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# Hail-induced nest failure and adult mortality in a declining ground-nesting forest songbird

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ABSTRACT—Natural catastrophes are known to impact wildlife populations, however opportunities to directly measure the demographic effects associated with such events are rare. Given the projected increase in severe storms due to climate change, understanding how these weather events influence small wildlife populations will become increasingly important for conservation. During the spring 2017 nesting season, we observed a severe localized hailstorm that afforded us an opportunity to measure the immediate demographic effects on a small breeding aggregation of Golden-winged Warblers (*Vermivora chrysoptera*). The hailstorm produced approximately 2.5 cm diameter hail and apparently caused the failure of 89% (8/9) of monitored Golden-winged Warbler nests in a patch of early-successional forest in north-central Pennsylvania. Seven of the 8 failed nests contained broken eggs and all nests at the site showed signs of nest cup damage. Two dead Golden-winged Warbler females were found within 0.5 m of their nests. We suspect that additional mortalities of female and male Golden-winged Warblers occurred because several thorough searches of the early-successional patch revealed little territorial or renesting behavior in the following weeks. We noted hail-caused vegetation damage across the site characterized by varying levels of defoliation and destruction to herbaceous vegetation, *Rubus*, and even saplings and canopy trees. Storm events such as the one described here are well known to cause mortality in grassland species; however, events that result in forest-dependent passerine mortality are notably less common. We consider here the potential long-term implications of extreme weather events on bird populations, particularly those of conservation concern. *Received 25 October 2017. Accepted 20 August 2018.*

Key words: avian, breeding season, climate, hailstorm, natural catastrophe, *Vermivora chrysoptera*.

## Pérdida de nidos y mortandad de adultos por granizo en un ave de bosque en declive que anida en el suelo

RESUMEN (Spanish)—Se sabe que las catástrofes naturales impactan a las poblaciones de la fauna silvestre, aunque las oportunidades para medir directamente los efectos demográficos asociados con tales eventos son raras. Dado que se proyecta un incremento en tormentas severas por causa del cambio climático, entender cómo estos eventos del estado del tiempo influencian a pequeñas poblaciones de fauna silvestre ganará mayor importancia para su conservación. Durante la temporada de anidación de primavera 2017, observamos varias tormentas severas locales de granizo que nos dieron la oportunidad de medir los efectos demográficos inmediatos en una pequeña agregación reproductiva del chipe *Vermivora chrysoptera*. La tormenta generó granizos de

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aproximadamente 2.5 cm de diámetro y aparentemente causó la pérdida del 89% de los nidos en estudio de este chipe en un parche de bosques sucesionales tempranos en el norte-centro de Pennsylvania. Siete de los ocho nidos fallidos contenían huevos quebrados y todos mostraron signos de daño a la copa de los nidos. Encontramos dos hembras muertas a menos de 0.5 m de sus nidos. Sospechamos que hubo mayor mortandad de hembras y machos de V. chrysoptera porque varias búsquedas detalladas de este parche de hábitat sucesional revelaron pocos comportamientos territoriales o comportamiento de reanidación en las semanas subsiguientes. Notamos daños a la vegetación por causa del granizo a todo lo ancho del sitio, caracterizado por niveles variables de defoliación y destrucción de la vegetación herbácea, *Rubus*, y hasta plántulas y árboles de dosel. Los eventos de tormenta como el que se describe aquí son bien conocidos como causa de mortandad en aves de pradera; sin embargo, aquellos que resultan en mortandad de paserinas dependientes del bosque son notablemente menos comunes. En este trabajo consideramos las implicaciones potenciales a largo plazo de eventos extremos del tiempo en poblaciones de aves, particularmente aquellas cuya conservación es preocupante.

Palabras clave: aviar, catástrofe natural, clima, estación reproductiva, tormenta de granizo, *Vermivora chrysoptera*.

Small populations are well known to experience extinction risk from stochastic events such as severe weather (Shaffer 1981). In fact, exceptionally small colonies or sub-populations may be lost entirely after only 1 or 2 extreme weather events (Thomas et al. 1996). Catastrophic weather events can act on populations either directly or indirectly. Direct impacts on populations are characterized by adult mortality or reproductive failure resulting in immediate local population decline (e.g., Carver et al. 2017). Indirect impacts of weather, in contrast, may reduce habitat quality (occasionally leaving adults/young unharmed) and subsequently impede adult survival and future reproductive success over time via habitat degradation (e.g., Engstrom and Evans 1990). Catastrophic weather events that impact small wildlife populations are varied including unseasonal frosts, severe wind, droughts, and extreme flooding, to name a few (Moreno and Møller 2011). Another stochastic weather event that may be an important factor impacting wildlife is hail (Saunders et al. 2011). Interestingly, although many reports exist describing the sometimes lethal impacts of hail on wildlife, it appears that birds are disproportionately affected by hailstorms (Narwade et al. 2014).

