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Research Article

Citizen Science Observations of Monarch Butterfly Overwintering in the Southern United States

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Members of the public have long had a fascination with the monarch butterfly, *Danaus plexippus*, because of its amazing long-distance migration to overwintering sites in central Mexico, and many participate in online citizen-science programs where they report observations of its life history in North America. Here, we examine a little-studied aspect of monarch biology, the degree of overwintering in the southern United States. We compiled 9 years of sightings of overwintering monarchs in the southern United States that were reported to Journey North, a web-based citizen science program, to map the distribution of areas where monarchs are capable of surviving during the winter (i.e., in January and February), differentiating between adult sightings and sightings of breeding activity. We also statistically compared the latitudes of adult and breeding sightings, examined differences across years in latitude of sightings, and quantified the number of monarchs reported with each sighting. Of all 254 sightings, 80% came from Florida and Texas, with the remainder coming from South Carolina, Louisiana, Georgia, Alabama, Mississippi, North Carolina, and even one in Virginia. This distribution was generally consistent with the winter range predicted by prior investigators based on climatic conditions of this region. Sightings of adults were on average from higher latitudes than reports of breeding activity and there was significant variation across years in the average latitude of all sightings. The majority of sightings (94.2%) were of fewer than 10 adult monarchs per location, and there were no reports of clustering behavior that is typical of monarch overwintering in California and Mexico. The results of this investigation broaden our collective understanding of this stage of the monarch life cycle and, more generally, highlight the value of citizen science programs in advancing science.

1. Introduction

The life cycle of the monarch butterfly, *Danaus plexippus*, in eastern North America is unique among insects, as every fall the late-summer population undergoes a famous 3000 km$^+$ southward migration to overwintering sites in central Mexico [1]. There, they spend the winter clustered in high-altitude fir forests before flying back northward in March to recolonize their breeding range [2]. This fascinating life cycle has not only garnered the monarch a high degree of scientific attention [3, 4], but it has made it the focus of many "citizen-science" programs, whereby school children, public citizens, and naturalists document and collect observational data on various aspects of its biology. One of these programs is Journey North, a nonprofit education-focused organization with a website that allows users to input records of a variety of monarch-related observations. Several of these Journey North data sets have already contributed to the collective scientific knowledge of this insect's biology; sightings of northward-migrating monarchs were used previously to map the progression northward [2] and to estimate the rate of northward travel [5]. More recently, the sightings of fall roosts were mapped to elucidate the southward migration flyways [6]. Here, we use other data from this program to examine a little-studied aspect of monarch biology, the degree of overwintering in the southern United States.

Scientists have known for many years that not all monarchs in the population east of the Rocky Mountains reach

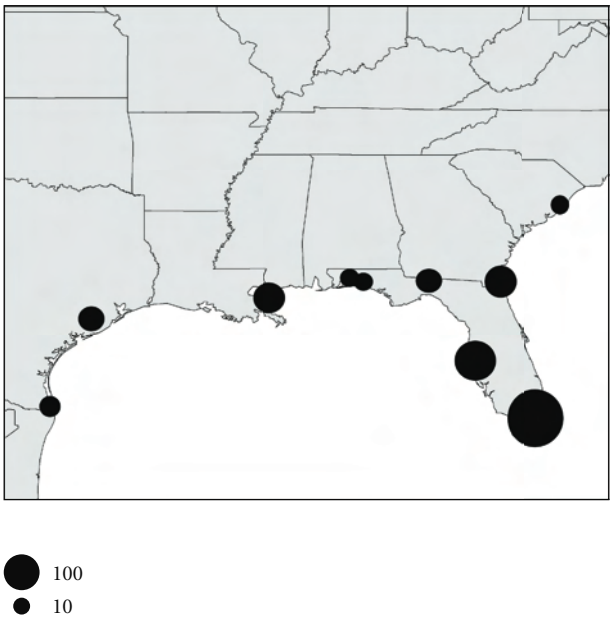

Figure 1: Predicted distribution of adult monarch butterflies in the southern United States in winter, based on a CLIMEX model that calculates suitable conditions for adult survival from environmental data (redrawn with permission from [12]). Size of black circles refers to an index score of abundance given by the CLIMEX model (not number of monarchs).

central Mexico each winter. Some have provided evidence that a small number ends up in Cuba [7]. Hilburn [8] reports monarchs occasionally arriving to Bermuda in the fall. In the United States, there is a well-known resident population in southern Florida [9, 10] that receives annual influxes of migrants from the larger eastern population [11]. Brower [1] compiled many early reports of monarchs wintering in peninsular Florida and other Gulf coast locations. And finally, based on regional climatic data and knowledge of adult survival thresholds, Zalucki and Rochester [12] modeled the predicted winter range of monarchs in the United States, which pointed to multiple *potential* wintering areas along the Gulf coast and Florida (Figure 1). These were areas where monarchs would be theoretically capable of surviving, given the typical temperature and moisture levels of the region in the winter. Thus, the collective evidence indicates that there are multiple areas in the southern United States where monarchs are capable of surviving during the winter.

