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Investigation of a Potential Relationship Between Wild Bird Populations and Human Lyme Disease Rate in Connecticut from 1991-2002

Tamam Slam Abad Al-Ali[1]

[1] Ornithology from University of Oklahoma, USA

Correspondence: Tamam Slam Abad Al-Ali, Ornithology from University of Oklahoma, USA. E-mail: tms_asa2008@yahoo.com

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Abstract

Lyme disease is the most common tick-borne disease in North America. *Borrelia burgdorferi*, is the pathogen, and the black-legged tick carries the bacteria and spreads it when feeding on the blood of animals and humans. At least 70 passerine species and one species of woodpecker in North American are parasitized by immature black-legged ticks. This hypothesis predicts that there would be a positive relationship between Lyme disease rates and bird numbers that infected with the pathogen, and there would be no relationship between Lyme disease rate and bird numbers that not known to be infected with the pathogen. The study depended on the North American Breeding Bird Survey (BBS) to get bird species for 14 routes across Connecticut, and on the Connecticut DHS to get Lyme disease rates for the time period of the study (1991-2002). The range of years was from 1991 to 2002 because of a change in how Lyme disease cases were reported starting in 2003. The bird data were: one group that included all 17 bird species that carry the pathogen, two species separately that are known to become infected by Lyme pathogen (American Robin and Gray Catbird), and a control species not known to carry the pathogen (American Redstart). The study found significant positive relationships between bird numbers and human Lyme disease rate in two routes for the SCLP group, one route for American Robin, three routes for Gray Catbird, and two routes for American Redstart. Only Gray Catbird had a significant negative relationship with human Lyme disease rate in one route. Based on the positive relationships that appeared for American Redstart, the control species, and the few significant relationships for birds known to carry the pathogen, the study rejected the hypothesis that there is a strong relationship between numbers of birds that could be infected with *B. burgdorferi* and the rate of Lyme disease in people as measured by the methods used in this study.

Keywords: Lyme disease, Lyme pathogen, black-legged tick, American Robin, Gray Catbird, American Redstart, Connecticut

1. Introduction

Lyme disease or Lyme borreliosis is a multi-system bacterial infection caused by spirochete bacteria called *Borrelia burgdorferi senso lato complex*. Lyme disease was first recognized in the United States in 1975 by Dr. Allen Steere, in the community of Lyme, Connecticut, but its cause was unknown until 1982. For cases reported in the United States to the Centers for Disease Control and Prevention (CDC), the average rate of Lyme disease in the ten states where it is most common was 31.6 cases for every 100,000 persons in 2005. The arthropod that carries the pathogen and spreads it when feeding on the animal's blood is the black-legged tick. The Lyme disease pathogen, *Borrelia burgdorferi sensu lato complex*, is a spirochete bacterium from the genus Borrelia in the family Spirochetaceae. Not all the complex strains are pathogenic in humans, but the genospecies that can cause Lyme disease in North America is *Borrelia burgdorferi sensu strico*.

The black-legged tick (or deer tick), *Ixodes scapularis*, carries the bacteria and spreads it when feeding on the blood of animals and humans in north-central United States, and Western black-legged tick, *Ixodes pacificus*, does so in the western U.S. When the tick acquires the pathogen in a blood meal, the tick will remain infected even during its molting period, and it will be ready to transmit the pathogen to the mammalian host. When the ticks feed on the animals that carry *B. burgdorferi* in their blood stream (these animals are called reservoir hosts, such as the white-footed mouse), the ticks will be infected, and *B. burgdorferi* will be transmitted from the tick's saliva to humans by the tick's bite and cause Lyme disease.. Adult female *I. scapularis* transmits Lyme disease pathogen to humans during its feeding, but adult male does not transmit the pathogen because the time period for its attached is not long enough to make the transmission The vector black-legged tick lives in forests with rich and moist under growth protecting against dryness, Therefore, people working in forests are particularly exposed to these ticks". In the eastern United States, and the Infection with the Lyme disease pathogen has three stages, beginning with erythema migrans and ending with Lyme arthritis or memory loss.

Brinkerhoff and his colleagues (2011) found published records indicating that at least 70 passerine species and one species of woodpecker in North American are parasitized by immature black-legged ticks. . These studies indicated that the bird species that most parasitized by immature *I. scapularis* are thrushes, brown thrasher, wrens, and several species of wood warbler. Studies that have shown that bird species can become infected with *B. burgdorferi*, and thus dispersing and migrating birds have the ability to increase the ranges of *B. burgdorferi* and *I. scapularis*. Brinkerhoff indicated if *B. burgdorferi* strains that infect birds can also cause disease in humans.

The role of birds in Lyme disease could be very large (Brinkerhoff et al., 2011) stated that ticks derived from birds can influence *B. burgdorferi* transmission dynamics, either "by establishing new enzootic Lyme disease foci through the deposition of infected larval ticks … or by dispersing infected larvae or nymphs that would then molt and parasitize humans.

1.1 Hypothesis

If birds play as an important role as reservoirs for dispersing Lyme disease, then there should be a positive relationship between the number of birds that have infection and the rate of Lyme disease in people. Also, the study would predict there is no relationship between Lyme disease rate and bird numbers for species not known to carry the pathogen.

The study chose Connecticut, a state in the New England region of the northeastern United States. Lyme disease was identified as a new disease in the town of Lyme in 1975 and today Connecticut still has a very high rate of the disease.

2. Methods

2.1 Bird's Data:

The study involved four groups. One group of birds included all 17 bird species that were found to be capable of being infected with *B. burgdorferi*-positive *I. scapularis* larvae (Species carrying Lyme pathogen, SCLP) (Table 1). The study also studied separately two species that are known to become infected by the Lyme pathogen: American Robin and Gray Catbird. Finally, the study used the American Redstart as a control species because at least two larvae were tested were not infected and thus this species may not be able to support the pathogen.

The American Robin (*Turdus migratorius*) is the largest thrush in North America (Cornell Lab of Ornithology n.d.). Male robins have rust-colored feathers on the chest, a yellow bill, a black head and white outlines around the eyes. Robins build a nest of grasses and middle layer of mud, lined with fine grasses, placed on horizontal limbs or shrub, tree, or on building). While American Robins are short distance migrants, some robins do not migrate. In fall, American Robins migrate in large flocks.

Gray Catbird (*Dumetella carolinensis*) is a species of mimid. It has a medium size with black cap and tail and a reddish brown patch under the base of the tail. Catbirds build their nest on horizontal branches hidden at the center of dense shrub, vines, and small trees (Cornell Lab of Ornithology. n.d). Gray Catbirds are Neotropical migrants.

The American Redstart (*Setophaga ruticilla*) is a unique warbler. The male is black with orange patches on the both wings, both sides of the breast, and at the base of its tail on either side. Redstarts nest in small trees or shrubs and use feathers and hair for lining, or they use other birds' nests. The nest is an open cup made of grasses, bark, and twigs with spider's silk. The American Redstart is an example of a bird with a wide migration route in North America because its route has an east to west width off about 2,500 miles.

