The Landscape and Demographic Features Associated with Ferret Badger Rabies in Taiwan East Area

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Abstract

This study evaluated landscape characteristics associated with the incidence of ferret badger (*Melogale moschata*) rabies in the East Epidemic Area, Taiwan, where the disease has been endemic from 2013 till date. This study included 268 cases of ferret badger rabies reported from 59 townships during 2013-2016. A multivariable logistic regression analysis revealed that for townships with elevation between 0 and 200 m, or between 201 and 600 m, the estimated probability of the incidence of ferret badger rabies for each township increases with the rise of forest area. For townships with elevation higher than 600 m, the association is negative, a fact reflected by the interaction effect between variables of forest and elevation fitted in the model. This model provided by the combination of different land use types, human population density and elevation measures of townships, may be used in estimating the incidence probability of prioritizing areas for ferret badger rabies control on oral vaccination.

Keywords: Taiwan; Ferret badger; Rabies; Epidemiology

Introduction

On July 17, 2013, RABV was detected in Taiwan ferret badgers in Taiwan Island [1]. Ferret badger (*Melogale moschata*) is the sole reservoir host for the rabies virus, and the epidemic is only prevalent in Taiwan Island [1,2]. Epidemiologically, it is indicated that there were the Main (West) and East epidemic areas separated by the Central Mountain Ranges [2,3]. The phylogeny of nucleoprotein and glycoprotein genes of ferret badger rabies virus revealed the RABV to be clustered in two distinct groups, TWI and TWII, which were consistent with the geographic segregation into the East and West areas separated by the Central Mountain Range [3]. Chiou et al. [4] indicated that RABV could be cryptically circulating in the environment. An understanding of the underlying mechanism might shed light on the complex interaction between RABV and its host. Lin et al. [5] indicated that the origin of the epidemic could be in the Eastern Taiwan, then the Formosan ferret badger rabies moved across the Central Mountain Range to western regions and separated into two branches. A retrospective study of Formosan ferret badger rabies indicated that the ferret badger population in Taiwan had been affected by rabies prior to 2010 [6].

Over the past several decades, studies of wildlife revealed that suitable habitat was a function of features of landscape and human demography, such as: human population density, road density, land ownership, forest type, agriculture type etc. Landscape ecologists use sophisticated analyses of habitat use that consider multiple characteristics of the environment. Consequently, habitat selection of the wildlife is the act of choosing the combination of available abiotic and biotic elements that best fulfills the life-history needs [7,8]. Evidence of the association of land use and human demographics in rabies epizootics has been reported. Identification of these factors influencing the spread of rabies can help to assess risk for rabies and provide the improved planning and efficient application of rabies control program [9-11].

The ferret badger is omnivorous wildlife mustelid, mainly feeding on invertebrates and fruits. The most important food sources of ferret badgers are earthworms and insects [12]. The body mass for adults were 0.90 ± 0.14 kg [13], or 0.8~1.6 kg [14]. The animal is considered a weak competitor and not usually found in urbanized areas accordingly [3,15]. Direct quantitative estimation of ferret badger population densities over broad geographic regions by usual conventional trapping and infrared cameras record in different elevations and locations would be prohibitively expensive. Consequently, using measures of landscape features and other factors that are predictive of favorable ferret badger habitat, offers an attractive alternative approach.

The objectives of this article were to examine the association between various environmental and demographic features of townships and the occurrence of ferret badger rabies in the East Epidemic Area in Taiwan.

Study area

The study included Hualien County, Taitung County and Pingtung County which constitute the East Epizootic Area of ferret badger rabies in Taiwan Island, excluding 3 island townships. Townships of above-mentioned 3 counties were included in the study, totaling 59 townships and 10,939 km^2 of land.

Data collection

All research data concerning ferret badger rabies from 2013 to 2016 in this research were downloaded from the governmental website of BAPHIQ http://www.baphiq.gov.tw/view.php?catid=10980, with the

permission of BAPHIQ. Methods of sample collection and diagnostic examination of rabid ferret badgers were described by Shih et al. [3]. Every case was geocoded by the location of townships. Once geocoded, each rabies case was assigned to the corresponding townships and the number of cases by township was categorized and calculated. A final total of 59 townships and 268 ferret badger rabies cases were included in the study. Average elevation of each township was downloaded from Taiwan Geospatial One-Stop (TGOS) website of the Ministry of Internal Affairs.

