The Impact of West Nile Virus on Birds in California's Hardwood Rangelands[1]

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Abstract

West Nile virus has undergone an unprecedented rate of infection in North America, sweeping from New York to California in four years. It attacked an exceptionally broad range of hosts/vectors over a broad geographic area. In 2004, the California Department of Health Services received approximately 98,000 reports of dead birds, representing tens of millions of birds killed by West Nile virus in California. The rates of dead bird reports in California Hardwood Rangelands varied from 54 $\pm$ 11 birds/km2 in the upper Sacramento River Valley to 3.7 $\pm$ 0.8 birds/km2 in the southern coastal foothills. Overall, about 80 percent of hardwood rangelands were in areas of moderate to high rates of West Nile outbreak. Areas suffering the highest rates of mortality had primarily blue oak and valley oak woodlands, and bird species in blue oak woodlands suffered the greatest potential exposure to West Nile virus.

Keywords: Bird deaths, hardwood rangelands, West Nile virus.

Introduction

California's hardwood rangelands have been challenged by three decades of suburban growth (Bolsinger 1988, Scott 1993, Wadell and Barrett 2005), focusing state woodland policies on habitat conversion and loss (State of California Resources Agency 2003, Hilty and others 2006). Wildlife diseases, in contrast, have failed to generate the global concern directed at suburban sprawl, because they typically occur as localized problems. That changed in 2004, when West Nile virus created the greatest mortality event in the recorded history of California wildlife. The 2004 outbreak defined a new role for infectious diseases in hardwood rangeland ecology and management. In this paper, we summarize the impact and pattern of this emerging disease on the state's woodland bird species.

West Nile virus (WNV) swept North America in four years, infecting the largest number of wildlife species over the greatest geographic area ever recorded for any epizootic. Mortality has been documented for more than 260 native and 110 exotic/domestic species in North America, ranging across all terrestrial vertebrate groups (Komar and others 2003, Marra and others 2004, USGS 2005). Given the wide range of taxa affected by the virus, it appears reasonable to assume that some level of morbidity and mortality occurred in every vertebrate species exposed to the virus and that the signal of this impact should be evident in the wake of the epizootic. Nevertheless, the impact of WNV has been difficult to document in wildlife populations (Caffrey and Peterson 2004).

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West Nile virus is spread primarily by mosquitoes, which become infected with the disease after a blood meal on an infected host. The mosquitoes can then pass the virus onto other vertebrates in subsequent blood meals, and in low percentages onto their own offspring. The amount of virus present in a host's blood (viremia) is critical in its transmission to mosquitoes, as is the ability of the virus to move from the gut to the salivary glands of the mosquito before the mosquito takes a second blood meal. West Nile virus is an old world flavivirus, similar to the encephalitis viruses already found in California and the United States. However, a new strain of WNV, which appeared in localized outbreaks in Israel and Europe in the late 1990s, causes higher levels of viremia in some species of birds (Brault and others 2003, Reisen and others 2005). Hence when WNV reached North America, it could be more efficiently spread among vertebrates with no previous exposure or resistance. WNV can also be passed from prey to predator and between individuals in close contact when the virus is ingested (McLean and others 2001, Nemeth and others 2006). Hence WNV has a number of pathways for movement, amplification, and persistence.

A number of North American birds showed little or no resistance to WNV when it was discovered in New York in 1999 (Komar and others 2003). American crows (for scientific names see table 1) and other peri-urban bird species helped to spread the disease in urban and suburban areas (Reisen and others 2005). It was detected for the first time in California in July 2003; by October 2003 it was detected in the cis-montane region of Southern California. A year later, it had been reported from all of the counties in California.

After its discovery, West Nile virus was systematically monitored across the United States, and an extensive surveillance program was instituted by the California Department of Health Services (CDHS 2003). The CDHS West Nile Virus Task Force collected more than 98,000 dead bird reports in 2004, providing data on the spread and impact of the disease on birds in California. These data allow us to examine the impact of West Nile virus on the woodland bird species of California. Here we attempt to estimate the overall impact of WNV on woodland bird species and to describe the pattern of the 2004 WNV outbreak across California's hardwood rangeland.

