Predicting Lyme Disease Incidence in Humans and Dogs

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Outline

Introduction

Research Goals:

- Predict new U.S. states where Lyme disease will occur.
- Determine whether inclusion of data on incidence in dogs improves the predictive ability of statistical models for human Lyme disease incidence.
- Identify the most significant predictor variables.

Lyme Disease

- Infectious disease.
- Transmited by the bite of three different species belonging to the genus *Borrelia*.
- 36 - 48 hours or more before the disease can be transmitted.

Symptoms of Lyme Disease

Early localized stage (3 - 30 days post tick bite)

- Erythema migrans
- Fatigue
- Fever
- Headache
- Muscle and Joint aches
- Swollen lymph nodes

Symptoms of Lyme Disease

Early disseminated stage (days to weeks post tick-bite)

- More EM lesions in other areas of the body
- Bell's palsy
- Swelling of large joints
- Due to meningitis, suffer from severe headaches and neck stiffness
- Changes in heartbeat

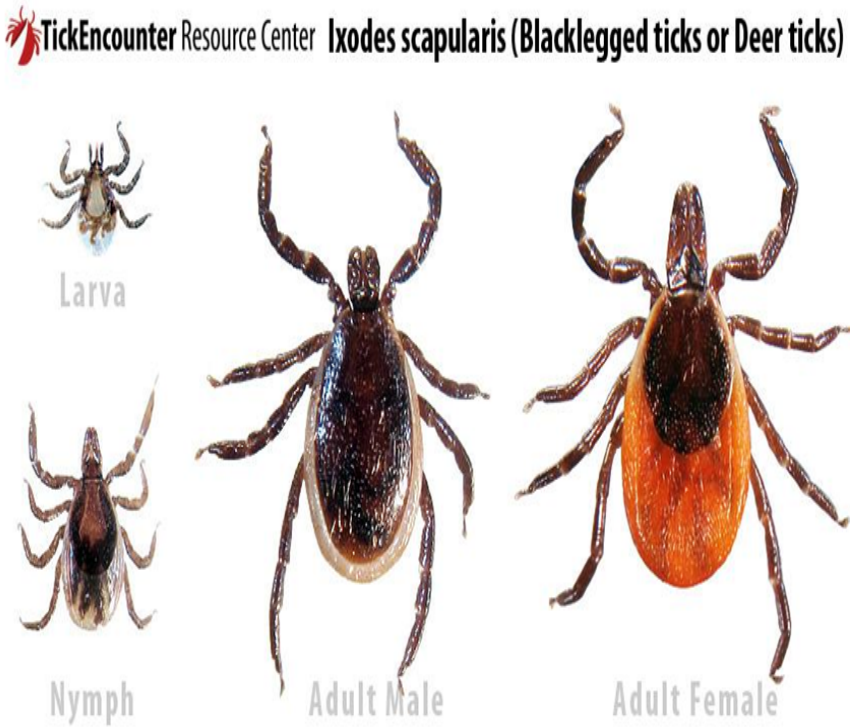
Why is it important to treat Lyme disease early?

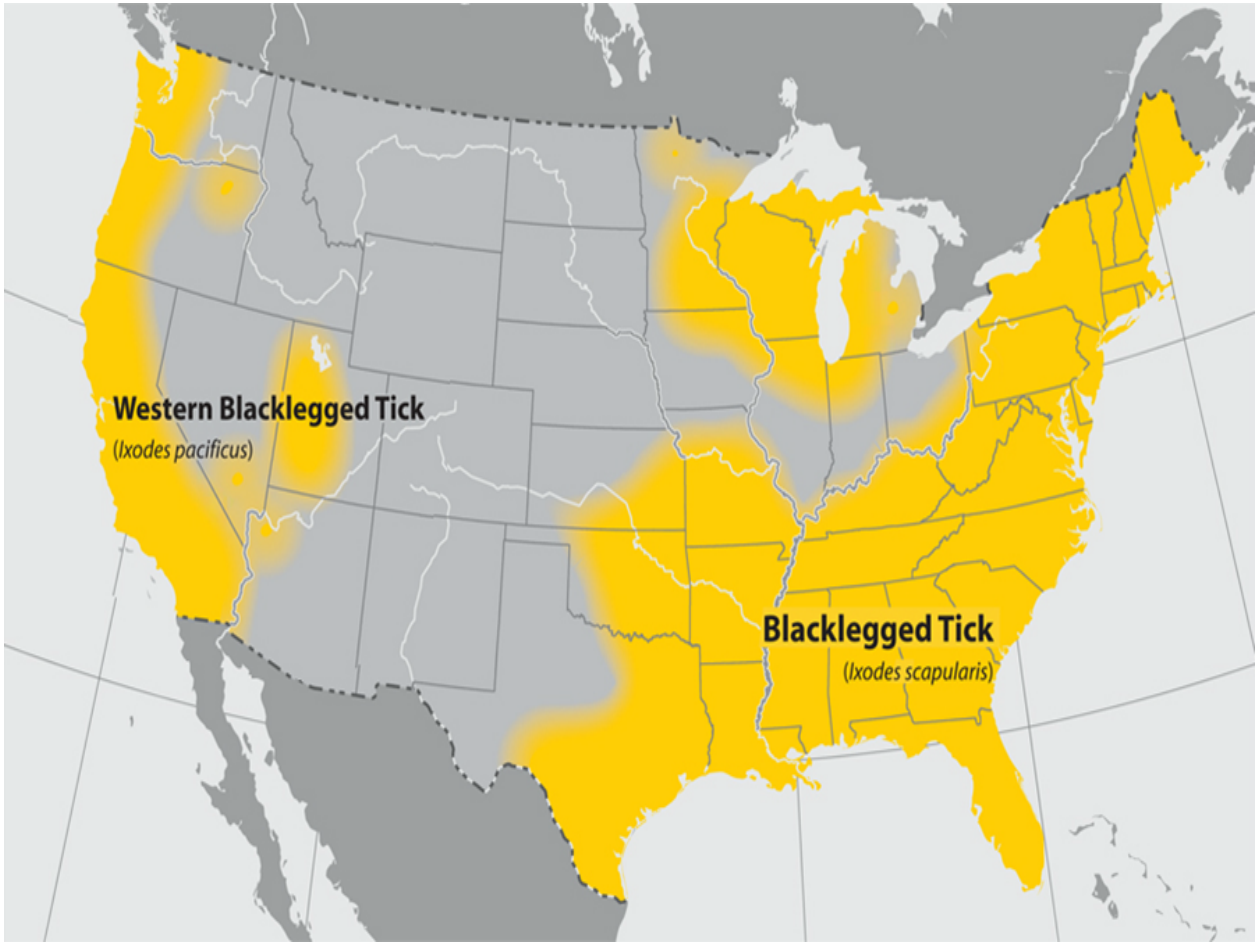
Prevention of the following:

