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Wildlife Science

Interspecific variation in wildlife responses to cattle, swine and chicken feed in the forests surrounding poultry farms

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ABSTRACT. To strengthen farm biosecurity, wildlife behaviors around livestock environments require significant attention. Livestock feed is considered one of essential factors that attract wildlife to the livestock environment. We experimentally studied wildlife response to cattle, swine, and chicken concentrated feeds in the forests surrounding poultry farms. In 14 feeding sites, four feed conditions were established: without feed (control); cattle feed; chicken feed; and swine feed. Wildlife behaviors at each feed point were monitored using infrared cameras. In 3,175 videos, 10 mammals were photographed on 10 or more occasions. Wildlife more frequently appeared at the points with feed than without feed. In addition, the number of videos that captured foraging or interest behaviors was largest for swine feed, followed by chicken feed, then cattle feed. There was a large difference among wildlife in their response to livestock feeds, although each species did not have a strong preference for a specific feed. Livestock feeds invite frequent visits by high and moderate response groups, especially omnivores and carnivores with omnivorous tendencies. Therefore, to protect against such wildlife intrusion, leftover feed and feed storage must be properly managed. This study also suggests that livestock feeds may not cause intrusions by rare response group species; hence, if their intrusions occur, they may be due to factors other than livestock feed. The study situation can partly reflect actual feed-stealing situations. The results will contribute to consider the properly management to protect livestock environments from wildlife intrusions.

KEYWORDS: feed damage, livestock, production management, wildlife

The sustainability of both agricultural and natural environments is in conflict, producing an inevitable problem. Damage caused by wildlife has become a serious problem in terms of environmental sustainability worldwide. In animal production, wildlife damage leads to economic [10] and time losses through damage to feed and facilities, as well as the spread of zoonotic diseases [7, 12, 14]. Cross-species disease transmission between wildlife, domestic animals, and humans is an increasing threat to public and veterinary health [8, 14, 22, 32, 33]. Hence, governments and administrations strongly promote the prevention of wildlife invasion to livestock farms to strengthen farm biosecurity. The behavior, ecology, and population dynamics of wildlife around livestock environments require significant attention [20, 21, 29, 31].

Wildlife often act as a carrier and/or vector of various diseases, including zoonotic diseases. As such, a number of studies have reported the epidemiological risks of wildlife. For example, in France, European badgers (*Meles meles*), wild boars (*Sus scrofa*), and red deer (*Cervus elaphus*), recognized reservoirs of bovine tuberculosis (bTB), frequently appear around farms, where indirect contact with cattle results in bTB inter-infection [16]. In Japan, salmonella has been isolated from crows and sika deer (*Cervus nippon*) in a cattle farmer [3], wild birds often carry bird flu [22, 33], and rats and wild birds mechanically transmit foot-and-mouth disease [15]. Additionally, there are many specific case reports of animal damage. In Japan, sika deer cause feed damage to crops [5] and silage [27], whereas rats bite wiring [9]. Given this accumulated information, there is an obvious need to consider effective countermeasures against wildlife-induced problems in agricultural environments.

On the other hand, wildlife have many reasons to appear in the livestock environment; these may relate to both the ecological characteristics of each wildlife species and the current environmental situation. Among these reasons, livestock feed is considered

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one of essential factors that attract wildlife to the livestock environment. Feed contaminated by wildlife excrement has been reported to be the source of salmonellosis and bTB infections, inducing the transmission of the pathogen [2, 4]. Therefore, feed damage directly induces economic costs and indirectly increases epidemiological risk through indirect contact between wildlife and livestock.

