The Impact of West Nile Virus on Ohio Birds

By Laura C. Gooch

2845 Scarborough Road
Cleveland Heights, OH 44118
lgooch@alum.mit.edu

West Nile virus came to the attention of the North American ornithological community in 1999, when it caused significant mortality among birds in the New York City area (Kilpatrick *et al.* 2007). The virus also made newspaper headlines that year when it caused significant illness in 62 people and led to seven deaths (Komar 2003). Over the next five years as West Nile virus spread across North America, the presence of dead birds was used by public health officials to track the advance of the disease (Brault *et al.* 2004, Eidson *et al.* 2001, Hayes *et al.* 2005). In response to the obvious mortality among members of some species, ornithologists began to assess the effects that the virus might be having on susceptible populations. In an effort to determine whether West Nile virus has had a lasting impact on Ohio birds, I compared count numbers for five selected species before and after the arrival of West Nile virus in the Cleveland area, in Ohio as a whole, and in the United States as a whole.

Background

Virus Life Cycle

West Nile virus (WNV) is a mosquito-borne virus that infects humans, some other mammals, birds, and mosquitoes. Birds and mosquitoes are the primary carriers of the disease. Some birds bitten by infected mosquitoes temporarily develop sufficient concentrations of virus in their blood to transmit the virus to uninfected mosquitoes, which in turn bite and infect other birds. If a bird survives WNV, virus levels in its blood subside after a few days to a low enough level that it can no longer transmit the virus. In addition, surviving birds carry antibodies that make them immune to further infection. Humans and some other mammals may also become infected when they are bitten by infected mosquitoes but rarely carry enough virus to pass the infection on to an uninfected mosquito (CDC 2009a, Hayes *et al.* 2005).

Symptoms and Mortality

Symptoms of WNV in humans may include fever, headache, fatigue, and, more rarely, a rash, eye pain, or swollen lymph glands. An estimated 80% of those infected exhibit no symptoms (CDC 2004). Symptoms in birds include lethargy, ruffled feathers, unusual posture, inability to hold the head upright, and uncoordinated movement (Komar *et al.* 2003). More than 300 species of native and exotic birds have been reported as infected in the United States (CDC 2009b). The degree of illness in birds varies widely from species to species. In laboratory studies, WNV caused no mortality in about two-thirds of species studied (Komar *et al.* 2003). By contrast, 100% of American Crows infected in laboratory studies have died, and high mortalities are observed in most other corvids, as well as in some other species (Komar *et al.* 2003, McLean

2006). Laboratory studies of bird mortality have been quite limited, and laboratory mortality figures may not be representative of mortality rates for birds in the wild.

Virus History

WNV was first isolated in Uganda in 1937 (McLean 2006). Historically, the virus has been found over a widespread area, including Europe, Africa, the Middle East, southern Asia, and Australia. The disease has not typically caused illness or death in birds in these areas (Brault *et al.* 2004).

WNV was first identified in North America near New York City in 1999 (Kilpatrick *et al.* 2007). After 1999, the disease spread north and south and moved steadily westward across North America, reaching Ohio in 2001(McLean 2006) and the West Coast in 2003 and 2004 (Hayes *et al.* 2005). Unlike WNV in the rest of the world, the North American strain of WNV (dubbed NY99) was characterized by the infection and illness of many bird species and frequent death for some. A 2004 study by Brault *et al.* showed that the NY99 strain of WNV was more deadly to American Crows than strains of WNV typically found in other parts of the world. The increased virulence of the NY99 strain was also seen in other corvids and in a variety of other bird species (McLean 2006).

Effects on Bird Populations

The effects of WNV on bird populations are often described as "patchy" and "focal" (McLean 2006). That is, the population of a species in one area may show a striking decline, whereas populations in adjacent areas may not be much affected. However, a 2007 analysis of USGS Breeding Bird Survey data through 2005 examined 20 species in six selected locations across the United States. This study indicated significant and, in some cases, sustained declines in the population of seven of the species examined. Not surprisingly, declines were most pronounced and sustained in American Crows, and crows declined significantly in every region considered. Other species that showed significant declines in one or more regions included Blue Jay, American Robin, Eastern Bluebird, Tufted Titmouse, Black-capped and Carolina chickadee (combined), and House Wren (Table 1). Blue Jay and House Wren populations rebounded to expected levels in 2005, whereas other species' populations remained suppressed (Ladeau *et al.* 2007).

WNV in Ohio

Although WNV arrived in Ohio in 2001, the virus did not become widespread until 2002 and did not have much impact here until late summer of that year. In 2002, there were 441 documented human illnesses in the state (U. S. Geological Survey 2003), with 31 deaths (Mandalakas *et al.* 2005). The Cleveland area was particularly hard-hit, with 50% of the state's documented cases occurring in Cuyahoga County (U. S. Geological Survey 2003), which then had 12% of the state's population (U. S. Census Bureau 2009). A human serology study conducted in Cuyahoga County indicated that an estimated 1.9% of the county's population (about 25,000 out of a total population of 1.3 million) had been infected by the end of 2002 (Mandalakas *et al.* 2005).

Documented infections in birds were widespread in Ohio in 2002, occurring in all 86 of Ohio's 88

counties that submitted dead birds for testing (U. S. Geological Survey 2003). The highest numbers of infected birds were reported from the state's urban areas, where dead or sick birds were more likely to be found and where the *Culex* spp. mosquitoes that are a primary carrier of the disease are more common (McLean 2006).

The reportedly patchy and focal nature of WNV's impact on bird populations is borne out by observations in Ohio. Birders on Cleveland's east side perceived the 2002 effect on the area's American Crow population to be severe, and crow populations in the area seem to have remained depressed in the eight years since 2002 (pers. obs.). Systematic point counts begun in 2001 at the Nature Center at Shaker Lakes in Cleveland's eastern suburbs recorded an average of 0.8 crows per count in 2001 and the spring of 2002. Between the fall of 2002 and the spring of 2009, counts averaged 0.01 crows per count, less than 15% of the previous level (J. West, unpublished data). After WNV, it became common not to see a crow in a morning's birding, and any increase in observations since has been slight. Other species that birders perceived to have been affected on the east side of Cleveland included Tufted Titmouse, Blue Jay, and Black-capped Chickadee. By contrast, although Ohio's state crow population was perceived to be affected by the 2002 epizootic, the perception from observations reported to *The Ohio Cardinal* has been that the population bounced back fairly quickly and completely (Whan 2004, Whan 2005, McCormac 2008).