Since 2002, the Journey North program has compiled winter observations of monarchs made by citizens and interested persons in the southern United States. In most cases, these sightings are made by people who were surprised to find a monarch in their area during the winter, given the well-known Mexican wintering colonies. As each winter sighting is reported, (and verified by Journey North staff), it is displayed on an online map for that year (http://www.learner.org/jnorth/). While these sightings, which are made by homeowners, amateur naturalists, and interested citizens, were not necessarily obtained with scientific rigor, over the course of 9 years, these sightings nevertheless collectively represent an important source of information on this phenomenon, which would otherwise be nearly impossible to study scientifically because of the spatial scope involved.

In the current study, we compiled and examined 9 years of reports of monarchs overwintering in the southern United States from the Journey North program in an effort to further scientific understanding of this phenomenon. Our objectives were to (1) map the distribution of overwintering monarchs using all available records (using sightings from 2002 to 2010), distinguishing between sightings of adults or of winter breeding activity, (2) compare the latitudes of the sightings in both categories and across years, (3) estimate the number of monarchs observed with each overwintering sighting, and (4) report on other observations of biological importance made by certain Journey North participants who are located in key points within the distribution of wintering sites. The results of this investigation will help fill a large gap in the collective knowledge of this aspect of the monarch butterfly life cycle in North America.

2. Methods

2.1. Journey North Sightings. We compiled sightings of monarchs from the "monarch overwintering" sightings database which is accessible within the archived sightings section of Journey North's website (http://www.learner.org/jnorth/maps/archives.html). These sightings represent observations of adults, eggs, and larvae of monarchs that are made and submitted online by Journey North participants during the wintering season. There is no specific format or requirement for the sightings, only that they be, to the best of the observer's knowledge, of wild monarch butterflies (i.e., not reared). Each report contains a date, location (i.e., town, state, and latitude and longitude), and a summary of the observation, which is usually a statement such as "We saw three adult monarchs flying around our garden today", or "We were surprised to find third-instar caterpillars on our milkweed plants in January". Some participants also include photographs of the sighting. While people are free to enter overwintering sightings from January through March of each year, for the current study we selected only those sightings from January and February. This was to eliminate the possibility that the monarchs sighted were individuals returning from Mexico, which occurs in March in the southern United States [2, 5]. We categorized each sighting into one of two groups: sightings of adults only, or sightings of breeding activity, which we considered as any observation of monarch eggs, larvae, pupae or of females ovipositing. If we could not discern which, category the sighting fit into based on the information given, we did not include that record. The sightings were then plotted onto a map of the southern United States using ArcView GIS software, based on the latitude and longitude coordinates with each record. Finally, we further categorized the sightings into one of three groups according to how many (adult) monarchs were seen, based on the notes provided by the observers:

Table 1: Summary of all sightings of "overwintering" monarchs (sightings of adults and breeding activity) made during the months of January and February from 2002 to 2010, broken down by state.

State	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
FL	9	13	6	7	7	8	12	24	13	99
TX	20	9	12	8	9	3	11	19	3	94
SC	0	0	0	2	6	2	7	1	1	19
LA	5	3	0	2	1	0	0	5	0	16
NC	1	0	0	0	4	1	0	0	0	6
GA	0	1	0	0	1	0	0	1	1	4
AL	0	0	0	0	1	1	0	0	0	2
VA	0	0	0	0	1	0	0	0	0	1
MS	0	0	0	0	0	0	1	0	0	1
All States	35	26	18	19	30	15	31	50	18	242

