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Authors: Dhondt, André A., Tessaglia, Diane L., and Slothower, Roger L.

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EPIDEMIC MYCOPLASMAL CONJUNCTIVITIS IN HOUSE FINCHES FROM EASTERN NORTH AMERICA

André A. Dhondt,[1,2] Diane L. Tessaglia,[1] and Roger L. Slothower[1]

[1] Bird Population Studies, Laboratory of Ornithology, Cornell University, Ithaca 14850, New York, USA
[2] e-mail aad4@cornell.edu

ABSTRACT: In the winter of 1993–94, house finches (*Carpodacus mexicanus*) with severe conjunctivitis (later shown to be caused by *Mycoplasma gallisepticum*) were first observed in suburban Washington D.C. (USA) and adjacent states. Using a large network of volunteer observers in eastern North America, we were able to track the monthly prevalence of the disease between November 1994 and March 1997. Using the information on 24,864 monthly data forms, we describe the very rapid spread of the conjunctivitis epidemic through the eastern house finch population. The epidemic first expanded mainly north, probably carried along by house finches on their return migration, then mainly toward the southeast, and later west. By March 1997, conjunctivitis had been reported from most of the eastern range of the house finch. The prevalence of the disease seemed to fluctuate seasonally with increases in the fall, probably as a result of dispersing juveniles. House finch numbers decreased throughout winter in areas with cold winters and high conjunctivitis prevalence, suggesting significant mortality associated with the disease.

Key words: *Carpodacus mexicanus*, citizen science, epidemic, house finch, maps, *Mycoplasma gallisepticum*, mycoplasmosis, survey.

INTRODUCTION

The house finch (*Carpodacus mexicanus*) is a small passerine that was introduced from western North America onto Long Island (New York, USA) about 1940. During the initial years the house finch population barely survived, with an estimated population of 80 individuals in the winter of 1947–48 (Elliot and Arbib, 1953). The population has grown very rapidly since then, and its range has expanded as far west in the USA as Minnesota and Louisiana (Veit and Lewis, 1996).

House finches with severe conjunctivitis (swollen, crusty or closed eyes) were first observed in February 1994 in the eastern USA from suburban Washington D.C., northern Virginia, and southern Maryland. By October 1994 birds showing clinical signs had been reported from nine mid-Atlantic states (Fisher et al., 1997). Diagnostic testing confirmed that the conjunctivitis symptoms were caused by a new strain of the non-zoonotic pathogen of poultry *Mycoplasma gallisepticum* (MG) (Ley et al., 1996, 1997; Luttrell et al., 1996), that had not been considered a primary pathogen of wild passerines (Whiteman and Bickford, 1989). The reasons house finches became infected by MG remain unknown. However, the habitual flocking of house finches at feeders and other sites with abundant food probably facilitates transmission through direct contact.

This outbreak offered a unique opportunity to use reports from members of the public to track an epidemic in a wild bird population because: (1) the disease was discovered when its geographic range was still limited; (2) the clinical signs of conjunctivitis are very obvious and are accompanied by changes in behavior due to blinding and weakening; and (3) house finches are common feeder birds.

We enlisted the help of Project FeederWatch volunteers in the eastern half of North America to track the expansion of this new disease. Project FeederWatch is an ongoing program of the Laboratory of Ornithology (Cornell University, Ithaca, New York, USA) and Bird Studies Canada (Long Point Bird Observatory, Port Rowan, Ontario, Canada) in which volunteer participants across North America report the birds observed at their feeders. This paper reports the results from the initial 29 mo of this sur-

vey, November 1994 through March 1997, during which conjunctivitis rapidly spread through the range of eastern house finches.

MATERIALS AND METHODS

In September 1994 we mailed detailed descriptions of the clinical signs of birds affected with the new strain of *Mycoplasma gallisepticum* to about 9,000 Project FeederWatch participants in the eastern half of the United States and Canada. The mailing included instructions on how to observe and record data and use computer-scannable data forms for data submission. Each form consisted of a matrix of 31 rows and 12 columns of bubbles on which participants recorded the observations of a single month. Data were reported by filling the appropriate bubble. Each row of bubbles corresponded to observations from each day of the month. The first column was used to record that observers had watched their feeder(s) on that day. The next 10 columns were used to record observations of healthy or sick birds of the following species: house finch, purple finch (*Carpodacus purpureus*), black-capped chickadee (*Parus atricapillus*), house sparrow (*Passer domesticus*), and dark-eyed junco (*Junco hyemalis*). The final column was used to report diseased birds of other species, to be described on the back of the form, where there also was space for comments, including details on numbers, behaviors, and clinical signs of diseased birds. We did not require participants to count the number of sick or healthy birds at their feeder. Participants could watch their feeders at any time of day, and for any amount of time. Participant identity (ID number), month and year and zip or postal code also were reported by filling appropriate bubbles.

Participants were requested to return the forms at the end of each mo, in order to closely track the epidemic. In the letter accompanying the data forms, we stressed the importance of returning the data forms even if no diseased birds had been observed. The participants clearly understood our message. Of the 24,864 data forms included in this report, 3,665 (15%) reported not having seen any house finches in that month, and 15,870 (64%) reported having seen healthy birds only. Therefore, in many regions, we were able to document the expansion of MG in house finches from its very inception.

Before scanning the forms, we first verified that participants had correctly filled in all fields containing critical database indexing information, participant ID number, zip or postal code, and month and year. Where participants provided comments, we categorized and coded that information. In particular, if a participant reported diseased birds, we coded whether their comments provided an adequate description of conjunctivitis-like symptoms (describing clinical signs and behavior associated with mycoplasmal conjunctivitis) and tried to distinguish clinical signs possibly caused by avian pox or other forms of conjunctivitis from those possibly resulting from MG. Diseased birds reported outside the known range of the disease were verified by letter or phone, where possible. During the mapping of the disease, we used a conservative approach to avoid constructing maps that included isolated outliers (see below).

Our database contains one record per observer per mo. The fields included in the database and used in this paper are month, year, participant's ID number, zip or postal code, latitude and longitude (the centroid of the observer's zip or postal code), state or province, and a code (SUM) summarizing house finch observations for that observer in the entire mo where 0 represented no house finches seen, 1 was for healthy birds only, 2 indicated at least one house finch observed in that mo and clinical signs of conjunctivitis were described adequately, and 3 was indicative of "sick" birds reported but no clinical signs were described. This latter group was recoded to 2 in the analyses because there were only 237 (<1%) such records, most of which stemmed from observers that had described the clinical signs adequately in earlier reports.

The main data set used in this study contains observations from the Canadian provinces of Ontario, Quebec, Newfoundland, New Brunswick, and Nova Scotia, and from the United States east of and including Minnesota, Iowa, Missouri, Tennessee, and Mississippi. We refer to this region as "eastern North America".

To compare the prevalence of the disease by season, states and provinces were grouped into four regions in order to have adequate sample sizes in each region for statistical analysis, and reflecting variations in prevalence in November 1994. These regions are the mid-Atlantic region including Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, Maryland, Delaware, and Washington DC; the Southeast region including Virginia, West Virginia, North and South Carolina, Georgia, and Florida; the Northeast region including Vermont, New Hampshire, Maine, Quebec, Nova Scotia, New Brunswick, and New Foundland; and the Midwest region including Minnesota, Wisconsin, Michigan, Ontario, Iowa, Missouri, Illinois, Indiana, Ohio, Kentucky, Tennessee, Mississippi, and Alabama.