Methods

We used dead bird data from the California Department of Health Services West Nile Virus Hotline (hereafter referred to as the Hotline) to calculate the impact of West Nile Virus on woodland birds in California. The Hotline, a telephone and Internet system, received reports of dead birds from individuals across the state of California. The primary goal of the Hotline was to guide the WNV dead bird testing program, providing early detection of WNV as it moved into communities across the state. A secondary goal of the system was to use dead bird reports (primarily crows and other corvids) to monitor the patterns of WNV outbreaks (CDHS 2003). Citizens were urged to use the system with public service announcements, but many reports came through local animal damage control agencies and mosquito abatement districts. Information flowed through a central CDHS office in Richmond, California. Callers provided the street addresses, dates, numbers, and in a surprising number of cases, the species of dead birds they found around their neighborhoods and houses. From January to October 2004, approximately 77,000 callers had reported approximately 90,500 bird deaths. At the height of the 2004 WNV outbreak, CHDS employed more than 20 staff members to receive phone calls, assisted by 8 volunteers from the UC Cooperative Extension Master Gardener's Program in Riverside County.

The CDHS dead bird reports were voluntary and provided a large but non-systematic sample of the actual mortality caused by WNV. Several authors (Balcomb 1986, Philibert 1993, Tobin 1990, Ward 2006) have identified biases in dead bird detection, including (1) bird species are differentially detectable, given their size, plumage, habitat use/occurrence; (2) bird carcasses can be detected for different periods of time, based on decomposition conditions (e.g., insects, moisture), and vertebrate scavengers; (3) birds can die in places where they will not be detected; (4) the number of observers impacts the detection rates and estimates of density. Sick birds also can be removed from detection when they are eaten by predators or when they move away from their point of infection. Ward and others (2006) also points out that not all detections are reported. In our case, each dead bird report required (1) that the caller knew about the Hotline or was directed to the Hotline by a third party; (2) that callers were motivated to provide information; and (3) that callers succeeded in getting their information into the system. This was an exceptionally large task with a large number of potential disruptions. Nevertheless, the Hotline received more than 90,000 calls during the 2004 WNV outbreak, and this volume of dead bird data allowed us to partition and sub-sample the data to detect patterns of the epizootoic.

We geo-coded the addresses provided by callers using ARCGIS© software in order to describe the spatial pattern of bird mortality in California woodlands. We grouped these data points into sample units by census tracts. Because raw data was biased by the number of observers available at any location, we standardized observations across sample points by dividing the number of dead bird reports within each census tract by the number of single-family detached-housing units within its boundaries. We used single-family detached houses rather than total households because very few records came from multiple family housing. Data on single-family housing were taken from Tiger files of the U.S. Census Bureau 2000 census (U.S. Census Bureau 2000). In order to make these numbers ecologically relevant, we created a reference unit of dead bird reports per 1,000 houses, which is equivalent to an area of approximately 250 acres or 100 hectares, based on average housing densities in California. All dead bird numbers in this paper are reported in these units. Next we divided the observed rate of reporting by 0.27 for urban areas and 0.1 for rural areas to account for detection and reporting errors (Ward and others 2006).

We then corrected these estimates using the ratios of West-Nile positive dead birds to the total number of dead birds tested between 1 January and 27 October 2004 by the CDHS WNV Surveillance program. During this period, CDHS tested approximately 5,034 dead birds for WNV. Of these birds, 62 percent (3,105) tested positive for WNV (Riesen 2005).

There remain several shortcomings of this protocol. The system was designed to detect the initial cases of the disease and thus some birds were tested from areas before the disease outbreak occurred as well as after WNV outbreaks had subsided in October. Furthermore, testing ceased in areas with particularly high rates of bird death because the number of dead birds available for sampling threatened to swamp the testing system. Hence, the reported proportion of WNV-positive birds among dead birds submitted for testing is a conservative estimate of the rate of mortality. In addition, there is no test for the absence of WNV. Birds that tested positive for WNV were unambiguous and provided surveillance information for CHDS program; however, birds that were scored negative included both uninfected birds and birds that had been killed by WNV where the virus escaped detection. Finally, some portion of the birds with the virus present may nonetheless have died of other causes unrelated to WNV, creating an over-estimate of the mortality caused by WNV.

