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Documenting the Spring Movements of Monarch Butterflies with Journey North, a Citizen Science Program

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INTRODUCTION

Although the overwintering location of the eastern North American population of the monarch butterfly in central Mexico has been known to the scientific community since 1976 (Urquhart 1976), scientists have only begun to understand how the annual spring recolonization of eastern North America proceeds. It had previously been thought that overwintering monarchs continued their northward spring migration until they reached their summer destinations, laying eggs along the way. This had been termed the "single sweep hypothesis" (Malcolm et al. 1993). This hypothesis has since been replaced by the "successive brood hypothesis," which argues that the majority of overwintering monarchs only migrate northward in the spring to the southern United States, laying eggs along the way. Their offspring then complete the journey northward to the upper reaches of the monarchs' breeding range (Cockrell et al. 1993; Malcolm et al. 1993).

Cockrell and colleagues (1993) provided the most comprehensive, large-scale documentation of the spring migration of eastern monarchs thus far. By surveying for immature stages of monarchs on milkweed transects at 62 locations and latitudes during the spring migration, they estimated the dates at which the eggs were laid, and thus documented the temporal and spatial distribution of ovipositing (migrant) females. However, one drawback to this method of quantifying migration is that dates of oviposition may not necessarily reflect the true timing of arrival of migrants to an area, since females may not oviposit on the date of arrival. It is possible that after arriving at a location, females may require a period of time to find milkweed plants on which to lay their eggs. Further, this method assumes that females oviposit equally along the migration route, while in actuality many external factors other than the urge to oviposit may cause a female to stop migrating. During fall migration, monarchs can be forced to land because of wind conditions unfavorable for migration (Davis and Garland, this volume). Such conditions must also influence migrating adults in the spring as well. Moreover, milkweed emergence rates and quality can vary spatially, and females may not choose to oviposit at all places they stop. Thus, a more direct way to document the spatial and temporal patterns of spring migration is to observe the arrival of adult butterflies to locations throughout the migration range. Until now, this has not been possible, as this task would require large numbers of observers operating simultaneously throughout the migratory pathways.

The timing of spring migration is unlikely to be the same each year since many aspects of the life history of monarchs show an annual variation, as do biotic and abiotic factors affecting their habitat in springtime. Breeding populations fluctuate annually (Swengel 1995; Prybsy and Oberhauser, this volume), which leads to corresponding fluctuations in the numbers of fall migrants (Brower 1995; Walton and Brower 1996). Further, the temporal distribution of fall migration varies each year (Walton and Brower 1996). Annual variation may also exist in the proportion of monarchs that successfully complete the fall migration to Mexico (Garland and Davis 2002). This, in turn, leads to an annual variation in the numbers of overwintering monarchs, as reflected in yearly measurements of the area of the overwintering colonies (García-Serrano et al., this volume). Finally, owing to predation at the overwintering colonies (Brower and Calvert 1985) and catastrophic weather events (Calvert et al. 1983; Brower et al., this volume), the numbers of monarchs that survive through the spring will also vary. Thus, the number of monarchs that migrate each spring is expected to fluctuate between years. Coupled with this, North America's climatic and weather patterns vary widely each spring during the northward migration of the overwintering generation, the development of the first spring generation, and its subsequent migration, all of which affect the pace of the spring migration (Zalucki and Rochester, this volume; Feddema et al., this volume). There is little published documentation of an annual variation in any aspect of the spring migration of monarchs, although Cockrell and colleagues (1993) briefly noted a yearly variation in spring oviposition dates at several latitudes in their 3-year study.

Aside from the study by Cockrell and colleagues (1993), much of our knowledge on the patterns of spring migration of the eastern monarch population is based on short-term studies carried out at specific sites along the migration pathways (e.g., Riley 1993; Knight et al. 1999). Although these studies are necessary to examine key aspects of the spring migration in detail, long-term, wide-scale quantitative programs are needed to gain a fuller understanding of it (Brower 1995). Long-term programs that quantify the fall migration at specific sites along the migration route have been established (Walton and Brower 1996; Garland and Davis 2002; Davis and Garland 2002), but more wide-scale programs are needed for the fall migration as well (Brower 1995).

