

Effects of West Nile Virus on Sensitive Species in the Lower Sacramento Valley, California: An Evaluation Using Christmas Bird Counts

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ABSTRACT

We used Christmas Bird Count (CBC) data from the Lower Sacramento Valley (LSV) of California to evaluate population changes in four species — Western Scrub-Jay (*Aphelocoma californica*), Yellow-billed Magpie (*Pica nuttalli*), American Crow (*Corvus brachyrhynchos*), and Oak Titmouse (*Baeolophus inornatus*) — that have been reported to be susceptible to effects of West Nile virus (WNV). Following a major WNV disease outbreak in Sacramento County in 2005, we compared 2005-2006 (hereafter 2006) CBC counts of these species with numbers previously reported on 8 LSV CBCs. Compared to the previous 10-year average, 2006 populations declined on 6 counts for the American Crow and on 7 counts for the other three species. For the study area as a whole, species declined by 33-56% from their 2005 abundances and by 38-46% from their abundances predicted by their 25-year population trends. These declines were statistically significant for the scrub-jay and magpie. Severe weather conditions (wind, rain, and flooding) occurred on 6 of 8 counts, potentially confounding the evaluation of potential WNV effects. An evaluation of past weather on populations showed that different types of bad weather resulted in moderate declines for the scrub-jay, moderate increases for the crow, and no consistent pattern for the magpie and titmouse. Using past responses of species to different weather conditions to correct for weather effects on 2006 populations showed declines due to non-weather factors (and thus potentially WNV) of 30% for the scrub-jay and nearly 50% for other species. We also compared changes in abundances of 9 common, non-WNV-susceptible species to determine their responses to severe 2006 weather. Susceptible species declined more severely than non-susceptible species, suggesting that declines of susceptible species were not due simply to weather. Finally, comparison of numbers on two counts with good weather showed substantial declines both from abundances in 2005 and from the 10-year average, suggesting that a substantial decline occurred that is not attributable to weather. Notwithstanding the complications of severe weather in the 2006 CBC season, results strongly suggest that these four susceptible species declined due to WNV during 2005-2006. Longer-term effects of WNV are uncertain, but deserve continued attention.

West Nile virus (WNV) is a mosquito-borne disease that poses a substantial health threat to humans, horses, and certain birds, especially corvids (Corvidae), some grouse (Phasianidae), and raptors (Falconiformes,

Strigiformes) (Fitzgerald et al. 2003, Naugle et al. 2004, Caffrey et al. 2005). Since its detection in the eastern U.S. in the early 1990s, the disease has spread rapidly westward across North America (Reisen et al. 2004, McLean 2006). Effects on wildlife populations are not fully known, but some corvid populations, especially American Crows, (*Corvus brachyrhynchos*), declined rapidly and substantially in some areas following WNV outbreaks (Yaremych et al. 2004, Caffrey et al. 2005).

WNV was first documented in California in 2002 (Reisen et al. 2004) and was first detected in the lower Sacramento Valley (LSV) in 2004 (Trochet 2005). The disease followed a typical pattern of increasing rapidly in the year after detection in LSV counties. High disease incidence in mosquitoes and numbers of cases of human disease in 2005 in Sacramento led to the characterization of Sacramento County as the epicenter of the 2005 WNV infection (http://diseasemaps.usgs.gov/2005/wnv/wnv_ca_human.html). A large-scale campaign of aerial insecticide spraying was initiated in August 2005 to control mosquitoes in large areas of Sacramento County (Trochet 2005).

Susceptible Species

Requests by public health authorities to report dead birds in California produced reports of over 8,000 dead Yellow-billed Magpies (*Pica nuttalli*), many of which came from the LSV (H. Ernest pers. comm.). Considering that only a small proportion of dead birds were found and reported, these numbers have raised concern regarding population and genetic effects on magpies. No precise population estimates exist for Yellow-billed Magpies, but Rich et al. (2004) estimated the population as 180,000 with “poor accuracy” and identified it as “Watch List Species” due to restricted range and low population size. Despite reports of a substantial number of mortalities (and likely higher undetected mortality) relative to the population size, potential effects on magpie populations are uncertain.

In addition to the Yellow-billed Magpie, the LSV supports two other common corvids, the Western Scrub-Jay (*Aphelocoma californica*), and American Crow. (The Common Raven [*Corvus corax*], although apparently increasing on LSV counts, is not common in the area and is not addressed here.) Substantial number of these corvids and the Oak Titmouse (*Baeolophus inornatus*) have been found dead in the LSV, and tested carcasses also have shown high incidence of WNV (H. Ernest and A. Engilis, Jr., pers. comms.), raising concerns about their populations. Therefore, we focused our analysis of CBC data on these four species (hereafter “WNV-susceptible species”).

Within the LSV, the four target species exhibit different patterns of distribution, abundance, migratory status, and tendencies to roost communally. These factors may influence severity of effects from WNV and the ability to detect effects using CBC data.

The Western Scrub-Jay is widespread within the western U.S., with the largest concentration in California (Root 1988, Sauer et al. 2005). The species is a year-round resident in most of its range, and, while there are some seasonal movements, no regular migratory movement occurs (Curry et al. 2002). Within the LSV, this jay is a common resident in human residential areas, oak and other native woodlands, and scrub areas.

The Yellow-billed Magpie is endemic to California with its population center (i.e., highest densities and largest populations) in the LSV and central Coast Ranges (Sauer et al. 2005). The magpie occurs in lower density suburban areas (especially those developed in former orchard lands), riparian and oak savannah habitats, and extant orchards. The magpie is non-migratory, but individuals aggregate into localized winter roosts that can support up to a thousand or more individuals (Crosbie 2004, Crosbie et al. 2006).

