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Original article

Sexual dimorphism in the spotted flying lizard *Draco maculatus* (Gray, 1845) (Squamata: Agamidae) from Thailand

Nattawut Srichairat,[a] Prateep Duengkae,[b,*] Pattanee Jantrarotai,[a] Yodchaiy Chuaynkern[c]

[a] *Department of Zoology, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand*
[b] *Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[c] *Department of Biology, Faculty of Science, Khon Kaen University, Khon Kaen 40002, Thailand*

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ABSTRACT

Two hundred preserved specimens of the spotted flying lizard, *Draco maculatus*, from Thailand consisting of 121 males and 79 females were examined using 21 morphometric raw data, 25 character ratios and 4 meristic characters to assess sexual dimorphism. The results of univariate analysis showed that there were 9 morphometric raw data, 15 character ratios and 3 meristic characters that can be used for discrimination of sexual differences. The morphological data based on significant differences revealed that males are larger than females. The results of discriminant analysis based on significant differences of the nine morphometric raw data could be used to construct a sexual discrimination equation (*D*). The sexual discrimination equation could be directly used to identify correctly the two sexes for 98.0% of cross-validated grouped cases, since positive *D* scores indicated males and negative *D* scores indicated females and 97.5% of the males and 98.7% of the females were correctly assigned.

Introduction

Sexual dimorphism (SD), defined as a phenotypic difference between the males and females of a species, is a common phenomenon in animals, with most species, including reptiles, being dimorphic rather than monomorphic (Schoener, 1977; Mouton and van Wyk, 1993; Stamps, 1993; Andersson, 1994). Generally, sexual dimorphism is defined at three levels. First, sexual size dimorphism (SSD) is based on two basic hypotheses: the intrasexual selection hypothesis, suggesting sexual selection for large males, and the fecundity advantage hypothesis, suggesting natural selection for large females (Thompson and Withers, 2005). Second, there is SD in body shape (Adriana et al., 2005) and third, there is SD in ornamentation (qualitative characters) such as scale pattern and coloration (Cooper and Greenberg, 1992). The lizards are a good model for studying the evolution of SD because this group presents a remarkable variation in both the direction and magnitude of SD (Cox et al., 2003).

In all *Draco* species, there is sexual dimorphism with differences between males and females in color and dewlap size; the males having brighter and longer dewlaps than females and furthermore, males usually have cervical and caudal crests while the females are usually larger than males (Musters, 1983; Shine et al., 1998). The spotted flying lizard (*Draco maculatus*) adult male presents as elongated and usually rounded distally sometimes with a pointed tip dewlap, cervical and caudal crest (Taylor, 1963; Musters, 1983). *D. maculatus* is distributed in all regions of Thailand (Musters, 1983; Chuaynkern and Chuaynkern, 2012) and little information is available on the morphometric and meristic differences in intrapopulations of *D. maculatus* in Thailand. Therefore, the purpose of this study was to analyze the morphometric and meristic differences between males and females of *D. maculatus* in Thailand. The information from this study would be useful to support species identification of *D. maculatus* to assess the population for sustainable conservation in Thailand.

Materials and methods

From 1967 to 2012, 200 preserved specimens (121 males and 79 females) of *D. maculatus* in 70% ethanol were sampled from collections in the Thailand Natural History Museum (THNHM) and the National Science Museum, Pathum Thani province, Thailand and investigated for morphometric characters using a vernier caliper to the nearest 0.05 mm (Fig. 1) and meristic counts under a stereo microscope (Figs. 2 and 3). There were two sets of

* Corresponding author.
E-mail address: prateep.du@ku.ac.th (P. Duengkae).