Wildlife behaviors toward feed are only occasionally observed, but feed damage frequently occurs on the farm. On commercial farms in Japan, the barns for housing beef and dairy cattle are relatively open, compared to those for swine and poultry, hence they are easily invaded by wildlife. Reports about wildlife feed-stealing are biased for cattle farms (e.g. raccoon dogs, *Nyctereutes procyonoides*: [27]; wild boar, *S. scrofa*: [27]). Sakamoto *et al*. [20] reported that raccoon dogs, feral cats (*Felis catus*), black rats (*Rattus rattus*), and house mice (*Mus musculus*) used an entire cattle farm and had indirectly contact with each other both in and out of the barns in southern Kyushu. In contrast, few studies have reported wildlife invasions on poultry (but see [23], [29]) and swine (but see [26]) farms; however, wildlife responses to feed and direct and/or indirect contact between animals on these farms are understudied. To create a logical strategy to strengthen farm biosecurity, there is an inevitable need to develop appropriate wildlife countermeasures; to achieve this, there is a need to understand the response of each wildlife species to specific livestock feed, the preferred livestock farm types, and the environmental situations that induce frequent the invasions of wildlife.

The components of cattle, swine, and chicken concentrated feeds are not hugely different (Fig. 1, Table 1). On the other hand, wildlife foraging behaviors may vary between species. Therefore, we hypothesized that most wildlife species would prefer all types of feed; hence, wildlife would appear more frequently with feed present than without feed present. In contrast, we hypothesized that the frequency of foraging behaviors would vary between species. To clarify the preferred feeds and species responses to livestock feeds, we experimentally studied wildlife response to cattle, swine, and chicken concentrated feeds using a cafeteria test-like method in the forests surrounding poultry farms in Miyazaki Prefecture.

MATERIALS AND METHODS

Study sites and feeding conditions

The appearance of wildlife may vary depending on the livestock species; hence, at the first step, the study was conducted around specific farms. In Miyazaki Prefecture, the bird flu is a serious problem. In addition, it is reported that wildlife intruding poultry farms often steal eggs and poultry [31], however it is unclear that livestock feeds could cause these wildlife invasions. Therefore, two feeding sites were set up in the seven forest areas near the poultry farms (maximum distance=2 km from the farm) in Miyazaki Prefecture (14 feeding sites in total). At each site, multiple wildlife species had been camera trapped during a preliminary survey conducted from January to July 2019. The seven sites are broad-leaved forests, four are coniferous, and three are mixed forests composed of broad-leaved and coniferous trees (Table 2). There are streams in the vicinity of five sites. In each site, four feed conditions were established: 1) without feed (control); 2) cattle feed; 3) chicken feed; and 4) swine feed (Fig. 2). The control

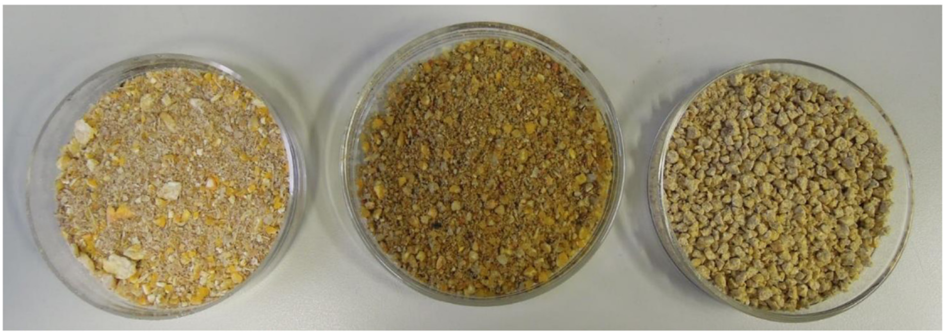

Fig. 1. Cattle, chicken, and swine feeds presented to wildlife in the study sites.

