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Sexual dimorphism of craniomandibular size in the Eurasian otter, *Lutra lutra*, from South Korea

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ABSTRACT. Sexual size dimorphism of craniomandibular morphology of the Eurasian otter *Lutra lutra* in South Korea was analyzed using linear measurements. In total, 32 skulls (18 males and 14 females) and 22 linear measurements (16 cranial and 6 mandibular measurements) were used. Our results showed statistically significant sexual dimorphism between male and female skull size. Multivariate analyses using the cranial and mandibular traits showed significant differences between the sexes, respectively. The most dimorphic trait was ectorbital breadth (EOB), and the EOB of the male was approximately 10% greater than that of the female. This type of sexual size dimorphism, in which males are generally larger than females, is a general pattern shown in family Mustelidae. Several researchers have suggested various hypotheses about the factors causing sexual size dimorphism, i.e., 'resource partitioning model' and 'sex-specific pressure model'. Our results are consistent with these hypotheses, and we suggest that these factors would have affected the sexual size dimorphism of the Eurasian otter in Korea.

KEY WORDS: craniomandibular morphology, Eurasian otter, *Lutra lutra*, sexual dimorphism

The sexual size dimorphism is a common feature of the family Mustelidae, and the size of males is usually greater than that of females. Studies on the sexual dimorphism in cranial and mandibular traits have been reported on several mustelid species, including the Eurasian otter, *Lutra lutra* [1, 5, 6, 10, 18–20, 23, 24]. Nonetheless, osteological studies of the Eurasian otter in the Korean peninsula have not been performed to date.

The Eurasian otter is an internationally protected species by CITES I (the Convention on International Trade in Endangered Species I) and IUCN Redlist (International Union for Conservation of Nature and Natural Resources Redlist). This species was historically distributed throughout the Korean peninsula, but the number of otters has decreased sharply owing to such reasons as indiscriminate trapping, reduced food due to contamination of rivers, and habitat destruction caused by dam construction since the Korean War. Because this species in Korea is not only endangered but also a rare aquatic animal, it is protected and designated a Natural Monument (no. 330). The purpose of this study was to analyze the sexual dimorphism in skulls of the Eurasian otter from the Korean peninsula.

MATERIALS AND METHODS

Specimens

This study is based on measurements of crania and mandibles of the Eurasian otter in Korea, which are mostly in the possession of the Korean Otter Research Center (KORC). We examined sexual dimorphism using 31 crania (males: 18 and females: 13) and 32 mandibles (males: 18 and females: 14) of Eurasian otters from the Korean peninsula. These dead bodies were collected by researchers of the KORC and had been deposited in the KORC. Skeletal specimens were prepared by researchers and are stored in the Department of Anatomy and Cell Biology, College of Veterinary Medicine, Seoul National University, Seoul, Korea (Table 2).

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Table 1. List of cranial and mandibular measurements of the Eurasian otter used in this study

Category	Acronym	Measurement
Cranium	CBL	Condylobasal length
	SL	Total length: akrokranion-prosthion
	FL	Facial length: frontal midpoint-prosthion
	oNCL	Upper neurocranium length: akrokranion-frontal midpoint
	BB	Maximum breadth of braincase: euryon-euryon
	MB	Mastoid breadth: otion-otion
	ZB	Zygomatic breadth: zygion-zygion
	IOB	Infraorbital breadth
	EOB	Ectorbital breadth
	MOH	Maximum inner orbita height
	BSL	Basal length: basion−prosthion
	PTL	Palatinum length: staphylion−palatinoorale
	CB	Occipital condyle breadth
	oPR	Length of the upper premolar row: alveolar distance Pl-P4
	oMR	Length of the upper molar row: alveole M1
	oZR	Length of the upper tooth row: alveolar distance C-M1
Mandible	UH	Coronion-basal point of angular process
	AL	Angular length: infradentale processus-angularis
	CL	Total length: infradentale-processus condylis
	uZR	Length of lower tooth row: alveolar distance C-M2
	uPR	Length of lower premolar row: alveolar distance P2-P4
	uMR	Length of lower molar row: alveolar distance M1-M2