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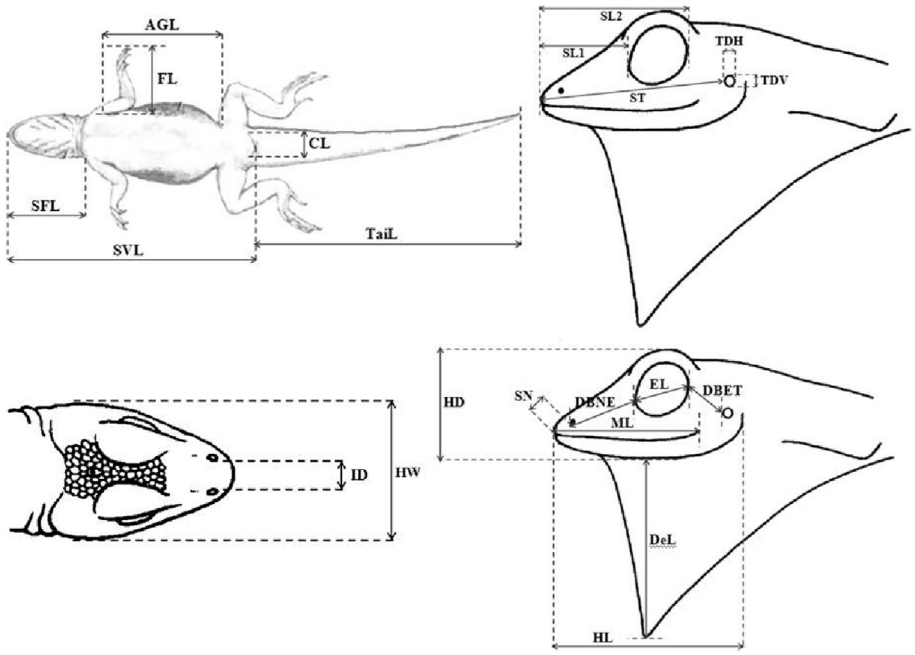

Fig. 1. Morphometric characters of *Draco maculatus*. Snout–vent length (SVL), snout–forelimb length (SFL), forelimb length (FL), axilla-groin length (AGL), tail length (TaiL), cloacal length (CL), head width (HW), internarial distance (ID), head length (HL), head depth (HD), mouth length (ML), dewlap length (DeL), snout to nostril (SN), distance between nostril to anterior edge of eye (DBNE), distance between posterior edge of eye to anterior edge of tympanum (DBET), eye length (EL), snout to anterior edge of eye (snout length 1 (SL1)), snout to posterior edge of eye (snout length 2 (SL2)), snout to anterior edge of tympanum (ST), tympanum diameter in vertical (TDV), and tympanum diameter in horizontal (TDH). The figure is modified from Musters (1983) and Stebbins (2003).

morphological characters in this study consisting of 46 morphometric (21 raw data and 25 character ratios) and 4 meristic characters that were investigated as shown in Tables 1 and 2, respectively. Morphometric differences between the sexes were analyzed using an independent sample *t* test and discriminant analysis. The meristic characters were compared between males and females using the Mann–Whitney *U* test. The descriptive statistics reported for each variable consisted of the sample size (*N*), mean, standard deviation of the mean (SD), minimum (Min), maximum (Max), *p*-value (at a significance level of 0.05). The SPSS software version 16 (SPSS Inc.; Chicago, IL, USA) was used to carry out the statistical analyses.

Results

Univariate analysis

Descriptive parameters and significance levels ($p < 0.05$) of morphometric and meristic characters are separately presented for males and females in Tables 3 and 4, respectively.

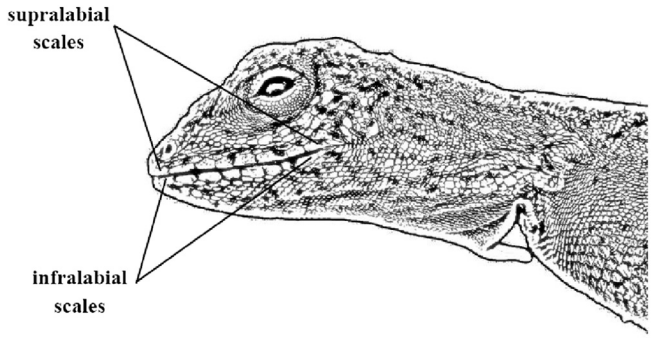

Fig. 2. Supralabial and infralabial scales of *Draco maculatus*.