Citizen science programs allow for large-scale and simultaneous data collection, by having individuals from the public observe and record data on natural events and then submit their data to a central repository for analysis. The Cornell Lab of Ornithology, a pioneer of citizen science programs for the study of birds, runs several backyard bird-watching programs. The data collected in these programs have already allowed Cornell scientists to document and study, among other things, the spatial variation in the winter abundance of birds (Wells et al. 1998), and the spread of a novel disease in house finches (*Carpodacus mexicanus*) across most of eastern North America (Dhondt et al. 1998; Hartup et al. 1998; Hochachka and Dhondt 2000; Dhondt et al. 2001; Hartup et al. 2001). These studies attest to the power and scope of citizen science.

Three large-scale citizen science programs focused on monarch butterflies have been established. In the Monarch Larva Monitoring Project, volunteers collect data on the spatial and temporal abundance of monarch eggs and larvae (Prysby and Oberhauser 1999; this volume). Monarch Watch is a volunteer-based organization that tracks the fall migration by distributing numbered monarch tags and collecting and disseminating the resulting capture-recovery data (Monarch Watch 2002). These programs provide important information on aspects of breeding biology and fall migration, respectively.

Journey North (Journey North 2002) is a citizen science program that documents the spring migration of monarchs. It was established in 1994 to fill a crucial gap in our knowledge of the spring movements. In this Internet-based program, volunteers across North America watch for migrating adult monarchs in the spring and record the date and location of the first monarch seen. The data are then entered on-line and collated and stored by Journey North. Participants can view on-line maps of all sightings on the Journey North website and follow the northward migration of monarchs each spring.

The Journey North program has been described only once in the scientific literature (Donnelly 1999), and no results of the program have been presented to date. Here, we provide a more complete overview of the program. We show what Journey North has revealed about the spatial patterns of spring migration, and how consistent the patterns are from year to year. Next, we address several questions that remain unanswered about the spring migration. In particular, we use the Journey North data to test for annual variation in the timing of spring migration at four different latitudes, as well as variation in the duration of the migration.

METHODS

The Journey North program

Journey North is funded by Annenberg/Corporation for Public Broadcasting, a project within the Corporation for Public Broadcasting whose mission is to use media and telecommunications to advance excellent teaching in America's schools. As such, the project's most important purpose is to engage students in grades K through 12 in a global study of wildlife migration and seasonal change. Using the Internet, students share their field observations with classmates across North America.

The Journey North monarch program begins in February each year. Everyone who contributes observations to Journey North must register on-line. Registration is free, but participants must provide their e-mail address for quality control purposes. Participants are asked to watch for monarchs as they go about their daily activities throughout the spring and summer months. While they are encouraged to standardize their observation methods (set aside a time of day, survey the same location, etc.), the data accepted by Journey North are not limited to those collected by standardized methods.

When the participants observe a monarch for the first time in the spring, they record this observation at the Journey North website. On the website, participants enter the monarch sighting date, the nearest town, their state or province, latitude and longitude (if known), their e-mail address, their names or their teaches' names, and any other comments. Besides dates of first adults, participants can also record sightings of overwintering monarchs and the dates they first observe milkweed, their first monarch egg, first monarch larvae, and any other related monarch observations.

Beginning in February each year, Journey North publishes weekly monarch migration updates (a map of monarch sightings) based on the sightings received from participants up to that point (figure 14.1). The updates are distributed by e-mail to all participating sites and posted to the Journey North website. The updates begin when monarchs are still at the Mexican overwintering sites, about 6 weeks before the migration usually enters Texas.

In addition to Journey North's own on-line observation network, the project actively seeks contributions of sightings from outside sources. These include butterfly listservs, nature center contacts, and individual contacts. Staff personnel enter these sightings into the Journey North database. Latitude and longitude can be entered by participants, but because observers often do not have this information readily available, the Journey North database appends latitude and longitude coordinates overnight, using the "nearest town" as a geographic reference. These coordinates are obtained from the U.S. zip code database for U.S. sightings. Canadian and Mexican latitude and longitude coordinates are entered manually. All data are currently stored online where they can be viewed by the public.

A great deal of personalized communication takes place between Journey North staff and the observation network. All sightings reported to the database are reviewed on a daily basis. The comments are read and the observer is contacted if there is a need for clarification. Great care is taken to assess the validity of observations, particularly when they are unusual. Sightings by schoolchildren are reported by their teachers, not students, and teachers play an important role in validating observations before submitting them. Journey North personnel remove questionable observations from the database.

