Impacts of a Severe Hailstorm on a White-tailed Deer Population in East-central Alabama

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Abstract - Hailstorms capable of producing damaging hail ≥2.5 cm in size are rare but can have a significant impact on wildlife, with mortality events well documented with avian species. However, there is still a poor understanding of the impacts damaging hail can have on ungulate survival. We had a unique case study, when a hailstorm produced hailstones up to ~7 cm in diameter in the area of Camp Hill, AL, and the nearby Auburn Captive Deer Facility (ACF) on 26 March 2023. With the ACF being completely enclosed with fencing, we were able to conduct extensive surveys for mortality cases of *Odocoileus virginianus* (White-tailed Deer) shortly after the hailstorm. We detected no cases of mortality attributed to the storm. We speculate that no mortality occurred due to the ACF containing mature forests with adequate overstory that provided structural cover for deer from hailstone strikes. Further examination of the literature found that a substantial proportion of hail-induced mortality has occurred in agricultural areas, wetlands, and grasslands where there was limited to no canopy cover. This result may suggest that deer inhabiting forested regions are at less risk from hailstorms compared to conspecifics inhabiting open habitat.

Introduction

Catastrophic weather events can have major negative implications on wildlife at community and population levels within a given area (Parmesan et al. 2000). These implications can be measured through indirect impacts such as habitat degradation (Engstrom and Evans 1990, Walter et al. 2013) or through direct impacts such as event-related mortality (Fiss et al. 2019, Glasrud 1976). Direct mortality due to extreme weather is well documented in large-scale events such as droughts (Bright and Hervert 2005, Hillman and Hillman 1977, Wato et al. 2016), floods (Samuel and Glazener 1970, Williams et al. 2001, Wuczyński and Jakubiec 2013), tornadoes (Wiedenfeld and Wiedenfeld 1995), and extreme temperatures (Barlas et al. 2011, Stoddart 1985), with some documentation of mortality from localized phenomena such as lightning strikes (Glasrud 1976, Shaw and Neiland 1973, Steyaert et al. 2018).

Hail is another localized type of weather event that can cause direct mortality of numerous individuals in a short span of time (Merrill 1961, Smith and Webster 1955); however, it is often difficult to examine the implications due to the difficulty associated with predicting when and where extreme hail events will occur (Carver et al. 2017). Additionally, researchers are faced with a limited ability in finding intact carcasses that can be directly attributed to trauma-induced mortality from hail. Based on a limited amount of studies, hailstones ≥2.5 cm are often classified

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Manuscript Editor: Michael Conner

as having the potential to injure or kill wildlife (Carver et al. 2017, Sarasola et al. 2005), with the vast majority of hail-induced mortality observed in avian species (Heflebower and Klett 1980, Higgins and Johnson 1978, Narwade et al. 2014, Roth 1976, Sarasola et al. 2005) and some small mammals (Jones 1952, Narwade et al. 2014). Small avian and mammalian species are likely more susceptible to severe injury from hail strikes than larger animals due to their smaller body size and/or more fragile bone composition (Carver et al. 2017, Dumont 2010).

Research assessing the impacts of hailstorms on large mammals in general and ungulates in particular is limited. The only published studies we could find that documented hail-induced mortality in large ungulates took place in India (*Antilope cervicapra* (L.) [Blackbuck], *Boselaphus tragocamelus* (Pallas) [Nilgai], and *Gazella bennettii* (Sykes) [Chinkara]; Narwade et al. 2014) and South Africa (*Aepyceros melampus* (Lichtenstein) [Impala]; Mason 1990). While hailstorms of the magnitude (≥2.5 cm) described in these reports are generally uncommon, they do occur in many parts of the world, including North America (Dewey 2019) and have the potential to negatively impact native North American ungulate species such as *Odocoileus virginianus* (Zimmermann) (White-tailed Deer) and *O. hemionus* (Rafinesque) (Mule Deer). Both White-tailed Deer and Mule Deer, as well as some other ungulates such as *Cervus canadensis* Erxleben (Elk), *Bison bison* (L.) (Bison), and *Antilocapra americana* (Ord) (Pronghorn), have ranges that overlap the areas in North America that have the greatest risk of extreme hail events. Although, public accounts have reported White-tailed Deer being killed in hailstorms (Fegely 1993, Pates 2021), there has yet to be a scientifically documented case study that has empirically examined hail-induced mortality in North American ungulates.

In this study, we surveyed a captive population of White-tailed Deer inhabiting natural habitats for cases of direct hail-induced mortality after a storm event at ~0245 in the morning on 26 March 2023 in Camp Hill, AL, produced hailstones >2.5 cm. This study was unique in that we were able to extensively study the area where a captive population resided within several days of the storm event. Our specific objective was to thoroughly search for, and quantify, cases of mortality that were directly attributed to hail. We hypothesized that we would find cases of hail-induced mortality within the population since Narwade et al. (2014) documented mortality of ungulates of similar skeletal body sizes to White-tailed Deer under similar hailstorm conditions (i.e., hail greater than 2.5 cm).