We also received a small number of reports from states further west in the Great Plains (from North Dakota to Texas) because the disease was recently confirmed in a house finch from Texas (P. Luttrell, pers. commun.). These results are not included in the overall analysis for eastern North America but will be used for qualitative descriptions, especially regarding the timing of the first observations of conjunctivitis. Only three of 59 participants in the Great Plains states submitted 16 or more data forms and would hence qualify as "regular" (see below). The 17 participants in Texas, Kansas, Nebraska and North Dakota who reported conjunctivitis saw mainly healthy birds; each participant sent an average of 6.8 data forms, and reported diseased birds on average in 2.4 mo.

Because we tried to determine if the prevalence of conjunctivitis changes over time by using repeated observations at the same locations, we used the McNemar test for the significance of changes (Siegel, 1956). In each comparison, an observer is assigned to one of four categories, depending on whether the observer reported healthy birds in both periods (A), reported healthy birds in the first period and diseased birds in the second (B), diseased birds in the first period and healthy in the second (C), or diseased birds in both periods (D). Under the null hypothesis, the numbers in categories B and C are equal. Because we wanted to determine when and where the major changes in prevalence occurred, we grouped the observations into 2 mo periods consisting of early winter (November–December), late winter (January–February), spring (May–June), and fall (August–September). We compared successive periods including only observers that had observed house finches in all 4 mo of the two periods being compared. For that reason, the sample sizes varied between comparisons. Observers who reported diseased birds in any one of the two successive mo of a period were classified in the "conjunctivitis" category. In a similar way, we compared data from successive winters, whereby we used 4 mo rather than 2 mo periods. Reports from the same observer were compared between the first and second, and second and third winter of the study. Only observers who submitted data in all 4 mo of each winter were included in the comparison.

Maps depicting the monthly distribution of the prevalence of disease are interpolated surfaces created for illustrative purposes as well as to estimate the area of the range of the disease and were produced using Arcview version 3.0a (Environmental Systems Research Institute, Redlands, California, USA). Each monthly distribution map included only data from observers in states east of or bordering the Mississippi river and who were "regular" observers, that is, they reported during at least 16 mo of the study. Conjunctivitis reports, that were isolated from other reports by more than 200 km, were treated as non-occurrences during the surface interpolation but were always displayed as isolated occurrences on the resulting map. In the case in which multiple participants from a single zip code reported during the same month, the location of each was shifted by 10 to 100 m in order to represent each as a separate observation. The bar scale and the north arrow on each map are subject to the distortion characteristics of the Albers Equal Area projection (Snyder, 1987) and can only be considered as approximate.

For the purpose of simplicity, the interpolation surface was an inverse distance weighted surfaced created with Arc/Info's (Arc version 7.1.1; Environmental Systems Research Institute) GRID PointInterp command using all points within a 200 km radius, a quadratic decay component and a 25 × 25 km cell. The interpolation on the presence and absence of conjunctivitis resulted in a prevalence map ranging from 0 (absent) to 1 (present in all observations in the neighborhood). The low number and uneven distribution of participants and, in particular, the paucity of participants on the fringes of the region under study produced an interpolated surface which may exaggerate the extent of the apparent prevalence in areas with few participants. To minimize this, cells with a prevalence of <0.05 were categorically truncated to 0. To estimate the beginning of the epidemic, we calculated a linear regression (Sokal and Rohlf, 1980) of $\sqrt{}$-area covered by the disease against mo for the initial 6 mo of the survey, and extrapolated backwards.

Three maps are included which differ slightly from those created with the method described above. Figure 3 shows the November 1994 distribution of conjunctivitis based on "regular" participants but the points displayed are for any participant who reported conjunctivitis that month. Figure 6 shows the distribution of conjunctivitis in March 1997, including all participants who reported that month, including the states of Texas, Oklahoma, Kansas, Nebraska, South Dakota and North Dakota. The dark gray represents the presence of the disease based on "regular" participants, the medium gray represents the disease based on all participants, and the light gray represents the reported absence of the disease based on all participants. Figure 8 shows the range limit of the disease based on manually tracing the limit of the range for consecutive Novembers based on the "regular" participants.

Between November 1994 and March 1996,

J. Bickal, a bird bander (Lawrenceville, New Jersey, USA) mist-netted 881 house finches at feeders in her garden and marked birds individually using U.S. Fish and Wildlife Service bands (U.S. Fish and Wildlife Service Bird Banding Laboratory, Laurel, Maryland, USA). Several individuals were recaptured in different months. Using our descriptions of clinical signs of mycoplasmal conjunctivitis, she recorded whether or not captured birds showed such clinical signs. Based on her data, we calculated the percentage of house finches captured by her that showed conjunctivitis in each month. We used a linear correlation coefficient (Sokal and Rohlf, 1981) to compare her percentage of diseased individual birds with our measure of prevalence based on the percentage of participants (= sites) who reported at least one sick house finch in a given month and region/all participants who observed at least one house finch in that month and region.

RESULTS

Number of participants and selection of samples

Details on the regional distribution and participation frequency of the 3,213 volunteers from eastern North America who submitted data are given in Table 1. There were 1,680 (52%) individuals who submitted their first form in November 1994. There were 534 (17%) participants who returned at least 16 forms (essentially one form each month, because many participants discontinued feeding birds in summer), most of which (492 = 93%) started in the first month of the survey. There were 1,764 (54%) participants who submitted fewer than six data forms, and 645 (20%) participants contributed only one month of data. The total number of data forms included in this analysis is 24,864.

House finch behavior could have biased the way our survey measured the prevalence of the disease. For example, if diseased birds used feeders in greater proportion than non-diseased birds, our absolute estimate of disease prevalence would have been inflated. To reduce that possible effect, we grouped observations by month. Because nearly all participants who reported diseased birds also reported healthy birds in the same month, our prevalence values reflected the actual situation at each particular feeder. A bias in our calculations of disease prevalence would have occurred only if sick birds used the feeders but healthy birds did not. Bias in the description of changes in prevalence over time also could have been introduced by the addition of new participants, because they observed diseased birds, or by losing participants because they did not observe diseased birds. To evaluate the extent of this possible source of bias, we calculated prevalence for two independent subsets of data. One subset includes the participants who submitted at least 16 data forms ("regular participants"), most of which started in November 1994 and have continued throughout (although some stopped reporting in the summer months because they discontinued feeding). The second subset contains all other reports. Changes in prevalence of the epidemic in eastern North America were qualitatively similar between the two subsets (Fig. 1). There

TABLE 1. Regional breakdown of number of participants who submitted data forms on mycoplasmal conjunctivitis in house finches from the eastern half of North America (see definition in text).

	Participation				
Region	ALL[a]	NOV94[b]	<6[c]	>15[d]	NOV94 >15[e]
AT[f]	1,418	727	804	195	179
MW[g]	1,193	634	647	221	203
SE[h]	407	192	230	69	64
NE[i]	195	127	83	49	46
Total	3,213	1,680	1,764	534	492

[a] ALL is the total number of participants who submitted data forms.

[b] NOV94 is the number of participants who first submitted data in November 1994.

[c] <6 is the number of participants who submitted less than six forms total.