As adult monarch sightings are reported each year and the locations and dates are updated on the on-line migration maps, one thing becomes evident about the timing and distribution of the spring migration. As the migration expands into a particular area, multiple sightings are usually reported on the same day, and in some cases within hours of each other, particularly in areas where many observers are located. Thus, we are confident that the participants accurately record the wave of arriving monarchs. However, in some cases sightings of migrating monarchs by two or more different citizens in the same location are separated by over 1 week. In these cases, the second observer's "first monarch sighting" was not the actual date of first arrival to the area, as reported by the first observer. This is one drawback to the Journey North program, since it cannot be known whether the observer saw one of the actual first monarchs in the area. However, these cases represent roughly 5% of the data for each year (pers. observ.); thus the analyses reported in this chapter should not be largely affected.

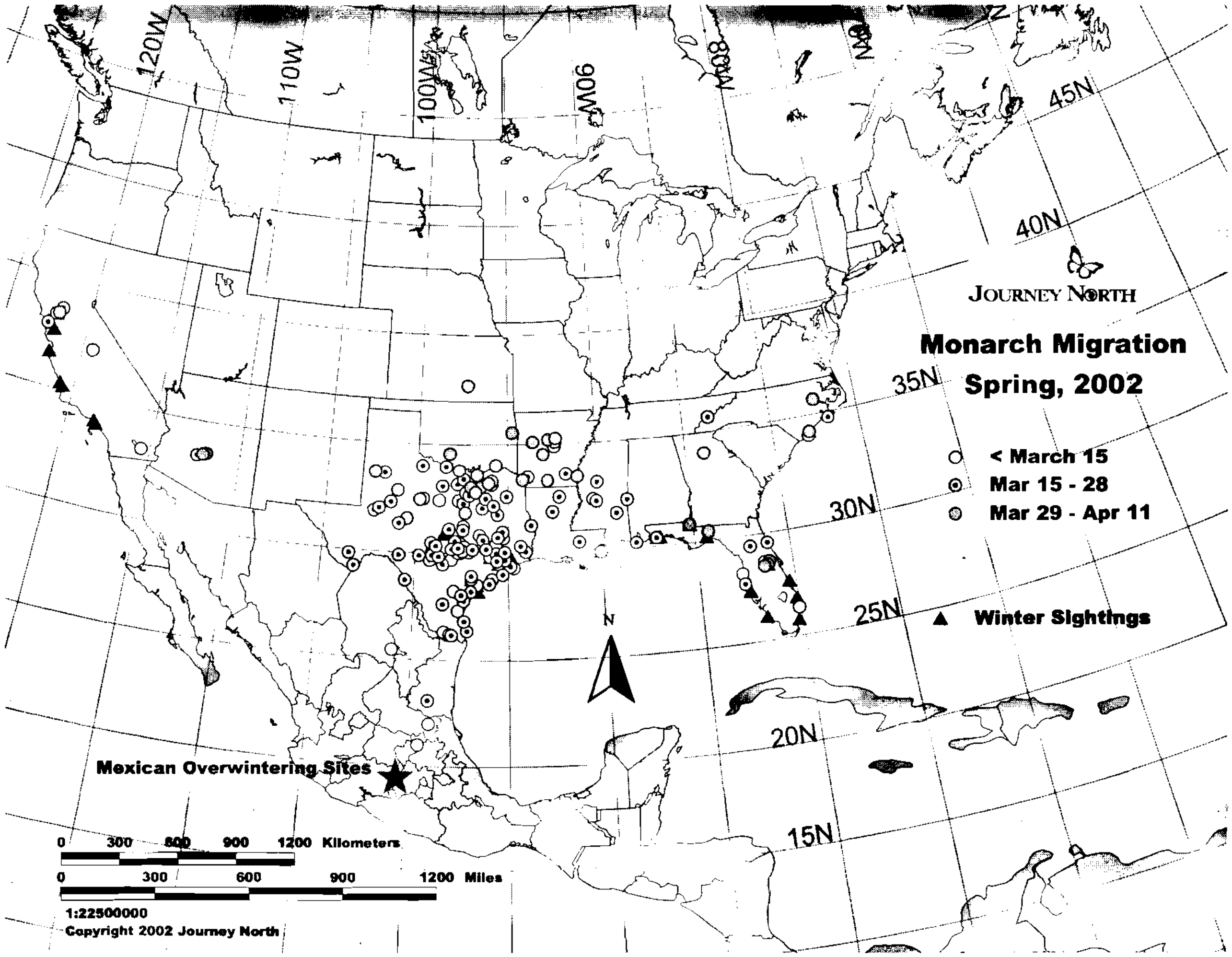

Figure 14.1. Sample map of spring monarch migration (2002) presented on the Journey North website, produced by data from participants.

