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GROWTH AND SEXUAL DIMORPHISM OF CRANIOMETRIC MEASUREMENTS OF THE RED FOX (*VULPES VULPES* L.) IN TRANSCARPATHIA

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РІСТ ТА СТАТЕВИЙ ДИМОРФІЗМ КРАНІОМЕТРИЧНИХ ПОКАЗНИКІВ ЛИСИЦІ ЗВИЧАЙНОЇ (*VULPES VULPES* L.) НА ЗАКАРПАТТІ

ABSTRACT

Purpose of the work. This study investigates sexual dimorphism in the red fox (*Vulpes vulpes*) population of Zakarpattia based on the analysis of 75 skulls from the Zoological Museum of Uzhhorod National University. To address existing gaps in knowledge, 26 cranial measurements were evaluated with consideration of both age and sex. This approach enabled the assessment of growth dynamics, the characterization of morphological variation, and the identification of key features of sexual dimorphism within the population. The results provide baseline data for future studies and contribute to a broader understanding of intraspecific variation across the species' range.

Methodology. Craniometric traits were analyzed across different sexes and age groups. Statistical analyses were conducted using SPSS, PAST, and MS Excel. Both univariate and multivariate analyses of variance (ANOVA) were applied, revealing significant differences between sexes and among age groups. Additionally, Principal Component Analysis (PCA) was performed to identify the measurements contributing most to overall variation.

Scientific novelty. The study provides essential morphometric baseline data for red foxes in a poorly studied region and improves understanding of intraspecific variability. The findings emphasize the combined influence of growth patterns, sexual selection, and ecological factors in shaping cranial sexual dimorphism.

Conclusions. Cranial growth was most pronounced up to 5–6 months of age, followed by a slowdown and occasional negative increments. The results suggest that sexual dimorphism in this population is primarily shaped by sexual selection and male–male competition, with larger males potentially having a reproductive advantage. At the same time, environmental constraints, particularly food availability, may limit excessive body size, leading to an optimal size range shared by both sexes. Size-related niche differentiation may further reduce intraspecific competition.

Key words: *Vulpes vulpes*, craniometry, sexual dimorphism, growth patterns, Transcarpathia

АНОТАЦІЯ

Мета роботи. У цьому дослідженні проаналізовано статевий диморфізм популяції лисиці звичайної (*Vulpes vulpes*) на Закарпатті на основі вивчення 75 черепів із колекції Зоологічного музею Ужгородського національного університету. З метою детальнішого вивчення було проаналізовано 26 краніометричних показників з урахуванням віку та статі. Такий підхід дав змогу оцінити динаміку росту, охарактеризувати морфологічну мінливість та визначити ключові ознаки статевого диморфізму в межах популяції. Отримані результати формують базу даних для подальших досліджень і сприяють кращому розумінню внутрішньовидової мінливості в межах ареалу виду.

Методологія. Краніометричні показники аналізувалися з урахуванням статі та вікових груп. Статистичний аналіз виконано із застосуванням програм SPSS, PAST та MS Excel. Було використано як однофакторний, так і багатофакторний дисперсійний аналіз (ANOVA), що виявив статистично значущі відмінності між статями та віковими групами. Додатково проведено аналіз головних компонент (PCA) для визначення показників, які роблять найбільший внесок у загальну варіацію.

Наукова новизна. Дослідження надає базові морфометричні дані для лисиці звичайної в недостатньо вивченому регіоні та поглиблює розуміння внутрішньовидової мінливості. Отримані результати підкреслюють поєднаний вплив динаміки росту, статевого добору та екологічних чинників на формування краніального статевого диморфізму.

Висновки. Найінтенсивніший ріст краніальних ознак спостерігався до 5–6 місяців, після чого відзначалося його уповільнення та поодинокі випадки негативного приросту. Отримані результати свідчать, що статевий диморфізм у досліджуваній популяції зумовлений насамперед статевим добором і конкуренцією між самцями, при цьому більші самці можуть мати репродуктивну перевагу. Водночас екологічні обмеження, зокрема доступність кормових ресурсів, можуть стримувати надмірне збільшення розмірів тіла, сприяючи формуванню оптимального розміру, спільного для обох статей. Розподіл екологічної ніші, пов'язаний із розмірними відмінностями, може додатково зменшувати внутрішньовидову конкуренцію.