Table 2. Institutional number of specimens used in this study

Seoul National University	
Male (n=9)	KJ1162, KJ1203, KJ1204, KJ1206, KJ1209, KJ1210, KJ1212, KJ1214, KJ1217
Female (n=8)	KJ1150, KJ1152, KJ1157, KJ1159 (mandible only), KJ1160, KJ1163, KJ1189, KJ1216
Korean Otter Research Center	
Male (n=9)	M1, M2, M3, M4, M5, M6, M7, M8, M9
Female (n=6)	F1, F2, F3, F4, F5, F6

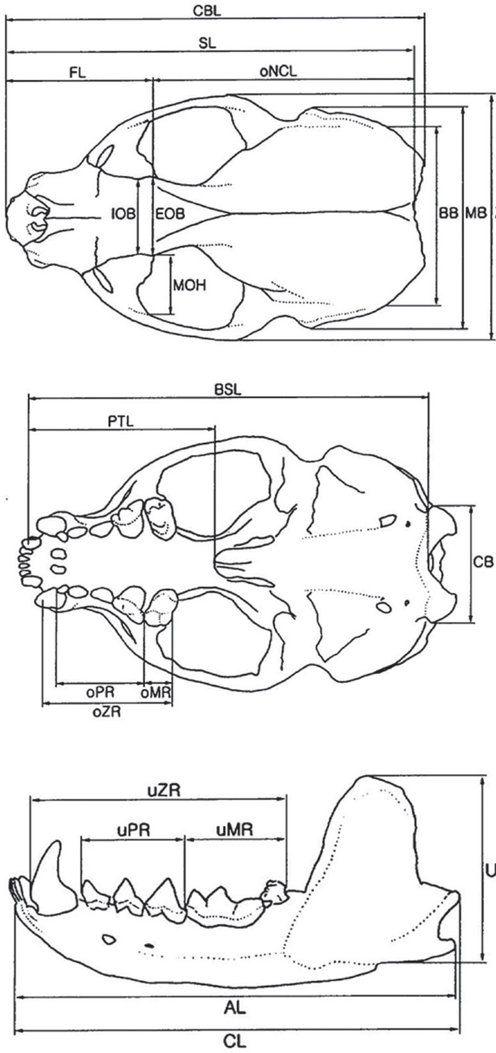

Fig. 1. Skull measurements of the Eurasian otter used in this study.

Statistical analyses

Following the definitions of Pertoldi *et al.*, we measured 22 skull dimensions (16 cranial and 6 mandibular traits, Fig. 1 and Table 1) to the nearest 0.05 mm by one of the authors (K. Y. K.) with digital vernier calipers (Mitutoyo, Tokyo, Japan) [15]. Only adult specimens were used to minimize age-related bias using the most common aging criteria, i.e., obliteration of sutures and tooth wear [15]. For the assessment of craniomandibular sexual dimorphism, we conducted standard methods of univariate and multivariate comparisons. As a univariate analysis, we compared the mean values of each measurement using the Mann-Whitney *U*-test. Multivariate analysis of variance (MANOVA) was used to evaluate the overall dimorphism of cranium and mandible using PAST (PAleontological STatistics) Version 3.10, respectively [8]. We executed multivariate analyses (combination of Principal Component Analysis, PCA and Discriminant Analysis, DA). For PCA, we estimated eigenvalue, factor loading, proportion and principle score. The estimated factor scores are shown by the 2-dimensional scattergram. Discriminant analysis was used to determine if the traits used in this study were useful for distinguishing between males and females. For these analyses, log-transformed data sets of each measurement were used. In the PCA and DA, cranial and mandibular traits were analyzed separately: cranial PCA (cPCA) and mandibular PCA (mPCA) of PCA and cranial DA (cDA) and mandibular DA (mDA) of DA. All analyses were conducted with PASW Statistics v18 program (IBM Acquires SPSS Inc., Chicago, IL, U.S.A.).