Field-site Description

The study took place at the Auburn Captive Facility (ACF), located in east-central Alabama just outside of the town of Camp Hill in Tallapoosa County (32°49'40.4"N, 85°38'41.9"W). The facility was 174 ha and surrounded by a fence 2.6 m in height that was constructed in 2007. The population of White-tailed Deer within the facility were able to undergo natural behavior, while still captive, and were all descendants of deer within the area when the fencing was installed in 2007. No additional individuals were introduced to the facility from outside the fence, and hunting was not permitted. Predation was rarely documented within the ACF.

The climate at the ACF was classified as humid subtropical. Data from the weather station in Alexander City (USC00010160) indicated average annual temperatures varied from a low of 10.4 °C to a high of 23.8 °C with an overall average of 17.11°C, and the average annual precipitation for the area was 144.76 cm (NOAA National Centers for Environmental information 2023). The property consisted of roughly 44% open pastureland and 56% forested land (Dewitz and US Geological Survey 2021). Primary tree species consisted of *Quercus* spp. (oak), *Liquidambar styraciflua* L. (American Sweetgum), *Carya* spp. (hickory), and *Pinus taeda* L. (Loblolly Pine), with naturally regenerated understory thickets consisting of *Rubus* spp. (blackberry), *Juniperus virginiana* L. (Eastern Redcedar), and *Ligustrum sinense* Lour. (Chinese Privet). Pasturelands at the ACF consisted of predominantly *Cynodon dactlyon* (L.) Pers. (Bermuda Grass) with *Festuca* spp. (fescue), *Andropogon gerardi* Vitman (Big Bluestem), *Sorghum halepense* (L.) Pers. (Johnson Grass), *Paspalum dilatatum* Poir. (Dallisgrass), and *P. notatum* Flüggé (Bahia Grass) in smaller proportions. The facility is in the piedmont region of the state, and elevation at the site varies from 190 to 225 m above sea level. There are 2 creeks within the facility that provide a source of water for the deer, and supplemental feed was provided via protein feeders to ensure in-facility vegetation was not over-browsed.

Methods

Hail quantification

We quantified hail intensity by damage to local resources after the storm. Specifically, the nearby town of Camp Hill had a tornado shelter, ~2.6 km from the facility. On this shelter, the impact marks from the hail were clearly visible in the dust film on the shelter (Fig. 1), which we utilized as an approximate estimation for hail size (Crenshaw and Koontz 2002, Verhulst et al. 2018, Petty and Monhemius 2021). On the shelter, we marked five 1-m^2 squares using blue painter's tape. Within each square we counted and measured the hail marks that were greater than 2.5 cm, based on the size that has been classified as damaging hail to wildlife in previous research (Carver et al. 2017). Each hail mark had a rounded edge and a directional splatter pattern from impact. We measured the marks by the diameter of the rounded portion of the mark where splatter was minimal to give the most accurate representation of the size of the hailstones that were impacting the area. Additionally, we had a pickup truck parked at the facility that received damage and was heavily dented by the hail (Fig. 2). We also measured the hood and roof of this truck in a similar fashion to the tornado shelter with a single 1-m^2 square of both the hood and roof, respectively. We then used both sets of measurements of the hail marks to calculate both an average size of the hailstones greater than 2.5 cm and the density in which this size hailstone fell. We also obtained physical measurements of hail from reports provided by the National Weather Service (NWS Birmingham, Alabama Weather Forecast Office 2023). Based on NWS reports and our hail mark data, we were able to classify the hail event using the ANELFA scale for hail intensity (Dessens et al. 2007).

Facility search

Prior to our search, we established transects using ArcGIS Pro® (version 3.1.1; ESRI Inc. 2023) every 40 m spanning the entire area inside the fence and running on an east–west axis to minimize transect disruption from the creeks that ran through the facility. We initially searched our facility on 27–28 March 2023 during daylight hours beginning at least 1 hour after sunrise and ending no less than 1 hour before sunset when light would be sufficient for the search. We had 3 observers on March 27th and 4 observers on March 28th. Two of the observers conducted searches on both days. Transect searches were conducted simultaneously by observers on adjacent