Methods

Data

To evaluate whether the perceived population declines in Ohio were significant and whether the apparent impact of the virus was sustained over time, I analyzed data from the USGS Breeding Bird Survey (BBS) (U.S. Geological Survey 2010, Sauer *et al.* 2008) and Audubon Christmas Bird Count (CBC) (National Audubon Society 2002). I looked at counts of five species: American Crow (*Corvus brachyrhnchos*), Blue Jay (*Cyanocitta cristata*), Tufted Titmouse (*Baeolophus bicolor*), Black-capped and Carolina chickadee (treated together) (*Poecile atricapilla* and *P. carolinensis*), and American Robin (*Turdus migratorius*).

Breeding Bird Survey Data: For the BBS data for the United States and Ohio, I looked at two versions of the data: uncorrected average count per reported route (available through 2009) (U.S. Geological Survey 2010) and the annual indices calculated from the BBS's own analysis of trends for each species and region (available through 2007) (Sauer *et al.* 2008). The BBS annual indices calculate an overall regional trend by averaging the trends from individual routes and incorporating a number of corrections to weight the trend from each route based on route distribution, habitat, the population represented by the route, observer experience, and other factors. The BBS indices are probably a more appropriate indicator of changes in population over a region than the simpler "uncorrected count per reported route" (Link and Sauer 1998). Comparison of results from the two BBS data sets is complicated by the fact that the average count per reported route is available through 2009, whereas the annual indices are

available only through 2007. The two different versions of the BBS data usually show significant change for the same populations.

For the Cleveland area, I used BBS count data from Routes 18 and 118, the only routes near the city. Both routes are located near the southern edge of Cuyahoga County, though neither route is located entirely in the county, and Route 118 is entirely in Lorain and Medina Counties. Route 18 was replaced by Route 118 in 1995, with a single year of overlap of the two routes. In addition, data for these routes are entirely missing in 1978, 2002, 2008, and 2009. Although the route change may introduce some error into the analysis, examination of the data indicates that it is reasonable to assume that the two routes are counting from the same population. Given the "patchy" nature of WNV outbreaks, data from these routes may not be fully representative of changes in populations in the immediate Cleveland area, which is more urban than the route area. In addition, other factors, such as change in observers, weather differences, and habitat change make results based on data from a single BBS route problematic.

Data from the BBS are generally considered more useful for evaluating the possible impact of WNV than CBC data, since the BBS presumably counts birds that breed in the count area and were therefore exposed to WNV in that area (Wheeler *et al.* 2009). In addition, BBS counts are conducted by skilled observers in a consistent manner and in good weather.

Christmas Bird Count Data: For the CBC data, I generally examined the number of birds observed per party hour for the Cleveland count circle, for the state of Ohio, and for the US as a whole. Using the CBC to evaluate the impact of WNV is complicated by the fact that the CBC counts birds that may not have summered and been exposed to WNV in the count area. In addition, counts are conducted on fixed dates regardless of weather and may not be conducted in the same way or by the same individuals from year to year (Butcher 1990).

For most species, using the number of birds reported per party hour is a reasonable (if imperfect) way to account for changes in observer effort over time. However, this approach may not be appropriate for birds like American Crows, for which a large fraction of the birds counted in winter will be those that congregate in large roosts in known locations. In a typical year, between 50% and 75% of the crows reported to the Ohio CBC will be in three or four roosts of between 5,000 and 25,000 birds each (*The Ohio Cardinal* reports, 1991 to 1999). Year-to-year changes in CBC party hours will have had little impact on the number of birds reported from these large roosts. Large crow roosts also occasionally move (Renfrow 2001), and movement of one large roost into or out of a count circle may dramatically change the number of crows reported for the state. An additional pitfall of using Ohio's CBC data is that there are a few count circles that are reported in *The Ohio Cardinal* that are not reported to Audubon for inclusion in their CBC database. Although this probably does not have a significant impact for species that are well dispersed across the state, its impact on the reported crow count is significant. The Clark County count circle, which typically reports between 10,000 and 20,000

American Crows (14 to 38% of the state's total), is published in *The Ohio Cardinal* (see issues dated 1991 to 2007) but is not in the Audubon database. An unwary user who compares historical Audubon data with current *Ohio Cardinal* figures may report a population increase that has not actually occurred.

In an effort to compensate for all of these problems with the use of CBC data for American Crow populations, I analyzed the total reported count of American Crows as well as the crows reported per observer hour for the Cleveland count circle and for Ohio. For Ohio, I also examined total counts as reflected in *The Ohio Cardinal* and as reflected in the Audubon database.

Analysis

I evaluated counts of the five selected species over approximately 40 years, beginning in 1966 (BBS) or 1970 (CBC) and continuing through the end of the available data in 2007 (BBS indices), 2008 (CBC), or 2009 (BBS count per reported route). For each species, I compared average counts normalized for effort before and after the onset of WNV using Student's t-test for populations with unequal standard deviations. For Ohio and Cleveland American Crow counts from the CBC, I also compared the total counts (not normalized for effort) before and after WNV onset. Because so many comparisons were being made, the critical value for statistical significance of p was set at 0.001. Many counts showed trends in the period before WNV, so I compared the post-WNV counts to the decade before WNV (1992 to the last pre-WNV count) as well as to the entire period before WNV. Because BBS data are collected in June, before WNV had significant impact in Ohio in 2002, I considered 2003 to be the first post-WNV count for the BBS, and 2002 to be the first post-WNV count for the CBC.

Table 1 - Expected Impact of West Nile Virus
(from Ladeau, et al., 2007)

Species	Expected Impact	Impact shown in Ladeau, et al., 2007		
		# of Regions Studied	Regions w/ Significant Impact	
			#	Percent
American Crow	high	6	6	100%
Blue Jay	high	4	1	25%
Tufted Titmouse	high	4	4	100%
Chickadees	moderate	4	2	50%
American Robin	moderate	6	3	50%

Ladeau, et al., 2007, used 26 years of BBS data to evaluate the impact of WNV on 20 bird species in six regions across the US, including the Northeastern US (CN, DE, MA, NJ, PA, RI), Maryland, Virginia, Illinois, Colorado, and Oregon.