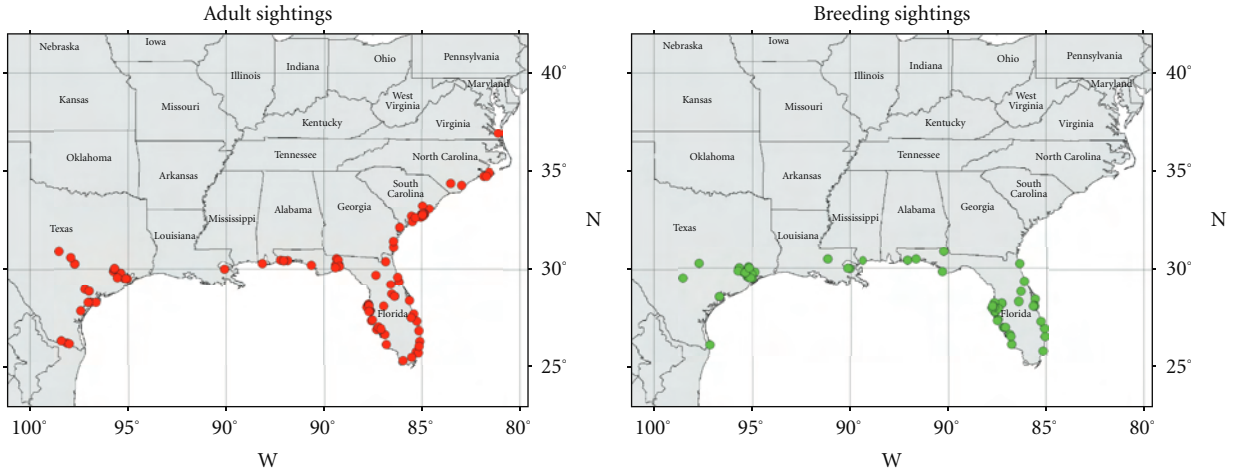

Figure 2: Locations of winter sightings of (a) adult and (b) breeding monarch butterflies (i.e., larvae, pupae, or ovipositing females) in the southern United States, as reported to Journey North in January and February from 2002 to 2010.

one adult; a small number of adults (2–9 individuals); or 10 or more adults. In some cases, observers reported seeing "lots of larvae" or "milkweeds covered with larvae", and in these cases we assumed that there were less than 10 adult monarchs present (since a single female can produce many larvae).

2.2. Data Analyses. We were primarily interested in knowing if the latitude of sighting (response variable) differed between breeding and adult categories, which necessitated the use of circular statistics [13]. Therefore, using the data from all sightings, we used a Watson-Williams test to compare latitudes between categories. We used a similar test to compare latitudes across years. Analyses were conducted using MATLAB software with the CircStat toolbox installed [14].

3. Results

3.1. General. A total of 242 sightings of overwintering monarchs were made over the 9-year time frame of this study (Table 1). Of these, 193 (80%) were of sightings in Texas and Florida. The other sightings came from South Carolina, Louisiana, Georgia, Alabama, Mississippi, North Carolina, and even one in Virginia during the winter of 2006 (see verification of this sighting below). We note that all of these are coastal states and in fact most sightings occurred along the coastlines of these states (below).

3.2. Spatial Distribution of Sightings. The distribution of sightings differed visibly between the two categories. Sightings of adult monarchs from all years are mapped in Figure 2(a), which shows that sightings occurred in each of the 9 states listed above, with locations appearing to generally fall close to the coastline. However, sightings of breeding monarchs, which also appeared to fall along coastlines, were only made at locations below 31° N latitude (Figure 2(b)). The adult monarch sightings in Virginia in February 2006 were extremely unusual because of the high latitude, however, the observers who made this report (David and Joyce Williams) provided detailed evidence to support the observation. During the prior fall (of 2005),

Table 2: Summary of average latitudes of monarch winter sightings across all years and sighting categories (adults only or confirmed breeding). Numbers in parentheses indicate 95% confidence intervals. Means and confidence intervals calculated using circular statistics [13].

Year	Adult(s) only		Breeding		Combined	
2002	29.7°	(0.7)	29.0°	(0.9)	29.4°	(0.5)
2003	29.2°	(0.8)	29.0°	(0.6)	29.1°	(0.5)
2004	29.0°	(1.5)	29.8°	(0.3)	29.5°	(0.5)
2005	30.7°	(1.0)	28.7°	(0.9)	29.5°	(0.8)
2006	31.7°	(1.3)	28.6°	(1.0)	30.7°	(1.0)
2007	29.7°	(1.8)	28.9°	(1.1)	29.5°	(1.3)
2008	30.4°	(1.1)	28.9°	(0.7)	29.7°	(0.7)
2009	28.8°	(0.7)	29.3°	(0.4)	29.0°	(0.4)
2010	28.2°	(1.6)	28.2°	(1.0)	28.2°	(0.9)
All years	29.8°	(0.4)	29.0°	(0.2)	29.4°	(0.2)