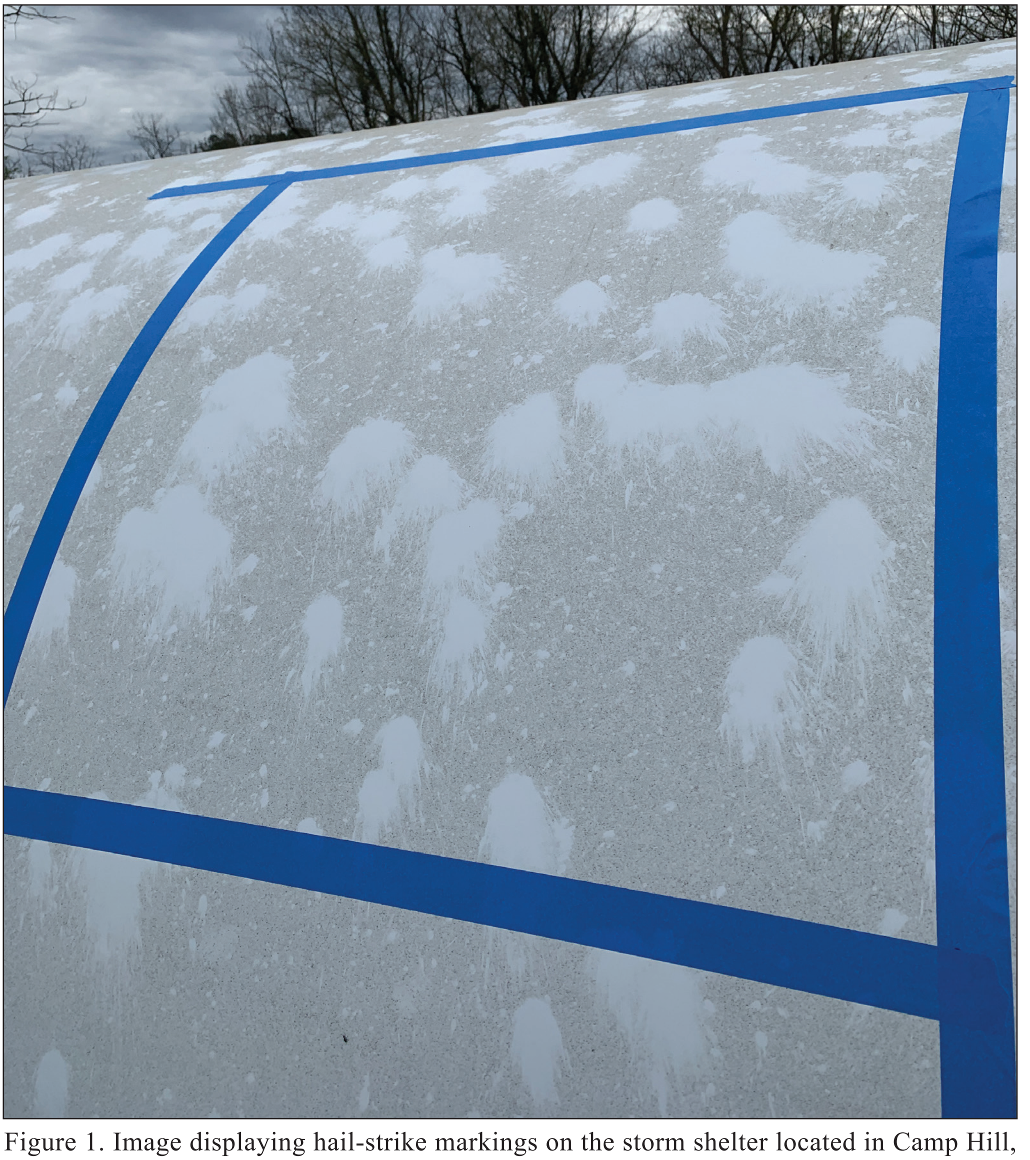

Figure 1. Image displaying hail-strike markings on the storm shelter located in Camp Hill, AL, ~2.6 km from the Auburn Captive Facility. Blue tape represents boundaries of 1-m^2 box used for hail counts. Photograph © Matthew T. McDonough.

transects. Each observer used Avenza Maps® (version 4.2.2; Avenza Systems 2023) with the transects and boundaries loaded on the map. While walking the transect, each observer then tracked their movement path along the transect to account for deviations from the transects while walking due to obstacles. Due to the depth and flow rate of the creek, some transects had to be stopped at the banks of the creek and continued at the adjacent point on the opposite bank. Each observer marked the locations of deer carcasses that were found at the time of the initial search regardless of estimated time since death. However, we disregarded carcasses without flesh as being deaths due to the storm 2 days prior to our search but still marked them to account for any carcasses during secondary searches. To help ensure an

Figure 2. Image displaying hail strike markings on a work truck at the Auburn Captive Facility. Photograph © Tristan J. Swartout.

adequate search of the ACF, additional searches were conducted during surveys for a separate study from 15–16 April 2023. Transects for this search were 15 m apart and conducted in a similar manner to the first search.

Sightability

To determine the sightability of deer along the transects, we created cardboard cut outs that had a height of 30.5 cm and a width of 132.1 cm, which was the averaged measurements for female deer within the facility from head to rump (T.J. Swartout, Auburn University, Auburn, AL, unpubl. data). These cut outs were then painted in 8 equal-sized sections with an alternating checkered pattern. These cut outs allowed us to estimate the sightability of a deer-sized object.