Table 1. Labeling data values on the feed ingredient compositions (%) of the commercial diets

Ingredient	Cattle	Chicken	Swine
Grains	67	64	81
Oil seed meal	7	18	16
Brans and food processing by-products	24	8	1
Animal origin feeds	0	3	0
Others	2	7	2

Table 2. Summary of the feeding sites and the number of videos photographed

Feeding sites	Forest types	Presence of streams	Camera trapped period	The number of videos photographed at each point				Total
				Control	Cattle	Chicken	Swine	
A1	Bload-leaved	Absence	9/30–10/7	6	54	130	157	347
A2	Mixed	Absence	9/30–10/7	6	150	86	–	242
B1	Bload-leaved	Presence	10/3–10/10	76	119	30	119	344
B2	Coniferous	Absence	10/3–10/10	7	–	42	37	86
C1	Bload-leaved	Absence	10/15–10/22	20	169	186	–	375
C2	Coniferous	Absence	10/15–10/22	3	2	–	37	42
D1	Bload-leaved	Presence	10/17–10/24	15	105	–	295	415
D2	Bload-leaved	Presence	10/17–10/24	4	119	115	96	334
E1	Coniferous	Absence	10/25–11/1	14	147	–	132	293
E2	Mixed	Absence	10/25–11/1	12	39	62	64	177
F1	Bload-leaved	Absence	10/29–11/5	4	21	24	107	156
F2	Bload-leaved	Presence	10/29–11/5	–	20	146	36	202
G1	Coniferous	Absence	11/11–11/18	1	5	1	1	8
G2	Mixed	Presence	11/11–11/18	11	12	76	210	309
Total				179	962	898	1,291	3,330

"Mixed" indicates the mixed forest composed of bload-leaved and coniferous trees. "–" indicates no data because of malfunction of the camera.

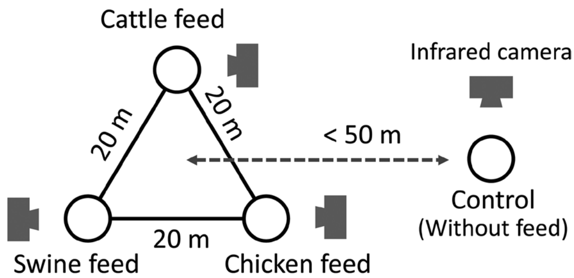

Fig. 2. Example of a set of feeding conditions and the arrangement of cameras. Cattle, chicken, and swine feeds were respectively placed on a point corresponding to the corner of an equilateral triangle. The control point was established on the animal trail, and a triangle of three feed points was established near the control point (<50 m).

point was established on the animal trail, and a triangle of three feed points was established near the control point (<50 m). In the control point, fallen leaves and twigs were removed and make the photographed area stand out. A 500 g sample of the commercial concentrated feeds (Fig. 1, Table 1) for cattle ("Teppen M" for beef cattle, JA Nishinihon Kumiai Shiryou, Kobe, Japan), chicken ("Shin-Miyazaki Jitokko shiage" for Miyazaki Jitokko chicken, JA Nishinihon Kumiai Shiryou), and swine ("Miyazaki pigtory C" for fattening swine, JA Nishinihon Kumiai Shiryou) were respectively placed on a point corresponding to the corner of an equilateral triangle with a side length of 20 m (Fig. 2). Prior to this study, we confirmed that *A. argenteus* and *A. speciosus,* which may have the smallest home ranges among the wild mammals living in the study sites, could easily move 20 m (Sakamoto, personal observation for *A. argenteus*, Sakamoto *et al*. [19]). Therefore, wild mammals were exposed to a cafeteria test-like situation when they reached one of the three feed points.

Camera trapping

Camera trapping at each site was conducted for seven days during September 30 to November 18, 2019; it began at 18:00 JST (Japan Standard Time: UTC + 9) on the first day, and ended at 17:59 on the seventh day. A camera was placed in front of the control and each of the three feed points, respectively; four cameras were placed at each site at the same schedule. A total of 16 infrared cameras, encompassing 12 (Coolife, Guangdong, China) and 4 (Blackloud, Guangdong, China) trail cameras, were used; these two camera models had similar trigger speeds and detection ranges. Two cameras were changed because these cameras got out of order. To investigate the attractiveness of each feed, wildlife behaviors at each feed point were monitored; the number of videos increased as an individual's length of stay increased. Hence, each camera was set to record a 10-sec video, with a shooting interval of 30 sec. All procedures were conducted in the field; hence all procedures were reviewed by The Animal Experimentation Committee at the University of Miyazaki, and then reviewed and approved by the Division of Natural Environment, the Miyazaki Prefectural Government, according to the advice from The Animal Experimentation Committee at the University of Miyazaki.

