Analysis of the Spatiotemporal Behavior of Red Junglefowl and Free-Range Chickens using a WiFi Positioning System

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ABSTRACT

This paper describes two experimental studies that analyzed the spatiotemporal behavior of red junglefowl and free-range chickens using a WiFi (wireless fidelity) positioning system. The major findings obtained from the experimental study of junglefowl were: the experimental field was mostly dominated by one junglefowl, but the replacement of the dominant junglefowl occurred once in the experimental period, and this replacement took place over two days; junglefowl were temporally separated in the experiment field, and the closest distance between two junglefowl at a given point in time was 108 m; the home ranges of junglefowl overlapped to some extent (8%); the lower bound of the home range of a junglefowl was 2.1 ha; junglefowl change roosting places at nights; one junglefowl was found to have a walking speed of 32 m/min and a flying speed of 415 m/min. The major findings obtained from the experimental study of free-range chickens were: the shapes of the home ranges of three cocks were different and they overlapped to some extent, and the overlap was larger than that of the junglefowl; the home ranges of some hens were almost the same as those of their cocks; the home ranges of young hens were different from those of the cocks; the home ranges of hens with chicks were different from those of the cocks; the chickens that formed a group in daytime did not always roost together at the same site at night; chickens did not always sleep at the houses where they were kept; and the home range expanded when food was not given, but the extent of expansion differed from chicken to chicken. In particular, the expansion rate of the young hens was the largest. These empirical finding demonstrates that the WiFi positioning system was very useful for continuously observing animal behavior over space and time, although it has a few limitations.

Key Words: red junglefowl, free-range chicken, WiFi positioning systems, spatiotemporal behavior, home range

INTRODUCTION

Understanding animal behavior over time and space is one of the major subjects in animal science. To achieve this understanding, the trajectory data of animals in an area over a certain length of time, at least a few days, are indispensable. To acquire such data, two methods are commonly used in animal ecology: a telemetry system (Millsoaugh and Marzluff, 2001) and a global positioning system (GPS) (El-Rabbany, 2006). These methods each have their own advantages and disadvantages, depending on the environments in which the animals will be studied, as well as the animals' characteristics themselves.

An advantage of a telemetry system is that the weight of a tag is light, e.g., one of the lightest tags is 0.5 g. A disadvantage, on the other hand, is that a researcher has to operate the antenna constantly during any observation period; therefore, the researcher has logistical difficulties when attempting to observe many animals over day-and-night periods for several days.

In contrast, an advantage of a GPS is that once a GPS logger (tag) is fixed on an animal, trajectory data are continuously stored in the logger as long as its battery lasts. However, to obtain the data, the animal must be recaptured. If recapture fails, we cannot obtain the data from the GPS logger. Another difficulty is that the weight of a GPS tag is heavier than that of a telemetry tag. In 2005 when our experiment was carried out, the lightest one was 65 g (a tag of around 25 g is currently available, but the battery lasts at most a day). According to Ando and Osawa (1970), the weight of a device that does not disturb the free movement of an animal is less than 5% of its weight. Therefore, the weight of an animal to which a 65 g GPS tag is attached should be more than 1.3 kg. Consequently, we could not fix GPS loggers on junglefowl. To overcome those difficulties, we employed a WiFi positioning system.

The studies presented in this paper were performed under the Human–Chicken Multi-Relationship Research Project. This project pays special attention to chickens, and has studied their domestication in Thailand for several years. In this project, we carried out two experimental applications of a WiFi positioning system: the first was applied to red junglefowl living near the Wildlife Research Station in Khao Ang Rue Nai Wildlife Sanctuary, Thailand, and the second to free-range chickens kept in the Chiang Rai Livestock Technology Transfer Center in Thailand.

This paper first describes the methods for applying a WiFi positioning system to acquiring the trajectories of junglefowl and chickens. Next, the procedures of the two experiments are detailed and the resulting data are shown. Last, some characteristics of the spatiotemporal behavior of the animals are discussed, together with the advantages and disadvantages of the WiFi positioning system.

MATERIALS AND METHODS

WiFi positioning system

We employed a WiFi positioning system developed by AeroScout (Redwood City, CA). The system consists of tags, activators, receivers (with antennas), power-over-Ethernet hubs, WiFi access points, and a managing engine. Tags are fixed on animals and send the position data (x–y coordinates) by radio waves. The weight of a tag is 35 g, and its dimensions are 62×40×17 mm. Receivers receive transmitted data from tags through an antenna and send the data to a managing engine by wire. The managing engine processes the position data through access points, and displays the positions of animals on its display in real time.