We divided the facility into 5 habitat types—pine forest, hardwood forest, mixed forest, shrub/scrub, and open field—by reclassifying the NLCD dataset (Dewitz and US Geological Survey 2021) to fit into these generalized habitat types using ArcGIS Pro®. For each of the 5 habitat types, we were able to determine the proportion that each type made up of the total area within the facility: 44.2% open field, 25.9% mature deciduous forest, 19.0% mature pine, 8.0% mixed forests, and 2.9% shrub and riparian bottomland (Fig. 3A). Within each of these habitat types, we created 10 random sampling points using a random-point generator in ArcGIS Pro®. We conducted sightability surveys on 4 April 2023 during daylight hours with 3 observers. The 3 observers were individuals who also conducted transect surveys the week prior. At each point, the carboard cut out was placed upright to imitate the size of a deer laying on its side. From the cut out, an observer then walked along a north–south axis and estimated the percentage of the board that could be seen at every 5-m interval out to 40 m. Additionally, each point and adjacent areas were compared to the cover-type map to provide ground-truthing of the cover type and increase accuracy of the distribution of habitat types within the facility. Based on these surveys, we estimated sightability right along the transect to be 100%. We then fit he sightability of the board at each distance within each cover type to respective linear models per cover type with the software program R (version 4.0.3; R Development Core Team 2020) implemented in Rstudio (version 2023.03.0; Rstudio Team 2023).

Coverage

To measure the coverage of our search, we used the true paths of each observer along the transects in ArcGIS Pro® to create a raster layer of the Euclidean distance of the center of each cell to the nearest transect using the 'Euclidean Distance' tool. Using the raster calculator, we created layers of the study area where the slope of each linear model per cover type was applied to the true distance of each cell from the nearest walked path. The linear models used to create these layers were constrained between the values of 100% visibility and 0% visibility. Then, using the raster calculator tool, we created a raster where the sightability of each cell was drawn from the layers of the linear models of sightability based on the cover type of the corresponding cells within our cover-type layer and the distance to the nearest transect.

Literature search

We chose to do a literature search to emphasize the lack of research on the topic of hail-induced mortality. We conducted searches in Google Scholar for peer-reviewed articles, as this is an extensive and inclusive global literature search engine. For our searches, we conducted broad-scale searches and then subsequent narrower searches based on the findings in the broad-scale searches. We conducted our searches using basic terms related to hail-induced mortality events such as "hail", "mortality", "hailstorm", "damage", "trauma", and "extreme weather" both singularly and in combination with other listed terms. We then used these terms in conjunction with taxa that were included in the returned results from our broad-