Statistical analysis

Each 10-sec video was treated as one shot. The shooting date and time, animal species, and recorded behaviors were analyzed from the videos in which we could identify the animal species. Observed behaviors were classified into three types: foraging; interest; indifference. Situations where an animal was apparently eating the feed or chewing near the feed were defined as foraging. It is difficult to judge mastication in mice, so in instances where mice stopped near the feed, picked up something, and made a gnawing gesture, we defined it as foraging. Interest was defined as sniffing and gazing at the feed with stopping or wandering near the feed. Other instances when an animal was standing away from the feed and passing by the video frame were defined as indifference. We ranked higher in the order of foraging, interest, and indifference. When two or more species were filmed in one video, the behavior of each species was recorded. When an animal demonstrated two or three types of behaviors in one video, the higher rank behavior was recorded. For example, when an animal demonstrated foraging and interest, only foraging was recorded. Similarly, when multiple individuals of the same species were observed in one video, the higher rank behavior was recorded. For example, if a raccoon dog appeared in a distant location and another raccoon dog was foraging in a video, only foraging was recorded.

All statistical analyses were performed using generalized linear mixed models in R version 3.6.2 [17], with the "glmer" function in the statistical package "lme4" [1]. To analyze animal appearance at the feeding points, the number of videos photographed was used as the dependent variable, and the feed conditions were used as the independent variable. In addition, to calibrate differences in the frequency of animal appearances between feeding points, the feeding points were set as a random effect. Some cameras malfunctioned and lost data due to bad weather conditions. Therefore, only data from points with a set of three feed conditions and/or a set of four conditions including the control treatment were analyzed. When analyzing the relative attractiveness among feed conditions, foraging and interest were categorized as feeding-related behaviors, and the number of videos of feeding-related behaviors was used as the dependent variable.

RESULTS

Among the 14 feeding sites, 13, 13, 11, and 12 cameras worked well in the control, cattle feed, chicken feed, and swine feed conditions, respectively (Table 2). From 3,330 videos, we identified the following species: 13 mammals: red fox (*Vulpes vulpes*), raccoon dog, feral cat, Japanese badger (*Meles anakuma*), Japanese marten (*Martes melampus*), Japanese weasel (*Mustela itatsi*), Siberian weasel (*Mustela sibirica*), wild boar, sika deer, Japanese hare (*Lepus brachyurus*), Japanese macaque (*Macaca fuscata*), large Japanese field mouse (*Apodemus speciosus*), and small Japanese field mouse (*Apodemus argenteus*); and 9 birds: great tit (*Parus major*), pale thrush (*Turdus pallidus*), White's thrush (*Zoothera dauma*), brown-eared bulbul (*Hypsipetes amaurotis*), Japanese green woodpecker (*Picus awokera*), oriental turtle dove (*Streptopelia orientalis*), Chinese bamboo partridge (*Bambusicola thoracicus*), and two subspecies of copper pheasant (*Syrmaticus soemmerringii soemmerringii* and *Syrmaticus soemmerringii ijimae*). Since it was difficult to identify the mouse species and the weasel species from more than a few videos, they were integrated together as mice and weasels, respectively. In 3,175 out of 3,330 videos, 10 mammals were photographed on 10 or more occasions. Raccoon dogs were the most frequently photographed species (2,458 videos; 13 sites), followed by mice (256; 12), wild boars (226; 12), Japanese badgers (58; 9), sika deer (53; 8), Japanese macaques (51; 4), Japanese martens (39; 12), weasels (12; 3), Japanese hares (12; 4), and red foxes (10; 1).

