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SHORT COMMUNICATION **Regional Study**

A local case report of dispersal characteristics in two male raccoons (*Procyon lotor*) in Oita Prefecture, Japan, revealed using Geographic Information System

Minami W. Okuyama[1,2], Yoshihisa Tsurunari[1], Ken-ichiro Shimada[3] and Kei Uchida[4]

[1] Center for Education and Research of Disaster Risk Reduction and Redesign, Oita University
700 Dannoharu, Oita-shi, Oita 870-1192, Japan
[2] Faculty of Medicine, Oita University
1-1, Idaigaoka, Yufu City, Oita 879-5593, Japan
[3] Environmental Policy Division, Environmental Affairs Department, Oita City
2-31, Niagemachi, Oita 870-8504, Japan
[4] NPO Oita environmental conservation forum
6-50-304, Nishishinchi 2, Oita 870-0901, Japan

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Abstract

Behavioral differences during and before/after dispersal were identified in two male raccoons (*Procyon lotor*) fitted using global positioning system (GPS) collars in Oita Prefecture, Japan. One male raccoon dispersed in a yearling spring, whereas the other dispersed in a yearling winter. The timing and direction of dispersal might reflect raccoon density in terms of differences in harvest pressure between municipalities in Oita. In both individuals, the average travel speed increased, and subsequently, the average travel distance per day rose during dispersal compared with periods before/after dispersal. During dispersal, forest use decreased, whereas artificial and agricultural land use increased in one individual, suggesting that this individual preferred anthropogenic areas for dispersal.

Key Words: GIS, male dispersal, raccoons

Dispersal is an important strategy for several species[18]. Natal dispersal in mammals is the movement of individuals spreading from the place where they were born to their first breeding site. Usually, a young animal leaves its birthplace permanently during mating dispersal[10]. Patterns of natal dispersal are typically male-biased in polygynous or promiscuous species[5,10]. Males may disperse to avoid competition for resources or females, or to avoid inbreeding with related females in the natal area[5,10,14,15]. Raccoons (*Procyon lotor*) possess a promiscuous mating system, mate in winter, and give birth in spring[9,11]. Young male raccoons usually practice natal dispersal, whereas those young females tend to remain within their natal areas[8]. The timing of young male raccoons' dispersal varies based on different sites conducted in North America, from juvenile (0 years old) autumn to yearling (1 year old) winter[3,6,8,21,22]. Thus, the timing of male dispersal could vary due to several factors, including their population density, food resource availability, and climatic conditions in the study area[3,6,8,21,22].

Understanding the details of raccoon

* Corresponding author: Minami W. Okuyama
Center for Education and Research of Disaster Risk Reduction and Redesign, Oita University
700 Dannoharu, Oita-shi, Oita 870-1192, Japan
E-mail: okuyama-m@oita-u.ac.jp
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Table 1. Individual information of three male raccoons fitted with GPS collars in this study

ID	The location of capture	The date of capture	Body weight (kg)	Crown rump length (cm)	Age class	Sexual maturation	Data collection period	Dispersal period
HIT1073	Hita city	18 Nov. 2019	3.8	ND*	Juvenile	Immature	19 Nov. 2019 - 6 May 2020	Not observed
OIT3067	Oita city	30 Dec. 2020	6.2	56.0	Yearling	Mature	1 Jan. 2021 - 29 Jul. 2021	1 Jan. 2021
YFU3161	Yufu city	7 Nov. 2021	5.8	53.5	Juvenile	Immature	12 Nov. 2021 - 29 May 2022	22 - 29 May 2022

ND*: No data

dispersal is warranted for managing the raccoon population. In Japan, where raccoons are invasive alien species under the Act on the Prevention of Adverse Ecological Impacts Caused by Designated Invasive Alien Species (Act No. 78 of 2004; Ministry of the Environment), an understanding of how their populations expand is significant to effectively manage undesirable invasions[23]. The interaction between dispersal distances and mate finding abilities affects the population growth rate, leading to the colonization of new areas[20]. Therefore, the present study aimed to identify the detailed behavior associated with the raccoons' dispersal using a time-based global positioning system (GPS) localization system, as well as to clarify differences in behavior during and before/after dispersal.