Ключові слова: *Vulpes vulpes*, краніометрія, статевий диморфізм, закономірності росту, Закарпаття

Introduction

The red fox is highly adaptable and can thrive in a wide variety of habitats across almost all continents (Heltay, 1989). This broad distribution has led to the development of around 44 subspecies (Larivière & Pasitschniak-Arts, 1996).

Studies of red fox populations from different parts of the world have produced varied results. In the Czech Republic, significant sexual differences were found in five of the 21 craniometric traits examined (Brudnicki et al., 2009). In Hungary, such differences appeared mainly among sexually mature individuals, while they were less pronounced in younger animals; nevertheless, female skulls still differed markedly from those of males (Csányi et al., 2023). Clear sexual dimorphism has also been documented in populations from North America (Churcher, 1960), Australia (Forbes-Harper et al., 2017), the Czech Republic (Hartová-Nentvichová et al., 2010), Slovakia, Romania, and Ukraine (Hell et al., 1989).

Age in foxes is usually estimated using cranial suture ossification or dental characteristics (Churcher, 1960; Heltay, 1989). However, data on the red fox in Transcarpathia remain scarce. According to Korchynskyi et al. (1993), between 1946 and 1992, only 10.5% of all published studies on the Carpathian region's mammalian fauna focused on this group, highlighting the need for more comprehensive research.

With the aim of filling this knowledge gap, we examined 26 cranial measurements, taking into account both age and sex. This allowed us to investigate growth patterns, explore morphological variation, and identify the main features of sexual dimorphism within the population. Our study provides baseline data that can support future research on the red fox in this understudied region and contribute to a better understanding of intraspecific variation across its range.

Materials and Methods

In recent study we measured 75 skulls of red foxes from the scientific collections of the UzhNU Zoological Museum, including 14 skulls each from males and females in all age groups, except for 24-month-old females, of which only five were measured. Fox skulls included in the study were collected from 1951 to 1976 in Transcarpathia. To assess sexual variation, skulls from all age groups were included. Age determination was carried out based on the sagittal suture (Fig. 1). We were able to distinguish three age groups: 5–6 months, 11–12 months, and older than 24 months. Measurements were taken using a caliper with an accuracy of 0.1 mm.

For statistical analysis, we used the software packages SPSS, PAST and MS Excel. Data were analyzed using univariate analysis of variance (Univariate ANOVA) and multivariate analysis of variance (Multivariate ANOVA). Since the dataset includes many craniometric traits, we also performed a Principal Component Analysis (PCA) which allows us to assess which measurements explain the largest proportion of the variation.

List of cranial measurements:

1. Total length: akrokranion – prosthion (TL).
2. Basal length: basion – prosthion (BL).
3. Neurocranium length: basion – nasion (NL).
4. Upper neurocranium length: akrokranion – frontal midpoint (UNL).
5. Viscerocranial length: nasion – prosthion (VCL).
6. Facial length: frontal midpoint – prosthion (FL).
7. Greatest length of the nasals: nasion – rhinion (GLN).
8. Median palatal length: staphylion – prosthion (MPL).
9. Length of the molar row (LMR).
10. Length of the premolar row (LPR).
11. Length of the carnassial, measured at the cingulum (LC).
12. Greatest breadth of the carnassial (LBC).
13. Greatest mastoid breadth: otion – otion (GMB).
14. Greatest breadth of the occipital condyles (GBOC).
15. Height of the foramen magnum: basion – opisthion (HFM).
16. Maximum width of neurocranium: euryon – euryon (MWN).
17. Maximum zygomatic width: zygion – zygion (MZW).
18. Least breadth of skull: breadth at the postorbital constriction (LBS).
19. Frontal breadth: ectorbitale – ectorbitale (FB).
20. Least breadth between the orbits: entorbitale – entorbitale (FBO).
21. Greatest palatal breadth: measured across the outer borders of the alveoli (GPB).
22. Least palatal breadth: measured behind the canines (LPB).

