Risk Analysis of Feline Immunodeficiency Virus Infection in Tsushima Leopard Cats (Prionailurus bengalensis euptilurus) and Domestic Cats Using a Geographic Information System

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ABSTRACT. In this study, based on the data from FIV screening surveys of captive cats conducted by the Kyushu Veterinary Union and collaborators as part of the infection control program for Tsushima leopard cats (Prionailurus bengalensis euptilurus), we elucidated the spatial distribution of FIV-positive individuals among leopard cats and domestic cats using a geographic information system. Data from FIV screening surveys carried out among 86 leopard cats (1996–2006) and 713 captive domestic cats (2001–2006) were used for analysis. The analysis results were then spatially layered with the population density of leopard cats and that of captive domestic cats estimated from the number of households and used for assessment of FIV infection risk in each area. The prevalence rates of FIV were 3% (3/86) in leopard cats in Kami-shima, 13.6% (38/280) in domestic cats in Kami-shima and 10.6% (46/433) in domestic cats in Shimo-shima.

The distribution of FIV on Tsushima Island was not uniform; on Kami-shima Island, FIV-positive domestic cats were concentrated in particular areas. We also performed risk analysis based on the population density of leopard cats, the prevalence rate of FIV among domestic cats, and the estimated population density of captive domestic cats and identified high FIV infection risk areas.

All FIV-positive leopard cats were found in the identified high FIV infection risk areas.

KEY WORDS: conservation medicine, domestic cat, feline immunodeficiency virus, geographic information system, Tsushima leopard cat.

The Tsushima leopard cat (Prionailurus bengalensis euptilurus) is a small felid that inhabits only Tsushima Island (Nagasaki prefecture, Japan). This species is endangered because of its restricted habitats and small population size, which is estimated at approximately 80–110 individuals [9].

The population of Tsushima leopard cats has declined since about 40 years ago. The reasons for this decline have been suggested to be habitat loss from forest plantation, mortality from traffic accidents and ecological interaction with feral domestic cats [8].

Recently, Tsushima leopard cats have been exposed to the threat of disease from feral domestic cats. Nishimura et al. [16] reported that feline immunodeficiency virus (FIV) was isolated from a wild Tsushima leopard cat captured in 1996, and polygenetic analysis of the env gene sequences indicated that the FIV from Tsushima leopard cats belongs to a cluster of subtype D FIVs from domestic cats. The results indicate the occurrence of interspecies transmission of FIV from the domestic cat to the Tsushima leopard cat in the wild [16]. Following this report, two FIV-positive Tsushima leopard cats were indentified in 2000 [13] and 2002 [14]. These are the only cases of interspecies trans-

mission of FIV from domesticated cats to wild felid species to be reported worldwide at present.

FIV causes immune deficiency in domestic cats, and most infected individuals that develop symptoms die within 1 year [3, 6]. This condition may similarly occur in Tsushima leopard cats, indicating that FIV from domestic cats on Tsushima Island is new threat for the Tsushima leopard cat. With no infectious diseases other than FIV having been identified as a threat for the continued existence of the population of Tsushima leopard cats, the goal of the present study was to control FIV infection on Tsushima Island.

At the time that FIV was detected in Tsushima leopard cats, there was no veterinary medical facility for pets on Tsushima Island. The Kyushu Veterinary Union established the Tsushima Leopard Cat Conservation Council, which is funded by the council members, and it has provided veterinary medical services since 2001. The veterinary medical activities include sterilization and FIV testing of domestic cats and are conducted across Tsushima Island. However, considering that Tsushima covers an area of 700 km² with a population of 36,000, treating all domestic cats would require considerable time. To save the endangered Tsushima leopard cat, measures against FIV need to produce good results in the shortest possible time. Therefore, this suggested that a more efficient method of implementing these measures was required.

