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Spatiotemporal patterns of rabid dogs and cats and the opinions of personnel responsible for disease control in Thailand

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ABSTRACT

The aim of this study was to evaluate the patterns of rabies cases in dogs and cats in Thailand from 2013 to 2016 via spatiotemporal analysis. We also assessed the opinions of responsible district-level personnel regarding risk factors and control measures for rabies. Evaluation of rabies case patterns was based on secondary data from a national online database, and a structured questionnaire was used to obtain the opinions of district-level personnel. A total of 1202 cases (1202/13058, 9.21 %) of rabid dogs and cats were documented between 2013 and 2016, with the majority of cases involving dogs (1165/13058; 8.92 %). The spatiotemporal analysis indicated that most of the cases were recorded in central Thailand and that there was a general trend of an increase in rabies cases from the beginning of 2013 to the end of 2016. Month-by-month analysis for each year suggested that the number of rabies cases tended to increase over the course of the year in 2013 and 2016. Results from the autocorrelation indicated that the correlation coefficient tended to be similar in adjacent time lags. In terms of the opinion analysis, only one factor (i.e., the presence of a forest that served as a habitat for carrier animals in the district) was statistically significant ($P < 0.05$) in the final binary logistic regression model. The results of this study may facilitate planning for effective rabies control in Thailand.

1. Introduction

Rabies is caused by RNA viruses belonging to the *Lyssavirus* genus of the Rhabdoviridae family in the order Mononegavirales [1]. All mammals can be infected with rabies, with infected dogs and cats being able to directly transmit the virus to people via bite or direct contact. In Thailand, rabies was first officially reported in 1929 [2] and cases have been reported continuously up to the present day. The human mortality rate due to rabies was reported to be 0.02 per 100,000 people in 2016 [3]. A previous study conducted in Thailand reported that 58.8 % of domestic animals that tested positive for rabies were unowned and of unknown origin. The majority (84.2 %) of the rabid animals were unvaccinated [2].

An important risk factor for human infection is the high density of dogs in a specific area, which greatly increases the likelihood of rabies exposure and infection [4]. Residents in Thailand are particularly susceptible due to the fact that stray dogs and cats are scattered throughout the country. The Department of Livestock Development (DLD) operates under the Rabies Act (BE 2535, 1992) and is the primary rabies prevention and control authority in Thailand. The main control measures aim to limit the number of populations at risk and include the following: sterilization of animals, temporary declaration of epidemic areas, designation of rabies-free

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areas, and vaccination [5]. Nevertheless, the continuing presence of rabies in Thailand reflects the persistence of risk factors for infection and the inability of current control measures to completely eradicate the disease.

Rabies control measures in Thailand are generally enacted under the direct command of the central DLD. Commands flow from the central DLD through the following hierarchy: regional DLD, provincial DLD, and district DLD. Thus, as local DLD officers at the district level operate at the front lines of infection and disease control, it is imperative to evaluate their current opinions on disease risk factors and control measures.

Therefore, the aim of this study was to evaluate spatiotemporal patterns of rabid dogs and cats in Thailand from 2013 to 2016. Furthermore, we also assessed the opinions of responsible district-level DLD personnel regarding risk factors and control measures for rabies. The results of this study will facilitate effective planning of disease control measures by informing relevant authorities of regions and time of the year that are associated with a higher risk of rabies infection.

2. Materials and methods

2.1. Study framework and data collection

This study consisted of two parts. In the first part, spatiotemporal patterns of confirmed rabies cases in dogs and cats were analyzed using secondary data obtained from the Thai Rabies Net database [5], which is maintained by the DLD of Thailand. Our analysis included data collected from January 2013 to December 2016. A total of 1202 rabies cases (total records were 13058 for dogs and cats) were confirmed in dogs (1165) and cats (37) using the fluorescent antibody technique on brain samples in an authorized laboratory [5]. These brain samples originated from across Thailand and were either 1) obtained from the DLD necropsy laboratory via the passive surveillance system for the reporting of suspected rabid animals, or 2) obtained through purposive sampling under the active surveillance system.

The second part of this study assessed the opinions of district DLD officers who were responsible for the management of rabies. A

