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AVIAN WILDLIFE MORTALITY EVENTS DUE TO SALMONELLOSIS IN THE UNITED STATES, 1985–2004

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ABSTRACT: Infection with *Salmonella* spp. has long been recognized in avian wildlife, although its significance in causing avian mortality, and its zoonotic risk, is not well understood. This study evaluates the role of *Salmonella* spp. in wild bird mortality events in the United States from 1985 through 2004. Analyses were performed to calculate the frequency of these events and the proportional mortality by species, year, month, state, and region. Salmonellosis was a significant contributor to mortality in many species of birds; particularly in passerines, for which 21.5% of all mortality events involved salmonellosis. The proportional mortality averaged a 12% annual increase over the 20-yr period, with seasonal peaks in January and April. Increased salmonellosis-related mortality in New England, Southeastern, and Mountain-Prairie states was identified. Based on the results of this study, salmonellosis can be considered an important zoonotic disease of wild birds.

Key words: Avian disease, avian mortality, avian salmonellosis, epidemiology, *Salmonella*, songbird fever.

INTRODUCTION

The importance of avian wildlife in maintaining or transmitting zoonotic pathogens (e.g., West Nile virus, avian influenza virus) has increasingly been recognized by both wildlife and public health officials. Bacteria within the genera *Salmonella* are known to cause disease in humans, domestic animals, and wildlife, although their relative importance to wildlife populations, and the public health risks associated with wildlife salmonellosis, are not as well understood. Wild birds are recognized to be *Salmonella* carriers, particularly of *S. enterica* subsp. *enterica* serovar Typhimurium (*S.* Typhimurium; Friend and Franson, 1999; Pennycott et al., 2006). However, large-scale die-offs of birds in the United States and other countries associated with *Salmonella* spp. have been reported (Pennycott et al., 2002). All bird species are considered susceptible to *Salmonella* spp. infection, but the outcome of infection depends on variables such as host species susceptibility, host age, concurrent stresses, and serovar and strain virulence (Friend and Franson, 1999; Connolly et al., 2006).

Although most immunocompetent birds exhibit no clinical signs, those that do typically die. Clinical signs can include rapid breathing, neurologic dysfunction, drooping wings, diarrhea, ruffled feathers, severe lethargy, and arthritis (Friend and Franson, 1999). Gross lesions of affected birds may include: yellow, caseous nodules or plaques in the esophagus; a swollen, crumbly liver with nodules or spots; and pale, fibrinous material adhered to the intestinal lining (Mikaelian, et al., 1997; Friend and Franson, 1999). Bacterial culture to isolate and identify species and serovar of *Salmonella* may also be utilized to definitively diagnose disease.

Since the 1980s, the US Geological Survey National Wildlife Health Center (NWHC) has maintained a database that houses information on wildlife mortality events that have occurred throughout the United States, both those investigated by the NWHC and those reported by collaborating wildlife officials and other laboratories. The database can be used to track

mortality events temporally, geographically, and by species, enabling wildlife managers to, among other things, make important decisions on disease control and prevention and to determine areas of future scientific investigation. The data collected include locations, dates, species involved, pertinent history, number sick and dead, and available diagnostic information. The objectives of this study were to evaluate the role of *Salmonella* spp. in avian wildlife mortality events and to identify spatial and temporal trends of avian wildlife mortality events involving *Salmonella* spp. from 1985 through 2004.