Recently, a geographical information system (GIS) has
been utilized in infection control measures. This system enables analysis of the spatial distribution and density of infected animals and thus allows for efficient determination of where and how to implement necessary measures [1, 2, 19]. The previous epidemiological surveys of FIV on Tsushima Island only focused on determining the prevalence of FIV [13, 14], and no study has analyzed the spatial distribution of individual FIV-positive domestic cats and Tsushima leopard cats. Furthermore, none of the investigators around the world has ever analyzed the spatial distribution of FIV among domestic cats using GIS for control of FIV infection. We hypothesized that the use of GIS would allow us to identify the high FIV infection risk areas for Tsushima leopard cats by geographically layering multiple types of information, such as the spatial distribution, prevalence of FIV and population densities of captive domestic cats and leopard cats. The implementation of intensive measures in high FIV infection risk areas should enable the most efficient and effective control of FIV infection among Tsushima leopard cats.

In the present study, based on the data from FIV screening surveys carried out among captive domestic cats and Tsushima leopard cats on Tsushima Island, we elucidated the spatial distribution of FIV-positive leopard cats and domestic cats using a GIS. We also performed geographical infection risk analysis based on the population densities of leopard cats and domestic cats in an attempt to identify high FIV infection risk areas in which measures should be implemented preferentially.

MATERIALS AND METHODS

Serologic survey: The data from serologic surveys carried out among 86 leopard cats and 713 captive domestic cats were used for analysis. Blood samples were collected by the staff of the Tsushima Wildlife Conservation Center, Ministry of the Environment, from leopard cats captured for survey purposes or those rescued after being hit by motor vehicles between 1996 and 2006. Blood samples were collected by veterinarians belonging to the Kyushu Veterinary Union from domestic cats brought to veterinary hospitals by their owners between 2001 and 2006. A serologic survey was performed free of charge for all animals. The present study included no stray cats.

All FIV test results in these data were obtained within 1 hr after blood sample collection using a commercially available rapid FIV antibody test kit (Snap Combo, IDEXX, Westbrook, MN, USA or Witness, Synbiotecs, Kansas City, MO, U.S.A.).

Risk analysis of FIV infection: The FIV test results of all animals were compiled in a database together with animal species, place of capture (leopard cats) or address of owners (domestic cats), sex and test date. The statistical data for the population distribution in 2006 were used to estimate the population densities of captive domestic cats in each area. Because the exact population density of the Tsushima leopard cat is unknown, 10 grades of relative density indexes based on estimations on a 1-km mesh were used [9].

All of these data were entered into a GIS software (ArcView ver. 9.2, ESRI Japan, Tokyo, Japan) and analyzed as described below. Since leopard cats are preferably distributed in cultivated areas and an aqueous environment and tend to avoid high-altitude areas [22], data analysis for determining the FIV-infection risk among leopard cats was performed by dividing the survey area into several watersheds of rivers flowing from levels higher than 100 m above sea level down into the ocean.

For geographical assessment of the risk of FIV transmission from domestic cats to leopard cats, the density of FIV-positive domestic cats was expressed as number per watershed. The number of domestic cats in captivity was estimated from the number of households (20% of all households) [21] in each watershed. The density of FIV-positive domestic cats was calculated by multiplying the estimated number of domestic cats per watershed by the prevalence of FIV among domestic cats in each watershed and then dividing by the area (km²) of each watershed.

For assessment of the risk of FIV transmission from domestic cats to leopard cats, the relative density of FIV-positive domestic cats in each watershed was rated in 3 grades (high, medium and low). The estimated population density of Tsushima leopard cats was recalculated for each watershed using the GIS, and their relative densities in each watershed were also rated in 3 grades.

Given that FIV is transmitted via contact with infected animals, watershed areas in which the relative density of either FIV-positive domestic cats or leopard cats was rated as “high” and that of the other species was rated as either “high” or “medium” were identified as high FIV infection risk areas for Tsushima leopard cats. In contrast, watershed areas in which the relative density of either species was rated as “low” and that of the other species was rated as either “low” or “medium” were considered low infection risk areas.

Statistical analysis: The statistical significance of differences in FIV prevalence was assessed using the chi-square test.

RESULTS

Seroprevalence of FIV in captive cats and Tsushima Leopard cats: The results of FIV screening among the 86 Tsushima leopard cats and 713 domestic cats are summarized in Table 1. The names of the regions for which the data are summarized are shown in Fig. 1.

