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

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).
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
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

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 |
|----------|-----|----------|-----|---|------|---------|---------|-----|-----------|-------------------|
| 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.
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).

**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
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

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

| Variable | cPC1   | cPC2   | cPC3   |
|----------|--------|--------|--------|
| CBL      | 0.730  | 0.068  | 0.263  |
| SL       | 0.746  | 0.576  | 0.254  |
| FL       | 0.648  | 0.632  | 0.213  |
| cNCL     | 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  |
| eMR      | 0.826  | −0.024 | 0.309  |
| ePR      | 0.501  | 0.330  | 0.468  |
| eZR      | 0.795  | 0.432  | 0.013  |

| Eigenvalue | 11.44 | 1.14  | 0.99  |
| Proportion  | 71.52 | 13.16 | 6.21  |
| Cumulative  | 71.52 | 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.
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 Witig (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.

ACKNOWLEDGMENTS. We are grateful to the Korean Otter Research Center and the Laboratory of Anatomy and Cell Biology at Seoul National University (Professor, Junpei Kimura) in Korea for allowing us to examine their specimens. We express our gratitude to all the members from the institutions mentioned above for the assistance given to us during our visits. This research was supported by Research Program (Biomimetics) through the National Institute of Ecology.

REFERENCES

1. Abramov, A. V. and Baryshnikov, G. F. 2000. Geographic variation and intraspecific taxonomy of weasel Mustela nivalis (Carnivora, Mustelidae). Zoosyst. Ross. 8: 365–402.
2. Abramov, A. V. and Tumanov, I. L. 2003. Sexual dimorphism in the skull of the European mink Mustela lutreola from NW part of Russia. Acta Theriol. (Warsz.) 48: 239–246. [CrossRef]
3. Abramov, A. V. and Puzachenko, A. Y. 2005. Sexual dimorphism of craniofacial characters in Eurasian badgers, Meles spp. (Carnivora, Mustelidae). Zool. Anz. 244: 11–29. [CrossRef]
4. Brown, J. C. and Lasiewskie, R. C. 1972. Metabolism in weasels: the cost of being long and thin. Ecology 53: 939–943. [CrossRef]
5. Buchalczyn, T. and Ruprecht, A. L. 1977. Skull variability of Mustela putorius Linnaeus, 1758. Acta Theriol. (Warsz.) 22: 37–120. [CrossRef]
6. De Marinis, A. M. 1995. Cranometric variability of polecat Mustela putorius, London, 1758 from North–Central Italy. Hystric 7: 57–68.
7. Erlinge, S. 1979. Adaptive significance of sexual dimorphism in weasels. Oikos 33: 233–245. [CrossRef]
8. Hammer, O., Harper, D. A. T. and Ryan, P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Paleontol. Electronica 4: 9.
9. Kang, J. H. 2012. Lutra lutra. pp. 6–57. In: Natural Monument (Animal): Propagation, Preservation Research III (Kang, J. H. ed.), National Research Institute of Cultural Heritage, Daejeon.

10. Lau, A. C. C., Asahara, M., Han, S. Y. and Kimura, J. 2016. Sexual dimorphism of the Eurasian otter (Lutra lutra) in South Korea: Craniodental geometric morphometry. J. Vet. Med. Sci. 78: 1007–1011. [Medline] [CrossRef]

11. López-Martín, J. M., Ruiz-Olmo, J. and Padró, I. 2006. Comparison of skull measurements and sexual dimorphism between the Minorcan pine marten (Martes martes minoricencis) and the Iberian pine marten (M. m. martes): a case on insularity. Mammm. Biol. 71: 13–24. [CrossRef]

12. Lynch, J. M., Conroy, J. W. H., Kitchener, A. C., Jefferies, D. J. and Hayden, T. J. 1996. Variation in cranial form and sexual dimorphism among five European populations of the otter Lutra lutra. J. Zool. 238: 81–96. [CrossRef]

13. Lynch, J. M. and O’Sullivan, W. M. 1993. Cranial form and sexual dimorphism in the Irish otter (Lutra lutra). Biol. Envir.: Proc. R. Ir. Acad. 93B: 97–105.

14. Moors, P. J. 1980. Sexual dimorphism in the body size of Mustelids (Carnivora): the roles of food habits and breeding systems. Oikos 34: 147–158. [CrossRef]

15. Pertoldi, C., Loeschcke, V., Braun, A., Bo Madsen, A. and Randi, E. 2000. Craniometrical variability and developmental stability. Two useful tools for assessing the population viability of Eurasian otter (Lutra lutra) populations in Europe. Biol. J. Linn. Soc. Lond. 70: 309–323. [CrossRef]

16. Radinsky, L. B. 1981. Evolution of skull shape in carnivores: 2. Additional modern carnivores. Biol. J. Linn. Soc. Lond. 16: 337–355. [CrossRef]

17. Ralls, K. 1977. Sexual dimorphism in mammals: avian models and some unanswered questions. Am. Nat. 111: 917–938. [CrossRef]

18. Ralls, K. and Harvey, P. H. 1985. Geographic variation in size and sexual dimorphism of North American weasels. Biol. J. Linn. Soc. Lond. 25: 119–167. [CrossRef]

19. Reichstein, H. 1957. Schädelvariabilität europäischer Mauswiesel (Mustela nivalis L.) und Hermeline (Mustela erminea L.) in Beziehung zu Verbreitung und Geschlecht. Z. Säugetierkd. 22: 151–182.

20. Reig, S. 1997. Biogeographic and evolutionary implications of size variation in North American least weasel (Mustela nivalis). Can. J. Zool. 75: 2036–2049. [CrossRef]

21. Rozhnov, V. V. and Abramov, A. V. 2006. [Sexual dimorphism of marbled polecat Vormela peregusna (Carnivora: Mustelidae)]. Izv. Akad. Nauk Ser. Biol. 33: 183–187 [in Russian]. [Medline]

22. Shubin, I. G. and Shubin, N. G. 1975. Sexual dimorphism and its peculiarities in mustelines (Mustelidae, Carnivora). Zhurnal Obshchei Biologii 36: 283–290 [in Russian with English summary]. [Medline]

23. Wiig, Ø. 1982. Sexual dimorphism in the skull of the feral American mink (Mustela vison Schreber). Zool. Scr. 11: 315–316. [CrossRef]

24. Wiig, Ø. 1986. Sexual dimorphism in the skull of minks Mustela vison, badgers Meles meles and otters Lutra lutra. Zool. J. Linn. Soc. 87: 163–179. [CrossRef]