We used USGS Breeding Bird Censuses (BBC; http://www.pwrc.usgs.gov /birds/bbc.html) to estimate the relationship between bird density and the corrected dead bird reporting rates in sample areas. These censuses were conducted on 10-ha plots (n=247) across California, starting in 1937. They provide the broadest estimates of the density of breeding pairs of California species in urban and woodland areas. In addition, there are several estimates of urban bird densities in the published literature with numbers ranging from 1,000 (ref) to 1,300 (ref) breeding pairs/100 ha. We first calculated worst-case, median-case, and best-case estimates of the impact of West Nile virus in urban areas for all species combined. We then calculated the same three values for species in which reasonable data exists to estimate their urban densities (number of breeding pairs and offspring per year per unit area) and their mortality to WNV.

Results and Discussion

Dead Bird Reports

Californians reported approximately 98,500 dead birds to the CDHS West Nile Virus Hotline from January through October 2004. About 80 percent of these reports came from single calls to the Hotline, while 20 percent came from multiple reports from single callers. Approximately 24 percent of these reports came from hardwood rangelands, 60 percent from suburban communities in Southern California, 10 percent from suburban communities in Northern California, and the rest from mountain and desert areas.

Correcting for Detection and Reporting Errors

If the numbers of dead bird reports is corrected to account for detection and reporting errors, then the corrected estimate of WNV-related deaths in California rises to about 640,000 birds killed in the areas where reporting occurred. The corrected factors (0.27 for urban and 0.1 for rural) should be considered conservative because both the detection and reporting rates in California dead bird reports are likely to be lower than those of Ward and others (2006), since their rates were calculated for dead crows with contact information printed on the carcasses placed in observable locations by researchers rather than dying in natural situations. Most passerines are much less conspicuous than crows and are likely to die in inconspicuous refuges. In addition, most dead bird records came from callers who were motivated by concern over WNV more than the death of yard-birds (T. Scott, unpublished data). Indeed, 94 percent of individuals filing dead bird reports made no subsequent reports to the Hotline, whereas, about 1 percent of callers made >3 calls to the Hotline. Furthermore, a substantial proportion of individuals failed to contact the Hotline, either because they did not know the Hotline existed, failed to connect to the Hotline, or were unmotivated to call. Finally, public information was focused on a subset of birds (corvids, raptors, icterids, finches, and sparrows), reducing the extent and numbers of other taxa reported. The number of callers who reached the WHV Hotline but did not leave any information (approximately 35 percent) provides a minimum estimate of the number of individuals who observed bird deaths but failed to provide information. At the present time, other factors cannot be estimated.

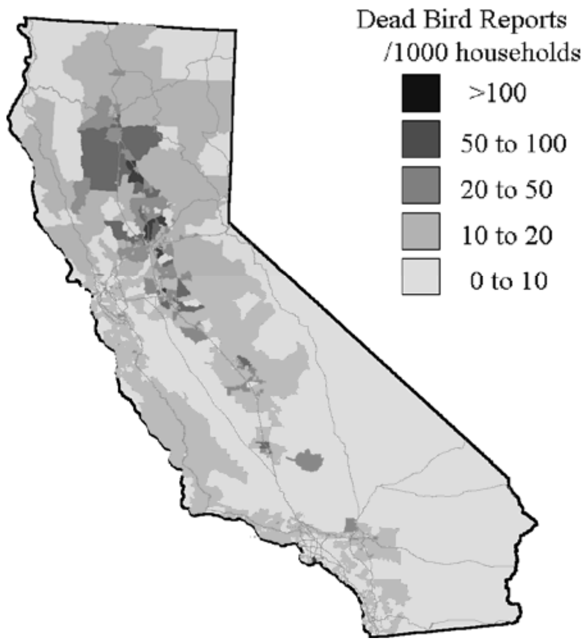

Figure 1—Statewide pattern of the 2004 California Department of Health Services West Nile Virus Hotline dead bird reports (non-crow), grouped by U.S. Census Bureau 2000 census tracts (see text). Densities are reported as dead birds per 1,000 households, approximately equivalent to dead birds per 100 ha. Interstate and major state highways are shown in gray.

