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INVITED ARTICLE

Studying feral horse behavior from the sky

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Abstract

Unmanned aerial vehicles, commonly known as drones, have become widely available in recent years. A drone provides a bird's eye view, which is useful in detecting and observing wild animals. One strength of imagery obtained by a drone is that it enables the capture of the two-dimensional spatial relationship of animals on the ground. I and colleagues have investigated the spatial relationships of feral horses at both intra- and inter-group levels. At the intra-group level, the distribution of the inter-individual distance of horses follows a certain pattern, indicating repulsion and attraction forces taking place among group members, similar to those in a school of fish, flock of birds, or swarm of insects. At the inter-group level, multiple unit groups aggregate to form a herd, suggesting the existence of a multilevel social structure. Automation of the analysis of the recordings of a drone, including target animal detection, individual identification, and motion tracking, presents a way forward. Drones and other emerging technologies will enhance our understanding of swarm behavior both in vivo and in vitro.

Keywords Drone · Feral horse · Spatial positioning · Multilevel society · Mathematical modeling

1 Introduction

Biological organisms have adapted to diverse environments in the evolutionary course of the Earth. Primates, including humans, occupy terrestrial spaces whereas fish swim in the water and birds fly in the sky. Humans are able to swim in the water to some extent but cannot fly in the air at all. Controlled flight was, thus, long a human dream, which was realized when the Wright brothers flew the world's first motor-operated airplane on December 17, 1903 [1]. More than a century has since passed. There have been cumulative technological advances since the Wright brothers, and aircraft have become a popular mode of transportation. Yet, an aircraft is not something that the individual can easily obtain privately. However, the recent propagation of unmanned aerial vehicles, so-called drones, has enabled us to obtain a bird's eye view relatively easily, through the private ownership and use of the drones.

Researchers have begun using drones in observing animals from the sky, with the number of studies using drones for animal research notably increasing from around 2015 [2]. In 2015, I and colleagues established a research site to study feral horses at Serra D'Arga in Portugal [3]. The first flight of a drone to observe the horses from the sky at this research site took place in February 2016. This paper reviews the study of animals using drones, focusing on a series of investigations on feral horses conducted at our research site in Portugal.

Horses are ideal animals for a drone observation because they often stay in an open area, with few obstacles (e.g., trees) between the horses on the ground and the drone in the sky. In addition, horses are exceptional among ungulates in that they form a stable social group, allowing the analysis of their social behaviors [4]. A social group of horses typically comprises an adult male classed as a stallion, multiple adult females called mares, and their dependent offspring [3, 5]. Such a group is called a harem. A harem sometimes has two or more adult males [5, 6]. Both male and female offspring disperse from their natal group when they grow older. Females typically join another harem group after dispersal, whereas males either form an all-male group, called

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a bachelor group, or become solitary, until they acquire females to form their own harem group.

2 Spatial positioning of horses in a group

Prior to the recent prevalence of drones, researchers used other technologies, such as the global positioning system (GPS), acceleration sensors, and small mobile cameras, to monitor the position, movement, and other spatial characteristics of animals [7]. The use of a miniaturized electronic device of the GPS and other devices to be attached to an animal is termed bio-logging [8]. In applying bio-logging technologies, however, researchers need to capture the animals to attach a device to them. It is not difficult to capture certain species of animals, such as homing pigeons, but it is generally difficult to capture a large wild animal. With the aid of a drone, it becomes possible to obtain positional data of wild animals without capturing them.

Inoue et al. [9] used a drone to investigate the spatial positioning of feral horses at Serra D'Arga in Portugal for the first time. The study was exploratory as there had been no similar attempt to collect spatial data on animals using a drone. One constraint of using a drone is that the battery of the drone lasts only about 15 min, and the video recording of horses was, thus, considered impractical in an initial attempt. Inoue et al. [9], thus, took a still image from the sky every 30 min and analyzed the spatial positioning of the horses in the acquired imagery (Fig. 1). The target was one harem group of horses, comprising eight adult individuals, including a stallion and seven mares. Three states of the group were first determined, namely foraging, moving, and resting states. The analysis then focused on the foraging state by excluding the moving and resting states. The unit of length in the analysis was the average body length of the eight individuals. This length was adopted because the height of the drone from the ground varied and the scale of the images, thus, differed across observations, such that it was not possible to obtain absolute values of distances in units of meters or centimeters. In contrast, the average body length of the same individuals of the target group should remain constant.

