

Chapter 15

Behavior of Sika Deer in Clear-Cut Areas, Plantations, and Their Surroundings



Takahiro Ohba

Abstract In this chapter, I will report on the home ranges of sika deer in western Shizuoka Prefecture during an entire year when no seasonal migration occurred, based on highly accurate information regarding their location. The study area had well-established forestry industries and included clear-cuts and plantations, as well as their surroundings. The average home range of female sika deer ($n = 7$) in the study area was 73 ha (± 30.4 SD), which was fixed and had little overlap with neighboring herds. The overlapping core areas were limited to open environments suitable for sika deer feeding. The home ranges of male adults ($n = 2$) were 73–101 ha and separated by several kilometers, including during the mating period. Sika deer often invaded plantations at night in locations where protective fences had been installed, and the invasions lasted until the fence was repaired. As sika deer did not immediately reinvade the plantation area following the repair, the protective fences were considered to be highly effective. However, they took advantage of some of the entrances created by wild boars who had broken the protective fences. As such, the removal of individuals with home ranges around plantations, in addition to reducing labor costs and ensuring the effective management of protective fences, is important to reduce feeding damage caused by sika deer.

15.1 Introduction

Approximately 60% (25.1 million ha) of Japan's land area is covered by forests, of which approximately 40% (10.35 million ha) are plantations. In these areas, conifers suitable for architectural purposes, such as the fast-growing Japanese cedar (*Cryptomeria japonica*) and the Japanese cypress (*Chamaecyparis obtusa*), have been planted. Many of these plantations were established during the post-World War II period of reconstruction and high economic growth (1950–1970) because of a policy

T. Ohba (✉)

Forestry and Forest Products Research Center, Shizuoka Prefectural Research Institute of Agriculture and Forestry, Hamamatsu, Shizuoka, Japan
e-mail: takahiro1_ohba@pref.shizuoka.lg.jp

aimed at expanding forests by cutting down those consisting of natural broad-leaved trees and replacing them with conifer-centered plantations. Currently, most plantations have reached their harvest period after more than 50 years of being planted. However, the presence of sika deer, which damages planted trees, is a major obstacle to the clear-cutting and reforestation of plantations that have reached their harvest season. Forest damage by sika deer became apparent at the beginning of the 1990s, and approximately 20% of forests nationwide have been damaged by these animals in recent years. Approximately 6000–7000 ha of plantations are damaged per year, accounting for approximately 80% of the forest damage caused by wild birds and animals (Ministry of Agriculture, Forestry, and Fisheries [MAFF] 2021).

Sika deer can damage forestry systems by not only causing the slow growth and death of plantation trees and material deterioration due to peeling but also being responsible for the peeling of bark (Iijima and Nagaike 2015) and feeding on standing tree saplings (Akashi et al. 2015; Uno et al. 2019) in natural forests. They also feed on herbaceous plants in the understory of forests (Tamura and Yamane 2017) and semi-natural grasslands (Otsu et al. 2019) resulting in the loss of these species and soil erosion (Furusawa et al. 2003; Chaps. 23 and 27). Additionally, there are concerns related to the decline of potential ecosystem services and ecosystem functions of forests, such as national land conservation and water recharge (Ministry of Agriculture, Forestry, and Fisheries [MAFF] 2021).

To reduce the impact of sika deer on forestry systems and natural forests, it is necessary to continue culling or relocating animals that are in excess of the expected increase of the population in natural conditions and reduce the numbers (Iijima et al. 2013; Chap. 16). In particular, using measures that are based on detailed behavioral information of sika deer as part of forestry operations is important, so that their capture in forestry sites with clear-cuts or plantations is more effective.

This chapter describes a follow-up survey that was conducted to clarify the home ranges of sika deer inhabiting the clear-cut areas, plantations, and their surroundings, as well as the frequency and timing of invasion into plantations to ensure the effectiveness of captures and maintenance of protective fences in the study area. For this survey, a collar including a telemetry transmitter with a global navigation satellite system receiver (hereafter, “GPS collar”) was attached to sika deer.