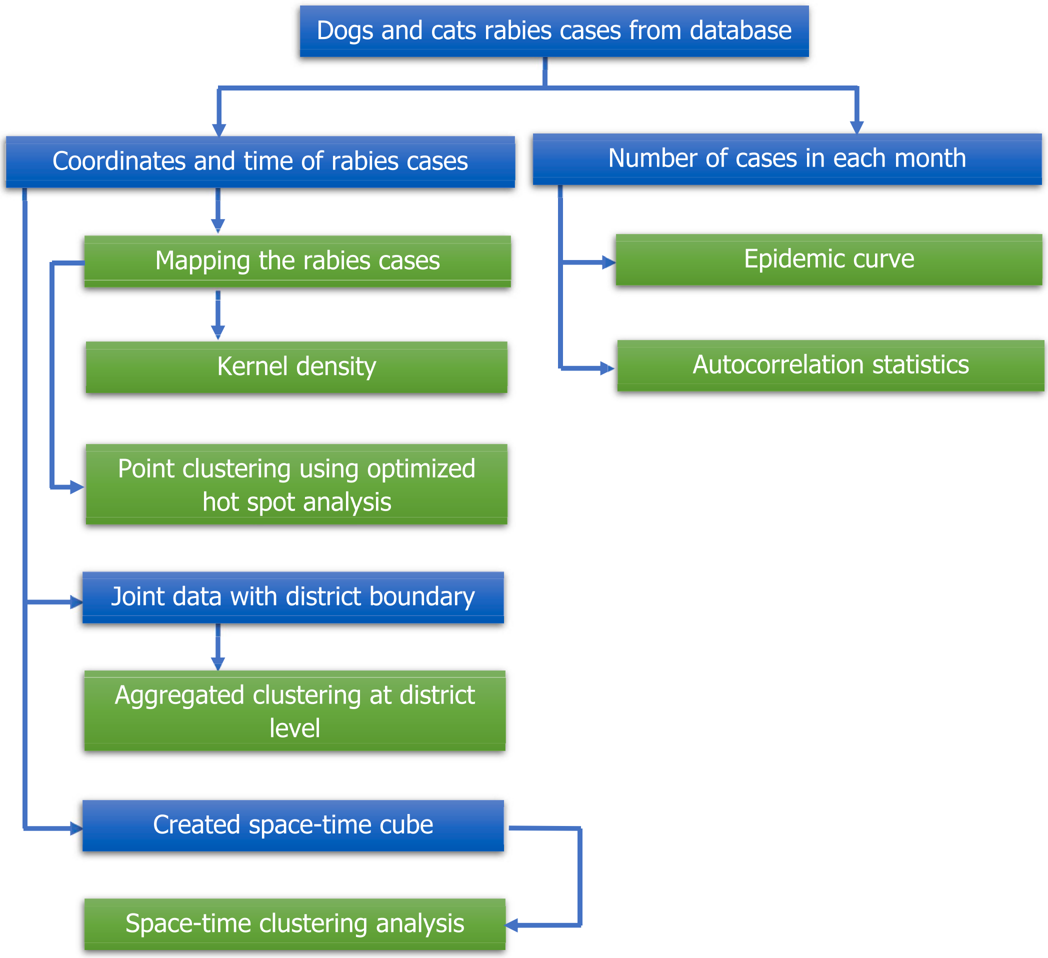


Fig. 1. A Flowchart of spatiotemporal analysis.

structured questionnaire was used to collect data from 878 respondents throughout Thailand. The questionnaire comprised both closed and open-ended questions. All questions pertained to the respondents' opinions of the disease situation, risk factors, and control measures in 2016 (Appendix). As part of questionnaire development, five rabies experts from a university (1 expert) and the DLD (4 experts) checked the consistency of the questions and the objectives of the study. The questions were subsequently modified based on their feedback and recommendations. The finalized questionnaire was sent by post to each district DLD office and was completed by one veterinarian or one para-veterinarian per district. A total of 250 (250/878 = 28.47 %) officers completed and returned their questionnaires.

The study protocol was carried out in accordance with the Declaration of Helsinki. The data set and questionnaire were approved by the DLD, based on their guidelines for anonymous research (approved code: 0610.04/567).

2.2. Data analysis

2.2.1. Spatiotemporal analysis

A framework for the spatiotemporal analysis is shown in Fig. 1. Microsoft Excel 2010 (Microsoft, Redmond, Washington, USA) was used for data manipulation, case counting, as well as the creation of line graphs and epidemic curves. In the evaluation of the spatial and spatiotemporal distribution of rabies cases, we assigned one case per coordinate in WGS 1984 UTM zone 47 N. Thus, 1202 co-ordinates were analyzed using ArcGIS 10.8.2 (ESRI, Redlands, California, USA). We mapped the cases and analyzed kernel density, point clustering (using optimized hot spot analysis), aggregated clustering at the district level (using cluster and outlier analysis [Anselin local Moran I]), and spatiotemporal clustering (using emerging hot spot analysis). Temporal analysis with autocorrelation was performed with NCSS 2019 19.0.9 (NCSS, LLC., East Kaysville, Utah, USA); the correlation coefficient for the number of rabies cases by month was determined.

2.2.2. Opinions from district DLD personnel

Of the 878 questionnaires sent to district DLDs, 255 (31.88 %) were completed and returned. Five returned questionnaires were incomplete (either completely unfilled or with missing responses to a few questions). Thus, 250 (28.47 %) questionnaires were included in the data analysis. However, one respondent did not answer the question regarding risk factors. Thus, 249 questionnaires were used in the analysis of risk factors.