Table 2 - Summary of Significant Changes in Mean Decade Before WNV vs. Post-WNV

	BBS Count/Route		BBS Indices		CBC Count/Observer Hr		CBC Total Count		Ohio Cardinal Total Count	
	Means 1992-2002/ Post-WNV 2003-2009	P	Means 1992-2002/ Post-WNV 2003-2007	P	Means 1992-2001/ Post-WNV 2002-2008	P	Means 1992-2001/ Post-WNV 2002-2008	P	Means 1992-2001/ Post-WNV 2002-2008	P
Cleveland										
	Cleveland BBS data are missing for 1978, 2002, 2008, and 2009									
American Crow	**49/14**	**1.10E-04**	NA	NA	**8.5/1.6**	**7.27E-05**	**890/130**	**5.04E-05**	na	na
Tufted Titmouse	**17/3**	**5.09E-05**	NA	NA	1.8/1.2	NS	na	na	na	na
Ohio										
American Crow	**38/32**	**7.10E-04**	**36/25**	**8.67E-07**	**14/9.2**	**7.55E-05**	51,900/38,100	NS	66,700/56,300	NS
Tufted Titmouse	**14/9.7**	**1.29E-04**	**9.2/6.0**	**4.09E-04**	1.6/1.2	NS	na	na	na	na
American Robin	73/80	NS	97/119	4.89E-04	4.3/5.7	NS	na	na	na	na
USA										
American Crow	**34/30**	**8.98E-06**	22/21	NS	11.6/11.3	NS	na	na	NA	NA
Blue Jay	13/12	NS	**9.7/8.3**	**6.31E-05**	1.8/1.7	NS	na	na	NA	NA

Bold entries show statistically significant decline post-WNV. Shaded entries show a statistially significant *increase* post-WNV.

na indicates data not analyzed; NA indicates data not available.

NS indicates a reported result that is not statistically significant with P < 0.001.

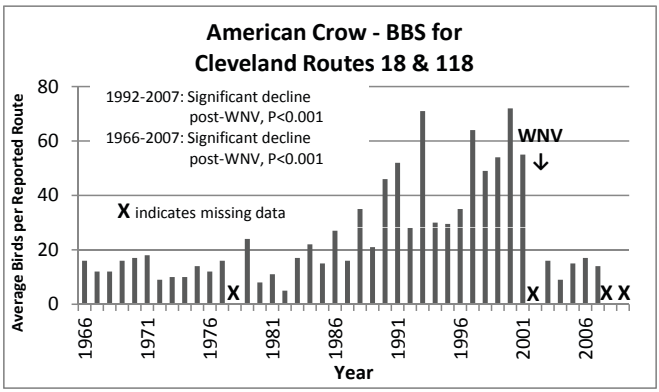

Figure 1. West Nile Virus (WNV) impacts in the Cleveland region as documented by Breeding Bird Survey (BBS) and Christmas Bird Count (CBC) observers.

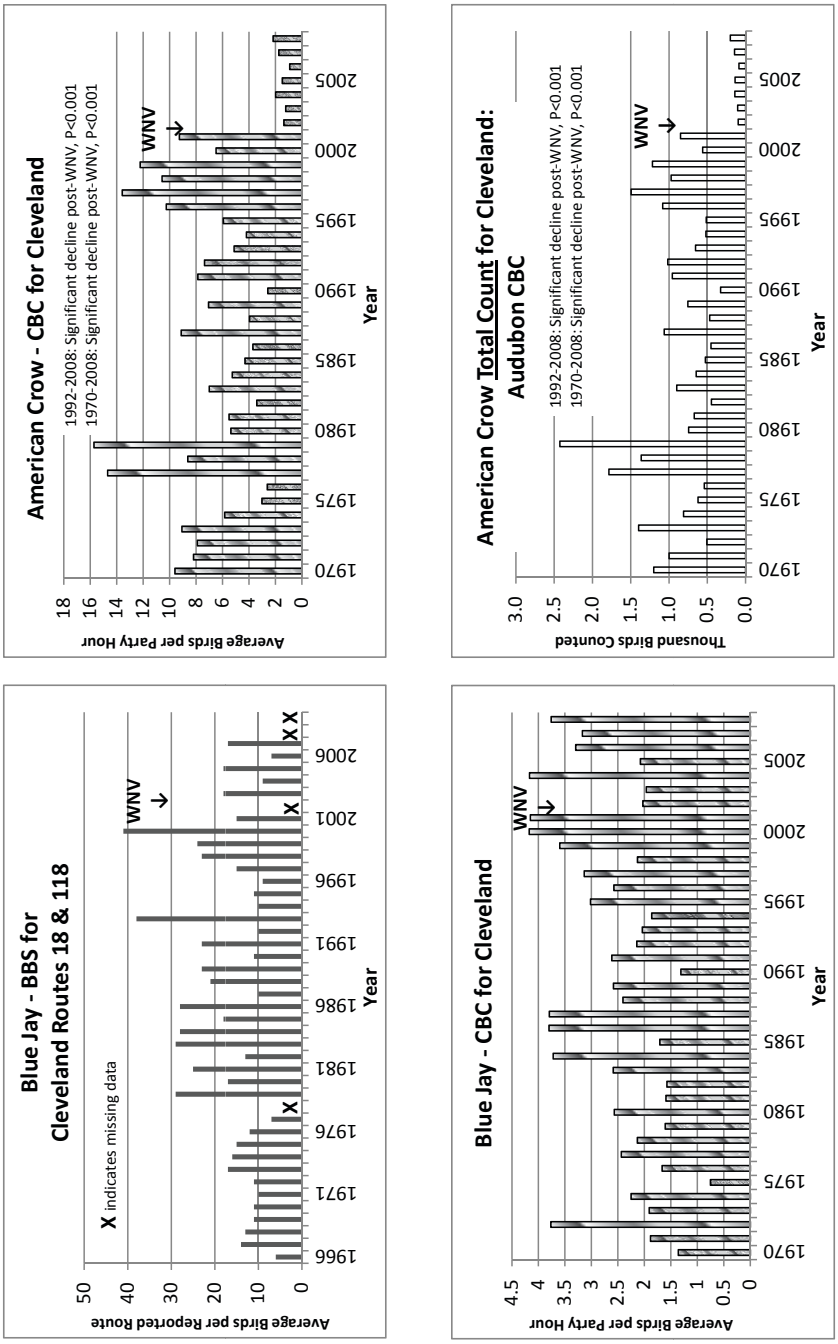

Figure 1, continued.

