Merlin photo by George Jameson.

Effects on Wildlife

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The Situation

We still don't know much, yet, about WNV's actual effects on wildlife populations. Our efforts to document impacts continue to be hampered by the limited information available; only a couple of papers have been published so far on populations of individually-marked birds, where individuals had been under observation both before and after exposure to WNV (see Field Studies, below). Because lots of birds live in areas unoccupied by humans, and sick birds of all kinds tend to seek out secluded, quiet areas, those that are found dead represent only a small, biased fraction of those that have died. The understandable focus on humans by state health departments and the prohibitive costs of large-scale animal testing have also severely constrained our ability to even estimate the loss of wildlife.

The Setting

We know that the strain of WNV that was introduced to the United States in 1999 is extremely "virulent" (highly pathogenic): not only can it cause severe disease in infected individuals, but it can also somehow achieve a higher "viremia" (the level of virus particles circulating in the blood of infected hosts) than our native arthropod-borne viruses[1]. Thus **some hosts circulate unusually high levels of virus particles, which infect a greater number and more types of mosquitoes**. This increases local virus transmission and puts more birds, humans, and other animals at risk of infection.

We also know that the virus is capable of overwintering; even though mosquitoes become inactive during the winter months in temperate regions, the virus has reappeared each spring since 2000 to begin transmission cycles again. Virus particles were isolated from hibernating female mosquitoes in New York City in February 2000[2] and more recently in such places as Lehigh County, PA, and Monmouth County, NJ, in the winter of 2003[3,4]. In addition, infected female mosquitoes can produce infected eggs (see "The Virus: How is WNV spread from host to host?"), and these may then overwinter (see "The Vectors: Mosquitoes, in brief"). Much remains to be found out about other possible means by which the virus may persist over winter months, and scientists view this as a particularly important piece of the WNV story.

We know that individuals of more than 290 species of birds and 30 species of mammals have become infected since 1999, of which **at least 220 bird species and 20 mammal species are North American residents. (American Alligators have been infected, as well.)** The list maintained by the USGS National Wildlife Health Center includes all species known to have contracted WNV in the wild and under captive and farmed conditions in North America since 1999.

Yet knowing which species are capable of being infected doesn't tell us much about WNV's effects, if any, on their populations. Different species react differently to being infected (see "The Victims") – in some, you can't even tell that individuals *are* infected - and even within species, as in humans, the responses of individuals can vary dramatically. Under laboratory conditions, corvids (crows, jays, and magpies) suffer high mortality: 39 of 40 experimentally infected American Crows died[9,34,44], as did three of three Black-billed Magpies, three of four Blue Jays, and five of nine Fish

Crows[9]. Of other species infected under lab conditions, mortality for two House Finches and two Ring-billed Gulls was 100%, whereas members of 19 other species fared slightly to much better[9].

Those of us interested in attempting to document WNV's effects on birds and other animals have our hands tied at the moment; many of the sources of information are indirect, and not of much help. Things will undoubtedly become more clear in the next few years, as the short- and long-term impacts of WNV's presence unfold.

Sources of Information

Dead Birds:

Lots of dead birds have been reported to authorities since 1999, but the birds found dead by people are a biased sample of those that have died – they tend to be members of species that occur in habitats occupied by humans, and of those, they tend to be the most conspicuous ones (bird carcasses generally don't last long on the ground - they are often quickly scavenged by other animals); carcasses of large or colorful species are more likely to be found before being scavenged. In addition, most public health departments eventually quit monitoring dead birds, sometimes after only one or two local birds tested positive, because of their focus on human health and the tightness of their budgets. Even if we did have solid "dead bird" data, we have no idea yet about the relationships between the numbers of individual birds found dead by people and the numbers of different species that have actually died.

