Drone Observation for Complex Multilevel Societies

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Drones made it possible to obtain the identification, accurate positioning, or movement of more than a hundred individuals in a multilevel social group. In addition, in multilevel social groups, drones facilitate the observation of heterogeneous spatial positioning patterns and mechanisms of behavioral propagation, which are different from those in a single-level group.

Keywords: drone ; UAV ; orthomosaic ; multilevel society ; complex society

1. Introduction

How have the various animal societies evolved? What is the mechanism for maintaining social groups? Various studies have been conducted to answer these questions, including field observations and laboratory experiments using captive animals. In-lab studies are extremely important for testing hypotheses because they can be controlled experimentally; however, not all animals exhibit natural sociality in captivity. Quantitative studies of animals in the wild are also essential for comparing various types of social systems, which leads to an understanding of the proximate and ultimate factors that shape animal societies.

Recent advances in analysis and observation techniques, such as network analysis and global positioning system (GPS) tags/logger, have contributed to advances in the study of animal societies in the wild [1]. The use of unmanned aerial vehicles (UAVs) or drones is applicable to wildlife studies. In the 2000s, technological advances and the deregulation of GPS accessibility led to the commercial release of small general-purpose drones. Since then, the use of drones has rapidly increased in various research fields [2]. The advantage of drones in wildlife studies is that they can observe the behavior and movement of numerous animals simultaneously with high resolution. It is even possible to obtain images of a few centimeters/pixels with errors of <10 cm in a geographical location [3]. Drones do not require animal capture and they are less costly compared to alternative methods, such as GPS tags and loggers. In addition, they can be used to survey locations that are difficult to access on foot [4]. Alternatively, flight time, flight range, and techniques for detecting animals from aerial images have often been limited to observation and data collection [5]; however, these problems are gradually improving.

2. Using Drones to Understand Group Structure and Measuring Social Relationships in a Multilevel Society

2.1. The Necessity of Quantitative Assessment of the Multilevel Social Group Structure

Although the definition of a multilevel society more or less varies among studies, there are three main conditions by which a multilevel society is recognized; (1) The existence of a stable core unit: members of the same unit are physically closer to each other than to individuals who are not [6][7][8][9][10]. Membership is usually very stable, and the composition does not change for months or even several years [11][12][13]; (2) Aggregation of multiple units: different units usually exhibit fission–fusion characteristics and gather to create a temporal multiple-unit group [11][14][15]; (3) Social relationships among units: associations among units are determined not only by environmental, but also by social factors. Certain units are more likely to associate with or avoid each other than for randomly interacting situations to occur [7][10][13]. When animals have more than two levels of social hierarchy, Conditions 2 and 3 are also applicable to higher-level social groups, and members of lower-level groups have stronger bonds than those of higher-level groups [16].

As mentioned in the above sections, most of the studies used the association index (AI), the ratio of inter-individual distance that is smaller than a certain threshold, and subsequent cluster analysis to verify that the subject species has a multilevel society [7][13][17][18]; however, the threshold for ascertaining AI is often determined without any objective basis (but see studies on golden snub-nosed monkeys [15]). In several cases, the results of clustering are supported by behavioral data, such as movement or membership stability [7]. However, the lack of a unified definition makes interpopulation and species comparisons difficult. Drone observations can help obtain accurate positional data and enable a more quantitative assessment of the population structure of multilevel societies, which may facilitate more rigorous detection and comparisons among studies.

2.2. How to Apply Drone Methods

To date, there is only one case in which a drone was used to examine whether there is a multilevel society and to measure its social relationships [19]. Regarding the horses included in this study, more than 100 individuals were scattered over an area of several hundred meters. To capture all of them in one frame, a drone needs to fly at an altitude of over one hundred meters, which is too high for individual identification, and the distortion of the lens makes it difficult to calculate the exact distance. To solve these problems and to accurately calculate the identified positions, the present study applied the orthomosaic technique. An orthomosaic is a non-distorted map-like image created by connecting a series of successive photographs. Detailed 3D shape recovery is performed by: (1) Automatic acquisition of feature points; (2) Camera position and orientation estimation and calculation of three-dimensional coordinates of feature points; (3) Point cloud generation using multiview image measurement; (4) Automatic surface shape modeling [20][21][22]. Each image was captured at a low altitude of approximately 40–50 m, so that the resolution was sufficiently high for individual identification. The horse population was primarily identified by direct observation from the ground, and their features were matched with the aerial images. In addition, each pixel in the orthomosaic is embedded in the GPS information, which enables accurate distance measurements. This technique has been primarily used for vegetation [23][24][25], topographic surveys [26][27] and population surveys of wild animals [4][28][29]. Thus, it was the first attempt to apply it to animal social studies. Combined with individual identification, this orthomosaic method has the advantage of being able to monitor social associations in the long term by adding individual information on positional data, whereas previous drone studies could not track individuals.