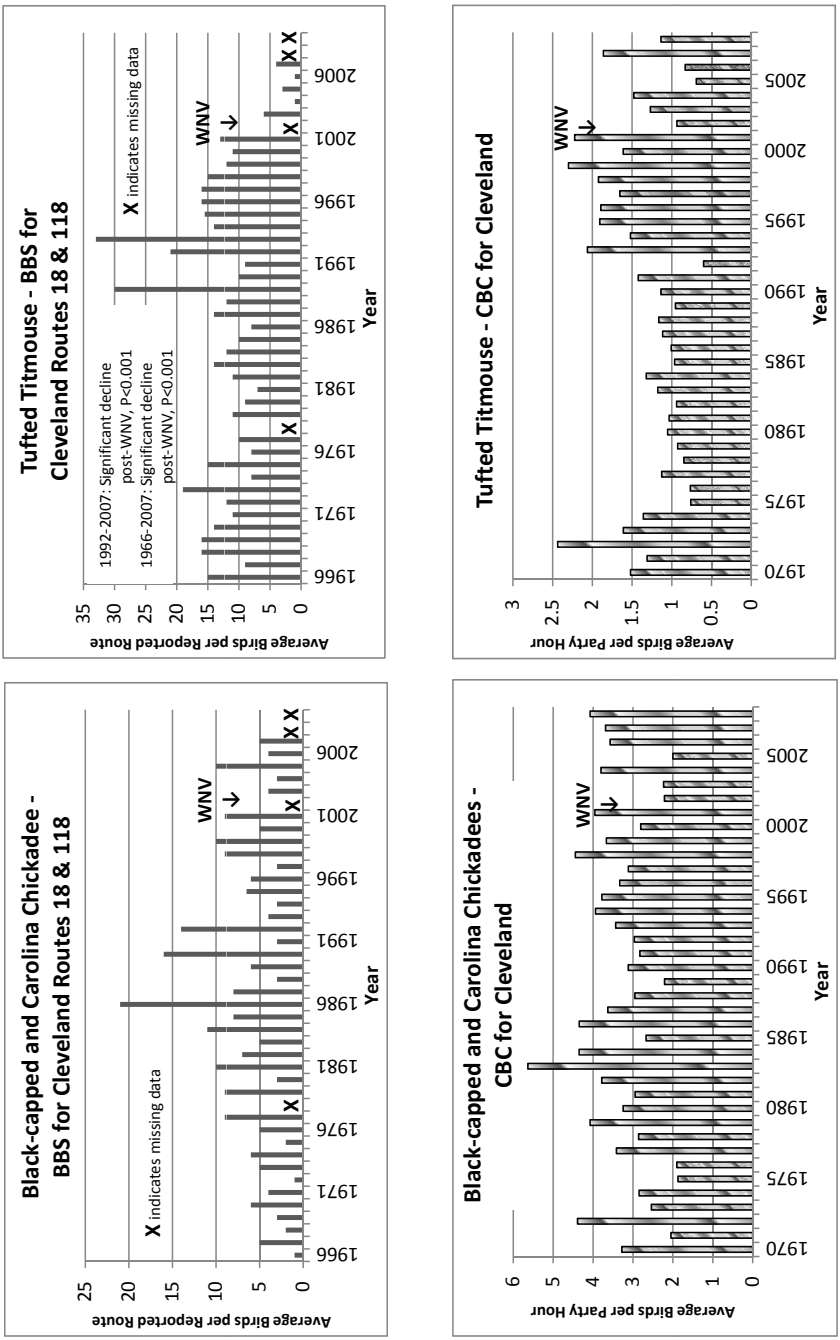

Figure 1, continued.

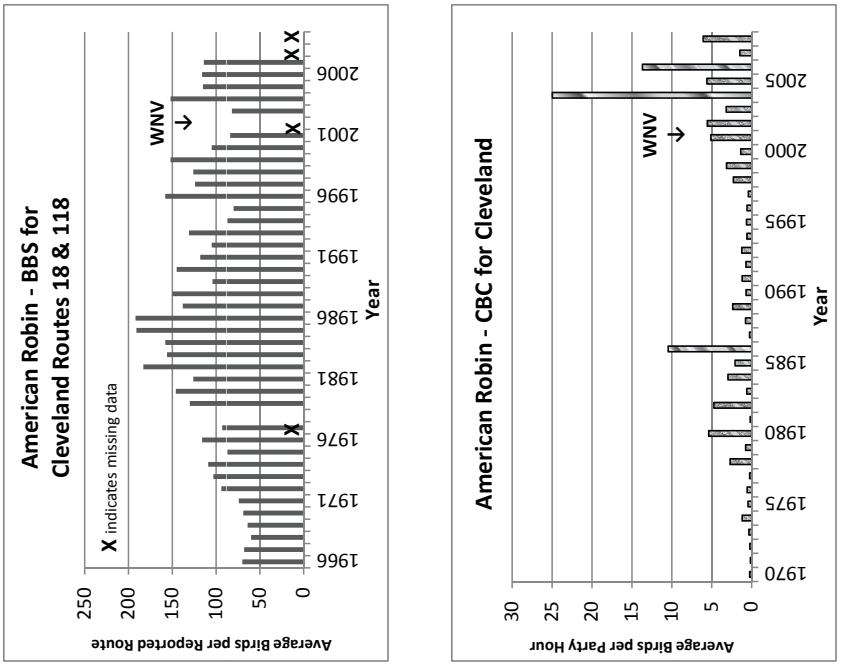

Figure 1, continued.

Results

Cleveland Area (Figure 1, Tables 2 and 3)

In the Cleveland area, American Crow showed statistically significant declines in the wake of WNV in all analyses of both BBS and CBC data. The decline in the crow population was significant when compared with both the decade immediately before WNV (Table 2) and the entire period considered (Table 3), and the decline followed either a significant increasing trend (BBS) or fairly stable counts (CBC) over the previous several decades. Since the onset of WNV, all counts for the BBS have been lower than any since 1987 and all study period counts for the CBC have been lower than any since before 1970. No recent population rebound is evident, although BBS counts are missing for 2008 and 2009. The 2009 CBC results, which were released after the end of this study, indicated some minor increase in crow numbers.

Cleveland's Tufted Titmouse counts also showed significant declines post-WNV on the BBS, but the decline was not significant for the CBC. As for crows, the BBS decline was significant compared with both the preceding decade and the entire period considered, and post-WNV counts have all been lower than any pre-WNV count since the survey began in 1966. Although there was no statistically significant decline of Tufted Titmouse counts from the Cleveland CBC, visual examination of the CBC data shows an apparent decline in counts after WNV, with some possible recovery. Cleveland CBC titmouse counts are typically

approximately one to two birds per observer hour, and the impact of running across an extra bird or two may have masked population decline and/or recovery. However, the 2009 CBC (not included in the statistical analysis) showed the highest number of titmice per party hour ever recorded, indicating that the Cleveland area population seems to have recovered from any WNV effects.