To obtain an estimate of species populations, the study depended on the North American Breeding Birds Survey (BBS). The BBS IS international avian program initiated in 1966 to study North American bird populations. The study chose the 14 BBS routes (the Routes by their BBS ID number and name) through Connecticut towns that were active from 1991-2002. Each survey route is 24.5 miles long with stops at 0.5-mile intervals. At each stop, a 3-minute point count is conducted.

Table 1. The 18 Passeriformes bird species used in this study. Seventeen species have the ability to be a vector for Lyme disease as shown by testing positive for *Borrelia burgdorferi*, and one species is not known to carry *Borrelia burgdorferi*. Based on Brinkerhoff et al. (2011). Nest and foraging location information are from the Cornell Laboratory of Ornithology (www.allaboutbirds.org).

❖ Passeriformes species known to carry *Borrelia burgdorferi*

Family Name	Scientific Name	Common Name	Nest	Foraging
Troglodytidae	*Thryothorus ludovicianus*	Carolina Wren	Cavity	Ground
Troglodytidae	*Troglodytes aedon*	House Wren	Cavity	Foliage Gleaner
Turdidae	*Catharus fuscescens*	Veery	Ground	Ground
Turdidae	*Catharus guttatus*	Hermit Thrush	Ground	Ground
Turdidae	*Turdus migratorius*	American Robin	Tree	Ground
Mimidae	*Dumetella carolinensis*	Gray Catbird	Shrub	Ground
Mimidae	*Toxostoma rufum*	Brown Thrasher	Shrub	Ground
Parulidae	*Mniotilta varia*	Black–and-White Warbler	Ground	Bark Forager
Parulidae	*Helmitheros vermivorus*	Worm-eating Warbler	Ground	Foliage Gleaner
Parulidae	*Setophaga citrina*	Hooded Warbler	Shrub	Foliage Gleaner
Parulidae	*Parkesia noveboracensis*	Northern Waterthrush	Ground	Ground
Parulidae	*Seiurus aurocapillus*	Ovenbird	Ground	Ground
Parulidae	*Geothlypis trichas*	Common Yellowthroat	Shrub	Foliage Gleaner
Parulidae	*Setophaga petechia*	Yellow Warbler	Shrub	Foliage Gleaner
Emberizidae	*Melospiza melodia*	Song Sparrow	Shrub	Foliage Gleaner
Cardinalidae	*Cardinalis cardinalis*	Northern Cardinal	Shrub	Ground
Cardinalidae	*Pheucticus ludovicianus*	Rose-breasted Grosbeak	Tree	Foliage Gleaner

❖ Control Passeriformes species not known to carry Borrelia burgdorferi

Family Name	Scientific Name	Common Name	Nest	Foraging
Parulidae	*Setophaga ruticilla*	American Redstart	Tree	Foliage Gleaner

2.2 Lyme Disease Rate

To get the time period of the study for Lyme disease rates, the study depended on Lyme disease statistics from the Connecticut Department of Public Health. Rates are reported as cases per 100,000 people. The study range of years was from 1991 to 2002 because of a change in how Lyme disease cases were reported starting in 2003. (They were using physicians reporting, after 2003 they began use both physicians and laboratory tests). The data were by towns.

2.3 Data Analysis

Because the study was analyzing each route separately, the study needed to correct for multiple tests to avoid accepting as biologically significant a relationship that was actually simply due to chance (a Type I error). To do so, the study used the sequential Bonferroni technique (Rice, 1989), with a table-wide alpha level for statistical significance of 0.004 for analyses involving all 14 routes.

2.4 Weather Data

To get a sense about whether the weather affects Lyme disease rate, the study used data from weather stations close to each route from National Oceanic and Atmospheric Administration. Weather data were from 1991 to 2002. These files reported departure from normal monthly precipitation (DPNP) and departure from normal monthly temperature (DPNT) data as hundredths of an inch and tenths of a degree Fahrenheit. The study compared Lyme rate with annual DPNP and DPNT to see if there was a relationship, and the study used annual data because the Lyme disease rates are reported for full years. The study also checked to see if there was a relationship between DPNP and DPNT and bird numbers that were observed across years. The study focused on June because June is during the period when *I. scapularis* nymphs feed and when the bird surveys were made.

Table 2. Observer identities for Connecticut Breeding Bird Survey routes used in this study. Routes that had statistically significant positive relationships between bird number and Lyme disease rate across all bird species are highlighted in bold. Data are from http://www.pwrc.usgs.gov/bbs/.

Routes	1991	1992	1993	1994	1995	1996
001 Mystic	1220021	1220021	1220021	1220021	1220021	1220021
003 Buckingham	1040203	1040203	1040203	1040203	1040203	1040203
004 Uncasville	1120202	1120202	1120202	-	-	-
005 Woodstock	990195	990195	990195	990195	990195	990195
006 Westbrook	1040289	1040289	1040289	1160112	-	-
007 Willimantic	990138	990138	990138	990138	990138	1040533
008 Woodbury	1090042	1090042	1090042	1090042	1090042	1090042
009 Sherman	1090154	1090154	1090154	1090154	1090154	1090154
010 Greenwich	1120147	1110084	1120147	1110084	1000323	1000323
012 Warren	1090042	1090042	1090042	1090042	1090042	1090042
014 Mid Haddam	1090166	1090166	1090166	1090166	1090166	1090166
015 Southington	1090398	1090398	1090398	1090595	1090595	1090595
102 New Hartford	-	-	-	1070245	1070245	1070245
116 Granby	1070073	1070073	1070073	1070073	1070073	1070073
Routes	1997	1998	1999	2000	2001	2002
001 Mystic	1220021	1220021	1220021	1220021	1220021	1220021
003 Buckingham	1090398	1090398	1090398	1090398	1090398	1090398
004 Uncasville	990195	990195	990195	990195	-	990195
005 Woodstock	-	-	-	-	-	-
006 Westbrook	-	1160112	1160112	-	-	-
007 Willimantic	1040533	1040533	1040533	1040533	1040533	1040533
008 Woodbury	**1090042**	**1090042***	**1140406**	**1140406**	**1140406**	**1140406**
009 Sherman	1090154	1090154	1090154	1090154	1090154	1090154
010 Greenwich	1000323	1000323	1000323	1000323	-	-
012 Warren	**1090042**	**1140406**	**1140406**	**1140406**	**1140406**	**1140406**
014 Mid Haddam	-	-	-	-	-	-
015 Southington	1090595	1090595	1090595	1090595	1090595	-
102 New Hartford	1070245	1070245	1070245	1070245	1070245	1070245
116 Granby	-	-	-	-	-	-

*This is most likely to be an error and should be observer 1140406 based on large increases in the number of birds counted in 1998 compared to 1997.