These devices were configured according to the environmental conditions of the experimental areas. Prior to the experiments reported in this paper, we tested the WiFi positioning system in the Koishikawa Botanical Garden in Tokyo to see what area a single receiver could cover in a tree-covered area. We found that the maximum distance between two receivers was 75 m.

The WiFi position system represents a position by a discrete point on a one-meter grid. Therefore, the precision of a position cannot be better than one meter. The time interval for transmitting two successive positions was set to one second. Therefore, a trajectory of a chicken is represented by the sequence of discrete time points on a discrete grid. The time interval may however be longer than one second, depending on environmental conditions in an experimental field, because transmission may fail.

In the following two subsections, we describe the materials and methods adopted in the experimental studies on junglefowl and on free-range chickens, respectively. Because Okabe *et al*. (2009) described the latter experiment in detail, we focus on the former, outlining the latter.

Materials and methods of the experimental study of junglefowl

The experimental field for the study of junglefowl was a 150×300 m area densely covered with trees and bushes near the Wildlife Research Center in Khao Ang Rue Nai Wildlife Sanctuary, Thailand (N13°24′32″–13°24′42″ and E101°52′37″– 101°52′42″). The experimental field was not enclosed and the natural environment outside the experimental field was similar. A 6 m wide road (the gray stripe in Figure 1) ran through this area. The configuration of the WiFi devices in the field is illustrated in Figure 1.

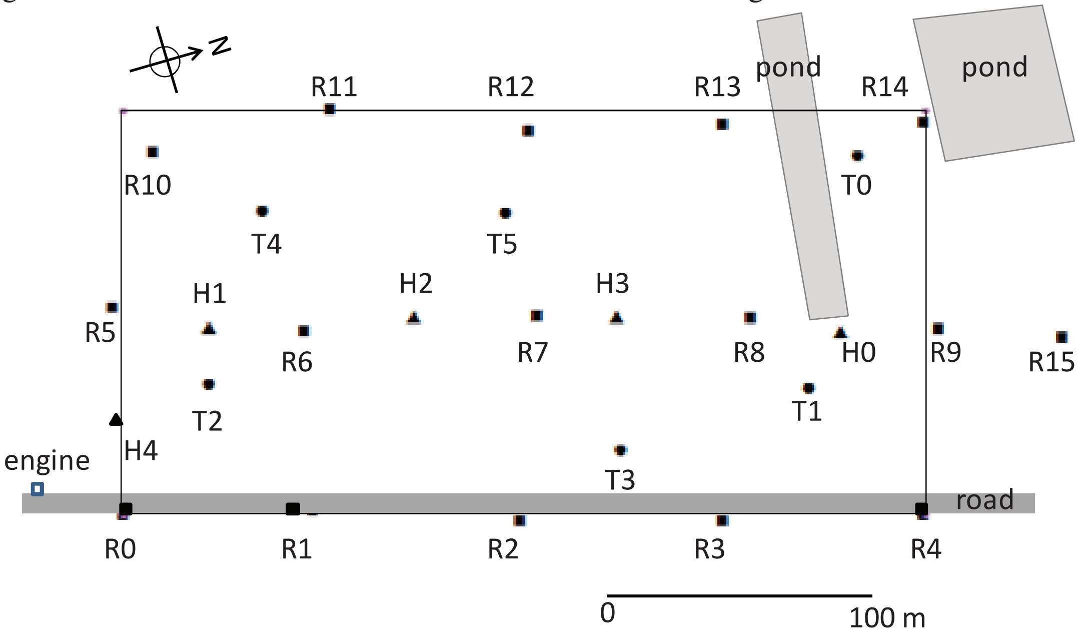

Figure 1 The configuration of the WiFi devices in the experiment field near the Wildlife Research Center in Khao Ang Rue Nai Wildlife Sanctuary, Thailand (R1–R15: receivers, H0–H4: hubs, T0–T5: fixed tags).

The experiment was carried out from February 12 to March 10, 2008 including installing and uninstalling the WiFi positioning system. Prior to this experiment, we observed junglefowl around the Wildlife Research Center (including the experimental field) over a year, and noticed that there were five junglefowl staying in or stepping into the experimental field. We trapped one male junglefowl (referred to as RJF1) on February 12; one male (RJF2) and one female (RJF3) on February 14; two males (RJF1 and RJF4) on February 16 (RJF1 was trapped again); and one male (RJF5) on March 4. We released them soon after fixing tags on their backs. The WiFi positioning system was able to record the positions of junglefowl (provided that they were within the experimental field) from February 22 to March 10.