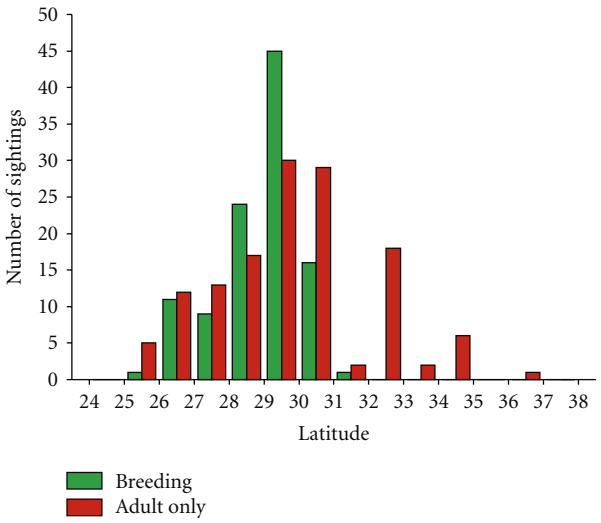

Figure 3: Distribution of the sighting latitude of adult and breeding monarch butterflies in January and February from 2002 to 2010.

these participants had been capturing and tagging adult monarchs with numbered MonarchWatch stickers [15], and in February of 2006 they observed a tagged monarch in their yard in Virginia Beach. They subsequently captured two monarchs two weeks later and discovered that both had been tagged by them in the fall on two successive days (September 25 and 26). Thus, they are confident that these monarchs stayed in the vicinity of their yard in Virginia from September 05 through March 06.

3.3. Statistical Analyses of Sighting Latitudes. Consistent with the spatial pattern shown in Figure 2, the initial Watson-Williams test indicated that the average latitudes of all adult sightings (mean = 29.8° ± 0.4) differed significantly from that of the breeding sightings (mean =29.0° ± 0.2; $F_{1,240}$ = 10.11, P = .0017; Table 2, Figure 3). Given that 1° latitude is equivalent to 111 km, this equates to an average difference of 89 km between categories. This difference is also apparent when viewing the annual averages in Table 2, where in 6 of the 9 years, the average latitude of adult sightings was greater than that of the breeding sightings. The second Watson-Williams test revealed significant variation across years in the average latitudes of sightings ($F_{8,233}$ = 3.32, P = .0013). This variation can also be seen in Table 2, where a noticeable decline in latitude occurred in the last year of records (2010); in this year, the average latitude of all sightings was approximately 1° or 111 km lower than most prior years.

The drop in latitude in 2010 can be attributed to the unusually cold winter in that year in the southern United States, when many observers reported below-freezing January temperatures in regions where it normally does not freeze. In Port Lavaca, TX (a gulf-coast town in southern Texas), one of us (H. Aschen) observed 3-4 monarchs per day in December and January until the first week of January when Texas had one of the hardest freezes in almost twenty years, down to 24 (°F). After that, H. Aschen saw no butterflies. Moreover, after the freeze, H. Aschen contacted a number of other regular monarch observers in southern Texas and asked if they had seen monarchs, and all reported none. Later, another observer from League City, Texas reported to Journey North: "I've spotted only one monarch since our big freeze, most of my milkweed was lost." There was also a noticeable difference in the location of sightings during this season, which is evident in Table 1. In most years, the proportion of sightings that come from the state of Florida ranged between 23% and 53% of the total. However, in the 2010 overwintering season, 72% of all sightings came from Florida, and of these, all were between 25 and 28° north latitude.

3.4. Numbers of Monarchs Seen. Of all 242 sightings, 89 (36.8%) were of single adult monarchs, 139 (57.4%) were of a small number of adults (i.e., less than 10), and 14 sightings (5.8%) were of 10 or more adults. Collectively then, 94.2% of the sightings were of fewer than 10 monarchs per location. Of the reports of 10 or more adults, all were of monarchs seen flying or nectaring in gardens and areas with flowing plants. None of the reports (in any category) made mention of clustering or roosting behaviors that are typical of monarch overwintering in Mexico or California (e.g., [16, 17]).

4. Discussion

This study adds to the collective knowledge of monarch butterfly biology in a number of ways. First, the map of all adult monarch sightings over the 9-year period considered here (Figure 2(a)) effectively elucidates the current range in the southern United States where monarchs are capable of surviving during the winter, which is not dissimilar from the predicted range based on suitable climate conditions for adult survival (Figure 1, [12]). In the same way, the map drawn from the sightings of breeding monarchs (Figure 2(b)) shows where monarchs are able to form continuously-breeding populations. These maps, plus the statistical analyses of the latitudes associated with the sightings, make it clear that the breeding locations are at lower latitudes in general than the sightings of adults. In fact, the breeding locations appear to be restricted to areas below the 31° N parallel. It should be pointed out, however, that larval forms could have been present (but not seen) in the sites where only adults were observed, so this latitudinal threshold is likely not absolute.