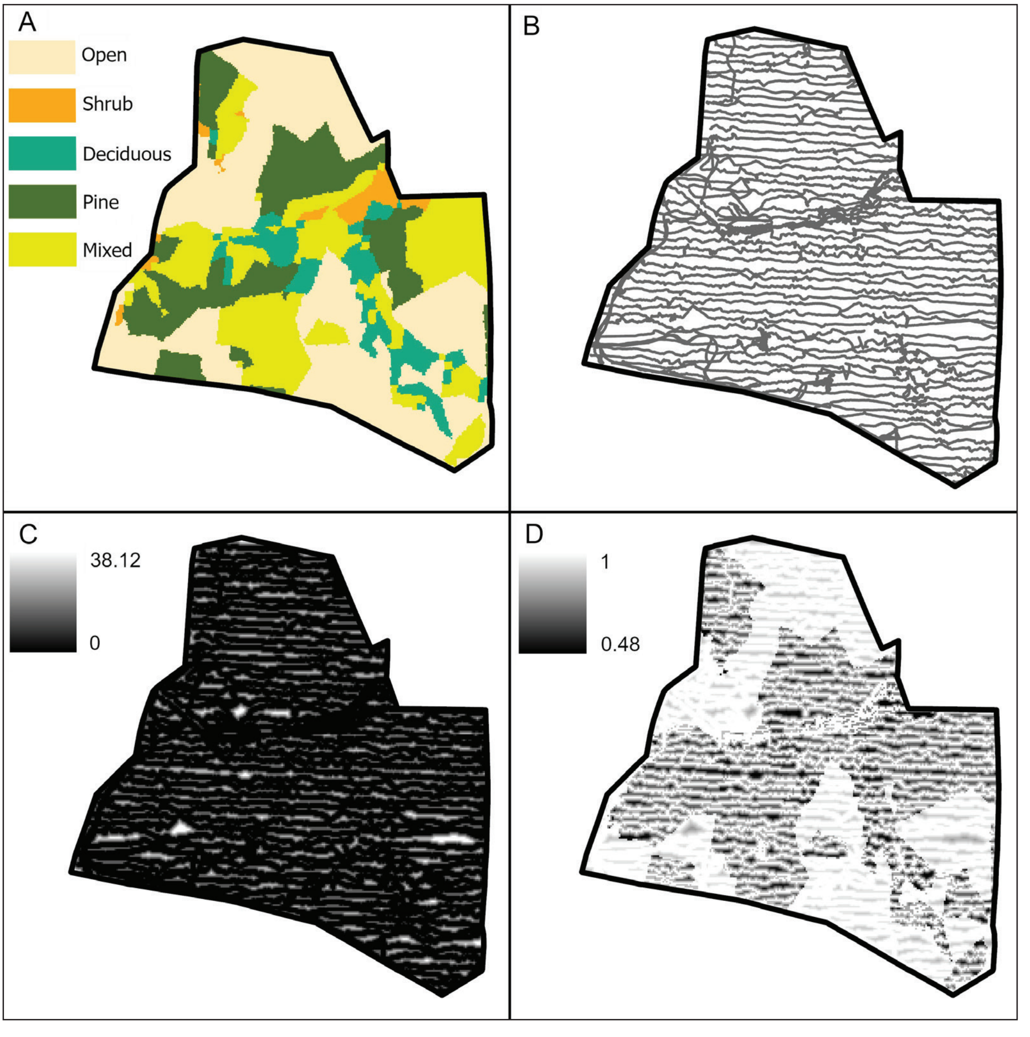

Figure 3. Multimap display of multiple criteria of the Auburn Captive Facility (ACF). (A) Map representation of cover types within the ACF based on the NLCD 2019 dataset (Dewitz and USGS 2021). (B) Visible transect surveys at the ACF computed by Avenza Maps® that were conducted 27–28 March 2023. (C) Euclidean distance to nearest transect survey. (D) Sightability at the ACF based on computing of cover type and distance to nearest transect.

scale search and those related to our species of interest, White-tailed Deer, to narrow our search topics. These taxa terms were “mammal”, “ungulate”, “White-tailed Deer”, “Mule Deer”, “Pronghorn Antelope”, “Nilgai”, “antelope”, “small mammals”, “rodent”, “avian”, “bird”, “songbird”, and “waterfowl”. We then searched the broad-scale terms in conjunction with geographical terms related to our study area to find documentation of these events in similar geographic regions. These terms were “North America”, “United States”, “Southeast”, and “Alabama”. We repeated these searches in Access World News and Nexus Uni for news articles and non-peer reviewed reports of mortality.

Results

In the early morning of 26 March 2023, a large-scale storm event passed through central Alabama producing severe storms that caused significant damage in the region (NWS Birmingham, Alabama Weather Forecast Office 2023). In the town of Camp Hill, the storm event developed into a hailstorm that produced baseball-sized hail (Fig. 4) and caused significant damage to cars and left holes in the roofs of houses. Based on radar imagery provided to us by the National Weather Service (NWS), the hailstorm produced large damaging hail from approximately 0253 to 0300 at the ACF (G. Satterwhite, NWS Birmingham Office, Birmingham, AL, pers. comm.). From our analysis of density of hail marks, we found the average count of large hail (≥2.5 cm) was 53.71 (SE = 5.03) hail per m^2 based on measurements of our five 1-m^2 squares on the Camp Hill storm shelter and an additional two 1-m^2 squares on the work truck at ACF. When only measuring impacts where the hail mark was ≥2.5 cm, the average diameter of the mark based on our samples of the truck and storm shelter was 5.70 cm (SE = 0.93). We had 11 impact strikes within the squares that had diameters over 10 cm with the largest impact measured at 13.4

Figure 4. Image displaying hail that fell in Camp Hill, AL, during the 26 March 2023 storm event. Photograph © Lori G. Eckhardt.

cm in diameter, although these diameters are likely the result of the hailstones compressing and expanding in size upon striking the truck and storm shelter. Physical measurements of hail were made by observers in Camp Hill, with NWS confirmed reports of diameters of 6.98 cm and some unconfirmed reports of hail up to 8 cm in diameter (NWS Birmingham, Alabama Weather Forecast Office 2023). Based on these reports, hail of this size would be classified as the A5 class on the ANELFA scale (Dessens et al. 2007), which is the highest possible class and categorized as extremely dangerous to the welfare of humans and animals. From 1955 to 2021 there were 20 hailstorms in Tallapoosa County, AL, that reported hail ≥2.5 cm (Fig. 5) and 2013 hailstorms in the state of Alabama in this timespan under the same criteria (NOAA Storm Prediction Center 2023). Alabama averaged 5.4 hail events per year where the hail was ≥5.08 cm and less than 1 event per year where hail was ≥7.62 cm (Table 1).

In our primary survey, observers walked 82.82 km along designated transects (Fig. 3B). From these transects, any given point within the ACF was within 0 and