Prior to the analysis, the accuracy of location data was verified. Even if there were clearly large errors in some points in the obtained location data, in some cases, these could not be excluded by only using an index value indicating the degree of deterioration of positioning accuracy, determined with the number of GPS satellites used to calculate the position, as well as their arrangement. The main cause for this was the multi-path error due to receiving reflected radio waves. With car navigation and portable GPS systems, it is possible to converge multi-path errors by providing continuous locations. However, as the GPS collars used calculation procedures and time limits that only enabled positioning for short periods to reduce battery consumption, it was impossible to correct the error. Therefore, I used another method for extracting highly accurate location points by setting reference values for the elevation error and dilution of precision (DOP) values.

Sika deer's preferred plants flourish in sunny clear-cuts and plantations and attract these animals to such areas, which induces feeding damage to planted trees. As such, the installation of protective fences, as well as their maintenance, is indispensable for the prevention of feeding damage. However, as damage to protective fences themselves and the invasion of wild animals are unpredictable, regular patrolling is required, which involves hiking on steep terrain and high labor costs. Therefore, to save labor costs in patrols, prevent intrusion in a short period of time, and build an animal intrusion detection and reporting system that suppresses damage to planted seedlings, a machine monitoring test was conducted in which a sensor was installed inside the protective fence to detect and report animal invasions.

15.2 Survey Site

The survey site spans across Hamamatsu City, including Tenryu-ku, Sakuma-cho, and Tatsuyama-cho in western Shizuoka prefecture, which is approximately 200 km west of Tokyo. The site includes the Kashi (1059 m altitude) and Shirakura (1027 m altitude) mountains, and a massif where the Tenryu River moves southward to the east (35°N, 137.8°E). Japanese cedar and Japanese cypress plantations represent most of the study area's vegetation, and in recent years, clear-cutting and reforestation have been promoted in the central part of national forests.

The survey site adjoins AMEDAS Sakuma Observatory (latitude 35.1°N, longitude 137.8°E, altitude 150 m), where an average annual rainfall of 2231.8 mm and an average annual temperature of 14.6 °C have been recorded. There is occasional snowfall in winter, but snowfall is not continuous.

15.3 Methods

15.3.1 Extraction of Location Data With Reduced Error

From April to June 2010, GPS collars (Tellus Basic 1D; GPS chip SirfSTARIII, Followit AB, Lindesberg, Örebro, Sweden) were placed in five sites outside the survey area (in Shizuoka Prefecture) with different topography and vegetation conditions: an open area on the roof of a building, a flat Japanese cypress forest on a hill, a Japanese cedar forest on a north-facing slope, a Japanese cypress forest on a north-facing valley, and a Japanese cedar forest on a northeast-facing valley. The collars were fixed with a tripod, and location data was collected for 8–11 consecutive days. Using the obtained location results, I examined a method for extracting data with reduced error.

15.3.2 Home Range

A tranquilizer gun was used to administer xylazine-ketamine to immobilize the animals so that the GPS collars could be placed. I used a syringe with a capacity of 3 ml. The amount of ketamine was 333 mg/3 ml and the amount of xylazine was 57 mg/3 ml, and this composition was the same for all individuals. All procedures involving animal capture were approved by Shizuoka Prefecture under “Wildlife Protection and Proper Hunting Act” (Ministry of the Environment). Ketamine hydrochloride was administered by a trained individual licensed by a drug researcher under the Drug Control Act. Individuals that escaped after being shot with the tranquilizers and later became immobile were searched using infrared thermography (PS-32, Teledyne FLIR LLC, Wilsonville, Oregon, USA). The GPS collars (GLT-03, Circuit Design, Inc., Azumino City, Nagano, Japan) were attached to the immobilized individuals, and their body weights were measured. The GPS collars were fitted to ensure that they would not slide out of their heads, but also not tighten or scratch the animal’s neck. In addition, an ear tag (Aussie tag/F2+LM1 With number, Fujihira Industry Co., Ltd., Bunkyo-ku, Tokyo, Japan) widely used in livestock management was attached so that individual identification was possible through direct observation or an automatic camera. After the work was completed, atipamezole hydrochloride was intramuscularly injected to promptly awake the animal.

