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1. Introduction

Spatial positioning of individuals within groups is related to multiple ecological factors. There are large differences on individual's benefit between central and peripheral area in a group. Therefore, consideration of spatial positioning of individuals are needed in any behavioral study in group-living animals.

Although the importance of spatial positioning of individuals has been recognized for long time, previous studies have mainly focused on the theoretical frameworks and limited empirical studies in the wild have been conducted. In addition, most of the empirical studies were not able to track all individuals in the group, namely the entire group. In addition, there were lack of the accuracy in terms of obtaining spatial positioning of individuals. Therefore, we have not understood not only the dynamics and the complexity of spatial positioning of individuals, but also its basic characteristics in many species. One of reasons which might cause these lacks is a technical barrier that it is difficult to simultaneously obtain the spatial positioning of all individuals in one group. Using Global positioning system (GPS) to obtain positioning at short intervals could solve this problem. However, GPS has the weight limitation in itself and also needs to capture individuals. Therefore, GPS is not the perfect device for any studies which focus on spatial positioning of individuals.

In the present study, I introduced the drone technology as an alternative technology into the field survey of feral horses living in Serra D'Arga in northern Portugal. Horses form stable harem groups and bachelor groups which are consisted of young males. Horses are suitable animals as the first target of the study using drone because individuals in the study site are tolerant to the noise of drone and human observers. In the present series study, I aimed to establish a method using drone to record characteristics of the spatial positioning of individuals within groups in feral horses. The aerial survey revealed the characteristics in multiple scales including location of nearest neighbor, inter-individual distance, the sex difference in relative spatial positioning, and the spread of groups. Following these descriptive studies, I inferred a mechanism which maintains inter-individual distance based on comparison between observed data and s mathematical simulation.

2. Materials and method

The field observation was conducted on the Serra D'Arga mountain in northern Portugal (8°42′N,

41°48′E). It is 825 m high, with a plateau at the top which provides a habitat for the Garrano breed of horses that were our study subjects. There were more than 200 identified individuals in 2016. Group size ranged from one to 13. The field survey using the drone (DJI Phantom 3 standard/advanced, and Mavic Pro) was conducted during 57 days between June 2016, May-July 2017, and May-July 2018. The images were recorded from 0900 to 1800h every day. The altitude of drone was approximately 25-80m.

Individuals' coordinate was defined as middle point between the base of the neck and the base of the tail. Mean length between the base of the neck and the base of the tail was used as unit of distance. All of statistical analysis were conducted with R.

For the mathematical simulation, agent-based model was used to infer the dynamics of the force working between individuals. Based on attraction-repulsion model, force model was constructed as a function of inter-individual distance. To estimate the range of the force, I examined topological model and numerical model. Root mean square error was used for comparison between the observed dataset and the simulated dataset.

3. Results

3-1 Spatial positioning of individuals in a group of feral horses: a case study of using drone technology

There was a sex difference in relative spatial positioning. The male was located in peripheral area comparing with females. Distribution of inter-individual distance followed Gamma distribution. In comparison among social networks which were based on mean distance, proximity, and grooming frequency, mean distance network was not correlated to grooming network (QAP test, $r = -0.14$, $p = 0.27$).

3-2 Lateral position preference in grazing feral horses

In the positioning of nearest neighbor, the spatial lateralization was found. Density maps of nearest neighbours showed clear trends of locations that significantly differed from uniform distribution ($p < 0.01$, Rayleigh test). Nearest neighbours were significantly more likely to be located in the left rear area than in the right rear area ($p = 0.021$, binomial test), but a trend for increased frequency in the right front area compared with the left front area was not significant ($p = 0.3$, binomial test).

3-3 The effect of group size, social composition, and relative positioning on group cohesiveness

in feral horses

We examined the effects of group size, social system, and relative spatial positioning on the spread of the group, and obtained quantitative data from multiple groups using drone technology. The results revealed that the spread of the group increased significantly as a function of group size ($p < 0.0001$). The spatial centrality of a group at the intergroup level had a negative influence on the spread of the group ($p < 0.0001$).

3-4 Mathematical model for estimating the dynamics of forces between individuals in feral horse groups during grazing

Comparison between the observed dataset and the simulated one suggested that the repulsion force works within about four body lengths, while attraction became dominant over 5 BL, and the range of force was within 7 BL in the groups with seven or eight individuals.

4. Discussion

In the present study showed several features of spatial positioning of individuals in groups of feral horses. In addition, the dynamics of the force working among individuals was estimated. These quantitative descriptions of the spatial positioning with multiple scales is the first record in feral horses. The findings in this study will contribute to future works on the behavior of feral horses. The present study has not directly observed individual costs and benefits including predation risks, and foraging efficiency. These factors are intimately related to the decision making of individuals to the spatial positioning. Therefore, further behavioral observations will reveal the complex relationships among the spatial positioning and those ecological factors. In addition, the procedures which were suggested in the present study will be applicable to other species even in the cases where using GPS is difficult. Recent development of the measuring technique and data analysis will give us much understanding of decision making at individual's level to the spatial positioning and emergence of phenomena at the entire group.