RESULTS

Sexual dimorphism

Descriptive statistics are given in Table 3. Univariate analysis of variance showed highly significant sexual dimorphism in all 22 skull measurements. Overall, sexual dimorphism was shown in skull (MANOVA, Wilks' lambda=0.27, df=16, *P*-value=0.041

Table 3. Simple statistics and morphological comparisons of cranial and mandibular variables in each sex of the Eurasian otter

Category	No.	Variable	Sex	N	Mean	Minimum	Maximum	S.D.	Ratio (%)	Mann Whitney *U*-test	
										Z	*P*
Cranium	1	CBL	Male	18	116.32	106.10	125.00	5.89	108.01	−3.883	***
			Female	13	107.70	96.25	110.92	3.70			
	2	SL	Male	18	113.82	102.40	122.06	5.75	107.78	−3.923	***
			Female	13	105.60	94.10	108.25	3.74			
	3	FL	Male	18	44.92	40.98	48.20	2.51	107.91	−3.323	***
			Female	13	41.63	37.15	44.72	2.00			
	4	oNCL	Male	18	73.99	65.30	80.90	4.55	107.98	−3.523	***
			Female	13	68.52	60.10	70.80	2.67			
	5	BB	Male	18	52.43	43.31	57.97	3.73	103.06	−2.442	*
			Female	13	50.87	45.35	53.12	2.16			
	6	MB	Male	18	64.04	57.45	69.01	3.56	105.90	−2.642	**
			Female	13	60.47	50.15	63.09	3.27			
	7	ZB	Male	18	72.23	62.93	79.65	4.61	108.51	−3.287	***
			Female	13	66.56	62.96	71.14	2.62			
	8	IOB	Male	18	21.16	17.15	24.39	1.82	107.68	−2.282	*
			Female	13	19.65	15.85	22.69	1.84			
	9	EOB	Male	18	24.10	18.26	29.05	2.85	110.94	−2.602	**
			Female	13	21.72	18.80	25.31	1.92			
	10	MOH	Male	18	17.23	15.20	20.67	1.27	104.88	−2.022	*
			Female	13	16.43	15.00	17.70	0.84			
	11	CB	Male	18	31.33	28.86	35.20	1.70	105.03	−2.522	*
			Female	13	29.83	24.00	31.45	1.71			
	12	BSL	Male	18	107.97	97.25	116.62	5.37	107.66	−3.723	***
			Female	13	100.29	91.90	103.20	3.00			
	13	PTL	Male	18	52.36	47.70	56.35	2.51	109.18	−4.004	***
			Female	13	47.96	44.20	50.26	1.88			
	14	oMR	Male	18	12.23	11.40	13.00	0.46	104.89	−3.163	***
			Female	13	11.66	10.10	12.15	0.54			
	15	oPR	Male	18	24.84	23.40	27.11	1.05	105.54	−2.964	**
			Female	13	23.54	21.56	27.19	1.44			
	16	oZR	Male	18	35.61	33.23	38.00	1.59	107.22	−3.423	***
			Female	13	33.21	30.51	35.65	1.34			
Mandible	17	UH	Male	18	33.27	30.20	36.35	1.84	110.02	−3.989	***
			Female	14	30.24	27.35	32.18	1.33			
	18	AL	Male	18	73.47	66.90	78.32	3.65	109.12	−4.008	***
			Female	14	67.33	61.90	71.00	2.37			
	19	CL	Male	18	74.84	68.27	80.18	4.01	109.21	−3.837	***
			Female	14	68.53	60.80	71.65	2.74			
	20	uZR	Male	18	44.62	42.00	46.60	1.42	108.62	−4.578	***
			Female	14	41.08	39.10	43.01	1.07			
	21	uPR	Male	18	18.99	17.25	20.40	1.01	105.27	−2.470	*
			Female	14	18.04	16.10	20.50	1.01			
	22	uMR	Male	18	18.29	16.74	19.40	0.76	106.15	−3.154	***
			Female	14	17.23	15.68	19.00	0.82			