Materials and methods of the experimental study of free-range chickens

The experimental field for the study of the free-range chickens was a cleared 200×200 m area surrounded by bushes (being naturally enclosed, this contrasted with the junglefowl case) and eight small concrete block one-storied houses (a few people lived in two houses (HH1 and HH2 in Figure 2) who worked outside during the daytime, while the other houses were empty) in the Chiang Rai Livestock Technology Transfer Center in Thailand ($N 19^{o}59'58'' - 20^{o}00'04''$ and $E 99^{o}49'50'' - 99^{o}49'58''$). The configuration of the WiFi devices and houses for humans and chickens in the experimental field is illustrated in Figure 2.

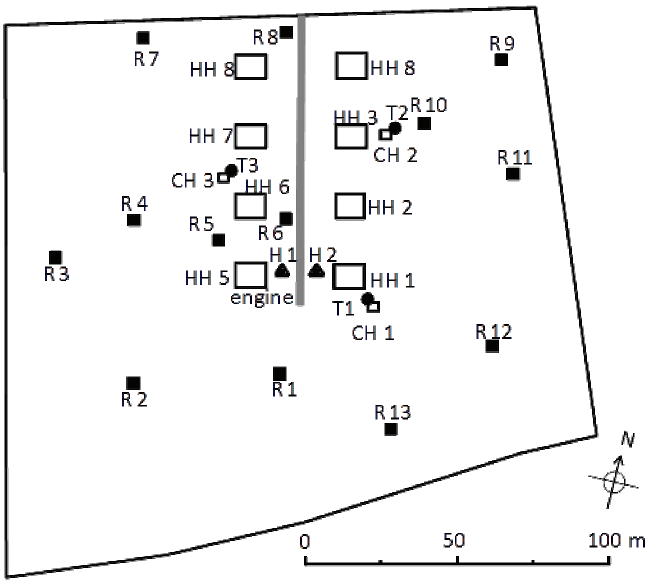

Figure 2 The configuration of the WiFi devices in the experimental field in the Chiang Rai Livestock Technology Transfer Center in Thailand (R1–R13: receivers, H1, H2: hubs, HH1–HH8: houses for humans, CH1–CH3: houses for chickens, T1–T3: fixed tags).

The subjects were eighteen chickens, called *Kai Chon* in Thai, and were moved to the chicken houses (CH1, CH2, and CH3 in Figure 2) on October 5, 2005. One 12-month-old cock (referred to as CH*i*_C1, where *i* corresponds to the *i*-th chicken house in Figure 2) and five hens of varying ages were kept in each chicken house CH*i*. Specifically, the composition of each family was as follows.

Chicken house CH1 housed one cock, denoted by CH1_C1, five 6–7-month-old hens with no baby chickens (chicks), CH1_H1, CH1_H2, …, CH1_H5;

Chicken house CH2 housed one cock CH2_C1, one 6–7-month-old hen with chicks, CH2_H1_M, two 2–3-month-old hens (young hens), CH2_H2_Y, CH2_H3_Y, and two 6–7-month-old hens without chicks, CH2_H4, CH2_H5;

Chicken house CH3 housed one cock CH3_C1, four 6–7-month-old hens without chicks, CH3_H1, CH3_H2, CH3_H3, CH3_H5, and one 6–7-month-old hen with chicks, CH3_H4_M.

The experiment was carried out from November 2 to 9, 2005. On November 3, we opened the doors of the chicken houses and let the chickens free. We continuously obtained the data from November 4 to November 9. Food was given once in the morning and once in the afternoon until November 5, but not thereafter although food that was given on November 5 remained available until November 6.

RESULTS AND DISCUSSION

We now discuss the spatiotemporal behavior of junglefowl and of free-range chickens, respectively, analyzing the data obtained from the two experiments.

The results of the experimental study of junglefowl and discussion

Because the results are heavily dependent on the quality of the data, we begin by discussing data quality, which was mainly determined by the stability of signal reception from the tags fixed on junglefowl moving in the experimental field. Unfortunately, the stability was less than we expected. There were at least four reasons. First was trouble with the receivers. During the experimental period, several receivers sometimes failed; specifically, receiver R3 (see Figure 1) on February 28 and 29, March 1, 2, and 8 for a few hours; receiver R4 on February 27 and 28 for a few hours; receiver R13 on March 8 for an hour; receivers R14 and R15 from February 29 to March 8 for three hours. It was difficult to maintain the large-scale WiFi positioning system for a month.

Second, the density of bushes was higher than that in the Koishikawa Botanical Garden. We realized that the bushes in the experimental field were a more obstructive factor than we had anticipated (as junglefowl walk on the ground).

Third, the experimental field looked flat, but it was actually slightly rolling. As a result, the radio waves transmitted from a junglefowl on the ground were interrupted by small hills.