A total of 21 deer were captured from 2013 to 2019, and the location data were obtained from 15 deer equipped with GPS collars, 3 males and 12 females. The remaining six animals did not recover from anesthesia and died. Separately, four individuals (9I, 10I, 11H, and 12J) were attracted by bait and automatically attached with a GPS collar for short-term tracking (Table 15.2, Fig. 15.1). Generally, location data was collected 12 times per day, every 2 h (every odd hour in Japan time).

The tracking of the individuals was based on the beacon waves emitted from the GPS collars. While checking the direction of the tracked individual using a directional antenna, the individuals were approached to a distance of several hundred meters and downloaded the position data by remote control. The Geographic

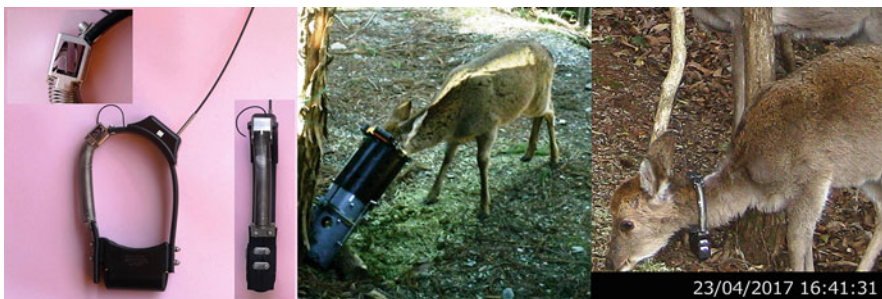


Fig. 15.1 Automatically attachment procedure of the GPS collar to the deer (№9I, №10I, №11H, №12J). A GPS collar was attached by triggering its deployment when the deer placed its head in the feeder to feed

Information System (GIS) software (ArcGIS Desktop ver.10 and ver.9 with Extension: Spatial Analyst, ESRI, Redlands, California, USA) was used to extract data with an altitude error of ≤ 30 m and a horizontal dilution of precision (HDOP) of ≤ 4 as high-precision location points. The Home Range Tools for ArcGIS (Center for Northern Forest Ecosystem Research 2007) were used to obtain the home range using the fixed kernel method. Since the home ranges need to be based on several highly accurate location points, the bandwidth was set to 20 m to prevent the home range from being extended to outside the used location points. The 95% fixed kernel was considered the home range area, and the 50% fixed kernel was considered the core area.

15.3.3 Invasion of Sika Deer into New Plantations Enclosed by Protective Fences

A pyroelectric infrared sensor, which is inexpensive and used in automatic photographic cameras, was used to detect the intrusion of sika deer. Five communication terminals (with pyroelectric infrared sensors) were installed in two plantations in the survey area and monitored from November 2020 to May 2021. However, since this sensor also detects temperature changes due to solar radiation, false detections during the daytime occur frequently, especially in areas with open environments, such as plantations. Therefore, monitoring was limited to nighttime to avoid false detections by the sensor, and detections were confirmed by the location information provided by the GPS collars to assess whether there was an intrusion by sika deer.

Among the GPS-tracked individuals, the locations of those that invaded the plantations enclosed by protective fences were analyzed with GIS software. The extracted high-precision location points were overlaid on the polygons created by the protective fences based on the field survey data and base map satellite images, and the location points that were inside the protective fence at the time of intrusion were extracted. The length of the intrusion period and the dates of stay for each day and night were estimated from the date and time details of the obtained location points. In this study, I considered daytime as the time from 9:00 to 15:00 h and nighttime as the time from 21:00 to 3:00 h. All the protective fences installed around the plantations in the study area had the same characteristics (height 1.8 m (bottom 1.0 m contains reinforced fibers), hem 0.6 m, 5 cm mesh polyethylene net).