The distribution of the inter-individual distance, calculated as the distance from the midpoint of one individual to that of another individual, of all pair combinations of the group had a certain shape (Fig. 2). This distribution pattern was statistically significantly different from a random pattern. The distribution of the inter-individual distance of nearest neighbors had a similar pattern. These distributions have a peak distance around three body lengths. If two individuals approach too closely, within three body lengths, then they will separate. If the two individuals are too separated, then they will approach each other. Previous studies on fish schools and bird flocks support a zonal model, where the spatial positioning of the fish and birds can be explained by a repulsion area of close proximity in which two individuals repel each other, an alignment area of mid-range proximity in which two individuals tend to face the same direction, and an attraction area of far proximity in which two individuals attract one another [10–12]. The results of Inoue et al. [9]

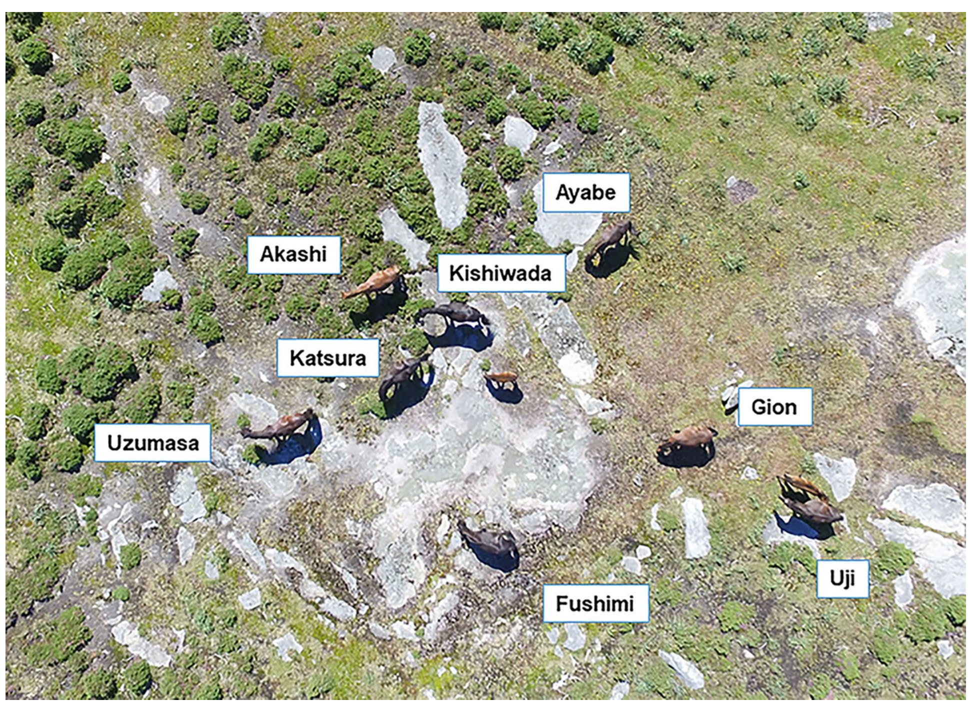

Fig. 1 A harem group of feral horses filmed using a drone. The names of adult individuals are superimposed on the photograph