In 3,175 videos of the 10 mammals, 160 and 3,015 videos were observed in the control and feed conditions, respectively. Behaviors observed with the feed conditions were classified into three types: 1,886 instances of foraging, 557 instances of interest, and 572 instances of indifference. A set of data for all conditions, including the control and three feed points, was obtained from seven sites (Table 2). The number of videos photographed with feed was larger than the number without feed (Fig. 3, n=7 sites, swine vs. control: estimate ± SE=1.71 ± 0.10, z=16.85, P<0.001; chicken vs. control: 1.07 ± 0.11, z=9.82, P<0.001; cattle vs. control: 0.76 ± 0.11, z=6.72, P<0.001). A set of data for the three feed points was obtained from eight sites (Table 2). The number of videos that captured foraging or interest behaviors was largest for swine feed, followed by chicken feed, then cattle feed (Fig. 4, n=8 sites, swine vs. chicken: 0.37 ± 0.06, z=6.05, P<0.001; cattle vs. chicken: −0.53 ± 0.08, z=−6.84, P<0.001).

Raccoon dogs, mice, and wild boars accounted for 77.4, 8.1, and 7.1% of the videos, respectively (in total, 92.6%=2,940/3,175 videos). Raccoon dogs, wild boars, and mice accounted for 84.45, 6.75, and 5.77% of the total feeding-related behaviors demonstrated by wildlife, respectively (in total, 96.97%=2,369/2,443 instances). The total number of behaviors observed at the control and feed points were compared across species (Fig. 5). The frequencies of foraging and feeding-related behaviors per total number of species photographed at the three feeds points were as follows: Raccoon dog: 68.7% and 85.5%, wild boar: 55.1% and 83.3%; mice: 37.3% and 55.3%; Japanese badger: 27.5% and 62.5%; Japanese martens: 28.9% and 63.2%; Japanese macaque: 2.7% and 40.5%; red fox: 1.0% and 40.0%; weasels: 0% and 40.0%; Japanese hare: 0% and 12.5%; and sika deer: 0% and 30.0%. Moreover, pale thrush (64 videos; 4 sites) and oriental turtle dove (16 videos; 4 sites) also demonstrated foraging or interest behaviors.

DISCUSSION

In line with our hypothesis, wildlife more frequently appeared at the points with feed than without feed, suggesting that livestock feed could be one of the risk factors to invite wildlife to the livestock environment. In addition, the number of videos that captured foraging or interest behaviors was largest for swine feed, followed by chicken feed, then cattle feed. In terms of ingredient

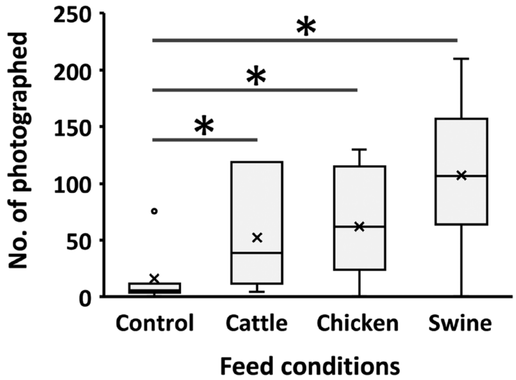

Fig. 3. The number of mammals photographed was significantly larger in the feed than control (without feed) condition (*P<0.001, n=7 feeding sites).

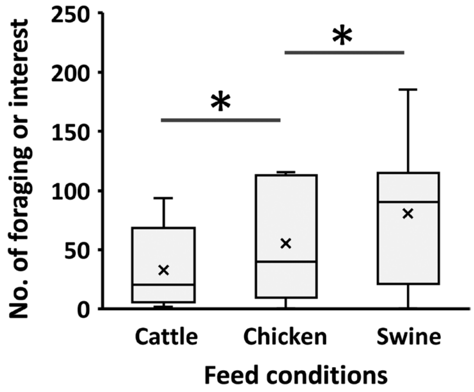

Fig. 4. The number of captured foraging or interest behaviors was largest for swine feed, followed by chicken feed, then cattle feed (*P<0.001, n=8 feeding sites).

