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Seasonality of canine leptospirosis in the United States and Canada and its association with rainfall

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Abstract

A retrospective study was undertaken to describe seasonal patterns of leptospirosis diagnosed at veterinary teaching hospitals in the United States and Canada, and to determine if occurrence of cases (diagnoses) was associated with rainfall. The veterinary medicine database (VMDB) was searched for records of dogs in which a diagnosis of leptospirosis was made, and average monthly rainfall recorded at the city where each hospital is located was calculated from historical data. Time-series analysis was used to identify the variables that best described occurrence of cases of leptospirosis. Three-hundred and forty dogs were diagnosed with leptospirosis at 22 veterinary teaching hospitals between 1983 and 1998. Most cases ($n = 184$) were diagnosed between August and November during each year of the study. A significant correlation ($r = 0.41$) was detected between the number of cases of leptospirosis diagnosed and average rainfall recorded 3-months prior to diagnosis. The best-fitting (Akaike's corrected information criterion = 2.01) regression on the leptospirosis case series included cases diagnosed in the previous month and 12-months previously, and rainfall recorded 3 months previously. Leptospirosis has a seasonal distribution (late summer to fall), and rainfall can be used to predict the occurrence of leptospirosis. Leptospirosis can affect the health of dogs seriously and its prevalence is increasing, but the disease is preventable by vaccination.

Keywords: Leptospirosis; Canine; United States; Canada; Time-series; Rainfall

1. Introduction

Leptospirosis occurs in many domestic animal species, and in humans. Canine leptospirosis is characterized by acute renal and/or hepatic failure with or without coagulation abnormalities (Harkin and Gartrell, 1996; Birnbaum et al., 1998). Many different

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Leptospira serovars have been identified. The epidemiology of leptospirosis is characterized by a primary host species that acts as the reservoir for each serovar. Leptospirosis due to *Leptospira interrogans* serovars canicola and icterohaemorrhagiae has been reported in dogs in the United States and Canada for more than 100 years (Bolin, 1996). Dogs are the reservoir species for *L. interrogans* serovar canicola, and rats are the reservoir species for *L. interrogans* serovar icterohaemorrhagiae. More recently, leptospirosis caused by other serovars—such as *L. interrogans* serovar bratislava, *Leptospira kirschneri* serovar grippotyphosa and *L. interrogans* serovar pomona—have been described. These serovars have a range of reservoir species, including voles, raccoons, skunks, opossums, mice, pigs and cattle (Hanson, 1982; Bolin, 1996; Wohl, 1996; Birnbaum et al., 1998; Adin and Cowgill, 2000; Sykes, 2001).

Ward et al. (2002) estimated the prevalence of leptospirosis in dogs presented to veterinary teaching hospitals in the United States and Canada between 1970 and 1998, using recorded information (annual number of diagnosed cases/annual estimated population at-risk) in the veterinary medicine database (VMDB). Between 1970 and 1982, the prevalence of leptospirosis decreased. However, between 1983 and 1998, the prevalence increased significantly ($P < 0.01$), with an annual increase of 1.2 cases per 100,000 dogs examined. Middle-age, male gender, and herding, hound, working and mixed breed-groups were risk factors for leptospirosis diagnosed. Ward (2002) found that cases of leptospirosis diagnosed at veterinary teaching hospitals in the midwest region of the United States between 1993 and 1998 were clustered. However, changes in the demographics (age, gender and breed) of dogs presented at veterinary teaching hospitals did not explain the clustering observed, and it was suggested that *Leptospira* serovar or environmental factors was responsible for the clustering of canine leptospirosis observed.