Using this method, this drone study also revealed the spatial structure characteristics of a multilevel society. The inter-individual distance in a single-level animal group, such as bird flocks, fish swarms and angulate herds, is generally described using an attraction–repulsion model [30][31][32]. Individuals try to maintain almost identical nearest-individual distances, where attraction and repulsion forces are in equilibrium. Indeed, inter-individual distances are not always homogeneous due to temporal fluctuations and various other factors (social relationships [33][34], positions in a group [35], individual properties [36], and environmental factors [37][38]), but such effects are often continuous, thus the overall distance distribution is expected to show unimodality [9]. However, in a multilevel society, the same unit members showed higher cohesion and different units were scattered at relatively farther distances (yet closer than randomly positioned points), and such a structure was represented by the bimodal structure in the inter-individual distance histogram. This structure in a multiunit group has been suggested in a study on red uakari [9]; however, this is the first time that it has been verified using quantitative data.

This study indicates that different thresholds are necessary for the evaluation of intra- and inter-unit relationships. In measuring intra-unit relationships, it would be appropriate to set the threshold around the first peak of the histogram of inter-individual distances, whereas it should be around the second peak for the inter-unit relationship to be measured; otherwise, the network can become too sparse. Horses form a two-layered multilevel society (only core unit and second-level social organization), but for a three- or four-layered society, such as the gelada society, it is even more difficult to evaluate every type of proximity relationship with a single threshold. Obtaining continuous interindividual distances could provide objective reasoning for selecting the threshold and enable a more accurate assessment of stratified relationships in a complex society. Accurate inter-individual distance data are difficult to obtain by direct observations from the ground; thus, aerial observations from drones will contribute to a more precise evaluation and detection of multilevel societies.

Furthermore, the aerial observation provided positional information on individuals and units in a multiple-unit group. It would have been feasible to identify to whom an individual was close using the previous methodology; however, it was impossible to know where individuals were located in a group. The individual was positioned heterogeneously in a multi-unit group, and this also raises a question about their collective behavior because most of the models for such studies assumed a homogeneous inter-individual distance in a group. How do multilevel social animals maintain the cohesion of a specific group structure?

3. Collective Behavior in a Multilevel Society

To understand the mechanism of cohesion, it is essential to investigate the group structure and the group coordination behavior. Groups of animals often exhibit coordinated behavior among individuals, and previous studies have revealed that the central tenet of collective behavior is that simple repeated interactions between individuals can produce complex adaptive patterns at the group level [30][39]. In several species, from simple multicellular organisms (Placozoa) to vertebrates, such as fish, birds, and even human pedestrians, it is believed that local interactions among several nearest-individuals are sufficient to explain the emergence of global patterns [39].

Drones have also been used in the collective behavioral studies of terrestrial animals. A famous example is the study of the collective migration of caribou [33]. Drones succeeded in obtaining the movement of wild caribou using videos with automatic tracking based on machine learning, and a model was created to explain their movement patterns and local interactions among individuals. Auto-tracking of terrestrial animals has been conducted in various terrestrial animals such as plains zebras [40], horses [41], and wildebeest [42] (for a more general review on drone utilization for the investigation of group coordination, see [1][5][43]).

However, most previous studies have focused on collective behavior in a single group of animals, and there is a paucity of knowledge about group coordination in a multilevel society. One of the major differences in collective behavior in a multilevel society is that they interact with multiple units.

