

Little Evidence of Leaf Damage to Dwarf Palmetto (*Sabal minor*; Arecaceae) during an Unusual Arctic Outbreak

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Abstract: The dwarf palmetto (*Sabal minor*) is a widespread understory palm of the southeastern United States. This palm is expected to be one of the species that exhibits a range shift in response to climate change, and the population at the northwestern edge of its distribution in Oklahoma appears to be increasing in both numbers and extent. However, this palm may also be susceptible to cold damage during unusually severe winters, which could potentially limit the spread of this species. An unusually cold arctic outbreak spread across the southern Great Plains during 13–17 February 2021, with minimum temperatures of -11°C recorded in Houston (Texas), -15°C in San Antonio (Texas), and -26°C in Oklahoma City (Oklahoma). In order to evaluate the effects of the arctic outbreak on *Sabal minor*, I examined individuals in four counties (one site in Brazoria County, TX; one site in Brazos County, TX; two sites in McCurtain County, Oklahoma; and two sites in Oklahoma County, Oklahoma) in the period of 5–16 March 2021. At nearly every site, 30 individuals were examined, and the number of palmate leaves as well as the extent of the green area on the leaf was visually estimated, with percentages rounded to the nearest 5%. There was little evidence of cold damage from southeastern Oklahoma to coastal Texas, with palmate leaves retaining a median of 85% green area. However, some damage was noted in seedlings at the northernmost population in McCurtain County, Oklahoma. In contrast, extensive leaf damage was noted in dwarf palmetto plantings in Oklahoma County, Oklahoma, with plants retaining a median of only 5% green leaf area. The results of this study suggest that arctic outbreaks are unlikely to prohibit the continued spread of this species at the northern edge of its native range but may cause damage to multiple plant growth stages that could reduce the rate at which the species survives and reproduces.

Keywords: climate change; dwarf palmetto; Oklahoma; *Sabal minor*; Texas



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1. Introduction

Changes in mean precipitation and temperature have been linked with distributional shifts in a number of species [1,2], and these shifts are expected to continue to occur in the coming decades [3]. However, extreme weather events can also be key drivers of biodiversity [4,5]. For example, the poleward edge of a species' distribution may not necessarily remain in the same place, as cold weather outbreaks can potentially reduce or eliminate a species at the edge of its range. In Florida, for instance, the northeastern Atlantic coast region is a mangrove-salt marsh transition zone, and the extent of the mangroves declined substantially after severe freezes in the 1940s and 1980s [6].

Palms are expected to be impacted by climate change [3,7], with the range of some species apparently expanding poleward in recent years [8,9], as well as expanding in distribution after being introduced to areas outside of their native range [7,10]. However, palms can also be negatively affected by cold-weather outbreaks. Broschat [11] summarized these types of injuries as chilling injury (which may occur when tropical species are exposed to temperatures below 10°C), radiational freeze injury (when radiational cooling on leaves may cause the leaf temperature to drop below freezing), and hard freeze damage (when both air and plant temperatures drop below freezing). Some palm species are more resistant to cold damage [12], and Larcher and Winter [13] note that not all parts of a palm are equally

susceptible to cold damage, with the petioles and the apical meristem being more cold-hardy than the leaves. Additionally, cold-hardiness may be affected by age, as seedlings may be considerably less cold-tolerant than adult plants [14].

One species that may be responding to climate change is the dwarf palmetto (*Sabal minor*; Arecaceae), an understory, typically acaulescent palm of low-lying areas from North Carolina west to southeastern Oklahoma, south to Florida and Texas [15]. In Oklahoma, the dwarf palmetto is restricted to extreme southeastern Oklahoma [16]. There is also an isolated population in northeastern Mexico [17]. This palm is remarkably cold-hardy, and has been reported to eventually recover from temperatures dropping to -20.6°C , which can defoliate the plant [18]. Widespread leaf damage, where the appearance of the leaves changes from green to brown, reportedly occurs when it is exposed to -13.5°C [13]. The dwarf palmetto appears to be increasing both in extent [16,18], and number [19] at the northern edge of its range and is predicted to be substantially affected by climate change [3].