One of the few things we *do* know about actual avian mortality as a function of West Nile virus is that the 14,122 dead birds that tested positive nationwide in 2002[5] , and the 12,066 that did so in 2003[37], represent only "the tip of the iceberg;" the actual number is likely 100-1000 times higher (Nick Komar, arbovirus specialist at the Centers for Disease Control and Prevention).

We also know that American Crows are being hit hard; from 1999-2002, more than 57,000 dead crows were collected by authorities[1,5,6,7], and thousands more were discovered but uncollected. Recent data suggest that the number of crows that have been found may underestimate the number that have died by a factor of ten[12].

Limited data suggest that WNV may have contributed to the large numbers of White Pelicans and Ring-billed Gulls found dead in the U.S. in 2003[38], but documentation of possible population-level effects awaits further study. Preliminary data from the field (see below) indicate Greater Sage Grouse are experiencing high WNV-related mortality.

Outbreaks in Captive Situations:

Two papers have been published on the effects of WNV outbreaks at captive breeding facilities, and both provide some scary information. The data below are informative, and they may point to species on which we should keep our eyes (and possibly direct our management efforts), but they do not, by themselves, enable us to assess, or estimate, population impacts in the wild.

Shrikes: In August of 2002, WNV reached a **captive breeding facility** (at the Toronto Zoo) for endangered **Eastern Loggerhead Shrikes** (the migratory subspecies of the Loggerhead Shrike, of which only an estimated 100 pairs remain in the wild in North America)[46]**. Forty-three shrikes were in residence**, with access to outdoor aviaries. **After the first two shrikes died**, all individuals were confined to indoor areas to prevent exposure to mosquitoes, and all were housed individually. **Three more shrikes died over the next several days, and the bodies of all five victims were riddled with viral particles**[46].

None of the survivors had antibodies in their blood, suggesting 100% mortality (no individuals had been exposed and survived). At the time of testing for antibodies, **all surviving shrikes were**

vaccinated with the "horse" vaccine (see "The Virus: What about a vaccine?"), and **84% subsequently produced antibodies**. Thus vaccination against WNV will likely be incorporated into management strategies for this species, at least under captive conditions[46].

Owls: During late summer of 2002, an outbreak of WNV at the **Owl Foundation in Ontario, Canada**, caused a high number of owl deaths. **There were 245 owls in residence (but 10 were kept inside), of which 108 died** between July 26-September 28[47]. The foundation was experiencing a louse infestation at the time, to which some of the early owl deaths were attributed, and thus not all carcasses were tested for WNV.

If you link to the article, you can see more details about more species than reported here, but **owls with northern native breeding ranges suffered high mortality: Snowy Owls, Northern Hawk Owls, Great Gray Owls, Boreal Owls, and Northern Saw-whet Owls all experienced WNV-related death rates of over 90% (the number at risk for each species ranged from 11 to 27)**; medium-large body size may have contributed to exposure rate[47]. **For no other species (of 12 other owls) did death rate exceed 17%, and some species had 100% survivorship. Of the species that experienced low WNV-related mortality, many individuals had antibodies in their blood, indicating their capability to survive exposure to WNV**[47].

Prevalence of Infection in Recovered Carcasses:

Data from two "passive" surveillance studies provide windows onto the possible relationships between avian mortality and WNV across relatively large areas: **in both New York State and Kentucky, thousands of bird carcasses were tested and the percentage of each species infected by the virus determined**. The data are biased, again, by the fact that people tend to find the bodies of some kinds of birds more often than others. It is also the case that being infected with WNV isn't the same as dying from WNV (infected birds may have died from other causes), yet a high prevalence of infection suggests that WNV may be contributing to mortality. Thus the results from these studies provide insight into the possible role that WNV has played in the deaths of individuals from different species.

American Crows photo by Carolee Caffrey. Both members of this pair, together since at least 1998, survived the first WNV season in Stillwater, OK, as did their one-and-a-half year old daughter and three young of the year. One year later, however, only the male breeder – on the left here – was still alive.