To see the influence of these factors, we analyzed the position data of the fixed tags. In theory, the position of a fixed tag is supposed to remain the same, but in practice the coordinates of the fixed tags were distributed around the center with a directional bias (Figure 3); the average distance from the center was 3.62 m with a standard deviation 2.71 m, meaning 95% of points were within 6.63 m of the mean position. The position data were transmitted every second from the tags on junglefowl, but the received data had an average time interval of 7 seconds, with a standard deviation of 5.76 seconds. Many position data were lost during transmission and the time interval was very unstable.

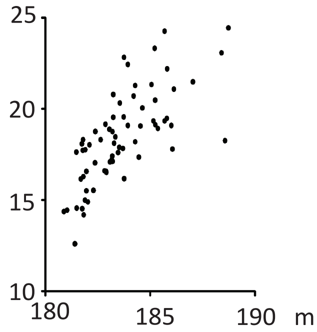

Figure 3 The coordinates of a fixed tag, T3 in Figure 1, from 07:59–09:04 on March 4while junglefowl RJF1 and RJF5 stayed in the experimental field. The origin is the left lower corner of the experimental field in Figure 1.

Finally, during nights when a junglefowl perched at about 10 m high on a roosting tree (we estimated the height from its droppings), the position data showed systematic large fluctuations. Assuming that the junglefowl did not move at night, we discarded those data. We also discarded position data from outside the experimental field because the WiFi system was imprecise outside the experimental field (although we acquired outside position data to some extent).

Together, those factors produced unstable position data. This instability made our analysis very hard and the implications are not always decisive. However, considering that this study is one of the earliest studies (probably the first) applying a WiFi positioning system to junglefowl, we describe our analysis and its implications, hoping that they are helpful for further studies on junglefowl.

As mentioned in the preceding section, we fixed tags on five junglefowl. However, only three junglefowl, RJF1, RJF4, and RJF5, went in and out of the experimental field. The periods over which those junglefowl stayed in the experimental field are shown in Figure 4 (the numbers along the line segments indicate the minutes of stay and those on the right margin indicate the total minutes in each day). Inspecting these time and position data, we identified the following eight findings.

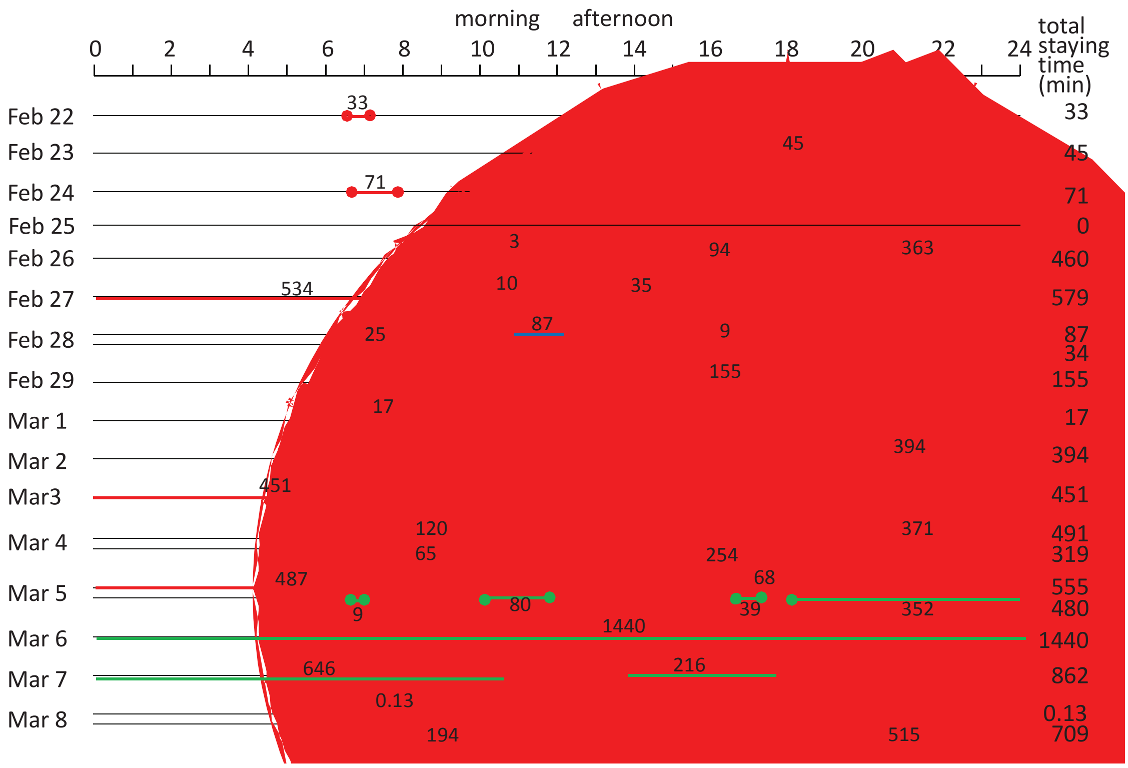

Figure 4 The time periods in which junglefowl RJF1 (red), RJF4 (blue), and RJF5 (green) stayed in the experimental field during February 22–March 8, 2008.