In 13–17 February 2021, an arctic outbreak spread cold weather across the US [20]. Dubbed Winter Storm Uri by the Weather Channel [21], this winter weather outbreak caused an estimated USD 600 million in agricultural losses in the state of Texas alone [22]. This storm brought the coldest temperatures in decades to the southern Great Plains, with Houston (Texas) temperatures dropping to -11°C (the coldest temperature since 1989), San Antonio (Texas) reaching -15°C (the coldest temperature since 1989) and Oklahoma City (Oklahoma) reaching -26°C (the coldest temperature since 1889; [23]). Widespread snow also occurred with this storm; by the time Winter Storm Uri ended, approximately 75% of the continental US was covered in snow [23]. This arctic outbreak provided an opportunity to explore the potential effects of unusually low temperatures on a palm species that is predicted to shift its range in response to climate change, and I hypothesized that apparent leaf damage would be greatest in areas that experienced the coldest temperatures.

2. Materials and Methods

In order to evaluate the effects of the arctic outbreak on *Sabal minor*, I examined individuals in four counties in Oklahoma (OK) and Texas (TX), USA, including Bobcat Woods in San Bernard National Wildlife Refuge in Brazoria County, TX ($28^{\circ}52'56''\text{ N}$, $95^{\circ}35'6''\text{ W}$); Lick Creek Park in Brazos County, TX ($30^{\circ}33'31''\text{ N}$, $96^{\circ}12'37''\text{ W}$); Red Slough Wildlife Management Area ($33^{\circ}44'9''\text{ N}$, $94^{\circ}39'0''\text{ W}$) and Beavers Bend State Park ($34^{\circ}8'16''\text{ N}$, $94^{\circ}41'9''\text{ W}$) in McCurtain County, OK; and the Oklahoma City Zoo ($35^{\circ}31'23''\text{ N}$, $97^{\circ}28'21''\text{ W}$) as well as a private residence in Choctaw ($5^{\circ}28'44''\text{ N}$, $97^{\circ}13'2''\text{ W}$), both of which were in Oklahoma County, OK in the period of 5–16 March 2021 (Figure 1). *Sabal minor* is native in three of these counties, but not in Oklahoma County. However, there are extensive plantings of these species at the Oklahoma City Zoo. Additionally, at a private residence in Choctaw, there are 13 mature individuals grown from seed collected in McCurtain County, Oklahoma.

At each location, I examined 30 individuals with palmate leaves, except for the private residence in Oklahoma County where only 13 individuals were present. I recorded the number of palmate leaves and visually estimated the percentage of the leaf area that remained green. This visual estimation consisted of examining each leaf of the palm and mentally estimating how much of each leaf appeared brown. The percentages for all leaves were then averaged for the plant. Percentages were rounded to the nearest 5% (e.g., a leaf that appeared to be 72% green was recorded as 70% green). However, plants were only recorded as 0% green if no green was visible; plants that would have been rounded to 0% green but still possessed some green (i.e., the percentage green was $<2.5\%$) were recorded as $<5\%$ green. This was performed in order to differentiate between plants that may have been dead, and plants that were badly damaged but were still alive.