Identifying and describing seasonal patterns of leptospirosis during a period of increasing prevalence (1983–1998) might assist development of causal hypotheses (Ward et al., 2002). Leptospirosis is more commonly diagnosed in late summer and early fall (Bolin, 1996; Brown et al., 1996; Harkin and Gartrell, 1996). Leptospiral organisms shed in the urine of infected animals can survive for long periods in surface water. Susceptible hosts are infected through contact with contaminated water. Bacteria enter through the damaged skin or mucous membranes of exposed animals (Adin and Cowgill, 2000). Flooding has been associated with outbreaks of leptospirosis in humans and animals, and leptospirosis is an occupational hazard for rice- and sugarcane-field workers and a recreational hazard for swimmers and campers and during sporting events (American Public Health Association, 2000). Gardening, the presence of dogs around the home, and walking through ponds or stagnant water have been identified as risk factors for human cases of leptospirosis (Douglin et al., 1997). Rainfall might be useful in predicting the number of cases of canine leptospirosis. Adin and Cowgill (2000) identified a 71% correlation between the annual number of cases of canine leptospirosis diagnosed at the University of California Veterinary Teaching Hospital between 1990 and 1998 and the annual amount of rainfall in the San Francisco Bay area. An association between rainfall and leptospirosis also has been suggested in other species. Carroll and Campbell (1987) found that leptospirosis due to serovar hardjo—in inland central Queensland, Australia, beef cattle herds—was serologically more prevalent following rain and on farms with high water-holding-capacity soils. Miller et al. (1991) also found a 34% correlation between isolation rates of serovar hardjo from mature cattle and mean precipitation amount in United States herds. In a study of 2551 horses in New York State, Barwick et al. (1997, 1998) found an association between a soil-and-water index and the risk of exposure to five *Leptospira* serovars.

Preventing exposure of dogs to areas of land that have been flooded recently—or natural waters that are contaminated with *Leptospira* serovars—could effectively reduce the occurrence of leptospirosis. If rainfall predicts leptospirosis, efforts to increase pet-owner awareness of the seasonal risk of *Leptospira* exposure to their pets and themselves could be beneficial. Also, promoting vaccination of dogs against leptospirosis prior to a seasonal increase in exposure could be an option. The objectives of this study were to describe seasonal patterns of leptospirosis diagnosed at veterinary teaching hospitals in the United States and Canada, and to determine if cases were associated with rainfall.

2. Materials and methods

2.1. Data source

The selection of records used in this study has been described previously (Ward et al., 2002). The VMDB was used to identify records of dogs examined at 22 veterinary teaching hospitals located at schools and colleges of Veterinary Medicine in the United States and Canada between 1 January 1983 and 31 December 1998, in which a diagnosis of leptospirosis had been made. When records are reported to the VMDB, a standard diagnostic code is provided by the clinician in charge of each case. The VMDB diagnosis code for leptospirosis is 010017200. All records in the VMDB were searched for this code. During the study period, 1,067,214 dogs were examined, the mean number of years of reporting to the VMDB for hospitals was 12, and 340 cases of leptospirosis (33 per 100,000 dogs examined; 95% CI, 29–36 cases per 100,000 dogs) were identified (Ward, 2002). For each of the 340 records identified, the date of diagnosis was recorded in the VMDB. For each hospital included in the study, the rainfall (in.) recorded (National Climate Data Centre, US Monthly Precipitation for Cooperative & NWS Sites, http://lwf.ncdc.noaa.gov/oa/climate/online/coop-precip.html; National Snow and Ice Data Center, 2000. Adjusted Monthly Precipitation, Snowfall and Rainfall for Canada, 1874–1990. EOSDIS NSIDC Distributed Active Archive Center, University of Colorado at Boulder, http://nsidc.org/data/docs/daac/nsidc0072_canadian_precip. gd.html) at the city where the hospital was located was identified for each month in which data were reported to the VMBD, and for each month up to 12 months previous to diagnosis.

2.2. Data analysis

The linear trend (regression coefficient, $b = 0.018$, $t = 7.55$, $P < 0.001$) in the time-series of cases of leptospirosis that previously was identified (Ward et al., 2002) was removed using linear regression. Time-series analysis (Shumway, 1988) was used to identify temporal patterns in the series of cases of leptospirosis, and the relationship between rainfall and the diagnosis of leptospirosis at veterinary teaching hospitals between 1983 and 1998. (Time-series analysis is a method that allows inferences to be drawn from data consisting of serial observations which are correlated over time, by incorporating correlated error terms into the model that is used (Shumway, 1988).)