Comparing Dead Birds Records With Birds Tested for WNV

Sixty-two percent of dead birds tested in California in 2004 were positive for WNV (Reisen 2005). However, birds from areas and dates inclusive of WNV outbreaks (15 May to 30 September) had an overall higher rate (68 percent) of WNV-positive birds (2,198 positive results among 3,233 birds). The proportion of WNV-positive dead birds ranged from 35 percent for dead raptor (hawks and owls) species to 100 percent of western bluebirds (*table 1*). About 60 percent of all non-corvid passerine birds tested positive for WNV; however, only about 50 percent of common backyard species including house sparrows, house finches, and California towhees) were positive for the virus, compared to 68 percent of less common species.

We assume that the proportion of positive/tested birds was a function of (1) the prevalence of WNV, (2) the exposure and infection rate of each species, (3) the susceptibility of each species to WNV-related mortality, and (4) the likelihood that birds submitted for testing died of other causes. Dead raptors, because of their size, color, and prestige, may have drawn more attention; hence raptors may have been submitted more frequently than passerine birds, and raptors that died of non-WNV related causes may have been better represented than passerine species that died of non-WNV related causes. Even with this bias, species of dead raptors had higher proportions of WNV-positive individuals than would be predicted, based on studies of experimental infection (Nemeth and others 2006a, 2006b).

Table 1—*Proportion of individuals that tested positive for WNV, adjusted for dates when West Nile virus was present in sampling areas. Calculated from the subset of bird tested within the WNV outbreaks (15 May to 30 September).*

Species	Proportion WNV-Positive [a]	Dead Birds Tested
Western Bluebird (*Sialia mexicana*)	1.00	6
Brewers Blackbird (*Euphagus cyanocephalus*)	0.91	12
Yellow-billed Magpie (*Pica nuttalli*)	0.87	288
Black-billed Magpie (*Pica pica*)	0.85	7
Black-headed Grosbeak (*Pheucticus melanocephalus*)	0.81	11
American Kestrel (*Falco sparverius*)	0.8	15
Western Scrub-Jay (*Aphelocoma californica*)	0.79	630
Mourning Dove (*Zenaida macroura*)	0.72	11
American Robin (*Turdus migratorius*)	0.70	24
Steller's Jay (*Cyanocitta stelleri*)	0.69	85
American Crow (*Corvus brachyrhynchos*)	0.69	1711
Red-tailed Hawk (*Buteo jamaicensis*)	0.66	32
Acorn Woodpecker (*Melanerpes formicivorus*)	0.60	10
House Sparrow (*Passer domesticus*)	0.54	37
California towhee (*Pipilo crissalis*)	0.53	15
Black Phoebe (*Sayornis nigricans*)	0.50	6
Northern Mockingbird (*Mimus polyglottos*)	0.50	8
Western Screech Owl (*Megascops kennicottii*)	0.50	8
House Finch (*Carpodactus mexicanus*)	0.46	61
Cooper's Hawk (*Accipter cooperii*)	0.40	51
Common Barn Owl (*Tyto alba*)	0.38	47
Red-shouldered Hawk (*Buteo lineatus*)	0.30	23
Great Horned Owl (*Bubo americanus*)	0.29	17
Common Raven (*Corvus corax*)	0.25	108

Experimental infections of birds indicates that magpies and other corvids have lower resistance to WNV than many species of passerine birds (Komar and others 2003); this susceptibility is mirrored in the CDHS data by high values for all species of corvides with the exception of common ravens, which did not exhibit high prevalence of WNV. The number of WNV-positive house sparrows was far higher than would be expected, given their moderately low rates of mortality during experimental infections with WNV (Reisen 2005). House finches had a lower rate of WNV-positive birds than house sparrows, even though they appear to be more susceptible to the WNV (Reisen 2005). These results suggest that common species may have had higher proportions of non-WNV related deaths reported to the Hotline because they occur in much higher densities around suburban housing.