23. Breadth at canine alveoli (BCA).

24. Skull height without the sagittal crest (SHSC).

25. Skull height (SH).

26. Length of neurocranium: staphylion – basion (LN).

Results and discussion

The growth of craniometric parameters is most intensive up to 5–6 months, after which, over the next six months, the mean of growth is 2.21 % for males and 3.70 % for females. After the first year, the mean of growth amounts to 3.52 % in males and 0.89 % in females. In processing the data, we also observed negative growth during this period. Postorbital breadth exhibits a growth trend opposite to all other traits (Fig. 2.). Hartová-Nentvichová (2010) arrived at the same conclusion. The braincase area posterior to the orbits is undeveloped in juveniles and progressively narrows with the growth of the masticatory muscles (Ansorge, 1994).

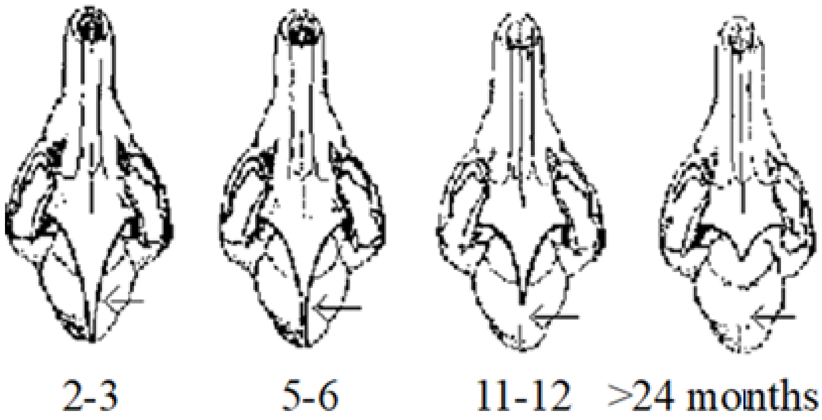

Fig. 1. Change of the sagittal suture during ontogeny (Heltay, 1989)

The Principal Component Analysis (Fig. 3) indicates a moderate sexual dimorphism in skull morphology. Males show a larger dispersion, particularly along PC1, suggesting higher variance in size-related traits. Females form a more compact cluster. Despite the shift between group centroids, considerable overlap remains between the convex hulls, implying that individual variation exceeds sex-based differentiation.

Fig. 4 and 5 compare males and females, highlighting measurements with high loadings on PC1 – including total length, basal length, nasal length, greatest mastoid breadth, greatest breadth of the occipital condyles, and maximum zygomatic width – which drive most of the separation among individuals along this axis.

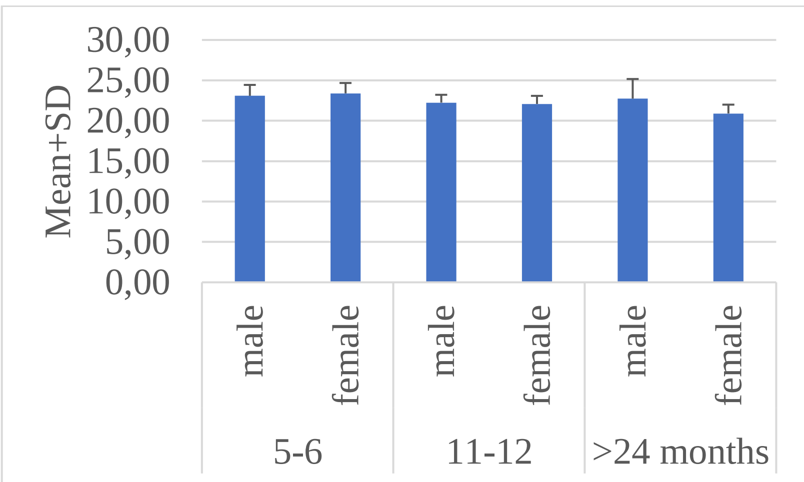

Fig. 2. Comparison of the breadth at the postorbital constriction (LBS) between sexes and across age groups