3. Results

The highest Lyme disease rate was recorded for 009 Sherman in 2002 (1,197.8 per 100,000 people), while no cases of Lyme disease were recorded for 116 Granby in 1994. Across the range of years that the study focused on, the study found an increase in Lyme disease rates (Table 3). Generally, in 1991 mean Lyme disease rate was lower than other years (mean rate was 89.8 per 100,000 people), while 2002 recorded the highest mean rate of Lyme disease (mean rate was 362.4 per 100,000 people).

Across the 14 routes, the two highest mean Lyme disease rates per 100,000 people were for 005 Woodstock (mean rate was 490.9) and 009 Sherman (mean rate was 490.9). The two routes with the lowest mean Lyme disease rate per 100,000 people were 015 Southington (mean rate was 24.9) and 116 Granby (mean rate was 28.4).

The study checked if the weather conditions departing from normal measurements affected Lyme disease rates and the number of birds that were observed across years. Neither annual departure from normal precipitation (DPNP) nor annual departure from normal temperature (DPNT) (Table 4) had a strong effect on Lyme disease rate for all routes because the study found no statistically significant regression results after applying the Bonferroni correction technique. Similarly, the study did not find any significant relationship between June DPNP (Table 5), or June DPNT (Table 6) and the number of birds counted because there was again no statistically significant regression after applying the Bonferroni correction technique.

Table 3. Lyme disease rates by Breeding Bird Survey route. Data are from Connecticut Department of Public Health. Highest and lowest individual rates are two highest and lowest mean rates are underlined.

Routes	1991	1992	1993	1994	1995	1996	1997
001 Mystic	39.3	54.3	49.0	121.8	114.8	177.8	168.0
003 Buckingham	138.3	290.8	303.3	312.8	227.8	323.5	304.5
004 Uncasville	181.4	190.8	179.2	161.3	176.0	408.3	246.8
005 Woodstock	137.7	147.7	239.0	404.0	360.3	577.0	782.3
006 Westbrook	186.0	280.7	154.7	184.7	134.0	256.3	211.7
007 Willimantic	90.5	78.8	106.5	132.5	222.3	304.5	307.0
008 Woodbury	6.0	9.0	32.8	9.0	32.8	106.5	58.8
009 Sherman	41.5	87.3	130.3	457.0	236.8	532.3	427.3
010 Greenwich	45.8	63.5	72.8	173.8	103.3	196.8	97.3
012 Warren	8.0	8.0	24.3	62.3	78.7	165.3	118.0
014 Mid Haddam	357.3	461.7	454.0	233.3	196.7	422.3	310.7
015 Southington	6.4	9.6	13.4	14.6	16.6	21.2	7.8
102 New Hartford	16.5	3.0	3.5	23.8	3.0	23.3	17.8
116 Granby	2.8	8.5	2.8	0.0	2.8	10.8	13.8
Mean	89.81	120.96	126.10	163.62	136.11	251.84	219.39
SD	101.64	138.93	131.99	145.95	106.26	185.33	208.57

Routes	1998	1999	2000	2001	2002	Mean	SD
001 Mystic	203.5	168.8	157.8	151.8	274.8	140.10	69.04
003 Buckingham	380.0	257.0	233.0	202.8	311.3	273.73	64.85
004 Uncasville	421.5	185.0	241.3	254.5	307.0	246.08	89.66
005 Woodstock	676.3	632.7	610.7	596.0	727.0	<u>490.89</u>	225.35
006 Westbrook	282.0	229.3	192.7	170.0	174.3	204.69	48.23
007 Willimantic	393.5	230.0	275.5	306.5	337.5	232.08	106.51
008 Woodbury	182.0	238.8	361.3	243.3	523.8	150.31	165.18
009 Sherman	725.5	759.8	745.5	549.5	<u>1197.8</u>	<u>490.85</u>	338.67
010 Greenwich	169.3	253.8	246.8	172.8	227.0	151.88	73.20
012 Warren	256.0	356.0	484.0	406.3	557.7	210.39	196.22
014 Mid Haddam	318.7	200.3	201.0	136.0	155.7	287.31	116.47
015 Southington	28.2	27.8	43.0	60.2	50.2	<u>24.92</u>	17.64
102 New Hartford	46.3	49.0	116.0	104.5	141.8	45.69	48.32
116 Granby	13.8	56.0	55.0	86.8	88.0	<u>28.40</u>	33.50
Mean	292.60	260.30	283.10	245.77	<u>362.40</u>		
SD	217.50	207.13	204.08	165.94	307.19		

Table 4. Summary of linear regression results of Lyme disease rate on two measures of annual weather conditions

	Annual DPNP[a]			**Annual DPNT**[b]		
Routes	b1	r^2	P	b1	r^2	P
001 Mystic	-8.42	0.18	0.48	35.45	0.38	0.11
003 Buckingham			N/A			N/A
004 Uncasville	10.09	0.58	0.04	20.09	0.05	0.56
005 Woodstock	7.58	0.09	0.69			A/N
006 Westbrook			N/A	-3.01	0.02	0.84
007 Willimantic			N/A			N/A
008 Woodbury	0.89	0.004	0.88	8.71	0.35	0.59
009 Sherman	107.84	0.73	0.03	127.08	0.48	0.19
010 Greenwich	4.37	0.11	0.53	1.72	0.002	0.93
012 Warren			N/A	39.56	0.99	0.07
014 Mid Haddam	11.39	0.51	0.18	-0.21	0.000	0.99
015Southington	-0.15	0.003	0.95	1.23	0.03	0.73
102 New Hartford	-8.35	0.36	0.29	0.46	0.000	0.97
116 Granby	-3.08	0.34	0.06	4.53	0.03	0.60

[a] DPNP, departure from normal precipitation in inches. [b] DPNT, departure from normal temperature in degrees Fahrenheit. N/A, no data available.