15.4 Results and Discussion

15.4.1 Extraction of Location Data with Reduced Error

The success rate of positioning in conifer plantations was 96–99% (Table 15.1). However, at the position of the GPS collar installed at a fixed point, an error of up to

Table 15.1 Positioning and extraction results of GPS (Tellus Basic 1D, Follwitt AB, Sweden) for each condition

	Positioning success		3D positioning		HDOP ≤ 4		Elevation error ≤ 30 m		Highly accurate positioning points (D) & Exclusion point			
	(B) (B/A %)	ME (m)	(C) (C/B %)	ME (m)	(D) (D/B %)	ME (m)	(E) (E/B %)	ME (m)	(F) (F/B %)	ME (m)	(G) (G/B)	ME (m)
Terrain and vegetation												
Flat on a hill, open land	318 (100)	10.3	318 (100)	10.3	280 (88)	9.3	288 (91)	8.0	258 (81)	7.2	60 (19)	23.6
Flat on a hill, cypress forest	343 (99)	18.5	343 (100)	18.5	297 (87)	13.8	278 (81)	11.4	248 (72)	9.7	95 (28)	41.4
North-facing slope, cedar forest	334 (97)	38.5	301 (90)	37.3	213 (64)	33.0	99 (30)	17.5	75 (22)	15.1	259 (78)	45.2
North-facing valley, cypress forest	332 (96)	30.5	323 (97)	30.3	239 (72)	25.1	141 (42)	18.3	106 (32)	15.7	226 (68)	37.5
Northeast-facing valley, cedar forest	332 (97)	46.4	307 (92)	44.5	233 (70)	37.2	104 (31)	20.1	85 (26)	18.2	247 (74)	56.2

ME mean error

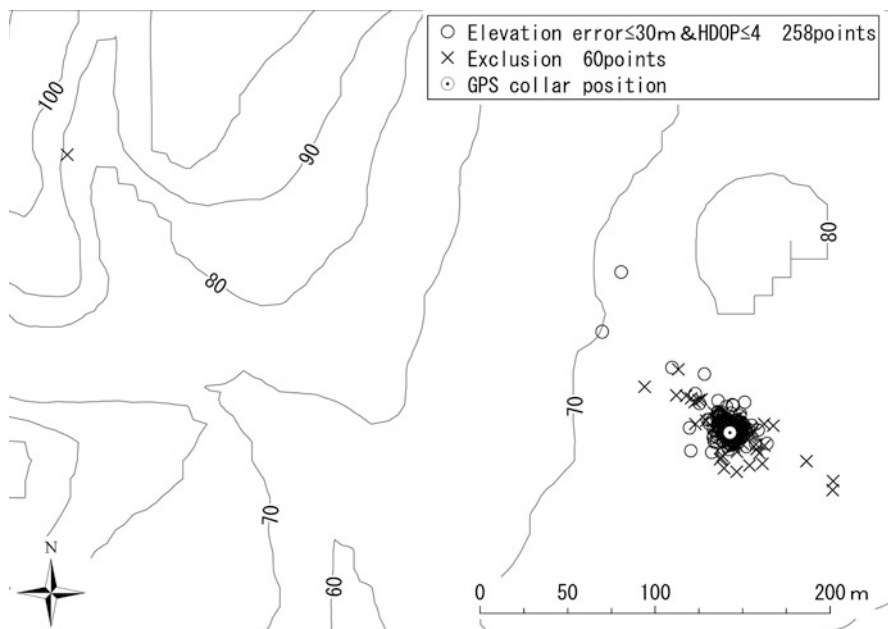


Fig. 15.2 High-precision positioning and exclusion points of GPS (Tellus Basic 1D, Followit, Sweden) for an open area on the roof of a building

several 100 m occurred in the horizontal distance, not only in the conifer plantations but also in the open areas and even for three-dimensional data (Figs. 15.2 and 15.3).

Therefore, using GIS software, most data with large horizontal errors could be excluded by comparing the elevation value obtained by the GPS collars installed at fixed points with the actual elevation value based on the horizontal coordinates of the data using the Fundamental Geospatial Data Digital Elevation Model and only extracting data whose difference was within a 30 m range. The elevation error is considered to be approximately twice the horizontal error (Department of Defense 2020).