Questionnaire responses were summarized as descriptive statistics using Microsoft Excel 2010. Responses to questions on risk factors were on a 5-point ordinal scale (no risk, low risk, moderate risk, high risk, and uncertain). These responses were dichotomized as no risk and risk (low risk, moderate risk, or high risk); responses of "uncertain" were removed from the analysis. Thus, the binary outcome (no risk, risk) served as the independent variable, and its association with the dependent variable (presence/absence of rabies in each district in 2016) was assessed with Pearson's chi-squared test and binary univariate and multivariable logistic regression using NCSS 2019 19.0.9. For binary logistic regression, backward elimination was used to determine the inclusion of independent variables in the final model.

3. Results

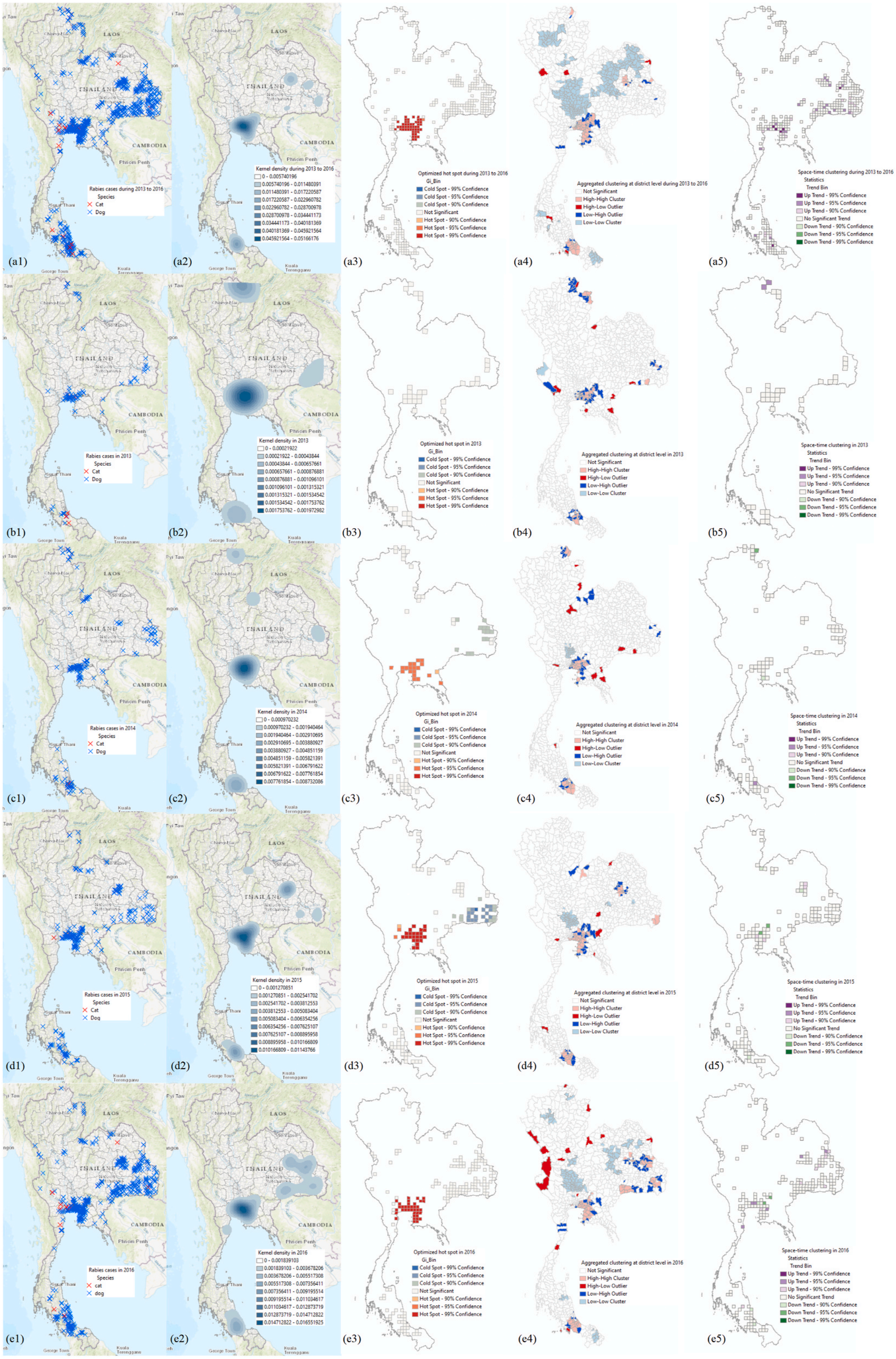
3.1. General information and spatiotemporal analysis

3.1.1. General information

A total of 1202 (1202/13058, 9.21 %) confirmed cases of rabid dogs (1165/13058; 8.92 %) and cats (37/13058; 0.28 %) were documented in the Thai Rabies Net database between 2013 and 2016. The numbers of confirmed rabies cases in dogs in 2013, 2014, 2015, and 2016 were 91 (91/2359; 3.86 %), 231 (231/2176; 10.62 %), 308 (308/3068; 10.04 %), and 535 (535/5455; 9.81 %), respectively; the numbers of confirmed cases in cats were 6 (6/2359; 0.25 %), 6 (6/2176; 0.27 %), 3 (3/3068; 0.09 %), and 22 (22/5455; 0.40 %), respectively. The numbers of rabid dogs and cats detected by the passive surveillance system in 2013, 2014, 2015, and 2016 were 93 (87/478; 19.46 %), 227 (227/618; 36.73 %), 301 (301/769; 39.14 %), and 424 (410/769; 55.14 %), respectively; the numbers detected by the active surveillance system were 4 (4/1881; 0.21 %), 10 (10/1558; 0.64 %), 10 (10/2299; 0.43 %), and 133 (133/4686; 2.84 %), respectively (Table 1).

