OnLine Journal of Biological Sciences 2 (12): 785-788, 2002
ISSN 1608-4127

Subspecific Size Variation in the Hill Mynahs *Gracula religiosa* in Thailand

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Abstract: Two subspecies of Hill Mynah *(Gracula religiosa)* occur in Thailand, the northern race *(G. r. intermedia)* and the southern race *(G. r. religiosa)*. The southern race is larger than the northern race and has two separate patches of yellow wattle on the ear-coverts, whereas the northern race has a yellow connection between the anterior and posterior wattles. The variation in morphology was investigated by measuring eleven external morphological characteristics of 749 live birds from different habitats throughout Thailand. Birds from different latitudinal zones of Thailand were studied in five equal-interval zones from 5° 30′ to 20° 30′ N. A descriptive analysis of morphological variables for birds from each latitudinal zone indicated that the average head area, bill size, body size, wing length and tarsus length increased toward the south. One-way analysis of variance among the zones for all morphological parameters showed significant F-ratios. All morphological measurements were negatively correlated with latitude except for tail length which had a positive coefficient. Comparison of morphological variation with climatic variation especially with relative humidity suggests that climatic adaptation may account for subspecific variation in the morphology of this species.

Key words: *Gracula religiosa*, Hill Mynah, subspecific variation, morphology

Introduction

Ten subspecies of Hill Mynah *(Gracula religiosa)*, occur in Asia from India and China to Indonesia and the Philippines (Peters, 1962). Two of these are sedentary in Thailand (Lekagul and Round, 1991): the northern race *(G. r. intermedia)*, which inhabits northern India, China, Burma, Laos, Cambodia, Vietnam, northern and central Thailand (Ripley and Ali, 1987; King *et al.*, 1991; Meyer, 1992) and the southern race *(G. r. religiosa)* which inhabits the southern part of Thailand, Malaysia and Indonesia (Glenister, 1983; Mackinnon and Phillips, 1994). Morphological differences between northern and southern races are obvious. The northern race has smaller bill, head and body than the southern race. Also the shape of yellow wattle of the northern race includes a yellow connection between the anterior and posterior parts which does not appear in the southern race.

Geographic variation in morphology of birds has been studied by systematists for subspecies description and evolutionary biologists for understanding speciation process (Johnston and Selander, 1971; Zink, 1989). Contributions to the geographic variation are various: climatic variation (Blem, 1981; Aldrich and James, 1991; Martin, 1991; Kratter, 1993); latitudinal variation (Johnston, 1994); seasonal variation in diet and foraging technique (Martin and Pitocchelli, 1991); stability for perching (Grant, 1971) and migratory movements (Wiedenfeld, 1991; Twedt *et al.*, 1994). Since the two subspecies in Thailand cross a latitudinal gradient, the body size and geographic variation were speculated. Therefore, we studied size variation of Hill Mynahs in Thailand to examine morphological differentiation and to detect the variation among populations.

Materials and Methods

Study areas: There were 33 study sites in Thailand between latitude 5° 30′ N and 20° 30′ N (Fig. 1). Latitudinal zones were divided as five equal-interval zones:
Zone one = 20° 30′ to 17° 31′, Zone two = 17° 30′ to 14° 31′, Zone three = 14° 30′ to 11° 31′, Zone four = 11° 30′ to 8° 31′, Zone five = 8° 30′ to 5° 31′.
Climatic factors including temperature, rainfall and relative humidity were recorded for each of these zones.

Morphological measurements: A total of 749 Hill Mynahs were trapped at 33 different localities from August to December of 1994 to 1998. Only adult birds (> 1 year) were studied by examining the yellow wattles. Young birds normally have pink and pale wattles. Sex determination from the distinctive shape of body: cone shaped in males and round shaped in females was confirmed by sex chromosome identification using tissue culture technique (Archawaranon and Mevatee, 2002). The study groups consisted of 434 males and 315 females.