MATERIALS AND METHODS

The NWHC database was searched for all avian mortality events that occurred within the United States from 1985 through 2004, and those events which involved *Salmonella* spp. as the primary or secondary cause of the mortality event were identified. Data from active West Nile surveillance during 2000–2004 was excluded, although the initial mortality event identified in 1999 was included because these data were obtained through the same passive reporting system as all other mortality events. Descriptive analyses were performed using Epi Info v3.3.2 (CDC, Atlanta, Georgia, USA), and the frequency of *Salmonella* mortality events was determined by year, month of onset, state, migratory flyway (US Fish and Wildlife Service [FWS], 2003) and FWS region (FWS, 2001). In addition, since multiple species were often associated with any given mortality event, the frequency of each species identified was calculated to determine the number of these events in which each species was involved. Proportional mortality was determined by comparing salmonellosis-related events to all causes of avian wildlife mortality events. Multivariate logistic regression, using SAS v9 (SAS Institute, Inc., Cary, North Carolina, USA), was performed to examine the association between the proportional mortality and the following factors of interest: year, month of onset, flyway, and FWS region. Associations were tested with Type 3 deviance tests. Adjusted estimates for proportional mortality, year, onset month, flyway, and FWS region were obtained by appropriate back-transformation (i.e., point intervals and confidence intervals were originally reported on the logit and log scales by the software and then back-transformed to proportions and counts, respectively).

RESULTS

The search of the NWHC database yielded 3,472 avian wildlife mortality events in the US between 1985 and 2004. The total estimated number of dead birds reported during this period was over 4.5 million. Of the 3,472 total events, 186 (5.4%) were classified as avian wildlife *Salmonella*-related mortality events. Mortality in these events ranged from one to 11,888 (median 38) wild bird deaths per event. Over 68,000 wild bird deaths were estimated to result from these salmonella-related mortality events, representing 98 species from 12 orders. The unadjusted proportional mortality of salmonellosis among all avian wildlife mortality events varied among these 12 orders (Fig. 1). Species primarily affected were passerines, colonial nesting birds, and waterfowl, although one event involved a hawk. An average of 2.7 different species were involved in each event (range: 1–24), with 110 events involving multiple species. Passerines were the primary species affected, and in far more *Salmonella*-related events ($n=129$) than any other bird group, although some passerine events also involved piciformes ($n=4$) or columbiformes ($n=5$) in smaller numbers. In events where passerine species were identified, 47 (36.4%) events involved only fringillids (most commonly siskins, finches, redpolls), while another 28 (21.7%) events involved fringillids and other passerine species. Of the events involving passerines, 75 (58.1%) were associated with mortality at bird feeders or feeding areas, with another seven (5.4%) possibly linked to feeding birds.

Colonial nesting birds were the primary species affected in 50 events, although some of these also included passerine species ($n=1$) and waterfowl ($n=11$) in smaller numbers, and three events involved mostly waterfowl, although some colonial nesting species were also affected. Of the events involving colonial nesting birds, eight (16%) reported involving only the young-of-the-year and juveniles.