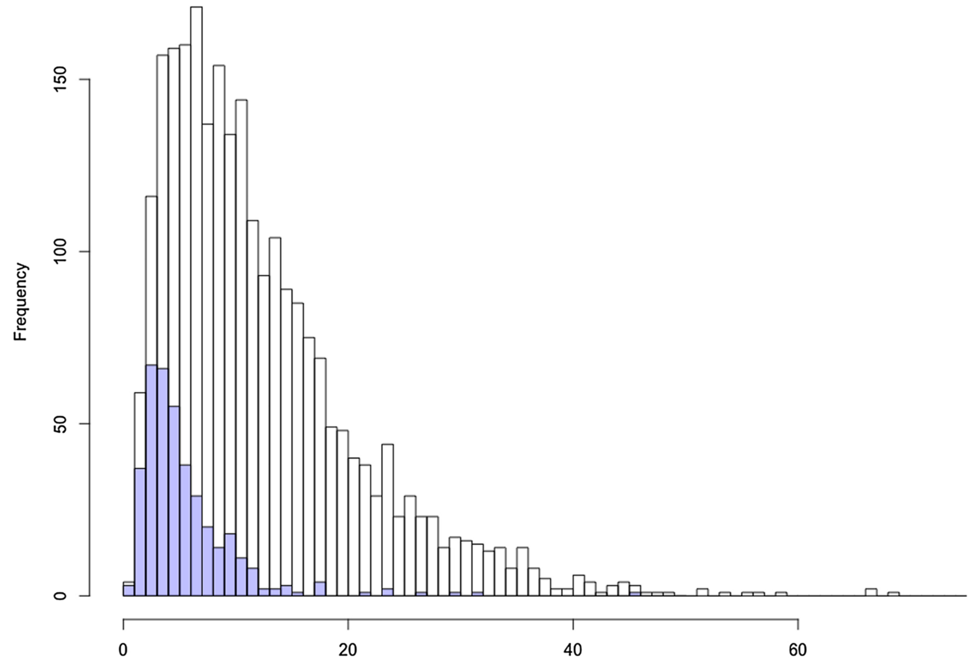

Fig. 2 Distribution of inter-individual distances in a group of horses. White bars are data for all pair combinations in the group. Purple bars are data for nearest neighbors (color figure online)

suggest that a similar repulsion–attraction force applies to feral horses when foraging.

Uzumasa was the only adult male in the group. The distance between Uzumasa and the central position of the group was significantly larger than the distance between the remaining females and the group center. One possible interpretation is that the male in a group monitors other horses in surrounding groups and sometimes confronts another male in another group, resulting in the male being at the periphery of the group.

3 Laterality in positioning

Inoue et al. [13] found other characteristics by looking at the positioning of the nearest neighbor among feral horses during foraging more closely (Fig. 3). The nearest neighbor tended to be located not at the back but rather toward the left or right side of a horse. In addition, there was a preference in the lateral position in that the nearest neighbor tended to be located at the left rear of a horse more frequently than at the right rear. One possible interpretation is that the horse at front tends to view another horse at the back with its left eye; i.e., the horse in front makes a slight turn to look using the left eye when another horse approaches. This interpretation is linked to a possible brain laterality where information obtained via the left eye predominantly proceeds to the right hemisphere and the right hemisphere is dominant in processing social information, such as the presence, identity, movement and state of another individual [14].

Infants of various different species of animal, including the horse, Pacific walrus, Siberian tundra reindeer, saiga antelope, muskox, kangaroo, sheep, orca, and beluga whale, are known to be more often on the right side of their mothers than on the left [15–19]. In such a situation, infants on the right side of their mothers use their left eye to monitor their mothers. Researchers consider that infants take the initiative in positioning in situations of rest or slow movement and prefer to view their mothers using the left eye, which is linked to the right brain hemisphere, for social information processing. The result of Inoue et al. [13] suggests that the predominant use of the left eye is not limited to the mother–infant relationship but extends to an adult–adult pair, which is not surprising considering that laterality in brain hemispheres is consistent from infancy to adulthood.

Caution is needed, however, to interpret Inoue et al.'s [13] results, as they analyzed still images and it was, thus, not possible to verify how this laterality in positioning formed. In showing the cause of laterality bias in the positioning of nearest neighbors among feral horses, video recordings are needed to determine how the alignment is established.

4 Multilevel society

A multilevel society is a social structure with nested levels of organization [20]. Humans constitute a multilevel society, from the family as the core unit, to the local community, country, and global community. Among nonhuman animals, there are multilevel societies for various taxonomic groups, including primates, elephants, and cetaceans [21–24].

