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Sexual Size Dimorphism and Morphological Sex Determination in the Black-billed Magpie in South Korea (*Pica pica sericea*)

Lee, Sang-im[1,2], Hyunjoo Jang[2], Soohyung Eo[3] and Jae Chun Choe[1]*

[1]*Laboratory of Behavior & Ecology, Division of EcoScience, Ewha Womans University, Seoul 120-750, Korea*

[2]*Laboratory of Behavioral Ecology & Evolution, Department of Biological Sciences, Seoul National University, Seoul 151-742, Korea*

[3]*Warnell School of Forest Resources, University of Georgia, Athens, GA 30602, USA*

ABSTRACT: Statistical tools for determining sex in the sexually monomorphic black-billed magpie based on morphological characters have been developed based on studies of European and North American populations. However, since no morphological method has been developed for black-billed magpies in Korea, it has been difficult to conduct field studies that require information about the sex of individuals. We present two discriminant equations for determining sex of second-year (SY) and after-second-year (ASY) magpies in north- and mid-western part of South Korea. Based on morphological measurements on 105 SY (56 females, 49 males) and 72 ASY (36 females, 36 males) individuals, we found body mass, wing chord, and head length to be the most useful features for morphological sex determination. The accuracy of our method was 86.5% for SYs and 93.1% for ASYs, which is similar to values reported previously from American and European magpies. Since the equations contain morphological traits which are only minimally susceptible to seasonal variation and measurement errors, our discriminant equations should be both useful and robust for sex determination on black-billed magpies in the northern and mid-western regions of South Korea.

Key words: Black-billed magpie, Body mass, Head length, Morphology, Sex determination, South Korea, Wing chord

INTRODUCTION

Field studies of wild avian species often require the determination of their sex via morphological measurements. However, morphological sex determination is often difficult in sexually monomorphic species. Traditional methods for determining sex in such species involve discriminant function analyses (DFA) based on measurements of large number of samples from the field (Desrochers 1990, Wilson 1999, Delestrade 2001, Zenatello and Kiss 2005) or from a mixture of field and museum sources (Bond et al. 1991, Berlin et al. 2001).

In the black-billed magpie, a species displaying sexual monomorphism for most physical characteristics and only slight size dimorphism (males are larger than females by 10%; Birkhead 1991), there is considerable overlap between females and males in almost all morphological measurements for adults and juveniles (Birkhead 1991). For this reason, sex determination in the field is difficult in the absence of behavioral cues or noticeable size differences in breeding pairs (Birkhead 1991).

Previous studies of sex identification based on morphological characters in magpies have primarily been conducted on the American black-billed magpie (*Pica hudsonia,* formerly *Pica pica hudsonia*, Reese and Kadlec 1982, Charf 1987), whose morphological characters are slightly different from other subspecies of the nominate species of *Pica* (i.e. *P. pica*). Black-billed magpies of the species found in Korea, China and Japan (*P. pica sericea*) are slightly larger than American magpies, and have shorter black tips on the primary feathers than American and European magpies (Birkhead 1991, Goodwin 1986). However, there have been no quantitative analyses to date on the morphological traits of black-billed magpies in Korea, which makes it difficult to conduct field studies that require information on the sex of the individuals.

We quantified sexual size dimorphism and developed statistical tools for sex determination in black-billed magpies in Korea based on multiple morphological characters. Sex determination based on morphological traits is less time-consuming and costly than molecular sexing (e.g. Griffiths et al. 1998), and is useful in cases where taking blood samples is not feasible. We provide separate discriminant equations for young and adult birds to permit more reliable sex determination according to the age class of the individuals.

* Corresponding author; Phone: +82-2-3277-4512, e-mail: jaechoe@ewha.ac.kr

MATERIALS & METHODS

We collected and measured 151 dead magpies from 4 cities and towns in the northern and central regions (Cheolwon, Chonnan, Chungju, Cheongyang) of western South Korea. Birds were shot either by KEPCO (Korea Electric Power Corporation) workers or by local hunters between late February and early April of 2000, 2003 and 2004. In Korea, magpies often build their nests on electricity pylons and cause short-circuits, and it is legal to shoot magpies during the nest-building phase of the breeding season. The magpie corpses were individually packed immediately after collection and stored at −20℃ for three to four months until measurements could be taken.

Morphological traits used in this study included

(i) Skeletal measures: lengths of tarsus, ulna, sternum keel and head, lengths and widths of bill (both from the base and from the distal edge of the nostril) and skull;

(ii) Feather measures: lengths of wing chord (flattened), 10^{th} primary, tail, black tip of the longest primary feather;

(iii) Others: Body mass and skull volume.