Autocovariance (ACF) and partial autocovariance (PACF) functions of the time-series of cases were constructed. ACF measures the dependence between values (x_t and x_{t-p}) of the same variable observed at different times, where p is the time lag (Shumway, 1988). The ACF is the standardized ACF estimated between all values observed up to the selected time lag, p. PACF can be described as a corrected ACF between x_t and x_{t-p} obtained by conditioning on the intervening values $x_{t-1}, x_{t-2}, \ldots, x_{t-p+1}$ (Shumway, 1988). The ACF and PACF can be used as diagnostic tools to identify seasonal and cyclical trends in a time-series, and (tentatively) the order of the autoregression (by noting the value of p after which the PACF is essentially 0). Autoregression models were fit to the time-series of cases of leptospirosis. In an autoregressive model, the value of a variable at time t depends on the value of the variable at some previous time and on an additional random error. The best-fitting autoregressive model (lags $p = 0, 1, \ldots, 12$) describing the number of cases of leptospirosis diagnosed each month at veterinary teaching hospitals was chosen based on the goodness-of-fit criterion, Akaike's corrected information criterion (AICc), so that the model that minimized estimated variance after taking into account the number of model parameters was selected (Shumway, 1988; ASTSA—Applied Statistical Time Series Analysis, version 1.0. Shumway RH, 1994. Division of Statistics, University of California, Davis, 1994, http://www-stat.ucdavis.edu/∼shumway/tsa.html).

The most appropriate model describing the relationship between cases of leptospirosis diagnosed each month at veterinary teaching hospitals and monthly rainfall and cases of leptospirosis recorded previously (lags 0, $1, \ldots, 12$) was identified using vector autoregression (Shumway, 1988). Vector autoregression allows the interdependence structure between elements of a vector of time-series to be examined. AICc was used to select the best-fitting model, and the ACF and PACF of the selected model were examined for evidence of stationarity. No discernable trends (stationarity) should be present in these functions if the model adequately describes the time-series, that is, secular, seasonal and cyclical trends have been removed (Shumway, 1988). These functions also were examined for constant variance, independence and randomness using the cumulative spectrum, Box-Pierce and fluctuation tests, respectively, and for outliers using the z-distribution. The significance of estimated model coefficients was tested using a t-statistic (ASTSA version 1.0).

3. Results

The time-series of cases and the corresponding average monthly rainfall are shown in Fig. 1. Most cases ($n = 184$) were diagnosed between August and November (Table 1). Significant ($P < 0.05$) positive autocorrelations ($r > 0.14$) were detected between the number of cases of leptospirosis diagnosed at lags of 1, 11, 12, 13, 25, 37, 47, 48 and 59 months (Fig. 2), suggesting a seasonal (annual) component is present in the series. Significant ($P < 0.05$) negative autocorrelations ($r < -0.14$) were detected between the number of cases of leptospirosis diagnosed at lags of 7, 17, 18, 19, 28, 29, 30, 31, 42 and 54 months (Fig. 2). Significant ($P < 0.05$) positive and negative partial autocorrelations