The American Crow is widespread in North America and an abundant breeder and wintering species in the LSV (Sauer 1997, Sauer et al. 2005). Breeders defend territories in urban, suburban, and agricultural habitats. The wintering population appears to include both wintering birds from elsewhere and resident birds (Verbeek and Caffrey 2002). Wintering birds typically forage in a wide range of habitats, and aggregate into evening roosts containing hundreds to tens of thousands of individuals in urban and suburban areas, as well as in orchards and groves of evergreen trees in rural areas.

The Oak Titmouse is nearly endemic to California and is abundant in areas of the Sierra Nevada foothills, Coast Range and LSV areas that support oaks (CalPIF 2002, Sauer 2005). Titmice are non-migratory and territorial year-round (Cicero 2000).

Study Goals

The goals of this study were to evaluate the potential value of CBC information in assessing potential effects of WNV on key species and to compare winter populations recorded on CBCs in the LSV to determine if any declines were evident. Specific objectives were to:

- Determine if abundances of the 4 species on the 2005-06 CBCs (hereafter 2006) differed from abundances recorded prior to 2006,
- evaluate the magnitude of 2006 changes in abundance in relation to past variation in abundance,
- evaluate the potential effects of weather on species abundance and the potential contribution of weather conditions to any observed changes in 2006 populations, and
- draw conclusions regarding the usefulness and limitations of CBC data in interpreting effects of WNV on corvid and titmouse populations in the LSV and elsewhere.

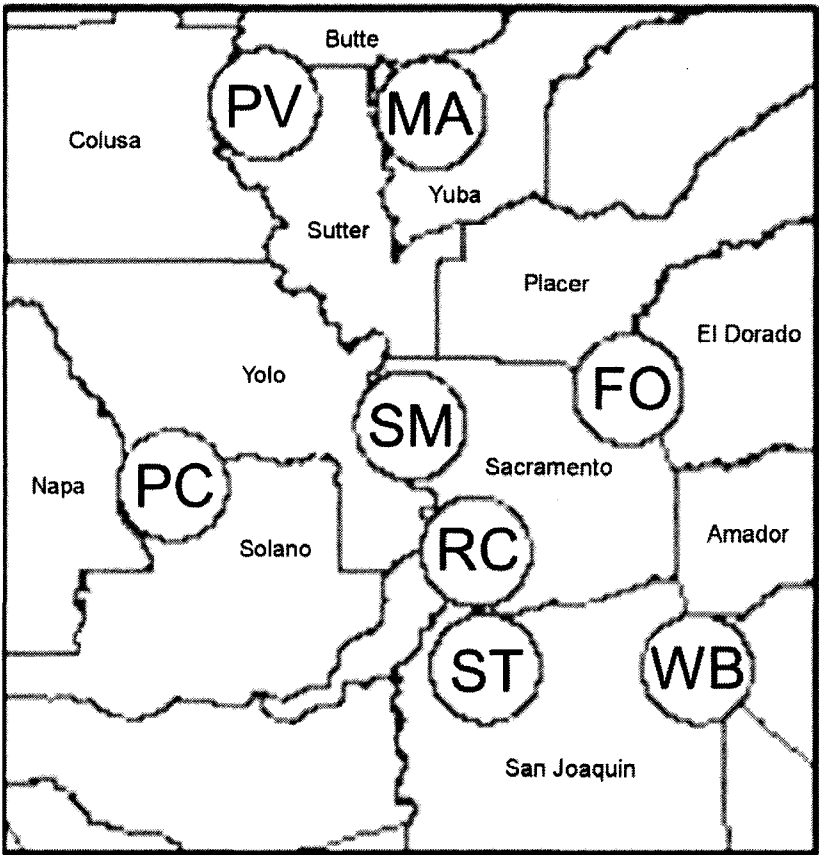


Figure 1. Map of the CBC circles used for these analyses. The circles are approximately to scale (i. e., 15 mi diameter). Circles are: FO-Folsom, MA-Marysville, PC-Putah Creek, PV-Peace Valley, RC-Rio Cosumnes, SM-Sacramento, ST-Stockton, and, WB-Wallace-Bellota.

WNV Evaluation Using CBCs

Evaluation of potential effects of WNV on corvids and the titmouse are hampered by the limited availability of a pre-WNV baseline, especially because WNV effects may be localized following its initial arrival. Also, many of the potentially affected species have not attracted detailed population studies because they have large populations.

Christmas Bird Counts (CBCs) serve as one of few long-term data sources with which to evaluate post-WNV populations. CBCs have been conducted at a variety of sites in the LSV by a large number of volunteers over many years (National Audubon Society 2005a, Manolis 2006, Pandolfino 2006). Notwithstanding their limitations, CBCs are one of few data sources that provide a long-term, relatively consistent basis on which to evaluate

population trends among resident and wintering species, particularly at regional, state, and continental scales (Dunn et al. 2005). CBCs have been one of the primary sources of information about the status of wintering and resident bird populations in the U. S. (Root 1988) and have been used elsewhere to evaluate potential effects of WNV on birds (Bonter and Hochachka 2003, Caffrey 2003, Caffrey and Peterson 2003).

STUDY AREA

We summarized corvid and titmouse abundance from eight CBCs in the LSV and nearby Sacramento-San Joaquin Delta region and adjacent foothills closest to Sacramento County, which was an area of high WNV incidence in 2005. We selected this area in order to evaluate regional effects and to incorporate a set of CBCs, in order to reduce annual effects of weather, observer effort, and other variables that typically affect results of individual counts (Dunn et al. 2005). We analyzed data from the following CBCs: Peace Valley, Marysville, Sacramento, Folsom, Putah Creek, Rio Cosumnes, Stockton, and Wallace-Bellota. These counts include portions of Butte, Colusa, Sutter, Yuba, Sacramento, Placer, El Dorado, Yolo, Solano, Napa, San Joaquin, Amador, Calaveras, and Stanislaus counties (Figure 1). We did not include the Lincoln CBC, although it falls within the area covered, because it had only been in existence for 3 years prior to the 2005-2006 count.