Table 1
Total number of rabid animals detected via passive and active surveillance in Thailand from 2013 to 2016.

Year	Passive surveillance			Active surveillance			Total		
	Number of rabid animals	Total number of suspected cases	Percentage	Number of rabid animals	Total number of suspected cases	Percentage	Number of rabid animals	Total number of suspected cases	Percentage
2013	93	478	19.46	4	1881	0.21	97	2359	3.86
2014	227	618	36.73	10	1558	0.64	237	2176	10.62
2015	301	769	39.14	10	2299	0.43	311	3068	10.04
2016	424	769	55.14	133	4686	2.84	557	5455	9.81
Total	1045	2634	39.67	157	10424	1.51	1202	13058	8.92



(caption on next page)

Fig. 2. Spatial distribution of rabid dogs in Thailand from 2013 to 2016.
The first row (a1–a5) shows the overall distribution of cases for all four years. Rows 2 (b1–b5) to 5 (e1–e5) shows the distribution of cases for each individual year. Columns 1–5 depict the following: incident cases (a1–e1), kernel density (a2–e2), optimized hotspot analysis (a3–e3), aggregated clustering at district level (a4–e4), and space-time clustering (a5–e5).

3.1.2. Spatiotemporal analysis

Rows 1 (Fig. 2; a1) to 5 (Fig. 2; e1) of the first column in Fig. 2 illustrate the overall distribution of rabies cases from 2013 to 2016 and the distribution for each individual year. Rabies cases were predominantly documented in dogs. The majority of cases were concentrated in central Thailand. Case density was also high in the lower part of northeast Thailand, as well as various regions in the south. Rabies cases were more densely distributed in 2016 (Fig. 2; e1) than in any other year.

The results of kernel density analysis are shown in column 2 of Fig. 2 (Fig. 2; a2–e2). The highest density of rabies cases was observed in central Thailand from 2013 to 2016; in some years, a high density of cases was also observed in the northeast and southern regions in Thailand, as well as small regions in the north. Point cluster analysis showed that central Thailand was a hot spot for rabies (Fig. 2; a3–e3). Four-year data showed that central Thailand was associated with the greatest risk at a confidence level of 99 %; separate analyses for each individual year found that 2015 and 2016 had the greatest risk of rabies at a confidence level of 99 %. The central region in Thailand includes Bangkok, which is connected to other provinces such as Chachoengsao, Chonburi, Samut Prakan, and Samut Songkhram.

The analysis of 4-year aggregated data at the district level (Fig. 2; a4–e4) revealed that the highest number of rabies cases of high-high cluster regions were in central Thailand, followed by areas in the south, north, and northeast. High-high cluster regions were observed in the central and lower southern regions of Thailand every year. The spatiotemporal clustering analysis indicated that the number of cases tended to increase (99 % confidence level) in some areas of central, eastern, northern, and southern Thailand (Fig. 2; a5–e5). Analysis of individual years showed trends for increasing cases (95 % confidence level) in some areas in the northern (in 2013), southern (in 2014), and central and northeastern parts of Thailand (in 2015 and 2016).

3.1.3. Temporal analysis

The epidemic curve showed that the number of rabies cases, as determined by both passive and active surveillance, tended to increase from the beginning of 2013 to the end of 2016 (Fig. 3). A month-by-month analysis for each year clearly indicated that the number of rabies cases tended to increase from the beginning to the end of the year in 2013 and 2016 (Fig. 4).

The autocorrelation analysis found that the correlation of rabies cases was highest in lag 1 ($r = 0.751$, $P < 0.05$), followed by a progressive decrease in lags 2–40 (Table 2).