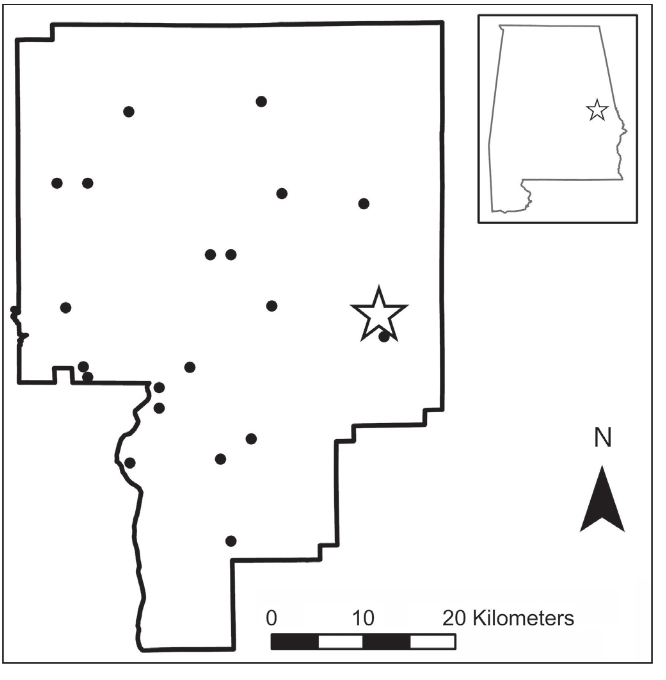

Figure 5. Map displaying hail events of ≥2.5 cm in Tallapoosa County, AL, from 1955 to 2021. Based on data from SVRGIS files (NOAA Storm Prediction Center 2023). The stars represent the location of Tallapoosa County in Alabama and the location of the Auburn Captive Facility, respectively.

Table 1. Annual frequency of hail events of specific hail diameters in Alabama. Based on data from SVRGIS files (NOAA Storm Prediction Center 2023).

Hail diameter (cm)	Average hail events per year
≥2.54	31.39
≥5.08	5.40
≥7.62	0.85
≥10.16	0.31
≥12.7	0.01
≥15.24	0.00

38.12 m of where an observer walked during our primary search (Fig. 3C). From our sightability analysis, ≥70% sightability was reported for 98.67% of the total area within the ACF, with a minimum sightability of 47.5% based on cover types and distance from survey transects (Table 2, Fig. 3D). Areas of sightability below 50% only made up 0.005% of the total area within the ACF. However, we detected no mortality of White-tailed Deer within the property indicative of hail-induced trauma during our primary survey, and no detection of recent mortality in the secondary survey several weeks later. We observed 1 case of mortality and 1 case of a severe injury (i.e., unable to fly) of an avian species of the family Passerellidae (new-world sparrows). Both cases were observed in open fields within the ACF during the primary survey on 27 March 2023. No other cases of mortality of other taxa were observed; however, our surveys were not structured to detect songbirds or small mammals.

Based on our literature search, we were able to determine the location (at least to the county level) of 20 events in the United States that reported wildlife mortality (Table 3, Fig. 6). Of the 20 reports, 14 were from peer-reviewed publications and 6 were non-peer-reviewed from newspapers. Bird (Aves) mortality accounted for 17 of the events, 1 event reported the death of solely mammalian species (Mammalia), and 2 events were mortality of multiple different taxonomic classes. Two events reported the deaths of White-tailed Deer. The events spanned across 14 states with years spanning from 1907 to as recent as 2021.

Discussion

We were unable to detect any White-tailed Deer mortality as the result of hail-induced trauma. To our knowledge, there are only 2 studies reporting ungulate mortality due to hail, with both occurring outside of the United States: 1 in South Africa (Mason 1990) and 1 in India (Narwade et al. 2014). However, newspaper articles in the United States have reported mortality of White-tailed Deer from hailstorms (Fegely 1993, Pates 2021). Interestingly, while no mortality was reported during our surveys, large hail diameters (i.e., diameters up to 7 cm) during this storm event should have been more than capable of killing an adult deer from a direct strike, based on other literature reporting deaths of ungulates with hail of similar sizes. For example, Pates (2021) reported 10 dead adult female White-

Table 2. Percent area covered of the Auburn Captive Facility (ACF) at specified percent sightability ranges. Sightability based on cover type and distance from survey transect.

Sightability (%)	% area covered
100	28.84
90 to 99.999	30.54
80 to 90	27.93
70 to 80	11.36
60 to 70	1.20
50 to 60	0.12
47 to 50	<0.01

Table 3**.** Literature documenting hail-induced mortality of taxonomic classes of wildlife in the continental United States. [Table continued on the following page.]

Source	Date	Location	State	Taxonomic Class	Primary species affected	Mortality
Henderson (1907)	Jun-1907	Lyons	Colorado	Aves	*Ardea herodias* L. (Great Blue Heron)	NA
Hochbaum (1955)	Apr-1954	Dunne and Clark counties	Wisconsin	Aves	*Anas* spp., *Cygnus columbianus* Ord (Tundra Swan)	>35
Merrill (1961)	Oct-1960	Elida	New Mexico	Aves	*Grus canadensis* (L.) (Sandhill Crane)	>1000
Halloran (1964)	Jun-1962	Wichita Mtn NWR	Oklahoma	Aves	*Meleagris gallopavo* L. (Wild Turkey)	NA
Roth (1976)	Nov-1973	Stuttgart	Arkansas	Aves	*Aix sponsa* (L.) (Wood Duck), *Anas* spp., *Anthya* spp., *Mareca* spp., *Spatula discors* (L.) (Blue-winged Teal)	106
Higgins and Johnson (1978)	Sep-1977	Chase Lake NWR	North Dakota	Aves	*Anas* spp., *Calidris* spp., Sandhill Crane, *Hirundo rustica* L. (Barn Swallow), *Larus* spp., *Pelecanus erythrorhynchos* Gmelin (American White Pelican)	226
Grover and Knopf (1982)	May-1978	Salt Plains NWR	Oklahoma	Aves	*Charadrius nivosus* (Cassin) (Snowy Plover)	18
Heflebower and Klett (1980)	Oct-1979	Washita NWR	Oklahoma	Aves	*Anas* spp., *Anser* spp., *Anthya* spp., *Branta* spp., *Fulica americana* Gmelin (American Coot), Sandhill Crane	3426
Schweitzer and Leslie (2000)	Jun-1992	Quivira NWR	Kansas	Aves	*Sternula antillarum* Lesson (Least Turn)	5
Leggett (1993)	Mar-1993	Pumpville	Texas	Aves	Wild Turkey	4
Associated Press (1998)	Jun-1998	Boxholm	Iowa	Aves	*Phasianus colchicus* L. (Ring-necked Pheasant)	NA
Ragan (2001)	Sep-2001	Rocky Ford	Colorado	Aves	Various waterfowl and shorebird genera	1479
Hall and Harvey (2007)	Mar-2005	Austin	Texas	Aves	*Quiscalus mexicanus* (Gmelin)(Great-tailed Grackle), *Sturnus vulgaris* L. (Common Starling)	291
Czaplewski et al. (2008)	Jun-2008	Boyd County	Nebraska	Aves	*Charadrius melodus* Ord (Piping Plover), Least Tern	6