Morphological measurements taken included surface area of head, volume of bill cone, degree of bill curvature, surface area of anterior wattle, length of posterior wattle, body mass, body length, body circumference, length of wing, tail and tarsus were made with vernier calipers, ruler and dividers (Proctor and Lynch, 1993). Surface area of the head was derived from the widest measurement of the individual's head multiplied by the length from local point to the end of nape. Volume of the bill cone was calculated from cone volume formula ($\pi r^2 h$) where h was the average bill length measured from bill tip to feathers of upper and lower bill and r was computed from the thickest circumference of bill. Degree of bill curvature were obtained by using a protractor to measure the degree between bill tip and the top of its head when the head was held straight. Surface area of the anterior wattle was measured from the width and the length of the anterior wattle whereas the length of posterior wattle was from the front edge to back edge of posterior wattle. Body mass was obtained by weighing. Body length was measured from bill tip to the end of its body before tail feathers appeared, whereas body circumference was measured around the breast. Wing length was taken from the bend of wing to the tip of the longest primary feather. Tail length was from the base of the feathers under the upper tail to the longest tail feather. Tarsus length was measured from the rear middle of the intertarsal joint to the bend of the tarsal bone. To minimize error all measurements were taken twice. Birds were released after the measurements.

Statistical analysis: The morphological measurements of 749 specimens were analyzed by descriptive statistics: mean, standard deviation and coefficients of variation (CV). Morphological variables were tested for significant variation among latitudinal zones by one-way ANOVA and Scheffe's pairwise tests. In order to see the relationships of all characteristics, latitude and climate, Pearson's product-moment correlation coefficients were calculated. The significant level was taken as $P \leq 0.05$.

Results

Size variation: Based on sign tests in a previous study, there were no significant morphological differences between sexes in each locality. Therefore, the sexes were pooled for further analysis. The average morphological characteristics were calculated for birds from the five equal interval of latitude (Fig. 1). Most morphological characteristics increased towards the lower latitude, this included head area, bill cone, bill curvature, body mass, body length, body circumference, wing length and tarsus length (Table 1). However,

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Table 1: Mean and standard deviation of morphological characteristics of Hill Mynahs in five different latitudinal zones of Thailand

Morphological characters	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Head area (cm^2)	17.28 ± 0.60	17.50 ± 1.09	17.86 ± 0.87	19.34 ± 1.29	21.48 ± 1.73
Bill cone (cm^3)	6.43 ± 0.08	6.79 ± 0.14	7.51 ± 0.12	8.23 ± 0.17	11.30 ± 0.29
Bill curvature (degree)	5.76 ± 1.13	5.76 ± 1.16	6.12 ± 1.03	7.18 ± 0.76	8.00 ± 1.34
Anterior wattle area (cm^2)	0.96 ± 0.18	0.96 ± 0.20	1.02 ± 0.21	0.98 ± 0.20	0.97 ± 0.27
Posterior wattle length (cm)	3.08 ± 0.32	2.85 ± 0.57	2.96 ± 0.43	3.10 ± 0.35	3.39 ± 0.51
Body mass (gm)	188.34 ± 15.95	199.16 ± 13.32	230.54 ± 17.02	239.75 ± 11.51	280.78 ± 17.74
Body length (cm)	18.02 ± 0.59	18.95 ± 0.89	19.12 ± 0.98	20.65 ± 1.14	22.16 ± 1.34
Body circumference (cm)	17.69 ± 0.45	18.25 ± 0.80	18.72 ± 0.92	20.22 ± 1.08	21.79 ± 1.22
Wing length (cm)	16.49 ± 0.62	16.54 ± 0.98	16.92 ± 1.16	17.50 ± 1.30	18.40 ± 1.23
Tail length (cm)	7.46 ± 0.47	7.49 ± 0.61	6.89 ± 0.86	7.03 ± 0.84	6.74 ± 0.81
Tarsus length (cm)	3.21 ± 0.12	3.44 ± 0.40	4.22 ± 0.17	4.36 ± 0.20	4.64 ± 0.30

Zone one = 20° 30′-17° 31′ N (n = 44), Zone two = 17° 30′-14° 31′ N (n = 190), Zone three = 14° 30′-11° 31′ N (n = 131), Zone four = 11° 30′-8° 31′ N (n = 132), Zone five = 8° 30′ -5° 31′ N (n = 252).