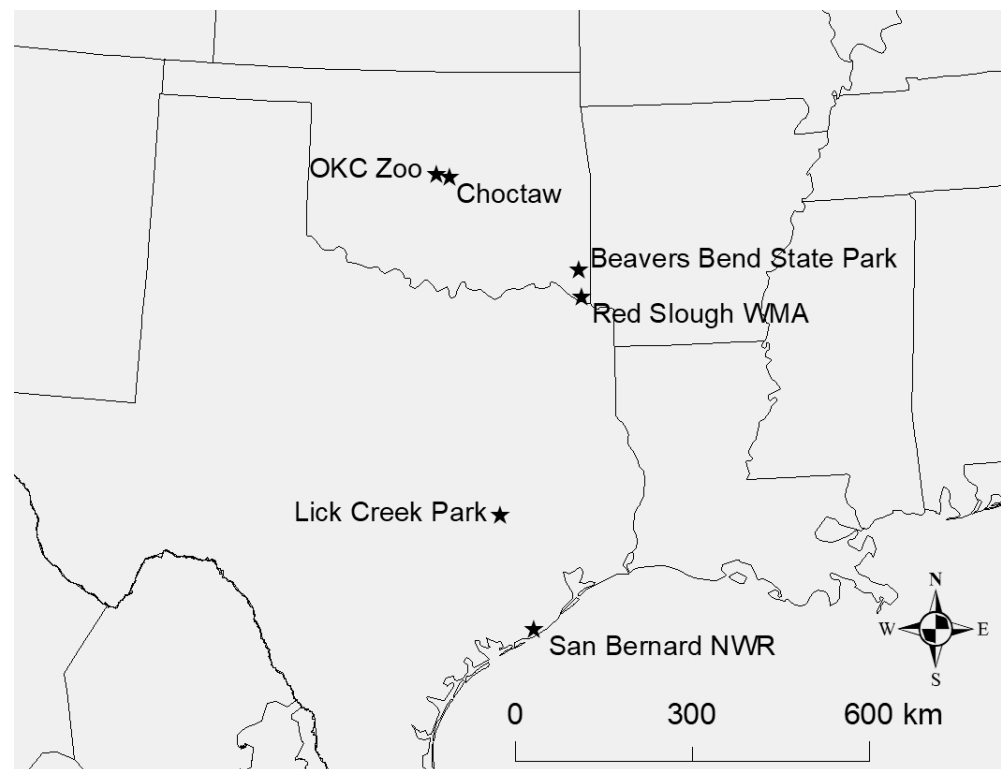


Figure 1. The locations in the US where palms were examined after the passage of winter storm Uri. Palms were examined at San Bernard National Wildlife Refuge in Brazoria County (Texas), Lick Creek Park in Brazos County (Texas), Red Slough Wildlife Management Area in McCurtain County (Oklahoma), Beavers Bend State Park in McCurtain County (Oklahoma), a private residence in Choctaw (Oklahoma County, Oklahoma), and the Oklahoma City Zoo (Oklahoma County, Oklahoma).

Additionally, notes were taken on whether there was evidence of reproduction (e.g., whether seedlings with strap leaves or individuals with split leaves were present), although cold damage to individuals lacking palmate leaves was not recorded. The three different leaf stages (strap leaves, split leaves, and palmate leaves) depend on the age of the plant [16]. Seeds germinate and produce strap leaves and may not develop split leaves for three years or more. Individuals next develop split leaves and then finally palmate leaves. Only individuals with palmate leaves will produce flowers and fruit (pers. obs.).

Finally, palms were revisited at the Oklahoma City Zoo on 24 June 2021 and at San Bernard National Wildlife Refuge on 30 June 2021 to explore whether the cold temperatures may have caused delayed mortality as well as to compare whether flowering rates were similar in the two locations. Temperature data were downloaded from the NOAA National Centers for Environmental Information [24] (graphs of air temperature are in Supplementary Material), and it was assumed that air temperatures experienced by the measured palms were similar to the temperatures measured at the nearby weather stations. Data were analyzed using a Kruskal–Wallis test, followed by a nonparametric multiple comparisons test using a Bonferroni correction.

3. Results

Figure 2 shows representative examples of leaves at each of the six locations. There was a significant difference in the number of palmate leaves ($\chi^2 = 25.2$, $df = 5$, $p = 0.0001$; Figure 3), with Beavers Bend State Park in McCurtain County having significantly fewer leaves than Choctaw (Oklahoma County, OK; $p = 0.005$), Oklahoma City Zoo (Oklahoma County, OK; $p = 0.028$), Red Slough WMA (McCurtain County, OK; $p = 0.002$) and Lick Creek Park (Brazos County, TX; $p = 0.0002$). Likewise, there was a significant difference in the amount of green per leaf for the two locations in central Oklahoma (Oklahoma City

Zoo and Choctaw) relative to the locations in southeastern Oklahoma and Texas ($p < 0.0001$ for all comparisons; Figure 3).