Land use

To study the association of different land use types, the area of each land use type was obtained for each township. The Taiwan Land Cover Data of 2008 edition from the "Land Use Investigation of Taiwan" was downloaded and used to extract land use data for the study area (http://lui.nlsc.gov.tw/LUWeb/FileDL/FileDLShow.aspx?page=1). For this study the land use types were categorized by Taiwan government into 9 types. The nine types are: 1. Agriculture, 2. Forest, 3. Transportation, 4. Water, 5. Architecture, 6. Public institution, 7. Entertainment, 8. Mine, 9. Others.

Statistical analysis

SAS Statistical Software version 9.4 was used to perform the data analysis. We calculated statistics for townships with cases and without cases for each of the landscape variables, and tested for differences of landscape variables, elevations, and human population density in townships with and without ferret badger rabies cases using the nonparametric Mann Whitney test. We then fitted a logistic regression model to the data, and used the fitted model to estimate the probability of incidence of ferret badger rabies for each township. In addition, spatial autocorrelation was also assessed and found to be present but low, and comparison showed that it did not affect the regression results. We therefore used the non-spatial model to present our findings.

Results

Landscape composition and rabies surveillance

There are 3 counties in total that comprises 62 townships in the East Epizootic Area in Taiwan. Two island townships in Taitung County, the Green Island and Orchid Island, as well as one island township in Pingtung County, the Liouciou Island, were excluded in this study. A total of 59 townships and 10,939 km² of land were included in the study. Among them, 25 out of the 59 townships reported at least one of the 268 ferret badger rabies cases during 2013 to 2016 period. The annual average number of cases during the 4 year-period in the 25 townships was 2.68 (268/25/4) per township. The maximum number of ferret badger rabies cases in townships was Chenggong, where a total of 82 cases was reported for the 4-year period. Table 1 indicates the land-use type and area in 59 townships of the East Epidemic. Table 2 indicates numbers of townships with cases from 2013 to 2016 annually, which implies the expansion trend of the ferret badger rabies at the East Epidemic Area.

Statistical analysis

Table 3 presents comparisons of areas of land use types, elevations, and human population density between townships with and without ferret badger rabies cases. At the 0.05 level of significance, forest area, architecture area, population density and elevation were found to be highly significantly different between the two groups of townships.

Land-use type	Area (km²)	Proportion %
Agriculture	1,684	15.39 (1,684/10,940)
Forest	7,682	70.23 (7682/10,940)
Transportation	135	1.23 (135/10,940)
Water	386	3.53 (386/10,940)
Architecture	165	1.51 (165/10,940)
Public institutions	36	0.33 (36/10,940)
Entertainment	27	0.25 (27/10,940)
Mine	14	0.13 (14/10,940)
Others	811	7.41 (811/10,940)

Table 1: Land-use type and area in 59 townships of the East Epidemic Area in Taiwan.

No.	Counties	2013	2014	2015	2016	Subtotal
1	Hualien	2	1	0	1	4
2	Taitung	10	1	1	1	13
3	Pingtung	3	1	4	0	8
	Total	15	3	5	2	25

Table 2: Number of townships with cases of ferret badger rabies occurred annually in the East Epizootic Area, Taiwan, 2013 ~ 2016.

Land use type	Difference of each type among townships		
(km²)	Median values		P values
	w/ cases, n=25	w/o cases, n=34	Total, n=59
Agriculture	25.20	24.10	0.624
Forest	112.50	2.95	0.000*
Transportation	1.90	2.00	0.319
Water	5.40	3.30	0.149
Architecture	1.50	2.85	0.007*
Public Institution	0.20	0.40	0.051
Entertainment	0.10	0.20	0.206
Mine	0.03	0.04	0.707
Others	6.30	3.90	0.058
Population Density (people/km²)	49.20	474.88	0.000*
Elevation (m)	380.00	28.00	0.000*

Table 3: Geographic differences between townships with and without ferret badger rabies cases, Mann Whitney test.

Townships with larger forest area, smaller architecture area, sparse population density and situated in higher elevation region appear to be more likely to have ferret badger rabies cases.