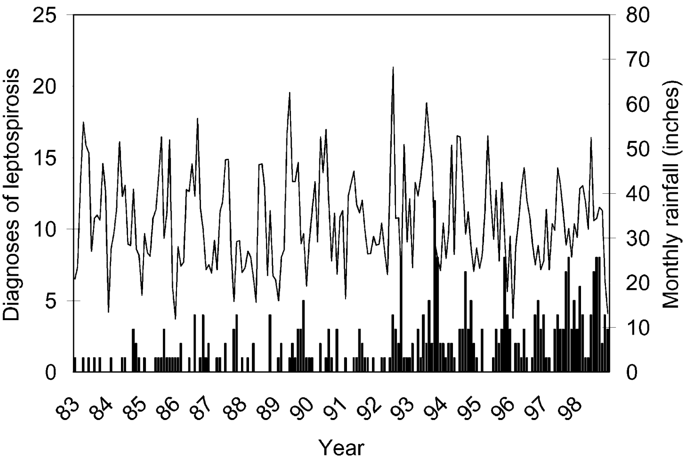

Fig. 1. Time-series of cases of canine leptospirosis (line) reported to the VMDB (USA and Canada), and average monthly rainfall (bars) recorded at the city where each hospital is located, January 1983 to December 1998.

were detected between the number of cases of leptospirosis diagnosed at lags of 1, 11, 12 and 47 months, and at 7 and 17 months, respectively (Fig. 3). Plots of the ACF and PACF indicated an annual, cyclical pattern of diagnosis of cases of leptospirosis and that the autoregressive order of the series was probably $\leq$12 months.

Significant positive and negative cross-correlations were detected between the number of cases of leptospirosis diagnosed and rainfall lagged by 2–5 months, and by 8–10 months, respectively (Table 2). The strongest correlation $(r = 0.41)$ was found between cases of leptospirosis and the average monthly rainfall recorded 3 months previously.

Table 1
Cases of canine leptospirosis reported to the VMDB (USA and Canada), 1 January 1983 to 31 December 1998

Month of diagnosis	Cases	
	Number	Percentage of total
January	20	6
February	16	5
March	18	5
April	11	3
May	13	4
June	22	6
July	31	9
August	37	11
September	37	11
October	53	16
November	57	17
December	25	7
Total	340	100

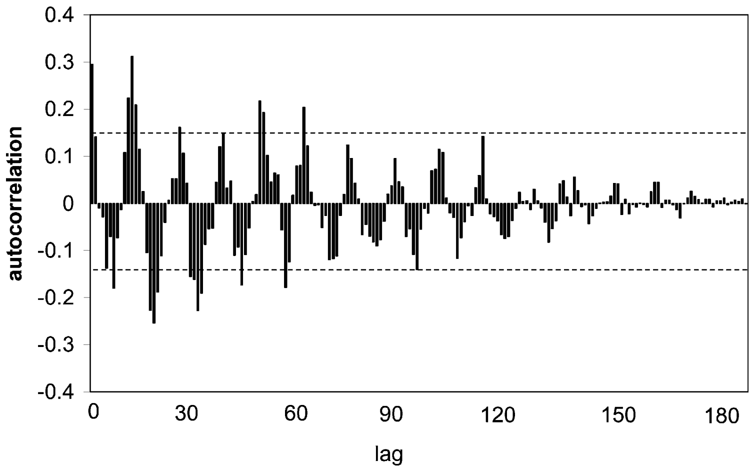

Fig. 2. ACF function of the time-series of cases of canine leptospirosis reported to the VMDB (USA and Canada), January 1983 to December 1998. 95% confidence limits are indicated (- - -). The lag unit is in months.

The best-fitting ($AICc = 2.14$) autoregressive model of cases of leptospirosis (based on the PACF of the case series, $1 \leq p \leq 12$) included only the number of cases diagnosed in the previous month ($b = 0.29$, $t = 4.25$, $P < 0.001$). The only average monthly rainfall that was associated was at a lag of 3 months ($b = 0.052$, $t = 3.84$, $P < 0.001$). The best-fitting ($AICc = 2.01$) regression model using both number of cases of leptospirosis and monthly rainfall included cases diagnosed in the previous month and rainfall recorded 3 months previously (Table 3). ACF and PACF of the residuals of this regression (not shown) appeared stationary, except for an autocorrelation ($r = 0.16$) at a lag of 12 months. Whilst