Passerines represented seven of the top

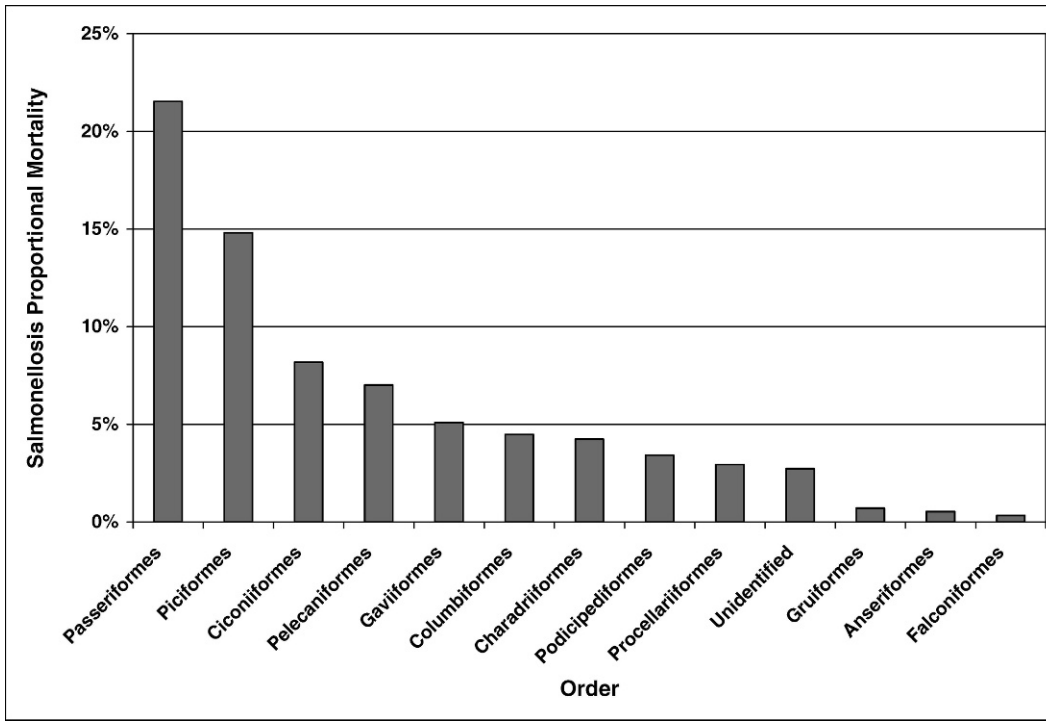

FIGURE 1. Salmonellosis proportional mortality, by order, in 3,472 avian wildlife mortality events in the United States from 1985–2004.

10 species involved in *Salmonella*-related events, and relative to all causes of mortality events, salmonellosis was a great contributor to mortality in these species (Table 1). Proportional mortality, by order, revealed that *Salmonella* was involved in 21.5% of all passerine mortality events (Fig 1).

A specific *S. enterica* serovar was identified and reported by a laboratory in 107 (57.5%) events. The serovar most commonly identified was *S. e.* Typhimurium (n=96). Other serotypes included *S. e.* Litchfield ($n=1$), *S. e.* Rubislaw ($n=1$), *S. e.* Typhi (n=1), *S. e.* Uganda ($n=1$), and 4,5,12:i-monophasic ($n=7$).

TABLE 1. The most commonly identified bird species in 186 avian wildlife *Salmonella*-related mortality events (AWSME) in the US from 1985 through 2004, with salmonellosis proportional mortality.

Common name	Scientific name	No. AWSME Events (%)	Proportional Mortality
Pine Siskin	*Carduelis pinnus*	54 (29.0%)	83.1%
American Goldfinch	*Carduelis tristis*	32 (17.2%)	65.3%
Northern Cardinal	*Cardinalis cardinalis*	32 (17.2%)	58.2%
House Sparrow	*Passer domesticus*	26 (14.0%)	35.1%
Evening Grosbeak	*Coccothraustes vespertinus*	23 (12.4%)	88.5%
Brown-headed Cowbird	*Molothrus ater*	20 (10.8%)	39.2%
Ring-billed Gull	*Larus delawarensis*	20 (10.8%)	10.8%
Double-crested Cormorant	*Phalacrocorax auritus*	15 (8.1%)	9.6%
American White Pelican	*Pelecanus erythrorhynchos*	14 (7.5%)	7.9%
Common Redpoll	*Carduelis flammea*	11 (5.9%)	84.6%