Furthermore, if the HDOP value recorded when the location was collected was limited to 4 or less, the amount of data was reduced but the error was smaller. The average error was higher for three-dimensional data, followed by the HDOP, elevation error, and finally elevation error + HDOP (Table 15.1). However, even with this method, not all data containing errors could be excluded (Figs. 15.2 and 15.3). In addition, the proportion of data that could be extracted as high precision location points varied considerably because of differences in topography and vegetation (shielding) (Table 15.1).

Considering that data with large vertical errors tend to also have large horizontal errors, the elevation error of the three-dimensional data was used as the main criterion. Furthermore, by limiting the data to those with DOP below a certain

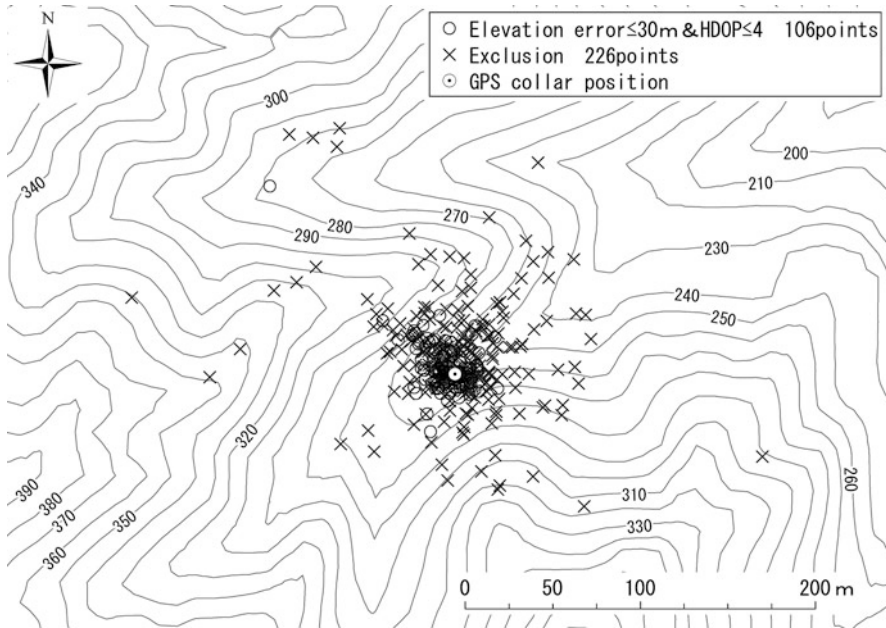


Fig. 15.3 High-precision positioning and exclusion points of GPS (Tellus Basic 1D, Followit, Sweden) in a cedar forest in a northeast-facing valley

level, it was possible to exclude location points with large errors to some extent. The extraction of data used for behavioral analyses from the location data of wild sika deer fitted with GPS collars using this method was considered appropriate. However, it should be noted that the location points, as well as their accuracy, are biased because of the influence of topography and vegetation (shielding) and do not accurately reflect the frequency of use; as such, the environment must be cautiously selected.

15.4.2 Home Range

The home range of seven females (1A, 3C, 5E, 8H, 14K, 16J, and 17L) that could be tracked for 350 days or more was 73.0 ± 30.4 ha (mean \pm SD) (Table 15.2); the core area was 10.2 ± 2.6 ha, which was 11–17% of the 95% home range kernel. Only two males (7G and 18 M) could be followed for more than 150 days, including during winter, whose home range was 73.0–101.0 ha and the core area was 7.6–16.4 ha.

When the location data of the tracked individuals was displayed together with GIS software, minimal home range overlap was found, except for the herds of 13K, 14K, and 15K, which were suspected to be infants with respective parents and may have been trapped in the protective fence and captured at the same time; the herds of

Table 15.2 Status of capture and tracking of sika deer and home range size in sugi and cypress plantations in western Shizuoka Prefecture, 2013–2019