In New York, **more than 12,500 birds from 213 species were examined**[8]. Although the authors of the paper demonstrate for crows that the prevalence of infection varied seasonally – zero during winter months, but 78% during September – they provided only combined totals for the other birds they mention. Thus the following prevalences reflect WNV's possible contribution to *annual* mortality. **Species with the highest prevalences of infection were American Crows (44%, n=5950), Merlins (33%, n=15), Kestrels (33%, n=33), Fish Crows (34%, n=116), Blue Jays (29%, n=1,284), House Finches (23%, n=43), Great Horned Owls (14%, n=63), and House Sparrows (14%, n=427)**. Among other dead songbirds found and tested in New York, only 3% were found to be infected with WNV[8].

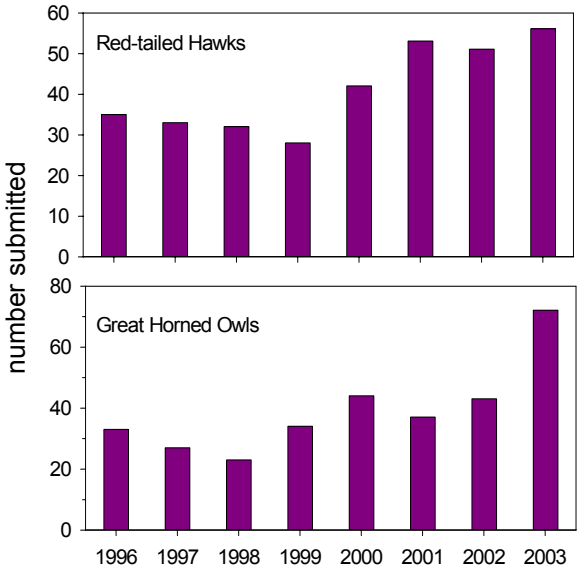
In Kentucky, **1,549 birds from 69 species were tested during the summer and fall of 2002**[10]. **For species for which at least 10 carcasses had been tested, some showed high incidences of infection: American Crows (87%, n=110), Eastern Bluebirds (86%, n=21), and Blue Jays (80%, n=219). Approximately half of all Northern Cardinals (59%, n=58), House Finches (50%, n=80), House Sparrows (55%, n=258), and American Goldfinches (43%, n=14) were infected**. Lower, but still potentially meaningful prevalences were found in Common Grackles (34%, n=124), American Robins (28%, n=198), Swainson's Thrushes (25%, n=12), Northern Mockingbirds (21%, n=14), Mourning Doves (17%, n=135), and Ruby-throated Hummingbirds (17%, n=12). **Several raptors**

showed high levels of infection, although the sample sizes were smaller: Red-shouldered Hawks (100%, n=4), American Kestrels (83%, n=6), Red-tailed Hawks (71%, n=7), and Great Horned Owls (86%, n=7)[10].

These data are suggestive, but do not provide much insight into actual population responses to WNV; we don't know from where the carcasses came, and even if we did, we don't know how many individuals (of the different species) were in those populations to begin with, the actual numbers that died from WNV-related causes, or anything about the abilities of different populations to compensate for WNV losses. Thus the prevalence of infection among carcasses doesn't tell us much, either, about WNV's effects on bird populations.

Rehab Data:

If we were able to systematically collect data from rehabbers across the country, we might be able to document trends of increasing submissions of impacted species that occur in places where people might find them. For example, data (below) on submissions of Red-tailed Hawks and Great Horned Owls to Tri-State Bird Rescue and Research (TSBRR) suggested possible increases in "WNV years" (2000 and thereafter; through 2003), but the number of Great Horned Owls submissions dropped to 21 in 2004 (during which 59 Red-tailed Hawks were brought in to TSBRR). Again, we don't know the relationships between the number of individuals found and the number that actually became ill or died from WNV infections.