[d] >15 is the number of participants who submitted more than 15 forms total in the period November 1994–March 1997.

[e] NOV94 >15 is the number of participants who submitted the first data in November 1994 and have submitted data for more than 15 mo.

[f] AT = mid-Atlantic Region (MA, CT, RI, NY, PA, NJ, MD, DE, DC).

[g] MW = Midwest Region (MN, WI, MI, ON, IA, MO, IL, IN, OH, KY, TN, MS, AL).

[h] SE = Southeast Region (VA, WV, NC, SC, GA, FL).

[i] NE = Northeast Region (VT, NH, ME, QC, NS, NB, NF).

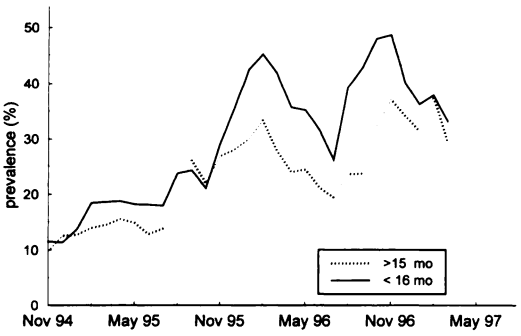

FIGURE 1. Comparison of changes in conjunctivitis prevalence in house finches in eastern North America (November 1994–March 1997) where >15 mo represents data from "regular" participants only, who reported in >15 mo, and <16 mo represents data from the other participants, who reported in <16 mo.

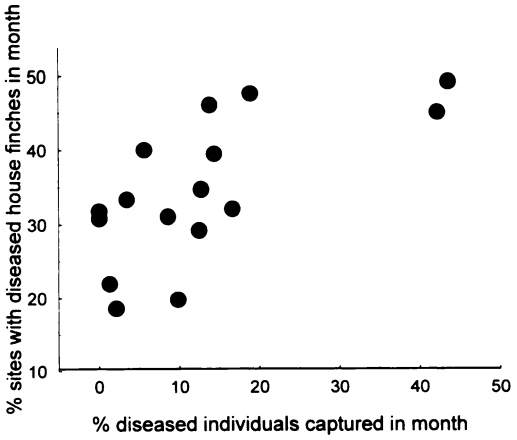

FIGURE 2. Comparison of conjunctivitis prevalence as measured by our survey in New Jersey to the % of house finches with conjunctivitis among the birds captured by J. Bickal at her feeders (November 1994–March 1996). Linear correlation coefficient r = 0.68 (n = 16, $P < 0.01$).

was a rapid increase in prevalence between November 1994 and February 1996 and subsequent fluctuations with highs during the winter months and lows during the breeding season. However, the absolute prevalence value is usually, but not always, about 10% lower among the regular participants than among the other group. Therefore, in order to describe changes in prevalence over time, we have used only the smaller subset of 532 regular participants.

Comparison of prevalence between the survey and captured birds in New Jersey

From November 1994 to March 1996, the percentage of house finches with conjunctivitis captured by J. Bickal in New Jersey varied between 0% in May (n = 7 house finches trapped) and July 1995 (n = 18) to 44% in January 1996 (n = 62). During the same period the disease prevalence in New Jersey, as measured through our survey, varied between 19% in December 1994 (n = 86 sites with house finches) and 49% (n = 61) in January 1996. The linear correlation between the two time series was statistically significant (Fig. 2), showing that variations in prevalence from our survey data reflect variations in the proportion of house finch individuals showing conjunctivitis in the same regional population.

Disease prevalence in November 1994

Using data from November 1994 submitted by regular participants only (Fig. 3), the interpolated surface mapping of conjunctivitis in house finches covers a semicircular area including Rhode Island, Massachusetts, southern Vermont, and southern New Hampshire, southern New York (extending into southern Ontario), most of Pennsylvania, Maryland, Delaware, northeastern Virginia and eastern West Virginia. In the mid-Atlantic region, 19% (n = 674) of observers with house finches at their feeders reported conjunctivitis. The black symbols outside the interpolated region (except one in Ohio and one in South Carolina that show the site of isolated regular participants) represent the locations of any participant reporting conjunctivitis that month. These additional observations suggest that in November 1994, the area with conjunctivitis reached farther west into Pennsylvania and farther south into West Virginia than the interpolated surface shows. In addition, perhaps the disease had already become es-

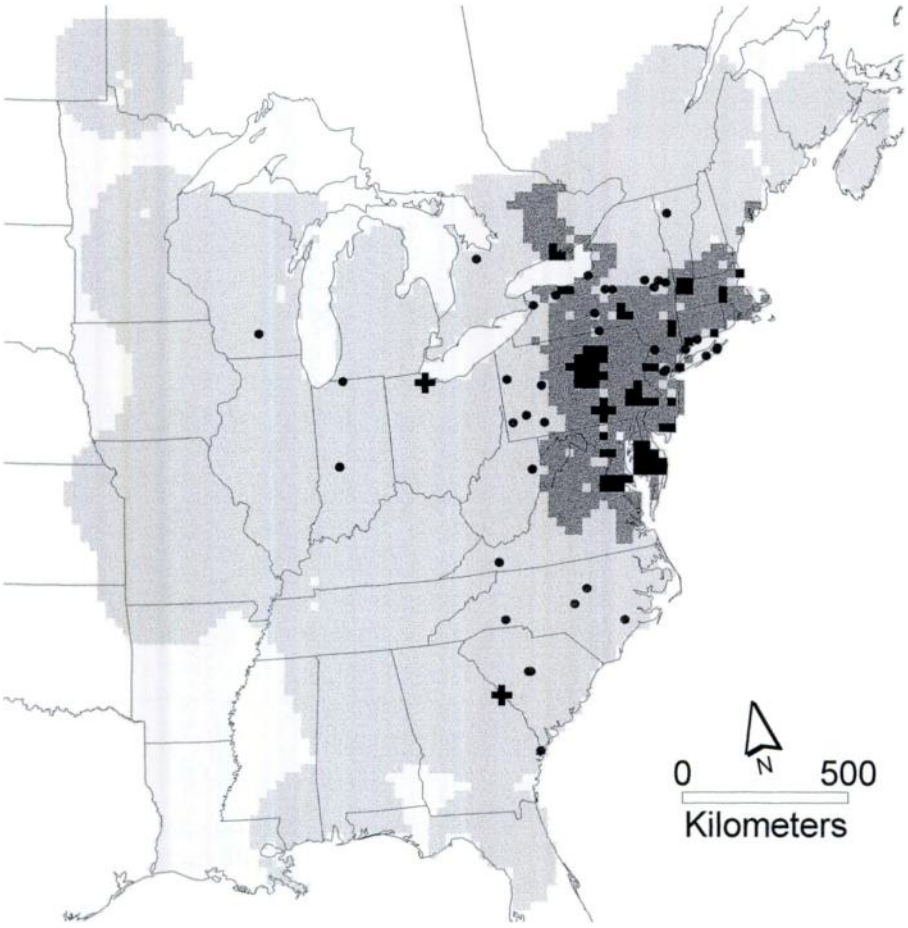

FIGURE 3. Map of the distribution of conjunctivitis prevalence in house finches in November 1994, the first month of the survey. The gray scale map is the interpolated surface (see text) of conjunctivitis prevalence based on "regular" participants; in light gray areas house finches were present and prevalence was 0–5%, medium gray indicates a prevalence of 5–33%, dark gray indicates a prevalence of >33%. The circles represent reports of conjunctivitis by non-regular participants, and the crosses stand for isolated reports of the disease by regular participants.

tablished in South Carolina and adjacent parts of North Carolina and Georgia. In these three latter states, 11% of all sites (n = 74) had diseased house finches (also see Fischer et al., 1997). If we interpolate the entire data set, we obtain two additional but isolated areas with conjunctivitis in the Southeast, one in eastern North Carolina, around the three locations shown on the map; and one reaching from eastern Georgia to westernmost Virginia, around the five locations shown on the map. Finally, farther west, the total data set contains three additional geographically isolated reports consisting of one from Wisconsin and two from Indiana.