Patterns of spring migration

Early in each spring migration, a considerable number of monarchs are sighted in the southeastern states before they are spotted at middle latitudes (pers. observ.). We investigated this pattern to determine whether it holds true in all years by determining the first monarch sighting for each state or province (within the range of the eastern population) in each of the 6 years, and then ranked these dates. We calculated the mean rank for each state over the 6 years, and then ranked these means to derive an overall "occupation order" of each state or province. We used these annual ranks to determine whether the order of state or province occupation is consistent among years, by performing Pearson correlations of the ranks between all year-to-year combinations.

Annual variation in migration timing

Sightings of overwintering adult monarchs are reported to Journey North each year. These sightings are usually in January or February, and occur mostly below 30° north latitude (pers. observ.). However, occasionally sightings of overwintering monarchs (in January and February) at or near 30° are reported. To ensure that these sightings did not confound our analyses of the spring migration, we only used sightings after 1 March. This resulted in little loss of data.

We used the Journey North data from 1997 to 2002 to determine whether annual variation exists in either the timing or the duration of the spring migration. To test for variation in timing among years, we first standardized the dates of the Journey North sightings across all years by transforming all dates into Julian dates (the number of days since 1 January). Since we were interested in the differences in timing at low, middle, and upper latitudes, we divided the sightings into four groupings, based on the latitude at which they were made. To simplify the groupings, we rounded all latitudes in the data set to whole numbers. For example, 36.7° north became 37° north. This resulted in sightings (Julian dates) of spring monarchs at 30° to 34°, 35° to 39°, 40° to 44°, and 45° north latitude and above for each year (see figure 14.1). We then performed separate one-way analyses of variance on the sighting dates in each of these four latitude groups between years to assess annual variation in the spring migration timing.

Annual variation in migration duration

To calculate travel time, one needs a starting point location, an end point location, and a measure of the time taken to go between the two. Here we assume the "end point" is a sighting of monarchs in the northern sections of the breeding range. Since we were interested in knowing how long it takes the population to reach the northernmost breeding areas, and whether this duration varies among years, we assume that sightings above 45° north latitude represent expansion of the population into the northernmost breeding range.

We define the "start date" of migration as the median date on which monarchs reached 30° north latitude in a given year (see figure 14.1). We used the median date rather than the mean date as it is less sensitive to extreme values (which exist at the lower latitudes). As such, the date of "migration initiation" in this case does not represent the date monarchs depart their overwintering colonies. Rather, it is the date monarchs begin to travel across the lower 48 states. Thus we calculated the median date of observations at 30° north (after rounding all latitudes to whole numbers) for each year (table 14.1). With these six annual start dates at 30° north latitude as the "start point," we then calculated the time (measured in days) taken to expand into the northernmost breeding range (45° and above) for each of the sightings at 45° and higher. We then performed a one-way analysis of variance on these "duration values" to assess annual variation in the average duration of migration.

Table 14.1. Average monarch arrival to 30° north latitude

Year	*N*	Mean date	Median date	Range (days)
1997	25	17 March	17 March	36
1998	25	26 March	21 March	73
1999	26	22 March	21 March	39
2000	26	13 March	12 March	26
2001	42	26 March	24 March	67
2002	74	18 March	17 March	27
Overall	218	19 March	17 March	73

Note: Based on Journey North data.

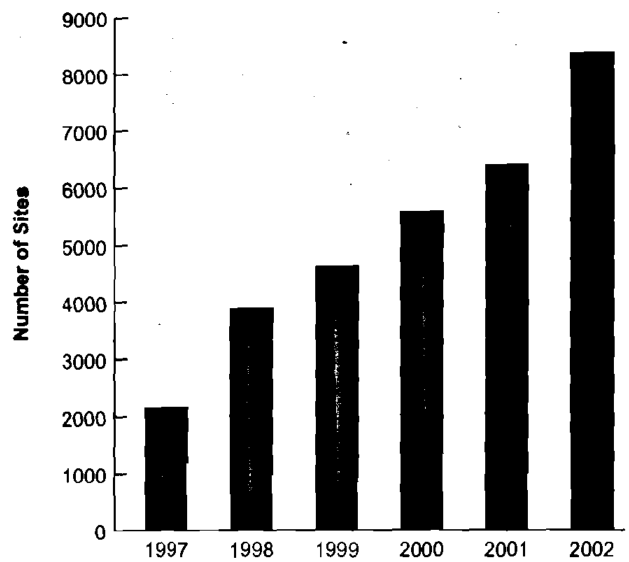

Figure 14.2. The number of registered monarch observation sites in North America from 1997 to 2002.