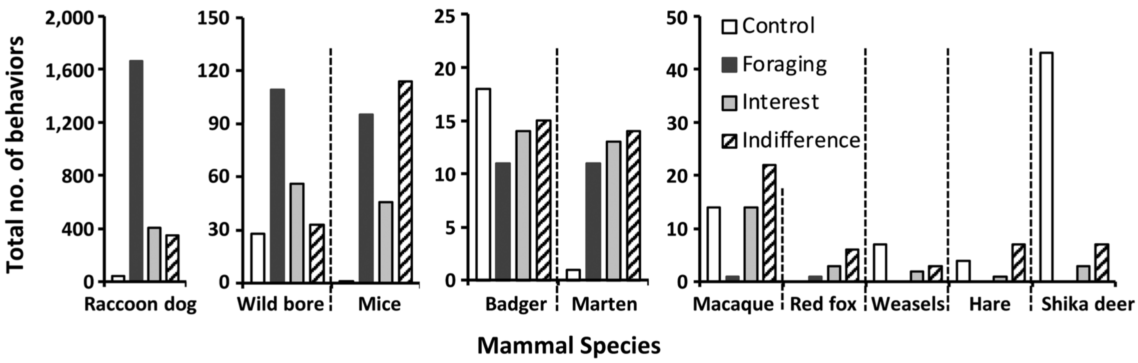

Fig. 5. The number of behaviors that each species demonstrated in front of the feeding points. At the control point, there was no feed present, hence all observed behaviors (e.g., standing and passing) were counted.

composition, the swine feed contained more grains than the cattle and chicken feeds. In addition, there was more oil seed meal and animal origin feeds in the chicken feed than in the cattle feed. Therefore, swine and chicken feeds seemed to attract wildlife, particularly those with omnivorous tendencies. More specifically, wildlife with omnivorous tendencies frequently appeared and foraged at the feeding points, although specific species did not appear to have a strong preference for swine and chicken feeds. Given that there is little variation in the components of swine and chicken feeds, and that most wildlife with omnivorous tendencies displayed similar preferences, it seems that they prefer swine and chicken feeds more than cattle feed.

There was a large difference among wildlife in their response to livestock concentrated feeds, although each species did not have a strong preference for a specific livestock feed. Wildlife can be divided into three groups: high, moderate, and rare response to livestock feeds. The high response group consisted of raccoon dogs, wild boars, and mice; these omnivores and carnivores with omnivorous tendencies frequently appeared at the feeding points and displayed foraging or interest behaviors toward the livestock feeds. Food stealing behavior by raccoon dogs and wild boars is frequently confirmed in cattle barns in the Kanto region [29]. Hence, generally, these two species are noticeable species in and around livestock farms, independent of livestock species, and farmland region. In many cases, mice demonstrated feeding and indifference at the same feeding point. Wild mice species often move their food to safe feeding or hording sites [24, 25]; they demonstrate these behaviors quickly and frequently, which may have resulted in capturing their frequent feeding and indifference behaviors in this study. Raccoon dogs and wild boars have large body sizes and they cannot climb well; hence, they may cause more serious problems in swine and cattle farms than in poultry farms. The study indicates that wild mice also prefer livestock feeds, and could become potential intruders like black rats and house mice. Therefore, there should be a focus on wild mice behaviors around livestock barns.

The moderate response group consisted of Japanese badgers and Japanese martens, which are carnivores with omnivorous tendencies. The frequencies of appearance and foraging were lower in Japanese badgers and Japanese martens than in the three species in the high response group; however, they also emerged in many sites in this study. In addition, they indicated a strong interest in the feeds. Japanese badgers make good use of earthworms and fruits [13], whereas Japanese martens switch their diets to small mammals, insects, and fruits, depending on the season [30]. Diet switching in broad-eating predators can encourage the intrusion of livestock farms; hence, they are additional target species that should be prevented from entering livestock farms. Japanese badgers use pastures intensively to feed on earthworms [28], so cattle farms may be good foraging sites for Japanese badgers. In contrast, Japanese martens, with their slender body shape, can climb well and eat many small birds, small mammals, and bird eggs in trees as well as on the ground. As such, Japanese martens would be more likely than Japanese badgers to invade poultry barns for the purposes of foraging. Recently, Japanese martens have been reported to invade a poultry farm and capture a rat in the barn [31].