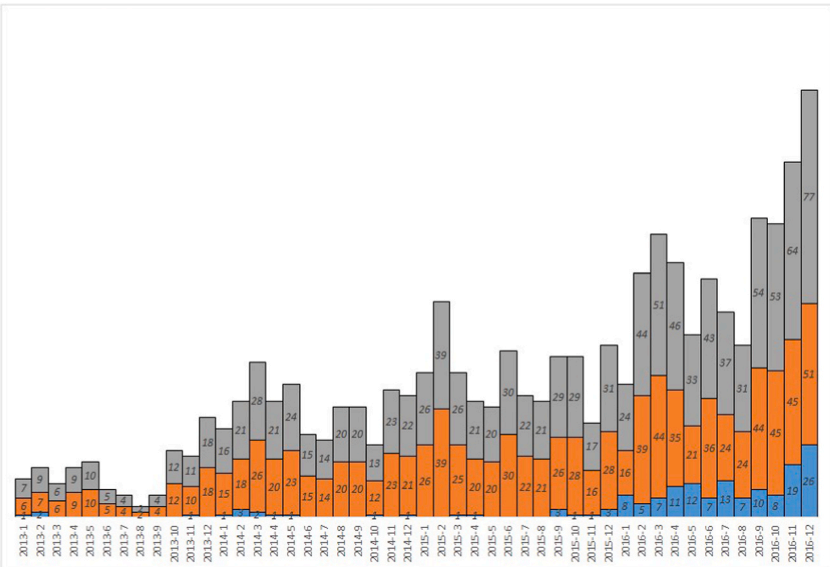


Fig. 3. Epidemic curve for rabid dogs documented in Thailand from 2013 to 2016. Gray bars represent the total number of cases detected via both the passive and active surveillance systems for each month. Blue and orange bars represent the number of cases detected by the passive and active surveillance systems, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

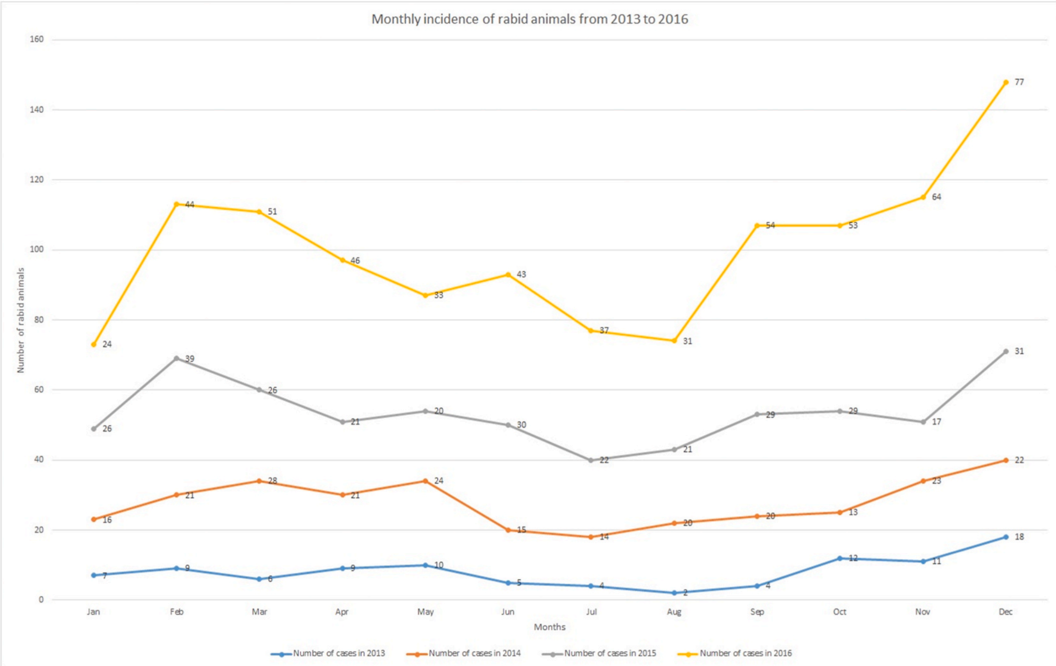


Fig. 4. Monthly incidence of rabid animals from 2013 to 2016. Months (January to December) are shown on the x-axis. The number of rabid animals is shown on the y-axis. Blue, red, gray, and yellow lines represent the number of cases in 2013, 2014, 2015, and 2016, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Results of temporal autocorrelation of rabies cases in Thailand from 2013 to 2016.

Time	Number of cases	Lag	Correlation	Time	Number of cases	Lag	Correlation
Jan-13	7	–	–	Jan-15	26	31	−0.174
Feb-13	9	1	0.751	Feb-15	39	32	−0.204
Mar-13	6	2	0.618	Mar-15	26	33	−0.203
Apr-13	9	3	0.532	Apr-15	21	34	−0.249
May-13	10	4	0.400	May-15	20	35	−0.291
Jun-13	5	5	0.400	Jun-15	30	36	−0.309
Jul-13	4	6	0.404	Jul-15	22	37	−0.353
Aug-13	2	7	0.338	Aug-15	21	38	−0.343
Sep-13	4	8	0.329	Sep-15	29	39	−0.343
Oct-13	12	9	0.288	Oct-15	29	40	−0.301
Nov-13	11	10	0.181	Nov-15	17	–	–
Dec-13	18	11	0.088	Dec-15	31	–	–
Jan-14	16	12	0.114	Jan-16	24	–	–
Feb-14	21	13	0.086	Feb-16	44	–	–
Mar-14	28	14	0.085	Mar-16	51	–	–
Apr-14	21	15	0.070	Apr-16	46	–	–
May-14	24	16	0.027	May-16	33	–	–
Jun-14	15	17	0.003	Jun-16	43	–	–
Jul-14	14	18	−0.007	Jul-16	37	–	–
Aug-14	20	19	−0.022	Aug-16	31	–	–
Sep-14	20	20	−0.038	Sep-16	54	–	–
Oct-14	13	21	−0.002	Oct-16	53	–	–
Nov-14	23	22	−0.002	Nov-16	64	–	–
Dec-14	22	23	−0.083	Dec-16	77	–	–

In this analysis, the maximum lag (the number of past observational correlation) of time is 40 specified by NCSS 2019 19.0.9. Significant if $|\text{Correlation}| > 0.288$.