Each CBC is conducted within a 24.1-km (15-mile) diameter circle that is surveyed annually by volunteers during the last 2 weeks in December and the first week in January (Dunn et al. 2005, Manolis 2006)). Average annual participation in individual LSV CBCs varied from 70-194 party-hours during the period 1997-2006. Count areas support a variety of habitats, including agricultural lands (rice and other grains, row crops, pasture, orchards, and vineyards); residential, commercial, and industrial development; managed wetlands (including wildlife refuges); oak and riparian woodlands; and annual grasslands.

METHODS

Data Acquisition and Summary

We acquired data on corvid and titmouse abundance on CBCs for the 25-year period from 1980-81 to 2005-06 from the National Audubon Society-Cornell Lab. of Ornithology web site (<http://www.audubon.org/bird/cbc/>). Hereafter, we refer to counts by the year of their end date (e.g., the 2005-2006 count year = "2006"), for consistency with the system used to assign count numbers (i.e., the 06 count for 2005-2006). We selected available data from each of the eight LSV CBCs, except that we did not use Marysville CBC data from before 2001, because coverage during that period was considered

inadequate. Data for 2006 CBCs were acquired directly from CBC compilers.

Consistent with CBC analysis recommendations (Dunn et al. 2005), we evaluated the appropriateness of different abundance measures (total number of individuals recorded and numbers per party-hour) in comparing annual populations. This concern was warranted especially for the magpie and crow, because of their communal roosting habits, which might make their numbers easier to count, regardless of count participation. Comparisons of numbers of individuals counted against the number of party-hours, however, showed that the numbers recorded for all species generally increased with increased party hours, thereby indicating that number per party-hour was an appropriate abundance measure.

Comparison of Species Abundances on the 2006 CBC and Prior Years

We compared 2006 CBC populations with previous populations in two ways: by comparing values with the previous 10-year mean and through regression analysis.

We summarized the patterns of population changes in 2006 by comparing the abundance of each species on each count with the previous 10-year abundance on that count. We then recorded the abundances in categories based on the magnitude of differences (<25%, 25-50%, >50%). We then evaluated the probability of the resulting outcome (number of declines versus increases in abundances) using the χ^2 goodness of fit test. Mean abundances per year for each species also were calculated across all counts for which data existed, to compare with the average abundance in 2006.

We also evaluated the deviation of 2006 abundances from the population trend based on the previous 25 years. Each species' population trend was estimated using multiple regression analysis, with time represented by a quadratic expression ("year" and "year squared"). Data from the Sacramento CBC were missing for the years 1998 and 2004. Because this CBC supported high numbers of magpies and crows, eliminating these counts from the count averages for the regression analysis biased results. Therefore, in the regression analysis we used the 10-year average for the period surrounding each of these years. We then evaluated the deviation of the species' 2006 abundances from the expected value predicted by the time trend in the regression equation. Percent change in abundance from the predicted value was examined using a t-test, to estimate the likelihood of recording the 2006 abundance value by chance (i.e., how likely it would be to record the 2006 value if no real population change had occurred).

Weather Effects on Abundance

We evaluated effects of weather on species abundances because some CBC compilers reported that severe rain and wind conditions on their 2006 count days reduced total numbers of individuals detected. Such changes

could be due to changes in bird behaviors that made them less detectable during adverse weather or differences in observer techniques (on-foot or in vehicles) or observer thoroughness. We used weather data provided by compilers as well as data from the nearest National Weather Service (NWS) stations (either Beale Air Force Base, Sacramento International Airport, Stockton, or Vacaville) acquired on each count-day for each count conducted during the 10-year period of 1997-2006. While NWS data was not always taken onsite and includes records for a 24-hr period (not just daylight hrs when most CBC counting occurs) we considered it an important adjunct to the qualitative information reported by CBC compilers.

We characterized weather in the following relatively crude categories based on the following conditions observed on count days:

- rain =>0.25 cm (0.1 inch) recorded
- wind = peak winds >32 km/hr (20 mph)
- rain and wind – both conditions listed above.

We use the general designations of “bad” weather when any of these conditions existed and “good” weather when none of the conditions were noted.

More refined characterization was not appropriate due to distances from weather stations to CBC circles, relatively few years (10) of data used (to minimize compounding effects of populations trends caused by other factors), and geographic variation in weather conditions within circles on count days.

We calculated the frequencies of these conditions for each count to assess the extent to which conditions on 2006 counts differed from those that occurred over the previous 10 years. Finally, we calculated average abundances of the four species under each of these conditions and calculated the percent difference in abundance between good and bad weather years on each count and across all counts in the LSV to evaluate species responses to weather conditions.

Weather Contributions to 2006 Population Changes

We conducted several comparisons to evaluate the potential contribution of weather to any changes observed in 2006 abundances of the four species. We compared the magnitude of the changes in species' abundances during 2006 with those that occurred under rainy or windy weather conditions in the past. Under this approach, if a decline in a species' abundance in 2006 substantially exceeded that predicted based on past weather, WNV could be considered as a potential cause of population decline.

Many compilers reported that weather was particularly severe on 2006 counts. This suggested that 2006 weather (rain, wind, and flooding) may

have been more severe than the “average bad weather conditions” characterized from previous counts. If so, the effects of weather on 2006 abundances could have been underestimated and residual effects potentially attributable to WNV could have been overstated. Therefore, we also tested for weather-related effects on abundance of WNV-susceptible species in 2006 by comparing their changes in abundance with the 2006 abundances of other species not known to be WNV-sensitive.