If we assume that the proportion of WNV-positive individuals represents a reasonably close estimate of the proportion of WNV-related deaths in the dead bird reports, then it is necessary to reduce the number of reports by the values reported in table 1. For species with small sample sizes, we assume that the overall proportion of WNV-related deaths was 68 percent of the sample for non-corvid passerines and 35 to 40 percent for non-passerines. If the ratio of WNV-positive dead birds to total dead birds is applied by species to the dead bird reports, then the total number of dead bird reports to overall estimates of dead birds reports involving WNV would drop to 61,500. With this as a corrected estimate of dead bird calls, the corrected estimate of

WNV-related deaths in California drops to about 400,000 birds killed in areas where reporting occurred.

Sampling Units for Dead Bird Reports

Almost all dead bird reports (>99 percent) were from single-family detached housing properties, such that sampling efficiency is linked to housing density. Approximately 51percent of 2000 census tracts in California had suburban housing densities (5 to 18 dwelling-units/ha); however, these census tracts cover only about 3.3 percent of the state's land areas. An additional 0.3 percent of the land area has urban housing densities (>18 units/ha) and 5 percent is in ranchettes (1 to 5 units/ha). The majority of the state land area (91.4 percent) is in census tracts with rural/wildland densities of <1 unit/ha. If all suburban housing areas are considered as the sample area, then dead bird reports covered approximately 13,400 km^2 or about 3.5 percent of the land area of California.

In order to report dead birds from rural clusters of housing, it was necessary to report data by housing unit rather than aerial measurements. In suburban census tracts (n=3551), density of housing was 10.01 + 3.3 units/ha, or 1,000 houses to 100 ha. The reporting rates were also equivalent with 5.2 + 8.0 reports/1,000 households and 5.1 + 8.4 reports/100 ha (R2 = 0.83; $p < 0.001$). Because these two units were equivalent, we used dead bird reports/1,000 houses to analyze rural/wildland census tracts where report/ha becomes less useful because of the sparse and highly variable numbers of observers.

Birds Reported Per Sample Unit

Statewide, the number of birds/1,000 houses (100ha) averaged 7.1 + 37.2 (SD) among U.S. Census tracts (n= 7,037). Corrected for reporting rates and non-WNV dead, a minimum estimate would be a statewide average of 0.18 dead birds/ha in urban (sampling) areas. This sample distribution, however, is a negative binomial, and the median of 5.01 dead birds/1,000 houses is a better descriptor for WNV dead bird reporting rates. About 17.6 percent of census tracts had >10 dead bird reports/1,000 houses and 0.8 percent of census tracts had >50 dead bird reports/1,000 houses. The highest reporting rates were grouped around 300 dead bird/1,000 houses, or 3 dead birds/ha, while 0.25 percent (35) of census tracts had reporting rates >100 dead birds/1,000 houses. About one-third of the dead bird reports could not be geo-referenced, so it is possible that the number of census tracts without dead bird reports could be substantially lower than 18 percent, and the median number of dead birds/1,000 households could have been up to a third higher (~7 reports/1,000 houses).

Non-Crow Deaths Per Sample Area

The number of non-crow bird deaths/1,000 houses was substantially lower than total (with crows), averaging 3.2 + 6.7 (SD) among census tracts (n=7,037). Corrected for reporting rates and non-WNV-positive dead, yields a minimum statewide estimate of 0.08 non-crow deaths/ha in urban (sampling) areas. The median of non-crow dead reported was 1.7 birds/1,000 houses. About 17.6 percent of census tracts had reporting rates >10 dead birds/1,000 houses, and 0.3 percent of census tracts had reporting rates >50 birds/1,000 houses. The highest reporting rate was around 60 dead birds/1,000 houses.

Non-Crow Mortality in Suburban Communities

There are relatively few estimates of urban bird densities, but Breeding Bird Census (BBC) data suggests that the minimum number of breeding pairs of California birds in suburban areas is probably on the order of 660 pairs/100 ha plot (based on an average of 81 + 14 (SD) pairs/10 ha plots in five BBC plots). The maximum density of breeding pairs is more variable. However, the maximum density of suburban birds is unlikely to exceed 1,400 pairs/100ha found in riparian oak woodlands (based on 140 + 63 singing males/10 ha plot; n=14). The density of suburban birds reported in the literature is intermediate at about 1,100 pairs/100ha (Blair 1994).