3.2. Opinions of district DLD personnel

3.2.1. Descriptive statistics

Opinions pertinent to rabies occurrence and control in Thailand, as provided by district DLD personnel, are presented in Table 3.

Table 3
Descriptive analysis of information pertinent to rabies occurrence and control in Thailand, as provided by district-level personnel in the Department of Livestock Development.

Opinions/practices	Quantitative responses			Qualitative responses
	Average	Median	Minimum–Maximum	(number of responses, %)
Number of dogs and cats in the responsible district (n = 250; expected average throughout the year)				
Owned animals (animal per year)	8336	5175	45–163,695	–
Stray animals (animal per year)	806	260	10–50,000	–
Month during which common rabies cases peaked (n = 436; multiple-choice responses)				
January	–	–	–	17 (3.90)
February	–	–	–	35 (8.02)
March	–	–	–	118 (27.06)
April	–	–	–	132 (30.28)
May	–	–	–	57 (13.07)
June	–	–	–	20 (4.59)
July	–	–	–	7 (1.60)
August	–	–	–	5 (1.15)
September	–	–	–	4 (0.92)
October	–	–	–	10 (2.29)
November	–	–	–	15 (3.44)
December	–	–	–	16 (3.67)
Most effective control measure for rabies (n = 250)				
Vaccination of dogs and cats once per year	–	–	–	213 (85.20)
Vaccination of dogs and cats two times per year	–	–	–	15 (6)
Vaccination of dogs and cats three times per year	–	–	–	22 (8.80)
Sterilization of dogs and cats once per year	–	–	–	101 (40.40)
Sterilization of dogs and cats two times per year	–	–	–	95 (38)
Sterilization of dogs and cats three times per year	–	–	–	54 (21.60)
Rabies vaccination covers all sub-districts (n = 250)				
Yes	–	–	–	130 (52)
No	–	–	–	120 (48)
Vaccination coverage in owned dogs and cats (n = 250)				
Percentage of vaccination coverage: 81–100 %	–	–	–	106 (42.40)
Percentage of vaccination coverage: 61–80 %	–	–	–	88 (35.20)
Percentage of vaccination coverage: 41–60 %	–	–	–	34 (13.60)
Percentage of vaccination coverage: 21–40 %	–	–	–	14 (5.60)
Percentage of vaccination coverage: 0–20 %	–	–	–	8 (3.20)
Vaccination coverage in stray dogs and cats (n = 250)				
Percentage of vaccination coverage: 81–100 %	–	–	–	29 (11.60)
Percentage of vaccination coverage: 61–80 %	–	–	–	48 (19.20)
Percentage of vaccination coverage: 41–60 %	–	–	–	30 (12)
Percentage of vaccination coverage: 21–40 %	–	–	–	41 (16.40)
Percentage of vaccination coverage: 0–20 %	–	–	–	102 (40.80)
Sterilization coverage in owned dogs and cats (n = 250)				
Percentage of sterilization coverage: 81–100 %	–	–	–	17 (6.80)
Percentage of sterilization coverage: 61–80 %	–	–	–	26 (10.40)
Percentage of sterilization coverage: 41–60 %	–	–	–	46 (18.40)
Percentage of sterilization coverage: 21–40 %	–	–	–	56 (22.40)
Percentage of sterilization coverage: 0–20 %	–	–	–	105 (42)
Sterilization coverage in stray dogs and cats (n = 250)				
Percentage of sterilization coverage: 81–100 %	–	–	–	3 (1.20)
Percentage of sterilization coverage: 61–80 %	–	–	–	7 (2.80)
Percentage of sterilization coverage: 41–60 %	–	–	–	27 (10.80)
Percentage of sterilization coverage: 21–40 %	–	–	–	38 (15.20)
Percentage of sterilization coverage: 0–20 %	–	–	–	175 (70)
Additional measure (or improved control measure) that should be taken (n = 250)				
Increase vaccination coverage in animals	–	–	–	211 (84.40)
Training livestock volunteers in effective vaccination	–	–	–	200 (80)
Elimination of stray dogs	–	–	–	150 (60)
Usage of oral rabies vaccine in stray dogs	–	–	–	148 (59.20)
Education of dog owners	–	–	–	133 (53.20)

The average numbers of owned and stray animals in each district throughout the year were 8336 and 806, respectively. The personnel considered that the number of rabid animals was most likely to peak in April (132/436; 30.28 %). Annual vaccination was deemed to be the most effective control measure (213/250; 85.20 %), followed by the sterilization of dogs and cats (101/250; 40.40 %). Over half (52 % [130/250]) of the personnel responded that rabies vaccination covered all sub-districts. In each district, a vaccination coverage of 81–100 % was achieved in 42.40 % (106/250) and 11.60 % (29/250) of owned and stray animals, respectively. A sterilization coverage of 81–100 % was achieved in 6.80 % (17/250) and 1.20 % (3/250) of owned and stray animals, respectively. The large majority of personnel (84.40 % [211/250]) considered an increase in vaccination coverage of the population at risk to be the most important control measure for rabies.