None of the other three species considered—Blue Jay, Black-capped/Carolina chickadees, and American Robin—showed a statistically significant increase or decrease in the Cleveland area after the onset of WNV.

Ohio (Figure 2, Tables 2 and 3)

Results for Ohio as a whole are similar to those for Cleveland. American Crows showed statistically significant declines compared with the preceding decade for both approaches to the BBS data and for the CBC count per observer hour. The CBC total crow count showed a marked decline that was not statistically significant, and the *Ohio Cardinal* total crow count showed a less-pronounced decline, also not statistically significant. For the BBS annual indices, there was also a significant decline compared with the more than three decades

Table 3 - Summary of Significant Changes in Mean Three to Four Decades Before WNV vs. Post-WNV

	BBS Count/Route		BBS Indices		CBC Count/Observer Hr		CBC Total Count	
	Means 1966-2002/ Post-WNV 2003-2009	P	Means 1966-2002/ Post-WNV 2003-2007	P	Means 1970-2001/ Post-WNV 2002-2008	P	Means 1970-2001/ Post-WNV 2002-2008	P
Cleveland								
Cleveland BBS data missing 1978, 2002, 2008, 200								
American Crow	**27/14**	**7.30E-04**	NA	NA	**7.4/1.6**	**7.48E-11**	**890/130**	**7.36E-11**
Tufted Titmouse	**14/3**	**1.43E-06**	NA	NA	1.4/1.2	NS	na	na
Ohio								
American Crow	30/32	NS	**32/25**	**1.22E-10**	8.6/9.2	NS	30,000/ 38,100	NS
Tufted Titmouse	11/9.7	NS	**10/6.0**	**2.56E-05**	1.4/1.2	NS	na	na
American Robin	65/80	2.78E-05	72/119	2.12E-08	2.6/5.7	NS	na	na
USA								
Blue Jay	**14/12**	**6.32E-06**	**11/8.3**	**1.07E-10**	2.0/1.7	NS	na	na
Tufted Titmouse	11/13	4.03E-07	8.4/9.8	NS	0.7/0.8	NS	na	na
Chickadees	8.1/9.2	NS	**9.4/8.7**	**1.41E-04**	2.9/2.9	NS	na	na
American Robin	38/38	NS	24/26	6.01E-06	15/12	NS	na	na

Bold entries show statistically significant decline post-WNV.
Shaded entries show a statistially significant *increase* post-WNV.
na indicates data not analyzed; NA indicates data not available.
NS indicates a reported result that is not statistically significant with P < 0.001.

Figure 2 (**Four following pages**). West Nile Virus (WNV) impacts across Ohio as documented by Breeding Bird Survey (BBS), Christmas Bird Count (CBC), and *The Ohio Cardinal* observers.

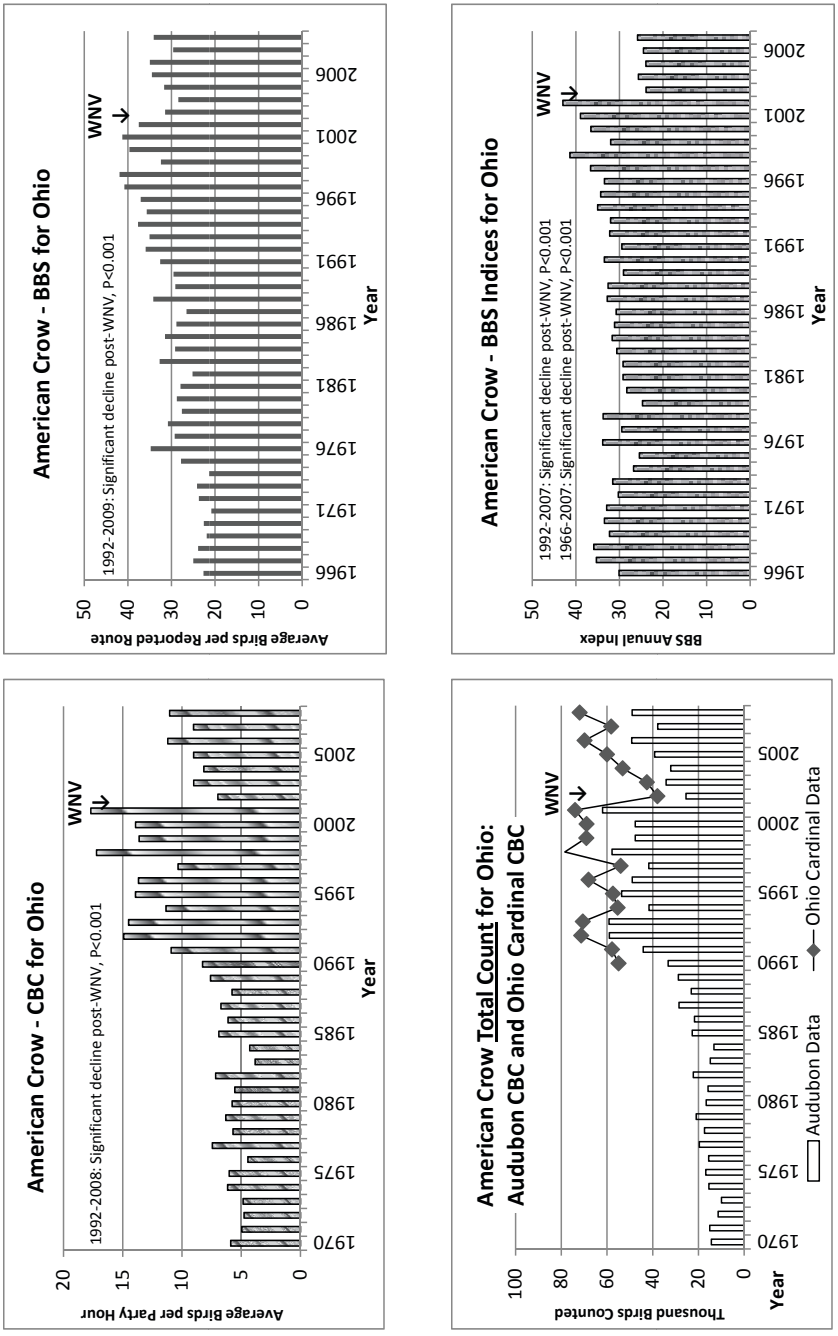

Figure 2, continued.