All of the skeletal and feather measurements were conducted with Vernier calipers to the nearest 0.01 mm. Body mass was measured with a digital balance to the nearest 0.01g. Skull volume was calculated as 'skull length × skull width^2 × π' (cm^3). Skull length was calculated by subtracting bill length from base from head length.

Individuals were classified into SY (birds in their second calendar year) or ASY (older birds in their third or more years) based on the length of black tip of the longest primary (Erpino 1968, Birkhead 1991) and the degree of color degradation of black tips on primary featners (Svensson 1992). Individuals with black tips longer than 20.0 mm were categorized as SY, and this corresponded to the categorization based on the degree of feather wear and color degradation because of the lack of molting in SY birds. Our dataset was comprised of 105 SYs (56 females, 49 males) and 72 ASYs (36 females, 36 males). Sex was determined by checking for the existence of testes or ovaries. Body masses of females with highly developed follicles or eggs in their bodies were excluded from the analyses.

Discriminant Function Analyses (DFAs) with forward variable selection were conducted with Statistica ver. 6 (Statsoft 2001) on SY and ASY birds separately. With forward variable selection, the initial F-to-enter value was set at 3.0. For each session of DFA, we first tested the heterogeneity of within-covariance matrices. As the results of these tests were not statistically significant, pooled covariance matrices were used throughout the DFA procedures (Morrison 1976).

RESULTS

Sex differences in morphological traits are shown in Table 1. For most traits, males were significantly larger than females, regardless of age class. Except for the length of black tip of the 7^{th} primary, which was used as an age marker, pectoral muscle depth was the only character for which the sex difference was not significant. Interestingly, male and female tail lengths were significantly different only in ASYs. Based on these findings, sexual size dimorphism in magpies seems to be established as early as the second year (or even before) in all features except for tail length.

Results of Stepwise Discriminant Function Analyses

For both SY and ASY birds, body mass, wing chord, and head length were selected as the key characters for morphological sex determination. The degree of sexual size dimorphism, calculated as the difference in mean values divided by the measurements of females, was 13.12% and 14.85% for body mass, 3.57% and 3.98% for wing chord, and 1.55% and 1.44% for head length in SYs and ASYs respectively (frequency distributions of these variables are depicted in Fig. 1). Although the same characters were selected in the discriminant equations for sexing SY and ASY birds, the order of steps in which the variables were added was different (Table 2).

The accuracy of the discriminant equation was 86.5% (7 individuals from each sex were misclassified) in SY birds, and 93.1% (2 females and 3 males were misclassified) in ASY birds. Therefore, the accuracy of morphological sex determination was lower in SYs than in ASYs. This is undoubtedly due to greater overlap between females and males in SYs than in ASYs in most of the morphological traits (noted as lower absolute *t*-values in Table 1). The discriminant equations were as follows:

for SY birds,

Female : $-1061.4 + (-1.08 \times mass) + (6.02 \times chord) + (16.13 \times head\ length)$

Male : $-1132.1 + (-1.04 \times mass) + (6.35 \times \text{chord}) + (16.54 \times head\ length)$;

and for ASY birds,

Female : $-1783.1 + (-1.08 \times mass) + (11.48 \times chord) + (21.21 \times head\ length)$

Male : $-1932.1 + (-1.00 \times mass) + (11.84 \times chord) + (22.02 \times head\ length)$.

DISCUSSION

Although the same sets of morphological traits can be used for sex determination in SY and ASY individuals and the level of

Table 1. Comparisons of morphological characters of female and male black-billed magpies. *t*-values and significance values from unpaired *t*-tests are shown ($^{***, **, *}$ and NS denote P<0.001, <0.01, <0.05 and 'not significant' respectively). The variables included in the discriminant equations are marked in bold.