Table 2: Test of morphological variation in five latitudinal zones. Explanation for latitudinal zones as in Table 1

Morphological characters	F -ratio	P	Significant Scheffe's test
Head area	320.28	<0.01	All pairs except ½ , 1/3 , 2/3
Bill cone	166.50	<0.01	All pairs except ½ , 1/3 , 2/3 , 3/4
Bill curvature	148.37	<0.01	All pairs except ½ , 1/3 , 2/3
Anterior wattle area	1.31	0.26	Non-significant
Posterior wattle length	38.84	<0.01	2/4 , 1/5 , 2/5 , 3/5 , 4/5
Body mass	369.10	<0.01	All pairs
Body length	353.52	<0.01	All pairs
Body circumference	441.85	<0.01	All pairs
Wing length	88.84	<0.01	All pairs except ½ , 1/3 , 2/3
Tail length	31.12	<0.01	All pairs except ½ , 3/4 , 3/5
Tarsus length	605.34	<0.01	All pairs

Table 3: Pearson product-moment correlation matrix among various morphological measurements and latitude (*P < 0.01)

Morphological characters	Latitude	Head	Bill cone	Bill curvature	Anterior wattle	Posterior wattle	Body mass	Body length	Circum-ference	Wing	Tail
Head area	-0.78*										
Bill cone	-0.65*	0.75*									
Bill curvature	-0.68*	0.70*	0.71*								
Anterior wattle	-0.02	0.03	0.03	0.11							
Posterior wattle	-0.39*	0.45*	0.34*	0.29*	0.21*						
Body mass	-0.81*	0.78*	0.66*	0.66*	0.01	0.36*					
Body length	-0.80*	0.85*	0.73*	0.70*	-0.03	0.37*	0.85*				
Body circumference	-0.84*	0.87*	0.75*	0.73*	0.01	0.33*	0.86*	0.92*			
Wing length	-0.55*	0.61*	0.48*	0.51*	0.15*	0.32*	0.53*	0.58*	0.63*		
Tail length	0.32*	-0.13	-0.11	-0.06	0.16*	0.01	-0.07	-0.13*	-0.14	0.08	
Tarsus length	-0.85*	0.72*	0.64*	0.63*	0.13*	0.35*	0.75*	0.75*	0.78*	0.57*	-0.30*

Table 4: Climatic circumstances in Thailand

Zone	Latitude	Temperature (°C)	Annual rainfall (mm)	Relative humidity (%)
1	20°30′ - 17°31′ N	25.98 ± 0.90	1299.03 ± 77.77	73.50 ± 0.50
2	17°30′ - 14°31′ N	27.03 ± 0.63	1266.94 ± 216.14	71.00 ± 2.78
3	14°30′ - 11°31′ N	27.47 ± 0.70	1718.08 ± 538.02	73.67 ± 2.91
4	11°30′ - 8°31′ N	27.00 ± 0.30	2539.25 ± 985.59	81.00 ± 1.22
5	8°30′ - 5°31′ N	27.24 ± 0.45	2047.44 ± 300.37	79.33 ± 1.56

Source: Meteorological Department, Thailand.

Table 5: The relationships with three climatic factors (*P < 0.05, **P < 0.01)

Morphological characters	Temperature (°C)	Annual rainfall (nm.)	Relative humidity (%)
Head area	0.19	0.31	0.65**
Bill cone	0.20	0.27	0.60**
Bill curvature	0.18	0.29	0.63**
Anterior wattle area	-0.13	-0.21	-0.15
Posterior wattle length	-0.01	0.17	0.61**
Body mass	0.23	0.40*	0.70**
Body length	-0.21	0.32	0.68**
Body circumference	0.23	0.36*	0.66**
Wing length	0.23	0.36*	0.64**
Tail length	-0.23	-0.33	-0.48**
Tarsus length	0.15	0.33	0.63**

anterior wattle area, posterior wattle length and tail length showed an irregular pattern. A high coefficient of variation appeared in four characteristics; anterior wattle, bill cone, bill curvature and posterior wattle (11-28). The highest variations were for head area, bill cone, bill curvature, anterior wattle, body mass, body length and body circumference occurred in the lowest latitudinal zone (zone five).