The prevalence rates of FIV among domestic cats were 13.6% (38/280) on Kami-shima Island and 10.6% (46/433) on Shimo-shima Island, with no significant difference in FIV prevalence rate between the two islands (P=0.23). The geographical distribution of FIV-positive domestic cats was not uniform; on Kami-shima Island, the prevalence was high in Kamiagata and Kami-tsushima, whereas no positive cat was found in Mine and Toyotama. A significant sex difference was found in the FIV prevalence rate; the preva-
Prevalence rate was higher in male cats (19.7%) than in female (7.9%) cats \( (P < 0.001) \).

The prevalence of FIV among leopard cats was 3% (3/86). All FIV-positive animals, including 2 males and 1 female, were captured in Kamiagata or Kamitsushima. No leopard cats were captured on Shimo-shima Island.

The location data for all the individuals subjected to FIV screening were entered into the GIS to visualize their spatial distribution (Fig. 2). The distances between the point at which each FIV-positive leopard cat was captured and the address of the nearest FIV-positive domestic cat were 400, 1,130 and 1,500 m.

### Table 1. Seroprevalence of FIV infection in domestic cats and Tsushima leopard cats

<table>
<thead>
<tr>
<th>Island</th>
<th>Kami-shima</th>
<th>Shimo-shima</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kamiagata</td>
<td>Kamitsushima</td>
</tr>
<tr>
<td>Domain</td>
<td>Male Female Unknown Male Female Male Female Male Female Male Female</td>
<td></td>
</tr>
<tr>
<td>Domestic cat</td>
<td>FIV+</td>
<td>n</td>
</tr>
<tr>
<td>Male</td>
<td>20 11 – 4 3 0 0 0 6 3 16 21</td>
<td>73 119 – 21 34 5 13 4 11 43 89 88</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tsushima leopard cat</th>
<th>FIV+</th>
<th>n</th>
<th>Prevalence rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>24 21 2 13 12 4 7 3 0 0 0 0</td>
<td>24 21 2 13 12 4 7 3 0 0 0 0</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1 1 0 1 0 0 0 0 0 0 0 0</td>
<td>1 1 0 1 0 0 0 0 0 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>

**FIV infection high risk area for Tsushima Leopard cats:**

On Kami-shima Island, where Tsushima leopard cats live, FIV-positive domestic cats were concentrated in particular areas, as described above. Thus, the FIV infection risk analysis was only carried out for Kamiagata and Kamitsushima, in which FIV-positive animals were found.

These areas were geographically divided into nine watershed areas (Fig. 1). The GIS-estimated density of FIV-positive domestic cats in each watershed area ranged from 0 (areas 7 and 8) to 0.7 (area 2) head/km² (Table 2).

Given this result, the estimated relative density of FIV-positive domestic cats was rated in three grade, low (0–0.2
head/km²), medium (0.3–0.4 head/km²) and high (0.5–0.7 head/km²). Moreover, the estimated population density of Tsushima leopard cats was rated in three grade, low (relative density index 3>), medium (relative density index 3–5) and high (relative density index 5<). The FIV infection risk for Tsushima leopard cats was assessed for each watershed area based on the relative density of FIV-positive domestic cats and the estimated population density of leopard cats. As a result, watershed areas 3, 5 and 6 were identified as high risk areas.

The 3 FIV-positive leopard cats were captured in watershed areas 3, 5 and 6, which is fully consistent with the identified high FIV infection risk areas (Table 2).

DISCUSSION

There was a substantial geographical variation in the prevalence rate of FIV among domestic cats on Tsushima Island; the prevalence rate varied among towns, ranging from 0% (Mine and Toyotama) to 27.4% (among male cats in Kamiagata).

Large epidemiologic surveys conducted among domestic cats in Japan have reported an FIV prevalence rate of 9.6% [12] or 12% [7]. Similar surveys conducted in North America have reported an FIV prevalence rate of 1.2–8.2% [4, 5, 10, 11, 17, 20, 23]. Compared with these survey results, the prevalence rate of FIV on Tsushima Island is considered relatively high.

On Tsushima Island, domestic cats are commonly kept outside houses. It is thus speculated that FIV can easily spread in areas with a high population density of domestic cats. Other previous studies have also shown a higher prevalence rate of FIV among cats kept outside houses than those kept inside houses [7, 12]. O’Connor et al. [18] conducted a large epidemiologic survey in North America and found that the prevalence rate of FIV among domestic cats kept outside houses is 4.8 times higher than that among domestic cats kept inside houses. From these findings mentioned above, it is speculated that captive domestic cats and leopard cats on Tsushima Island are at high risk of getting infected with FIV.