First, RJF1 dominated the experimental field in the period of February 22–March 3, 2008; RJF5 dominated in the period of March 6–8, 2008. The transition in dominance occurred during March 4–5. This implies that a 150×300 m area is dominated by one junglefowl and the replacement of the dominant junglefowl takes place over a few days (two days in this experiment).

Second, the periods in which two junglefowl stayed in the experimental field at the same time were very short except in the transition period. In fact, RJF1 and RJF5 were both in the experimental field for only eight seconds on one day (March 8). This implies that junglefowl are temporally separated in a 150×300 m area. In the transition period, however, both RJF1 and RJF5 stayed in the same field for 79 minutes on March 4 and for 39 minutes on March 5. The colocation on the second day (March 5) was much shorter than that in the first day (March 4) (also see Figures 5 and 6).

Figures 5 and 6 show the spatial relationship between RJF1 and RJF5 in the transition period. Inspecting these figures, we obtained the third finding: when both were in the experimental field at the same time, they were separated spatially, and the minimum distance between them was 121 m on March 4 and 108 m on March 5. When two junglefowl do not occupy the same place at the same time (i.e., the two do not meet at all), we call such a separation *temporal separation*.

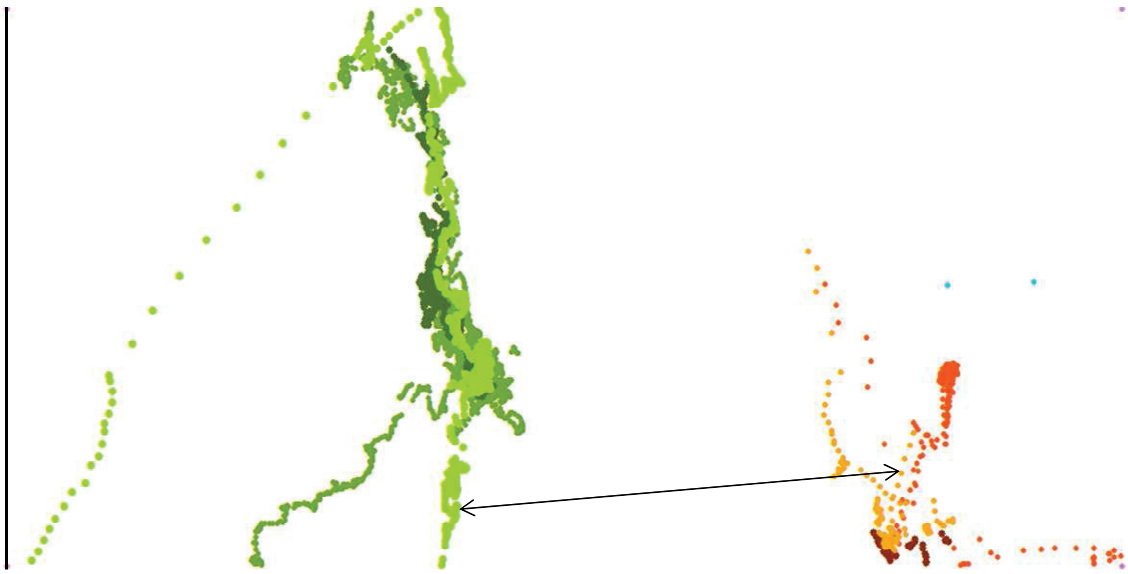

Figure 5 The positions of junglefowl RJF1 and RJF5 on March 4. The light-brown and light-green dots indicate the positions of RJF1 and RJF5, respectively, during 07:59–09:04; the dark-brown and dark-green dots indicate those during 18:04–18:18 (in these two periods, RJF1 and RJF5 coexisted in this field); the medium-brown and green dots indicate their positions during the rest of the time periods while the junglefowl stayed in this experimental field. Note that some of those dots overlap. The line segment indicates the minimum distance, which was observed at 09:02.