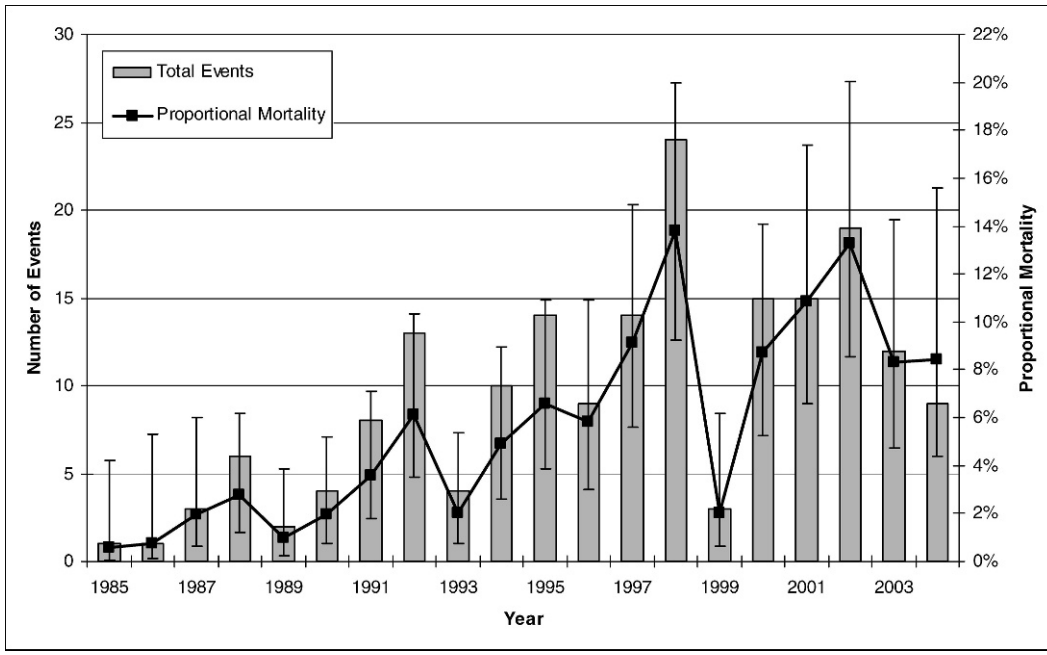

FIGURE 2. Annual avian wildlife *Salmonella*-related mortality events in the United States, and proportional mortality, 1985–2004 (error bars represent 95% confidence interval).

The multivariate analysis identified some significant spatial and temporal associations between *Salmonella*-related events and proportional mortality. The annual trend over the 20-year period showed a 12% increase in the proportional mortality (95% confidence interval=8–16%; Fig. 2). Although events occurred year-round, seasonality trends of event onset were also identified. Events involving passerines increased in November through May, with a peak in January, while events involving colonial nesting birds and waterfowl increased from June through August, with a peak in July. When adjusted for both the annual trend and the monthly fluctuations in reporting, peaks were identified for January and April (Fig. 3).

On examination of adjusted proportional mortality, no statistically significant differences in frequency or proportional mortality were noted among the four North American migratory flyways ($P>0.05$), nor among the FWS regions ($P>0.05$; Table 2). However, the Southeast and Mountain-Prairie regions had elevated proportional mortality values, while those of the Northeast region were lower. No obvious spatial trends in frequency were identified by state. The states most frequently reporting salmonella-related avian mortality events were as follows (Fig. 4a): California ($n=21$), Georgia ($n=20$), Wisconsin ($n=15$), North Dakota ($n=9$), Texas ($n=8$), Colorado and Washington ($n=7$ each), and Utah, Montana, and Florida ($n=6$ each). States with the highest proportional mortality were as follows (Fig. 4b): Vermont (33.3%), New Hampshire (20.0%), Georgia (16.1%), Colorado (13.7%), Alabama (13.0%), Massachusetts (13.0%), Tennessee (11.1%), Washington (10.1%), Michigan (9.7%), and Indiana (n=9.1%). These findings were consistent with the regional variations identified amongst FWS regions.