- Shooting pains
- Numbness or tingling in the hands or feet
- Problems with short-term memory

The Ticks

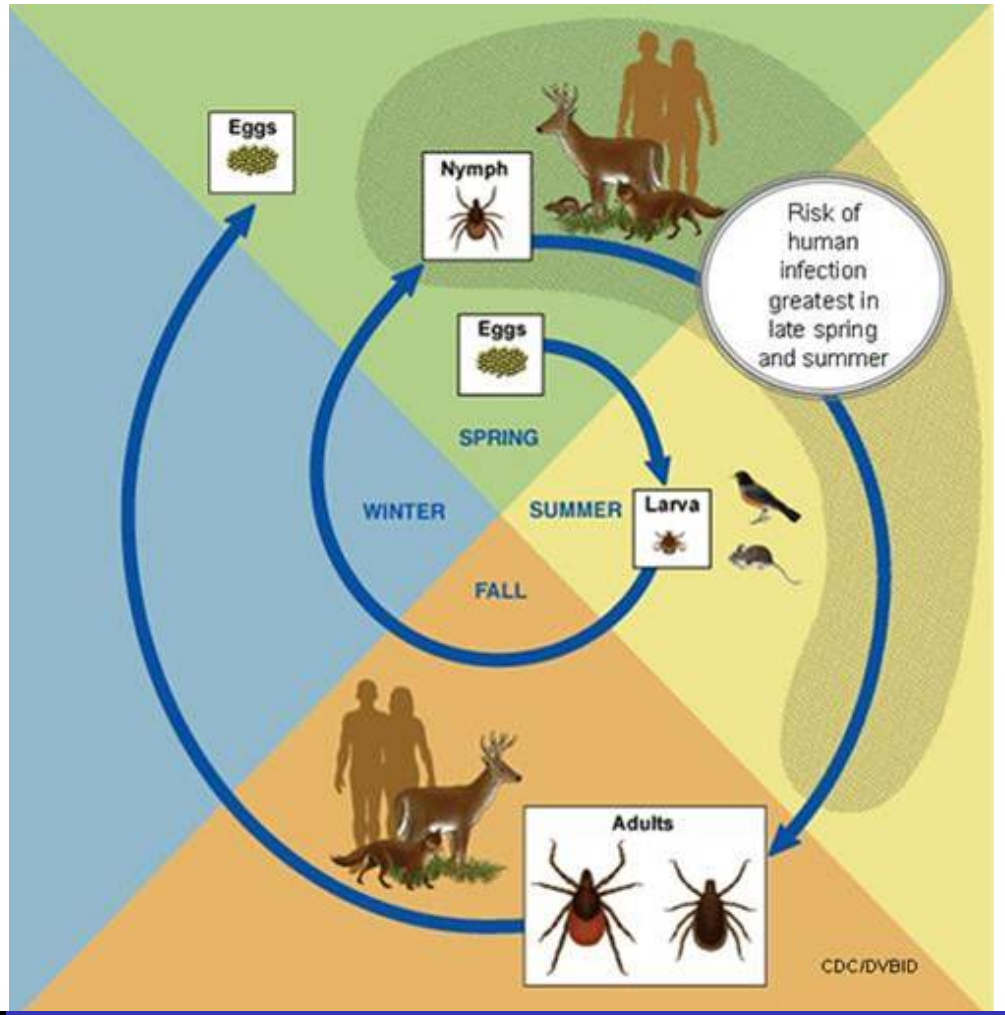
- Blacklegged Tick (*Ixodes scapularis*)
- Western Blacklegged Tick (*Ixodes pacificus*)




Western Blacklegged Tick
(Ixodes pacificus)
Blacklegged Tick
(Ixodes scapularis)

Life Cycle of Ticks

- Their life cycle typically lasts two years, comprising of 4 life stages: egg, larva, nymph and adult.
- At every life stage after egg, the tick must feed.

