

## **Drone observation reveals a multilevel society of feral horses**

Some mammalian and avian species, including humans, have developed social structures with nested levels of organization. This multilevel society is among the most complex social systems in animals. Most of the previous studies have provided only descriptive data due to difficulty in observation, but qualitative definition and description are essential to understand its function and evolutionary processes. In this study, we applied a drone observation to obtain accurate positional information of a feral horse population in Serra D'Arga, Portugal, to establish the methodology of quantitative study on a multilevel society. Equine groups are one of the taxonomic groups that have nested social structure, however, it was unclear whether domestic horses (*Equus caballus*) form it as well. Firstly, we aimed to uncover the evidence of multi-level society by defining unit groups from the positional data of individuals. We took aerial photos of a feral horse herd (>100 individuals) in 30 min interval and identified all the individuals by collecting their positional data. The analysis revealed (1) the existence of core unit groups, (2) aggregation of multiple units, and (3) the social relationships among different units. These three evidences support the fact that horses have multilevel society. We further investigated the mechanism of behavioral synchronization in a multilevel society. The agent-based simulation suggested that horses synchronize their behavior not only within the same unit members but also across units. This result is important for understanding the mechanism of multiple unit aggregation in a multilevel society. This study contributes to investigating various scientific questions related to the definition, mechanism and function of multilevel societies. Our framework could be applicable to other species and would promote multilevel social studies through comparisons with various species and populations in the future.