If weather (and not WNV) was the main cause of 2006 CBC population changes in susceptible species, then non-susceptible species also should have shown similar declines. To test this hypothesis, we compared abundances between the four WNV-susceptible species and a group of nine species who were resident, used similar habitats, and whose long-term annual variability was similar (coefficients of variation <0.40). This group included: California Quail (*Callipepla californica*), Mourning Dove (*Zenaida macroura*), Acorn Woodpecker (*Melanerpes formicivorus*), Bush-tit (*Psaltriparus minimus*), White-breasted Nuthatch (*Sitta carolinensis*), Bewick’s Wren (*Thryomanes bewickii*), Northern Mockingbird (*Mimus polyglottos*), Spotted Towhee (*Pipilo maculatus*), and California Towhee (*Pipilo crissalis*).

As another way to address the effects of WNV on abundance of susceptible species, we evaluated changes in 2006 populations from past counts within the two counts with good weather: Sacramento and Marysville. Sacramento was of particular interest because it had high WNV incidence in 2005. We evaluated changes in 2006 populations from 2005 and from the previous 10-year average for each count (a conservative analysis, since the 10-year average included some bad weather years which could suppress the average abundance). Since abundance changes in 2006 could not be attributable to weather at these counts, substantial changes in abundance presumably would be attributable to other causes, and thus potentially WNV. This comparison was not evaluated statistically, so is simply used to evaluate the direction and magnitude of any population change and consistency with other evaluations.

RESULTS

Changes in Abundance in 2006 compared to 1981-2005

Changes in species abundances in 2006 compared to the previous 10-year average for individual counts are summarized in Table 1. Declines occurred in 2006 on 6 (75%) of 8 counts for the American Crow and on 7 (88%) of 8 counts for the other three susceptible species. Thus, in total, declines occurred in 27 (84%) of 32 species-count combinations, while increases occurred on only 5 combinations (16%). This proportion of counts with declines was significantly different from an expected 50% ($\chi^2_{1,df} = 15.12, p < 0.001$).

Table 1. Changes in 2006 abundance for 4 WNV-susceptible species on 8 Lower Sacramento Valley CBCs. Table entries show the number of counts exhibiting changes, by category, in 2006 abundance compared to the previous 10-year average.

	Percent Decrease				Percent Increase			
	>50	25-50	0-25	Total	0-25	25-50	>50	Total
Western Scrub-jay	4	3		7	1			1
Yellow-bill. Magpie	2	4	1	7	1			1
American Crow	4	2		6	1		1	2
Oak Titmouse	4	3		7	1			1
Total	14	12	1	27	4	0	1	5
% of total	44	38	3	84	13	0	3	16

Abundance patterns over all LSV CBCs combined during the 1981-2005 period, and changes during 2006, are shown in Figures 2-5. Results are discussed for each species below.

Western Scrub-Jay — Abundance of scrub-jays on LSV CBCs during 1981-2005 have shown low variability ($R^2 = 0.46$) with a moderate increase in overall abundance suggested over time (Figure 2). Abundance in 2006 declined by 56% from 2005 to the lowest level recorded during the previous 25 years (Figure 2). The 2006 abundance was 46% below the value predicted from on past trends, which is highly significant ($p = 0.008$).

Mean scrub-jay abundances among counts showed relatively low variability over the last 10 years ($CV = 26\%$), with highest populations at Putah Creek (5.2 birds/party-hr) and lowest numbers in Marysville (2.2 birds/party hr). Variability in regional abundance (over all CBCs) also was low over the last 10 years ($CV = 17\%$).

Yellow-billed Magpie — Magpies showed moderate variability in abundance on LSV CBCs during 1981-2005 ($R^2 = 0.24$), with higher variability shown since 1993 (Figure 3). The population trend was increasing over the study period, with most of this increase occurring over the last 15 years (Figure 3). Magpie abundance in 2006 declined by 44% from the 2005 value to the lowest value in the previous 25 years. The 2006 decline of 48% from the predicted abundance based on the past trend was significant ($p = 0.03$).

Mean abundances varied moderately among different counts over the previous 10 years, ($CV = 59\%$) with high populations in Sacramento and Marysville (4.5-6.3 birds/party-hr) and low numbers in Folsom and Stockton (1.0-1.4 birds/party-hr). Regional abundance (over all CBCs) varied moderately over the previous 10 years ($CV = 32\%$), with no clear trend in abundance evident.

American Crow — American Crow counts showed high annual variability in abundance ($R^2 = 0.19$) over the 25-year period with lower variability after 1990 (Figure 4). The overall population trend is stable after an apparent

Figure 2. Abundance and trends of the Western Scrub-Jay (number/party hour) on 8 Lower Sacramento Valley Christmas Bird Counts, with 2006 declines from predicted value.