Monthly change in prevalence from November 1994 to March 1997

Figure 4 shows quantitative changes in conjunctivitis prevalence in each region by month, based on the data reported by the regular participants only. The trajectories differed between for the four regions. In the mid-Atlantic region, prevalence increased somewhat and seemed to fluctuate seasonally, with minima in July and maxima in mid winter. In the Southeast region,

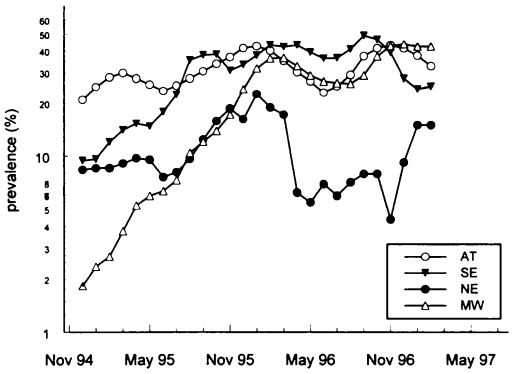

FIGURE 4. Comparison of conjunctivitis prevalence in house finches in four geographic regions (AT, mid-Atlantic; SE, Southeast; NE, Northeast; MW, Midwest) between November 1994 and March 1997. Plotted are the 3 mo running average of monthly prevalence values of regular participants.

prevalence increased rapidly, and by September 1995 had reached 51%. After that, it fluctuated with a new high value in October 1996 and a low value in January 1997. Prevalence increased slowly in the Northeast region with a maximum value in February 1996, but then prevalence decreased sharply with no diseased birds reported in December 1996. (Fig. 4 plots the 3 mo running average, so that the absence of diseased birds in a single month is not reflected). Finally, in the Midwest region, prevalence increased exponentially until February 1996 when it started to fluctuate seasonally, as in the mid-Atlantic region.

The above descriptions are relatively gross in that they describe quantitative changes in a fixed geographic area. An alternative way to describe the expansion of conjunctivitis is by mapping the disease. In Figure 5 we present interpolated surfaces of conjunctivitis prevalence in November and March in each of three winters using the same set of regular participants. The maps clearly show a rapid expansion of the disease from November 1994 to March 1995. By March 1995, the disease had expanded west and north covering most of New York and the southern half of Vermont and New Hampshire. However, it expanded most strongly toward the southwest, reaching northern Tennessee, with high prevalence values in West Virginia and Kentucky. A sufficient number of regular participants also reported conjunctivitis in Georgia and South Carolina, resulting in an isolated conjunctivitis region there. Three additional isolated locations of conjunctivitis were also detected in March 1995, two in North Carolina and one in Quebec.

By November 1995, house finches with conjunctivitis were reported from a wider range of states and provinces covering a region from southern Maine, Quebec, and Ontario in the north (by this point, the disease was well established north of the Great Lakes), to eastern Georgia in the south (with high prevalence values in South Carolina), to Michigan and Illinois in the west (with high prevalence values in Ohio). The nucleus in Kentucky expanded somewhat to include southern Illinois. Isolated reports stem from Iowa, Georgia and northern Florida.

The comparison of the March 1996 map to that for November 1995 shows the disease further expanding toward the south (Alabama, northwest Arkansas and Missouri) and a more complete coverage of the region between Kentucky and New York. Also conjunctivitis had almost completely disappeared from the northern part of the house finch's range. Healthy birds only occurred in northern New York, Vermont, New Hampshire, and Maine, although there remains an isolated report from Quebec. Also in eastern Ontario the disease seemed to be eradicated by March 1996.

By November 1996, conjunctivitis had spread west along the northern border of the range of the house finch, to become widespread in Wisconsin, southern Minnesota, and Iowa. At the same time, the range of the disease retracted somewhat in the Southwest and South, covering less of Missouri, Arkansas, Tennessee, and Alabama. During the winter, there again was some retraction of the conjunctivitis range