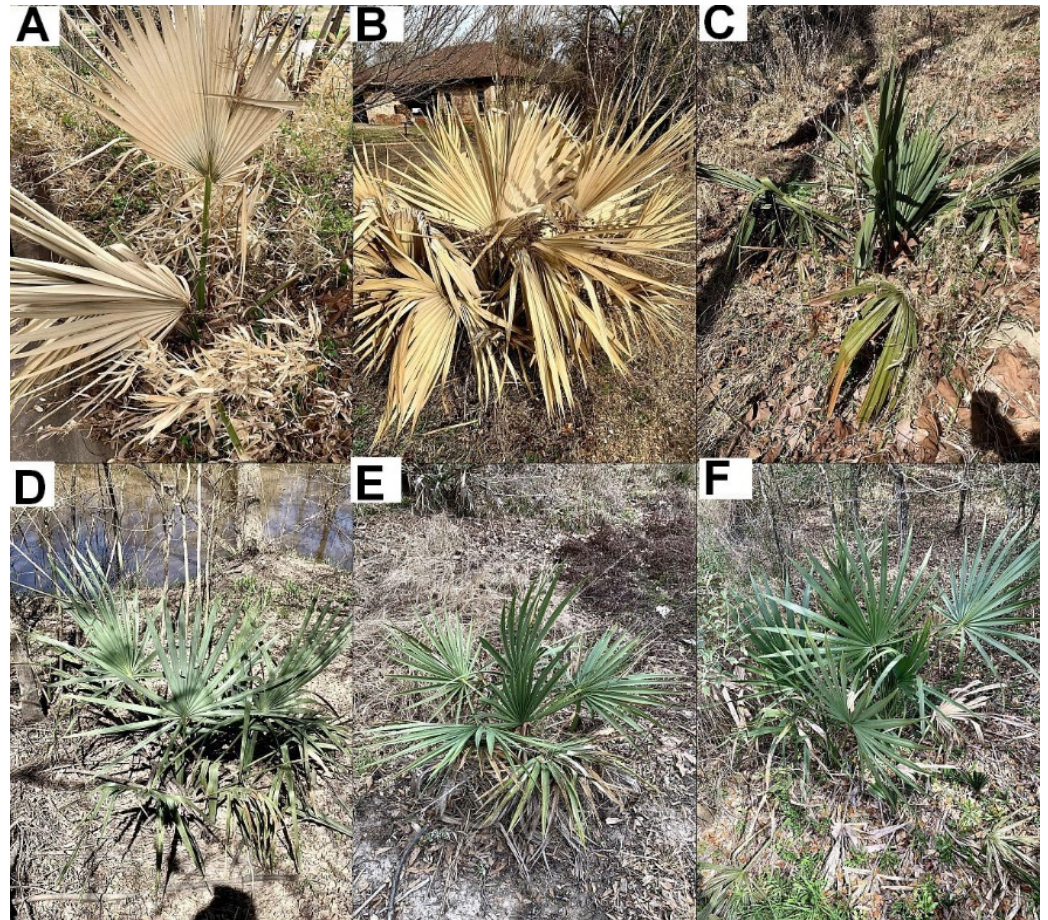
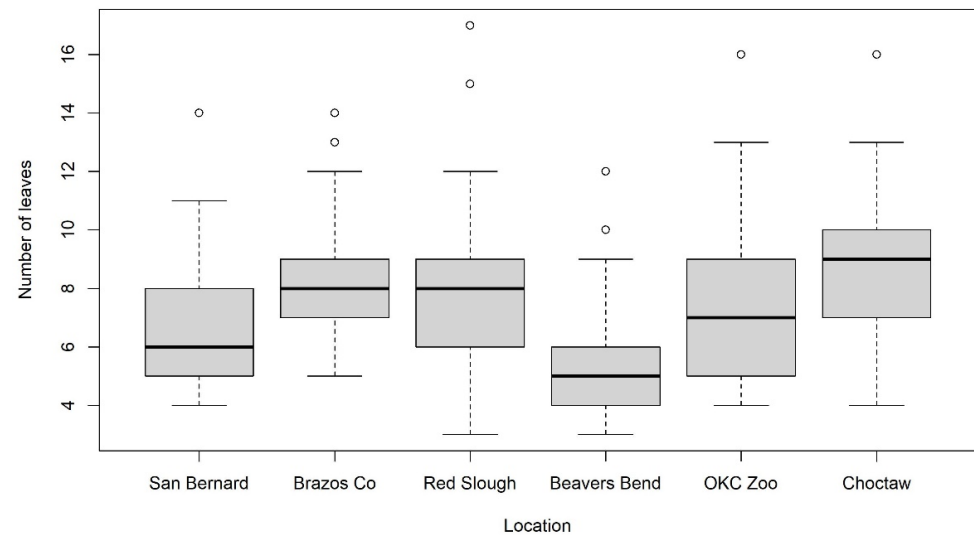


Figure 2. This figure shows typical examples of *Sabal minor* at each of the six locations after the passage of Winter Storm Uri. At the Oklahoma City Zoo (A) and the private residence in Choctaw (B), both in central Oklahoma, palms were a median of <5% green after temperatures dropped to $-26\text{ }^{\circ}\text{C}$ and remained below freezing for 11 days. At Beavers Bend State Park in McCurtain County, Oklahoma (C), where temperatures dropped to $-21\text{ }^{\circ}\text{C}$ and stayed below freezing for approximately seven days, leaves were a median of 85% green. Palms at the nearby Red Slough Wildlife Management Area (D), which experienced similar conditions, remained approximately 90% green. Lick Creek Park (E) in Brazos County, Texas, and Bobcat Woods at San Bernard National Wildlife Refuge (F) in Brazoria County, TX, showed similar amounts of green to palms in southeastern Oklahoma.