Table 5. Summary of linear regression results for number of birds observed versus departure from normal June precipitation data. Table-wide alpha level for statistical significance was P < 0.004 after sequential Bonferroni correction

	SCLP[1]			**American Robin**			**Gray Catbird**			**American Redstart**		
Routes	b1	r^2	P	b1	r^2	P	b1	r^2	P	b1	r^2	P
Mystic *001	0.47	0.002	00.9	1.27	0.05	0.49	1.16	0.15	0.24	0.20-	0.08	0.39
003 Buckingham	1.58	0.04	0.59	0.48	20.0	0.73	-0.37	0.02	0.68	0.34	0.08	0.42
004 Uncasville	0.48-	0.03	0.76	-0.32	0.02	0.78	-0.96	0.43	0.16	0.25	0.04	0.70
*005 Woodstock	-1.34	0.01	0.85	0.24	0.01	0.89	1.15	0.08	0.59	0.59	0.10	0.54
006 Westbrook	8.65	0.03	0.83	-0.42	0.001	0.98	5.23	0.26	0.49	0.12-	0.05	0.78
007 Willimantic	1.39-	0.01	0.79	1.52-	0.13	0.30	1.44	0.08	0.44	0.66-	0.33	0.09
008 Woodbury	19.21	0.09	0.35	0.16-	0.000	0.96	6.21	0.13	0.25	0.44	0.03	0.60
Sherman *009	1.12	0.02	0.70	-1.67	0.16	0.25	0.06	0.001	0.94	0.6	0.11	0.34
010 Greenwich	0.95	0.01	0.82	0.22	0.004	0.88	0.57	0.02	0.71	0.02-	0.002	0.90
012 Warren	-5.66	0.33	0.24	-0.76	0.09	0.57	-0.49	0.05	0.66	1.34	0.22	0.35
*014 Mid Haddam	4.45	0.57	0.08	1.38	0.05	0.66	-0.17	0.02	0.77	0.29	0.05	0.67
015 Southington	-0.17	0.001	0.94	-1.89	0.25	0.12	-0.02	0.000	0.97	0.07-	0.04	0.58
*102 New Hartford	-4.04	0.40	0.07	2.09	0.07	0.45	0.01	0.000	0.99	0.25	0.02	0.74
Granby *116	2.56	0.07	0.62	-0.70	0.17	0.42	-1.21	0.11	0.53	0.85	0.73	0.03

* Route had one observer for all years. [1]SCLP: Species carrying Lyme pathogen.

Table 6. Summary of linear regression results for number of birds observed versus departure from normal June temperature DPNT. Table-wide alpha level for statistical significance was P < 0.004 after sequential Bonferroni correction

Routes	SCLP[a]			American Robin			Gray Catbird			American Redstart		
	b1	r^2	P	b1	r^2	P	b1	r^2	P	b1	r^2	P
Mystic *001	-4.35	0.05	0.54	2.53-	0.07	0.45	-1.40	0.06	0.47	0.34	0.07	0.47
003 Buckingham	-1.90	0.03	0.62	1.09-	0.05	0.54	0.25	0.007	0.82	1.05-	0.47	0.03
004 Uncasville	3.85	0.17	0.42	1.78	0.07	0.61	3.66	00.6	0.07	1.41-	20.1	0.49
*005 Woodstock	0.01	0.000	0.99	1.80	20.3	0.24	0.39	0.01	0.85	0.02-	0.000	0.98
006 Westbrook	-11.02	0.22	0.54	4.22-	0.30	0.46	4.92	10.8	0.09	0.04	0.02	0.86
007 Willimantic	-0.03	0.000	0.99	1.90	20.1	0.32	1.93-	0.08	0.43	0.54	30.1	00.3
008 Woodbury	1.67	0.01	0.87	2.14	0.16	0.51	0.12-	0.002	0.94	1.27	0.45	0.22
Sherman *009	4.88	0.07	0.56	2.62	0.05	0.62	0.45	0.01	0.82	-1.86	0.16	0.38
010 Greenwich	-6.79	0.12	0.45	1.70-	00.1	0.51	0-3.4	30.3	0.18	0.16	00.1	0.50
012 Warren	2.32	0.03	0.80	2.32-	00.3	0.34	-0.68	0.03	0.76	3.01	20.5	0.17
*014 Mid Haddam	-0.92	0.01	0.90	-1.60	10.0	0.82	0-1.2	10.2	0.35	2.00	0.46	0.14
015 Southington	5.24	0.25	0.21	2.47	00.2	0.17	-0.52	0.04	0.63	-0.17	0.09	0.47
*102 New Hartford	0.85	0.01	0.76	0.74-	0.05	00.6	0.19	0.01	0.79	-0.19	0.006	0.85
Granby *116	-0.51	0.002	0.93	4.69	01.0	0.08	0.43	0.01	0.83	-0.36	0.12	0.49

* Route had one observer for all years. [a] SCLP: Species carrying Lyme pathogen.

Species Carrying Lyme Pathogen (SCLP): After using Bonferroni correction for multiple tests, the study found that only 008 Woodbury and 012 Warren had a statistically significant relationship between the number of birds observed from species carrying the Lyme pathogen and Lyme disease rate. All other routes had no statistically significant relationship between the number of birds observed and Lyme disease rate because P values for them were greater than 0.05.

American Robin: after using Bonferroni correction for multiple tests, the study found that only 012 Warren had a statistically significant relationship between the number of birds observed and Lyme disease rate. All other routes had no statistically significant relationship between the number of birds observed and Lyme disease rate because P values for them were greater than 0.05.

Gray Catbird: after using Bonferroni correction for multiple tests, the study found that only 008 Woodbury, 009 Sherman and 012 Warren had statistically significant positive relationships between Gray Catbird number and

Lyme disease rate. After Bonferroni correction for multiple tests, only 102 New Hartford still had a statistically significant negative relationship between the number of Gray Catbirds observed and Lyme disease rate. All other routes had no statistically significant relationship between number of birds and Lyme disease rate because P values for them were greater than 0.05.

American Redstart: after using Bonferroni correction for multiple tests, (008 Woodbury and 012 Warren). All other routes had no statistically significant relationship between the number of birds and Lyme disease rate because P values for them were greater than 0.05.

The study tried to find a logical or evident explanation for the result from these two routes, or the study needed to get an answer for the question: Is there a relationship between the result for these two routes and the observer identities? The study found that there were two observers for these two routes, but it was not an evident explanation because other routes also had more than one observer over years (1991-2002) and these routes did not show a positive relationship between the number of birds observed and Lyme disease rate

The study noticed that Gray Catbird group was the only group that had three statistically significant positive relationships between the number of birds observed and Lyme disease rate (008 Woodbury, 009 Sherman, and 012 Warren). The study found that appearance of positive relationship is related to the Gray Catbird's behavior. The Gray Catbird lives in dense shrubs between thickets of young trees, and nests at the center of dense shrubs, small trees, or in vines (Cornell Laboratory of Ornithology n.d.). Therefore, it will be in contact with the black-legged tick (*Ixodes scapularis*) that lives in forests with rich and moist undergrowth. Also, the tick's larva has a high molting success on Gray Catbirds (Brunner et al., 2011).

The American Redstart was my control species because this species may not be able to support the pathogen because at least two tick larvae were tested and were not infected with the pathogen (Brinkerhoff et al. 2011). However, the study found that there was a positive relationship between the number of American Redstarts observed and Lyme disease rate for 008 Woodbury and 012 Warren. Therefore, the result does not support this prediction and thus it does not support my hypothesis.