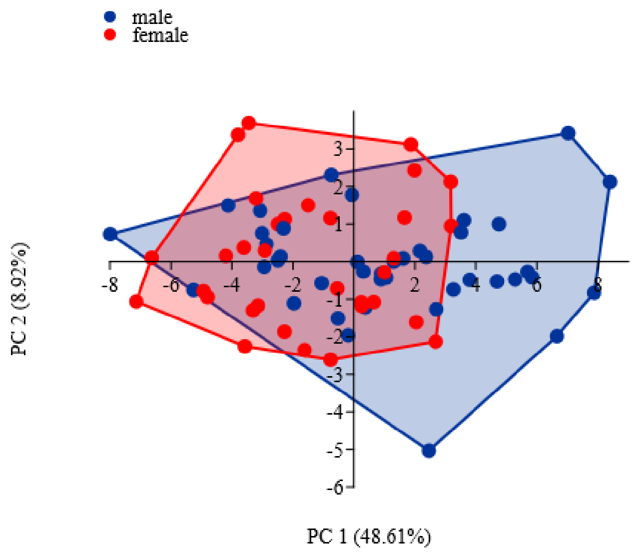

Fig. 3. Distribution of males and females revealed by PCA

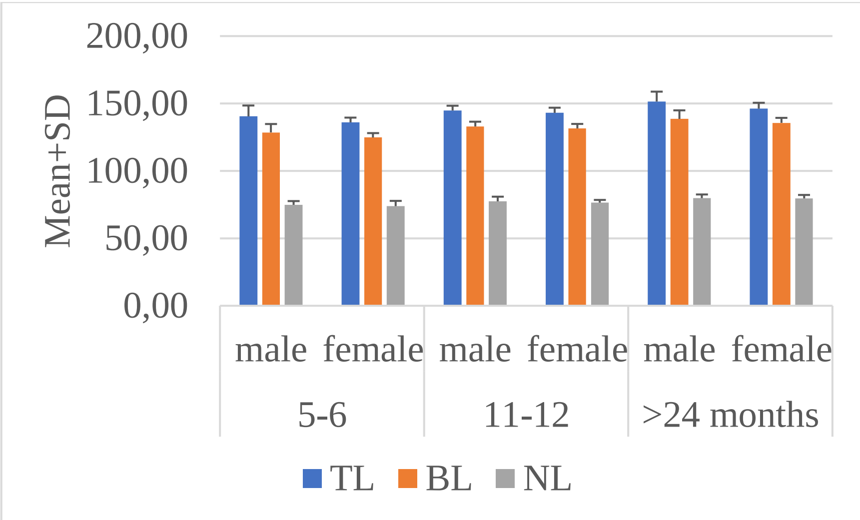

Рис. 4. Comparison of cranial length measurements with high PC1 loadings between sexes and across age groups

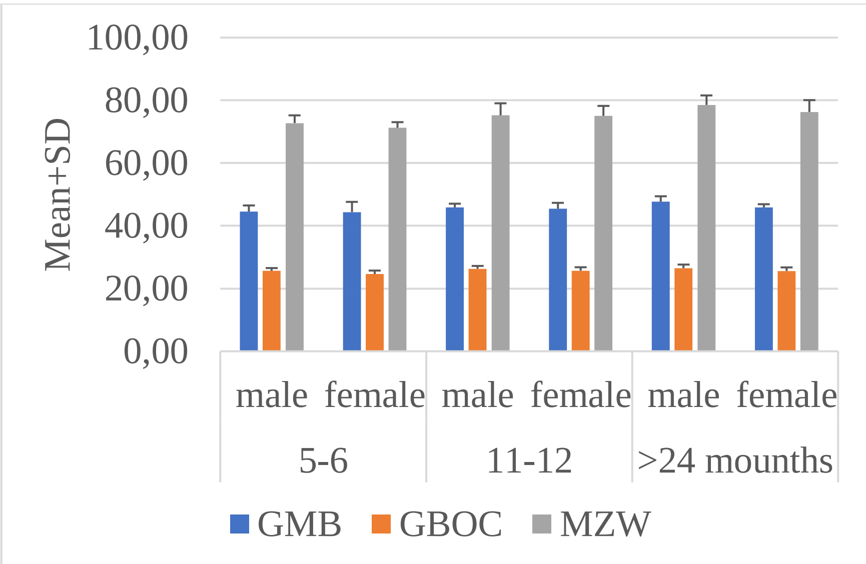

Рис. 5. Comparison of cranial breadth measurements with high PC1 loadings between sexes and across age groups

Adult females are 0.11–2.54 % smaller than adult males; however, in the case of the least breadth between the orbits, females are 0.79% larger. Multivariate analysis of variance (ANOVA) confirms these findings, showing significant differences between the sexes ($F = 2.20$; $p = 0.01$) and among the age classes ($F = 2.24$; $p = 0.00$). According to the tests of between-subjects effects (univariate ANOVA), there are significant differences between the sexes in 12 measurements and among age classes in 20.