Ratio: ratios of mean, male/female × 100 (%). *=0.01<P<0.05, **=0.001<P<0.01, ***=P<0.001.

for cranium and Wilks's lambda=0.30, df=6, P-value=0.001 for mandible). Males had significantly higher mean values for all measurements than females, and the ratio of both sexes ranged from 110.94 (EOB in cranium) to 103.06 (BB in cranium). The pattern of sexual dimorphism indices is shown in Fig. 4. The male skull showed the greatest differences in the width of ectorbital (variable 9) and the higher mandible (variable 17) than that of females (Fig. 4).

PCA

In the cPCA (cranial PCA), the first 3 principal components explained 71.52, 7.13 and 6.21% of the total variance, respectively (Table 4). Factor loadings of the cPC1 were all positive, thereby indicating that these variables are correlated with overall cranial size, especially considering that factor loading values of 12 traits (CBL, SL, FL, oNCL, MB, ZB, CB, BSL, PTL, oMR, oPR and oZR) of cPC1 were larger than 0.5. Scores of cPC1 and cPC2 were significantly different between sexes (P-value for cPC1=0.016

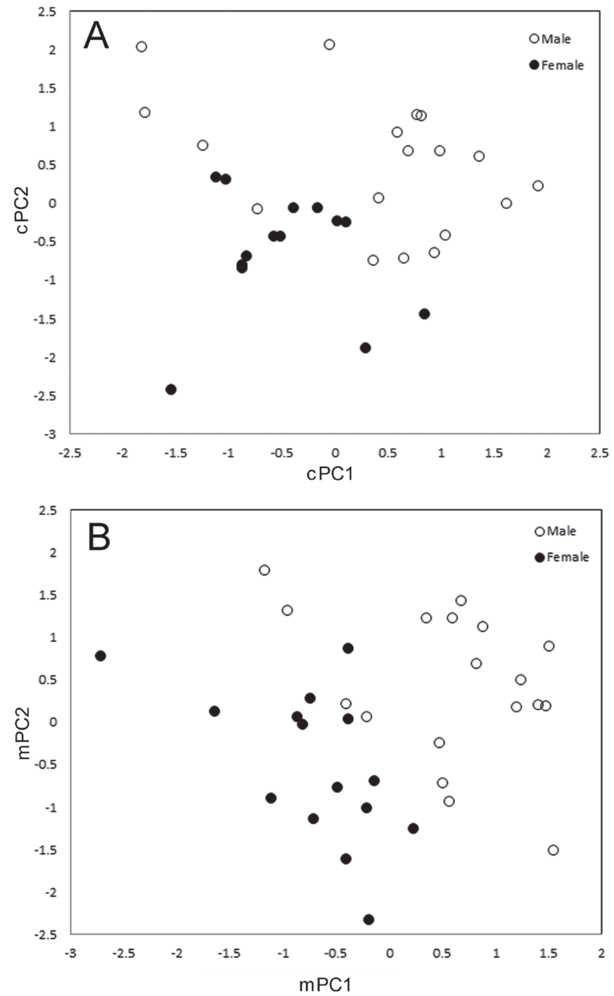

Fig. 2. Two-dimensional plots of the first and second principal component axes in cranium (A) and mandible (B) measurements. Closed: female and open: male.