In Bobcat Woods, San Bernard National Wildlife Refuge, Brazoria County, TX where the coldest temperature recorded during the outbreak was $-9\text{ }^{\circ}\text{C}$ and temperatures did not reach above freezing for approximately three days, individuals ($n = 30$) had a median of six palmate leaves (range 4–14 leaves), with a median of 85% green leaf area (range 60–95%). In Brazos County, TX where the temperature dropped to $-15\text{ }^{\circ}\text{C}$ and did not reach above freezing for approximately four days, palms had a median of eight palmate leaves ($n = 30$; range 5–14 leaves), with a median of 80% green leaf area (range 45–95%). In McCurtain County, where the temperature fell to $-21\text{ }^{\circ}\text{C}$ and stayed below freezing for approximately seven days, palms at Beavers Bend State Park had a median of five palmate leaves ($n = 30$; range 3–12 leaves) with a median of 85% green leaf area (range 60–100%), while palms at the nearby Red Slough Wildlife Management Area had a median of eight palmate leaves ($n = 30$; range 3–17 leaves), with a median of 90% green leaf area (range 75–95%). Seedlings and individuals with strap leaves were located at all locations except for Brazos County, TX. Some seedlings at Beavers Bend State Park in McCurtain County appeared to show leaf

browning consistent with cold damage, but the extent of this was not quantified. Seedlings at other locations did not appear to have been damaged by arctic outbreak.

A



B

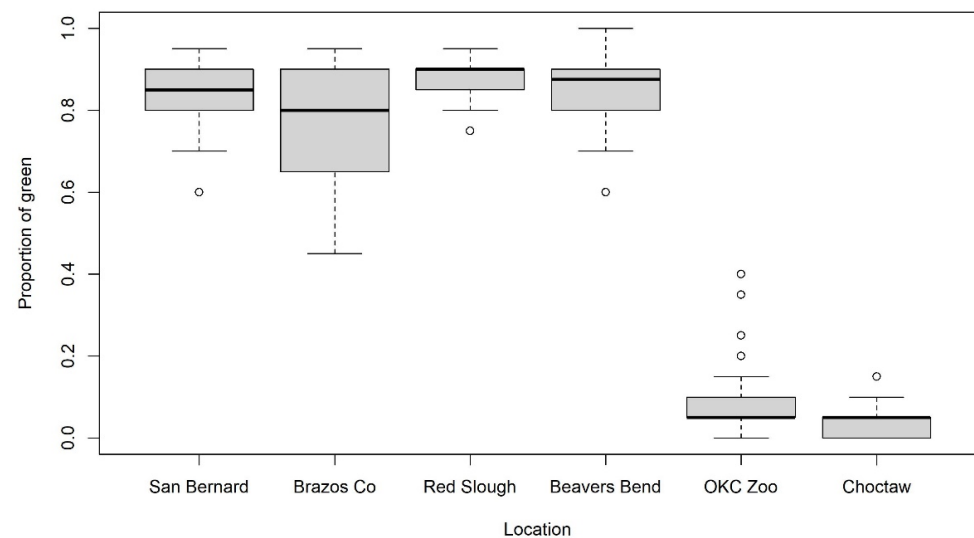


Figure 3. (A) This boxplot shows the number of leaves per palm at each location, arranged by latitude. No clear trend is evident, although the lowest number of leaves per palm is found at Beavers Bend State Park in southeastern Oklahoma. (B) The boxplot shows the amount of green on each leaf per palm at each location, arranged by latitude. Palms located at the highest latitudes, in central Oklahoma, had very little green. In contrast, palms from southeastern Oklahoma through to coastal Texas had approximately the same amount of green. Data for San Bernard NWR were collected on 8 March 2021 (19 days after Winter Storm Uri); Brazos County (abbreviated as “Brazos Co”) data were collected on 5 March 2021 (16 days after Winter Storm Uri); Red Sough Wildlife Management Area and Beavers Bend State Park data were collected on 15 March 2021 (26 days after Winter Storm Uri); Oklahoma City Zoo (abbreviated as “OKC Zoo”) data were collected on 16 March 2021 (27 days after Winter Storm Uri); and Choctaw data were collected on 10 March 2021 (21 days after Winter Storm Uri).