The Connecticut land use map (Figure 6) does not show an evident difference between the routes that had statistically significant positive relationships between the number of birds observed and Lyme disease rate (routes 008 Woodbury, 009 Sherman, and 012 Warren) and other routes. In other words, based on the geography that the Connecticut land use map shows, the study did not find obvious geographical differences between the routes that had statistically significant positive relationships between the number of birds observed and Lyme disease rate (routes 008 Woodbury, 009 Sherman, and 012 Warren) and other routes

There was no difference between the routes that had statistically significant positive relationships between the number of birds observed and Lyme disease rate (routes 008 Woodbury, 009 Sherman, and 012 Warren) and other routes (Figure 7). The study found that the low population sizes for these three routes' towns (693 - 10,807) was the same as that for routes 003 Buckingham and 005 Woodstock, two routes that had no significant relationship between the number of birds observed and Lyme disease rate.

From all the results that the study found in this research, the study rejected the hypothesis because there is no strong relationship between the number of birds that could be infected with B. *burgdorferi* and the rate of Lyme disease in people. Therefore, birds do not appear to play an important role for transmitting Lyme disease to people, at least using the methods I used here.

4. Suggestions

The study suggests to use another method by studying other individual bird species separately like the study did for American Robin, Gray Catbird and American Redstart, or to use other species as control species. Future studies should also verify that American Redstarts do not carry the Lyme disease pathogen. Researchers could also choose another state that has a high Lyme disease rate, such as New Jersey or Wisconsin, to try to repeat my findings. Another suggestion is to make a new study for the bird species the researcher used but using a different range of years, such as using the last five or ten years. Finally, because Lyme disease can affect dogs and horses (Carmel & Edwards, 1989), the study suggests that it would be interesting to study the relationship between the rate of Lyme disease in these domestic animals and the numbers of birds from species known to carry the Lyme disease pathogen.

Table 7. Summary of linear regression results for number of birds observed on Connecticut Breeding Bird Survey routes versus Lyme disease rate for 1991-2002. Bold italics indicate statistically significant relationship after sequential Bonferroni correction

Routes	SCLP[a]			American Robin			Gray Catbird			American Redstart		
	b1	r^2	P	b1	r^2	P	b1	r^2	P	b1	r^2	P
Mystic *001	1.29	0.26	0.09	3.57	0.48	0.01	1.42	0.02	0.64	-20.22	0.28	0.08
003 Buckingham	0.38	0.01	0.73	1.14	0.02	0.67	3.42	0.11	0.29	7.29	0.08	0.38
004 Uncasville	-1.99	0.33	0.14	-3.22	0.19	0.28	-7.02	0.39	0.04	-3.79	0.07	0.53
*005 Woodstock	2.69	0.12	0.50	-8.00	0.07	0.62	18.76	0.57	0.08	-16.87	0.09	0.55
006 Westbrook	-0.92	0.46	0.14	-2.39	0.39	0.18	2.64-	0.19	0.39	20.67	0.04	0.70
007 Willimantic	1.97	0.41	0.03	5.34	0.29	0.07	5.91	0.45	0.02	8.71-	0.04	0.53
008 Woodbury	0.93	0.72	*<0.001*	5.07	0.49	0.01	3.59	0.77	*<0.001*	24.51	0.79	*<0.001*
Sherman *009	-0.89	0.004	0.85	-17.94	0.38	0.03	31.18	0.57	*0.004*	27.13	0.15	0.21
010 Greenwich	0.61	0.04	0.57	-1.33	0.02	0.69	3.28	0.17	0.24	-53.02	0.33	0.08
012 Warren	1.14	0.78	*<0.001*	8.37	0.82	*0.001*	5.59	00.8	*<0.001*	17.74	0.71	*0.001*
*014 Mid Haddam	2.35	0.27	0.29	0.16	0.001	0.95	11.17	0.22	0.34	6.61	00.1	0.54
015 Southington	-0.43	0.26	0.11	-0.14	0.005	0.84	0.25	0.01	0.83	-4.87	0.11	0.32
*102 New Hartford	-2.58	0.68	0.01	-2.89	0.18	0.25	-11.37	0.79	*0.001*	-4.56	0.19	0.24
Granby *116	-0.06	0.06	0.66	-0.23	0.101	0.54	0.14-	0.05	0.69	0.36	0.02	0.78

* Route had one observer for all years. [a]SCLP: Species carrying Lyme pathogen

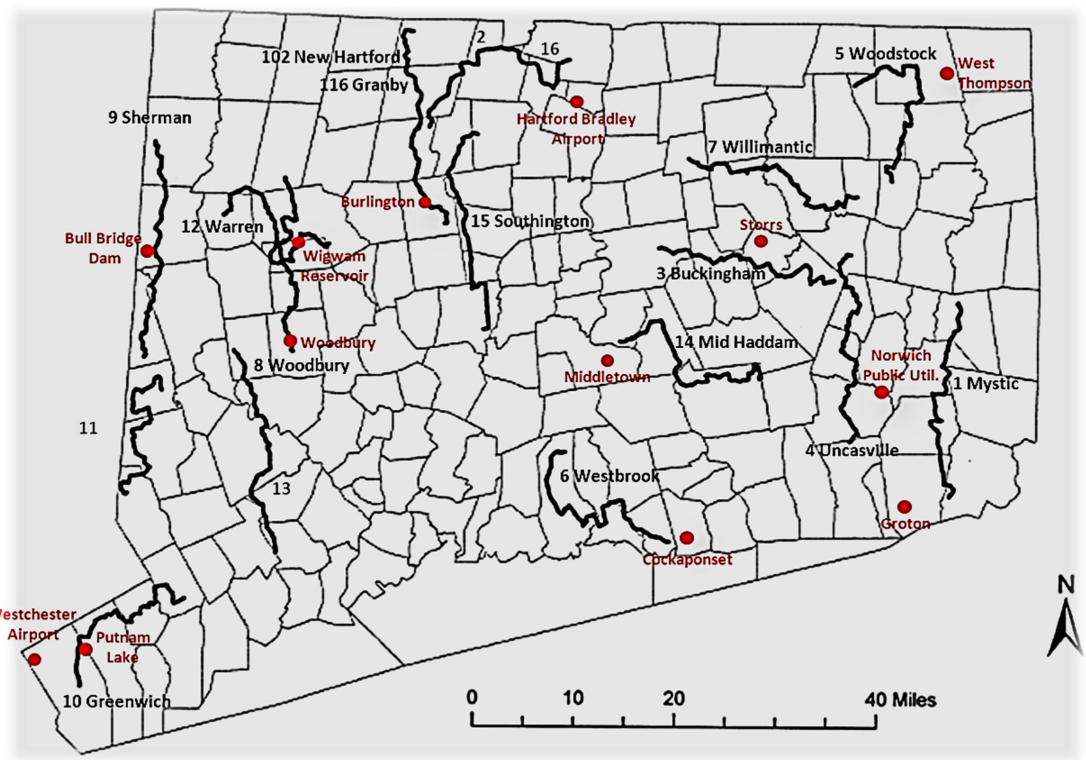

Figure 1. Connecticut Breeding Bird Survey routes and NOAA weather stations used in this study. The black words indicate the routes. The red words indicate the weather stations. Blue letters indicate routes not used in this study because they were not active routes