RESULTS AND DISCUSSION

Journey North participants

From 1997 to 2002, the number of participants submitting observations of spring monarchs has grown steadily each year, from 2171 in 1997 to 8380 registered sites in 2002 (figure 14.2). Based on questionnaires distributed in 2000 and 2001, we determined the setting in which Journey North was used during those years (figure 14.3). Although Journey North targets students, only 63% of the participants in 2000 and 2001 were students. Elementary students made up the bulk of the student participants. A large portion of the participants (21%) were families or individuals.

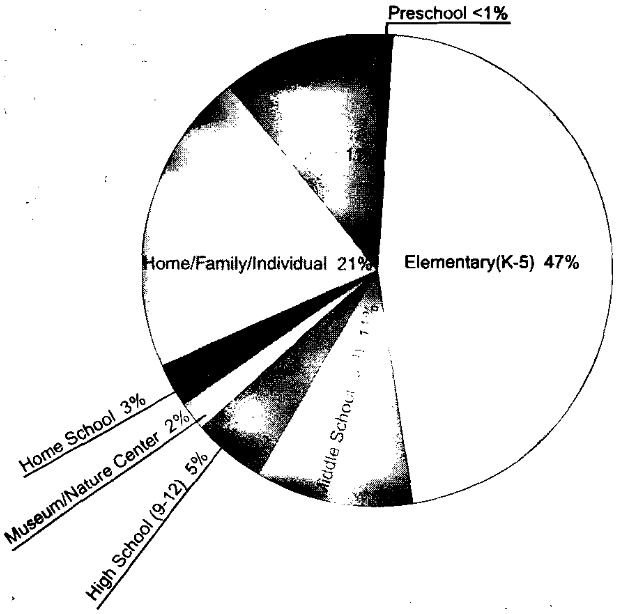

Figure 14.3. The occupation or setting in which participants used Journey North during 2000 and 2001.

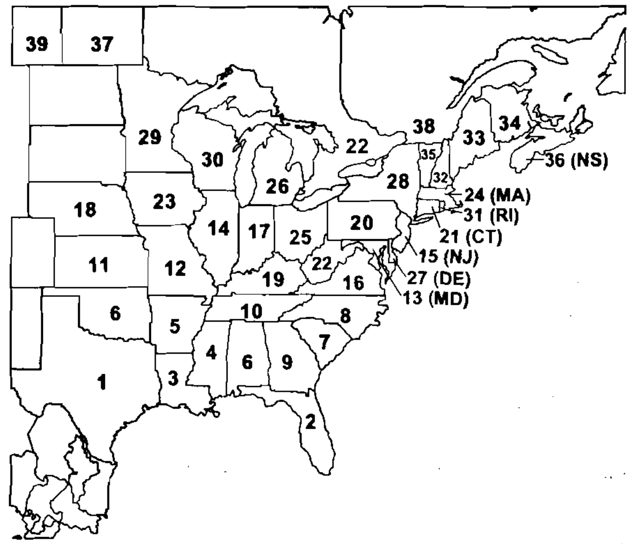

Figure 14.4. Average order of occupation of each state or province by monarchs during spring migration, based on first sightings of monarchs reported to Journey North. The ranks of the 6-year average of first arrival dates to each state or province are shown. Sightings before 1 March are excluded.

Patterns of spring migration

Once migrating monarchs reach the United States, the first state occupied is nearly always Texas, followed usually by either Florida or Louisiana (table 14.2, figure 14.4), although the Florida sightings may have been of monarchs originating in that state. Mississippi is usually next, followed by Arkansas and Oklahoma. It is not known whether monarchs are able to safely and regularly cross the Gulf of Mexico during migration as birds do (e.g., Gauthreaux 1999), although it is generally thought that they do not (Brower 1995). If this is true, then the sightings of early monarchs in the southeast, before sightings to the north, indicates that once the monarchs pass through Texas, some of them make an eastward movement across the southeastern states, before spreading across more northern latitudes. The migration then presses northward (probably composed mostly of second-generation monarchs) across a broad front, finally reaching the Canadian provinces, which are always last (figure 14.4). The order of state or province occupation was highly correlated between all year-to-year combinations (table 14.3), indicating that there is little variation in this overall pattern of spatial occupation during migration.