Table 4 presents the SAS output for a fitted logistic regression model of the data. Originally, forest area, architecture area, population density and elevation, the four variables that were found to be statistically significant in Table 3, were all included in the model. However, architecture area and population density were found to be insignificant in the model, and hence were dropped from further considerations. In addition, the elevation is classified into 3 classes to reflect the fact that it is found to be not linearly correlated with the probability of having ferret badger rabies: 0~200 m, 201~600 m, and >600 m. The class of townships with elevation between 0 and 200 m is served as the reference class of comparison in the model. The fitted model is:

$$\log \frac{\hat{p}}{1-\hat{p}} = -2.3839+0.0192 \text{ forest}+2.3275 \text{ middle}+3.4416 \text{ high}-0.0206 \text{ forest} \times \text{high}$$

where $\hat{p}$ is the estimated probability of incidence of ferret badger

rabies, forest stands for the forest area, middle is a dummy variable associated with the class of townships with elevation ranging between 201 and 600 m, high is a dummy variable associated with the class of townships with elevation higher than 600 m, and forest × high is the interaction effect between variables forest and high. Hosmer-Lemeshow goodness of fit test showed a P-value of 0.4039, an indication that there is no lack of fit of the model to the data. It follows from the model that the estimated probability of the incidence of ferret badger rabies for each township can be calculated as follows:

$$\hat{p} = \frac{1}{1 + \exp - 2.3839 \ + \ 0.0192 \ forest \ + \ 2.3275 \ middle \ + \ 3.4416 \ high \ - \ 0.0206 \ forest \times high}$$

where (middle=0, high=0), (middle=1, high=0), (middle=0, high=1) indicate the class of counties with elevation lower than or equal to 200 m, the class of counties with elevation between 201 and 600 m, and the class of counties with elevation higher than 600 m, respectively. For any township, once we know its elevation class, and forest area, the estimated probability can be easily found. For example, for a township with forest area=150 km², 1. If its elevation ≤ 200 m, we have forest=150, middle=0, high=0 and hence its estimated probability of having ferret badger rabies is

$$\hat{p} = \frac{1}{1 + \exp - (2.3839 \ + \ 0.0192 \ .150)} = 0.6215$$

2. If its elevation is between 201 and 600 m, we have forest=150, middle=1, high=0 and hence its estimated probability of having ferret badger rabies is

$$\hat{p} = \frac{1}{1 + \exp - (2.3839 \ + \ 0.0192 \ .150 + 2.3275)} = 0.9439$$

3. If its elevation is higher than 600 m, we have forest=150, middle=0, high=1, and hence its estimated probability of having ferret badger rabies is

$$\hat{p} = \frac{1}{1 + \exp - (2.3839 \ + \ 0.0192 \ .150 + 3.4416 - 0.0206.150)} = 0.7001$$

Following the same arguments, we can calculate the estimated probabilities of incidence of ferret badger rabies for each township, and Figure 1 provides a graphical summary of the results. The insight of the fitted model is apparently easier to interpret in terms of the plot.

According to Figure 1, we can first observe that the spread of forest areas associated with townships of different elevation classes are quite different. Townships with elevation less than or equal to 200 m generally have smaller forest areas and are less spread, ranging between 0.02 and 131.60 km². Townships with elevation between 201 m and 600 m follow have forest areas ranging between 16.1 and 301.8 km². Townships with elevation higher than 600 m have the widest spread of forest areas, ranging from 55 to 1447 km². We can also see from the plot that for townships with elevation between 0 and 200 m, or between 201 and 600 m, the estimated probability of incidence of ferret badger rabies is increasing with the rise of the area of forest. Instead, for townships with elevation higher than 600 m, the estimated probability of incidence of ferret badger rabies is decreasing with the increase of the area of forest, a fact reflected by the interaction effect between variables forest and high fitted in the model. Nevertheless, if we draw a vertical line above any value of forest area in the plot, we can conclude that for townships with the same forest area, it is always true that townships with elevation ranging between 201 and 600 m have the highest estimated probability of the incidence of ferret badger rabies, followed by townships with

elevation higher than 600 m. Townships with elevation less than or equal to 200 m are least likely to find ferret badger rabies cases.