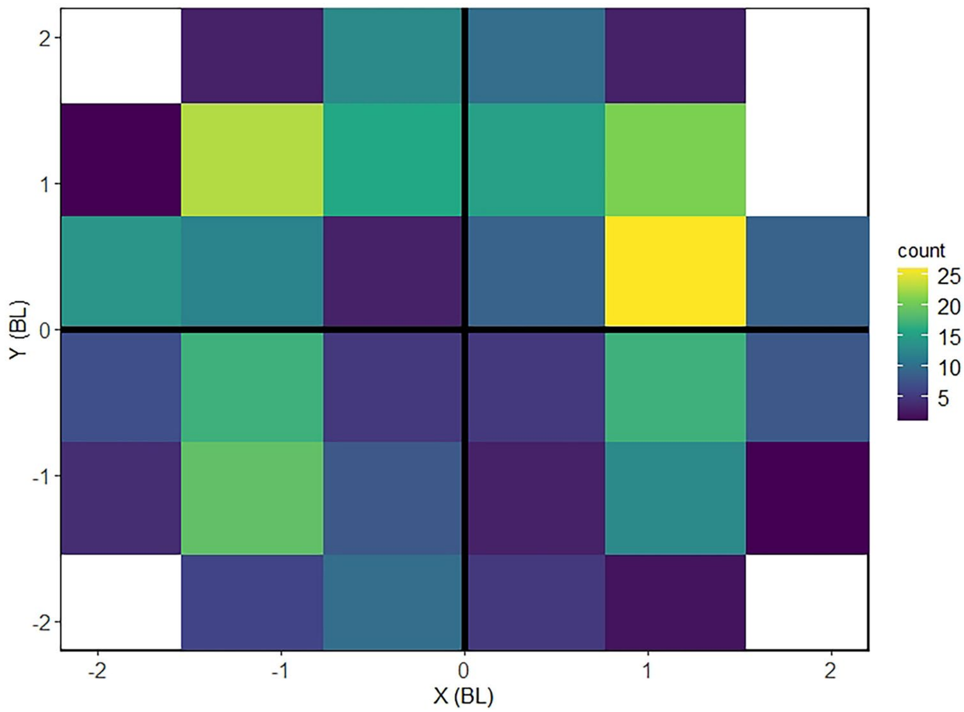

Fig. 3 Density plot of the nearest neighbor positions of horses

Well-known examples are the societies of hamadryas baboons and geladas [25, 26]. The smallest unit is the unit group, and many different unit groups form a band, team, clan, or troop. In equine species, plains zebras, Przewalski's horses and a subspecies of Asian wild asses are also reported to have a multilevel society, but whether feral horses have a multilevel society remains a controversial topic [5, 27–29].

At Serra D'Arga, almost 150 horses gathered on the sweep of the plains in the spring and summer seasons of 2016–2018. These horses constitute multiple unit groups that make up a herd (Fig. 4). Maeda et al. [30] aimed to quantitatively verify the multilevel society of the horses by measuring and analyzing inter-individual distances, thus addressing problems encountered in previous studies, which mostly provided only descriptive and qualitative data.

The first step was to confirm that the population consisted of multiple unit groups, harems and bachelor groups, which could be expressed in terms of the inter-individual distances.

Fig. 4 Aggregation of multiple unit groups of horses with two-nine individuals per group

Maeda et al. [30] took aerial photographs using a drone at intervals of 30 min and identified all individuals in the photographs. To cover all individuals on the plains, the drone continuously took photographs while airborne, and these photographs were combined as orthomosaic photographs. A total of 238 orthomosaic snapshots were used in the analysis, covering a total of 21,445 individual horse locations for 127 individual horses excluding foals.

The first hypothesis of the study was that if the population was not multilevel but just a mixture of individuals, then the distributions of the inter-individual distance would have a shape with only one peak corresponding to an average distance between two individuals, whereas if the herd comprises small unit groups, then the distributions of the inter-individual distance would have a shape with two peaks, with one peak representing the peak of the inter-individual distance within a unit group and the other peak representing the average distance between unit groups. The results showed two peaks, supporting the idea that there were unit groups within the herd.