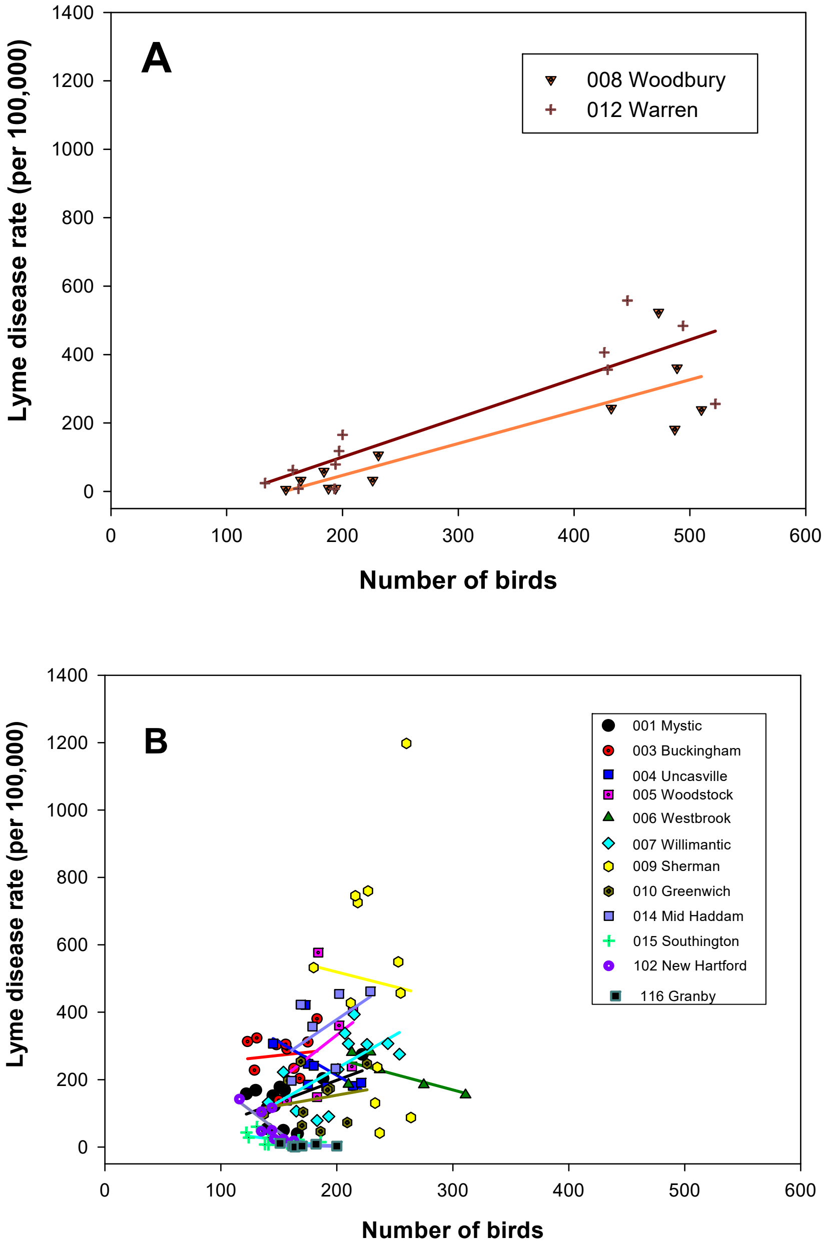

Figure 2. Relationship between numbers of birds counted from species carrying Lyme pathogen and the rate of Lyme disease for Connecticut Breeding Bird Survey routes from 1991 -2002. A) Routes for which this relationship was statistically significant positive after sequential Bonferroni correction. B) Routes for which this relationship was not statistically significant after sequential Bonferroni correction

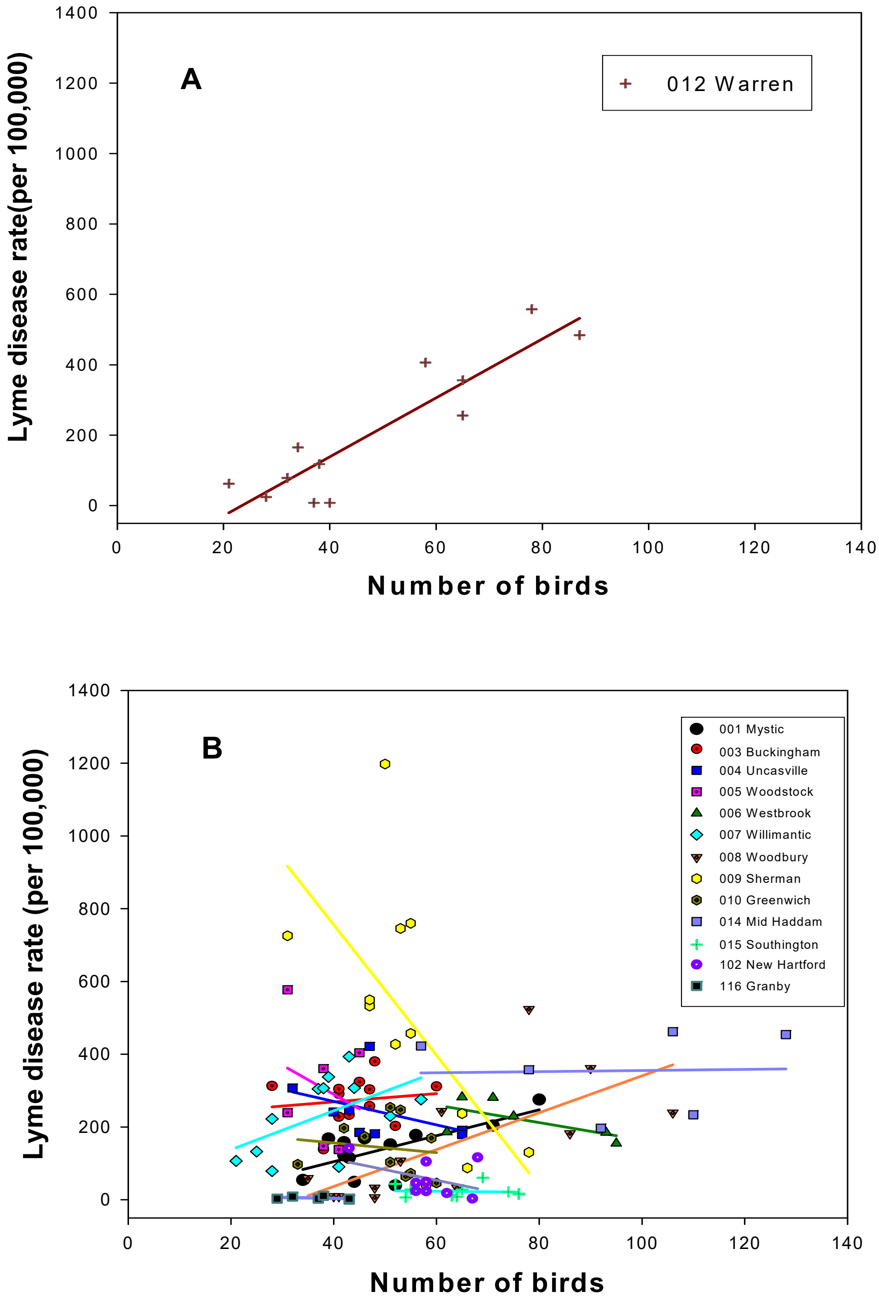

Figure 3. Relationship between number of American Robin and the rate of Lyme disease for Connecticut Breeding Bird Survey routes from 1991 -2002. A) Routes for which this relationship was statistically significant positive after sequential Bonferroni correction. B) Routes for which this relationship was not statistically significant after sequential Bonferroni correction