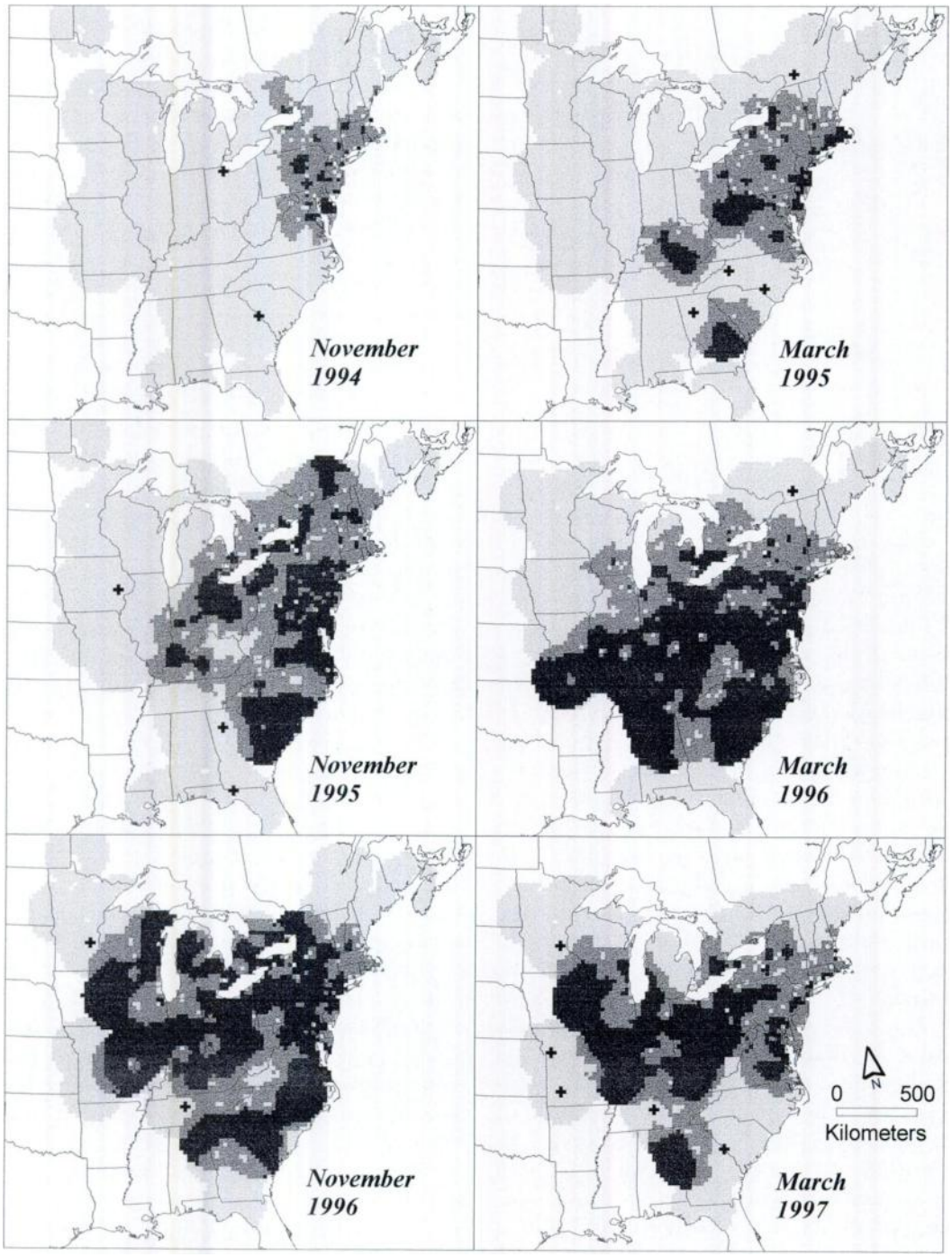

FIGURE 5. Distribution of conjunctivitis prevalence in house finches for each November and March of the 1994–1997 study period. The gray scale map is the interpolated surface (see text) of conjunctivitis prevalence based on "regular" participants; in light gray areas house finches were present and the prevalence was 0 to 5%, medium gray indicates a prevalence of 5 to 33%, dark gray is for a prevalence >33%, and crosses represent isolated reports of the disease.

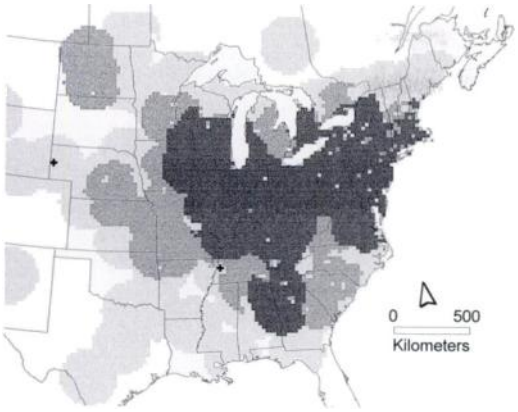

FIGURE 6. Distribution of conjunctivitis prevalence in house finches in March 1997 as calculated using reports of all participants; dark gray is for a prevalence of >5% using reports of "regular" participants only; medium gray represents a prevalence of >5% using reports of all reporting participants, including those from west of the study area, light gray areas show where house finches were reported, but prevalence <5% and crosses represent isolated reports of conjunctivitis in house finches.

in the north, with northern Wisconsin, peninsular Michigan, and Ontario becoming mostly disease-free by March 1997. There also is an apparent retraction in the Southeast. In Figure 6, we verify this result by using all the observations reported for March 1997, including the reports of the 59 participants reporting from the Great Plains states, 17 of which reported conjunctivitis. Figure 6 illustrates that by March 1997, conjunctivitis had actually spread still farther west, than reflected in data from regular participants alone. Conjunctivitis was reported from as far as North Dakota, Nebraska, and Kansas, and was still present in the Southeast. Although no participants from Texas reported diseased birds in March 1997, diseased birds were reported in Texas in February, March, April, and May 1996, and again in February 1997. This latter report came from McGregor (near Waco, Texas), where a bird with confirmed mycoplasmal conjunctivitis was obtained (P. Luttrell, pers. commun.) in April 1997.

If we omit a single isolated report from March 1996 in Nebraska, the disease seems to have reached the states to the north of Texas one winter later than when first reported in Texas. We had a report from North Dakota in October 1996 and reports from Nebraska and Kansas in November 1996. In these three states, participants reported diseased birds in almost every following month through March 1997. In March 1997 two of five participants in North Dakota, three of eight in Nebraska, and one of five in Kansas reported conjunctivitis.

Statistical analyses of changes in prevalence

To determine the statistical significance of the changes described above, we compared reports from the same observer between winters and during successive 2 mo periods (Table 2).

The prevalence increased very significantly ($P < 0.01$) in each region from winter of 1994–95 to winter of 1995–96, but it only increased significantly ($P < 0.05$) in the Midwest region from winter 1995–96 to winter 1996–97 (Table 2). The more detailed comparisons of successive 2 mo periods showed some differences in the patterns of change in the different regions (Table 2). Prevalence increased significantly overall and in two of four regions (not in the Midwest; $P < 0.1$ in the Northeast) from November–December 1994 to January–February 1995, indicating that the changes in geographic expansion illustrated in Figure 5 between November 1994 and March 1995 are important. Between January–February 1995 and May–June 1995 there was a non significant increasing trend in disease prevalence which reaches probability level of $P < 0.1$ in the mid-Atlantic region. From May–June to August–September of 1995 disease prevalence increased significantly in three of four regions, and overall, with an almost significant ($P < 0.1$) trend in the Northeast. The only later significant increases in prevalence are between November–December 1995 and January–February 1996 in the Midwest region, which reflected well what was seen when comparing the

TABLE 2. Comparison of mycoplasmal conjunctivitis prevalence in house finches using repeated observations by the same participants in different periods.

Time/Region[a]	n[b]	1-1[c]	1-2[c]	2-1[c]	2-2[c]	χ^2 1[d]	P[e]	% 1st period[f]	% 2nd period[f]
Winter 94–95 to winter 95–96									
AT	195	73	45	17	60	12.7	***	39.5	53.8
SE	55	25	17	3	10	9.8	**	23.6	49.1
NE	25	15	7	0	3	7.0	**	12.0	40.0
MW	178	111	56	3	8	47.6	***	6.2	36.0
All east	453	224	125	23	81	70.3	***	23.0	45.5
Winter 95–96 to winter 96–97									
AT	58	24	4	10	20	2.57		51.7	41.4
SE	11	3	2	2	4	0.00		54.5	54.5
NE	6	3	0	2	1	2.00		50.0	16.7
MW	42	13	9	1	19	6.40	*	47.6	66.7
All east	120	43	16	15	46	0.03		50.8	51.7
November–December 94 to January–February 95									
AT	414	256	48	28	82	5.26	*	26.6	31.4
SE	93	74	13	2	4	8.07	**	6.5	18.3
NE	47	42	3	0	2	3.00	°	4.3	10.6
MW	358	335	12	9	2	0.43		3.1	3.9
All east	912	707	76	39	90	11.9	***	14.1	18.2
January–February 95 to May–June 95									
AT	173	97	29	17	30	3.13	°	27.2	34.1
SE	47	32	2	7	6	2.78	° D	27.7	17.0
NE	24	20	2	1	1	0.33		8.3	12.5
MW	163	140	14	8	1	1.64		5.5	9.2
All east	407	289	47	33	38	2.45		17.4	20.9
May–June 95 to August–September 95									
AT	126	65	26	13	22	4.33	*	27.8	38.1
SE	33	15	11	2	5	6.23	*	21.2	48.5
NE	23	18	3	0	2	3.00	°	8.7	21.7
MW	132	104	15	5	8	5.00	*	9.8	17.4
All east	314	202	55	20	37	16.3	***	18.2	29.3
August–September 95 to November–December 95									
AT	116	52	17	13	34	0.53		40.5	44.0
SE	33	18	1	2	12	0.33		42.4	39.4
NE	15	8	2	1	4	0.33		33.3	40.0
MW	113	77	13	5	18	3.56	°	20.4	27.4
All east	277	155	33	21	68	2.67		32.1	36.5
November–December 95 to January–February 96									
AT	226	94	22	22	88	0.00		48.7	48.7
SE	74	35	10	8	21	0.22		39.2	41.9
NE	22	12	2	5	3	1.29		36.4	22.7
MW	208	121	28	12	47	6.40	*	28.4	36.1
All east	530	262	62	47	159	2.06		38.9	41.7
January–February 96 to May–June 96									
AT	119	53	8	23	35	7.26	** D	48.7	36.1
SE	47	13	9	8	17	0.06		53.2	55.3
NE	12	11	0	0	1	0.00		8.3	8.3
MW	145	76	16	23	30	1.26		36.6	31.7
All east	323	153	33	54	83	5.07	* D	42.4	35.9

TABLE 2. Continued.