The second hypothesis was that the spatial alignment within a herd was not a product of the random distribution of groups. To prove this, a null model was created in which groups were placed randomly within the research area, and the inter-unit distance of these randomly created groups was then measured. The result showed a peak in the empirical data located at a shorter distance than the peak for the null model. This suggest that the units were indeed attracting each other to form a herd, and that the spatial alignment was not just a coincidence.

The third hypothesis was that there was a certain type of stable pattern in inter-group positioning. Maeda et al. [30] conducted a social network analysis using the inter-group distance as an index. The results showed that bachelor groups, comprising only males, were located in the peripheral area in contrast with harems. Among harems, the small harems, comprising a small number of individuals, were also in the outer zone in contrast with larger harems. An additional analysis on centrality also showed that the larger groups had greater centrality. Figure 5 presents a schematic view of these results, showing the hierarchical relationships between harems.

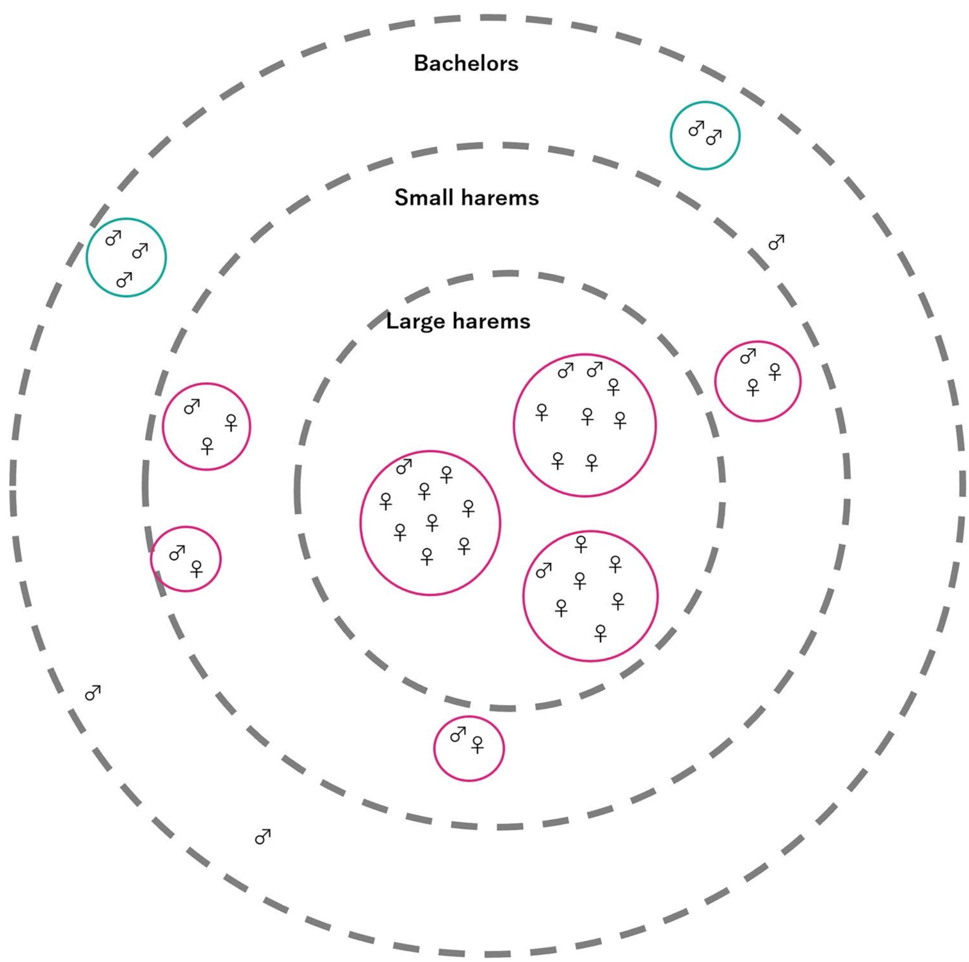

Fig. 5 Schematic of the multi-level social structure of horses

5 Movement analysis

After obtaining results from still images taken by a drone as described above, researchers of feral horses at Serra D'Arga proceeded to record video using a drone to analyze the movements of the horses. Ringhofer et al. [31] focused on herding behavior as the first step of movement analysis.