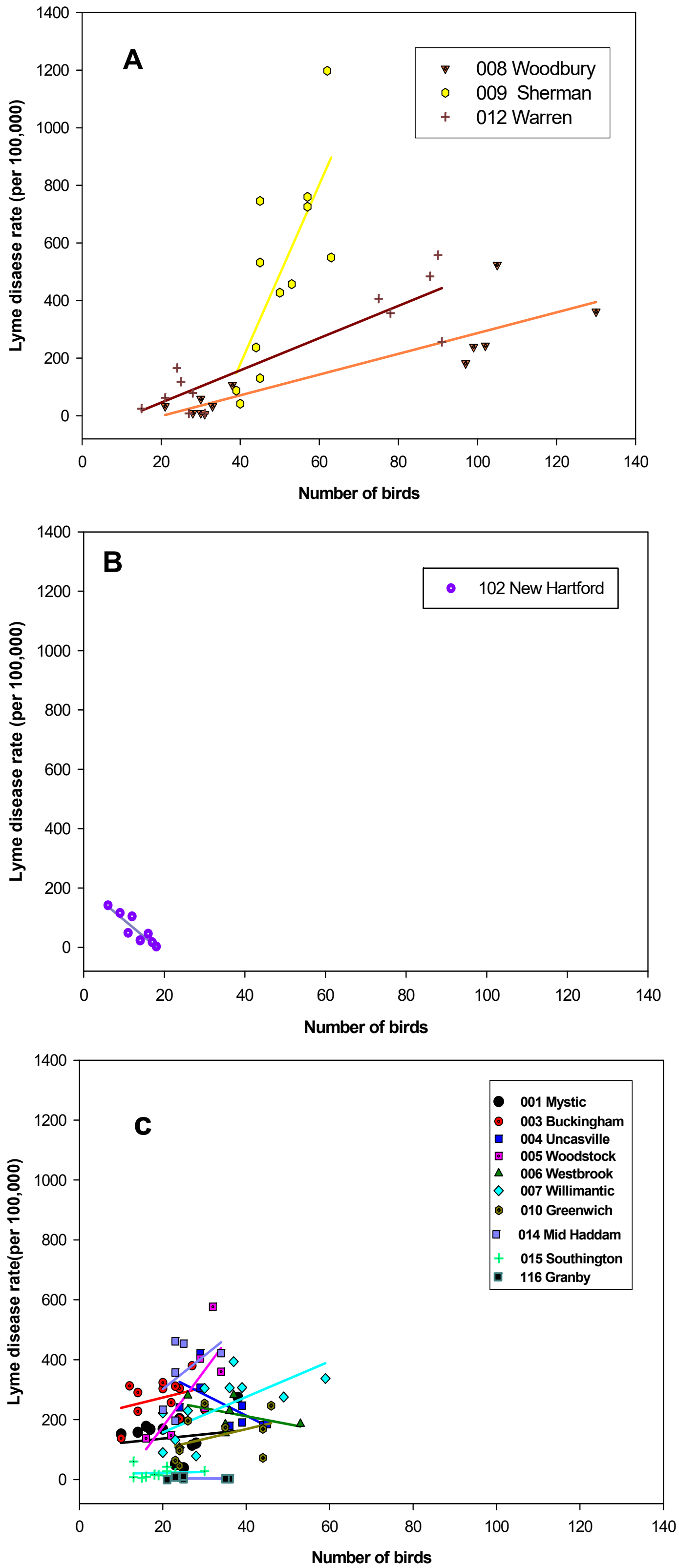

Figure 4. Relationship between number of Gray Catbirds and the rate of Lyme disease for Connecticut Breeding Bird Survey routes from 1991-2002. A) Routes for which this relationship was statistically significant positive after sequential Bonferroni correction. B) Routes for which this relationship was statistically significant negative after sequential Bonferroni correction. C) Routes for which this relationship was not statistically significant after sequential Bonferroni correction