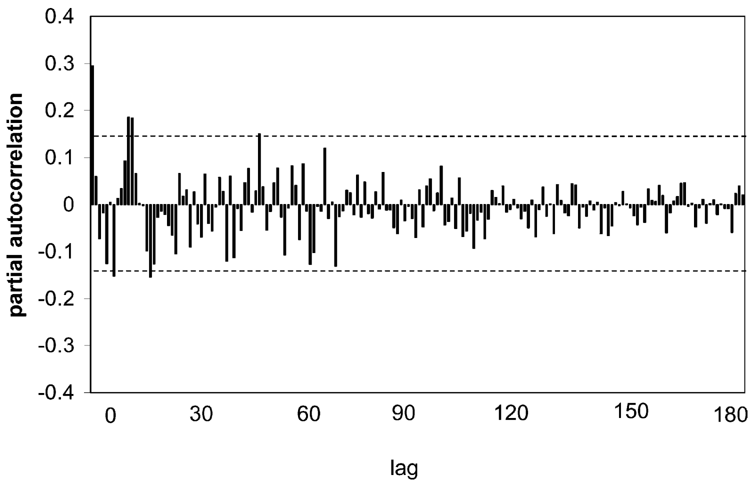

Fig. 3. PACF function of the time-series of cases of canine leptospirosis reported to the VMDB (USA and Canada), January 1983 to December 1998. 95% confidence limits are indicated (- - -). The lag unit is in months.

Table 2
Cross-correlation between 340 cases of canine leptospirosis reported to the VMDB (USA and Canada), 1 January 1983 to 31 December 1998, and average monthly rainfall recorded at the city in which each hospital ($n = 22$) is located, lagged by 0–12 months

Lag (months)	Correlation	
	r	*P*
0	−0.02	0.92
1	0.13	0.05
2	**0.24**	**0.01**
3	**0.41**	**0.01**
4	**0.28**	**0.01**
5	**0.18**	**0.01**
6	0.06	0.31
7	−0.01	0.94
8	**−0.20**	**0.02**
9	**−0.28**	**0.01**
10	**−0.29**	**0.01**
11	**−0.13**	**0.08**
12	0.02	0.83

Table 3
Best-fitting (AICc = 2.01, variance = 2.60, d.f. = no. of observations − variable lags = 192 − 1 − 12 − 3 = 176) regression model of cases of canine leptospirosis reported to the VMDB (USA and Canada), 1 January 1983 to 31 December 1998

Variable	Lag (months)	*b*	S.E.	*t*	*P*
Constant	–	−2.02	0.43	−4.71	<0.001
Cases of leptospirosis	1	0.17	0.068	2.49	0.013
Cases of leptospirosis	12	0.21	0.073	2.94	0.003
Monthly rainfall (in.)	3	0.0059	0.0012	4.92	<0.001

inclusion of cases of leptospirosis diagnosed 12-months previously did not improve the fit of the model (AICc = 2.01), the estimated coefficient of this term was significant ($P = 0.003$). The ACF of the residuals of this modified regression (not shown) appeared stationary, except for an outlier detected at a lag of 130 months ($z = 4.32$, $P < 0.001$). The ACF of the residuals appeared to have constant variance, and to be independent and random.

4. Discussion

Although the proportion of dogs (37 per 100,000) diagnosed with clinical leptospirosis in the United States and Canada (Ward et al., 2002) is low relative to other canine diseases, leptospirosis has a case-fatality risk of up to 20% (Bolin, 1996; Harkin and Gartrell, 1996; Birnbaum et al., 1998) and is preventable by vaccination. Also, the prevalence of leptospirosis is increasing (Ward et al., 2002), causing concern to veterinarians and their clients (Bolin, 1996; Prescott et al., 1999; Sykes, 2001). Knowledge of the association between leptospirosis and rainfall allows pet-owner education to be promoted to reduce exposure of dogs to *Leptospires*, and potential seasonally targeted vaccination. In addition, leptospirosis is a zoonosis and the presence of dogs has been identified as a risk indicator for human leptospirosis (Douglin et al., 1997). Efforts to reduce exposure of dogs might have important public-health benefits by reducing exposure of pet-owners to common sources of *Leptospires*.

