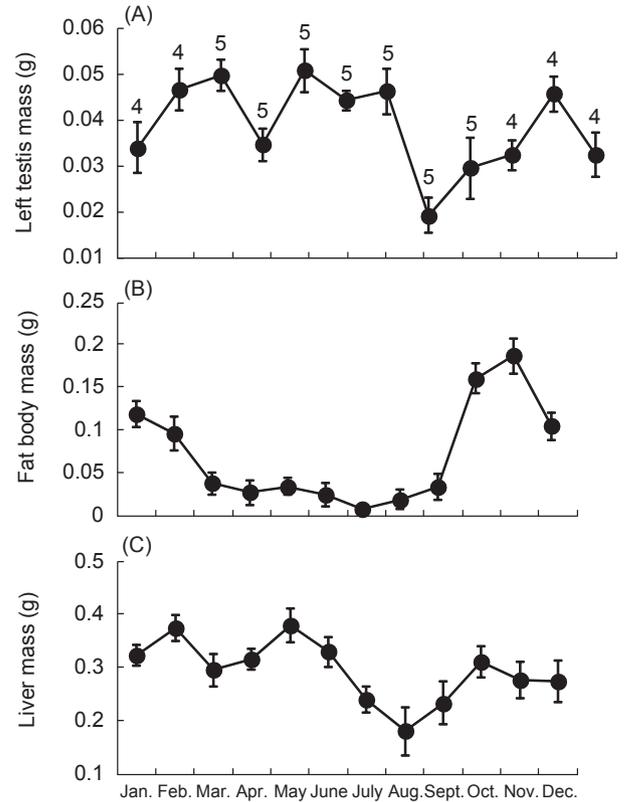
The left testis mass showed a significant monthly variation ( $F_{11,82} = 2.33$ ,  $p = 0.01$ ; Fig. 3A), with an increase commencing in Feb. and a high being sustained from May to July. The male fat body mass showed significant monthly variations ( $F_{11,82} = 4.92$ ,  $p < 0.0001$ ; ANCOVA, Fig. 3B), with a decrease to the lowest value from Mar. to Sept. and an increase to a peak in Nov. The male liver mass showed significant monthly variations ( $F_{11,82} = 3.65$ ,  $p = 0.0003$ ; ANCOVA, Fig. 3C).



**Fig. 1.** Monthly sampling distribution of pregnant *Emoia atrocostata* on Orchid I., Taiwan. Adult females were reproductively active from Mar. to Aug., and all adult females were in a non-reproductive state from Sept. to Feb. Black columns indicate the distribution of pregnant females with oviductal eggs.



**Fig. 2.** Variations (mean  $\pm$  S.E.) in the mean fat body mass (A) and liver mass (B) during the annual reproductive cycle of *Emoia atrocostata* females on Orchid I., Taiwan. Numbers above the bars indicate sample sizes.



**Fig. 3.** Variations (mean  $\pm$  S.E.) in the mean testis mass (A), mean fat body mass (B), and liver mass (C) during the annual reproductive cycle of *Emoia atrocostata* males on Orchid I., Taiwan. Numbers above the bars indicate sample sizes.

## DISCUSSION

Sexual dimorphism is common in many lizard species (Fitch 1981, Huang 1996, Pianka and Vitt 2003), and is usually attributed to sexual selection or trophic divergence (Huang 1996, Ramirez-Bautista et al 2008). Males had larger body sizes than females in *E. atrocostata*, which is consistent with an oviparous Orchid I. skink, *S. incognitus* (Huang 2010), but contrasts with the viviparous *S. indicus*, the females of which had larger SVLs than males (Huang 1996). Fitch (1981) stated that females of viviparous species tend to have a relatively large body in order to support the growth of embryos in oviducts for a much longer period than those of oviparous species. Shine (1985) demonstrated that widespread distribution of sexual dimorphism in trophic morphology among animals could be consistent with either sexual selection or trophic divergence. For example, head sizes may be related to prey sizes in several reptilian taxa in which larger head sizes might allow larger prey sizes to be subdued (Huang 2004). In the current study, males had larger head sizes than females, suggesting that they may have allometric growth or trophic divergence to decrease intersexual competition between males and females, because I observed no male-male competition (sexual selection) in the wild.

Stored lipids can be used for winter dormancy and reproduction (Derickson 1976). In *E. atrocostata* females, fat body masses were enlarged from Nov. to the following Feb. This suggests that energy is accumulated during this period for use in the active months. Small fat body masses in the reproductive season from Mar. to Aug. indicated that this energy was being used for reproductive activities, such as vitellogenesis and egg laying. Similar patterns of fat body fluctuations were also observed in males in which low values occurred in the reproductive season, and high values occurred before the dormant months.

Species in seasonal environments (i.e., temperate regions) experience cyclic reproduction and thereby avoid harsh climatic extremes, whereas species in aseasonal environments (i.e., tropical regions) may be able to continually reproduce (Pianka and Vitt 2003). Temperate-zone lizards have a consistent seasonal pattern of reproduction, with oviposition in the late spring or summer months (James and Shine 1985), and this generalization holds true for all scincid, pygopodid, gekkonid, agamid, and varanid taxa studied to date (Shine 1985), except for some viviparous lizards

which ovulate in autumn (Fitch 1970, Guillette 1983, Guillette and Cruz 1993). The present results indicate that in female *E. atrocostata*, the reproductive period commences in spring (Mar.) and lasts until summer (Aug.). This seems to fit the reproductive pattern of many temperate-zone lizards. These findings greatly differ from the generally accepted reproductive pattern of tropical lizards being capable of breeding throughout the year. Alcalá and Brown (1967) studied conspecific *E. atrocostata* in the Philippines, and found that reproduction occurred throughout the entire year, which contrasts with the current study on Orchid I. A probable reason may be the different climatic patterns in the 2 areas. For example, air temperatures in the Philippines at the latitude where the skink is found are relatively uniform throughout the year, from a minimum of 20°C to a maximum of 32°C, but on Orchid I., the minimum air temperature decreases to 10°C in winter. Obviously, lizards cannot reproduce in such harsh conditions on Orchid I., since their eggs will not hatch at temperatures as low as 10°C.

Various studies revealed that phylogenetic constraints have a strong influence on the seasonal timing of quiescence and recrudescence of gonadal activity in a few species (Fitch 1982, Vitt 1986, Guillette and Cruz 1993). The reproductive timing of the tropical population of *E. atrocostata* mentioned above compared to the current study of conspecifics does not seem to be adequately explained on phylogenetic grounds, but is more likely to reflect primary physiological responses to environmental stimuli as in some temperate-zone lizards.

The current clutch sizes of 1-3 eggs of *E. atrocostata* suggests that species distributed in the Philippines and Taiwan apparently have different clutch sizes (Alcalá and Brown 1967). This finding is in contrast with a study of clutch size variation in *E. atrocostata*, which found a consistent clutch size of 2 eggs among Philippine populations (Okada et al. 1992). The consistent clutch sizes of *E. atrocostata* are likely affected by small sample sizes, which may have been a factor in the 2 previous studies (7 lizards in the Philippine study and 4 in Okada et al.) (Alcalá and Brown 1967, Okada et al. 1992). Shine and Greer (1991) attributed an invariant clutch size to habitats with low variability. For example, spatial fluctuations in resource availability may be particularly low in tropical areas. Presumably, such limited resource supplies may greatly impact larger clutch size production. This pattern is also likely to be true in

Taiwanese tropical *E. atrocostata* with low resource availability.

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