The results of morphometric analysis showed significant differences in 24 characters consisting of 9 morphometric raw data—SVL, SFL, FL, TaiL, HL, HD, ML, DeL and DBET—and 15 character ratios—AGL/SVL, TaiL/SVL, HW/SVL, ID/SVL, HL/SVL, ML/SVL, DeL/SVL, EL/SVL, SL1/SVL, SL2/SVL, ST/SVL, FL/AGL, HW/HL, HD/HW and DeL/HL (Table 3).

The results of meristic analysis showed significant differences in three characters consisting of the number of infralabial scales, the number of subdigital lamellae on the fourth finger and the number of subdigital lamellae on the fourth toe (Table 4).

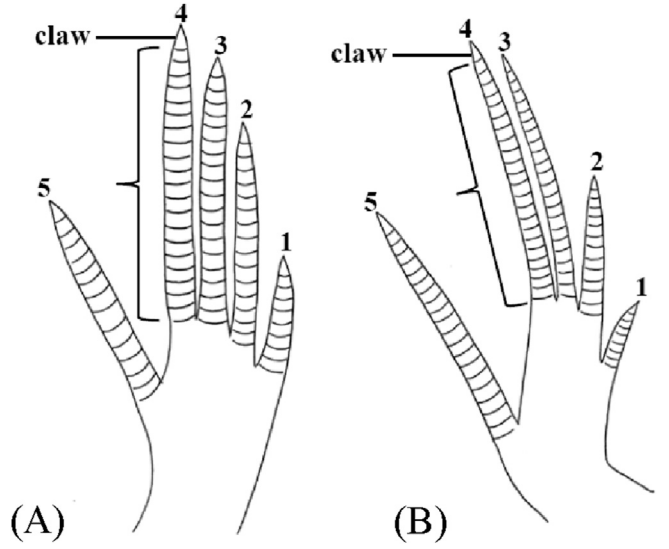

Fig. 3. *Draco maculatus* subdigital lamellae (brackets): (A) Subdigital lamellae on the fourth finger of the right forelimb; (B) subdigital lamellae on the fourth toe of the right hindlimb.

Table 1
Morphometric characters examined on 200 specimens from Thailand of *Draco maculatus*.

Morphometric character
- Snout–vent length (SVL): the tip of the snout to the vent
- Snout–forelimb length (SFL): the tip of the snout to the shoulder
- Forelimb length (FL): the left side from the axilla to the tip of the fourth finger when extended at right angles
- Axilla-groin length (AGL): the axilla to the anterior edge of hindlimb at its insertion into the body
- Tail length (TaiL): the vent to the tip of the tail
- Cloacal length (CL): the broadest part at the level of the cloacal opening
- Head width (HW): the widest part of the head
- Internarial distance (ID): across the nostrils at the snout
- Head length (HL): the tip of the snout to the posterior margin of the jaw
- Head depth (HD): the deepest part of the head
- Mouth length (ML): the tip of the snout to the mouth corner
- Dewlap length (DeL): maximally extended, from the ventral edge of the lower jaw to the tip of the dewlap
- Snout to nostril (SN): the tip of the snout to the anterior edge of the nostril
- Distance between nostril to anterior edge of eye (DBNE): the anterior edge of the nostril to the anterior edge of the eye
- Distance between posterior edge of eye to anterior edge of tympanum (DBET): the posterior edge of the eye to the anterior edge of the tympanum
- Eye length (EL): the anterior edge of the orbit to the posterior edge of the orbit
- Snout to anterior edge of eye (snout length 1 (SL1)): the tip of the snout to the anterior edge of the eye
- Snout to posterior edge of eye (snout length 2 (SL2)): the tip of the snout to the posterior edge of the eye
- Snout to anterior edge of tympanum (ST): the tip of the snout to the anterior edge of the tympanum
- Tympanum diameter in vertical (TDV): the dorsal edge of the tympanum to the ventral edge of the tympanum
- Tympanum diameter in horizontal (TDH): the anterior edge of the tympanum to the posterior edge of the tympanum
- To avoid any effect of size in analyzing morphometric characters, the following character ratios were used in the analysis: SFL/SVL, FL/SVL, AGL/SVL, TaiL/SVL, CL/SVL, HW/SVL, ID/SVL, HL/SVL, HD/SVL, ML/SVL, DeL/SVL, SN/SVL, DBNE/SVL, DBET/SVL, EL/SVL, SL1/SVL, SL2/SVL, ST/SVL, TDV/SVL, TDH/SVL, FL/AGL, HW/HL, HD/HW, HD/HL, and DeL/HL