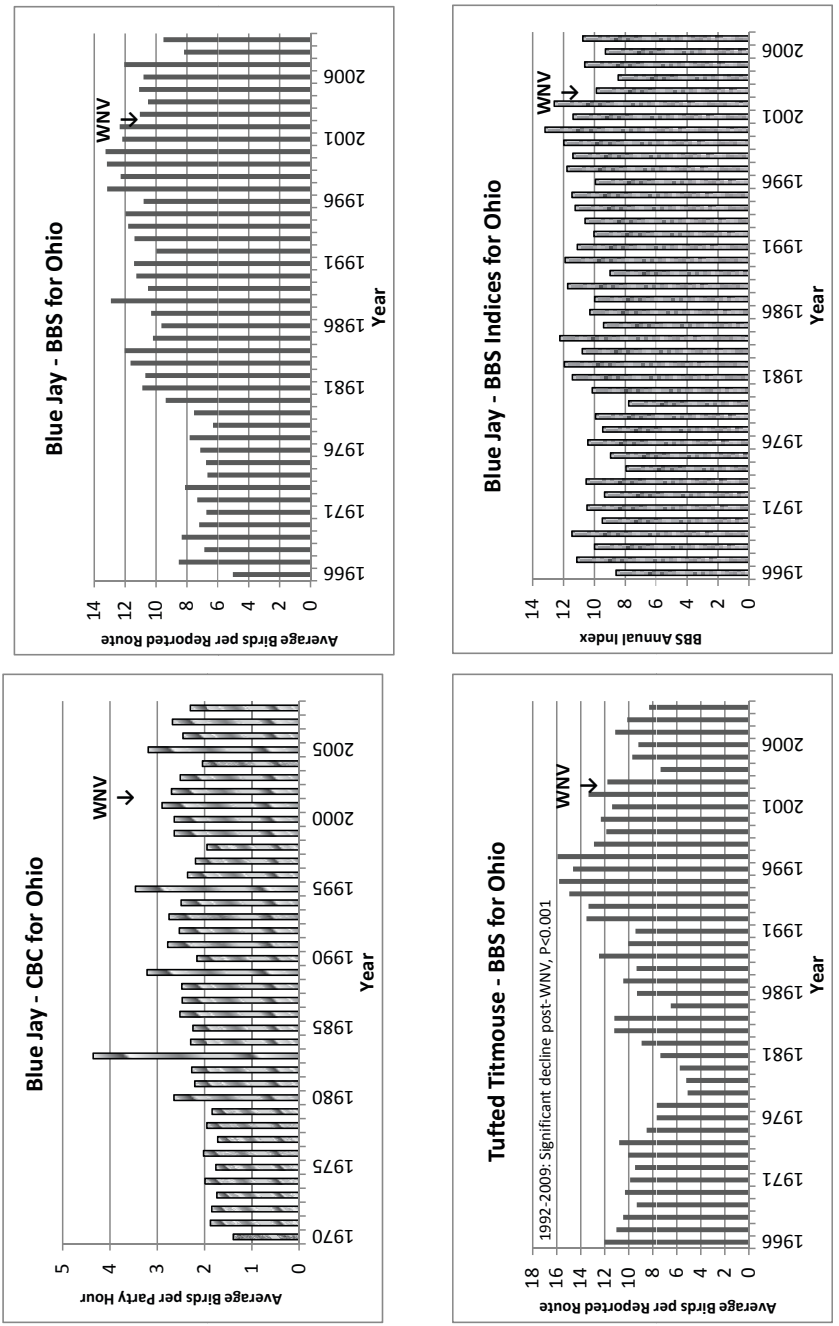

Figure 2, continued.

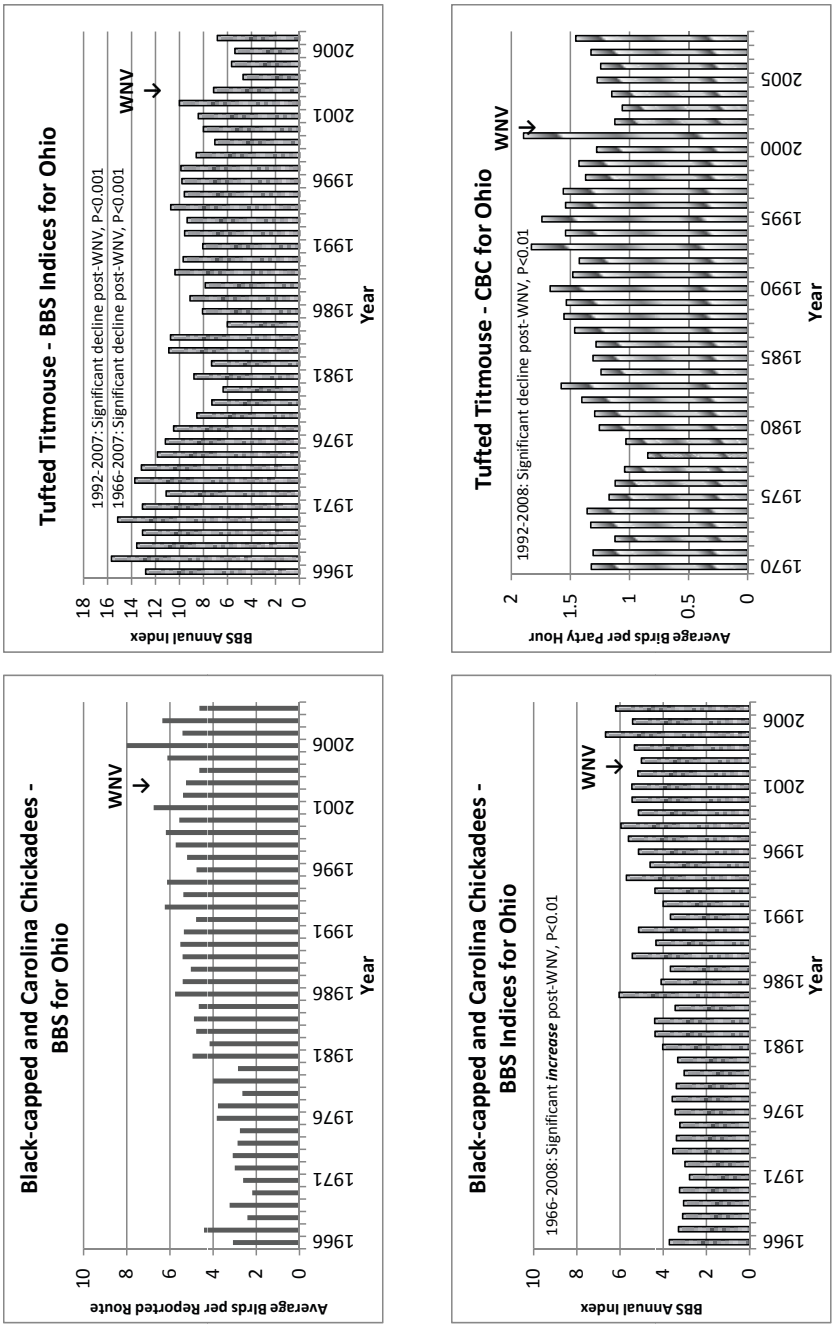

Figure 2, continued.