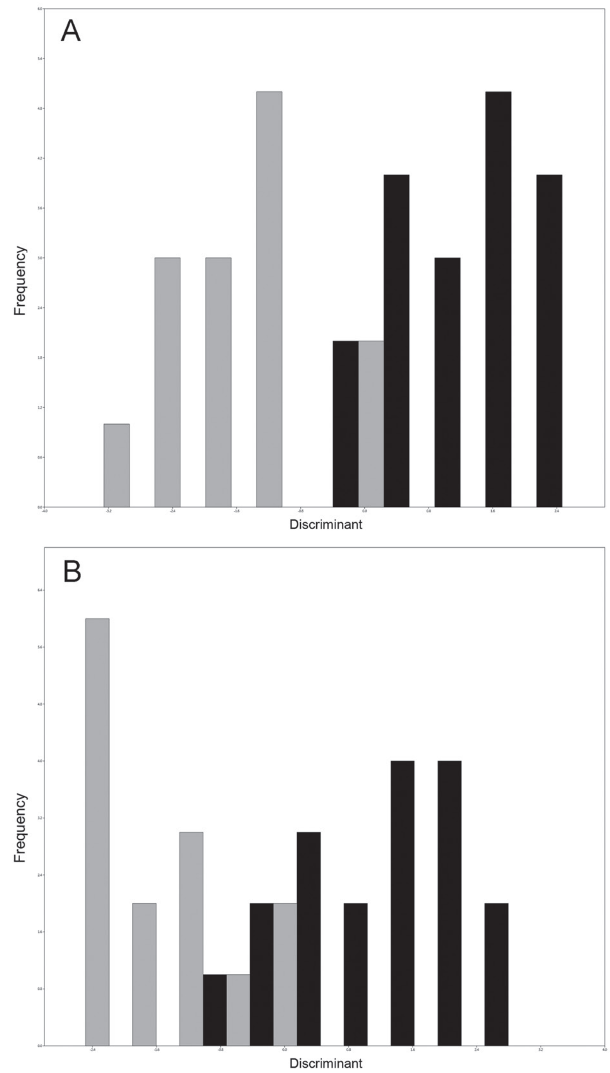

Fig. 3. Frequency distribution of DA1 scores by cDA (A) and mDA (B). Black: male, gray: female.

and *P*-value for cPC2=0.001) (Fig. 2A).

In the mPCA, the first two components explained 72.73 and 13.16% of the total variation, respectively (Table 5). Factor loadings of the mPC1 and mPC2 were all positive. Thus, these components are correlated with overall mandibular size. Factor loading values of four traits (UH, AL, CL and uZR) of mPC1 were larger than 0.5. Scores of mPC1 and mPC2 were significantly different between sexes (*P*-value for mPC1=0.001 and *P*-value for mPC2=0.020) (Fig. 2B).

DA

Using the first and second scores from cPC and mPC axes, 90.63% of males and 93.75% of females were correctly classified into each sex, respectively (Fig. 3). Standardized canonical discriminant coefficients for DA were large in SL (−1.181), MB (−1.067), IOB (−1.047) and CB (2.279) in cDA and large in AL (0.797), CL (−1.061) and uZR (0.923) in mDA.

DISCUSSION

In this study, we observed that skulls of the Eurasian otter distributed throughout the Korean peninsula show clear sexual dimorphism. The differences between sexes are primarily influenced by the general size factor (MANOVA, Wilks' lambda=0.35, df=8, *P*-value=0.001 with general size factor, and Wilks's lambda=0.67, df=7, *P*-value=0.151 without general size factor). Ectorbital breadth (EOB) exhibits the most significant sexual size dimorphism.

Although several studies focusing on the sexual size dimorphism in family Mustelidae have been reported, key factors for this phenomenon have not been clearly discovered. Lynch *et al*. analyzed and reported that skull sizes of males of the Eurasian otter were larger than those of females in most measurement points, except for only one measurement (postorbital constriction) out