Outside of its native range, palms were severely damaged in Oklahoma County, Oklahoma, where temperatures dropped to -26°C and did not reach above freezing for approximately 11 days. At the Oklahoma City Zoo, palms had a median of seven palmate leaves ($n = 30$; range 4–16 leaves), with a median of only 5% green remaining (range <5–40%). No palms appeared to be completely dead, but six of the thirty palms (20%) had <5% green. At a private residence in Oklahoma County, palms had a median of nine palmate leaves ($n = 13$; range 4–16 leaves), with a median of 5% green remaining (range <5–15%). No palms appeared to be completely dead, but four of the thirteen palms (31%) had <5% green. At both locations, approximately 50% of the individuals with strap leaves or split leaves appeared to have been damaged by the cold, with some individuals appearing completely brown.

The Oklahoma City Zoo site was revisited on 24 June 2021. Of the 30 individuals examined in March, two were now completely brown, while the remaining 28 had sprouted green palmate leaves. Additionally, 11 individuals (36.7%) were now flowering. The San Bernard National Wildlife Refuge palms were revisited on 30 June 2021. All 30 palms had sprouted green palmate leaves, and 14 of the 30 individuals (46.7%) were flowering.

4. Discussion

The limited amount of foliar damage observed on dwarf palmettos in response to the unusually cold arctic outbreak suggests that these periodic outbreaks of extreme low temperatures are unlikely to reduce the populations of this species at the northern edge of their range. An arctic outbreak reaching extreme south Texas during 1983, when temperatures dropped to -8.8°C in the Lower Rio Grande Valley, resulted in only minor leaf damage to the native palm *Sabal mexicana* [25]. Another severe freeze in 1989, when temperatures dropped to -8.9°C in Brownsville, resulted in no apparent leaf damage to the native *Sabal mexicana* [26].

Although Larcher and Winter [13] suggest that the leaves of mature dwarf palmettos are damaged by temperatures of -13.5°C , mature dwarf palmettos in Oklahoma with palmate leaves appeared to tolerate temperatures as low as -21°C as well as temperatures of below freezing for a week, with only a few individuals exhibiting minor evidence of leaf damage. It is possible that the observed difference may be due to the provenance of the seeds, as provenance has been linked with cold-hardiness in plants [27]. The individuals examined by Larcher and Winter [13] were grown in Europe and presumably were not from seeds taken from individuals at the northern edge of their range. Additionally, it is also possible that nutrient availability played a role, as nutrients can affect the apparent cold-hardiness of some palm species [28].

Although the arctic outbreak of 2021 did not cause apparent widespread mortality in dwarf palmettos, some mortality may have occurred. At the Oklahoma City Zoo, where temperatures dropped to -26°C and remained below freezing for approximately 11 days, two of the thirty individuals surveyed had turned completely brown by late June 2021, and it is possible that these individuals may not have survived the arctic outbreak. Solar radiation during cold stress may substantially increase plant physiological damage [29], and the dwarf palmettos in central Oklahoma likely experienced higher solar radiation than plants in the native range. Within the native range, dwarf palmettos are primarily an understory species [15], but the individuals planted in Oklahoma were planted in gardens rather than in forests, and so likely received more sunlight during the winter.

Additionally, it is also possible that these cold temperatures may have sublethal impacts that may reduce plant fitness, as cold temperature may be injurious to all stages of plant development [30]. Some individuals with split leaves or strap leaves exhibited substantial foliar damage in Oklahoma. Not all individuals exhibited this damage, however, and it is unclear whether the observed differences in damage to young palms was due to genetics or environmental factors. It is also possible that the arctic outbreak may have affected the number of individuals flowering in central Oklahoma, as the flowering rate at San Bernard National Wildlife Refuge in late June 2021 was 46.7% compared with 36.7%

in Oklahoma City during the same period. However, it is unclear whether the observed difference in flowering rates might be due to differences in phenology, precipitation, or some other factor.

5. Conclusions

Winter Storm Uri provided an opportunity to explore the effects of unusually low temperatures on foliar damage to dwarf palmettos. As hypothesized, the apparent leaf damage was greatest in central Oklahoma, the area that experienced the coldest temperatures. However, leaf damage in the native range appeared to be minimal, even when temperatures dropped to -21°C and stayed below freezing for a week. Overall, given that the mature individuals appeared to tolerate these extreme temperatures, and given that these temperatures did not appear to be lethal to most of the young palms, it seems likely that arctic outbreaks will play only a limited role in determining the northern edge of dwarf palmettoes during the 21st century.

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