3.2.2. Opinion of risk factors

Of the 54 assessed risk factors, the following 8 factors were statistically significant ($P < 0.1$) in the univariate analysis: 1) large number of stray dogs; 2) large number of stray cats; 3) stray dogs spread the disease to other animals by bite or close contact; 4) vaccinated animals with poor immunity after vaccination; 5) presence of a forest that served as a habitat for carrier animals in the district; 6) dogs and cats were infected by other animals (e.g., livestock); 7) seasonal breeding of dogs and cats influenced the spread of rabies; and 8) local dog and/or cat farms increased the at-risk population (Table 4). These factors were subsequently analyzed in a binary logistic regression model with backward elimination; only one factor (presence of a forest that served as a habitat for carrier animals in the district) remained significant in the final model ($P < 0.05$) (Table 5). Thus, rabies was 1.397 times (95 % confidence interval [CI] = 1.012–1.927) more likely to occur in districts with forest habitats for carrier animals compared to districts without such habitats.

4. Discussion

In this study, the annual proportion of confirmed cases to suspected cases of rabies in dogs and cats between 2013 and 2016 ranged from 3.68 to 10.62 %. The majority of confirmed cases involved dogs and were reported through a passive surveillance system. While the spatiotemporal analysis showed that rabies frequently occurred in many parts of Thailand, the most important hotspot for rabid dogs and cats was central Thailand. The temporal analysis suggested that rabies incidence tended to increase from the beginning of 2013 to the end of 2016. The questionnaire results indicated that district DLD personnel considered annual vaccination and sterilization to be the most important current control measures for rabies. In terms of additional measures required for the improvement of rabies control, most respondents indicated that increasing vaccination coverage was of foremost concern. Among all the proposed risk factors for rabies occurrence, only the presence of a forest that served as a habitat for carrier animals in a given district was found to be significant in a binary logistic regression model.

Rabies was found to be more common in dogs than cats. District DLD personnel reported that the number of stray dogs, sterilization, and vaccination were important factors for disease elimination. Reducing the number of stray dogs was considered to be the most important control measure. Recently, Thanapongtharm et al. [6] estimated that there were 12.8 million dogs in Thailand, including approximately 1.6 million stray dogs. According to our experience, it is very difficult to catch stray dogs for the purposes of vaccination or sterilization. Therefore, additional disease control measures have been proposed for dogs. For example, Chanachai et al. [7] reported that 65.6 % of stray dogs at study sites within Thailand were successfully vaccinated against rabies via an oral route. Nevertheless, the efficacy of an oral rabies vaccine in reducing disease incidence in Thailand requires further study. Investigations of oral vaccine efficacy in wild animals are particularly important, as these populations may be an important source of infection for domestic animals. An example of the successful use of an oral rabies vaccine in wild animals was previously described by Lojkić et al. [8].

We found that the majority of rabies cases were reported through the passive surveillance system; few confirmed cases were detected via the active surveillance system. This may have been due to the fact that the active surveillance system was established in order to declare rabies-free zones, which may not be suitable for endemic countries. Thus, the DLD should improve current systems for the routine detection of rabid animals, particularly in disease hotspots.

Rabies cases were primarily concentrated in central and southern Thailand, as well as the southern part of the northeastern region (Fig. 2). Kernel density analysis indicated that central Thailand consistently had the highest case density from 2013 to 2016. In addition, point clustering and spatiotemporal clustering analyses showed that central Thailand was the highest risk area for rabid dogs. We used aggregated data at the district level to define disease clustering, due to our concern regarding spatial autocorrelation. These results remained consistent with the point and spatiotemporal clustering analysis, which confirmed that central Thailand was an important hotspot for rabies. Thus, our data clearly indicate that central Thailand should be the highest priority area for rabies control in the country. This conclusion is supported by the results of previous studies conducted in Thailand [9,10].