Table 5 presents the summary statistics of population density associated with the three levels of elevation. Kruskal-Wallis test was performed to see the differences in population density. The P value is close to 0, which means there is a strong evidence that population densities are different among the three levels of elevations. In fact, townships with low elevation tend to be most populated, whereas townships with high elevation tend to be least populated. In addition, population density and forest area appear to be negatively correlated among the three levels of elevation. Since population density, forest area, and the elevation are strongly associated, population density becomes redundant once forest area and the elevation are included in a regression model. This provides a possible explanation why population density was found to be highly statistically significantly different between the townships with and without ferret badger rabies cases in Table 3, but was not found to be significant in the fitted logistic regression model.

Discussion

There are two ferret badger rabies epidemic areas in Taiwan, one on the east side of the Central Mountain Range and one on the west side. These two epidemic areas are considered as two independent groups in epidemiology [2] as well as in phylogeny of nucleoprotein and glycoprotein genes [16]. This study is the research results of the east epidemic area.

Having tested and analyzed by Mann Whitney test (Table 3) as well as the multivariable logistic regression analysis, we discovered that the elevation as well as the area of forest of townships had significant association, either positive or negative, with the incidence of ferret badger rabies (Table 4; Figure 1). Shih et al. [3] also pointed out that the incidence rates of ferret badger rabies are significantly different (p<0.001) between townships of elevations of lower or higher than 200 m. This study also found that human population densities of townships were highly significantly different among the 3 classes of elevations (Kruskal-Wallis Test, p<0.000, Table 5), which implies the influence (association) of people to the living resources of ferret badger habitats. In townships of low elevations, where few ferret badger rabies occurred, possibly due to the high human population density causes lack of green space to generate foods that ferret badgers favor, such as earthworms etc. Besides, high numbers of stray dogs that rely on humans to survive
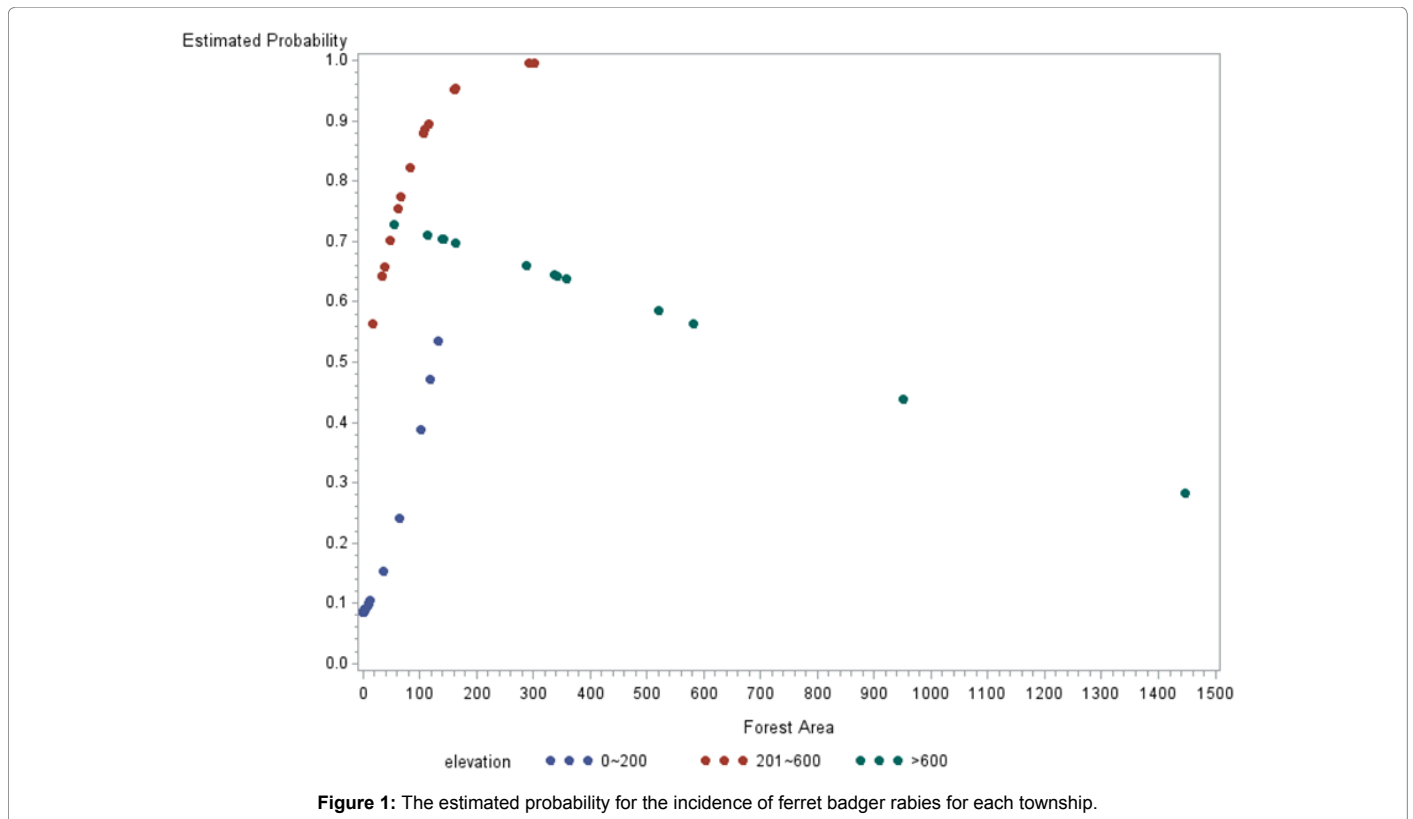
Parameter	Estimate	Standard Error	WaldChi-Square	Pr>Chi Sq
Intercept	-2.3839	0.6657	12.8257	0.0003
forest	0.0192	0.00970	3.9178	0.0478
middle	2.3275	0.9275	6.2971	0.0121
high	3.4416	1.1186	9.4664	0.0021
forest*high	-0.0206	0.00983	4.3796	0.0364