Results of this study confirm previous observations (Bolin, 1996; Brown et al., 1996; Harkin and Gartrell, 1996) that the occurrence of leptospirosis in dogs in the United States and Canada, peaks in late summer and fall. Only one previous study of the association between canine leptospirosis and rainfall in the United States has been published (Adin and Cowgill, 2000), based on 36 dogs that had leptospiral serologic tests performed at the University of California Veterinary Teaching Hospital between 1990 and 1998 and that had either a single serum antibody titer >1:800, or evidence of seroconversion on paired serum samples and clinical signs of leptospirosis. The correlation between annual rainfall and annual number of cases ($n = 9$) was estimated ($r = 0.71$). In contrast, the present study consisted of a longer study period (16 years) and a more geographically diverse population of dogs (>1 million dogs presented to 22 teaching hospitals, United States and Canada), and the time unit of analysis was months ($n = 192$) rather than years. Results of the present study enable a more definitive statement to be made that rainfall, in general, is a predictor of canine leptospirosis. The association identified between leptospirosis and rainfall is also supported by previous observations made on bovine (Carroll and Campbell, 1987; Miller et al., 1991) and equine (Barwick et al., 1997, 1998) leptospirosis, and the lag period of 3 months is consistent with the probable effect of flooded land and water-soaked soils on leptospiral organism survival (1–2 months) and an average incubation period for leptospirosis of 1–3 weeks (Hellstrom and Marshall, 1978; American Public Health Association, 2000). If infection is from contaminated, permanent water sources, flooding of such areas could additionally expose susceptible dogs to infection.

The serovars causing leptospirosis were not reported in records submitted to the VMDB. It is possible that the seasonal distribution of leptospirosis observed in this study could be caused by only one or a few serovars—whereas leptospirosis due to other serovars occurs uniformly throughout the year. A bivalent vaccine for protection of dogs against leptospirosis due to serovars canicola and icterohaemorrhagiae has been available widely since at least the early 1970s. It has been suggested that, because of the introduction of this bivalent vaccine, leptospirosis caused by serovars canicola and icterohaemorrhagiae has decreased in the United States and Canada (Wohl, 1996; Sykes, 2001). Recent case studies conducted on hospital populations located in different regions of the United States and Canada have failed to detect substantial proportions of dogs infected with serovars canicola or icterohaemorrhagiae (Brown et al., 1996; Harkin and Gartrell, 1996; Birnbaum et al., 1998; Adin and Cowgill, 2000). However, cases caused by infection with serovars bratislava, grippotyphosa and pomona might have increased (Harkin and Gartrell, 1996; Birnbaum et al., 1998; Prescott et al., 1999; Adin and Cowgill, 2000; Ribotta et al., 2000). Known reservoirs for serovars bratislava, pomona and grippotyphosa include pigs and possibly horses, pigs, cattle, skunks and opossums, and raccoons, skunks and opossums, respectively. If the seasonality of leptospirosis identified in this study is due to infection by these serovars, exposure to these reservoir species (or to environments contaminated by these species) is responsible. Bolin (1996) and Harkin and Gartrell (1996) suggested that housing developments that encroach on wildlife habitat leads to greater exposure of dogs to *Leptospira* serovars that have wildlife species as their maintenance hosts. This exposure is probably greater during the warm months of late spring through early fall, because of increase time spent outdoors by dogs. Contamination of land with waste from swine production is another possible explanation—if serovars bratislava and/or pomona are responsible—but it would seem unlikely that this could explain the seasonality of leptospirosis identified in the study unless waste is spread predominantly between August and November or that such epidemiological associations exist at specific study-sites.