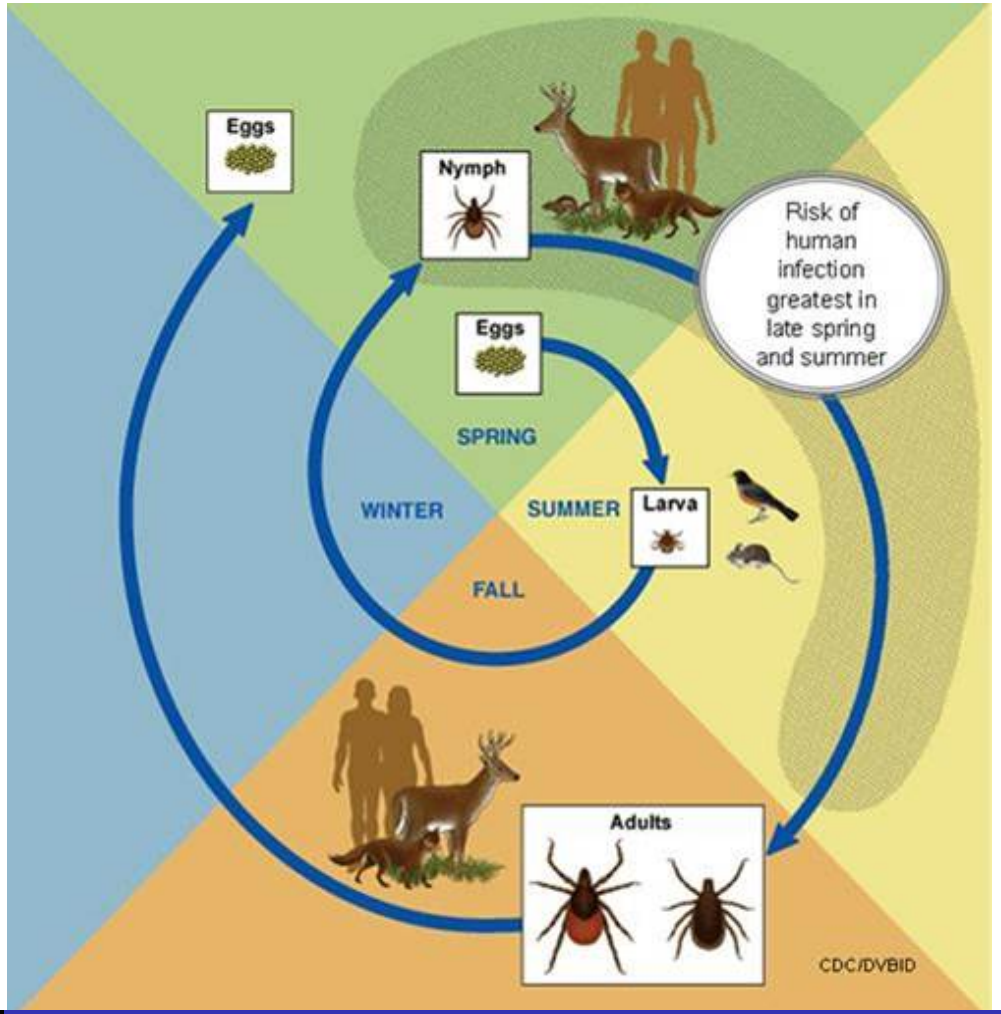


Infection Source

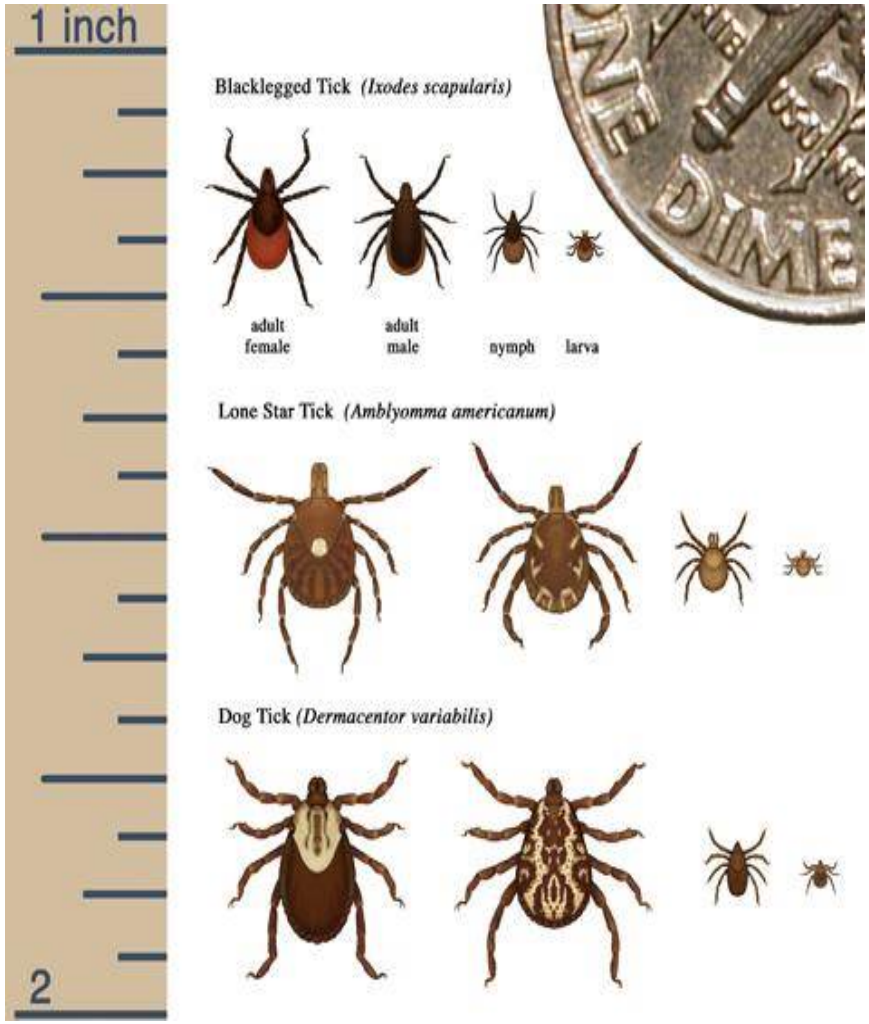
- Ticks are not born infected with *Borrelia burgdorferi*.
- White-footed mice (*Peromyscus leucopus*) is the primary reservoir.