Our results indicate significant sexual dimorphism in multiple cranial traits. Females and males differ significantly in total length (TL), basal length (BL), viscerocranial length (VCL), facial length (FL), nasal length (GLN), and the dimensions of the dental rows (MPL, LMR, LPR, LC, LBC). These differences suggest that males generally possess larger viscerocranial regions, as well as more robust dentition. Functionally, this may reflect differences in bite force, prey handling, or intraspecific competition, as larger male skulls can support stronger jaw muscles and larger teeth. Age-related differences were observed in nearly all cranial regions, including total length, basal length, neurocranial and viscerocranial lengths, facial length, palatal length, and cranial breadths (TL, BL, NL, UNL, VCL, FL, MPL, LMR, LPR, GMB, GBOC, MZW, BCA, LN, etc.). The most pronounced changes occur in the first year of life, indicating rapid growth in both the neurocranial and viscerocranial regions. In particular, facial length and palatal length increase with age, likely reflecting both masticatory development and adaptation to feeding ecology. Cranial breadths and condylar dimensions increase more gradually, consistent with the development of jaw musculature and overall skull robustness.

Overall, these results demonstrate that the skull undergoes coordinated growth, with certain regions (e.g., viscerocranium and dentition) showing faster changes, while others (e.g., neurocranial breadths) develop more slowly.

Sexual dimorphism in red foxes may result from sexual selection and the need to reduce competition between the sexes (Lynch, 1996). Male competition is often expressed through antagonistic behaviors, and larger males clearly have an advantage over smaller ones, giving them greater reproductive success (Abramov & Puzachenko, 2005). However, being larger can also be a handicap for males, especially in monogamous species where food is limited (Hartová-Nentvichová et al., 2010). In such cases, selective forces tend to favor an optimal body size that is similar for both males and females. Sexual size differences in red foxes may also lead to partial niche separation, helping to reduce intraspecific competition for food.

Conclusions

The study highlights intraspecific variation in red fox populations, including sex- and age-related cranial differences, and provides baseline morphometric data for further ecological and morphological research in understudied regions like Transcarpathia.

According to our results on fox skulls from Transcarpathia, craniometric growth is most intensive during the first 5–6 months, and slowing after. Growth rates differ between sexes in early age: females show relatively higher growth (3.70 %) than males (2.21 %).

After the first year, male growth exceeds female growth (3.52 % vs. 0.89 %), although occasional negative growth was observed in some parameters.

Postorbital breadth shows an inverse growth trend compared to other cranial measurements, reflecting the narrowing of the posterior braincase associated with the development of masticatory muscles.

Sex differences were significant in 12 measurements, age differences in 20.

Adult females were generally 0.11–2.54 % smaller than males, except for the least postorbital breadth, where females were 0.79 % larger.

Size differences between sexes are likely influenced by sexual selection and male–male competition.

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Заява про доступність даних / Data Availability Statement

Дані, що підтверджують результати дослідження, доступні у автора за обґрунтованим запитом / The data supporting the findings of this study are available from the author upon reasonable request.

Заява інституційної ревізійної ради / Institutional Review Board Statement

Для цього дослідження не було необхідності отримувати етичне схвалення, оскільки жодна тварина не зазнала шкоди під час неінвазивного дослідження / No ethical approval was required for this study, as no animals were harmed during the non-invasive research.

Заява про інформовану згоду / Informed Consent Statement

Інформована згода не застосовувалася, оскільки дослідження не включало участі людей / Informed consent was not applicable, as the study did not involve human participants.

Конфлікт інтересів / Conflict of interest

Автор заявляє про відсутність конфлікту інтересів / The author declares no conflict of interest.

Декларація про генеративний штучний інтелект і технології на основі штучного інтелекту в процесі написання / Declaration on Generative Artificial Intelligence and AI-enabled Technologies in the Writing Process

Під час підготовки цього рукопису не використовувалися технології генеративного штучного інтелекту / No generative artificial intelligence or AI-assisted technologies were used in the preparation of this manuscript.

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