Multivariate analysis

The results of discriminant analysis based on the significant differences of nine morphometric raw data—SVL, SFL, FL, TaiL, HL, HD, ML, DeL and DBET—could be used to construct a sexual discrimination equation (Equation (1)):

$$D = 3.495 - 0.066\text{SVL} - 0.022\text{SFL} - 0.051\text{FL} + 0.003\text{TaiL} - 0.346\text{HL} - 0.154\text{HD} + 0.264\text{ML} + 0.386\text{DeL} - 0.578\text{DBET} \quad (1)$$

The sexual discrimination equation could be directly used to identify the two sexes with 98.0% of cross-validated grouped cases correctly classified, since positive *D* scores indicated males and negative *D* scores indicated females, with 97.5% of the males and 98.7% of the females being correctly assigned.

Discussion

The morphological data based on significant differences composed of snout–vent length (SVL), snout–forelimb length (SFL), forelimb length (FL), tail length (TaiL), head length (HL), head depth (HD), mouth length (ML), dewlap length (DeL), distance between posterior edge of eye to anterior edge of tympanum (DBET), the number of infralabial scales, the number of subdigital lamellae on the fourth finger and the number of subdigital lamellae on the fourth toe revealed that males are larger than females for *D. maculatus* in Thailand. This study showed varying levels of sexual dimorphism in *D. maculatus* related to evolutionary adaptations. For example, sexual selection affects competition between males as the reproductive success of males is usually determined by their body size and consequently, intrasexual selection can drive the evolutionary adaptations of increased body size in males and result in sexual dimorphism with males becoming larger than females (Vitt and Caldwell, 2009). In other instances, the dewlap length differs between male and female *Draco* lizards, with the male dewlap length being longer than in females, as males use the dewlap in social displays such as courtship behavior (Shine et al., 1998). The results of character ratios showed less variation than in the morphometric raw data. Thus, the character ratios are suitable to use for discrimination between sexual differences as they reduce any size effect (Aghili et al., 2010). In this study, 15 character ratios—AGL/SVL, TaiL/SVL, HW/SVL, ID/SVL, HL/SVL, ML/SVL, DeL/SVL, EL/SVL, SL1/SVL, SL2/SVL, ST/SVL, FL/AGL, HW/HL, HD/HW and DeL/HL—could be used for sexual discrimination in populations of *D. maculatus* in Thailand.

Table 2
Meristic characters examined on 200 specimens from Thailand of *Draco maculatus*.

Meristic character
- Number of supralabial scales
- Number of infralabial scales
- Number of subdigital lamellae on 4th finger
- Number of subdigital lamellae on 4th toe

The results of multivariate analysis using discriminant analysis based on significant differences produced a sexual discrimination equation to support sexual discrimination in populations of *D. maculatus* in Thailand.

The morphometric and meristic characters could be used as an additional or diagnostic tool to support the qualitative characters for morphological study (Srichairat et al., 2014). The information from this study would be useful to assess the population of *D. maculatus* for sustainable conservation in Thailand.

Conclusion

Two hundred preserved specimens of the spotted flying lizard *D. maculatus* from Thailand consisting of 121 males and 79 females were examined using 21 morphometric raw data, 25 character ratios and 4 meristic characters to assess sexual dimorphism. The results of univariate analysis showed that there were nine morphometric raw data (SVL, SFL, FL, TaiL, HL, HD, ML, DeL and DBET) and 15 character ratios (AGL/SVL, TaiL/SVL, HW/SVL, ID/SVL, HL/SVL, ML/SVL, DeL/SVL, EL/SVL, SL1/SVL, SL2/SVL, ST/SVL, FL/AGL, HW/HL, HD/HW and DeL/HL), and 3 meristic characters (the number of infralabial scales, the number of subdigital lamellae on the fourth finger and the number of subdigital lamellae on the fourth toe) that can be used for discrimination of

Table 3
Descriptive analysis and independent *t*-test of morphometric characters of male and female specimens of *Draco maculatus* from Thailand.