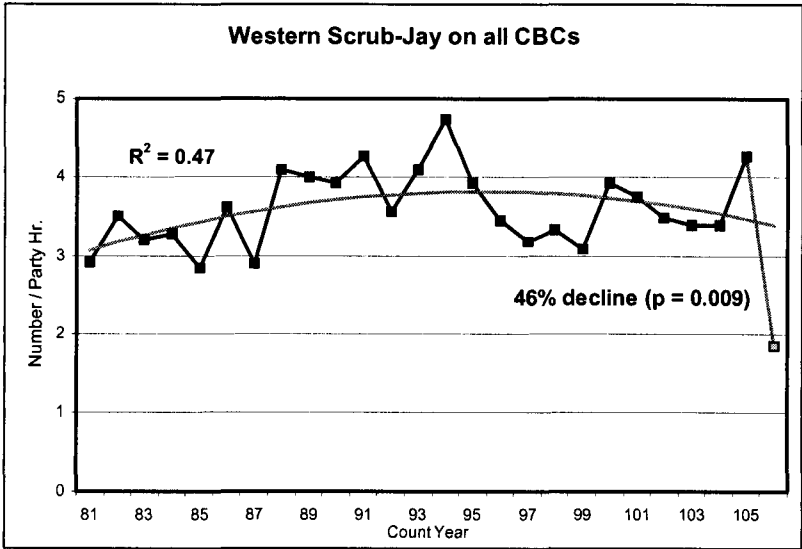


Figure 3. Abundance and trends of the Yellow-billed Magpie (number/party hour) on 8 Lower Sacramento Valley Christmas Bird Counts, with 2006 declines from predicted value. Missing values for counts 98 and 104 were replaced with 10-year averages (see Methods).

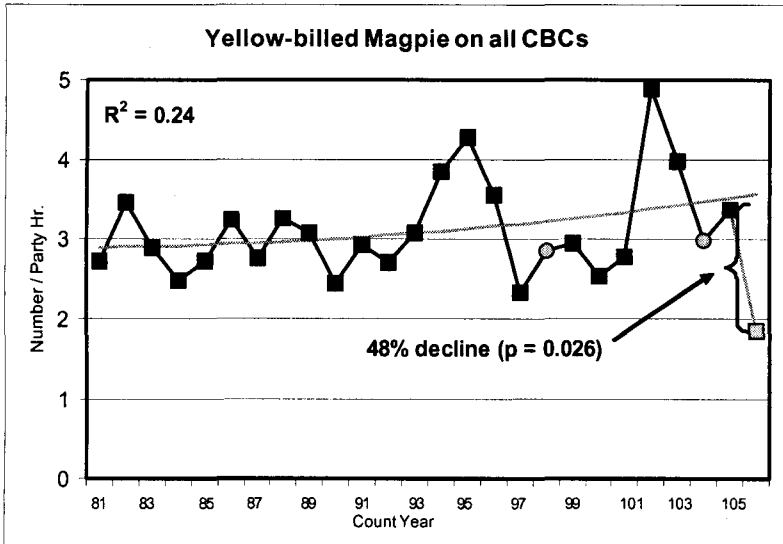


Figure 4. Abundance and trends of the American Crow (number/party hour) on 8 Lower Sacramento Valley Christmas Bird Counts, with 2006 declines from predicted value. Missing values for counts 98 and 104 were replaced with 10-year averages (see Methods).

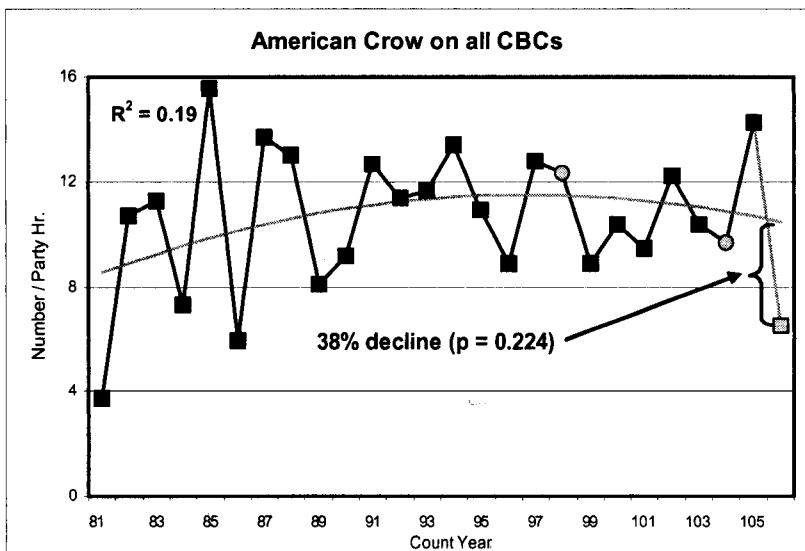
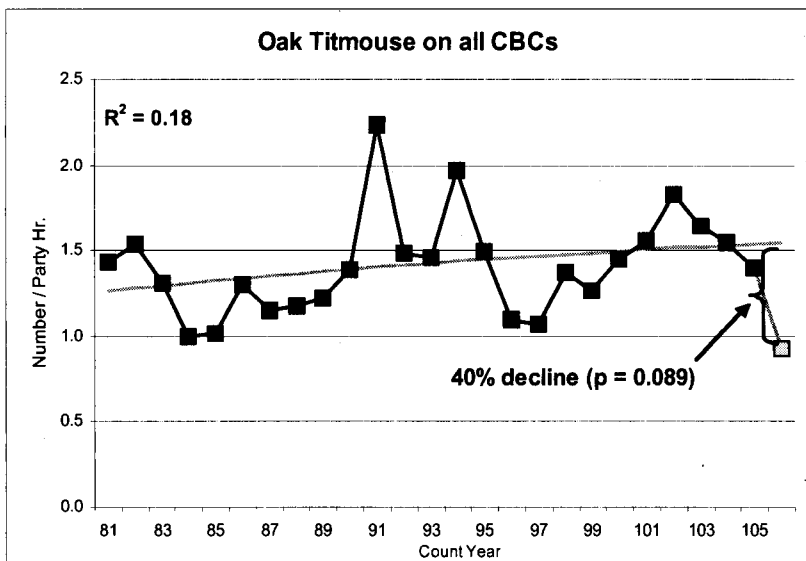


Figure 5. Abundance and trends of the Oak Titmouse (number/party hour) on 8 Lower Sacramento Valley Christmas Bird Counts, with 2006 declines from predicted value.



increase through the mid 1990s. Average abundance in 2006 was 55% lower than in 2005, to a lower level than had been recorded in the previous 17 years (Figure 4). The 2006 abundance was 38% below the predicted abundance based on the long-term population trend (Figure 4), a difference that was not statistically significant ($p = 0.22$).