Time/Region[a]	n[b]	1-1[c]	1-2[c]	2-1[c]	2-2[c]	χ^2 1[d]	P[e]	%1st period[f]	%2nd period[f]
May–June 96 to August–September 96									
AT	108	48	21	10	29	3.90	*	36.1	46.3
SE	45	9	8	8	20	0.00		62.2	62.2
NE	16	15	0	0	1	0.00		6.3	6.3
MW	143	76	23	20	24	0.21		30.8	32.9
All east	312	147	52	39	74	1.86		36.2	40.4
August–September 96 to November–December 96									
AT	73	28	11	9	25	0.20		46.6	49.3
SE	25	8	2	4	11	0.67		60.0	52.0
NE	4	4	0	0	0	0.00		0.0	0.0
MW	74	27	13	11	23	0.17		45.9	48.6
All east	176	66	26	24	60	0.08		47.7	48.9
November–December 96 to January–February 97									
AT	121	48	12	21	40	2.45		50.4	43.0
SE	33	12	3	9	9	3.00	° D	54.5	36.4
NE	8	6	1	1	0	0.00		12.5	12.5
MW	111	32	13	15	51	0.14		59.5	57.7
All east	274	98	29	46	101	3.85	* D	53.6	47.4

[a] Comparisons are between the periods indicated. The regions are defined in Table 1.
[b] n = number of participants.
[c] 1-1 is healthy birds only in both periods; 1-2 is healthy birds only in first period, conjunctivitis in second period; 2-1 is reverse; 2-2 is conjunctivitis in both periods.
[d] χ^2 value is from a McNemar test with one degree of freedom.
[e] *** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; ° = $P < 0.10$; D = decreased prevalence in second period.
[f] %1st period (%2nd) is prevalence in 1st (2nd) period, based on the observers included in this comparison only.

maps for November 1995 and March 1996 and between May–June and August–September 1996 in the mid-Atlantic region. Later comparisons yielded either no significant changes or significant decreases in prevalence. This was true for the comparison in the mid-Atlantic region between January–February 1996 and May–June 1996 and again for the comparison between November–December 1996 and January–February 1997 in both the mid-Atlantic and the Southeast regions. Again this statistical analysis validated the impression we obtained when comparing the maps for November 1996 and March 1997 (Fig. 5), where it appeared that the distribution of conjunctivitis has decreased.

In summary, between the winters 1994–95 and 1995–96 there was a significant increase in prevalence in house finch conjunctivitis caused both by a geographic expansion of the disease and by an increase in prevalence in the regions where already present. During the 1996–97 winter the disease became less prevalent in the Northeast, was decreasing in the mid-Atlantic and Southeast regions, but was further expanding toward the West.

The beginning of the epidemic

Ley et al. (1996), and Luttrell et al. (1996) reported the first case of a house finch with MG in February 1994 in suburban Washington D.C. House finches with conjunctivitis were observed at a feeder in Montgomery County (Maryland), just north of Washington D.C. beginning 20 January 1994 (J. Cook, pers. commun.). There were others who also observed diseased house finches in that part of Maryland soon after that, suggesting a possible epidemic. The studies of Ley et al. (1997) indicated very strongly that a single new slow growing strain of

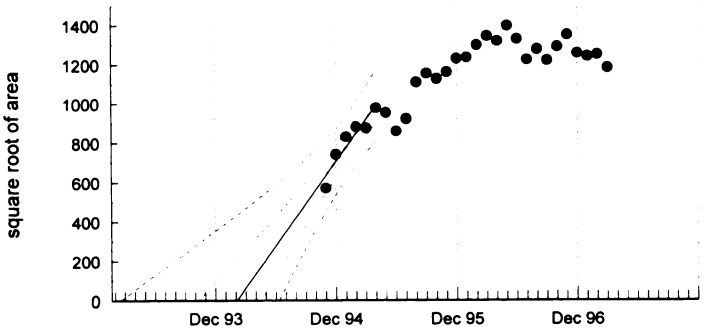

FIGURE 7. Regression of square root of area (in km^2) covered by conjunctivitis in house finches against month. The surface areas are based on interpolated maps for each month of the survey. The regression equation calculated through the first six months of the survey is $\sqrt{\text{-area}} = 562.1 \pm 49.56 + 71.4 \pm 12.73^{*}$ mo and the slope is significantly different from zero ($t = 5.61$, d.f. = 4, $P < 0.01$). The regression line intersects the x-axis in February 1994. The confidence intervals (CI) shown are the 95% and the 75% CI.

MG is causing mycoplasmal conjunctivitis in house finches and American goldfinches (*Carduelis tristis*). These observations suggested suburban Washington D.C. as the area where house finch mycoplasmal conjunctivitis first became apparent.

According to Hengeveld (1989), the square root of the area of an epidemic is a linear function of time. Therefore, we can use our monthly estimates of the geographic area covered by the disease to estimate the date when the epidemic started by extrapolating backwards. We plotted (Fig. 7) the square root of the area covered by the disease, based on the interpolated surfaces for each month starting in November 1994. During the initial 6 mo of the survey, the geographic region covered by the disease increased in a linear fashion. The rate of increase decreased during the summer of 1994 and increased again during fall and winter. By June 1996, the pattern became irregular and leveled off. The backward extrapolation using data from the initial 6 mo of the survey intercepted the x-axis in February 1994. The 95% confidence interval was between March 1993 and June 1994. This calculation suggested that this new disease arose sometime during the 1993–94 winter, although it could have started as early as March 1993 or as late as June 1994. The lower 75% confidence limit, also shown on the graph, was November 1993.

Absence of house finches

Although what proportion of house finches die as a result of conjunctivitis is unknown, we assumed that birds that become blind and debilitated have a reduced survival, especially during cold winters. Several participants reported that cats took diseased birds under feeders. One way to evaluate if house finches died as a result of becoming infected with MG was to compare the proportion of participants who reported not seeing any house finches between early and late winter. If a high prevalence of MG combined with cold winter weather caused a decline in house finch abundance during winter, the proportion of participants who did not see any house finches should increase from November–December to January–February. We arbitrarily designated a MG prevalence value of >20% as high and considered winters to be cold in all regions except the Southeast. By these criteria, we expected that the proportion of participants who reported house finches in November–December and not during January–February should be higher in six region/winters with cold winters and high prevalence but not in the other six (Table 3). In the former group, 82 participants observed house finches in early winter, but not in late winter, compared to 19 in which the reverse was true. In the latter group,

TABLE 3. Comparison of the number of participants who DID NOT observe house finches in November–December (% early) to the number of participants who did not observe house finches in January–February of the same winter (% late) using only repeated observations of the same participants.