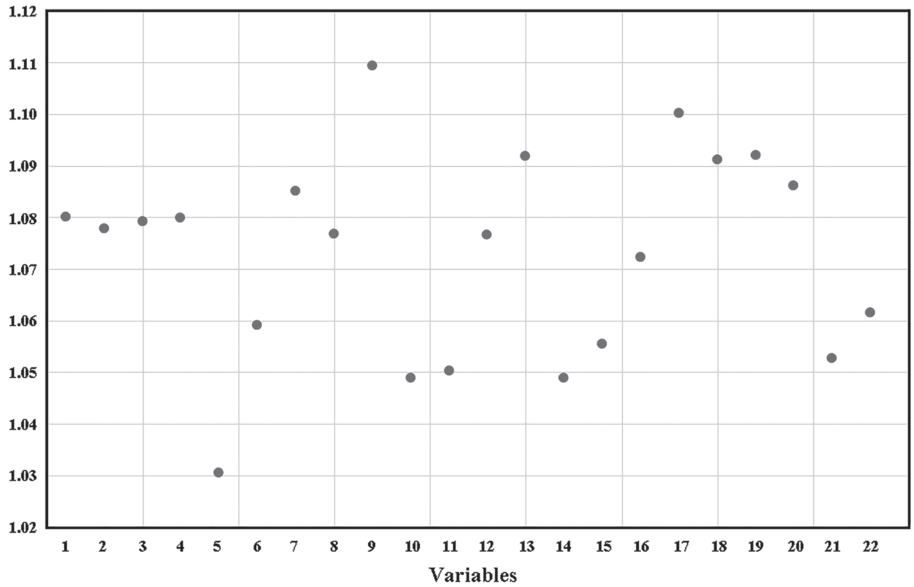

Fig. 4. Sexual dimorphism indices for *Lutra lutra*.

Table 4. Principal components that explains more than 80% of total variance from the cranial PCA

Variable	cPC1	cPC2	cPC3
CBL	**0.730**	**0.608**	0.263
SL	**0.746**	**0.576**	0.254
FL	**0.648**	**0.632**	0.213
oNCL	**0.741**	**0.523**	0.184
BB	0.070	**0.831**	0.254
MB	**0.615**	**0.670**	0.245
ZB	**0.554**	**0.713**	0.114
IOB	0.354	**0.801**	0.280
EOB	0.415	**0.841**	−0.124
MOH	0.160	0.153	**0.938**
CB	**0.802**	0.360	0.050
BSL	**0.714**	**0.608**	0.246
PTL	**0.646**	**0.616**	0.320
oMR	**0.826**	−0.024	0.309
oPR	**0.501**	0.330	0.468
oZR	**0.795**	0.432	0.013
Eigenvalue	11.44	1.14	0.99
Proportion	71.52	7.13	6.21
Cumulative	71.52	78.65	84.86

Bold: Principal component score>0.5.

Table 5. Principal components that explains more than 80% of total variance from the mandibular PCA

Variable	mPC1	mPC2
UH	**0.935**	0.248
AL	**0.949**	0.170
CL	**0.917**	0.188
uZR	**0.735**	**0.517**
uPR	0.278	0.111
uMR	0.229	**0.964**
Eigenvalue	4.36	0.79
Proportion	72.73	13.16
Cumulative	72.73	85.89

Bold: Principal component score>0.5.

of the five groups of the Eurasian otter living in Europe [12]. Rozanov and Abramov (2006) analyzed craniomandibular sexual size dimorphism of captured marbled polecat (*Vormela peregusna*) in Turkmenistan [21]. From this research, it was reported that skull sizes of females were smaller than those of males, approximately 3−11%. Abramov and Tumanov (2003) compared the sizes of skulls of the Eurasian mink (*Mustela lutreola*) between males and females from Russia [2]. Similarly, the skull size of males was approximately 8–15% larger than that of females. In addition to the above studies, several species belonging to the family Mustelidae had a similar tendency for sexual size dimorphism in skulls with several variation (e.g., Irish otter, Eurasian badger, and pine marten) [3, 11, 13]. As is shown in various studies of sexual size dimorphism for species belonging to the family Mustelidae, sexual size dimorphism is shown to be a very common feature of Mustelidae.