Crow abundances varied substantially among different CBC areas (CV = 113%), with populations by far the most variable among counts. Crows were most abundant in Sacramento (33 birds/party-hr), and showed intermediate abundance in Marysville and Peace Valley (14-17 birds/party-hr) and lower numbers elsewhere (0.6-7.1 birds/party-hr). Annual abundance over all CBCs varied markedly (CV = 42%). Some of the high annual variability is an artifact of missing data; low regional average counts in 1998 and 2003 likely results from the absence of count data from Sacramento in those years.

Oak Titmouse — Counts for the titmouse showed moderate variability ($R^2 = 0.18$) over the last 25 years, with a slightly increasing trend (Figure 5). The average abundance of titmouse in 2006 was 33% lower than in 2005 and lower than the abundance recording during any of the previous 25 years. The 2006 population was 40% below the predicted population, but this difference only approached statistical significance ($p = 0.09$).

Titmouse abundances varied substantially among counts (CV = 63%) with higher average annual populations in Folsom, Peace Valley, and Putah Creek (1.9-2.8 birds/party hr) and lowest numbers in Stockton and Sacramento (0.3-0.5 birds/party-hr). Regional abundance (over all CBCs) varied moderately over the 25-year period (CV = 34%).

Weather Conditions on 2006 and Previous Counts

The frequencies of different weather conditions on LSV CBCs differed between the period 1996-2005 and in 2006. Overall, before 2006, good weather occurred during 61% of counts, while adverse weather (rain, wind, or both) were recorded on 39% of count days. In contrast, good weather occurred on only 3 (38%) of 2006 LSV CBCs, while rainy or windy conditions occurred on 5 (58%) counts. In addition, although weather conditions on one other count (Rio Cosumnes) were good, much of the count area was extensively flooded from previous storms, which greatly reduced availability of habitats used by corvids (A. Engilis, Jr., pers. comm.).

Not only were bad conditions more frequent on 2006 counts than under average conditions, but the severity of storms were particularly great. Compilers for the Folsom, Putah Creek, Wallace-Bellota, Stockton counts all noted that weather conditions were much more severe than on typical bad weather days, with strong winds and heavy rain on count days. Thus, bad weather conditions during the 1996-2005 period may not reflect the severity of bad weather experienced on counts in 2006.

Table 2. Percent differences in abundance of WNV-susceptible species on CBCs conducted under windy and rainy weather conditions, compared to CBCs conducted under good weather¹ over the previous 10 years.

Species	Weather Conditions			
	Rain only	Wind only	Rain and Wind	All bad ²
Western Scrub-jay	-16	-21	-11	-17
Yellow-bil. Magpie	-4	+19	+4	+7
American Crow	+3	+19	+13	+4
Oak Titmouse	+10	+31	-15	+18

¹ - Good weather defined as days without measureable rain or winds that exceeding 32 km/hr (20 mi/hr); see Methods.

² - "All bad" weather category includes counts conducted under rain only, wind only, and both rain and wind.

Table 3. Changes in populations of WNV-susceptible species in 2006 compared to populations predicted from past weather responses.

Species	Average population change observed ¹	Changes predicted from past weather responses	Non-weather (= potential WNV) effect ²
Western Scrub-Jay	-43	-13	-30
Yellow-bil. Magpie	-31	+7	-38
American Crow	-47	+1	-48
Oak Titmouse	-32	+1	-33

¹ Averages were compared to the 10-year average abundance on counts

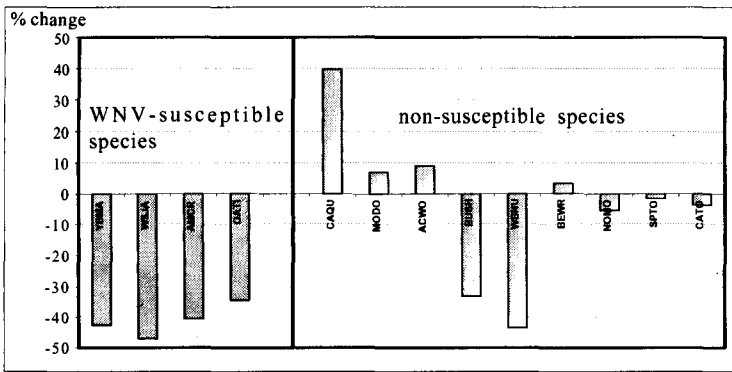
² Predicted 2006 population change with effects of weather removed, calculated by subtracting predicted weather related changes from observed populations. Where predicted effects of bad weather were positive, predicted non-weather effects were more negative than observed in 2006.

Table 4. Summary of 2006 population changes of WNV-susceptible species on the two Christmas Bird Counts conducted during good weather conditions.

Sacramento CBC					
Species	Abundance (birds/party hr)			% Change in 2005:	
	2005	2004	1995-2004 average	from 2004	from 1995-2004 average
Scrub-jay	1.8	3.2	3.0	-44	-41
Magpie	2.3	6.5	6.7	-65	-66
Crow	10.6	74.1	36.3	-86	-71
Titmouse	0.4	0.5	0.5	-31	-21
Average change				-56	-50

Marysville CBC					
Species	Abundance (birds/party hr)			% Change in 2005:	
	2005	2004	1995-2004 average	from 2004	from 1995-2004 average
Scrub-jay	2.31	2.08	2.15	11	7
Magpie	2.87	4.51	4.3	-36	-33
Crow	17.88	13.41	16.82	33	6
Titmouse	0.67	0.71	0.9	-6	-26
Average change				1	-11

Figure 6. Changes in 2006 abundances of WNV-susceptible and non-susceptible reference species compared to the previous 10-year average.