Table 3**, continued.**

Source	Date	Location	State	Taxonomic Class	Primary species affected	Mortality
Hightower et al (2018)	Jun-2015	Fremont County	Wyoming	Aves	*Oreoscoptes montanus* (Townsend) (Sage Thrasher), *Spizella breweri* Cassin (Brewer's Sparrow), *Pooecetes gramineus* (Gmelin) (Vesper Sparrow)	NA
Fiss et al. (2019)	May-2017	Centre County	Pennsylvania	Aves	*Vermivora chrysoptera* (L.) (Golden-winged Warbler)	2
MFWP (2019)	Aug-2019	Big Lake WMA	Montana	Aves	Various waterfowl genera	>11,000
Pates (2021)	Aug-2021	Conde	South Dakota	Mammalia	White-tailed Deer	10
Jones (1952)	Oct-1951	Mangum	Oklahoma	Various	*Accipiter* spp., *Colinus virginianus* (L.) (Northern Bobwhite), *Corvus brachyrhynchos* Brehm (American Crow), *Lepus californicus* Gray (Black-tailed Jackrabbit), *Sylvilagus audubonii* (Baird) (Desert Cottontail)	138
Fegely (1993)	May-1993	Zavala County	Texas	Various	Northern Bobwhite, *Dasypus novemcinctus* L. (Nine-banded Armadillo), *Didelphis virginiana* Kerr (Virginia Opossum), White-tailed Deer	>23

tailed Deer after a hailstorm produced hail up to 7 cm in diameter, while Narwade et al. (2014) reported the death of ungulates as large as Nilgai after hailstorms produced hail with diameters of 1–5 cm. Fegely (1993) reported the deaths of over a dozen 8-month-old juveniles and 2 adult female White-tailed Deer, with the majority having fractured skulls and broken limbs due to hail strikes from hail the "size of grapefruits". Furthermore, while no deaths occurred within the first few weeks after the storm event, it is possible that individuals acquired impairing injuries from hailstone strikes that may impact their subsequent ability to sustain natural behavior such as mobility and feeding. However, impairing injuries have yet to be documented.

We speculate that we observed no mortality due to high availability of forested cover types within the property providing refuge for the deer during the severe weather event. Reviewing the literature in the United States where White-tailed Deer mortality occurred from hail, events largely took place in non-forested areas where there was minimal to no forest canopy that would provide a structural overstory and midstory to aid deer in seeking refuge from direct hail strikes. For example, one case of a mortality event took place in South Dakota in an area largely consisting of conservation reserve program (CRP) grasslands and crop fields with limited tree-rows (Pates 2021), while the other case took place in southwestern Texas in an area consisting largely of open rangeland and *Prosopis* spp. (mesquite) thickets (Fegely 1993). On a global scale, Mason (1990) observed hail-induced mortality of 22 Impala in Kruger National Park in areas where the cover type was