This study was conducted in Oita Prefecture, Japan. The study sites include Hita City, which has a mountain corridor, and Yufu City and Oita City, which are rural residential areas. The Oita University Animal Ethics Committee (Approval No. 195102, 225101) approved all study protocols. Live raccoons were captured in cage traps (Havahart Live Animal Cage Trap Model 1079; Woodstream, Lititz, PA, USA) under the municipal eradication program, and were immobilized by administering an intramuscular injection of a mixture of 50 mg ketamine hydrochloride (Ketalar, Daiichi Sankyo Propharma Co., Ltd., Tokyo, Japan) and 0.8 mg medetomidine hydrochloride (Dorbene Vet, Kyoritsu Seiyaku Co., Tokyo, Japan). Additional ketamine hydrochloride was injected if immobilization was insufficient. Data, including sex, weight, and crown rump length of the raccoons, were recorded. Individuals were categorized as juvenile (0 years old), yearling (1 year old), or adult (over 2 years old) based on their body size and degree of wear on the incisors. In case of males, the size of the testes, including the preputium and the extrusibility of the penis, was checked to identify whether sexual maturity had been attained[17].

In this study, three young male raccoons were fitted with GPS collars (GLT-02, Circuit Design, Inc., Nagano, Japan) weighing approximately 260 g, representing 4.2%–6.8% of their body weight. The raccoons were awakened by administering 0.8 mg atipamezole hydrochloride (Atipame, Kyoritsu Seiyaku Co.) as the medetomidine hydrochloride antagonist. The raccoons were kept in the cage trap until they were fully awake. They were then released after being given water jelly and confirming that they did not choke on it. After study completion, the raccoons with the GPS collars were recaptured under the municipal eradication program and euthanized.

Raccoons rest during the daytime and are active during the night[2,12,22]; thus, the GPS was programmed to record a single location every one hour from 18:00 h to 6:00 h. The location data was downloaded at least once a week using an antenna (LA-03, Circuit Design, Inc.), a GPS collar controller (GLR-02, Circuit Design, Inc.), and an Android application (GL-Link Manager2, Circuit Design, Inc.). The location data were converted to ArcGIS format version 9.3 (ESRI, California, USA). The location points were plotted onto a map using the latitude and longitude information. Time periods in which the location points did not overlap but rather demonstrated a unidirectional movement were defined as the "Dispersal Phases"[8]. In this study, dispersal was recorded in two males captured in Oita City and Yufu City (Table 1). The periods other than the dispersal period were divided into five phases, 1 month long each, and subsequent analysis was conducted to understand changes in behavior and

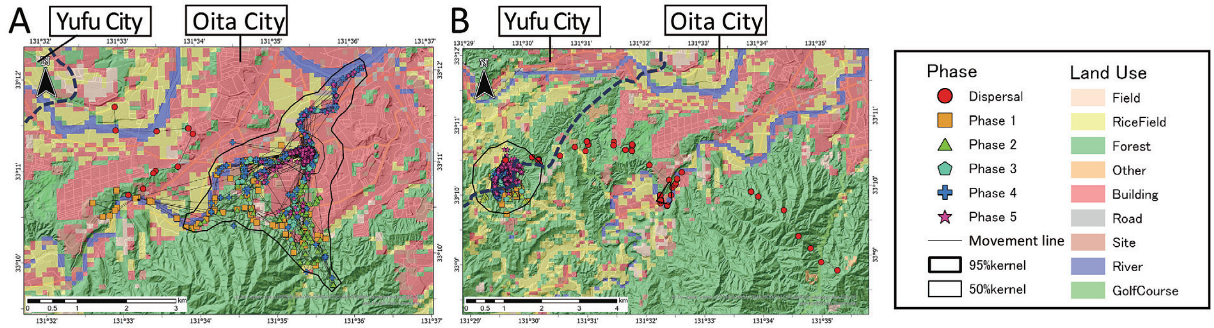

Fig. 1. Location data points of raccoon OIT3067 (A) and YFU3161 (B) in Oita Prefecture, Japan, displayed on a grayscale topographic map with a colored land-use patch background. Dark and thin lines represent home ranges calculated employing 95% and 50% fixed kernel methods, respectively. The dashed lines indicate a municipal boundary between Yufu City and Oita City.