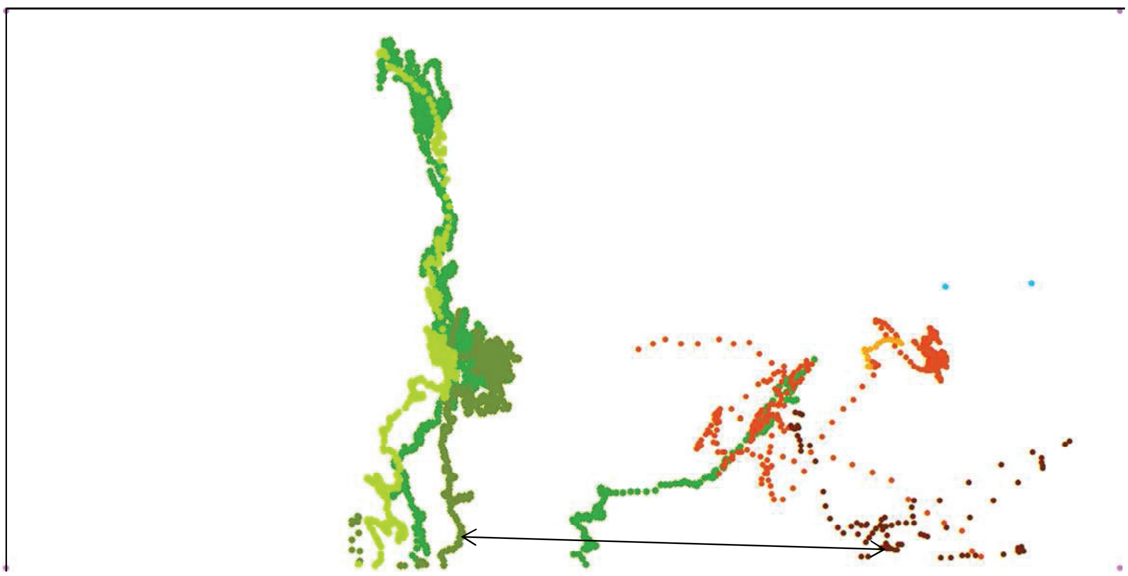

Figure 6 The positions of junglefowl RJF1 and RJF5 on March 5 (see the caption in Figure 5 except the time periods are 06:42–06:51 and 16:44–17:14). The line segment indicates the minimum distance, which was observed at 17:09.

Having noticed the temporal separation of junglefowl, we now question whether or not a junglefowl, say RJF5, walks in the area where another junglefowl, RJF1, once stayed but is now out of the area. That is to say, may two junglefowl visit the same place at a different time? To discuss this spatial relation, we introduce the concept of *home range*, which is defined as the minimum convex area that includes all the positions that a junglefowl visits at least once during a long period of time. The above question is then stated as: can two home ranges overlap? If not, we say such a separation is *spatial separation*. Note that spatial separation implies temporal separation, but the converse is not always true. To examine spatial separation, we created Figure 7, where the red, blue, and green dots indicate the positions of junglefowl RJF1, RJF4, and RJF5, respectively. The brown and green broken-line polygons in Figure 7 indicate the home rages of RJF1 and RJF5, respectively (note that the green dots outside the green broken-line polygon were the trajectory of a researcher carrying RJF5 into the area).

This figure shows the fourth finding: their home ranges overlapped and the overlapping area of RJF5 was 8% of its home range; sometimes a junglefowl stepped into the home range of another as if the junglefowl made a reconnaissance visit to that area.