Tri-State Bird Rescue and Research Inc, Newark DE

Field Studies:

American Crows photo by Carolee Caffrey. At sunrise, this family had just arrived at our trapping site (directly below them). Moments later, all five dropped to within range and were caught underneath our rocket net; not a common occurrence with these wary birds. This whole family disappeared within a month of the arrival of WNV in 2002.

Field studies of marked individuals offer direct views of some of the impacts of WNV on bird populations, but not many survivorship and mortality data have yet been published. Surprisingly, some of the most rigorous data available at the moment have to do with crows, which are among the least studied birds in North America (due, in part, to their uncanny ability to resist capture, which is required if individuals are to be marked). **In one of the few populations of marked American Crows in the U.S.,** in Stillwater OK, 46 of 120 individuals disappeared within 6 weeks of the arrival of WNV in late summer 2002[11]; 39 of the disappearances were estimated to be WNV related (i.e., **approximately 33% of the population died within 6 weeks of exposure**)[12]. The following year, crows in this population began disappearing in June and by November, approximately 56 of 78 crows (65%) had disappeared for WNV-related reasons; added to "natural losses," 82% of young crows were dead by their first fall, which resulted in the **loss of 72% of the population over one WNV season**[12]. Data from two other studies also indicate American Crows are dying at rates high enough to disrupt population dynamics (in both of these studies, radio transmitters on crows enabled their carcasses to be found): in Champaign-Urbana, Illinois, in 2002, **19 of 28 (68%) mostly hatch year crows died and tested positive for WNV**[13], and in Ithaca, NY, **WNV claimed the lives of 35-40% of approximately 150 crows in 2003**[14].

American Crows have been shown to be vulnerable to infection via every possible transmission route examined so far (see "The Virus: How is WNV spread from host to host?"), and most of those infected die; **only 1 of 40 experimentally infected crows survived**[9,34,44]. Limited data indicate the high mortality experienced by crows infected under lab conditions likely reflects the situation in the wild: **only 3% of over a hundred wild-caught crows in IL had WNV antibodies in their blood**[13]**, i.e., very few living crows have survived infection; they've just been lucky so far**. As such, unless some aspect of the WNV transmission cycle changes, crow numbers may be expected to decline precipitously in the next few years as WNV continues to entrench itself in habitats across North America.

Researchers studying **Greater Sage Grouse** at five sites in Montana, Wyoming, and southern Alberta made the startling discovery that in WNV's first year of presence at four of the sites, **average survivorship of adult females declined 25% during July and August (of 2003)**[35]. Greater Sage Grouse had historically been widespread, but loss and degradation of nesting and brood-rearing habitat – the result of human activities – has resulted in the species being extirpated from much of its original range, and an estimated range-wide decline of 45-80%. Survivorship of females has been indicated as an important factor in the species' recovery, and the increased mortality in the face of WNV occurred at a time of year when female survival is typically high. **None of 112 sage grouse tested after the outbreak had WNV antibodies in their blood, suggesting that they lack resistance**[35]. Sage grouse are on the endangered species list in Canada, but were recently declined federal status in the U.S. (in December 2004 by the USFWS). Surface water sources (breeding habitat for mosquitoes) - created for agricultural irrigation, drinking access for livestock, and oil and gas activities – in an otherwise xeric landscape - attract female sage grouse and their offspring, and may be exacerbating the WNV situation[35]. In a subsequent paper, some of the same researchers compared survivorship of female sage grouse at four different sites within the same general area; one with WNV present and three without. **Between July 1-August 31 2003, female survivorship at the WNV site was only 20%, compared to 76% at the non-WNV sites**[36]**. In addition, unprecedented declines in lek attendance – numbers of grouse at courtship areas - the following spring for**

both males and females at the WNV site suggest that male sage grouse are highly vulnerable, too, and that local populations may be threatened with extinction[36].