Morphometric character	Male ($N = 121$)			Female ($N = 79$)			*p*-Value
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
SVL[a]	73.65 ± 9.61	38.70	90.70	69.43 ± 8.34	35.70	83.70	0.002
SFL[a]	24.23 ± 2.94	14.15	29.70	22.87 ± 2.73	13.10	26.85	0.001
FL[a]	31.04 ± 3.88	18.30	37.55	29.26 ± 3.41	16.00	35.35	0.001
AGL	40.39 ± 5.51	21.20	49.20	39.17 ± 4.88	19.40	48.50	0.111
TaiL[a]	112.21 ± 18.22	35.70	150.50	101.70 ± 13.76	53.90	126.35	0.000
CL	5.02 ± 0.82	2.25	6.80	4.84 ± 0.95	2.05	6.95	0.149
HW	8.58 ± 1.03	4.85	10.55	8.62 ± 1.00	5.30	10.70	0.798
ID	2.70 ± 0.33	1.60	3.25	2.72 ± 0.36	1.70	3.65	0.662
HL[a]	15.08 ± 1.60	8.70	17.55	14.60 ± 1.67	8.20	17.40	0.043
HD[a]	7.41 ± 0.80	4.15	8.90	7.11 ± 0.81	3.70	8.60	0.011
ML[a]	11.54 ± 1.28	6.60	14.05	11.15 ± 1.38	6.15	13.20	0.040
DeL[a]	26.73 ± 5.37	7.10	37.60	12.27 ± 2.34	5.20	18.15	0.000
SN	1.74 ± 0.32	0.75	2.90	1.69 ± 0.32	0.60	2.90	0.257
DBNE	3.71 ± 0.50	1.85	4.65	3.57 ± 0.54	1.80	4.85	0.067
DBET[a]	3.31 ± 0.44	1.70	4.10	3.17 ± 0.38	1.85	3.90	0.028
EL	5.92 ± 0.51	4.25	7.20	5.81 ± 0.47	4.35	7.10	0.128
SL1	5.60 ± 0.74	2.70	6.90	5.41 ± 0.75	2.70	6.70	0.075
SL2	10.79 ± 1.16	6.25	13.20	10.46 ± 1.19	5.80	12.40	0.053
ST	12.97 ± 1.43	7.20	15.40	12.61 ± 1.47	6.65	14.65	0.089
TDV	1.87 ± 0.33	1.10	2.65	1.85 ± 0.33	1.00	2.45	0.649
TDH	1.55 ± 0.23	1.00	2.25	1.55 ± 0.24	0.85	2.00	0.923
SFL/SVL	0.33 ± 0.02	0.30	0.38	0.33 ± 0.02	0.29	0.38	0.631
FL/SVL	0.42 ± 0.03	0.35	0.52	0.42 ± 0.02	0.36	0.48	0.900
AGL/SVL[a]	0.55 ± 0.02	0.49	0.60	0.56 ± 0.02	0.52	0.60	0.000
TaiL/SVL[a]	1.53 ± 0.17	0.53	1.78	1.47 ± 0.13	0.91	1.70	0.011
CL/SVL	0.07 ± 0.01	0.05	0.09	0.07 ± 0.01	0.04	0.09	0.203
HW/SVL[a]	0.12 ± 0.01	0.09	0.18	0.12 ± 0.01	0.11	0.16	0.000
ID/SVL[a]	0.04 ± 0.00	0.02	0.05	0.04 ± 0.00	0.03	0.05	0.000
HL/SVL[a]	0.21 ± 0.01	0.18	0.24	0.21 ± 0.01	0.18	0.23	0.000
HD/SVL	0.10 ± 0.01	0.08	0.13	0.10 ± 0.01	0.08	0.12	0.081
ML/SVL[a]	0.16 ± 0.01	0.14	0.18	0.16 ± 0.01	0.14	0.18	0.008
DeL/SVL[a]	0.36 ± 0.05	0.17	0.47	0.18 ± 0.02	0.13	0.24	0.000
SN/SVL	0.02 ± 0.01	0.01	0.04	0.02 ± 0.01	0.02	0.04	0.529
DBNE/SVL	0.05 ± 0.00	0.04	0.06	0.05 ± 0.01	0.04	0.07	0.192
DBET/SVL	0.04 ± 0.01	0.03	0.05	0.05 ± 0.01	0.04	0.06	0.536
EL/SVL[a]	0.08 ± 0.01	0.07	0.11	0.08 ± 0.01	0.07	0.12	0.018
SL1/SVL[a]	0.08 ± 0.01	0.06	0.09	0.08 ± 0.01	0.07	0.10	0.012
SL2/SVL[a]	0.15 ± 0.01	0.13	0.17	0.15 ± 0.01	0.14	0.18	0.001
ST/SVL[a]	0.18 ± 0.01	0.14	0.20	0.18 ± 0.01	0.17	0.21	0.002
TDV/SVL	0.03 ± 0.01	0.01	0.04	0.03 ± 0.01	0.02	0.04	0.084
TDH/SVL	0.02 ± 0.00	0.01	0.03	0.02 ± 0.00	0.01	0.03	0.166
FL/AGL[a]	0.77 ± 0.05	0.66	0.95	0.75 ± 0.05	0.64	0.87	0.004
HW/HL[a]	0.57 ± 0.04	0.47	0.80	0.59 ± 0.03	0.51	0.70	0.000
HD/HW[a]	0.87 ± 0.07	0.61	1.06	0.83 ± 0.06	0.65	0.95	0.000
HD/HL	0.49 ± 0.03	0.42	0.56	0.49 ± 0.03	0.40	0.55	0.358
DeL/HL[a]	1.75 ± 0.26	0.74	2.31	0.84 ± 0.11	0.57	1.11	0.000