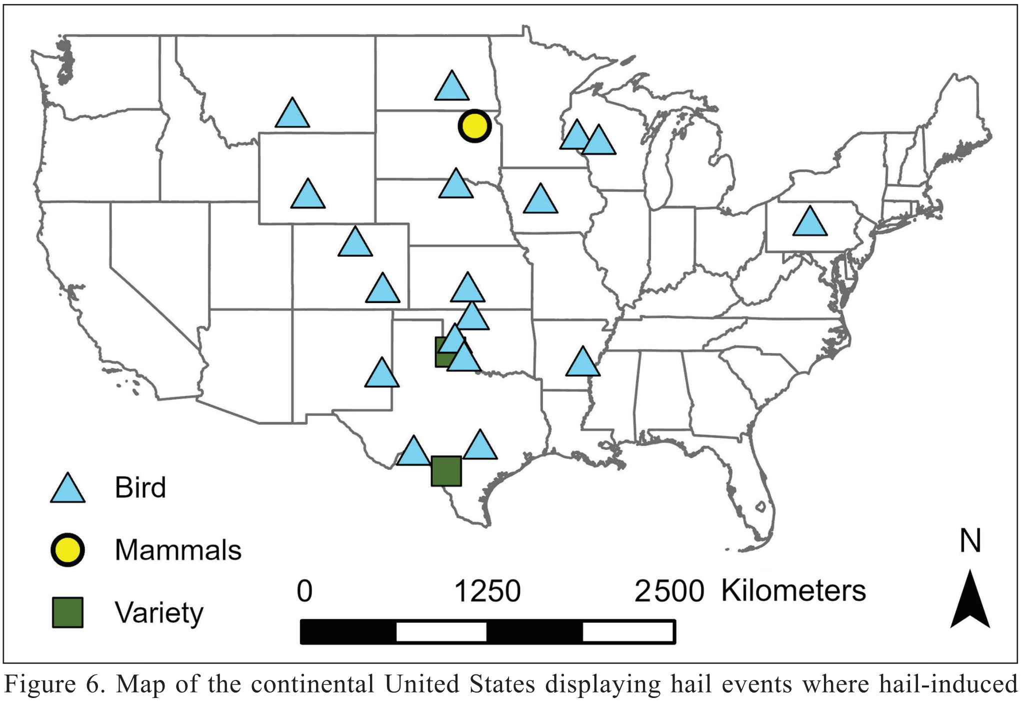

Figure 6. Map of the continental United States displaying hail events where hail-induced mortality of wildlife was documented. Events separated by taxonomic classes: Aves, Mammalia, and various.

largely *Colophospermum mopane* (J. Keirk ex Benth.) J. Léonard (Mopane) savanna and shrubland. Additionally, a large majority of hail-induced bird mortality events in the United States occurred in open areas such as bodies of water (Merrill 1961, Ragan 2001), wetlands (Fyfe 1957, Heflebower and Klett 1980, Higgins and Johnson 1978, Montana Fish, Wildlife and Parks 2019), or areas of expansive agriculture and prairies (Hightower et al. 2018, Smith and Webster 1955). We did observe a case of mortality and a case of a severe injury in a species of songbird that may be attributed directly to hail-stone strikes. However, it has been found that other factors from storms (e.g., strong winds, lightning, etc.) can also impact songbird survival (Glasrud 1976, Roth 1976); thus, hail as the cause of direct mortality of the songbird remains inconclusive. It can be speculated that animals move to the nearest area of cover as a likely strategy during severe weather. In India, Narwade et al. (2014) reported that ungulates desperately sought cover from hail by jumping in bodies of water or seeking refuge in shrubland thickets. Documentation of White-tailed Deer behavior during severe weather is very limited. Samuel and Glazener (1970) found White-tailed Deer fawns moved to higher ground during Hurricane Beulah, while Abernathy et al. (2019) observed that deer drastically increased movement during the day of hurricane Irma and sought refuge in areas of denser vegetation; neither study observed deer mortality due to the hurricanes. While these studies and others (Garstang 2009, Kirschvink 2000, Streby et al. 2015) documented animals altering behavior prior to or during severe weather or natural disasters, there is still a poor understanding of what subtle cues may cause this change in behavior and how long in advance an animal can detect these cues. It is possible deer at the ACF may have detected incoming severe weather and altered behavior by avoiding open areas on the property. Future research needs to examine deer movement to better understand habitat selection and movement rates prior to, during, and post severe weather events.

While we are aware these findings only represent 1 population, we speculate severe hailstorms may have minimal impact on White-tailed Deer populations in the southeastern United States due to the rarity of these events and generally adequate forested canopy cover that may act as a refuge from hail strikes. It is worth mentioning that hailstorms of this magnitude may have greater negative consequences for herd viability during the fawning season when fawns are largely stationary during their first few weeks of life (DeYoung and Miller 2011) and more prone to trauma from impact strikes, especially in regions where fawn bed-site selection has limited canopy cover (Michel et al. 2020, Uresk et al. 1999). Furthermore, hail events of this magnitude may increase in frequency in the future due to a changing climate (Brimelow et al. 2017, Raupach et al. 2021). As a result, further research is warranted to better understand White-tailed Deer behavior during severe weather events that can risk individual survival.

Acknowledgments

We thank Arielle Fay, Travis Stoakley, and Steve Zenas who helped with our primary survey of the ACF. We also greatly appreciate all those who funded and supported our research through the years: Code Blue Scents, EBSCO Industries, PRADCO Outdoors Brands, Moultrie Feeders, Summit Tree Stands, and Deer & Deer Hunting Magazine. We are grateful to John Kobar from NOAA and Gerald Satterwhite from NWS for help with retrieving data regarding the storm event. Special thanks to Victor Jackson and Chad Newbolt for providing maintenance of the facility. Finally, thank you to Dr. Mike Conner and 2 anonymous reviewers for their help and useful insight in the editing of this manuscript.

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