Citizen Science:

In lieu of direct information from the field for most species, the data from citizen science monitoring programs may offer our best estimates as to the impacts of WNV on North American wildlife. Citizen science monitoring programs are those in which large numbers of volunteers – citizen scientists – count birds in specific contexts and report the findings in standardized ways. Data from the Christmas Bird Count (CBC), the Great Backyard Bird Count (GBBC), the Breeding Bird Survey (BBS), and Project FeederWatch (PFW) have begun to be examined for evidence of possible effects of WNV, but no analyses have yet been published in refereed journals. Those of us interested in interpreting such data really needed to wait a couple of years in order to be able to put any detected population declines into context – bird population sizes change from year to year for many reasons. Thus not only will we look for species' declines subsequent to exposure to WNV, but we will look to see if recent declines are different than declines that have occurred in the past.

Great horned owl nesting photo by Gary M. Stolz, US Fish & Wildlife Service

Preliminary examinations of CBC, GBBC, and PFW data suggest that crows may be experiencing declines detectable even at these large scale levels[15,16,17], and hint of declines in chickadee, titmouse, Blue Jay, and Great Horned Owl numbers, as well[15,16]. So far, detected declines appear patchily distributed – areas of declines are distributed among areas experiencing local increases or no obvious changes in population sizes[15]. Much still remains to be done with the data from citizen science programs: a couple of years from now, these monitoring efforts may provide the best information available with regard to the wildlife side of WNV.

Related Things We Know, and Don't Know

We know:

- **Horses are particularly vulnerable to WNV**: in 2002, 15,257 equine cases of clinical infection were reported to authorities, and approximately one third of those cases ended in death[18]. The number of clinical equine cases was lower in 2003 (=5181[18]), probably as a function of both increased vaccination and decreased testing. **Vaccination of horses prior to exposure to WNV is highly recommended; approximately 1/3 of unvaccinated horses die of WNV infection, and approximately 17-20% of survivors are left with residual neurological deficiencies[18]**. Check with your veterinarian for details regarding vaccination. On these pages, additional information on the horse vaccine and other protective measures can be found at **"**The Virus: What about a vaccine?**"** and **"**What You Can Do: Protect Your Pets**."** More detailed information regarding horses and WNV can be accessed at the websites of Fort Dodge and the US Department of Agriculture's National Center for Animal Health Programs and Animal and Plant Health Inspection Service.

- **West Nile virus has now become established in North America**; it is not going to go away. North American birds will likely forever be subject to the presence of this virus. Some species will likely remain unaffected. Others, unable to evolve resistance, or immunity - the ability to beat back the virus – may come to occur at lower numbers and/or to be restricted to areas of

their ranges free of mosquitoes. Some species will adapt as resistance is passed from survivors to their offspring, and some populations will rebound from lowered numbers as resistance increases. But some populations may dwindle to numbers too low to survive or rebound, and some species may go extinct. Species and populations already in trouble because of habitat destruction and other human-mediated threats to their continued existence are particularly vulnerable.

- **Farmed alligators have been hit hard by WNV**: In addition to the hundreds of alligators presumed to have died as a function of WNV infections in Florida and Georgia in 2001 and 2002[40,28], hundreds more died on farms in Louisiana in 2003[42]. A recent paper documents the high experimental infection rate of juvenile American alligators, and the high viremias maintained by infected individuals for periods of up to two weeks[45]. Individuals became infected via mosquito bites and the ingestion of infected prey, and tankmates of infected individuals became infected at high rates[45]. A study of farmed crocodiles in Israel also demonstrated a high rate of infection with WNV[43]. Given the high levels of virus found in many individuals in the recent study[45] (and those that had died in Florida in 2002 - high enough to infect mosquitoes[19]), and the role of various reptiles in the epidemiology of other New World arboviruses (references 13-15 in #43, below), American alligators may prove to be important players in the transmission cycle of WNV.