Species codes are: YBMA = Yellow-billed Magpie, WSJA = Western Scrub-Jay, AMCR = American Crow, OATI = Oak Titmouse, CAQU = California Quail, MODO = Mourning Dove, ACWO = Acorn Woodpecker, BUSH = Bushtit, WBNU = White-breasted Nuthatch, BEWR = Bewick's Wren, NOMO = Northern Mockingbird, SPTO = Spotted Towhee, CATO = California Towhee.

Weather effects on species abundance over 1995-2005 were variable among species (Table 2). Only the scrub-jay consistently showed lower average abundance on counts conducted under bad weather conditions, while the crow showed higher numbers on bad weather days. Both the magpie and titmouse showed variable responses to different types of bad weather, but they showed increased numbers on all types of bad weather days combined. Comparison of 2006 abundances with predictions based on the weather conditions on the count day (Table 3) shows that 2006 abundances for all 4 species were substantially lower (-30 to -50%) than predicted by weather conditions.

Our comparison of differences in 2006 populations across all CBCs relative to the previous 10-year average showed a strong and significant pattern of decline for the four WNV-susceptible species and no similar consistent response for other similar species (Figure 6). Of the 9 WNV-resistant species selected, 6 (67%) showed no significant change in abundance (changes of -5 to +9% in average abundance), while one species (California Quail) increased significantly ($p < 0.001$) and two species (Bush-tit and White-breasted Nuthatch) declined significantly ($p < 0.0001$). This analysis showed that WNV-susceptible species suffered declines in 2006 that were more severe than for other species with similar abundance patterns that are not thought to be WNV sensitive.

The 2006 abundance of the four susceptible species within the Sacramento count area (where weather was good) declined by 31-86% from 2005 and by 21-71% from the species' 10-year average abundances, suggesting that a substantial decline occurred (Table 4). This information, while for a single site, is consistent with a true decline in the population consistent with an effect of WNV. Results for the Marysville count, also conducted under good weather, but where apparent WNV incidence was lower (http://diseasemaps.usgs.gov/2005/wnv/wnv_ca_human.html) showed mixed results, with a decline for the Yellow-billed Magpie, and limited or no effect for other WNV-susceptible species.

DISCUSSION

Limitations on Use of CBC Data to Analyze Localized WNV Effects

Our analysis shows substantial declines in numbers of these four WNV-susceptible species in the 2006 CBC. Unfortunately the severe weather conditions during 2006 confounded the analysis of apparent effects of WNV. Several other limitations regarding the use of CBC data to assess WNV effects are important.

First, LSV count circles have been established nonrandomly and thus may not proportionately survey all habitats and geographic areas accord-

ing to their true abundance. While this proportionality has not been evaluated, the effects may be minor, considering that relatively few habitats (agricultural, urban and suburban areas, annual grassland, oak woodland, riparian, and open water) dominate the area. Similarly, coverage and survey intensity of different areas within count circles may not be equal, although normalizing abundances as birds/party-hr reduces potential bias of this effect (Dunn et al. 2005).

Second, publicity regarding the arrival of WNV and its effects on corvids may have encouraged CBC participants to pay more attention to counting corvids. (Effects on titmice were not widely reported or recognized.) If it occurred, however, this effect would have increased the proportion of the true population counted, and would have had a conservative effect on our conclusions (i.e., made the potential WNV effect less than it really may have been).

Third, the roosting habits of species may obscure accurate assessment of effects. The crow and magpie both roost at night in large flocks. The knowledge by CBC participants of the locations of these roost sites, and the resulting effort expended in conducting counts at and near these roosts, may affect the resulting abundance values. Annual variation in coverage or roosting areas adds observer-based annual variability to estimates, which may obscure actual population trends. Our methods, however, encompass such variation, so that the statistically significant declines that we detected are robust demonstrations of declines beyond observer effects.

Fourth, winter migratory habits of the American Crow likely affect our ability to detect changes in its local population. Although the other WNV-susceptible species do not regularly migrate, resident crow populations in the Central Valley apparently are augmented in winter by birds that migrate from other breeding areas (Verbeek and Caffrey 2002). Thus, effects of WNV on the local breeding crow population may be obscured by augmentation of winter populations with birds from other breeding areas with different WNV histories.

Fifth, the distribution and abundance of WNV apparently was variable and localized within the study area during the study period. While WNV has been recognized to spread over substantial new areas from year to year (National Audubon Society 2005b), its prevalence in any given year varies within regions, including the LSV. In 2005, WNV detections in humans and birds were high in Sacramento but lower in a number of surrounding counties (http://diseasemaps.usgs.gov/2005/wnv/wnv_ca_human.html). In 2006, after our study period, WNV prevalence declined in Sacramento County but increased in Yolo County (http://diseasemaps.usgs.gov/wnv_ca_human.html).

Finally, our use of a reference group of species to compare responses to weather is relatively imprecise. Species to be included in the analysis could be determined by a variety of factors, including habitats used,

foraging or nesting habits, body size, or detectability by counters during poor weather. Nonetheless, we believe that our selection of WNV-resistant species, all of which showed relatively low annual variation in abundance, provides a good reference for comparison to WNV-susceptible species.