DISCUSSION

Based on this study's analyses, salmonellosis can be considered an important

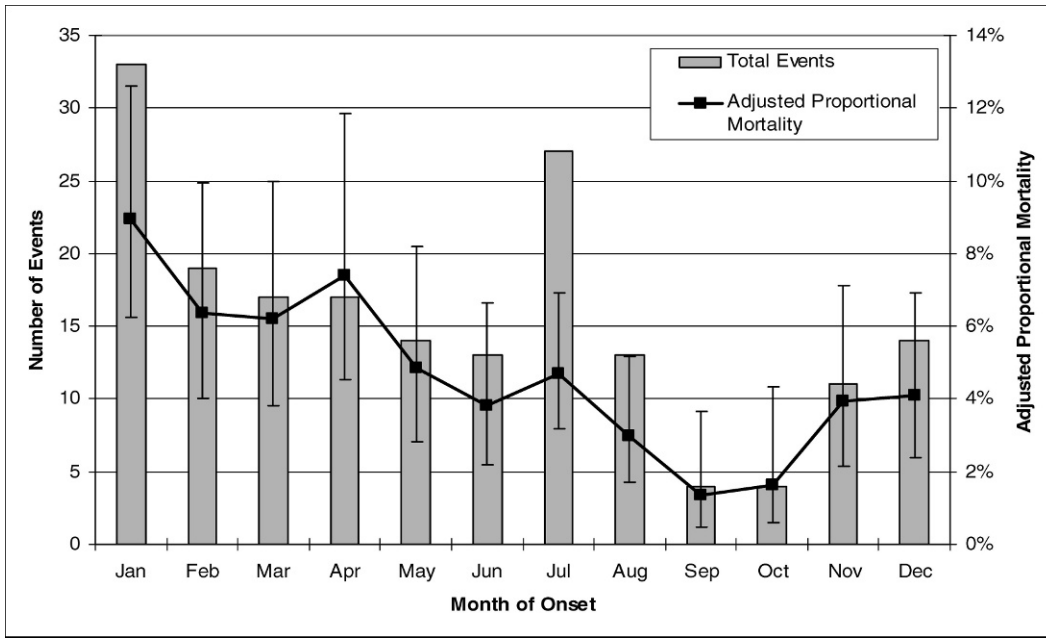

FIGURE 3. Avian wildlife *Salmonella*-related mortality events, by month, and proportional mortality adjusted for annual variations in the United States, 1985–2004 (error bars represent 95% confidence interval).

wild bird disease. With nearly 100 avian species from 12 avian orders identified in *Salmonella*-related mortality events, this disease appears to affect a wide range of birds. Furthermore, this study documents numerous bird species for which salmonellosis is involved in over half of the mortality events reported, supporting the significance of this disease in certain avian species. In addition to species susceptibility and organism virulence, species-specific avian ecology likely helps to explain some of the observed variations in frequency and proportional mortality. Since the likely route of transmission between wild birds is fecal-oral, social and feeding behavior may relate to the differences in frequency of fatal infection. Additional research is necessary to better understand the differences observed in this study.

Since data in the epizootic database were mostly obtained through passive reporting, there is the potential for reporting bias to affect the results. Mortality events entered into the database are limited to those in which a formal investigation was performed and to those for which an authoritative source could confirm the reports. In addition, no standard protocol is followed for reporting

TABLE 2. Frequency of 186 avian wildlife *Salmonella*-related mortality events (AWSME) in the US, 1985–2004, with salmonellosis proportional mortality adjusted for annual variation by migratory flyway and US Fish and Wildlife Service (FWS) Region[a].

Geographic Units	No. AWSME	Adjusted Proportional Mortality	95% Confidence Interval
Flyway			
Atlantic	47	4.4%	3.2–5.9%
Pacific	49	4.6%	3.4–6.1%
Mississippi	46	4.6%	3.4–6.2%
Central	44	5.2%	3.8–7.1%
FWS Region[a]			
Pacific	36	4.2%	3.0–5.8%
Southwest	15	4.8%	2.9–8.0%
Great Lakes	33	4.3%	3.0–6.1%
Southeast	42	6.0%	4.3–8.3%
Northeast	18	3.0%	1.9–4.8%
Mountain	40	6.0%	4.4–8.3%
Alaska	2	4.7%	1.1–17.7%

[a] FWS regions, as identified on http://www.fws.gov/where/, accessed 18 April 2006.