Nymphs

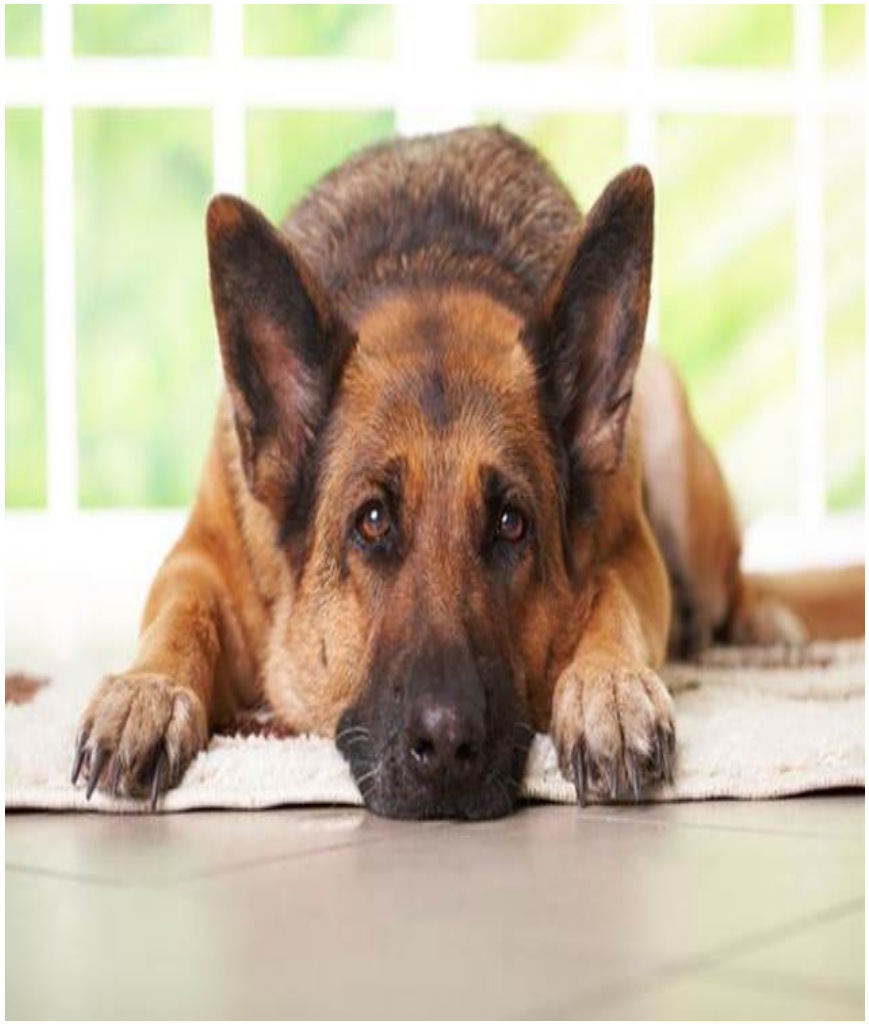
- Nymphs seek larger hosts
- Commonly found in near ground vegetation



- Humans acquire the infection through Nymphs
- Takes 36 to 48 Hours
- Adult ticks can also infect hosts



- Hard to detect infection
- Often found during yearly testing
- Canary?



Data Sets for Model Fitting:

- Human Lyme Incidence from 2007 - 2011
- Dog Incidence Rates from 2011

Data Sets for Prediction:

- Human Lyme Incidence from 2012
- Dog Incidence Rates from 2012

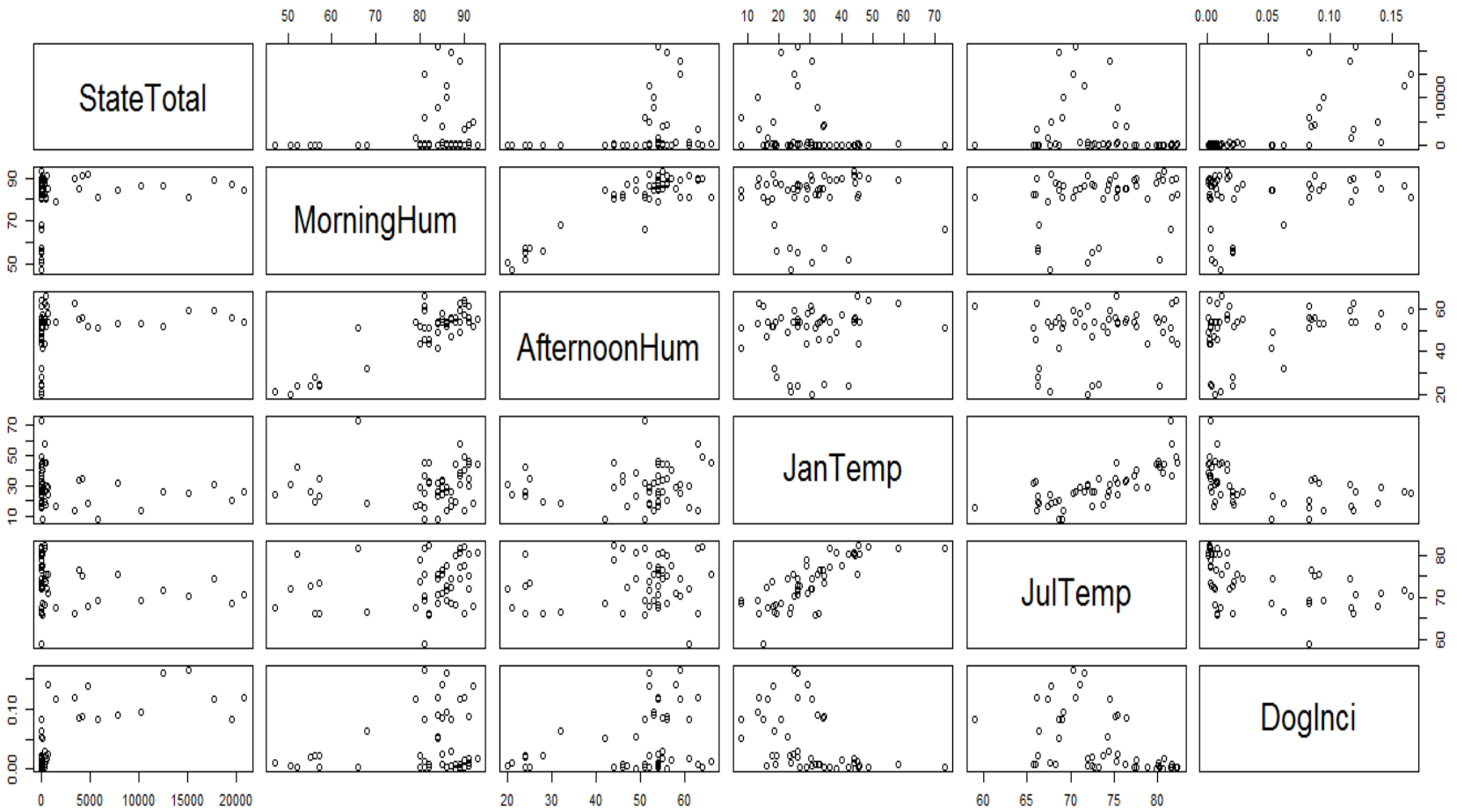
General Predictor Variables

1. Temperature
   - www.esrl.noaa.gov/psd/data/usclimate/tmp.state.19712000.climo
2. Humidity
   - www.currentresults.com/Weather/US/humidity-by-state-in-summer.Php
3. Land Usage
   - www.ers.usda.gov/data-products/major-land-uses.aspx#.U68Oqx_HnVM
4. Elevation
   - en.wikipedia.org/wiki/List_of_U.S._states_by_elevation
5. Dog Incidence Rates
   - www.capcvet.org/parasite-prevalence-maps/