land use over time before/after dispersal. Travel distance (m) and speed (m/h) were calculated from the location points. The 95% and 50% fixed kernel method[24] was employed for estimating the home range size. The adehabitatHR package for R was used for statistical analysis[1]. We utilized the land use subdivision 100 m square mesh data (the Digital National Land Information by Ministry of Land, Infrastructure, Transport and Tourism; https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-L03-b.html) and prepared a land-cover GIS layer. The total proportion of each land use type was identified by represented with the mesh data to which each point belongs, and was subdivided as: building: densely populated areas, such as residential and urban areas; site: athletic stadiums, airports, racetracks, baseball stadiums, schools, harbor areas, vacant land on artificially developed land, etc.; rivers and lakes: artificial lakes, natural lakes, ponds, fish farms, as well as rivers and riverbanks in river areas; forest: areas densely covered with perennial plants; rice field: wet, dry, marsh, and lotus rice fields and rice paddies; field: other agricultural land.

In two male raccoons, OIT3067 and YFU3161, which exhibited dispersal behavior, the total distance traveled during dispersal was 4.1 km and 14.3 km, which are almost within the range of 4.8 km[22] and 34 km[3], reported in previous studies conducted in North America. OIT3067 was a yearling at capture and became an adult in the following spring. It was fitted with a GPS collar and was released on December 31. It traveled from 6:00 AM on January 1 until 6:00 AM on January 2. This period was classified as the dispersal period (Supplementary Material, Figure S1, B). It then settled in a certain home range around a medium-sized river as classified in phases 1–5 (Supplementary Material, Figure S1, C-G). The other raccoon, YFU3161, was a juvenile at capture and became a yearling the following spring. It was fitted with a GPS collar and was released on November 8. It resided on its home range around small rivers in the Forest until May 21 (Supplementary Material, Figure S2, B–F). YFU3161 started to travel widely from 0:00 hours on May 22 and dispersed until it was recaptured at 20:00 on May 29 (Supplementary Material, Figure S2, G). One of the limitations of this study is that none of the individuals covered the entire period from the start to the end of dispersal. Therefore, the distance and duration of dispersal are underestimated, and both raccoons in this study likely traveled over longer distances for longer periods. Similarly, previous studies that employed the mark-recapture methods or radio telemetry methods, which calculate dispersal by connecting two points before and after a long travel, failed to demonstrate the entire dispersal process[3,6,8,21,22], particularly their trajectory and exact start and end time. High-frequency GPS is expected to help overcome the technical limitations of the mark-recapture and radio telemetry methods. However, the appropriate timing to capture raccoons needs to be set, considering battery life, which enables collecting data of the entire dispersal, whose start