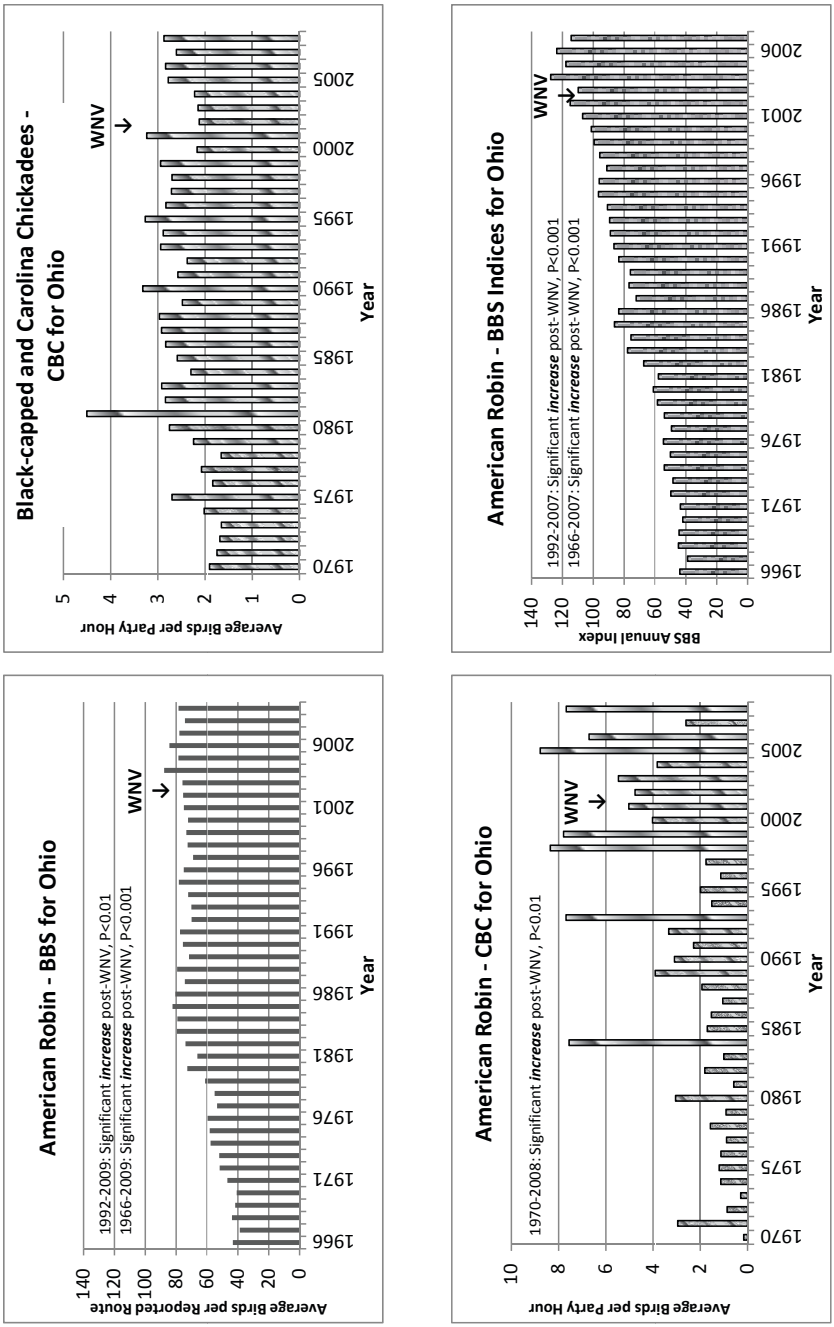

Figure 2, continued.

pre-WNV. All BBS annual indices for Ohio since WNV have been lower than any prior BBS index. Visually, all data sets seem to show some slow recovery of the crow population since the first post-WNV count. All data except for the BBS indices suggest that Ohio's crow population may have been approaching its pre-WNV level by the end of the study period.

Counts of Tufted Titmouse for Ohio show almost the same pattern as those of American Crow. Both BBS data sets indicate statistically significant declines post-WNV compared with the previous decade, and the BBS indices show the decline to be significant compared with all previous indices. Although the decline in counts for the CBC is not significant at the 95% confidence level for $P<0.001$, there is a visually apparent decline post-WNV. In addition, all post-WNV counts are lower than any in the previous decade for both approaches to the BBS data. Visual examination of the data suggests that Ohio's population of Tufted Titmice may have been approaching its pre-WNV levels by the end of the study period.

In addition to the declines noted, American Robin showed statistically significant *increases* in Ohio BBS indices post-WNV, perhaps as the continuation of a long-term upward population trend. In laboratory studies, robins have been shown to have relatively low mortality from WNV, and are thought to be one of the important carriers of the virus, since they develop fairly high virus levels in their blood without suffering ill effects (Kilpatrick *et al.* 2007, Komar *et al.* 2003, LaDeau *et al.* 2007). No statistically significant changes were observed in either Blue Jays or Black-capped/Carolina chickadees.

USA (Tables 2 and 3)

Data for the US as a whole paint a much less coherent picture than those for Cleveland or Ohio. American Crow counts show a significant decline only for the uncorrected BBS data compared with the previous decade. Visual examination of the BBS annual indices also shows an apparent decline, but the change is not statistically significant. Blue Jays show post-WNV declines for several of the comparisons made; however, these declines appear to be part of a decades-long downward trend in Blue Jay counts. Tufted Titmice show significant *increases* for the uncorrected BBS compared to the full period, but this increase also appears to be part of a long-term trend, as does the decline in the BBS index for chickadees.