Flooding has been associated with outbreaks of leptospirosis in humans and animals (Rentko et al., 1992) and exposure to water contaminated with the urine of infected animals is an occupational hazard for sanitary and agricultural workers, and also a recreational hazard for humans (Hanson, 1982; American Public Health Association, 2000). Transmission of leptospiral organisms via direct contact is considered uncommon; transmission via contaminated soil and water is the usual route of infection (Twigg et al., 1969). Furthermore, soil moisture and low acidity favor the survival of leptospiral organisms (Twigg et al., 1969). Environmental changes that result in a greater proportion of land being regularly flooded, or a period of above average rainfall, is therefore a plausible explanation for leptospirosis seasonality. The location of dogs included in this study was unknown—because specific or approximate (for example, town/city and/or zipcode) information is not recorded in the VMDB—and location of the veterinary teaching hospitals at which dogs were presented was used as a proxy variable for dog location. Given the resolution of data, it was not possible to examine an association between leptospirosis and flooding, because flooding is generally more localized than rainfall. Although the occurrence of large, unusual floods can be more easily identified, there was no evidence of discrete epidemics of leptospirosis within the time-series.

The correlation between cases of leptospirosis diagnosed and rainfall recorded 3 months prior to the month of diagnosis was moderate (41%). Considering that the location of each veterinary teaching hospital and the rainfall recorded at these sites was used as a proxy variable for the (unknown) rainfall occurring at the home/home-range of each case, this correlation provides evidence that rainfall is involved in increasing the risk of leptospirosis in dogs. No reports of the distribution of dogs presented to veterinary teaching hospitals in the United States or Canada have apparently been published. However, in a study of antimicrobial-resistance in 147 dogs presented to the Purdue University Veterinary Teaching Hospital between August and October 2001, the median distance between owner's address and the hospital was 77 miles (95% CI, 71–88), and 75% were ≤ 110 miles (MP Ward, unpublished data). The distribution of distances was right-skewed (skewness statistic = 0.31). If these data can be used as a guide for hospitals included in the present study, use of hospital locations is probably an appropriate proxy for dog location. Assuming that the inaccuracy resulting from using a proxy variable is non-systematic, the strength of association between leptospirosis and rainfall estimated (41%) might be an underestimate. Future studies need to use more accurate information on the location of dogs during their lifetime (and the environmental conditions to which they are exposed), to accurately estimate the strength of this association. Although veterinary teaching hospitals in the United States and Canada generally have a community-practice component, they are also referral hospitals and dogs examined at these hospitals might not be representative of all dogs in the target population—pet dogs living in the United States and Canada. Dogs with leptospirosis might be more likely to be examined at a veterinary teaching hospital than dogs receiving routine veterinary care. However, leptospirosis presents as an acute illness (without a specific diagnosis at presentation) and because dogs generally receive veterinary care locally for acute illnesses, referral bias is unlikely to have cause substantial bias in this study. In addition, if it can be assumed that referral bias was equivalent between hospitals included in this study—and constant during the study period—then this source of bias is irrelevant in a study to estimate the strength of association between disease and potential risk factors, in contrast to a survey estimating population-specific frequency of disease or exposures. From data available in the VMDB, it is not possible to estimate hospital- or year-specific referral bias.

Further studies are required to estimate the strength of this association more accurately. This could be achieved in follow-up studies by recording the amount of rainfall occurring within each dog's home-range, and documenting the amount and type of outdoors activity of each dog. The use of a geographical information system and remotely sensed data, such as the vegetation index, may assist identification of foci of infection in dog populations. Knowledge of how leptospirosis occurrence is associated with rainfall might be used to educate pet-owners to reduce seasonal-exposure of dogs to *Leptospires*, and (potentially) to seasonally target vaccination. Because of its public-health importance, predicting the occurrence of leptospirosis is also potential valuable in reducing exposure of pet-owners to the sources of *Leptospires* that their pets may also be exposed.

5. Conclusion

Rainfall 3 months previously is a predictor of the occurrence of canine leptospirosis in the United States and Canada.

References

Adin, C.A., Cowgill, L.D., 2000. Treatment and outcome of dogs with leptospirosis: 36 cases (1990–1998). J. Am. Vet. Med. Assoc. 216, 371–375.