Conclusions Regarding 2006 WNV Effects

Notwithstanding the confounding effects of severe weather that occurred during a number of the 2006 CBC counts, our analysis shows population declines in WNV-susceptible species that are beyond those expected from weather effects and consistent with effects of 2006 WNV-based population declines. This evidence included: 1) declines of WNV-susceptible species that were greater than predicted by modeling past weather effects (Table 3); 2) declines that were much stronger than for other similar but WNV-resistant species; and 3) declines that occurred for all susceptible species on the Sacramento CBC, and for the magpie and titmouse on the Marysville CBC, both counts on which weather was not adverse.

The case for the decline of the Yellow-billed Magpie appears strongest, in part because its abundance was predicted to increase under adverse weather conditions observed (Tables 2 and 3). The reasons for this response to bad weather are uncertain. Explanations could be observer-based (e.g., more time spent driving than walking, which could result in observation of more birds/party hr) or species-based (e.g., magpies may become more conspicuous by moving into open in agricultural and turf areas to feed on surfaced earthworms). For example, during January 2006, we observed large flocks of magpies foraging in Yolo County agricultural fields during a severe rainstorm.

The substantial observed decline in WNV-susceptible species on the Sacramento CBC, which was conducted under good weather conditions and within the area recognized as the epicenter of the 2005 WNV outbreak, suggests a WNV effect on populations, particularly for the scrub-jay and magpie. Other evidence of substantial declines in several winter roosting populations of magpies in this area during 2005 (S. Crosbie pers. comm.) also supports the conclusion that magpie populations declined substantially in the Sacramento area in 2005.

Finally, the detection of relatively substantial declines in 2006 populations of the Bushtit and White-breasted Nuthatch on LSV CBCs raises concerns for these species, which have not been previously identified as susceptible to WNV. Although we did not analyze effects of bad weather on these species, their substantial declines in the LSV during 2006 suggest that they should be included in future analyses of WNV effects in this area and elsewhere.

Long-term Implications of WNV

The long-term effects of WNV on susceptible populations are unknown. Despite the rapid continental spread of the disease and dramatic anecdotal accounts of effects, only a handful of scientific studies have evaluated effects on populations. In general, studies have shown no long-term population effects on populations, even in areas where initial effects were substantial (Caffrey 2003, Caffrey and Peterson 2003). If disease resistance develops within populations, the effect of WNV on populations is likely to be relatively short-lived, unless declines are so great as to affect the population's ability to recover demographically or if significant genetic diversity is lost. These species all likely have the reproductive capacity to recover from declines of the magnitude we identified in 2006. In fact, most species have recovered from past declines of similar magnitude caused by other factors (see Figures 2, 3, 4, and 5). As of early 2007, Scrub-Jays sampled in the Sacramento region are finally starting to show evidence of WNV antibodies, suggesting that disease resistance is developing (S. Wright pers. comm.). If declines continue, potential for longer-term effects exist, as suggested by lack of recovery of a small population of Yellow-billed Magpies poisoned elsewhere during ground squirrel control (Reynolds 1995).

Of the susceptible species in the LSV, the Yellow-billed Magpie is of greatest conservation concern, because of its endemic status, restricted range, suggested high-susceptibility to WNV, high rate of apparent decline observed in this study and others (S. Crosbie, S. Smallwood pers. comm.), and highly social breeding and wintering behavior.

CONCLUSION

Numbers of WNV-susceptible species recorded on LSV CBCs clearly declined during 2006. Notwithstanding the confounding effects of severe weather on many counts during 2006, available evidence suggests a high likelihood of WNV-related declines in numbers of Western Scrub-Jay and Yellow-billed Magpie, and likely declines for American Crow and Oak Titmouse. These species, and the Bushtit and White-breasted Nuthatch, warrant continued population monitoring. CBCs should be useful in assessing the annual and long-term status of species, especially since the high proportion of severe weather days seen in 2006 is unlikely to be repeated soon. Evaluation of other data sources (e.g., Breeding Bird Surveys, Great Backyard Bird Count) and focused species monitoring are warranted to better understand local and regional effects over both short-term and longer-term timeframes, and to determine if management actions are warranted.

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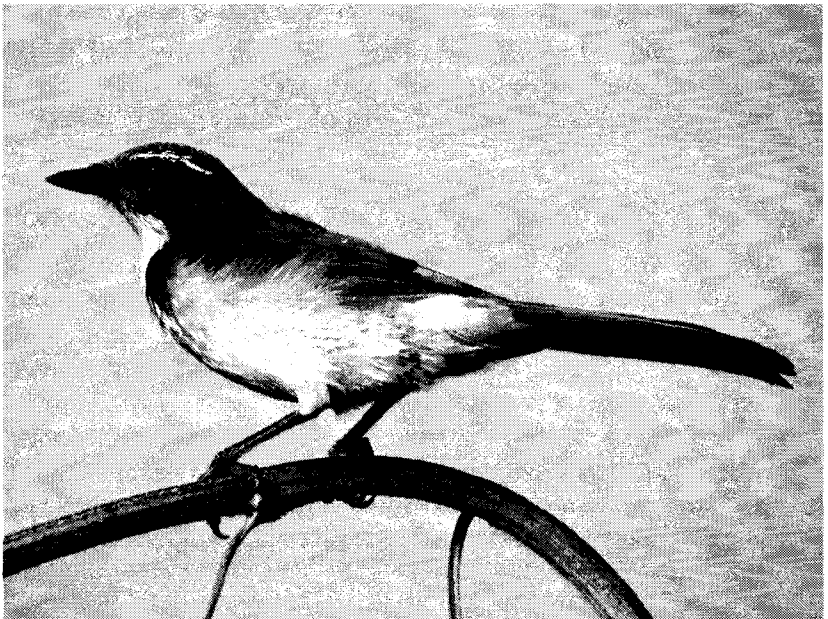


Figure 7. Western Scrub-Jay (*Aphelocoma californica*), Rosemont area, Sacramento County, October 1984.

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