Instances of hail-induced mortality in birds have been reported sporadically over the past several decades and are both geographically and taxonomically widespread (e.g., Heflebower and Klett 1980, Sarasola et al. 2005, Hall and Harvey 2007, Narwade et al. 2014). Despite the broad geographic and taxonomic scope of these events, reported cases of hail-related mortality seem most common in grassland-dominated landscapes and their associated species (Higgins and Johnson 1978, Carver et al. 2017). For instance, 600 Sandhill Cranes (*Grus canadensis*) and >2,000 ducks (subfamily: Anatinae, Aythyinae) were reported dead after a 1977 hailstorm at the Washita National Wildlife Refuge in Oklahoma (Heflebower and Klett 1980). In September 1977, 151 American White Pelican (*Pelecanus erythrorhynchos*) mortalities were reported along with individuals from 11 other species after a severe hailstorm in North Dakota (Higgins and Johnson 1978). A 1951 hailstorm in southwestern Oklahoma directly caused the deaths of 45 Swainson's Hawks (*Buteo swainsoni*) and 30 American Crows (*Corvus brachyrhynchos*), among other species (Jones 1952). Cases of hail-related mortality have also been reported during migration (Newton 2007, Diehl et al. 2014). Fewer reports exist regarding the impact of hail on species during the nesting cycle. Carver et al. (2017) reported a nest failure rate of 50% from a sample of over 200 nests in eastern Colorado mostly belonging to Lark Buntings (*Calamospiza melanocorys*). Hightower et al. (2018) reported a cumulative nest failure rate of 45% for 3 species of sagebrush songbirds at sites intensely impacted by a hailstorm in Wyoming. Still, we are unaware of any reports of hail-related mortality and nest failure for birds breeding in early-successional forests. We present here the result of a severe hailstorm that occurred on 30 May 2017, which significantly impacted nest success in a small breeding aggregation of Golden-winged Warblers (*Vermivora chrysoptera*) in north-central Pennsylvania.

The Golden-winged Warbler is a small (~9 g) steadily declining Neotropical migratory songbird that breeds throughout portions of the Appalachian Mountains and the Great Lakes region (Rosenberg et al. 2016). Population declines prompted the species to be petitioned for listing under the Endangered Species Act in 2011 (Rosenberg et al. 2016). The Appalachian segment of the bird's range has experienced the steepest population declines with annual rates as high as –7.89%, –8.78%, and –7.36% in Tennessee, West Virginia, and Pennsylvania, respectively, over the past 50 yr (Sauer et al. 2017). In fact, the Appalachian segment of the

bird's breeding range now constitutes less than 5% of the overall population (Roth et al. 2012). In Pennsylvania particularly, the Golden-winged Warbler's distribution is largely composed of small breeding populations scattered across the central and northeastern portion of the state (Larkin and Bakermans 2012). Although Golden-winged Warblers breed within heavily forested landscapes, they nest on the ground within patches of relatively open-canopy early-successional forests or shrublands (Confer et al. 2011).

## Methods

On 30 May 2017, we observed a severe weather event that produced hail approximately 2.5 cm in diameter for approximately 15 min between 1300 and 1315 h EST. The event spanned several kilometers along Pennsylvania Route 144 in Sproul State Forest (41°9′52″N, 77°52′47″W) in Centre County, Pennsylvania. The hailstorm occurred within the context of an ongoing 4 yr study that examined nesting success and post-fledging ecology of Golden-winged Warblers; however, this is the first such storm that we observed in our study area. As part of that effort, field crews searched for, located, and monitored Golden-winged Warbler nests within patches of early-successional forest within Sproul State Forest in Centre/Clinton counties, Pennsylvania. We had been monitoring Golden-winged Warbler nests at 8 early-successional forest patches prior to the storm, each of which contained 2–10 adult male Golden-winged Warblers (mean = 6). On the morning after the hailstorm (31 May 2017), we resumed nest monitoring activities. We documented nest failures and recorded detailed notes on the status of eggs, adults, and vegetation at early-successional patches in which extensive damage to the vegetation was apparent.