Discussion

This analysis indicates that there have been significant declines in the populations of American Crow and Tufted Titmouse in Ohio following the onset of WNV in the late summer of 2002. These declines have been sustained over a number of years, with slow recovery of these populations toward the end of the study period. Blue Jay, Black-capped and Carolina chickadee, and American Robin populations were not significantly affected. Results of this analysis are consistent with more sophisticated assessments of the effects of WNV, such as Ladeau *et al.* (2007) and Wheeler *et al.* (2009).

In the Cleveland area, the declines in crow and titmouse populations were much more pronounced than the decline for the state as a whole, emphasizing the patchy and focal nature of WNV's impact on

birds. The data suggest that these populations had limited recovery through the end of the study period and that the titmouse population had fully recovered by the end of the summer of 2009 (after the end of the study period). My personal experience with American Crows on Cleveland's east side suggests that they had also begun to increase by the end of the study period.

Mortality from a viral epizootic tends to decline as susceptible individuals die, leaving a resistant population. However, this may not be the pattern that is followed by some bird species infected with the NY99 strain of WNV. For American Crows and some other corvids, there is little evidence that any significant number of infected birds survive to develop immunity to WNV. Because the virus is now established throughout the US, additional outbreaks can be expected wherever there is suitable mosquito habitat. Although such outbreaks become less severe as adults of carrier species (e.g., Blue Jay, American Robin, and House Sparrow) survive infection, become immune, and can no longer transmit infection, the virus can be expected to continue to infect mosquito populations, birds, and humans, albeit at lower levels than in the years immediately following its introduction into the US (Hayes *et al.* 2005, Wheeler *et al.* 2009). It will be interesting to observe and track the populations of susceptible species over time.

Literature Cited

Brault, A. C., S. A. Langevin, R. A. Bowen, N. A. Panella, B. J. Biggerstaff, B. R. Miller, and N. Komar. 2004. Differential virulence of West Nile strains for American Crows. *Emerging Infectious Diseases* 10: 2161-2168.

Butcher, G. S. 1990. Audubon Christmas bird counts. Pages 5-13 *in* J. R. Sauer and S. Droege, eds. *Survey designs and statistical methods for the estimation of avian population trends.* Biological Report 90(1). U. S. Department of the Interior: Fish and Wildlife Service, Washington, D. C.

CDC. September 29, 2004. *Information and guidance for clinicians - West Nile virus: clinical description.* U.S. Department of Health and Human Services: Centers for Disease Control and Prevention.

CDC. 2009a. *West Nile virus.* U.S. Department of Health and Human Services: Centers for Disease Control and Prevention: Division of Vector-Borne Infectious Diseases. http://www.cdc.gov/ncidod/dvbid/westnile/birds&mammals.Htm

CDC. 2009b. *West Nile virus: vertebrate ecology.* U.S. Department of Health and Human Services: Centers for Disease Control and Prevention: Division of Vector-Borne Infectious Diseases. http://www.cdc.gov/ncidod/dvbid/westnile/birdspecies.htm

Eidson, M., N. Komar, F. Sorhage, R. Nelson, T. Talbot, F. Mostashari, R. McLean, and the West Nile Virus Avian Mortality Surveillance Group. 2001. Crow deaths as a sentinel surveillance system for West Nile virus in the northeastern United States, 1999. *Emerging Infectious Diseases* 7: 615-620.

Hayes, E. B., N. Komar, R. S. Nasci, S. P. Montgomery, D. R. O'Leary, and G. L. Campbell. 2005. Epidemiology and transmission dynamics of West Nile virus disease. *Emerging Infectious Diseases* 11: 1167-1173.

Kilpatrick, A. M., S. L. LaDeau, and P. P. Marra. 2007. Ecology of West Nile virus transmission and its impact on birds in the western hemisphere. *The Auk* 124: 1121-1136.

Komar, N. S. 2003. West Nile virus: epidemiology and ecology in North America. *Advances in Virus Research* 61: 185-234.

Komar, N., S. Langevin, S. Hinten, N. Nemeth, E. Edwards, D. Hettler, B. Davis, R. Bowen, and M. Bunning. 2003. Experimental infection of North American birds with the New York 1999 strain of West Nile virus. *Emerging Infectious Diseases* 9: 311-322.

LaDeau, S. L., A.M. Kilpatrick, and P.P. Marra. 2007. West Nile virus emergence and large-scale declines of North American bird populations. *Nature* 447: 710-713.

Link, W. A., and J. R. Sauer. 1998. Estimating population change from count data: application to the North American breeding bird survey. *Ecological Applications* 8: 258-268.

National Audubon Society. 2002. The Christmas Bird Count Historical Results [Online]. Available http://www.audubon.org/bird/cbc 2009

Mandalakas, A. M., C. Kippes, J. Sedransk, J. R. Kile, A. Garg, J. McLeod, R. L. Berry, and A. A. Marfin. 2005. West Nile virus epidemic, northeast Ohio, 2002. *Emerging Infectious Diseases* 11: 1774-1777.

McCormac, J. 2008. Winter 2007-2008 overview and reports. *The Ohio Cardinal* 31(2):1-44.

McLean, R. G. 2006. West Nile Virus in North American birds. *Ornithological Monographs* 60: 44-63.

Renfrow, F. 2001. A history of the crow roost at Cincinnati. *The Ohio Cardinal* 24:91-93.

Sauer, J. R., J. E. Hines, and J. Fallon. 2008. The North American breeding bird survey, results and analysis 1966 - 2007. Version 5.15.2008. USGS Patuxent Wildlife Research Center, Laurel, MD. http://www.mbr-pwrc.usgs.gov/bbs/bbs.html

U. S. Census Bureau. 2009. Census data for 2000. http://factfinder.census.gov/home/saff/main.html?_lang=en

U. S. Geological Survey. 2003. *West Nile virus – Ohio: cumulative maps*. U.S. Department of the Interior, U.S. Geological Survey. http://diseasemaps.usgs.gov/2002/ohio/oh_human_apr_22.html

U. S. Geological Survey. 2010. *North American breeding bird survey.* U.S. Department of the Interior, U.S. Geological Survey, Patuxent Wildlife Research Center. http://www.pwrc.usgs.gov/bbs/

Whan, B. 2004. Winter 2003-04 reports. *The Ohio Cardinal* 27:52-68.

Whan, B. 2005. Winter 2004-2005 overview and reports. *The Ohio Cardinal* 28:41-55.

Wheeler, S. S., C.M. Barker, Y. Fang, M.V. Armijos, B.D. Carroll, S. Husted, W.O. Johnson, and W.K. Reisen. 2009. Differential impact of West Nile virus on California birds. *The Condor* 111: 1-20.

The Counties of Ohio