3.1. Previous Studies of Collective Behavior in a Multilevel Society

To date, most of the studies on group movement in a multilevel society have focused on the traveling order. Most of them described and analyzed only the order of departure or arrival because the data were collected by direct observation or video recording from the ground, and it was difficult to obtain positional data [44][45][46]. It is not yet clear whether there is a distinctive rule in collective behavior when compared with single-level societies. Some argue that multilevel societies have no particular means for collective decision mechanisms. The properties of departure (sex bias of initiator and individuals in the front, decisive factor of departure, and correlation between dominance rank and leadership) in Guinea baboons living in a matrilineal multilevel society were more similar to single-level and matrilineal baboon species, such as chacma, yellow, and olive baboons, rather than multilevel and patrilineal hamadryas baboons [45]. The results suggest that their movement pattern is more influenced by matrilineality/patrilineality, not by whether they have a multilevel society.

Alternatively, experimental studies on collective decisions in human societies suggest that multilevel social groups can have a distinctive advantage over a single-level society when finding better solutions to a complex problem [47]. Fully connected groups tend to be stuck with local optima; on the other hand, in a multilevel society, each unit can move freely to search for their own answers, and units are loosely connected to share different information, allowing them to combine local solutions and reach more optimal and complex answers. Derex and Boyd further argue that such a decision-making system could accelerate the accumulated cultural evolution, which is why humans have diverse and complex cultures compared to other apes who do not have a multilevel society [47][48]. In this study, information propagation was completely controlled by experimenters; thus, the verification of the hypothesis must be conducted in natural social settings.

3.2. How to Apply the Drone Method

Recently, some researchers have started using drones to reveal the characteristics of collective behavior in a multilevel society of equine species, domestic horses (*Equus caballus*) [49], and Przewalski's horses (*Equus ferus przewalskii*) [50].

The study of domestic horses investigated behavioral synchronization within and across units as a mechanism of group coordination using orthomosaics, which were taken at 30 min intervals. Combined with accurate positional data, the behavioral states (resting or active) of horses were coded. This study further implemented an agent-based model to explain synchronization in resting behavior, and the simulations suggested that resting and non-resting behavioral states are synchronized both within and across units in a multilevel society [49]. The same unit members spent most of their time within 15 m (10 body lengths) of each other; however, the closest distance between different units was approximately 40 m [19]. This suggests that there is an interaction between individuals at a much greater distance and in greater numbers than previously thought.

A study on Przewalski's horses used drone videos and recorded the movement of approximately 240 individuals. Their migration behavior showed a strict hierarchy of leaders and followers within and between units [50]. They assumed that only the leader of each unit is responsible for inter-unit behavioral propagation, whereas others only recognized the behavior of the same unit members. The simulation suggested that this modular leadership network could propagate behavior more effectively than a single-level network, and the proportion of leaders in horse multiunit groups almost matched the simulated the network with optimal behavioral propagation efficiency [50]. This study suggests a functional advantage of heterogeneous behavioral propagation in a multilevel society.

The use of videos enabled a higher resolution in the time frame compared to orthomosaics, following the movement of the horse multiunit group. However, the studies did not track individuals; thus, kinetic interactions among individuals were not analyzed. In addition, they did not provide individual identification, although they succeeded in identifying each unit and unit leader and were unable to show the social context of leadership emergence in a horse herd. The absence of individual identification would be due to the higher altitude of drone flights, and less physical variations in Przewalski's horses compared to domestic horses. The combination of orthomosaic techniques and video tracking may enable researchers to obtain both high-resolution images from low altitude for individual identifications and movement data from high altitude.

Drones made it possible to simultaneously observe all individuals in the population and measure proximity relationships, which contributed to the discovery of new facts. Both studies showed inter-unit propagation of movement/behavior, and the strength of synchronization was greater within units, implying that horses distinguish unit members from others. The study by Maeda et al. suggests that collective behavior in multilevel societies requires a different model from that in single-level societies. It was believed that the establishment of multilevel societies may require relatively high cognitive abilities [51] (although they have also been found in birds with a small brain [7]), and recent studies have revealed highly sophisticated social cognition in domestic horses [52][53][54][55], which may enable them to form a multilevel society. Further investigation of the details of cognitive requirements for the collective behavior of a multilevel social group will provide more insight into the cognitive constraints on the evolution of a multilevel society.

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