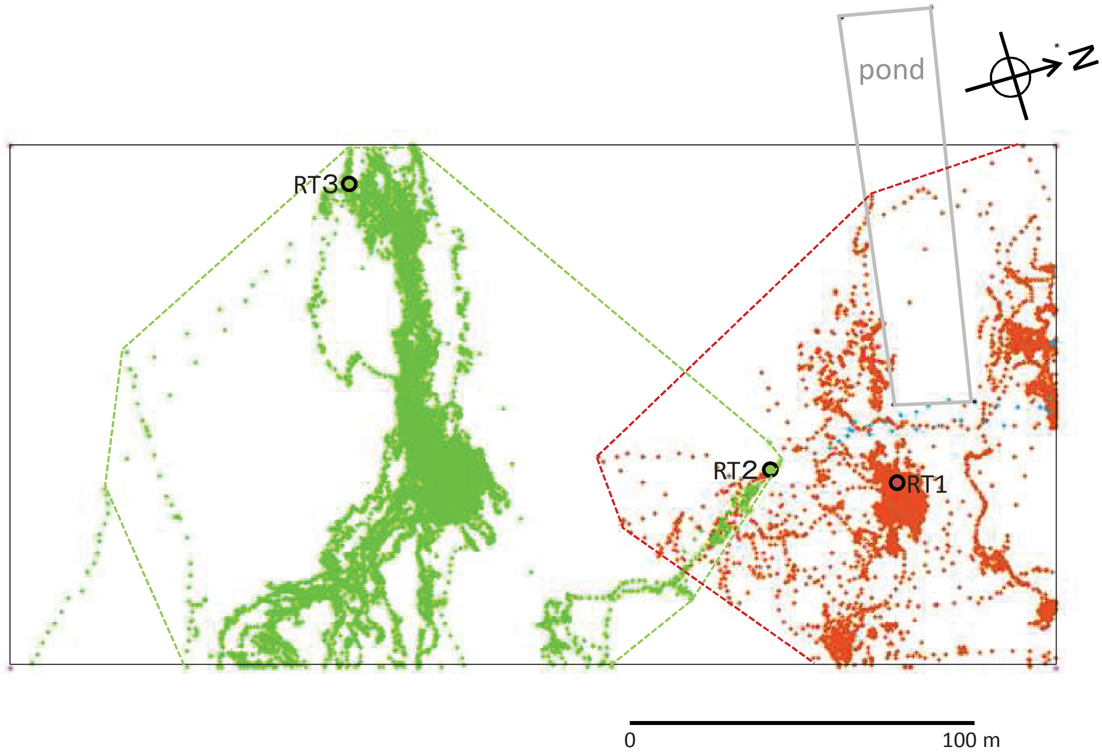

Figure 7 The positions of junglefowl RJF1 (red), RJF4 (blue), and RJF5 (green) in the experimental field during February 22–March 8, 2008. The black circles indicate roosting trees.

Both RJF1 and RJF5 repeatedly left and entered the experimental field. Therefore, it is difficult to estimate the area of the home range of a junglefowl, but RJF5 remained in the field almost all day on March 6. This is the fifth finding: the lower bound of RJF5's home range was 20.6 ha.

The sixth finding is about roosting places. As noted from Figure 4, RJF1 roosted at RT1 in Figure 7 on February 26, March 2, and March 4; RJF5 roosted at RT2 on March 5 and at RT3 on March 6 and 8. These facts imply that junglefowl do not always roost on the same place; they have a few favorite roosting trees and they wander from roosting tree to roosting tree.

The seventh finding is that the average walking speed of RJF5 was 32 m/min (1.92 km/h). It should be noted that its variance was so large (the standard deviation was 47 m/min) that the average speed might be a misleading value. This partly resulted from the variance in time intervals available for estimating speed. As noted earlier, the time intervals at which data was received by the WiFi system were not constant, although tags transmitted data every second. The time interval was sometimes one second but sometimes ten minutes. This variation gives different meanings of speed; for instance, a 32 m walk during one minute may be different from a 1.92 km walk in one hour (although they are mathematically the same speed), because a junglefowl may stop walking for a few minutes during the one hour. We may call the troublesome problem resulting from differences in time units (intervals) the *modifiable time unit problem*, which corresponds to the *modifiable area unit problem*, a notorious problem known in spatial analysis (Openshaw, 1984).

While the last finding is uncertain, it may be worth noting for further studies. We observed that junglefowl flew; in fact, when we released junglefowl, some of them flew away. They were soon out of sight in trees and it was difficult to see where they landed. In inspecting the data we found, fortunately, that RJF1 crossed a pond twice (see Figure 7), implying that RJF1 must have flown across the pond twice. We estimated from those data that in the case of a 12 m flight, the flying speed was 45 m/min (2.7 km/h); in the case of 52 m flight, the flying speed was 415 m/min (24.92 km/h). We were bewildered by this great difference, but recalling that the spatial resolution of the system was 3.62 m, we consider the latter value to be more reliable than the former, because of the much longer flight distance. In addition, we observed in a well-controlled experiment carried out in a park in Tokyo on February 17, 2007 that the maximum speed (almost flying) of a white leghorn was 367 m/min (22 km/h). Alternatively, it may be that the junglefowl hovered during the 12 m flight, because, as seen in Figure 7, the flight was not straight, but crooked. Further experimental studies are necessary to confirm the flying speed of a junglefowl.

The WiFi positioning system was actually useful for obtaining the above results, but installing and uninstalling the system in a bushy area required much labor and cost. In addition, the installation of the system possibly caused some junglefowl to leave the experimental field; in fact, we never received data from RJF2 and RJF3. We wanted to continue the experiment to stabilize the experimental environment, but our budget did not allow further continuation.