Herding is a behavior shown by male horses (Fig. 6). A male horse lowers his neck, which is a typical behavior of herding, and chases a female from behind. This behavior happens when a female moves far away from the group, and the male chases the female back to return her to the group, or the male chases females in a certain direction.

Ringhofer et al. [31] analyzed 12 instances of herding in video clips and showed that the females that moved first were those nearest the herding male at the beginning of the herding behavior. The movement initiation of the second and subsequent females was determined by the distance from the nearest moving female rather than by the distance from the herding male.

Go et al. [32] used the same set of video recordings to describe the movement pattern with a mathematical formula. A previous study that focused on the herding of sheep by a shepherd dog proposed a mathematical model for the movement of the sheep and dog. Go et al. [32] made a slight modification to the sheep–dog model, and compared the empirical data and the results of the model, which was a linear combination of the inertia, repulsion from the stallion, short-range repulsion, medium-range attraction, synchronization attraction, and attraction to the center of the group. The result showed that the modeling results matched the empirical data well. In addition, it was found that the medium-range attraction and synchronization forces could be ignored. Therefore, a model that comprises the inertia, repulsion from the stallion, short-range repulsion, and attraction to the center of the group can explain the movement pattern of the stallion and mares in herding events.

6 Limitations of past studies and future directions of research

Some decades ago, Reynolds [33] created computer graphics of a flock of birds by creating BOID (bird-oid object) and applied a mathematical model of forces that comprises separation, alignment, and cohesion. In the real world outside of computer graphics, biologists have recorded the behaviors of flocks of birds, schools of fish, and swarms of insects and confirmed that a zonal model that resembles Reynolds's model [33] and comprises forces acting at close, medium, and distant ranges can explain the actual movement patterns of these biological organisms. The detailed refinement of the mathematical explanation of the empirical data is in progress [10–12, 34].

The advancement of bio-logging technology has progressed the study of animal behaviors and movements [35, 36]. As outlined above, a drone is a useful addition to the collection of tools that can be used to study animals in the wild. Both bio-logging and drones have strengths and weaknesses. One strength of a drone is that it does not require the capturing of animals for filming, whereas such capture is necessary in the case of bio-logging. Compared with filming using a hand-held video camera at the height of the human eye, a drone can cover a wider area by flying several tens of

Fig. 6 Herding behavior of a stallion

meters. An aerial photograph is suitable for analyzing the spatial distributions of animals. A GPS device is also able to collect spatial data but it has measurement errors of several meters whereas a photograph taken by a drone allows a distance to be measured at a finer scale.

There are limitations to using a drone. First, the battery life of a drone is short. The battery of multi-rotor drone lasts only 20–30 min and that of a fixed-wing drone lasts several hours, whereas the battery of a bio-logging device generally lasts much longer; a multi-rotor drone is an aerial vehicle having more than two lift-generating rotors, which enables easy control and hovering but requires much energy, whereas a fixed-wing drone uses lift generated by its wings cutting through the air at a specific angle, which requires less energy but does not allow hovering. Second, a drone, especially a multi-rotor drone, is not able to fly if conditions are rainy or windy. A bio-logging device, in contrast, can be made waterproof. Third, a drone can be used only in an open space and is thus unsuitable for studying animals in a forest. Fourth, if a study requires the individual identification of animals, then identifying individuals in a photograph taken by a drone from the sky is not an easy task. As an example, Maeda et al. [30] identified 21,445 horses in the imagery, although there were only 127 unique horses, and it took them about 6 months to complete the identification and mark locations in the imagery. Automation of the process, including target animal detection, individual identification, and motion tracking, would be a way forward [37, 38].

By recognizing the strengths and weaknesses of the recent technologies, researchers will be able to plan a suitable method for the study of animal behavior and movement. The use of a drone and other emerging technologies will enhance our understanding of swarm behavior both in vivo and in vitro.

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