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A SIMPLE NUMERICAL INDEX FOR ASSESSING THE SPRING MIGRATION OF MONARCH BUTTERFLIES USING DATA FROM JOURNEY NORTH, A CITIZEN-SCIENCE PROGRAM

Additional key words: Monarch butterfly, *Danaus plexippus*, spring migration, Journey North, citizen science

Monarch butterflies, *Danaus plexippus*, in eastern North America are unique among butterflies, not only because they undergo a famous long-distance migration from breeding sites in Canada and the northern United States to the mountains of Central Mexico, but also because they are cherished by the general public to a large degree. As such, their population status is monitored closely each year by scientists, the media, and concerned citizens. Most people are aware that monarchs face many threats; in recent years scientists have documented deforestation of their wintering sites (Brower et al. 2002), chemical exposure in their breeding sites (Oberhauser et al. 2006), and reduced numbers of females throughout the population (Davis & Rendon-Salinas 2010). Thus, even though monarch populations tend to fluctuate over time (Swengel 1995; Walton et al. 2005), members of the public become especially concerned when the number of overwintering monarchs reaches an unusually low point, as occurred in 2002 following a catastrophic winter storm (Brower et al. 2004), or recently when their numbers reached an all-time low (since tracking began in the 1970s) in the winter of 2010 (Rendón-Salinas et al. 2010).

When low winter numbers occur, there tends to be a flurry of articles in the popular press, multiple interviews with scientists, and importantly, a close watch of the spring migration northward to look for signs of population recovery. One way this is done is by viewing online maps created by the Journey North program (www.learner.org/jnorth). This is a citizen-science program whereby school children, naturalists and interested citizens report the first sighting of an adult monarch butterfly in the spring, and these reports are displayed on a map online so that the spring recolonization of the monarch's breeding range can be tracked in real time (Howard & Davis 2004).

When viewing maps of the spring migration on the Journey North website and trying to assess the general health of the migration for any given year, it is tempting to compare the number of reports (i.e. sightings) of monarchs from year to year, and indeed, this is what many people (scientists and non-scientists) do. However, there is a problem with this approach that most overlook, in that the number of participants of this program has been increasing steadily each year (Figure 1). Thus, the number of sightings may not necessarily reflect the true status or health of any given spring migration, since the number of observers has not remained constant over time. Here, we describe a simple numerical index that is not largely influenced by the number of observers per year, and takes into account both the speed of the migration and its geographical breadth, which are both important components of a successful recolonization. This index can be easily graphed, which should allow for visual comparisons of the health of the spring migration from year to year.

Data Set. We used the spring adult sightings database from the Journey North program, selecting all data from 1997 through 2010. The details of this data set are described elsewhere (Howard & Davis 2004; Davis & Howard 2005). Briefly, school children and interested citizens report the date and location to Journey North when they observe their first adult monarch butterfly each spring throughout N. America. The sightings are verified and compiled by Journey North staff, and added to an online map of North America. The majority of sightings in this program come from the monarch population east of the Rocky Mountains, and for simplicity, we confined the current study to those data from this population (i.e. excluding all sightings west of -100ºW). Moreover, we also excluded all sightings from the state of Florida, since those reports are likely of monarchs dispersing from the resident populations there (Howard et al. 2010).

Spring migration index. Since the primary goal of the spring migration for monarchs (and for many other migratory organisms) is to recolonize their breeding range, and to do it as rapidly and efficiently as possible, the two components of the migration that would most reflect its progress would be the timing and the geographic spread. We derived values for both of these components for monarch migration in the following way. First, we selected all Journey North sightings that were reported at 30ºN latitude (± 0.5º) and calculated the average Julian date for these sightings each year (an index of timing). This latitude represents the approximate midpoint of the recolonization journey by the returning adults, which generally progress as far as

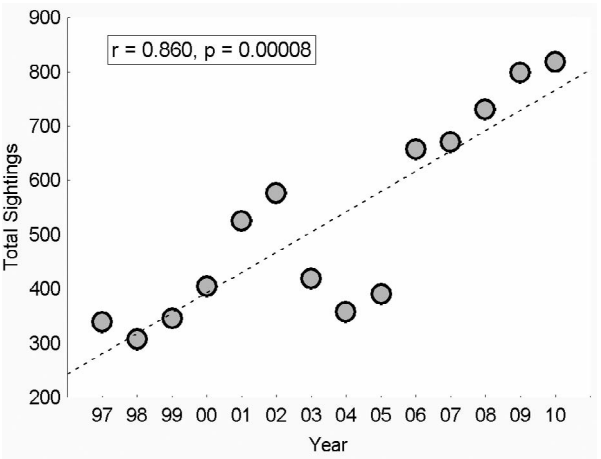

FIG. 1. Number of sightings of adult monarchs in the spring reported to Journey North from 1997–2010.