No leopard cat was captured on Shimo-shima Island, suggesting extinction of the species or an extremely small population size on the island. In contrast, leopard cats were
captured in almost all areas on Kami-shima Island, with only 3 FIV-positive individuals identified. The distance between the point at which each FIV-positive leopard cat was captured and the address of the nearest FIV-positive domestic cat ranged between 400–1500 m. A 3-year home range survey of Tsushima leopard cats [15] showed that the area of their home range varies between seasons, ranging between 115–1647 ha for males (2 cats) and 51–91 ha for females (1 cat). The maximum widths of the home ranges of these animals were 7.5 and 6.1 km for male cats and 1.9 km for female cats. These findings suggest that Tsushima leopard cats living around settlements are likely to come into contact with FIV-positive domestic cats.

The most effective measure for preventing FIV transmission to leopard cats would be to encourage people to keep domestic cats inside their houses; however, it is not realistic to dramatically change their custom of keeping cats outside their houses. Therefore, measures have been implemented across the island to reduce stray cats by promoting individual registration of captive domestic cats with microchips and sterilization.

However, in the present study, all FIV-positive leopard cats were found in the high FIV infection risk areas, suggesting that quarantining FIV-positive domestic cats that live in the high risk areas and are kept outside houses is more effective for preventing FIV transmission to leopard cats.

The number of FIV-positive domestic cats in the high FIV infection risk areas identified in this study was estimated to be 42 (calculated from Table 2). It should not be very difficult to identify and quarantine these animals. There was a sex difference in the prevalence of FIV among domestic cats. This difference has also been observed in previous studies [4, 7, 10, 23]. This may suggest that measures for domestic cats should preferentially target male individuals.

As a future measure to prevent FIV transmission to Tsushima leopard cats, implementation of intensive preventive measures in high FIV infection risk areas is recommended.

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Table 2. Risk assessment of FIV infection in Tsushima leopard cats

<table>
<thead>
<tr>
<th>Watershed area no.</th>
<th>Number of households</th>
<th>Estimated heads of captive cats</th>
<th>Area (km²)</th>
<th>Prevalence rate in FIV (%)</th>
<th>Estimated heads of infected captive cats</th>
<th>Estimated density of infected captive cats (heads/km²)</th>
<th>Relative density of infected captive cats</th>
<th>Relative density of leopard cats</th>
<th>Risk assessment</th>
<th>Number of leopard cats tested for FIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1358</td>
<td>272</td>
<td>33.7</td>
<td>3.2</td>
<td>8.8</td>
<td>0.3</td>
<td>M</td>
<td>M</td>
<td>M</td>
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<td>2</td>
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<td>M</td>
<td>M</td>
<td>2</td>
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<tr>
<td>5</td>
<td>357</td>
<td>71</td>
<td>64.0</td>
<td>27.1</td>
<td>19.4</td>
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<td>M</td>
<td>H</td>
<td>H</td>
<td>32 (1)</td>
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<tr>
<td>6</td>
<td>253</td>
<td>51</td>
<td>19.8</td>
<td>18.2</td>
<td>9.2</td>
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<td>H</td>
<td>M</td>
<td>M</td>
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<tr>
<td>7</td>
<td>364</td>
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<td>45</td>
<td>8.7</td>
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<td>2.2</td>
<td>0.2</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>3</td>
</tr>
</tbody>
</table>

H, M and L: high, medium and low, respectively.

a) Estimated from the number of households (20% of all households) in each watershed.
b) Calculated by multiplying the estimated head of captive cats by the prevalence of FIV among domestic cats in each watershed.
c) Calculated by dividing the estimated number of heads of infected captive cats by the area (km²) of each watershed.
d) Risk was rated as H when the relative density of either species was H and that of the other species was H or M. In contrast, risk was rated as L when the relative density of either species was L and that of the other species was L or M.
e) Number of leopard cats in each watershed area tested for FIV infection. The number of FIV-positive animals is shown in brackets.
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