The temporal analysis showed an overall increasing trend in rabies cases from the beginning of 2013 to the end of 2016. A month-by-month analysis for each year found that the case incidence increased from the beginning to end of the year in 2013 and 2016. However, some periods of temporal pattern may vary from month to month. Furthermore, this pattern did not appear to vary with season (Figs. 3 and 4, and Table 2). Moreover, case incidence rates were highly correlated between adjacent time periods (Table 2). Therefore, the incidence of rabies in a given month was greatly influenced by the number of cases in the preceding month. Further exploration of the data suggested that this temporal correlation was potentially influenced by adjacent regions with rabies cases. This may explain the aforementioned hotspots detected via spatiotemporal clustering. These findings are consistent with those of a previous study conducted in Canada [11]. In our opinion, these results indicate that current control measures in Thailand may not be comprehensive enough to eliminate rabies during each outbreak. In addition, the temporal analysis of some time periods revealed an erratic pattern. This suggests that disease control was not always implemented at the highest level at all times and/or in all regions. Therefore, future evaluations of the efficacy of rabies control measures should account for spatiotemporal correlations.

The presence of a suitable habitat for potential carrier animals was found to be the primary risk factor for rabies incidence. We hypothesized that the continuing presence of rabies in Thailand was due to the failure to prevent and manage recurrent transmission among carrier animals. Indeed, many studies have reported a cyclical transmission of the rabies virus among wild animals, domestic animals, and humans. For example, in China, researchers have presumed that rabies in wild animals possibly resulted from viral spillover from dogs [12]. Similarly, in Brazil, the occurrence of rabies in humans was associated with infected wildlife [13]. The mobility of wild carrier animals poses a very high risk of transmitting disease to domestic dogs [14]. The DLD should develop wildlife

Table 4
Results of univariate analysis of significant risk factors ($P < 0.1$) associated with rabies in Thailand.

Risk factors	Number of districts with rabies cases (%)	Number of districts without rabies cases (%)	*P* -value
Large number of stray dogs (n = 243)	83 (34.16)	145 (59.67)	0.069
No	2 (0.82)	13 (5.35)	
Large number of stray cats (n = 238)	82 (34.35)	141 (59.24 %)	0.066
No	2 (0.84)	13 (5.46)	
Stray dogs spread the disease to other animals by bite or close contact (n = 240)	83 (34.58)	142 (59.17)	0.065
No	2 (0.83)	13 (5.42)	
Vaccinated animals with poor immunity after vaccination (n = 233)	79 (33.91)	136 (58.37)	0.007
No	1 (0.43)	17 (7.30)	
Presence of a forest that serves as a habitat for carrier animals in the district (n = 234)	67 (28.63)	103 (44.02)	0.040
No	16 (6.84)	48 (20.51)	
Dogs and cats infected by other animals (e.g., livestock) (n = 231)	58 (25.11)	94 (40.69)	0.078
No	21 (9.09)	58 (25.11)	
Seasonal breeding of dogs and cats influenced spread of rabies (n = 236)	79 (33.47)	141 (59.75)	0.057
No	2 (0.85)	14 (5.93)	
Local dog and/or cat farms increased the at-risk population (n = 238)	59 (24.79)	95 (39.92)	0.090
No	23 (9.66)	61 (25.63)	

Please note that the total number of values for each factor were not equal to 249, as some personnel did not respond to all questions.

Table 5
Final binary logistic regression model.

Factor	Coefficient	SE	OR	95 % CI of OR	Wald Z-Value	*P*-Value
Intercept	−0.166	0.091	–	–	−1.819	0.069
Presence of a forest that serves as a habitat for carrier animals in the district (Reference = no risk)						
Risk	0.334	0.164	1.397	1.012–1.927	2.035	0.042

SE = Standard error, OR = Odd ratio, CI = Confidence interval.
Model $R^2 = 0.5528$.
The dependent variable was absence of rabies in each district in 2016; model for logit is (disease) = (presence of a forest) * intercept when disease = risk.

surveillance systems to improve the detection of rabid animals at the beginning of outbreaks, particularly in disease hotspots.

District DLD personnel commented that the yearly peak incidence of rabies cases was in April. This was inconsistent with the results of the epidemic curve and autocorrelation analysis. This reflects inadequate knowledge among local DLD officers and the need for additional educational interventions. This is particularly important, as increased knowledge contributes to improvements in attitudes and practice. Such interventions warrant further exploration in future studies. In terms of the opinions of DLD personnel regarding methods for rabies control, vaccination and sterilization were cited as the most important measures. Although, both measures were not found significant by chi-squared and binary logistic regression tests. This was because our variables in opinion risk factor analysis were highly specific for the definition of each while it reduced the sensitivity for statistical significance. Nevertheless, the opinions collected by the questionnaires reflect the current practice of district DLD officers and thus are very useful for informing the future development and improvement of rabies control measures in Thailand.

5. Conclusions

This study determined that central Thailand was the most important hotspot for rabies in domestic dogs and cats. The majority of district DLD personnel who were directly involved in disease control recommended that an increase in vaccination coverage should be the first priority for implementation. An analysis of rabies risk factors cited by district DLD personnel found that the presence of a forest that served as a habitat for carrier animals was the only statistically significant risk factor. Therefore, relevant agencies need to apply the knowledge gained from this study to implement and improve rabies control measures, particularly for dogs. Such measures will greatly contribute to the reduction of rabies incidence in both animals and humans in Thailand.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21969.

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