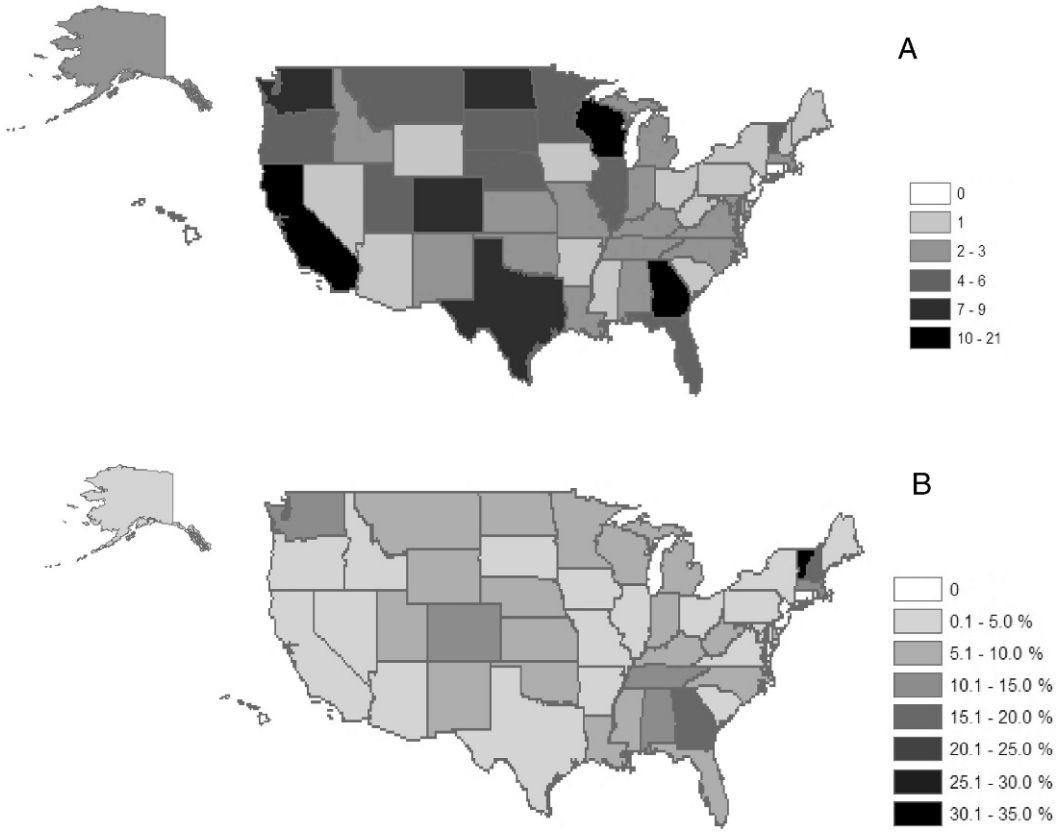

FIGURE 4. A) Frequency of avian wildlife *Salmonella*-related mortality events in the United States, 1985–2004 ($n=186$); B) Unadjusted proportional mortality rates in avian wildlife, by state, in the United States, 1985–2004.

or investigating wildlife mortality events (ProMed-mail 1998 and 2000). The inconsistency includes the variety of possible methods in which the salmonellosis diagnosis may have been made: based on gross necropsy lesions; culture of specific tissues or lesions; and the amount of laboratory diagnostic assays performed for sub-typing. In recent years, there were a number of bird feeder-related mortality events in the United States attributed to salmonellosis, but laboratory confirmation of the etiology of the mortality was not always clear (ProMed-mail, 1998, 2005a, 2005b). In addition, some bird species may be more likely to be reported (i.e., are more easily identified, more aesthetically valued). By standardizing the reported number of *Salmonella*-related events across each factor of interest with the reported number of mortality events from all causes, the potential effects of reporting bias have been reduced in this study. Nonetheless, the importance of salmonellosis in wild bird populations is likely underestimated, as this study included only reports in which *Salmonella* spp. infection was considered to have caused, or played an important role in, the wild bird mortality events, but did not include all events in which *Salmonella* spp. infection may have been detected but not deemed to have been the cause of the mortality events.