The rare response group consisted of Japanese macaques, red foxes, weasels, Japanese hares, and sika deer; these animals did not eat nor show strong interest in the livestock feeds in this study. Among these, a fox was confirmed at only one site, and it immediately left the feed point after a few bites of the feed; therefore, it is possible that they do not like livestock feed. Tsukada *et al*. [29] noted that the main purpose of fox appearance in barns may be rat predation because they rarely steal feed. Recently, weasels have been shown to invade a poultry farm and captured a rat in the barn [31]. Nonetheless, weasels did not demonstrate foraging behavior in this study. Thus, weasels may appear in poultry farms to capture rats or poultry, or to steal eggs. A feral cat was confirmed at only once, and it did not demonstrate foraging behavior. However, feral cats are frequently observed on a variety of livestock farms including poultry farms [20, 21, 31]. These results suggest that feral cats may invade to capture rats or poultry like the above carnivores. Similarly, sika deer did not forage on any livestock concentrates, although there are increasing reports of sika deer causing feeding damage to silage [27] and pasture fields [5, 6, 11]. Therefore, sika deer may induce serious problems, especially on cattle farms. Pasture fields are also damaged by wild boars [18]. As such, cattle farms require countermeasures against multiple even-toed ungulates.

Japanese badgers and sika deer were frequently photographed at the control point, indicating that individuals or herds of these species might frequently use the same animal trail.

Among the many kinds of birds living in the study sites, only pale thrush and oriental turtle dove demonstrated frequent foraging or interest behaviors; these birds often forage on the ground. In contrast, other bird species was photographed only 14 times in total, and they did not demonstrate foraging and interest behaviors. Pale thrush is a migratory bird, breeding in southeast Siberia, northeast China and Korea, and wintering in southern and central Japan. In Miyazaki Prefecture, we previously observed that pale thrush intruded in a cattle barn in the winter [20]. Therefore, pale thrush is a noteworthy target for monitoring livestock farm biosecurity. Crows are typical feed-stealing birds common in the livestock environment [23]. Our study sites were set up in the forest, even though all sites were close to the poultry farms; therefore, we did not expect any visits by sparrows or crows. The combination of feeds and other components of livestock farms may possibly attract these bird species, but we have no data to directly discuss this result. To clarify the responses of sparrows and crows to livestock feeds, farm surroundings as well as the livestock farms themselves need to be investigated.

In general, this study revealed that livestock feeds could be one of the risk factors to invite several wildlife to the livestock environment. Therefore, to protect against wildlife intrusion, leftover feed and feed storage must be properly managed. On the other hand, this study also suggests that there was a large difference among wildlife; high and moderate response groups, especially omnivores and carnivores with omnivorous tendencies, demonstrate higher response to livestock concentrated feeds. This suggests that intrusions by specific animals may not depend on the characteristics of the livestock feed itself. Livestock feeds may not attract intrusions by rare response group species, such as Japanese macaques, red foxes, weasels, Japanese hares, sika deer and possibly cats; hence, if their intrusions occur, they may be due to factors other than livestock feed. The present results are strongly affected by interspecific variation in response speed toward livestock feeds; therefore, the results do not directly indicate a food preference itself in each species. Furthermore, the results are also affected by the ecological context of wildlife populations, e.g. population fluctuation, season, vegetation of the study site, resource availability, and habitat itself (e.g. forest or urban). Therefore, long-term and repeated-measure studies to monitor wildlife basic ecology and behaviors surrounding the livestock farms in the local area are needed. In addition, future studies using similar settings should be conducted in multiple regions and seasons to reveal general responses of wildlife to livestock feeds.

CONFLICT OF INTEREST. The authors declare no conflict of interest.

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