SVL = snout–vent length; SFL = snout–forelimb length; FL = forelimb length; AGL = axilla-groin length; TaiL = tail length; CL = cloacal length; HW = head width; ID = internarial distance; HL = head length; HD = head depth; ML = mouth length; DeL = dewlap length; SN = snout to nostril; DBNE = distance between nostril to anterior edge of eye; DBET = distance between posterior edge of eye to anterior edge of tympanum; EL = eye length; SL1 = snout to anterior edge of eye (snout length 1); SL2 = snout to posterior edge of eye (snout length 2); ST = snout to anterior edge of tympanum; TDV = tympanum diameter in vertical; TDH = tympanum diameter in horizontal.
[a] In the same column indicates a significant difference ($p < 0.05$).

sexual differences. The morphological data based on significant differences revealed that males are larger than females. The results of discriminant analysis based on the significant differences of nine morphometric raw data could be used to construct a sexual discrimination equation (D) where $D = 3.495 - 0.066\text{SVL} - 0.022\text{SFL} - 0.051\text{FL} + 0.003\text{TaiL} - 0.346\text{HL} - 0.154\text{HD} + 0.264\text{ML} + 0.386\text{DeL} - 0.578\text{DBET}$. The sexual discrimination equation could be directly used to identify the two sexes with 98.0% of cross-validated grouped cases correctly classified, since positive D scores indicated males and negative D scores indicated females, with 97.5% of the males and 98.7% of the females being correctly assigned.

Table 4
Descriptive analysis and Mann–Whitney *U*-test of meristic characters in male and female specimens of *Draco maculatus* from Thailand.

Meristic characters	Male ($n = 121$)			Female ($n = 79$)			*p*-Value
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
Supralabial scales	8.76 ± 0.99	7	11	8.58 ± 0.97	7	11	0.242
Infralabial scales[a]	8.87 ± 0.98	7	12	8.58 ± 1.14	7	12	0.039
Subdigital lamellae on 4th finger[a]	25.69 ± 2.10	21	31	24.68 ± 1.96	21	29	0.002
Subdigital lamellae on 4th toe[a]	30.12 ± 2.05	26	35	29.39 ± 1.96	23	35	0.027

[a] In the same column indicates a significant difference ($p < 0.05$).

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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