American Public Health Association, 2000. Leptospirosis. In: Benenson, A.S. (Ed.), Control of Communicable Diseases Manual. American Public Health Association, Washington, DC, pp. 293–296.

Barwick, R.S., Mohammed, H.O., McDonough, P.L., White, M.E., 1997. Risk factors associated with the likelihood of leptospiral seropositivity in horses in the state of New York. Am. J. Vet. Res. 58, 1097–1103.

Barwick, R.S., Mohammed, H.O., McDonough, P.L., White, M.E., 1998. Epidemiologic features of equine *Leptospira interrogans* of human significance. Prev. Vet. Med. 36, 153–165.

Birnbaum, N., Center, S.A., Schermerhorn, T. et al., 1998. Naturally acquired leptospirosis in 36 dogs: serological and clinicopathological features. J. Small Anim. Pract. 39, 231–236.

Bolin, C.A., 1996. Diagnosis of leptospirosis: a reemerging disease of companion animals. Sem. Vet. Med. Surg. (Small Anim.) 11, 166–171.

Brown, C.A., Roberts, W., Miller, M.A. et al., 1996. *Leptospira interrogans* serovar *grippotyphosa* infection in dogs. J. Am. Vet. Med. Assoc. 209, 1265–1267.

Carroll, A.G., Campbell, R.S.F., 1987. Reproductive and leptospiral studies in beef cattle in central Queensland. Aust. Vet. J. 64, 1–5.

Douglin, C.P., Jordan, C., Rock, R. et al., 1997. Risk factors for severe leptospirosis in the Parish of St. Andrew Barbados. Emerg. Inf. Dis. 3, 78–80.

Hanson, L.E., 1982. Leptospirosis in domestic animals: the public health. J. Am. Vet. Med. Assoc. 181, 1505–1509.

Harkin, K.R., Gartrell, C.L., 1996. Canine leptospirosis in New Jersey and Michigan: 17 cases (1990–1995). J. Am. Anim. Hosp. Assoc. 32, 495–501.

Hellstrom, J.S., Marshall, R.B., 1978. Survival of *Leptospira interrogans* serovar pomona in an acidic soil under simulated New Zealand field conditions. Res. Vet. Sci. 25, 29–33.

Miller, D.A., Wilson, M.A., Beran, G.W., 1991. Relationships between prevalence of *Leptospira interrogans* in cattle, and regional, and regional, climatic, and seasonal factors. Am. J. Vet. Res. 52, 1766–1768.

Prescott, J.F., Key, D., Osuch, M., 1999. Leptospirosis in dogs. Can. Vet. J. 40, 430–431.

Rentko, V.T., Clark, N., Ross, L.A. et al., 1992. Canine leptospirosis: a retrospective study of 17 cases. J. Vet. Intern. Med. 6, 235–244.

Ribotta, M., Fortin, M., Higgins, R., 2000. Canine leptospirosis: serology. Can. Vet. J. 41, 494–495.

Shumway, R.H., 1988. Applied Statistical Time Series Analysis. Prentice-Hall, Englewood Cliffs, NJ, pp. 117–165.

Sykes, J.E., 2001. Canine leptospirosis—a re-emerging disease. In: Proceedings of the 19th Annual Meeting of the ACVIM, pp. 763–765.

Twigg, G.I., Cuerden, C.M., Hughes, D.M., Medhurst, P., 1969. The leptospirosis reservoir in British wild mammals. Vet. Rec. 84, 424–426.

Ward, M.P., 2002. Clustering of leptospirosis among dogs in the United States and Canada. Prev. Vet. Med., submitted for publication.

Ward, M.P., Glickman, L.T.G., Guptill, L., 2002. Prevalence of and risk factors for leptospirosis among dogs in the United States and Canada. J. Am. Vet. Med. Assoc. 220, 53–58.

Wohl, J.S., 1996. Canine leptospirosis. Comp. Small Anim. 18, 1215–1224.