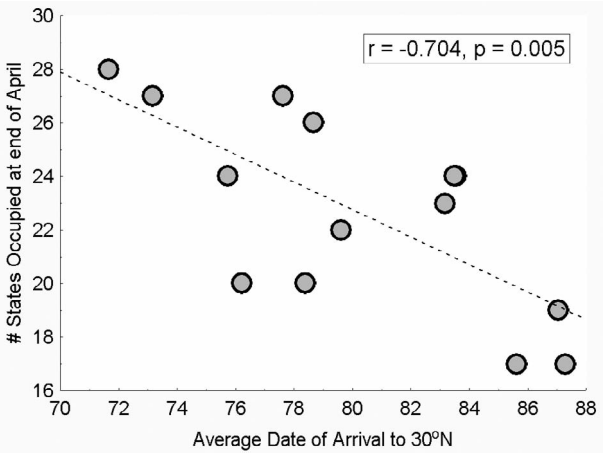

FIG. 2. Relationship between monarch arrival to 30 degrees north latitude and number of states occupied by monarchs at the end of April, for all years (14).

35ºN (Cockrell et al. 1993); the offspring of this generation then continue the northward spread (Howard & Davis 2004). Then, we selected all sightings reported up to the end of April, and counted the number of US states occupied by this time each year (an index of geographic breadth). These two scores are negatively related, so that in years when the migration reached 30ºN sooner, there were more states occupied by the end of April, and vice versa (Figure 2). Finally, we divided the number of states occupied (the values on the y axis) by the index of timing (the values on the x axis) to derive a single (unitless) numerical score that describes each year's migration. In this score, higher numbers reflect years when the initial migration wave proceeded rapidly and covered more states, and low scores the opposite.

The spring migration index calculated above can be easily graphed for visual comparisons between years (Figure 3). In doing so, one can see that the score for the spring of 2010 was low, as might be expected since the overwintering population was extremely low prior to this migration (Rendón-Salinas et al. 2010). In other years, such as in 2000, the migration arrived at 30ºN latitude early and was spread over a large area by the end of April, leading to a high index (0.39). We point out though that this index, as we have calculated it, represents the progress of only the initial phase of the spring recolonization, or that of the returning adult generation. While this generation is arguably the most important for setting the stage for the breeding season to come, one could also argue that the true success of the migration might be better indexed at a later stage, when the migration/recolonization is winding down. However, at these later stages (i.e. in June and July), it becomes increasingly difficult to tease apart actual migration from the commencement of breeding at any given site, and to know for certain which generation is being observed from the citizen-science reports. That is why we chose to focus on the reports from March and April, which are unquestionably of migratory adults returning from Mexico.

We reiterate that this spring migration index does not necessarily reflect the size of the returning generation, merely the spatial spread of the migration wave. One could argue that with larger numbers of monarchs in any given year, the spatial breadth occupied may in fact be greater, although this would likely be confounded by the varying numbers of observers in the data set (Fig. 1). Thus, it may be nearly impossible to index the 'size' of the returning generation with these data. We argue that this numerical migration score represents a useful

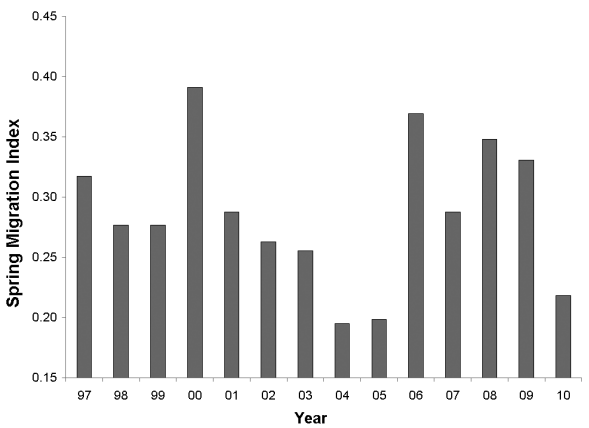

FIG. 3. Annual spring migration indices from 1997–2010. See text for description of index calculation.

alternative approach for monitoring the progress of the spring migration.

From a research standpoint, we hope that this simple scoring system will be useful to those interested in evaluating the progress of the monarch spring migration in terms of timing and breadth. It should allow for a rapid assessment of migration progress following winters with low population size, or perhaps for evaluating the effects of weather on spring migration progress. This index also will be helpful for tracking long-term trends in migration success. Given what many believe to be the precarious status of monarch populations in North America, any improvement in our ability to document and interpret how variations in the spring migration may reflect or impact population numbers should be welcome.

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