Variable	SY Female			SY Male			*t*-value	ASY Female			ASY Male			*t*-value
	Mean	SD	n	Mean	SD	N		Mean	SD	n	Mean	SD	n	
Body mass	209.04	17.21	56	236.46	17.82	49	-8.01^{***}	210.7	13.82	35	241.74	15.05	35	-9.11^{***}
Skull volume	0.14	0.012	56	0.16	0.014	49	-6.40^{***}	0.14	0.009	36	0.16	0.014	36	-6.32^{***}
Pectoral muscle depth	15.47	2.70	49	15.46	2.35	44	0.02^{NS}	15.57	3.00	31	16.74	3.26	24	-1.42^{NS}
Wing chord	192.16	5.23	56	199.63	4.99	49	-7.46^{***}	197.83	4.19	36	206.16	3.98	36	-8.77^{***}
Length of 10^{th} primary	59.10	4.56	56	61.37	3.38	49	-2.87^{**}	56.20	3.77	36	59.00	3.69	36	-3.23^{**}
Length of black tip of 7^{th} primary	29.11	5.04	56	28.67	4.08	49	0.48^{NS}	10.99	2.41	36	10.69	2.34	36	0.54^{NS}
Tail length	215.61	25.18	54	223.32	20.15	47	-1.68^{NS}	232.25	10.99	36	244.47	10.99	36	-4.78^{***}
Tarsus length	48.24	1.89	54	50.30	2.30	49	-4.98^{***}	47.99	1.95	36	50.14	2.12	32	-4.44^{***}
Head length	71.73	2.20	56	74.96	1.81	49	-8.13^{***}	71.75	1.60	36	74.76	1.94	36	-9.63^{***}
Skull length	34.53	1.89	56	35.89	1.47	49	-4.08^{***}	34.39	1.43	36	36.23	2.98	36	-5.28^{***}
Skull width	31.05	0.84	56	32.15	0.96	49	-6.29^{***}	31.01	0.72	36	32.74	0.90	36	-5.21^{***}
Ulnar length	57.55	1.86	55	60.55	2.05	49	-7.83^{***}	57.74	1.56	36	60.10	2.10	36	-6.33^{***}
Length of sternum keel	43.97	3.67	55	46.01	2.58	49	-3.25^{***}	43.10	2.97	36	44.98	3.06	36	-2.65^{**}
Bill length from nostril	24.78	1.46	56	26.34	1.31	49	-5.75^{***}	24.70	1.08	36	26.79	1.32	36	-7.43^{***}
Bill depth at nostril	12.88	0.69	56	13.64	0.69	49	-5.66^{***}	12.81	0.77	36	13.67	0.76	36	-4.77^{***}
Bill length from base	37.21	2.45	56	39.06	1.53	49	-4.59^{***}	37.36	1.79	36	39.36	2.05	36	-4.46^{***}
Bill depth at base	15.36	0.83	56	16.09	0.71	48	-4.77^{***}	15.36	0.74	36	16.10	0.97	36	-3.65^{***}

sexual size dimorphism in these variables was similar in SYs and ASYs, the relative contribution to total variance (noted as the step where the variable was added) differed among the variables. This may be due to the fact that the level of overlap between females and males for the variable, as well as the difference in the means, affects the contribution of a variable to the total variance. For example, the standard deviation of head length for SY birds was greater than that for ASYs (2.2 and 1.81 versus 1.6 and 1.94, for females and males, respectively), which made head length less important as the key for sex determination in SYs.

Charf (1987) found that two traits, wing chord and bill depth measured at nostril, allow sex determination in American magpies (*Pica hudsonia*) with 98% accuracy. In his analyses, head length (calculated as the sum of skull length and bill length from base) was not included in the discriminant equations. Reese and Kadlec (1982) sexed magpies of the same species using body mass, wing chord and skull length with 95.4% accuracy. Kavanagh (1988) found tarsus length, body mass, wing chord, bill length and bill depth to be the most useful morphological characters for European magpies, allowing sex determination in two populations in Ireland with an accuracy of 93.4%. The accuracy of our method for sexing adult birds does not differ substantially from the accuracies reported in previous studies from other populations. Since the authors did not employ the stepwise addition method, which permits determination of the relative importance of the variables, it is difficult to compare the efficiencies of the discriminant equations suggested in these papers and to draw general conclusions regarding the importance of each morphological character for sex determination in black-billed magpies.

Given the morphological differences among the subspecies (Birkhead 1991), the discriminant equations from previous studies are unlikely to effectively discriminate between the sexes in Korean magpies. Geographic variation in morphology on a smaller spatial scale may also lower the efficiency and general applicability of published discriminant equations when applied to populations geographically distant from the study population. Our discriminant equations are based on magpies in the northern and central areas of the western region of South Korea. Considering that the morpho-