Several hypotheses for sexual size dimorphism appearing in the family Mustelidae have been proposed, and this phenomenon seems to be driven by a compositive reaction of various reasons presented by researchers. First, the “resource partitioning model” is a widely cited hypothesis. According to this model, sexual size dimorphism in Mustelidae may occur to reduce intersexual resource competition [4, 22]. Each sex reaches the optimal body size for the ingested resource, respectively. For the male, the size of zygomatic breadth (ZB) is approximately 8.5% larger than that of the female. This value surpasses more than the average size difference of cranial measurements of 7.0%. The difference in size of ZB signifies the stronger jaw musculature and more powerful neck muscle of males compared to females [16], and this difference can be an evidence explaining resource partitioning in this species. The research results that can be compared with our study can be found in previous studies. Lau *et al.* reported that males have narrower postorbital constriction and larger temporal fenestra compared with female using geometric morphometric method [10], and Lynch *et al.* also reported that males have higher size value in all measurements than females except for the width of the postorbital constriction from five populations of Eurasian otter [12]. Lau *et al.* explained that males have broader facial cranium and snout than female, then these characteristics are closely related to the distribution of temporalis muscle, which makes the difference in biting force between males and females. These previous research results are consistent with the result of this study and are considered to support each other. In addition, we could find that there is a significant difference in the size of teeth between sexes. The differences range from 4.89 to 7.22% (oMR, oPR and oZR), greater in males than in females. It could also be used as evidence for the dietary separation between sexes. Sex-related dietary separation can be easily identified in many studies of the family Mustelidae, but unfortunately none of these studies have been conducted on Mustelidae distributed throughout Korea. In the case of the Eurasian otter in Korea, the difference in the sexual size dimorphism ratio is generally within the range of 3 to 10%. Compared to other studies of Mustelidae, these differences are considered to be of an average level, and therefore, the degree of dietary separation is expected to be similar to that of other species in Mustelidae.

Second, different sex-specific pressures may cause sexual size dimorphism, e.g. polygynous or promiscuous mating systems without paternal care [7, 14, 17]. This hypothesis includes both the smaller females and the larger males in sexual selection. According to this hypothesis, males prefer a larger body size to compete with other males for mating with females, and females do not need as much energy for daily maintenance as males do, but rather consume energy for rearing. In the case of males, they need much more energy for dominance and mobility [7]. In this case, we need to understand whether males participate in rearing or not. For the Korean otter, studies on the rearing of wild populations have not been conducted, but there is one very valuable study of rearing in captured otter individuals [9]. This study was basically designed to explore the possibility of artificial breeding for a pair of rescued otters. According to the study, the female gave birth to two litters, and Kang could observe that the male has no role in rearing despite being a father, and the young were nurtured entirely by the female. The male was alerted, prevented, and attacked by the female whenever he approached his cubs. This is a good example of sex-specific pressure being respectively applied to males and females, and it provides significant information in verifying the breeding system of the Eurasian otter.

In this study, we obtained linear morphological data from 32 Eurasian otters living in the Korean peninsula in addition to the geometric morphometric information from a previous study [10]. This study used linear measurement methods to analyze sexual size dimorphism, but Lau's study used geometric morphometrics for SSD [10]. Although the methodologies of the two studies are different, the results are generally consistent with each other and suggest similar conclusions that feeding habits may be a major cause. Although we discussed why the Eurasian otter develops sexual size dimorphism and the reason for why this is with some hypotheses reported by researchers, it is still unclear. Even Erlinge (1979) and Wiig (1986) referenced that these hypotheses could not explain adequately the sexual size dimorphism in the family Mustelidae [7, 24]. Therefore, we need a set of long-term, comprehensive, and systematic research plans for wild Eurasian otter monitoring in order to be able to establish the hypotheses fully.

The results of this study will provide fundamental and valuable information for conservation of Eurasian otters living in Korea, which are designated a Natural Monument (No. 330) and are protected by the Korean government as an Endangered Wild Species (Category I). With an accumulation of measurement data and further studies, i.e., growth rate of skull morphology, age determination for sexual maturation, and regional variation in morphology, these data would suggest a perception for management and conservation of this species.

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