	N-N[a]	N-Y[a]	Y-N[a]	Y-Y[a]	χ^2 1[b]	P[c]	% Early	% Late	Prediction[d]
All east									
1994–1995	111	35	49	912	2.33		13.2	14.5	
1995–1996	74	7	54	530	36.2	***	12.2	19.2	
1996–1997	20	4	21	263	11.6	***	7.8	13.3	
Mid–Atlantic region[f]									
1994–1995	14	9	16	414	1.96		5.1	6.6	+
1995–1996	8	2	15	226	9.94	**	4.0	9.2	+
1996–1997	3	3	9	115	3.00		4.6	9.2	+
Southeast region[f]									
1994–1995	12	5	3	93	0.50		15.0	13.3	−
1995–1996	5	0	1	74	1.00		6.3	7.5	−
1996–1997	5	0	3	32	3.00		12.5	20.0	−
Northeast region[f]									
1994–1995	40	6	8	47	0.29		45.5	47.5	−
1995–1996	29	1	10	22	7.36	**	48.4	62.9	+
1996–1997	2	1	5	8	2.67		18.8	43.8	−
Midwest region[f]									
1994–1995	45	15	22	358	1.32		13.6	15.2	−
1995–1996	32	4	28	208	16.0	***	13.2	22.1	+
1996–1997	10	0	4	107	4.00	*	8.3	11.6	+

[a] N-N = no house finches observed in both periods; N-Y = no house finches observed in first period, house finches seen in second period; Y-N = reverse; Y-Y = house finches observed in both periods.
[b] The χ^2 value is from a McNemar test with one degree of freedom.
[c] Significance levels as in Table 2.
[d] + represents a predicted increase, and − represents no such prediction (also see text).
[f] Regions are defined in Table 1.

the numbers were 42 and 27, a statistically significant difference ($\chi^2_1 = 8.57$, $P = 0.003$; χ^2-test for two independent samples, Siegel, 1956). Applying a McNemar test (see methods) to each region/winter separately we observed that in four of the six region/winters in which we expected an increase in the proportion of participants who no longer had house finches at the feeders in the second half of winter (prediction "+" in Table 3), the increase was statistically significant (Table 3). In none of the six region/winters in which we expected no increase (prediction "−" in Table 3) was the change significant. Therefore, our results are consistent with the hypothesis that in cold regions, MG increased the mortality of house finches during winter, compared to regions without MG.

DISCUSSION

When did the epidemic start?

Mycoplasmal conjunctivitis in house finches was first reported in early 1994 from the region in and around Washington D.C. (Fischer et al., 1997). The information available at present supports suburban Washington D.C. as being the area where mycoplasmal conjunctivitis first became apparent. There are three arguments why we believe the conjunctivitis epidemic in house finches began in the winter of 1993–94. First, the extrapolation from our survey results (Fig. 7) suggested that the disease started in February 1994. However,

the confidence interval is rather broad, and we could not exclude the possibility that the epidemic began as early as the summer 1993. Second, at the start of the survey in November 1994, 19% of the participants in the mid-Atlantic region reported conjunctivitis. How long did it take for prevalence to increase to 20%? Using the regular participants only, we determined the disease was just appearing in November 1994 in Ontario and Ohio. By September 1995, 10 mo later, prevalence had reached 22%. In three other states, conjunctivitis had not been reported by November 1994. Prevalence rose from 0% to approximately 20% after 9 mo in Indiana, 14 mo in Illinois, and 19 mo in Wisconsin. Based on our data, conjunctivitis prevalence in a large area the size of a state or province could reach 20% within 1 yr. However, in some states it appears to take somewhat longer. A third and final reason is that analyses of banding recoveries (Stewart, 1989; Hamilton, 1991) indicated that a large proportion of house finches from New York, Pennsylvania, and the Midwest undertake long-distance migratory movements. House finches banded during the breeding season in northern states have been recovered during winter in Tennessee, Alabama, Georgia, and South Carolina at more than 1,000 km from their banding site. Similarly, birds banded during winter in Tennessee were recovered during the breeding season in Illinois, Wisconsin, Pennsylvania, and New York. Hamilton (1991) concluded that there existed "strong north-south movements of house finches with seasonal changes." Belthoff and Gauthreaux (1991), also analyzing banding data, concluded that house finches in the east have become partially migratory, that fall migration occurs mainly in October and early November and spring migration takes place mainly in March and early April. *Mycoplasma gallisepticum* initially spread mainly northward from the Washington D.C. area (Fig. 8). This suggests strongly that birds became infected on their wintering grounds and carried the disease with them on their northward migration back to the breeding grounds. If the disease had originated during the 1993 breeding season, it seems unlikely that, in October 1994, MG would have been present between North Carolina and Massachusetts but would not have reached South Carolina and Georgia (Fischer et al., 1997).

Expansion of conjunctivitis through migration and dispersal

Assuming that the MG epidemic was spread mainly (or only) by house finches, we expected that the disease would have spread toward the Southwest in the fall and toward the Northeast in spring. However, the epidemic also spread very rapidly to the west, (Fig. 8). This suggested that house finches moved considerable distances in all directions, including the west and even the north. It is likely that these movements were made mainly by juveniles during their first summer and fall (Hill, 1993). Perhaps such movements are related to the range expansion (that has continued for the last 50 yr; Hill, 1993), of this introduced species whereby movements in all directions could have been advantageous.

Costs and benefits of citizen science

In citizen science projects volunteer members of the public participate in the collection of large data sets over extensive geographic regions following a single observational protocol (Bonney and Dhondt, 1997). Our study illustrated how such projects can generate valuable data that cannot be obtained in any other way. Because our participants reported birds both with and without conjunctivitis (or even no birds at all) it was possible to calculate a measure of disease prevalence and hence follow, in a very detailed fashion, how this new infectious agent swept through the population of a new host. The measure of prevalence used here was affected by a variety of factors such as the number of birds at a feeder, the observation intensity of a participant, and the likelihood that a par-