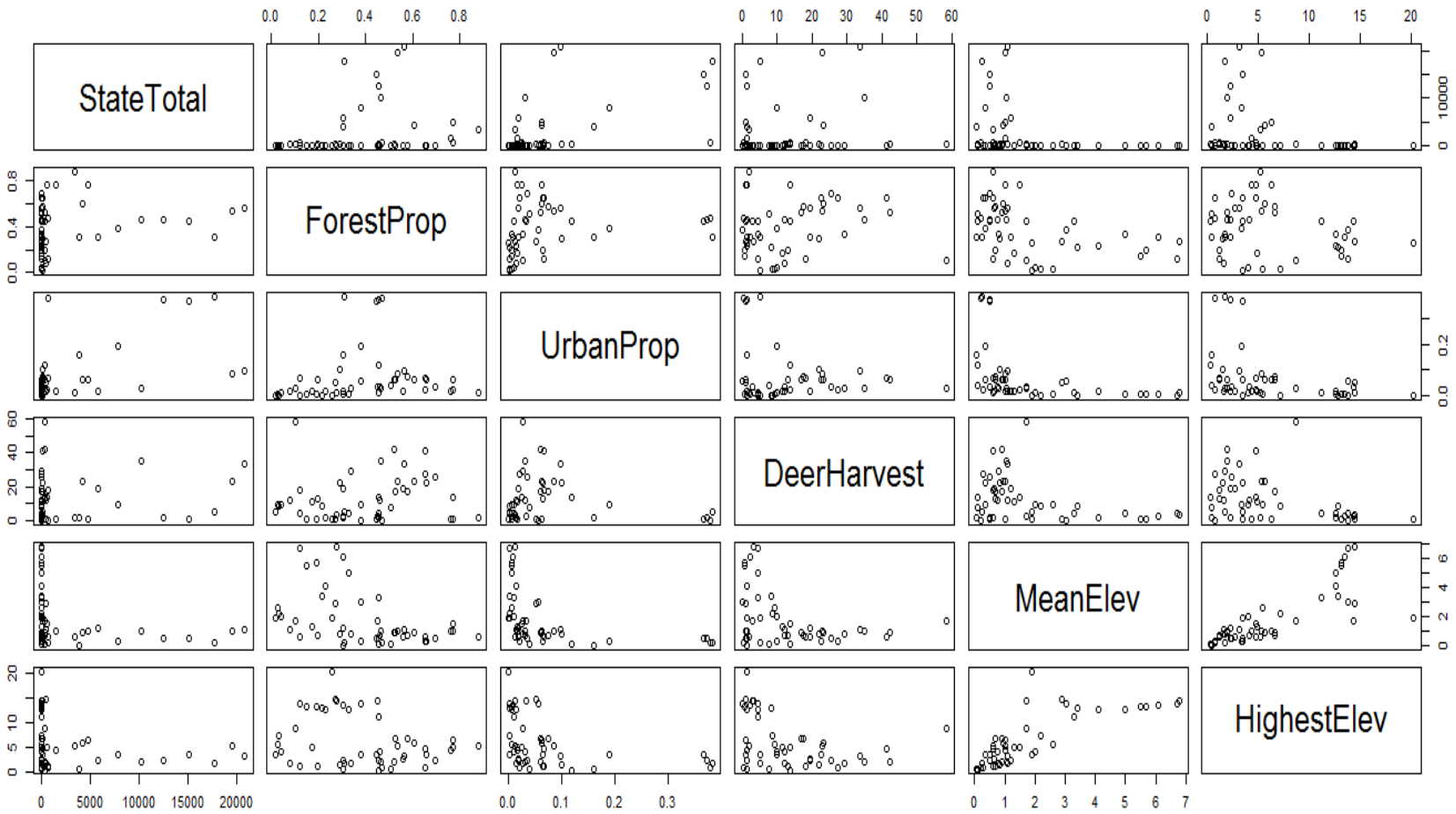
Variables

- Response Variable:
  - State Total
- Predictor Variables:
  - Dogs Incidence
  - Forest
  - Urban
  - Morning and Afternoon Humidity
  - January and July Temperatures
  - Deer Harvest
  - Mean and Highest Elevation

Model Variables



Model Variables



glm and hglm Models

- glm
  - Poisson regression model.
  - Ignores spatial autocorrelation in response variable, so significance of predictor variables is likely to be overestimated.
- hglm
  - Hierarchical poisson regression with a random effect for each state.
  - Conditional autoregressive model for random effects to capture spatial autocorrelation.
  - Empirical Bayes rather than fully Bayes model; MCMC was not used to fit.

glm and hglm Models

- glm model:

$$log(E(Y_i)) = \beta_0 + \beta_1(DogsInci_i) + \beta_2(ForestProp_i) + \beta_3(UrbanProp_i) + \beta_4(MorningHum_i) + \beta_5(AfternoonHum_i) + \beta_6(JanTemp_i) + \beta_7(JulyTemp_i) + \beta_8(DeerHarvest_i) + \beta_9(MeanElev_i) + \beta_{10}(HighestElev_i) + log(E_i)$$

- hglm model:

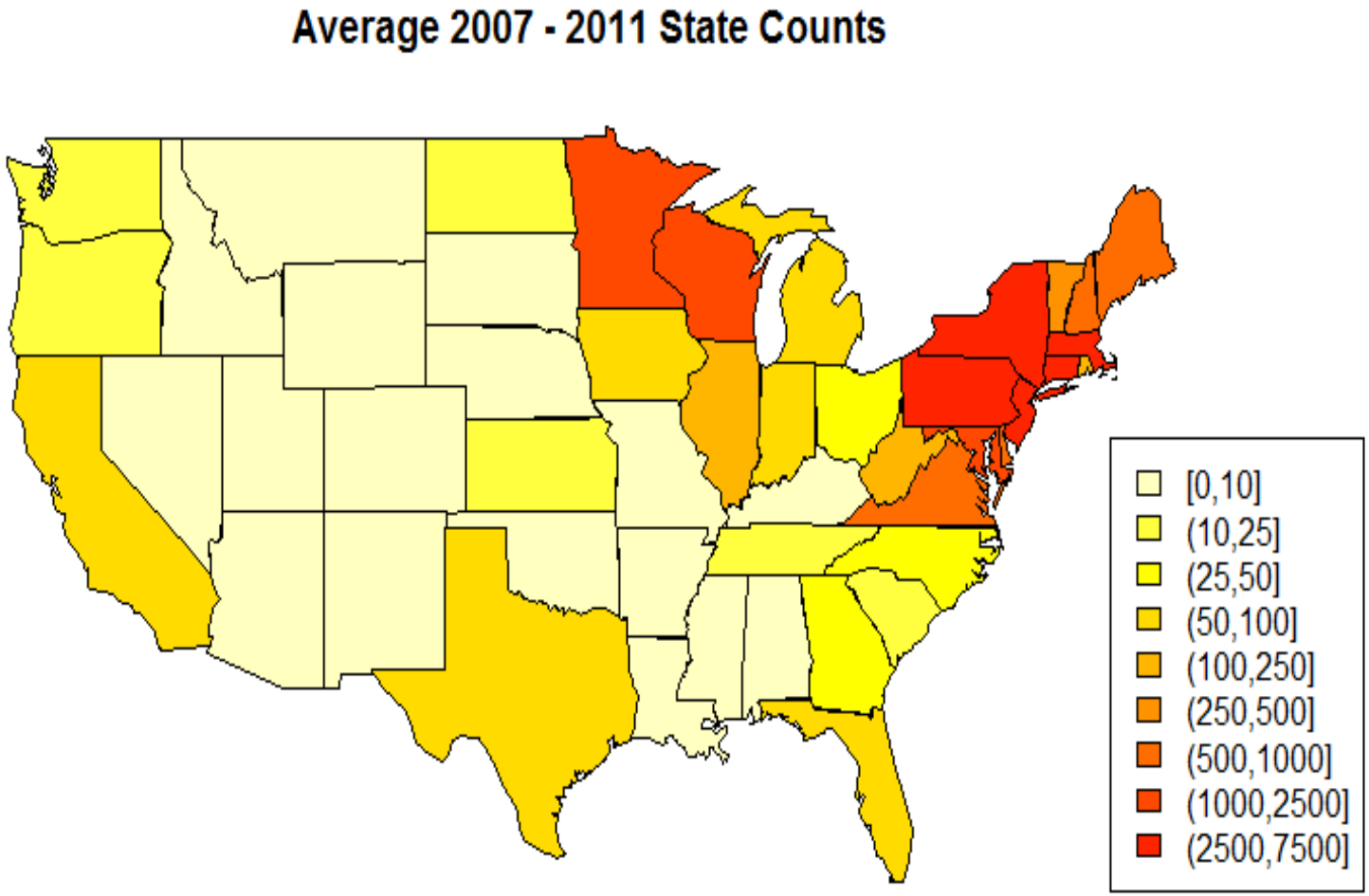
$$log(E(Y_i)) = \beta_0 + \beta_1(JanTemp_i) + \beta_2(JulyTemp_i) + \beta_3(DogsInci_i) + log(E_i) + \phi_i$$