The morphological variation in five latitudinal zones were compared with F-ratios (Table 2). Only that of the anterior wattle area was non-significant (F = 1.31, P = 0.26). Applying Scheffe's test for the differences among 10 possible pairs of latitudinal zones, significant differences were found in variation among all zones for body mass, body length, body circumference and tarsus length (P < 0.01). Meanwhile, head area, bill cone, bill curvature and wing length in zone one, two and three were not significantly different.

Correlation among morphological measurements and latitude: A Pearson's product–moment correlation matrix (Table 3) showed that eight of the eleven characteristics were significantly negatively correlated with latitude (P < 0.01). The high correlation coefficients showed that body measurements were highly correlated with each other and latitude, the lower latitude, the larger body mass, body length, body circumference, head area and tarsus length. Especially, body circumference and body length were the highest correlation (r = 0.92). While the correlation

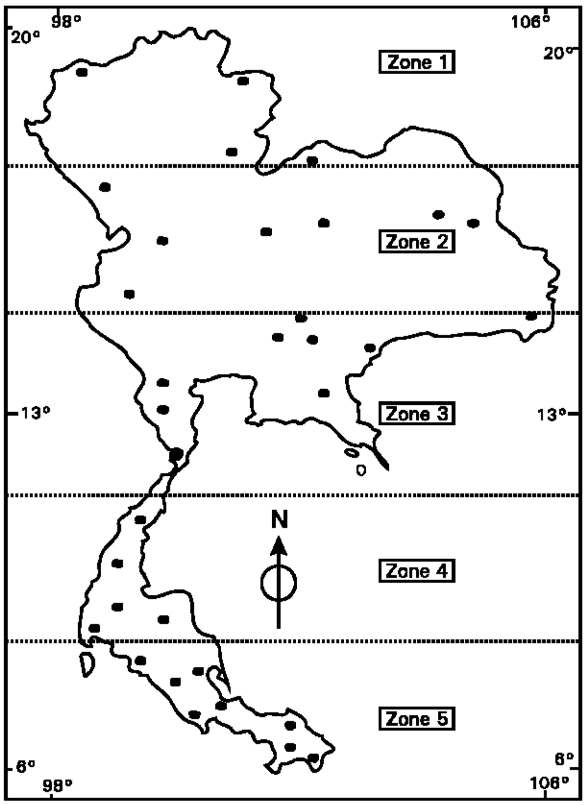

Fig. 1: Map of Thailand showing the localities of specimens of Hill Mynahs used in this study. Zone one = 20° 30′ - 17° 31′ N, Zone two = 17° 30′ - 14° 31′ N, Zone three = 14° 30′ - 11° 31′ N, Zone four = 11° 30′ - 8° 31′ N, Zone five = 8° 30′ - 5° 31′ N

between posterior wattle length and latitude was low. In contrast, tail length had a positive relationship with latitude and its correlation coefficient was the lowest ($r = 0.32$). Anterior wattle area did not correlate well with several other characteristics.

Correlation among morphological measurements and climate: When climatic factors (Table 4) were taken into consideration, it was found that temperature was not correlated with any of the morphological variables (Table 5). Although the average annual rainfall seemed to have higher correlation coefficients than those of the temperature, only the positive relationships with body mass, body circumference and wing length, were statistically significant ($P < 0.05$). Of the three climatic components investigated, the relative humidity correlated significantly ($P < 0.01$) with all morphological measurements except the anterior wattle. These correlation coefficients were positive while the relationship with tail length was negative.

Discussion

Overall, the morphological characteristics of Hill Mynahs varied with latitude. Eight out of eleven characteristics studied gradually became larger with decreasing latitude. Head, bill, body, wing and tarsus vary proportionately, the larger body, the larger head, the thicker bill, the longer wing and tarsus. These relationships describe patterns of geographic variation in morphology within this species. Bill curvature in higher latitudes is straight and corresponds with small bill cone. Southern birds have curved bills and large bill cones. We find that variation in bill curvature in the northern race is very high. This is not surprising due to the fact that the northern race was found in a very wide range of latitude from 9° to 20° 30′ N. The northern birds which inhabit higher latitudes have small external characters included straight bill whereas their members found in lower latitudes have larger measurements and curved bills. Meanwhile, the southern race in the lowest latitudinal zone has the highest variation for many morphological characteristics. The southern birds in this study areas which was found between 5° 31′ to 9° N, constitute only part of a wide distribution of *G. r. religiosa* and it is possible that this area is a transition zone between *G. r. intermedia* and *G. r. religiosa* where subspecific size variation was increased.