Table 4: Parameters estimates of the fitted model.

Human population density (person/km²)	Level of elevation		
	Low elevation (≤ 200 m) # townships=30	Middle elevation (201~600 m) # townships =16	High elevation (>600 m) # townships=13
Minimum	28	10	5
Median	598	96	11
Maximum	3391	146	110

Note: Kruskal-Wallis Test, p<0.000

Table 5: Comparison of human population density among the three classes of elevation.

Figure 1: The estimated probability for the incidence of ferret badger rabies for each township.

in townships of low elevations also pose threat to ferret badgers' survival, which is also stated and initiated as a new issue of the dog-human-wildlife interface [17]. In townships of middle elevations, there is a positive correlation between the incidence rate of ferret badger rabies and the area of forest. It is possibly due to it being a rich source of food that ferret badgers favor as well as having few stray dogs in the greenspace forest. In townships of high elevations, incidence of ferret badger rabies is low, and is negatively correlated with the areas of forest in townships. It is possibly due to the fact that cases of suspected ferret badger rabies are mainly found and notified to government by residents. Lower human population density in high elevations of townships (Table 5) implies lower rabies-infected ferret badgers being found accordingly.

This study is the first to utilize multivariable logistic regression analysis to study the association between landscape characteristics and ferret badger rabies incidence, thus the results differ from raccoon rabies. Jones et al. [9] uses multivariable logistic regression analysis to studied the large raccoon rabies epidemics and found the incidence has a positive correlation with a high percentage of agricultural land use, high water coverage in combination with low human population density, and low water coverage with high human population density. Recuenco et al. [10] utilizes Poisson multivariable regression analysis to study the raccoon rabies epidemics and found that the incidence rate of raccoon rabies has a positive correlation with low human population density, lack of river and lakes, and lack of highways. However, it has a negative correlation with elevations and wetlands. Raccoons are middle sized carnivores, weighing between 4 kg-10 kg, and having the ability to utilize human habitats. Due to their strong adaptability of food sourcing, they often appear in cities scavenging the leftovers from human garbage [18]. Rabies are spread by biting, therefore the incidence rate has an important relation to habitats of reservoir animals. Ferret badgers are small-sized carnivores, their habitat is different from raccoons, therefore the landscape characteristics of rabies incidence are different.

Conclusion

In conclusion, this research study can propose a model to predict the incidence rate of ferret badger rabies in the east epidemic area, and can be utilized for reference to oral vaccination administration to largely reduce the cost of epidemic prevention.

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Competing Interests

There are no competing financial or commercial interests.

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