# 松嫩平原常见鹤类足迹特征及足迹信息学分析

邓文攸[1] 武明慧[1] 吴庆明[1] 邹红菲[1]

（1. 东北林业大学野生动物与自然保护地学院 哈尔滨 150040）

**摘 要：**由于环境质量的波动，我国鹤类种群数量呈现出不同的波动趋势。松嫩平原作为东北三大平原之一，是我国湿地分布的主要地区和鹤类迁徙的重要停歇地，一直备受关注。鹤类足迹是受关注的内容之一，直接关系着鹤种的识别、种群数量、栖息地利用等生物学信息。伴随着后基因组时代来临，使用机器学习对生物数据进行挖掘，已经成为生物学研究的热点。本研究假设鹤足迹可以作为鹤类种间判别的依据，在此前提下，将传统形态测量学和支持向量机(SVM)相结合，探讨了该判别的可行性和准确性。以松嫩平原分布的五种鹤类作为研究对象(丹顶鹤、白鹤、白枕鹤、白头鹤、灰鹤)，采用样线法、定点观察法、同步观察法、实地测量法对五种常□鹤类的足迹特征、种间差异、成幼差异、季节差异、承痕体影响等进行了分析，结果如下。

(1)松嫩平原五种常□鹤类足迹种间差异显著。白枕鹤、丹顶鹤成体、白鹤成体在足迹□度特征方面高度相似；白鹤幼体、丹顶鹤幼体、白头鹤与灰鹤混合种群在足迹□度特征方面相似度较小。丹顶鹤成体与白鹤成体趾间角偏大，白枕鹤足趾间角偏小。

(2)鹤类足迹季节差异极显著，秋迁期足迹的□度和角度特征值均显著低于春迁期。

(3)鹤类足迹存在明显的成幼差异。丹顶鹤、白鹤成体的足迹□度显著大于幼体，且足迹□度波动大。白鹤趾间角成幼差异不明显，而丹顶鹤趾间角成体显著大于幼体。

(4)不同承痕体下的足迹特征差异显著。草甸、盐碱地、玉米地三类承痕体中足迹特征差异极显著，足迹□、足迹宽、Ⅱ趾□、Ⅲ趾□、Ⅳ趾□为盐碱地＞玉米地＞草甸，趾间角为草甸＞盐碱地＞玉米地。泥路与水稻田中足迹特征值仅与部分承痕体差异显著。

进一步分析表明，基于主成分分析的支持向量机的鹤类足迹判别算法可以用于鹤种判别；松软或湿润地区足迹会出现Ⅰ趾、玉米地中足迹角度多不对称，玉米地根茎、草甸水源、草甸植物旁的足迹单步与复步□偏小且较为深陷；足迹可以用于初步预测白头鹤灰鹤混群的种群数量、空间分布模式以及种群动态变化。本研究深入探究了鹤类足迹的多元差异及和承痕体对足迹的影响，并建立了基于主成分分析的支持向量机判别的鹤种判别算法，为鹤类种群监测提供了新的解决思路。

**关键词：**种间差异；成幼差异；季节差异；承痕体影响；鹤类足迹

## Foot characteristics and footprint informatics analysis of common cranes species in the Songnen Plain

**Abstract:** Due to fluctuations in environmental quality, crane populations in China show different fluctuating trends. As one of the three major plains in northeast China, the Songnen Plain has been of great interest as a major area of wetland distribution and an important stopover for crane migration in China. The crane footprint is one of the elements that have received attention and is directly related to biological information such as crane species identification, population size, and habitat use. With the advent of the post-genomic era, the use of machine learning to mine biological data has become a hot spot in biological research. In this study, we hypothesized that crane footprints could be used as a basis for interspecific discrimination of cranes, and on this premise, we combined traditional morphometry and support vector machine (SVM) to explore the feasibility and accuracy of this discrimination. Five species of cranes distributed in the Songnen Plain were used as the study objects (Red-crowned Crane, White Crane, White-naped Crane, Hooded Crane and Common Crane), using the line-intercept method,

sited-fixed observation method, synchronous observation method, and field measurement method were used to analyze the footprint characteristics, interspecific differences, adult and juvenile differences, seasonal differences, and substrate effects of the five common crane species, and the results are as follows.

(1) The interspecific differences in crane tracks were significant. White-naped Crane, adult Red-crowned Crane and adult White Crane were more similar in terms of footprint length characteristics; White Crane juveniles, Red-crowned Crane juveniles, and mixed populations of Hooded Crane and Common Crane were less similar in terms of footprint length characteristics. The angle between the toes of adult Red-crowned Crane and adult White Crane was large, and the angle between the toes of White-naped Crane was small. The support vector machine algorithm for crane footprint discrimination based on principal component analysis verified the feasibility of footprint as a discriminator of crane species.

(2) There were significant seasonal differences in crane footprints, and the length and angle eigenvalues of footprints in the autumn migration period were significantly lower than those in the spring migration period.

(3) There are obvious differences between adult and juvenile crane tracks. The footprint lengths of adult Red-crowned Crane and White Crane were significantly larger than those of juveniles, and the footprint lengths fluctuated greatly. The difference between adults and juveniles in the angle between the toes of White Crane was not obvious, while the adults in the angle between the toes of Red-crowned Crane was significantly larger than the juveniles.

(4) The footprint characteristics in different substrates differed significantly. The differences in footprint characteristics among meadow, saline and cornfield were highly significant, with the footprint length, footprint width, II toe length, III toe length and IV toe length being saline > cornfield > meadow, and the inter-toe angle being meadow > saline > cornfield. The trail feature values in the dirt road and rice field only differed significantly from some of the bearing traces.

Further analysis showed that the crane footprint discrimination algorithm based on support vector machine with principal component analysis could be used for crane species discrimination; footprints in soft or wet areas would show I-toe, footprint angles in maize fields were mostly asymmetrical, and footprints in maize field rhizomes, meadow water sources, and next to meadow plants had small and deeper sunken single and compound step lengths; footprints could be used for preliminary prediction of population size, spatial distribution patterns of mixed populations of Hooded Crane and Common Crane. The tracks can be used to predict the population size, spatial distribution pattern and population dynamics of the mixed flock of White-headed Crane and Gray Crane. In this study, we investigated the multivariate differences of crane tracks and the influence of substrate on tracks, and established a support vector machine discriminant algorithm based on principal component analysis for crane species discrimination, which provides a new solution for crane population monitoring.

**Key words:** Songnen Plain; Footprint; Support vector machine discrimination based on principal component analysis; Population monitoring.