Annual variation in migration timing and duration

There was significant annual variation in migration timing at all latitude groupings (p = 0.009, 0.000, 0.020, and 0.000 for groupings 30° to 34°, 35° to 39°, 40° to 44°, and 45° and above, respectively; table 14.4, figure 14.5). Further, there was significant annual variation in the calculated migration durations ($df = 353$, $F = 27.16$, $p < 0.001$; figure 14.6). The time needed by the population (which includes returning and newly emerged adults) to reach the upper portions of their breeding areas ranged from 88.1 days in 1997 to 64.8 days in 2001. Interestingly, the longest calculated spring migration (1997) immediately followed the largest overwintering population recorded thus far, while the shortest migration (2001) immediately followed one of the lowest overwintering populations to date (García-Serrano et al., this volume). However, this trend may not be consistent in all years. In 2002, a severe storm caused a much-publicized population crash in the overwintering population, leaving very low numbers left to remigrate in the following spring (Brower et al., this volume). During this year, the migration duration was the second longest of all 6 years of the Journey North data. Furthermore, despite the low numbers of adults in 2002, the timing of the start of the spring migration that year appeared to be similar to that for most other years. In fact the only aspect of

Table 14.2. Arrival ranking

State/province	1997	1998	1999	2000	2001	2002	Mean rank	Overall rank
TX	1	1	1	1	1	2	1.2	1
FL	1	3	3	5	2	1	2.5	2
LA	3	2	2	2	3	5	2.8	3
MS	5	6	4	3	4	3	4.2	4
AR	5	5	5	7	6	6	5.7	5
OK	8	4	7	6	7	10	7.0	6
AL	4	10	8	4	8	8	7.0	6
SC	10	14	6	9	8	6	8.8	7
NC	7	10	12	10	11	4	9.0	8
GA	11	8	17	8	5	12	10.2	9
TN	8	16	9	12	10	9	10.7	10
KS	17	9	9	13	15	11	12.3	11
MO	12	12	12	15	17	13	13.5	12
MO	20	19	12	11	16	17	15.8	13
IL	15	13	12	19	23	15	16.2	14
NJ	17	17	18	13	23	13	16.8	15
VA	15	20	20	15	13	20	17.2	16
IN	25	7	21	24	12	26	19.2	17
NE	27	15	16	20	19	19	19.3	18
KY	13	39		21	13	16	20.4	19
PA	21	25	22	32	28	17	24.2	20
CT	22	33	28	17	23	23	24.3	21
WV	19	30	31	22	22		24.8	22
ON	28	29	11	33	26	22	24.8	22
IA	30	31	25	25	18	21	25.0	23
MA	13	22	31	29	32	28	25.8	24
OH	26	33	19	25	28	25	26.0	25
MI	32	18	24	30	26	28	26.3	26
DE	24	32		18	28	31	26.6	27
NY	29	27	23	28	20	33	26.7	28
MN	31	23	25	27	33	26	27.5	29
WI	34	21	27	31	31	24	28.0	30
RI	23		35	22	36		29.0	31
NH	38	28	29	34	20	30	29.8	32
ME	39	23	37	35	33	34	33.5	33
NB		26	34	39	37		34.0	34
VT		35	30	36	35	35	34.2	35
NS	33	37	31	38			34.8	36
MB	35		38	36	38	31	35.6	37
PQ	36	37	35	40	39		37.4	38
SK	36	36	39		40		37.8	39

Note: Ranks of U.S. states and Canadian provinces by the first arrival dates of monarchs in each year. Average of ranks from all 5 years is also shown. Sightings before 1 March are excluded. States or provinces from which less than 4 years of data were collected are excluded. Some states or provinces were tied with others in the same year.

migration in 2002 that appeared different from other years was the late arrival of monarchs to the northern latitudes (see table 14.4, figure 14.5), and this appeared to be due to a colder than average spring in these areas (pers. observ.). Thus, it seems that the monarch population size has little to do with spring migration timing.