## Results

We found that, although our 2 farthest sites were only 20 km apart, only 1 site (hereafter Site A) appeared to be severely impacted by the storm, as evidenced by localized hail-related vegetation damage. All other sites in our study ($n = 7$) hosted Golden-winged Warbler nests that were not damaged by the storm and had no apparent vegetation damage. Nest monitoring at Site A revealed that 8 of the 9 nests being monitored therein were lost between the mornings of 27 May and 31 May 2017. Nest failure due to the hailstorm was restricted to Site A while 5 nests were simultaneously undamaged at a nearby site <1.5 km from the affected site. Eight of 9 (89%) known Golden-winged Warbler nests at Site A that failed from 27 to 31 May 2017 showed heavy nest cup damage, characterized by the flattening of the nest, and absence of attending adult females. Broken eggs were found within the cups of 7 of these nests (Fig. 1), while the other failed nest had a single intact egg lying just outside the nest rim on the ground. Two dead adult female Golden-winged Warblers were also observed within 0.5 m of their nests (Fig. 1). The only remaining active nest at Site A (Nest 5.1) displayed moderate nest cup damage characterized by flattening and loosening of nest materials on one side, and vegetation typically concealing the nest was matted down. Given the damage done to most nests at Site A, we were surprised to see the attending female of Nest 5.1 incubating her clutch on the morning of 31 May 2017. Nest 5.1 remained active through at least 4 June 2017; however, it had failed by 8 June 2017 due to depredation.

Vegetation impacts were noted throughout the entirety of Site A. In particular, vegetation typically associated with Golden-winged Warbler nests experienced significant damage. Goldenrod (*Solidago* spp.) was stripped of most leaves and/or matted down onto the forest floor. *Rubus* spp. canes, which were present within 1 m of 54% (22/41) of nests in the entire study area in 2017, were also matted down against the forest floor in many areas. Much of the woody vegetation including canopy trees, saplings, and shrubs, showed varying degrees of defoliation and the forest floor was covered in their freshly fallen leaves. We also noted the failure of one Common Yellowthroat (*Geothylpis trichas*) nest and one Field Sparrow (*Spizella pusilla*) nest at Site A on the morning of 31 May 2017, both of which appeared to have experienced significant nest cup damage (e.g., flattening and loosening of nest materials). These were the only other nests we were aware of at the time of the storm.

Upon subsequent visits to the study site on 31 May, 1 June, 4 June, and 8 June, we observed very little Golden-winged Warbler activity. Only 3 males and 2 females were observed during these


**Figure 1.** Examples of hail effects on a small breeding aggregation of Golden-winged Warblers (*Vermivora chrysoptera*) following a hailstorm in north-central Pennsylvania in 2017. (a) Broken eggs within the damaged cup of a Golden-winged Warbler nest. (b) A dead female Golden-winged Warbler approximately 0.5 m from her failed nest.

post-hailstorm visits. Prior to the storm, we observed a minimum of 10 males defending territories at the site, 9 of which also had nesting females. This constitutes a reduction in male density of 70% and the reduction of female density seems to have been comparable. At study sites other than Site A, no discernable decrease in male density was observed and both male and female adults remained active around nests. On 4 June, we found one renest at Site A from a pair of Golden-winged Warblers that had lost their first nest to the hailstorm. This nest eventually contained 4 eggs but was abandoned by 22 June 2017 due to unknown causes.

## Discussion

Although hail-induced avian mortality and nest failure is commonly reported for open landscapes, such as the midwestern United States where these types of storms are more frequent (Higgins and Johnson 1978, Carver et al. 2017), we provide here a description of the impacts hail can have on a songbird inhabiting early-successional forest. In our study system, a localized 15 min hailstorm seemingly caused the nest failure of 89% (8/9) of Golden-winged Warbler nests in one patch of early-successional forest. This was higher than the study-wide nest failure rate of 63% in 2017 and a nest failure rate of 80% in Site A during the 2016 breeding season (CJF, 2016, unpubl. data). Only one Golden-winged Warbler nest survived the immediate impact of the storm and it failed within 8 days post-storm. Consequently, loss of productivity from this patch of nesting habitat was significant. Site A produced a minimum of 10 fledglings during the 2016 breeding season (CJF, 2016, unpubl. data). After exhaustive efforts to locate nests after the hailstorm, we are unaware of any successful reproduction in Site A during the 2017 breeding season. Although it is possible that some nests were depredated between 27 May and 31 May, depredated nests in our study area typically involve the complete loss of all nest contents or few remaining eggshell fragments, whereas the failed nests in Site A contained smashed egg remains or intact eggs nearby, apparently launched outside the nest cup. We suspect that direct hail-strikes were responsible for the initial failures of 8 nests. We further suspect that damage to the vegetation that typically surrounds and conceals Golden-winged Warbler nests provided insufficient cover to avoid predation on the 2 nests monitored post-storm.