ID	Date of capture	Tracking days	Sex and age	Body mass (kg)	Total points	High accuracy positioning ratio (%)	Area of home range kernel (ha)		GPS collar model
							95%	50%	
1A	17 Dec 2013	423	AF	(40)	5058	51.3	54.5	7.3	GLT-01
2B	24 Jan 2014	145	YF	32	1722	63.6	58.5	9.5	GPS PLUS
3C	29 Jul 2014	488	AF	36.5	5864	41.8	50.3	8.5	GLT-01
4D	29 Oct 2014	133	AF	(30)	1598	61.2	22.1	3.7	GLT-01
5E	5 Oct 2016	679	AF	40	8153	46.5	57.8	9.1	GLT-03
6F	19 Oct 2016	165	AF	43	1973	97.6	3.5	0.9	GLT-03
7G	21 Oct 2016	255	AM	62	3128	46.8	73.0	7.6	GLT-01
8H	27 Dec 2016	670	AF	35	8032	55.4	70.5	11.8	GLT-03
9I	22 Feb 2017	16	YM	–	136	51.5	11.2	1.7	GLT-02A
10I	4 Apr 2017	16	J	–	136	66.2	13.6	1.5	GLT-02A
11H	5 Apr 2017	17	J	–	144	42.4	12.1	2.1	GLT-02A
12J	10 Apr 2017	130	J	–	1004	54.3	23.4	4.8	GLT-02A
13K	31 Jan 2018	79	AF	42	913	69.2	49.6	7.5	GPS PLUS
14K	31 Jan 2018	355	YF	26	4126	55.7	80.6	10.7	GPS PLUS
15K	31 Jan 2018	642	J	19	7711	34.9	48.6	4.0	GLT-03
16J	14 Sep 2018	782	AF	48	9370	64.0	59.4	8.7	GLT-03
17L	16 Nov 2018	760	YF	24.5	9107	35.4	137.9	15.0	GLT-03
18M	6 Nov 2018	156	AM	(70)	1864	78.4	101.0	16.4	GLT-03
19N	7 Oct 2019	34	AM	(75)	406	74.4	13.4	1.6	GLT-03
Average home range for female deer						73.0 ± 30.4	10.2 ± 2.6		

The average home range (\pm SD) for female deer was calculated from tracking data collected more than 350 days, shown in bold ID ($n = 7$). These are the seven animals for which the average area of the action area was calculated
 AF adult female, YF yearling female, AM adult male, YM yearling male, J juvenile. Figures in parentheses showed estimated body mass

8H and 17L (tracking periods do not overlap), which invaded the same plantation; and the herds of 12J and 16J, 8H and 11H, and 9I and 10I (9I, 10I, 11H, and 12J had GPS collars automatically installed), whose home ranges overlapped considerably (Fig. 15.4). A survey conducted by Imura (1980) in the Tanzawa Mountains in Kanagawa Prefecture, which is located to the east of Shizuoka Prefecture, showed that field signs such as footprints and fecal content of sika deer were rarely found between some adjacent districts and that individual exchange between districts was uncommon. Additionally, the home range of the six herds based on field sign mapping was 50–80 ha (average 63 ha). The findings of this study showed similar home range sizes, which also did not directly overlap.

In winter, individuals 13K, 14K, and 15K moved their home range to approximately 3 km away from its original location but traveled back and forth between the two, which does not qualify as seasonal migration. Individual 17L made nine round trips to the bottom of the mountain between December and January, which was also not considered seasonal migration, although the reason for these behaviors could not be identified. Despite the occasional deviation, the other females did not move their home ranges to new locations during the tracking period.

The two male adults, 7G and 18M, had stable home ranges after moving away from the survey site in November. Since there was almost no snow cover during winter, it is appropriate to think that the males moved to areas where females inhabit only during the mating season and that they do not move or stay in wintering areas.

As shown in Fig. 15.4, the home range of tracked individuals considerably overlapped with that of the same herd or did not overlap much with other individuals' home range in a different herd. It is likely that the surrounding female herds that are not related avoid each other, and within the same herd the home range is shared and inherited by the blood relatives. As a result, the home ranges of these herds have become more fixed, and there is a possibility that the herds were living separately from each other. In this study, the home range of each sika deer herd was fixed, and there was little overlap between them, even in environments with several clear-cut and reforested areas. Therefore, the removal of sika deer with home ranges around the plantations is expected to reduce the risk of invasion. Notably, the capture and attraction of sika deer to improve the removal efficiency may only work on limited herds whose home ranges include these areas.