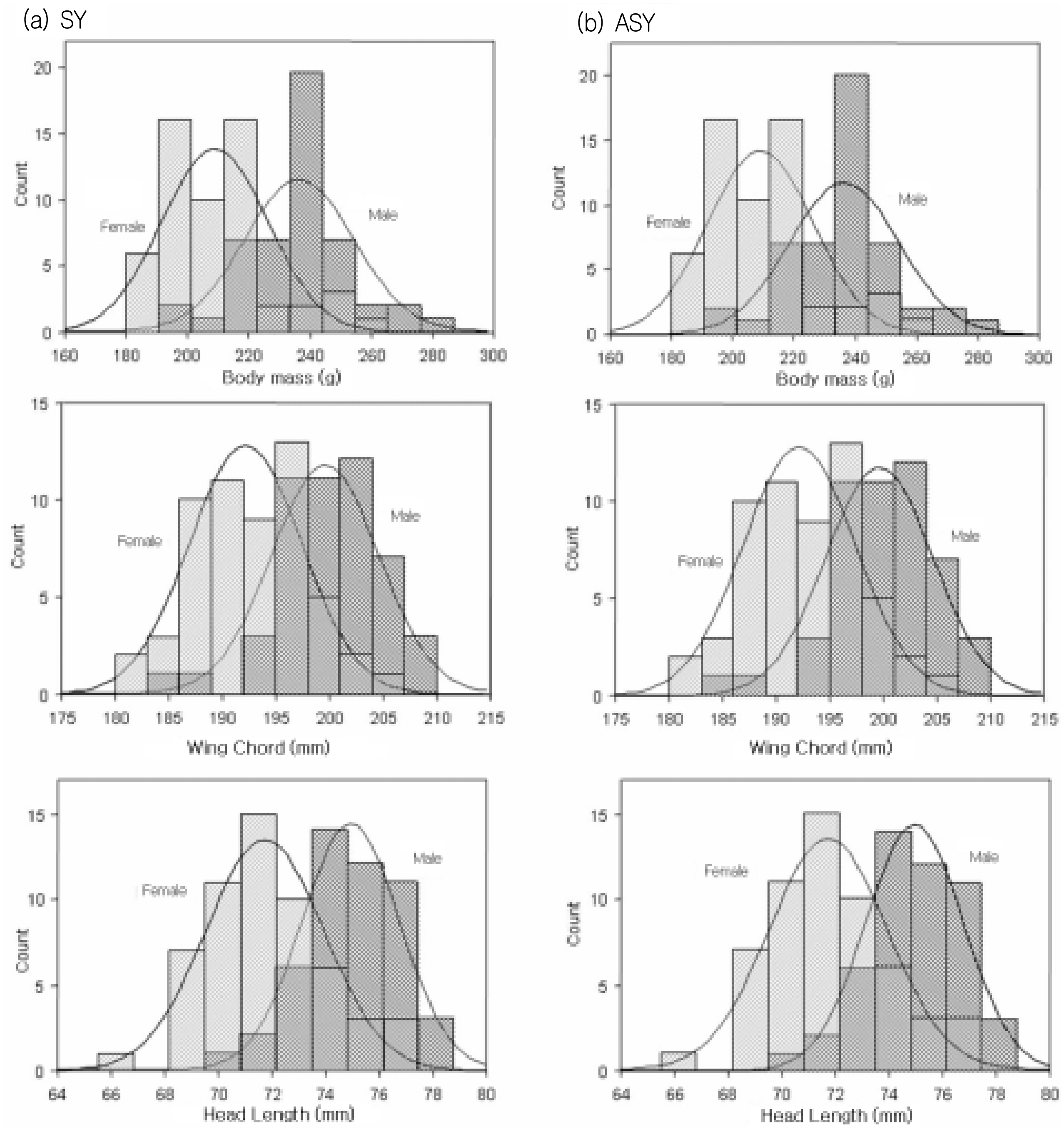

Fig. 1. Frequency distribution of body mass, wing chord, and head length of (a) SY and (b) ASY individuals of black-billed magpies in the northern and mid-western parts of South Korea.

logical traits of magpies vary among regional populations in South Korea (Lee 2006), our equations may not be applicable or may not produce similar levels of accuracy for magpies from other regions in Korea. To develop region-specific methods for sex determination, detailed measurements from many individuals from various regional populations should be made.

The discriminant equations derived in our study are based on traits that are easy to measure and therefore minimally susceptible to measurement error. In addition, these traits do not show pronounced seasonal variation. Head length, which is the most important trait for sexing ASYs, is the least seasonally variable. Although we do not have data on seasonal variation in body mass in Korean

Table 2. Summary of the results of forward stepwise discriminant analyses. Statistical significance of the variables is noted with *** (P<0.001).

For SY birds	Step	F to enter	Wilk's Lambda	F value
Body mass	1	62.38	0.6061	62.38***
Chord	2	11.17	0.5424	40.08***
Head length	3	5.25	0.5137	29.66***
For ASY birds	**Step**	**F to enter**	**Wilk's Lambda**	**F value**
Head length	1	79.59	0.4570	79.59***
Chord	2	21.94	0.3430	63.20***
Body mass	3	4.56	0.3205	45.93***

magpies, Kavanagh (1986) did not detect significant seasonal variation in the body masst of magpies in Ireland except during the breeding season. Wing chord may be susceptible to error in individuals with feather wear. However, this problem can be easily avoided by not capturing magpies near and during the molting period (June～September). Based on the results of this study, we believe that our discriminant equations should prove both useful and robust for sex determination on black-billed magpies in the northern and mid-western regions of South Korea.

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