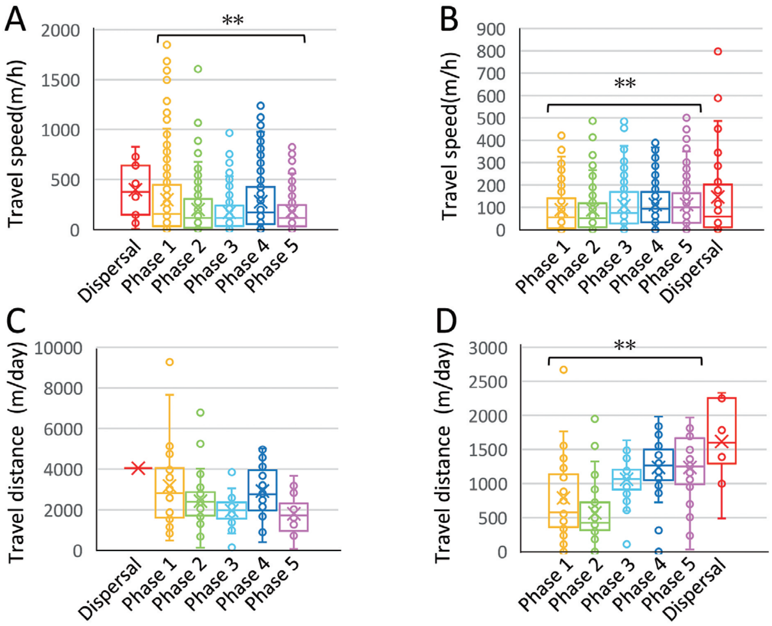

Fig. 2. Travel speed and distance of two male raccoons. A, B: Travel speed (m/h) and average speed across each phase (m/h) for OIT3067 (A) and YFU3161 (B). C, D: Travel distance per day (m/day) and average travel distance across each phase (m/day) for OIT3067 (C) and YFU3161 (D). Each figure illustrates significant differences using a Steel test, a pairwise comparison with the dispersal phase as the control group (**$P < 0.01$). In OIT3067 (C), the dispersal was recorded for one day, and only one data was obtained as travel distance per day, so it was excluded from the statistical analysis.

cannot be predicted. Further, releasing raccoons, which are designated as an invasive alien species in Japan, requires the understanding of those who capture them and the residents of the neighboring region. In particular, obtaining permission to re-release GPS-collared animals captured in remote locations can be challenging, making such research difficult.

In North America, the juvenile males have dispersed in autumn in Iowa[3], Michigan[21], and Ohio[22]. A study conducted by Clark et al.[3] has reported that some raccoons in Iowa mature quickly because of good habitat conditions, including abundance of waste grain, and can disperse in their first fall. In this present study, HIT1073 demonstrated no dispersal from November 19 (as a juvenile) to May 6 (as a yearling), when the location data were collected (Table 1). Two other individuals dispersed after becoming yearlings; however, differences in the timings of the dispersal were observed, indicating the unique situation surrounding raccoons in Japan, where they are designated as an invasive alien species and are subject to control and eradication. In Oita Prefecture, the population of raccoons is rapidly increasing, and the strength of the control measures varies from city to city. In raccoons, Capture per Unit Effort (CPUE), an indicator of the number of animals captured per 100 trap-nights (TN), demonstrates a significant positive correlation with the population size and has been confirmed to be an effective density index[13]. Due to low harvest pressure, higher densities of raccoons can be seen in Yufu City (CPUE: 11.11 raccoons/100TN during November 4–23, 2021, in this study), whereas high harvest pressure imposed by the local government, has led to low raccoon density in Oita City (CPUE: 0.49 raccoons/100TN from December 26, 2020, to January 28, 2021, and 0.00 raccoons/100TN from October 5, 2021, to January 12, 2022, in this study). YFU3161 remained in a high-density area of its birthplace in Yufu City and dispersed to Oita City in its yearling spring and was recaptured (Fig. 1B). The dispersal could be caused by the increased population density

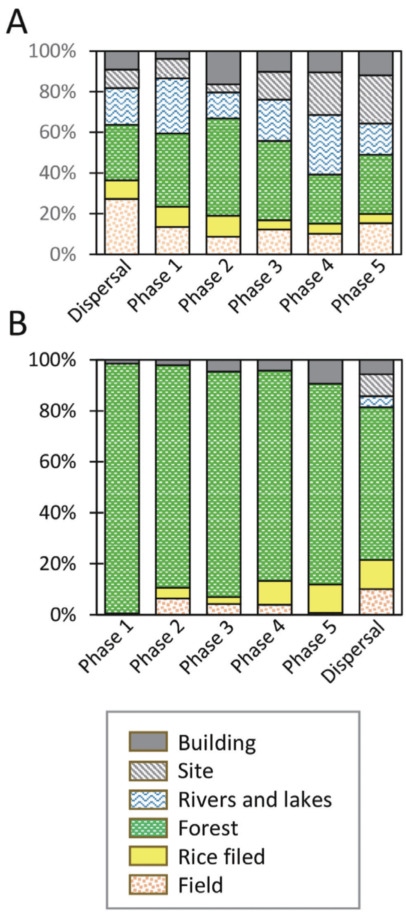

Fig. 3. Proportion of land use across each phase for two male raccoons, A: OIT3067 and B: YFU3161. In both figures (A, B), significant differences among phases were found by the Chi-square test ($P < 0.01$). During dispersal phase, no significant difference was observed in OIT3067 (A). In YFU3161 (B), the proportion of forest ($P < 0.05$), field, rivers and lakes, and site use ($P < 0.01$) showed significant discrepancies between the expected and observed values, with negative standard residual values for forest and positive for field, rivers and lakes, and site (Supplementary Material, Table S1).