We also provide direct evidence of adult mortality and support for more widespread mortality resulting from the storm because subsequent visits to Site A revealed a 70% reduction in adult male density. The lack of renesting behavior also suggested adult mortality. As we have records

indicating renesting attempts all through June and even into July in Sproul State Forest for Golden-winged Warblers (CJF, 2016, unpubl. data), it is likely that if present, these adults would have attempted a renest. Alternatively, some Golden-winged Warblers may have shifted to other early-successional patches that were less affected by the storm to renest. However, we never observed these adults (many of which were color-banded) in the nearby early-successional patches we were monitoring. While not a direct focus of our long-term study, we are unaware of any adult mortality occurring during the 2016 or 2017 breeding seasons in Sproul State Forest within sites other than Site A. Nearly all Golden-winged Warbler nest failures we documented throughout the course of our long-term study were followed by renesting attempts, suggesting the survival of both adults. Given that this breeding aggregation makes up a portion of an already small regional population of Golden-winged Warblers, adult mortality caused by this storm event could impact the Golden-winged Warbler population across our study area for years to come. Indeed, previous research has indicated that variation in adult mortality often has the largest effect on population intrinsic growth rates of most bird species as compared to other life history variables (e.g., juvenile survival, reproductive success; Stahl and Oli 2006). Assuming vegetation at Site A recovers for subsequent breeding seasons, we cannot rule out that the effects of this storm may be ameliorated by the dispersal of second-year birds and previously non-territorial individuals into Site A.

It seems likely that other open-cup ground-nesting birds that use early-successional habitat were similarly affected by the storm. Both a Field Sparrow nest and a Common Yellowthroat nest that we were opportunistically monitoring experienced damage similar to that of Golden-winged Warbler nests and failed as a result. It is possible that these 2 species experienced adult mortalities and nest failure rates comparable to those of Golden-winged Warblers in Site A. Indeed, both species use nesting habitat that is similar to the Golden-winged Warbler's, wherein absence of a dense canopy and less prevalent woody vegetation could make a direct hail-strike more likely. Additionally, point count surveys conducted annually from 2015 to 2017 within our study area found that Field Sparrows and Common Yellowthroats occupy habitat managed for Golden-winged Warblers at rates of 89% and 98%, respectively (DJM, 2017, unpubl. data). On subsequent visits to Site A, decreased bird activity was apparent, but no formal surveys were conducted. As with adult Golden-winged Warblers, we cannot rule out that these species relocated to patches less affected by the storm to attempt a renest as well. Given the vegetation damage to the early-successional patch and the adult mortality in Golden-winged Warblers and potential mortality in other species, it would be interesting to monitor how birds colonize this patch in subsequent breeding seasons.

Climate change models suggest that the frequency of severe storms often associated with hail may increase in the future (Trapp et al. 2007, Kapsch et al. 2012). Another climate model suggests that storms generating larger hail may become more frequent, but the overall prevalence of smaller magnitude hailstorms may decrease as a result of climate change across North America (Brimelow et al. 2017). In light of these climate change projections, researchers have cautioned that stochastic events like hailstorms may play an increasing role in perturbing avian populations (Saunders et al. 2011, Narwade et al. 2014, Carver et al. 2017). Our observations of nest destruction and adult mortality support these concerns and suggest that birds breeding in early-successional forest are susceptible to hailstorms and can even experience high nest failure rates similar to those of grassland birds (Carver et al. 2017). Finally, our results add further insight into storm avoidance behavior in Golden-winged Warblers. Although a previous study reported that Golden-winged Warblers can sense and avoid major storm events (Streby et al. 2015; but see Lisovski et al. 2018), our observation of female mortality following a major hailstorm suggests that at least some individuals either do not detect or do not respond to oncoming storms during the incubation phase.

As climate change continues to drive variations in the frequency and severity of weather events, major storm events including hailstorms should not be overlooked as potential threats to declining bird species that rely on forested habitat types. In addition to suggesting that hail-induced adult mortality and nest failure are not confined to grassland birds, our observations serve as a timely

example of a stochastic event disrupting reproductive success for an at-risk species.

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