Given these densities, the overall density of birds in reporting areas could have ranged from 1,950 birds/100 ha (600 equal sex ratio, 1 young/pair) to 5,600 (1,400 pairs, equal sex ratio, averaging two offspring per pair), with an intermediate density of about 3,800 birds/100 ha (1,100 pair/ha, 1.5 young per pair). The census tract average for non-crow dead bird reports can be adjusted up to about 8 dead birds/100 ha, given minimum error in detection and reporting. If these numbers are correct, then minimum proportion of non-crow birds (all species combined) killed across census tracts in urban areas could have ranged from about 0.03 percent to about 0.1 percent across the state. Census tracts in the areas with the highest reporting rates could have suffered a minimum of 2 percent death rates. Census tracts with exceptionally high reporting (top 0.2 percent) could have suffered minimum mortality rates of 2 to 25 percent.

Geographic Variation in Reporting Rates

Suburban areas in the Great Valley had the highest reporting rates for non-crow bird deaths during 2004 (*table 2*), with an average of 21.8 + 17.9 reports/ha. At the other extreme, the coastal areas of Southern California had reporting rates of 0.9 + 1.3. In general, low-elevation interiors area of California with large amounts of surface water had the highest reporting rates to the WNV Hotline; areas that were either dry (deserts) or cool (Sierra Nevada and coastline) had far lower rates.

Table 2—*Regional distribution of dead birds reported to the West Nile Virus Hotline by U.S. Census Tract in California (January to October 2004). Averages represent observed dead-bird-reports/1,000 households.*

Region	Urban Rates Mean ± SD (n)	Rural Rates Mean ± SD (n)
Central Valley		
Northern	21.8 + 17.9 (12)	19.7 + 15.5 (62)
Central	6.0 + 6.0 (251)	10.2 +17.4 (545)
Southern	5.5 + 3.4 (74)	8.8 + 7.9 (250)
Coast Ranges		
North	3.9 + 4.1 (26)	6.3 +4.0 (106)
Central	2.4 + 2.4 (59)	4.3 +3.0 (155)
Sierra Foothills		
Northern	3.5 +1.8 (5)	5.6 + 2.8 (75)
Southern	4.6 + 1.8 (7)	3.1 + 2.4 (14)
Southern California		
Interior	12.5 + 14.7 (390)	19.7 + 68.8 (522)
Coastal	0.9 + 1.3 (396)	11.3 + 18.6 (459)
Northeastern California	5.0 + 2.4 (9)	4.3 + 3.5 (16)
San Francisco Bay Area	1.4 + 1.9 (612)	3.8 + 7.8 (215)

Overlap Between Hardwood Rangelands and WNV

About 84 percent of California's hardwood rangelands was within 10 km of a reported WNV-positive dead bird. More important, 27 percent of hardwood rangelands occurred within census tracts where the strongest outbreaks of WNV were recorded (*table 3*). Blue oak and blue oak/pine woodlands had the highest overlap with WNV outbreaks (40 and 34 percent), while coastal oak and valley oak woodlands had the lowest overlap (5 and 1 percent of their respective areas). Valley oak woodlands have not been mapped for Central Valley riparian areas such as the upper Sacramento River. These areas had the highest recorded levels of dead birds and were probably the most heavily affected by West Nile virus. All of the highest areas of outbreak occurred within hardwood rangelands in areas dominated by blue oak woodland.

Estimating the impacts of WNV on woodland birds

The dead bird data area may be insufficient to estimate the population consequences of WNV for most woodland species, with two exceptions: the western scrub-jay and yellow-billed magpie. Reported deaths of both species were concentrated in the northern and central parts of the Central Valley, with 5 to 10 times the level of mortality found in coastal regions.

For western scrub-jays, it appears populations may have suffered over 50 percent mortality in areas of the Central Valley (*table 3*), and probably suffered local extirpations in all regions in which they occur. Reported mortality was far lower in coastal area (<1 percent), and was relatively low (<10 percent) in the central coast ranges, northeastern California, Southern California interior, and the southern Sierra foothills. Statewide, we estimate that this species suffered a minimum 2 percent population decline from WNV.