in the natal home range after the spring birth season, and the dispersal could have happened due to intensified competition for resources at that time. The abundance and distribution of sustenance resources may play a major role in the movements and spatial distribution of certain small carnivores[19]. Dispersal of yearling spring male raccoons has been reported in Iowa[3] and North Dakota[7]. The raccoon, OIT3067, dispersed during the winter of its yearling, before its first mating season after attaining sexual maturity. The timing of the raccoon dispersal may be associated with either physical or sexual maturity, leading to geographic variation in the timing of the raccoon dispersal[7]. This individual dispersed from its natal habitat in search of mates and to attain physical distance from closely related females as a reproductive strategy. In Texas, most males had dispersed before their second breeding season when they were sexually mature, although the timing of raccoon dispersal varied between their first and second winters[8]. In raccoons, dominant males have their own territories[7], whereas subordinate young males who are unable to have their own territory wander into territories of dominant males, adopting a reproductive strategy that increases mating opportunities[9]. Furthermore, adult male raccoons respond to the death of an adjacent adult male by shifting into the dead male's former home range[7]. OIT3067, which was captured in Oita City near the municipal boundary of Yufu City, had settled in an area of Oita City with high harvest pressure after dispersal in winter (Fig. 1A), indicating that it could secure a home range during the breeding season after attaining sexual maturity.

Statistical analysis of travel speed and distance among each phase was conducted using Steel test for pairwise comparison with the dispersal phase as the control group (Fig. 2) using add-in software Statcel4 (OMS Ltd, Saitama, Japan) for Microsoft Excel. In both individuals, travel speed (m/h) in the dispersal phase was significantly higher than in any other phase ($P < 0.01$), with a higher average speed (Figs. 2A, 2B). In OIT3067, the dispersal was recorded for one day and only one data was obtained as travel distance per day; thus, it was excluded from the statistical analysis (Fig. 2C). In YFU3161, travel distance per day (m/day) in the dispersal phase was also significantly higher than any other phases ($P < 0.01$, Fig. 2D). Both animals demonstrated an increase in the average travel speed and consequently an increase in the distance traveled per day. In particular, during the dispersal period, they rested less frequently and continued to move, thereby covering longer distances in shorter periods.

Fig. 3 illustrates the proportion of land use in each phase. A Chi-square test based on a two-way contingency table[4] (6 phases by 6 categories of land use) by software Statcel4 was used for data analysis. Significant differences among phases were found in both individuals ($P < 0.01$) by the Chi-square test. Thus, a standard residual analysis as post hoc[16] was applied to identify which combinations (phase by category) showed significant discrepancies between the expected and observed values (Supplementary Material, Table S1). Focusing on dispersal phase, no significant difference was observed in OIT3067 (Supplementary Material, Table S1, A). However, in YFU3161, the proportion of forest, field, rivers and lakes, and site use showed significant discrepancies, with negative standard residual values for forest and positive for field, rivers and lakes, and site (Supplementary Material, Table S1, B). The results indicated that YFU3161 decreased the use of forest and increased use of artificial and agricultural land, suggesting that this individual preferred anthropogenic areas during dispersal.

The present study, although conducted on only three animals (two of which were dispersed) as a local case, is the first to have described some characteristics of dispersal behavior observed in young male raccoons, including hourly travel speed, daily distance traveled, and the characteristics of the land used during and before/after dispersal. This study indicated that the difference in harvest pressure between municipalities in Oita Prefecture is responsible for differences in population density, which in turn may be responsible for the variations in the dispersal timing and dispersal direction of young male raccoons. To promote an eradication program that prevents the influx of raccoons that disperse from high-density areas, setting up trapping points in more open sites where raccoons have a greater chance of moving around, including agricultural fields and artificial land in low-density areas, may be effective. Furthermore, the dispersal season is not consistent in Oita Prefecture; thus, applying capture pressure throughout the year is important. This study still raises questions about whether the capture locations of these two individuals can be considered within their natal home range, and whether the long-distance travel cannot be considered dispersal, as it simply reflects seasonal migration. Future research with a longer study period is expected to reveal these issues through GIS telemetry.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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