Although anterior wattle area, posterior wattle and tail length varied in an irregular fashion, posterior wattle length tended to be longer in lower latitude and southern birds had shorter tails than northern birds. Anterior wattle was not related to latitude or body size, as a consequence, anterior wattle may not be an important character for a study on geographic variation. We hypothesize that the wattle is appropriate for an indication of some degree of social dominance. Hill Mynahs with longer wattles tend to dominate those with shorter wattles in another study (Archawaranon, in preparation).

The length of the tarsus relative to body mass has been found to relate to the structure of the perching substrate. A longer tarsus is associated with stable perches, a shorter tarsus is with unstable perches (Grant, 1971). The contribution of the evergreen habitat to tarsus length in Thailand remains an open question, although the southern birds live in evergreen habitat where tall trees are found.

Although the climate in the northern part of Thailand is cooler, the well-known ecogeographical generalizations describing parallels between morphological variation and climatic conditions may not apply in this study. Bergmann's rule stated that animals that lived in cold region tended to be larger than related animals in warmer climates (Kratter, 1993). Previous studies have shown that the robustness of this rule has been a matter of constant debate (James, 1970; Murphy, 1985). Zink and Remsen's study (1986) of North American birds showed that many species did not conform to the rule which predicted an inverse relationship between body size and climate variables such as latitude and temperature. In Canada, the Mourning Warbler *(Oporornis philadelphia)* was studied for macrogeographic variation in plumage and skeletal characters and it was concluded that birds did not conform to predictions based on Bergmann's rule (Pitocchelli, 1992). A study of Yellow Warbler *(Dendroica petechia)* in North America, Middle America and the Caribbean concluded that there was a steady decline from the largest birds near the Equator to the smallest ones in Northern Alaska (Wiedenfeld, 1991). However, Johnston and Salender (1964) found that House Sparrows *(Passer domesticus)* conformed to the original formulation of Bergmann's rule only as far south as 28° N latitude, but that tropical populations did not. Morphological variation in Hill Mynahs does not support Bergmann's rule. This may be due to the fact that Thailand is located in the tropics between 5° 30′ N and 20° 30′ N. Moreover, the latitude range of about 15° does not result in extreme differences of temperature even though the temperature in the north is lower in winter.

Although rainfall correlated only with body mass, body circumference and wing length, the relative humidity positively correlated with all characters except tail length which had a negative correlation. All characters, except tail length and anterior wattle length, increased in lower latitudes where the relative humidity is higher than in the north. Tail length decreased in the lower latitude with higher relative humidity.

The clines of these character variations are subject to local environment. James (1970) and Aldrich and James (1991) showed the effect of both temperature and humidity on body size variations. In Thailand, the lower latitude with higher relative humidity is in the south where there are Gulf of Thailand on the east and Andaman Sea on the west. Thailand has a northeast monsoon during October to February and a southwest monsoon during June to October. These two monsoons bring heavy rain to both eastern and western parts of the south almost all year. The duration of rainfall, the long and narrow shape of the south, with seas on both sides, cause high humidity. From this study, the correlations between rainfall and relative humidity was significant and expected ($r = 0.62$, $P < 0.01$). Consequently, the highly humid climate in lower latitudes results in a tropical rain forest and food abundance for a long period makes the foraging easier. We thus hypothesize from this study that the humid climate plays an important role on the subspecific size variation in Hill Mynahs which has developed through time.

Acknowledgment

The authors are grateful to R.H. Wiley, Department of Biology, The University of North Carolina at Chapel Hill for his advice and review of this manuscript. We greatly appreciate Pornchai Wongwasana 's assistance in the field work for the past five years. This research was supported by The Thailand Research Fund (BRG/07/2540).

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