The reasons, in part, for the long migration duration in 1997 and the short duration in 2001 can be seen in figure 14.5. In 1997 monarchs reached 30° north latitude early and the upper latitudes (45° and higher) very late in the season, causing a long migration duration for that year. In 2001, however, they reached 30° later, resulting in a short migration duration. Interestingly, in all years except 1997 monarchs seemed to reach the upper two latitude bands close to the same date, regardless of how early or late the migration began. Arrival to the middle

Table 14.3. Correlation matrix

	1997	1998	1999	2000	2001	2002
1997	1.0 $n = 39$	0.717 $n = 37$	0.825 $n = 37$	0.903 $n = 38$	0.818 $n = 38$	0.888 $n = 33$
1998		1.0 $n = 39$	0.820 $n = 37$	0.770 $n = 38$	0.764 $n = 38$	0.718 $n = 33$
1999			1.0 $n = 39$	0.854 $n = 38$	0.877 $n = 38$	0.898 $n = 31$
2000				1.0 $n = 39$	0.879 $n = 39$	0.867 $n = 33$
2001					1.0 $n = 39$	0.818 $n = 33$

Note: For each year combination, the order of state or province occupation (rank of first-sighting dates) is correlated. Pearson correlation coefficients and sample sizes are shown. *P* values for all correlations were less than 0.001.

Table 14.4. Latitudinal progression of monarch migration

North latitude	1997	1998	1999	2000	2001	2002	Overall average	Oviposition date
30°–34°	23 Mar (2.8) $n = 60$	3 Apr (5.4) $n = 65$	25 Mar (3.4) $n = 59$	20 Mar (2.6) $n = 67$	30 Mar (3.1) $n = 99$	25 Mar (2.8) $n = 190$	26 Mar (1.5) $n = 541$	1 Apr (3.3) $n = 26$
35°–39°	14 Apr (2.7) $n = 111$	25 Apr (5.0) $n = 66$	16 Apr (3.5) $n = 84$	13 Apr (2.7) $n = 115$	1 May (4.5) $n = 98$	24 Apr (5.4) $n = 101$	20 Apr (1.7) $n = 575$	24 Apr (8.0) $n = 10$
40°–44°	15 May (4.1) $n = 109$	20 May (3.4) $n = 122$	21 May (2.9) $n = 127$	16 May (2.4) $n = 171$	19 May (2.0) $n = 214$	1 Jun (3.2) $n = 192$	21 May (1.2) $n = 935$	24 May (5.6) $n = 15$
45°+	11 Jun (4.9) $n = 48$	24 May (4.4) $n = 51$	25 May (2.1) $n = 64$	23 May (3.8) $n = 45$	25 May (2.6) $n = 80$	2 Jun (3.3) $n = 71$	28 May (1.5) $n = 359$	

Note: Based on all Journey North spring sightings from 1997 to 2002. Average dates are shown with ±95% confidence intervals and sample sizes. Significant annual variation in arrival dates was found with each latitude group. Oviposition date was calculated from data presented in Cockrell et al. 1993.

latitudes (35° to 39°) is approximately 20 days following arrival to the lower (30° to 34°) ones, no matter how early or late the migration is (see figure 14.5), suggesting a constant rate of travel by monarchs throughout the lower latitudes. This implies that when the migration starts late, the arrival to the middle latitudes is also late. In addition, it suggests that the primary factor influencing the timing of arrival to the lower and middle latitudes may be the date migration started from the overwintering areas.

Arrival to the 40° to 44° latitudes is usually 1 month after arrival to the 35° to 39° latitudes (see figure 14.5). This longer interval between latitudes probably occurs because these monarchs represent the offspring of the overwintering adults. Moreover, the time needed by these butterflies to reach the last latitude level is usually very short (1 week or less, except in 1997).

Dates of arrival to each of the latitude categories did not correspond with previous information based on larval censuses. Cockrell and colleagues (1993) provided the dates of first oviposition at several latitudes in 1985 and 1986 (only one data point was presented for 1987 and consequently was not included in their article). If we categorize their published data according to our latitude groupings, we can derive average dates of oviposition for comparison with our average dates of arrival. The average