The suitability of wintering sites in the southern United States for overwinter survival, especially in the northernmost locations, appears to vary among years. This point is made especially clear by the reports from the 2010 wintering season, which indicated that monarchs wintering in most areas except southern Florida were either killed by freezing temperatures, or they suffered high mortality due to reductions in nectar or hostplant availability. This same conclusion was reached by Brower [1], who reviewed much of the early literature and anecdotal reports on monarch wintering in the southern United States and also determined the frequency of lethal winter temperatures (to adult monarchs) in this region. Thus, Brower concluded that "about once each decade weather conditions in northern Florida would result in 50% mortality if the butterflies remained dry, or 100% mortality if they were previously wetted by rain." Given that one of the 9 years examined here appeared to meet this scenario, Brower's conclusion appears to be supported by these data.

While the number of documented wintering locations in Figure 2 appears large, it is important to consider that the number of monarchs reported for most locations tended to be fewer than 10 adults. Thus, in comparison to the millions of adults that overwinter in the Mexican colonies each year, the number of monarchs wintering in the southern United States is likely only a tiny fraction of the eastern population. Furthermore, these monarchs that are present in winter months on the Gulf coast appear not to display the typical overwintering behavior seen in Mexico or California (e.g., [16, 17]), since there were no reports of clustering behavior or even aggregations on vegetation. As such, rather than calling these "overwintering sites" which calls into mind massive clusters of monarchs hanging from trees, they may be more appropriately termed "winter sightings of monarchs". To be fair, we must point out that the majority of the sightings in our data set were from homeowners viewing monarchs in their backyards (which are usually in urban areas), and not necessarily where monarchs might indeed form winter clusters, such as on Florida barrier islands. Plus, the nature of the sightings (made by amateurs and public citizens) might also account for the lack of clustering reports since clusters of immobile monarchs can be hard to observe. Thus, it may be that clustering monarchs are indeed present in some areas along the Gulf coast, and this citizen-science approach simply fails to detect them.

The apparent lack of clustering behavior observed here may also help to explain why the data from this study appear to contradict the conclusion reached by Batalden et al. [18], who demonstrated that wintering monarchs require different ecological niches than do breeding monarchs. In that study, the environmental conditions required by overwintering monarch colonies in central Mexico (from [19]) were compared to those of breeding monarchs in the United States. The wintering locations presented here (Figure 2) appear inconsistent with this conclusion until one considers that the "overwintering" conditions examined by Oberhauser and Peterson [19] reflected the conditions required by entire monarch *colonies*, which may be different from the winter conditions needed by small groups of (nonclustering) adult monarchs, which is what the majority of reports to Journey North entail.

Since the overwintering sightings program in Journey North has only been operating since 2002, we have no way of knowing if the patterns observed in the 9 years here are a new development in the biology of monarchs east of the Rockies, or if these locations (i.e., Figures 2(a) and 2(b)) have always hosted wintering monarchs. While the locations in southern Florida have likely been present for some time [1], we suspect that most of the locations along the northern Gulf coast are more recent, based on evidence that we do have for one Gulf coast location where we documented winter breeding activity (Baton Rouge, LA). Surveys of adult monarchs here in the mid-1980s [20] showed the earliest spring sightings of adults were always in mid to late March, which is consistent with the timing of the return of the Mexico cohort to this state [2], and there was no mention of adult presence earlier than this. Further, Riley attempted to document all milkweed species present on his survey routes and found 6 species: *A. longifolia*, *A. amplexicaulis*, *A. obovata*, *A. tuberosa*, *A. viridis*, and *A. verticillata*. Moreover, he reported that no milkweeds had emergent stems in late February. This is compared to the recent sighting from the Journey North database for this location, in which an observer reports that on January 8, 2009, monarch caterpillars were found on *A. curassavica* in its yard, and that no other milkweed species were present. At least for this location then, there seems to have been a change in the seasonal occurrence of monarchs over the last 30 years and a change in hostplant availability throughout the winter.

Aside from the changing conditions within wintering sites, the entire wintering range of monarchs in the United States is predicted to expand northward if global temperatures rise by as little as 0.1° C per latitude [12]. In fact, increasing global temperatures are already expected to shift spring and summer breeding distributions northward over the next 50 years [18], so it would also hold true that overwintering sites would progress northward as well. If this is the case, then it will be important to continue monitoring

the distribution of wintering areas in this region and watch for these predicted changes in the coming years. With the help and dedication of the many citizen scientists who follow the life of this fascinating insect, this goal should be attainable.

Acknowledgments

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