The results of the experimental study of free-range chickens and discussion

Like the study of junglefowl in the preceding subsection, position data were also unstable in this experiment but their stability was better. The fixed tags placed on the three chicken houses (Figure 2) showed that the positions of each fixed tag were dispersed over time around the center and that 95% points were within 5.63 m, which was shorter than in the junglefowl case by one meter. This better accuracy resulted from the fact that the field was mainly cleared ground with a few trees. With this accuracy in mind, we analyzed the spatiotemporal behavior of free-range chickens.

“Free”, as in free-range chickens, does not imply that chickens can walk freely around a field; their walking ranges are spatially restricted to some extent because of the interaction between chickens. We estimated the home ranges of the chickens by the kernel density estimation method (Sliverman, 1998). According to Okabe *et al*. (2009), the major findings are as follows.

First, the shapes of the home ranges of the three cocks were different, although they overlapped to some extent. This overlap was larger than that of junglefowl.

Second, there existed hens whose home rages were almost the same as their cocks (some hens followed their cocks). CH1_H1–H5 and CH2_H4 followed CH1_C1; CH2_H5 followed CH2_C1; and finally CH3_H1–H3 and CH3_H5 followed CH3_C1.

Third, the home ranges of the young hens CH2_H2_Y and CH2_H3_Y were different from those of the cocks.

Fourth, the home ranges of the hens with chicks were different from those of the cocks. The home range of the hen CH_H3_M with chicks was similar to those of the young hens during November 6–7, but then it was different on November 8.

Fifth, the groups formed in daytime were different from the groups as originally kept in the chicken houses. After being freed, the groups were: CH1_C1, CH1_H1–H5, CH2_H4; CH2_C1, CH2_H5; CH3_C1, CH3_H1–H4; CH2_H2_Y, CH2_H3_Y; CH1_H1_M; and CH3_H4_M.

Sixth, the chickens that form a group in daytime did not always sleep at the same site at night. The sleeping site of CH2_H5 was different from that of CH2_C1 and the sleeping site of CH2_H4 was different from that of CH1_C1, CH1_H1-H5. Chickens that belong to different groups in daytime may sleep at the same site. CH3_H4_M and CH2_H2_Y, CH2_H3_Y slept at the same site, the house CH2

Seventh, the chickens did not always sleep at the houses where they were originally kept. We observed that CH2_C1 slept under the floor of house H5; CH2_H4 and CH2_H5 slept in a tree near H5 and a tree in the east of the field (triangle in Figure 2), respectively; CH1_H1 was evicted from CH1 and slept on the roof of CH1.

Last, the home range expanded when food was not given, but the extent of expansion differed from chicken to chicken. In particular, the expansion rate of the young hens was large.

Having found the above behavioral characteristics of free-range chickens as well as those of junglefowl, we consider that the WiFi positioning system was very useful for continuously observing animal behavior over space and time. However, we noticed a few disadvantages of this system. First, WiFi devices are expensive. Second, the installation of the system requires several days with much labor. Third, the system cannot be employed in areas that humans cannot access. The WiFi positioning system, a new information technology, has these shortcomings, but with the rapid recent progress of information technologies, we expect that a new positioning system will be invented in near future to overcome those disadvantages and reveal the detailed spatiotemporal behavior of animals.

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REFERENCES

Ando, S and Osawa,A. 1970. Telemetry of the behavior of Pale thrush（*Turdus pallidus*）. Japanese Journal of Ecology , 20, 137-144.

El-Rabbany, A. 2006. Introduction to GPS: The Global Positioning System. Artech House.

Millspauch, J. and Marzluff, J. 2001, Radio Tracking and Animal Populations. Academic Press, New York.

Okabe, A., Satoh, T., Okabe, K., Nakagawa, T., Imamura, E., Matsushita, K., Nagano, K., Ishiwatari, Y., Amemoto, K., Hayashi. Y., Humihito, A. 2006. Applicability of a Wireless Fidelity Positioning System to Tracking Free-range Chickens (Gallus gallus domesticus) and Helmeted Guineafowl (Numida meleagris galeata). Journal of the Yamashina Institute for Ornithology, 38(1), 30-39.

Okabe, A., Satoh, T., Okabe, K., Imamura, E., Morathop, S., Jailanlka, C., Ratanasermpong, S., Hayashi, Y., Akishinonomiya, F. 2009. Home ranges of free-range chickens observed by a Wireless Fidelity (WiFi) positioning system. In H.R.H. Princess Maha Chakri Sirindhorn and H.I.H. Prince Akishinonomiya Fumihito (eds.). Chickens and Humans in Thailand: Their Multiple Relationships and Domenstication, 98-108.

Openshaw, S. 1984. The Modifiable Areal Unit Problem. Geo Books, Norwich.

Silverman, B.W. 1998. Density Estimation for Statistics and Data Analysis. Chapman & Hall/CRC, London.