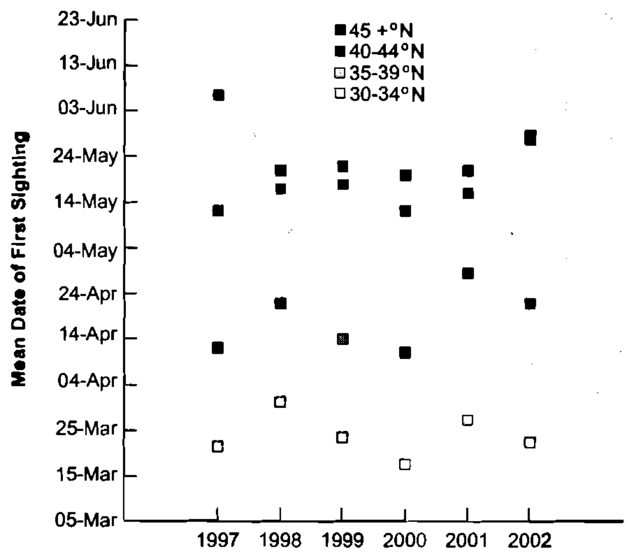

Figure 14.5. Annual variation in monarch arrival to each latitude group. Mean dates of first sightings are presented.

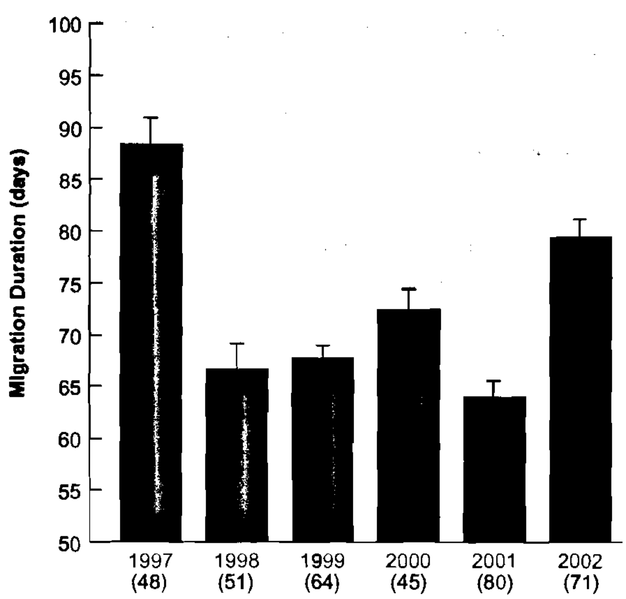

Figure 14.6. Average duration of migration (time needed to reach the upper breeding range), for years 1997 through 2002. Sample sizes for each year are indicated in parentheses. Standard error bars are shown with each average.

date of first oviposition at the 30° to 34° group was 1 April (n = 26, 95% confidence interval [CI] = 3.3 days), for the 35° to 39° group was 24 April (n = 10, 95% CI = 8.0 days), and for the 40° to 44° group was 24 May (n = 15, 95% CI = 5.6 days) (see table 14.4). We did not calculate an average date for the 45° and higher group since most of their sites in that group were censused in a different year. Each of these oviposition dates is 5 or more days later than our average dates of arrival to the same latitudes. Since their oviposition data were collected more than a decade prior to our data, detailed comparisons of the two data sets would not be meaningful. However, the data suggest that oviposition occurs later than monarch arrival to an area.

Annual variation in the timing of spring migration has not been previously documented in the scientific literature. That we found a yearly variation in the timing and duration of the spring migration could imply that at least in some years, environmental factors have a significant influence. In the fall monarchs travel faster when they migrate with tailwinds than with headwinds (Garland and Davis 2002), and also tend not to fly during unfavorable wind conditions (Schmidt-Koenig 1985; Davis and Garland 2002; Davis and Garland, this volume). It is not known if monarchs respond similarly to such weather conditions in the spring.

Alternatively, since female monarchs oviposit on emerging milkweeds as they migrate in the spring (Brower 1995), it may be that they are limited by the timing of milkweed emergence each year, which is also affected by environmental conditions. In one study in Louisiana, the arrival of spring migrant monarchs was closely synchronized with the availability of suitable milkweed host species (Riley 1993). Journey North data, along with corresponding large-scale environmental data, could elucidate whether this holds true across the breeding range. Further, owing to the geographic variation in spring climate (i.e., coastal areas tend to be warmer than inland areas), longitudinal variation may exist in the timing of milkweed emergence. This may lead to a corresponding longitudinal variation in spring migration and may explain the early eastward progression across southeastern states.

It is not known which, if either, of the above possibilities is more important in controlling the timing of spring migration, but we are currently using Journey North data to address this question. That these issues can be examined at all is due to the long-term and large-scale nature of the Journey North program. These results provide an example of how citizen participation in data collection can add greatly to our understanding of monarch butterflies.

Acknowledgments

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