The findings of this study showed some overlap between the core areas of different herds, for instance, between those of 1A and 5E in Japanese star anise fields, 8H and 17L in conifer plantations with strong thinning management, and 14K and 16J in hardwood plantations without protective fences. Environments with several understory species are preferred by sika deer as feeding grounds, and if such spots are near the edge of their home range, these may be shared with neighboring herds.

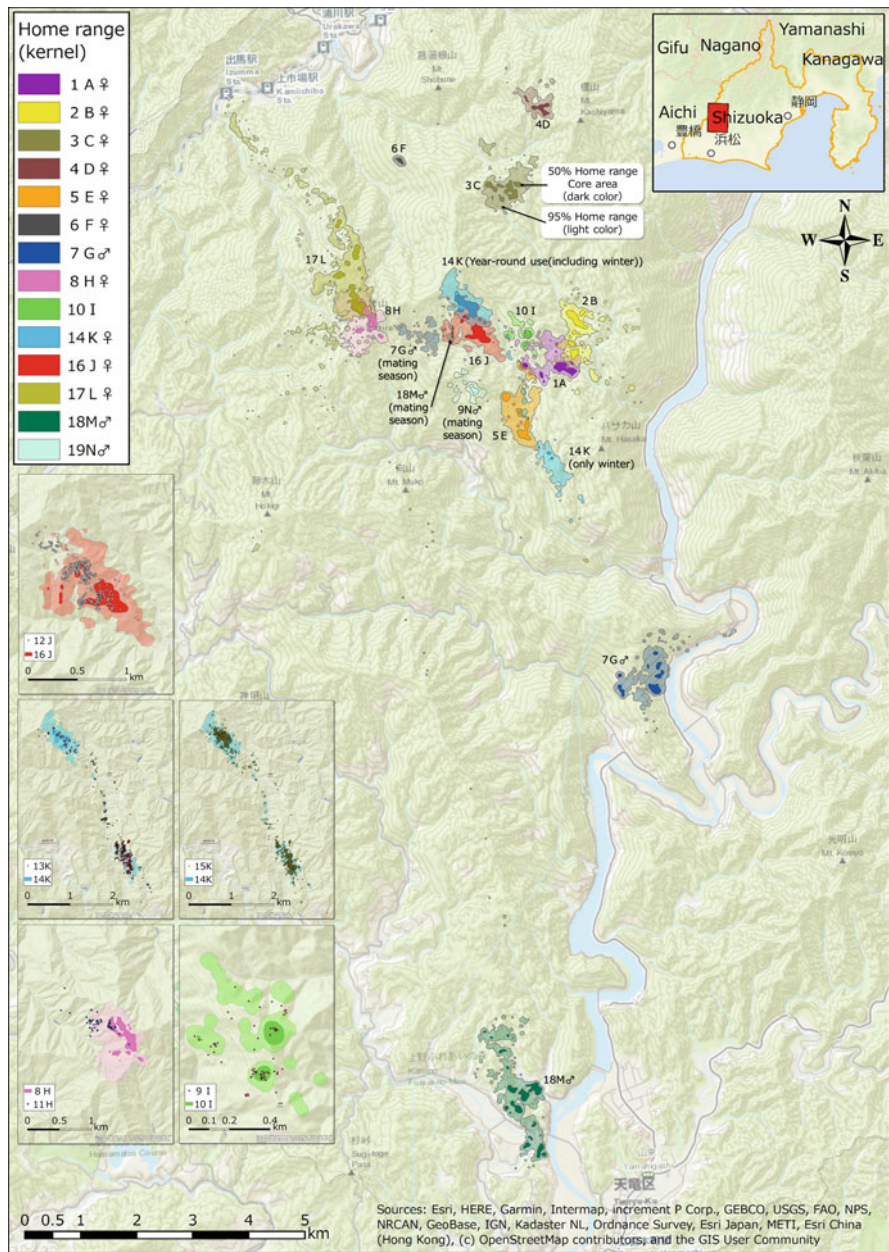


Fig. 15.4 Home range of 19 sika deer tracked in western Shizuoka Prefecture, 2013–2019