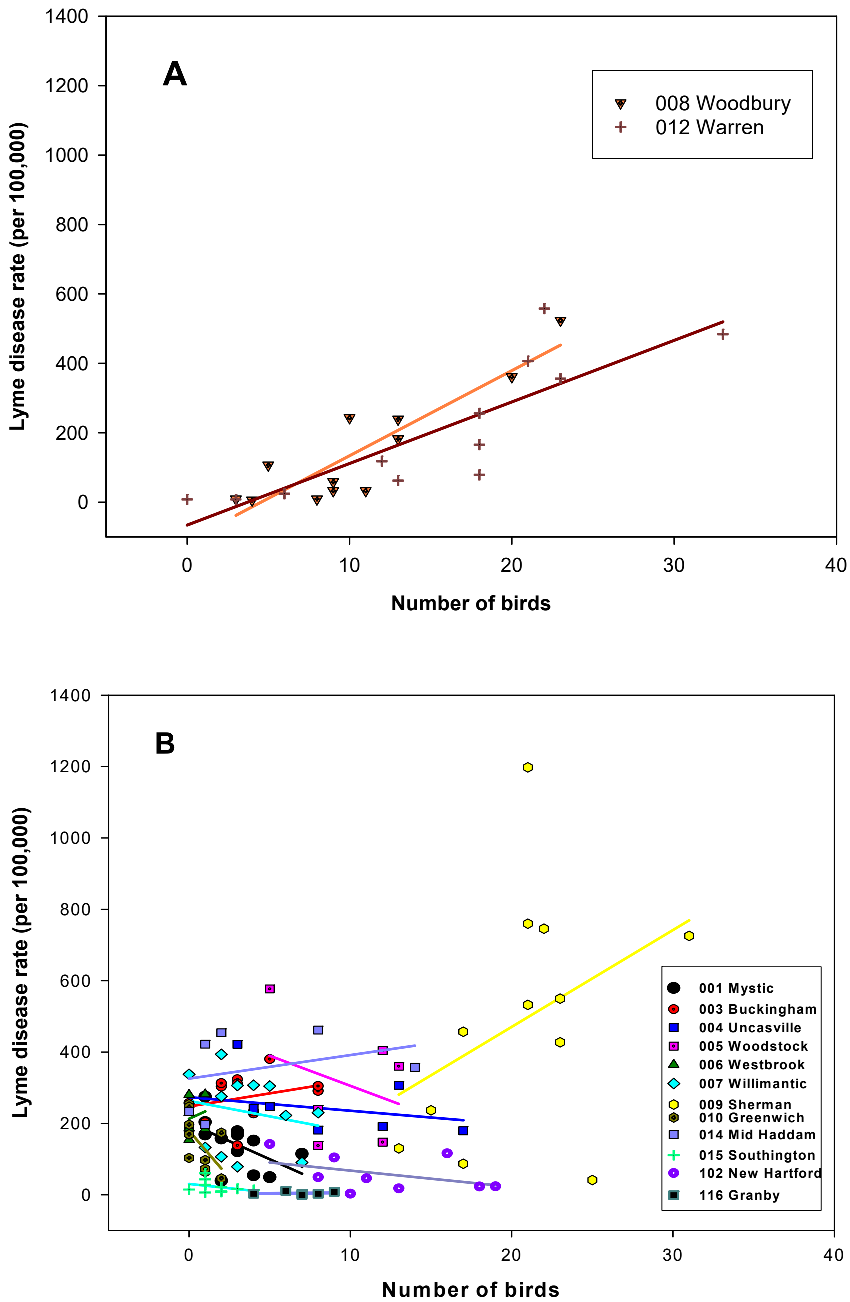

Figure 5. Relationship between number of American Redstarts and the rate of Lyme disease for Connecticut Breeding Bird Survey routes from 1991-2002. A) Routes for which this relationship was statistically significant positive after sequential Bonferroni correction. B) Routes for which this relationship was not statistically significant after sequential Bonferroni correction

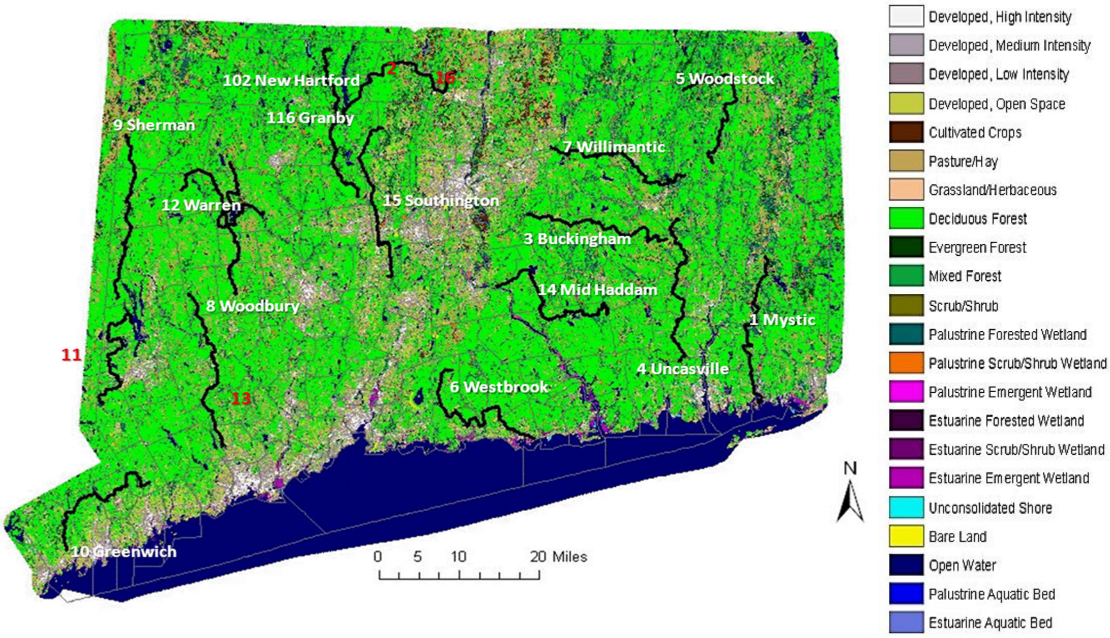

Figure 6. Connecticut Breeding Bird Survey routes and land use in 2001. Land use data are from http://www.csc.noaa.gov/crs/lca/northeast.html. Routes with red numbers indicate routes not used in this study because they were not active routes

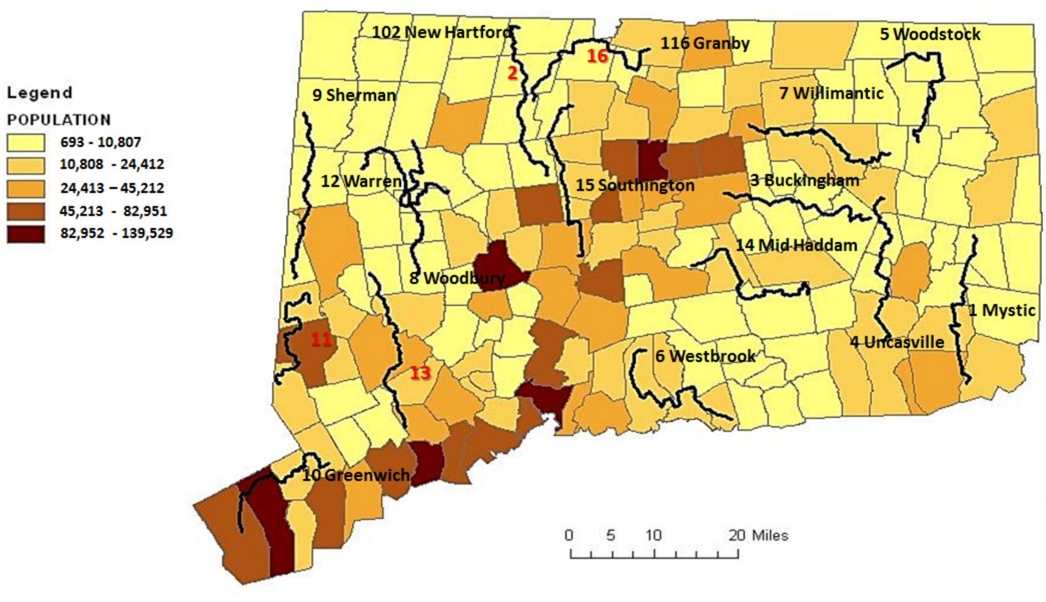

Figure 7. Connecticut Breeding Bird Survey routes and population size of Connecticut towns from the 2000 U.S. federal census. Census data are from http://factfinder2.census.gov using the file "Total Population (P001) - 2000 SF1 100% data". Colors represent groupings as determined by the Jenks Natural Breaks method. Routes with red numbers indicate routes not used in this study because they were not active routes

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