Table 3—*Regional distribution and estimated mortality of western scrub-jays based on dead birds reported to the West Nile Virus Hotline (January to October 2004). The number of U.S. Census Tracts in each sample are listed in table 2. High, intermediate, and low population densities are taken from literature (Curry and others 2002) see text. Estimate mortality rate (Est.) is based on reporting rates (0.27), WNV-positive rates (0.80), proportion of records geo-referenced (0.7).*

Region	Urban rate[a]	Rural rate[a]	Mean reported mortality[a]	Est. dead[a]	Percent dead by population density		
					High	Int.	Low
Central Valley							
Northern	4.7 ± 3.1	6.6 ± 4.5	6.3	26.9	9.8	19.2	29.9
Central	1.0 ± 1.1	1.7 ± 3.8	1.5	6.4	2.3	4.5	7.1
Southern	1.1 ± 1.2	2.0 ± 2.8	1.8	7.5	2.7	5.4	8.3
Coast ranges							
Northern	0.3 ± 0.7	0.8 ± 1.2	0.7	2.9	1.1	201	3.2
Central	0.1 ± 0.3	0.3 ± 0.6	0.3	1.2	0.4	0.9	1.4
Southern	0.1 ± 0.2	0.1 ± 0.3	0.1	0.2	0.1	0.2	0.3
Sierra foothills							
Northern	0.3 ± 0.5	1.1 ± 1.3	1.0	4.4	1.6	3.1	4.9
Southern	0.1 ± 0.5	0.5 ± 0.6	0.6	2.7	1.0	1.9	3.0
NE California	0.5 ± 0.8	0.6 ± 0.9	0.6	2.4	0.9	1.7	2.6
S interior	0.2 ± 0.5	0.5 ± 1.0	0.4	1.7	0.6	1.2	1.8
SF Bay area	0.1 ± 0.2	0.2 ± 0.7	0.1	0.5	0.2	0.3	0.5

[a]number of dead birds per 1000 houses or 250 ha.

Overall mortality among yellow-billed magpies, a California endemic, is more difficult to quantify because they nest in aggregations and often flock during the non-breeding season. However, the highest reported rates of magpie deaths (163 dead birds/1,000 houses in the central portion of the Central Valley, 49 dead-birds/1,000 houses in the northern Central Valley) would be sufficient to cause extirpation in typical population densities of the species (Reynolds 1995). The median reported rate of magpie deaths in the Central Valley census tracts (2.1 dead birds/1,000 houses) would result in a 40 percent decline in a typical population (6 pairs/100 ha) of this species.

Conclusions

The overall distribution of dead bird reports suggests that West Nile virus spread across the state but did not have a uniform impact across the state's hardwood rangelands. Dead bird reports were most frequent in the Central Valley, but appear to have been concentrated in hotspots that occurred in all types of hardwood rangeland. Some of these hotspots were sufficiently severe to cause local extirpations in at least two species of corvids, the western scrub-jay and the endemic yellow-billed magpie. At least 13 other species (*table 1*) also exhibited sufficiently high numbers of dead birds that tested positive for the presence of WNV that they are also likely to have suffered local extirpations. However, the majority of areas in California had dead bird reporting rates that would suggest mortality rates of <10 percent, which is perhaps why large-scale population declines were not reported among birds California's hardwood rangelands in 2004. The greatest numbers of dead birds were reported from the areas with the hottest summertime temperatures. High ambient temperatures increase the efficiency of mosquito transmission of WNV and shorten the development time of mosquitoes (Reisen and others 2006), which provides a plausible explanation of why hardwood rangelands in the Central Valley suffered the greatest impact of WNV and may be more susceptible to future invasion of mosquito-born viruses such as dengue or malaria.

Table 4—*Regional distribution of dead yellow-billed magpies reported to the West Nile Virus Hotline by U.S. Census Tract in California (January to October 2004). Rates are dead magpies reported per 1000 households.*

Region	Urban Rate	Rural Rate	Max. Rate
Central Valley			
Northern	8.90 + 10.5	5.2 + 9.54	48
Central	0.70 + 1.45	2.3 + 11.01	163
Southern	0.06 + 0.42	0.16 + 1.20	15
Central coast ranges	0.05 + 0.25	0.06 + 0.25	2
Northeastern California	0.60 + 1.22	0.04 + 0.14	3
San Francisco Bay Area	0.05 + 1.10	0.03 + 0.20	29

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