15.4.3 Invasion of Sika Deer into Plantations Enclosed by Protective Fences

Of the 19 individuals fitted with GPS collars, 6 (5E, 8H, 14K, 15K, 16J, and 17L) invaded the plantations where the protective fences had been installed (Table 15.2). Table 15.3 lists the characteristics of the plantations and the invasion. Although the invasion length varied, the percentage of days when sika deer were inside the fenced area at night was as high as 88–100%. However, the percentage of days when sika deer were inside the fenced area during the day was 0–87%, which was lower than that at night and had a large variation. As there was no individual that consistently invaded the plantations exclusively during the day, it was considered that limiting the monitoring period to nighttime would not considerably hinder the detection opportunity, as false detections by the pyroelectric infrared sensor are unlikely to occur. Based on this result, a machine monitoring test of the plantations was also conducted using an animal intrusion detection and notification system that combines a pyroelectric infrared sensor and low-power wide-area network communication.

The signal from the communication terminal was transmitted to a base station 7–10 km away via one repeater installed at a high location in the plantation and three

Table 15.3 The period and time of day when deer with GPS collar invade the planting area of the cedar and cypress

ID	Planting area	Planting date	Duration of invasion inside the fence	No. of days (A)	No. of days of invasion inside the fence (B) (B/A%)	Nighttime invasion (C) (C/B %)	Daytime invasion (D) (D/B %)
5E	Area A	May 2016	Aug 5–Dec 22, 2017	139	121 (87)	118 (98)	2 (2)
8H	Area B	Mar 2017	May 31–Jul 17, 2018	47	43 (91)	43 (100)	27 (63)
14K	Area C	May 2015	Oct 21–Oct 28, 2018	8	8 (100)	8 (100)	1 (13)
15K	Area C	May 2015	Oct 21–Oct 28, 2018	8	8 (100)	7 (88)	0 (0)
15K	Area C	May 2015	Jul 1–Oct 30, 2019 ^a	121 ^a	120 (99)	114 (95)	104 (87)
16J	Area D	Jun 2015	Nov 7, 2018–Apr 12, 2019	157	126 (80)	124 (98)	0 (0)
16J	Area D	Jun 2015	Dec 5, 2019–Mar 4, 2020	91	89 (98)	89 (100)	4 (4)
17L	Area B	Mar 2017	Mar 30–May 11, 2020	43	40 (93)	40 (100)	1 (3)

^aTracking period

repeaters installed in two transmission towers, where information was sent from the base station to the cloud server via a mobile phone line. Repeaters and communication terminals consume less power and run on batteries for long periods. Although the test in which made humans acted as invading animals was successful, verification of these results was attempted with an automatic camera, but there was no invasion of sika deer during that period.

It is likely that sika deer that invaded plantations often left those areas during the day. If the invasion of the sika deer was confirmed, it is possible to confine the individual inside the fence by closing the entrance at night. However, as occurred when individuals 8H and 15K invaded the plantations for a second time, sika deer sometimes remain there during the daytime; as such, when repairing the fence if it is broken, it is also necessary to ensure that no invading individuals are trapped.

Additionally, reinvasion did not occur immediately after repairing the fence with six animals. Based on this, it was considered that the avoidance effect of the protective fence on the sika deer was high (the sika deer's willingness to break through the protective fence was low). However, the holes in the fence's net with reinforced fibers were made by wild boars (*Sus scrofa*), which sika deer also used (Fig. 15.5). The wild boars' ability to cut the net is likely to be greater than that of sika deer, because of their fangs that can break through the protective fence causing the hem to flip up at the tip of their nose. Consequently, the effectiveness of the protective fence to prevent plantation damage from sika deer feeding may depend on the behavior of wild boars.

In conclusion, the removal of individuals with home ranges around plantations, in addition to reducing labor costs and ensuring the effective management of protective fences, is important to reduce feeding damage caused by sika deer in clear-cut areas and plantations.



Fig. 15.5 №16J exiting from the intrusion point (left), wild boar entering the planting area from the same point (right)

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