glm Tables of Coefficients and P-Values

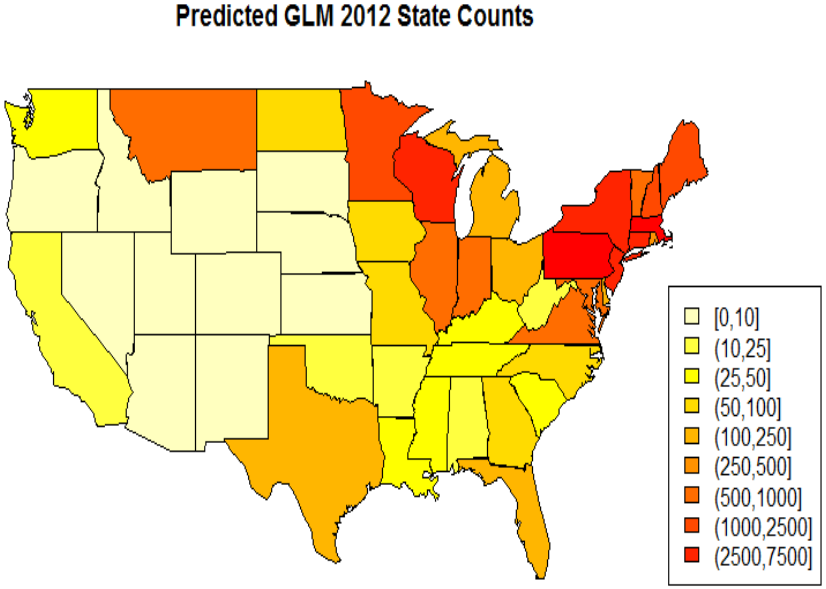
GLM	Estimate Std.	Std. Error	z-value	$Pr(>\|z\|)$
(Intercept)	-5.34295	0.31337	-17.049	$< 2e^{-}16$ ***
DogsInci	35.15061	0.23303	150.838	$< 2e^{-}16$ ***
ForestProp	-3.04855	0.05568	-54.744	$< 2e^{-}16$ ***
UrbanProp	-5.22102	0.08494	-61.462	$< 2e^{-}16$ ***
MorningHum	0.08860	0.00125	70.369	$< 2e^{-}16$ ***
AfternoonHum	-0.01621	0.00125	-12.934	$< 2e^{-}16$ ***
JanTemp	-0.06322	0.00186	-33.879	$< 2e^{-}16$ ***
JulyTemp	0.01028	0.00422	2.432	0.015 *
DeerHarvest	0.01362	0.00045	29.794	$< 2e^{-}16$ ***
MeanElev	-1.17139	0.02733	-42.854	$< 2e^{-}16$ ***
HighestElev	-1.79525	0.03726	-48.177	$< 2e^{-}16$ ***

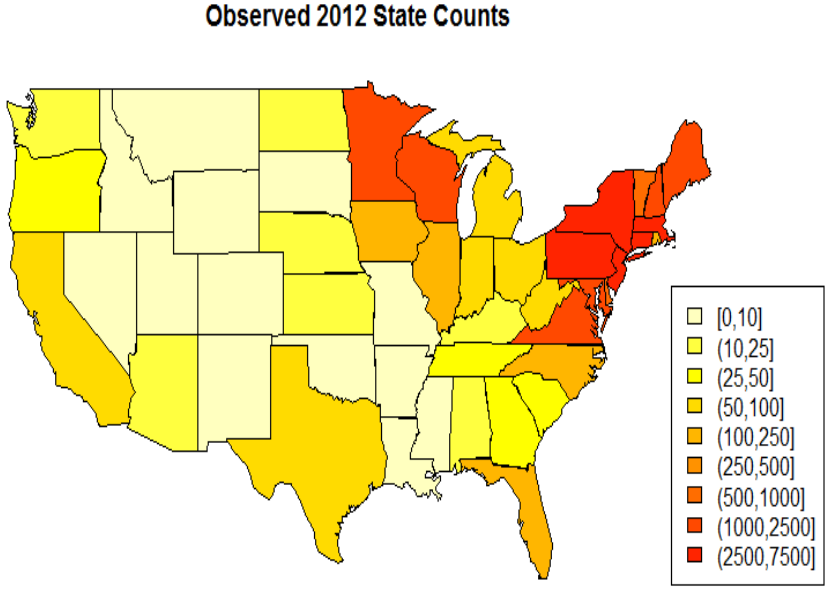
hglm Tables of Coefficients and P-Values

HGLM	Estimate Std.	Std. Error	t-value	$Pr(>\|t\|)$
(Intercept)	-10.55877	3.32192	-3.179	0.0864 .
DogsInci	29.22464	4.73341	6.174	0.0252 *
JanTemp	-0.10898	0.02742	-3.975	0.0579 .
JulyTemp	0.15415	0.05440	2.833	0.1053