- **The spread to the Caribbean and Central America is underway**: WNV has been found in Mexico[23], the Dominican Republic[24], Jamaica[25], El Salvador[26], Puerto Rico[21], Belize[20], Guadeloupe[48], Trinidad[48], and Cuba[48]. We're not sure how the virus made it to these areas, but many people suspect that migratory birds are involved (see "We don't yet know" below).

We don't yet know:

- **the actual range of animals that WNV can infect, why some species are more susceptible than others, or much about the susceptibility of different species**.

- **the percent of individuals within species that become ill after being infected, or the percent of those infected that die.**

- **about the duration of the immune responses of individuals in the wild, or anything about the subsequent lives of survivors – can they repair any damage done to their bodies and live "normal" lives?**

Coopers Hawk photo by Ralph Wright

- **about individual-to-individual transmission in the wild.** We *do* know, from lab experiments, that in the absence of mosquitoes, uninfected individuals of at least a few bird species can become infected through contact with infected conspecifics (members of the same species; see "The Virus: How is WNV spread from host to host?"), but does it happen in the wild? If it does, how frequently? And, would that mean that "social" species – those that forage and roost in groups (such as crows) – are at greater risk than equally susceptible, nonsocial, or solitary, species?

- **about the extent of prey-to-predator transmission in the wild**. Again, we know from laboratory experiments that individuals of at least several species of birds can become infected by eating infected prey (see "The Virus: How is WNV spread from host to host?"). We think it happens in the wild - a Red-tailed Hawk found dead in February 2000 in New York state tested positive for the virus, months after mosquito activity had ceased in the area,

suggesting the hawk became infected by eating an infected host[27]. Additionally, farmed alligators in Georgia (USA) are suspected to have become infected through ingesting infected horsemeat[28], and juvenile alligators have been shown to become infected via the consumption of infected mice[45]. Thus it is clear that we still have much to learn regarding possible transmission routes among wildlife species.

- **the extent to which birds may serve as dispersal vehicles** – are "viremic" migratory birds (those with measurable levels of virus particles in their blood) helping to spread WNV throughout the western hemisphere? Several types of evidence suggest that they are. West Nile virus has been detected in North American birds that migrate to and from the tropics (neotropical migrants)[29], and antibodies to WNV have been found in individuals from four migratory species just prior to their trips north from Mexico, Puerto Rico, and Jamaica[25]. Because WNV was not known to be established in either Mexico or Puerto Rico at the time of sampling, the migratory birds found positive there were likely infected in the United States[25], indicating that at least some individuals of some species are capable of surviving WNV infection and subsequently migrating. In addition, evidence implicates migratory birds as the introductory hosts of WNV in parts of Eurasia[30] (and references therein). Particles of viruses related to WNV (Eastern and Western Equine encephalomyelitis alphaviruses; EEE and WEE) have been isolated from actively migrating birds in the United States[31,32] and evidence suggests that the EEE epidemic in Jamaica in 1962 resulted from migrating birds carrying the virus there from the continental US[33]. West Nile virus has now been documented in the Dominican Republic[24], Mexico[23], Jamaica[25], El Salvador[26], Puerto Rico[21], Belize[20], Guadeloupe[48], Trinidad[48], and Cuba[48].Thus the fear that migratory birds might carry WNV to Central and South America appears to have already been realized. With the potential for year-round transmission in the tropics, birds already in decline because of habitat loss and destruction now face an even more uncertain future.

- **the extent to which WNV-related mortality will result in significant declines in bird populations**. Because we don't yet know about the extent of mortality in the wild, we can't speculate as to the ability of particular populations to rebound – to get back to "normal." Different species will have different abilities to rebound, because some species have higher reproductive rates (rates at which new individuals are added to the population) than others. Unfortunately, raptors (at the top of many food chains, and of which some species may potentially be suffering high WNV-related mortality) and crows have relatively low reproductive rates. The impacts of particular population declines on the ecological balance of local areas will not be known for years.

Wood Thrush photo Ohio Department of Natural Resources

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