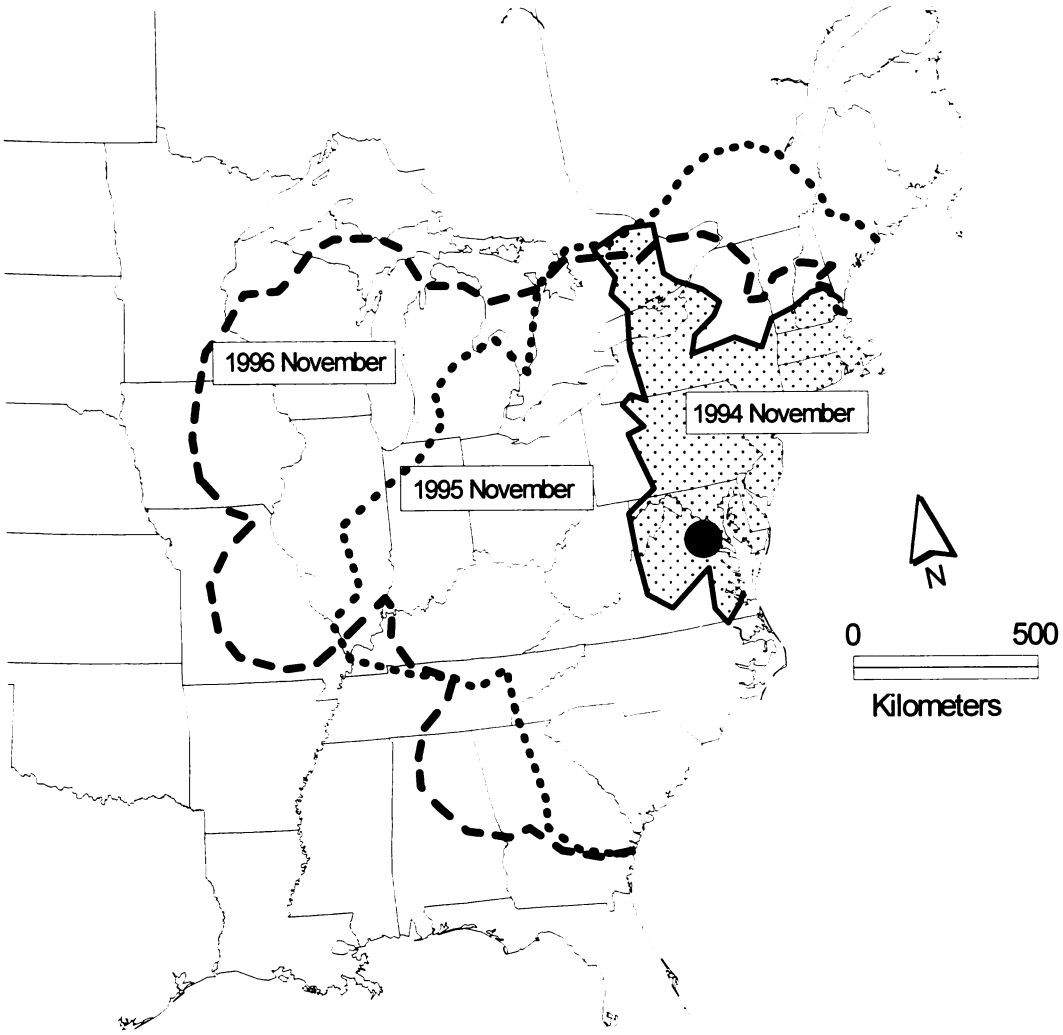

FIGURE 8. Map showing the range limits of the conjunctivitis epidemic in house finches for each November of the study based on reports from regular participants, where the black dot indicates the approximate origin of the epidemic in the winter 1993–94; the stippled area shows the distribution of conjunctivitis in November 1994; the dotted line delineates the limit of conjunctivitis in November 1995; and the dashed line represents the limit of conjunctivitis in November 1996.

ticipant recognized the clinical signs. Nevertheless, we found a significant correlation between the percentage of diseased house finches captured at one location and the disease prevalence in the same state (Fig. 2). This strongly suggested that the variations in disease prevalence in time and space reported by our survey reflected actual changes in the proportion of the eastern house finch population suffering from mycoplasmal conjunctivitis. Data from volunteer participants, most of which have little or no formal scientific training, needed to be handled carefully and critically. Participants might have been unable to distinguish between the clinical signs of mycoplasmal conjunctivitis and those caused, for example, by avian pox; or participants might simply have reported uncritically or made simple mistakes (such as filling in a bubble on the data form in the wrong column). That is why we requested

our participants to describe in detail the clinical signs they observed and why each description was evaluated before being entered into the database. That is also why we analyzed the data conservatively: when we mapped disease prevalence by interpolation, we excluded outliers.

Another problem with using volunteer participants is that not all participants reported for each month. Although we could use data from all participants to describe the situation in one particular month (as in Fig. 6), we clearly could not use the data from all the participants to measure the rate at which the epidemic spread. Therefore, when we calculated the rate of disease expansion, we used a subset of the data provided by regular participants only. All in all, we believe that such data, if handled carefully and critically, provide an invaluable source of information.

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LITERATURE CITED

BELTHOFF, J. R., AND S. A. GAUTHREAUX, JR. 1991. Partial migration and differential winter distribution of house finches in the eastern United States. Condor 93: 374–382.

BONNEY, R., AND A. A. DHONDT. 1997. FeederWatch: an Example of a Student-Scientist Partnership. *In* Internet Links for Science Education: Student-Scientist Partnerships. K. C. Cohen (ed.) Plenum Press, New York, New York, pp. 31–53.

ELLIOT, J. J., AND R. S. ARBIB, JR. 1953. Origin and status of the house finch in the eastern United States. Auk 70: 31–37.

FISCHER, J. R., D. E. STALLKNECHT, M. P. LUTTRELL, A. A. DHONDT, AND K. A. CONVERSE. 1997. Mycoplasmal conjunctivitis in wild songbirds: the spread of a new contagious disease in a mobile host population. Emerging Infectious Diseases 3: 69–72.

HAMILTON, T. R. 1991. Seasonal movement of house finches in the midwest. North American Bird Bander 16: 119–122.

HENGEVELD, R. 1989. Dynamics of biological invasions. Chapman and Hall, London, U.K., 160 pp.

HILL, G. E. 1993. House finch (*Carpodacus mexicanus*). *In* The Birds of North America, No. 46, A. Poole and F. Gill (eds.). The Academy of Natural Sciences. Philadelphia; The American Ornithologists' Union, Washington, D.C., pp. 1–24.

LEY, D. H., J. E. BERKHOFF, AND J. M. MCLAREN. 1996. *Mycoplasma gallisepticum* isolated from house finches (*Carpodacus mexicanus*) with conjunctivitis. Avian Diseases 40: 480–483.

———, ———, AND S. LEVISOHN. 1997. Epidemiologic investigations of *Mycoplasma gallisepticum* conjunctivitis in songbirds by Random Amplified Polymorphic DNA analyses. Emerging Infectious Diseases 3: 375–380.

LUTTRELL, M. P., J. R. FISCHER, D. E. STALLKNECHT, AND S. H. KLEVEN. 1996. Field investigations of *Mycoplasma gallisepticum* infections in house finches (*Carpodacus mexicanus*) from Maryland and Georgia. Avian Diseases 40: 335–341.

SIEGEL, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Kogakusha, Ltd. Tokyo, Japan, 312 pp.

SNYDER, J. P. 1987. Map Projections—A Working Manual. U.S. Geological Survey Professional Paper 1395. United States Government Printing Office, Washington D.C., 383 pp.

SOKAL, R. F., AND F. J. ROHLF. 1981. Biometry, 2nd edition. Freeman and Company, New York, New York, 859 pp.

STEWART, P. A. 1989. Movements of house finches banded in New York and Pennsylvania. North American Bird Bander 14: 118–119.

VEIT, R. R. AND M. A. LEWIS. 1996. Dispersal, population growth, and the Allee effect: Dynamics of the house finch invasion of eastern North America. American Naturalist 148: 255–274.

WHITEMAN, C. E. AND A. A. BICKFORD. 1989. Avian disease manual. 3rd Edition. Kendall/Hunt Publishing Company, Dubuque, Iowa, 242 pp.

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