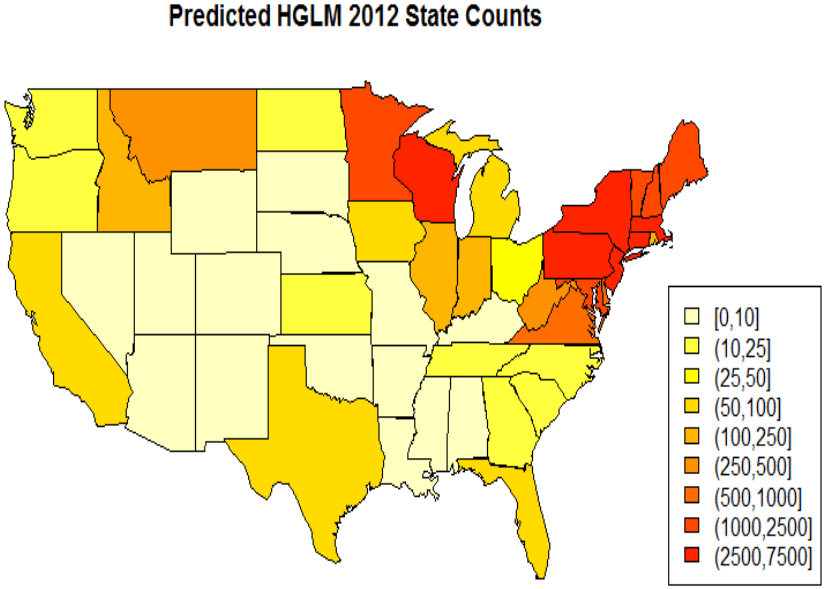

Average 2007 - 2011 State Counts
[0,10]
(10,25]
(25,50]
(50,100]
(100,250]
(250,500]
(500,1000]
(1000,2500]
(2500,7500]

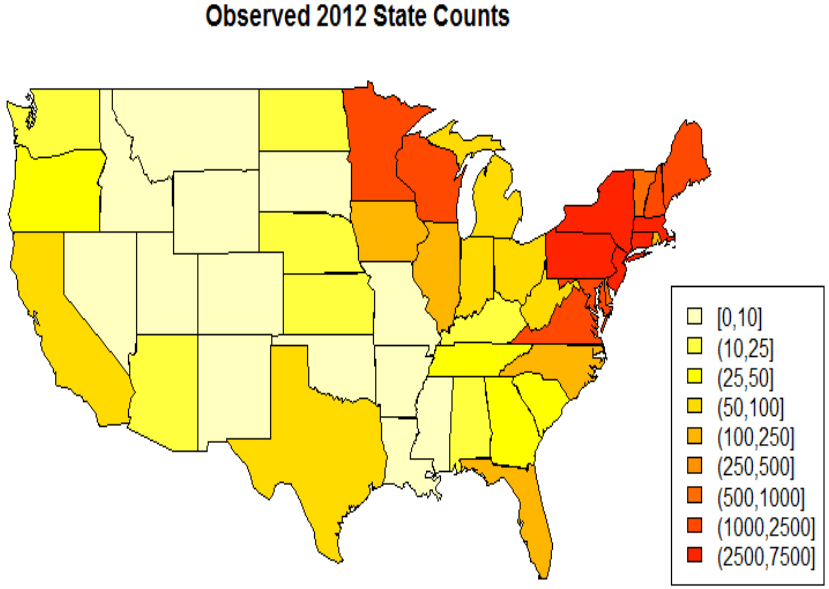
Predicted glm 2012 State Counts vs. Observed





Predicted hglm 2012 State Counts vs. Observed





Mean Squared Prediction Errors for 2012 Counts

Out of sample prediction using GLM model:

Model including dog incidence (Raw Counts): mean((Actual2012Counts - Predicted2012CountsDogs)^2)	249598
Model omitting dog incidence (Raw Counts): mean((Actual2012Counts - Predicted2012CountsNoDogs)^2)	402794.3
Model including dog incidence (log Transformation): mean((log(Actual2012Counts) - log(Predicted2012CountsDogs))^2)	11.00701
Model omitting dog incidence (log Transformation): mean((log(Actual2012Counts) - log(Predicted2012CountsNoDogs))^2)	10.4362

Study Limitations

- Lyme disease cases are tabulated by state of residence, not state of exposure.
- Not every case of Lyme disease is reported to CDC.
- All the variables are aggregated by state.
- No new states with Lyme disease incidence were found.
- 2012 cases were recorded differently.

Conclusions and Future Work

- hglm's predictions are much closer than glm's.
- Dog incidence rate is the most highly significant predictor in sample.
- January and July Temperatures were highly significant predictors.

Future Work:

- Report Models and Answers to the CDC.
- Write a paper for submission in an applied statistics journal.
- Predicting 2013 when incidence rates are available.

References

1. http://www.tickencounter.org/images/Ixodes_scapularis.jpg
2. www.cdc.gov/ticks/images/lgmap-blacklegged_tick.jpg
3. www.cdc.gov/ticks/images/lgmap-western_blacklegged_tick.jpg
4. www.cdc.gov/ticks/images/lifecycle.jpg
5. www.dcnature.com/photosfull/Whitefooted%20Mouse%20(Peromyscus%20leucopus).jpg
6. www.factmonster.com/ipka/A0004986.html

Citation for R

- @Manual, title = R: A Language and Environment for Statistical Computing, author = R Core Team, organization = R Foundation for Statistical Computing, address = Vienna, Austria, year = 2014, url = http://www.R-project.org/,

Citation for R packages

- @Article, title = hglm: A Package for Fitting Hierarchical Generalized Linear Models, author = Lars Ronnegard and Xia Shen and Moudud Alam, journal = The R Journal, year = 2010, volume = 2, number = 2, pages = 20-28, url = http://journal.r-project.org/archive/2010-2/RJournal_2010-2_Roennegaard et al.pdf,
- @Manual, title = maps: Draw Geographical Maps, author = Original S code by Richard A. Becker and Allan R. Wilks. R version by Ray Brownrigg. Enhancements by Thomas P Minka ¡tpminka@media.mit.edu¿, year = 2014, note = R package version 2.3-7, url = http://CRAN.R-project.org/package =maps,