Although not statistically significant when adjusted for year, month of onset, and flyway, spatial analyses identified two FWS regions of the country with increased

proportional mortality: the Southeast and Mountain-Prairie. In addition, contrary to the whole region, individual states of the Northeast also were found to have an increased proportional mortality. For many of the states in these areas, the increased proportional mortality may be explained by significant human population growth over the 20-year study period and the resulting pressures on wildlife populations. Expansion of human populations, and the correlated increased urbanization leading to decreased wildlife habitat, may increase contact between birds and thereby increase opportunities for disease spread. Another explanation is that the observed spatial trends are confounded by species distribution, and the areas with increased proportional mortality simply provide the habitat for the species most commonly affected. The popularity of bird feeders and feeding areas in now-residential areas may serve as a major factor, both in promoting spread of disease within certain species and in detecting wild bird mortality events. Additional investigation is necessary to better explore these observed trends.

No obvious reason could be found to explain the decrease in proportional mortality in 1999, relative to preceding and following years, as shown in Fig. 2. Further investigation into environmental data, including climate and other factors, is needed for a better understanding of the observed difference. In addition, it does not appear that the arrival and rapid spread of West Nile virus (WNV) into the continental United States affected the proportional mortality subsequent to 1999. However, for this analysis, we did not include among our mortality events the reports of dead wild birds to the national WNV surveillance program; they were excluded because of the differences in data collection and reporting, wherein the reported WNV-surveillance mortality was not defined in the same manner as the other mortality events in the database. Because of the broad surveillance program, and the manner in which the data were reported and recorded, it would have been difficult, inefficient, and inaccurate to attempt to separate the annual database information into separate reports that would correctly represent each reporting geographic region and the number of times each state was affected.

The observed seasonality is similar to that reported previously for birds in North America and in several European countries. Although salmonellosis-related mortality events in wild birds in the United States have been summarized previously (Friend and Franson, 1999; Hudson et al., 2000), this is the first known report that presents long-term data to support the generally accepted epidemiology. In Norway, outbreaks occur primarily in the winter, with peak occurrence in February and March (Refsum et al., 2003). In Great Britain, finch mortality due to salmonellosis mostly occurred from January through March, while that of House Sparrows (*Passer domesticus*) occurred from October through March (Pennycott et al., 2006). However, as evidenced by our findings, mortality events involving salmonellosis may occur year-round, as has been reported in New Zealand (Alley et al., 2002), Norway (Refsum et al., 2003), and the Canadian Atlantic provinces (Daoust et al., 2000).

The increase in passerine mortality, due to salmonellosis during the winter months, may represent a true increase. However, almost two thirds of the reports in passerines were mortality events occurring near bird feeders, and it is possible that because of environmental conditions, including limited availability of food in many areas, feeders may be used mostly in the winter. This may lead to increased observation and subsequently increased probability of detection during this time. The seasonality of events in colonial nesting birds is likely related to the population density of the birds and the increase in the susceptible population during the nesting season (Friend and Franson, 1999).

Because wild birds can act as inapparent carriers, the potential public health impacts of salmonellosis may be underestimated. Human *Salmonella* outbreaks have been potentially linked to direct and indirect contact with wild birds (Penfold et al., 1979; Kramer et al., 1996; Kapperud et al., 1998; Tauni and Österlund, 2000; Alley et al., 2002; Refsum et al., 2002; Nesse et al., 2005; Palmegren et al., 2006). Surveillance of wild bird populations and investigation of wild bird mortality events may yield useful information in characterizing and reducing human risk of wild bird-related salmonellosis. Genotype and antibiotic resistence patterns of *Salmonella* isolates from free-ranging wild birds in the southeastern United States suggest the strains found in wild birds are a potential threat to human populations (Hudson et al., 2000). More studies are needed to explore the potential of using wild birds as sentinels and to identify any potential public health risks posed by this wild bird disease.

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