Conservation Matters: Contributions from the Conservation Committee

A conservation concern: how many Monarchs are there?

Ernest H. Williams[1] and Lincoln Brower[2]

[1]Department of Biology, Hamilton College, Clinton, NY 13323 **ewilliam@hamilton.edu**
[2]Department of Biology, Sweet Briar College, Sweet Briar, VA 24595 **brower@sbc.edu**

Monarchs have been in the news a lot lately because of concerns that we are seeing fewer of them than we used to. The decline in their overwintering numbers, first brought to attention by Brower et al. (2012), has spurred a petition to the USFW Service to list them as threatened under the Endangered Species Act (the petition can be found at Center for Biological Diversity et al., 2014), and many other actions have begun on behalf of monarch conservation (e.g., a petition to UNESCO; Natural Resources Defense Council et al., 2015). Monarchs are beloved by many people, many of whom have little interest in other Lepidoptera or in broader conservation concerns. All of this interest raises the question: Just how many monarchs are there? The focus of this column is the eastern migratory population that migrates southward in the fall to overwinter in the mountains of central Mexico and then each summer repopulates North America east of the Rocky Mountains.

Size of the Mexican overwintering colonies

Many of us were eager to hear the report of the size of the overwintering monarch colonies this past winter. Monarchs are far too numerous to count individually, so instead the area of forest they occupy is quantified and used as a correlate of actual abundance. Colony areas are measured in December of each year because by that time, the butterflies have coalesced into dense aggregations in very localized places, and then staff from World Wildlife Fund-Mexico and the Monarch Butterfly Biosphere Reserve can record the perimeter of each colony using GPS, a compass, and a meter tape (Vidal & Rendon-Salinas, 2014). These measurements let them calculate the area of each colony. They then add together calculations from all colonies to produce the total area occupied by the overwintering monarchs.

Much is made in media reports about comparisons of the current and the previous winter's total area. The report for 2015-16 gave the measurement as 4.01 ha (each hectare equals 2.47 acres, an area that is less than 2 football fields). The measurement of 4.01 ha is three and a half times greater than the previous winter's measurement of 1.13 ha (recorded in December, 2014), and the media have celebrated this positive comparison. For example, NPR reported the following: "And now an environmental story with good news. After years of decline, monarch butterflies appear to be on the rebound" (Garvia-Navarro, 2016).

Much that underlies this optimistic report, however, is not so positive. Short-term changes are immediate and obvious, and that is what the media emphasize. Left unspoken is that monarch abundance remains in a long-term decline despite year-to-year variability in measurements (Fig. 1). The total overwintering area from 1994-95 through 2015-16 shows a continuing downward trend that is statistically significant. The average decrease each year over that 22-year span is 9% (this is the annual percentage decrease given by an exponential regression).

Annual weather patterns play an important role in these yearly fluctuations. When surviving female monarchs migrate northward in spring from the Mexican colonies, they oviposit on emerging milkweeds in Texas and other southern states (Malcolm et al., 1993). The monarchs that develop from these southern eggs, the first spring generation, continue the journey northward and repopulate the summer range. The summer population then continues to grow through another two or three summer generations (Flockhart et al., 2013). If the weather is cold and rainy in the area of springtime reproduction or so hot and dry that milkweeds and nectar sources are scarce, the first spring generation is smaller, leading to slower growth of the population and ultimately reduced abundance during the summer. Thus, variability in the weather from year to year has a strong effect on how many monarchs are produced. The long-term decline in overwintering abundance remains despite these annual fluctuations.

Limitations in measuring the overwintering colonies.

The current method of estimating abundance is to use a compass and measuring tape to determine the perimeter of each colony and then calculate its area (details given in Vidal & Rendon-Salinas, 2014). But one should understand the limitations of this method.

(1) Are all colonies known and measured? Brower and colleagues (Slayback et al., 2007; Slayback & Brower, 2007) surveyed the region by airplane to search for unknown colonies and did not find more. Occasionally, on-the-ground surveys have found additional small colonies, and the WWF-Mex reports do include them. If any existing colonies were unknown and not measured, then the reported area would be an underestimate of actual abundance,

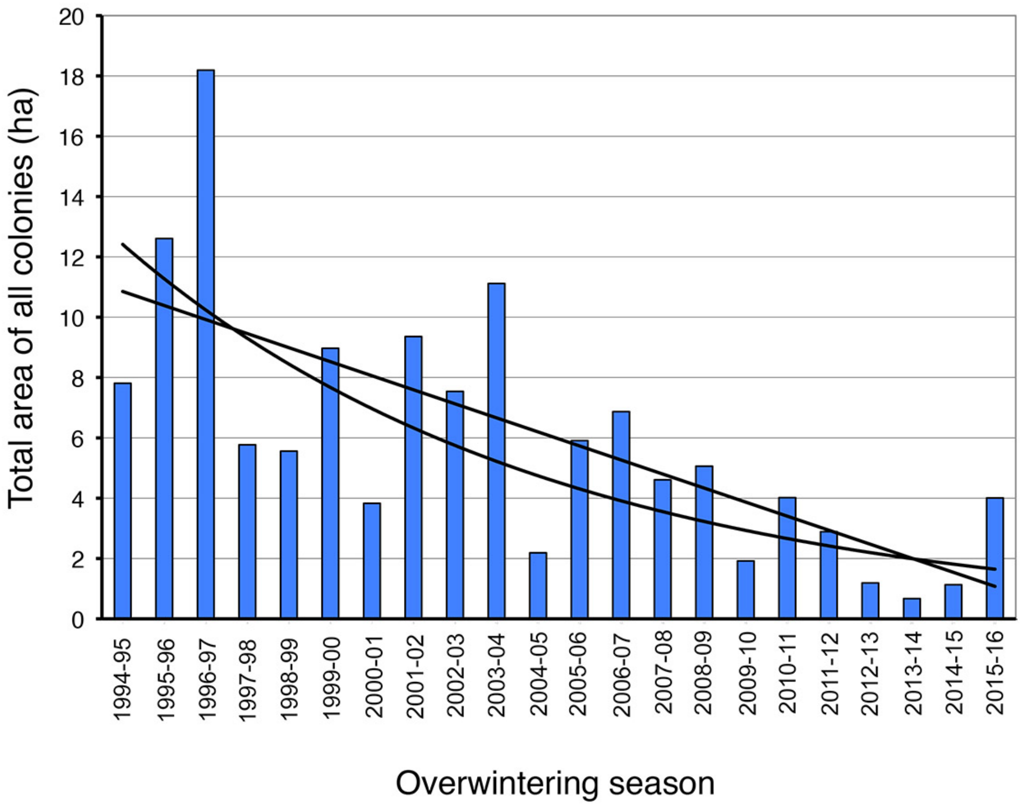

Fig. 1. Aggregate area of monarch overwintering colonies since 1994. The long-term downward trend is clear despite annual variability. The solid lines are linear and exponential regression lines.

but locations are pretty well known and consistent, so the question of completeness is a minor concern. The colonies were not all well known or visited only sporadically before the 1994-95 winter, which is why Fig. 1 begins with that year's measurement.

(2) What are the borders of the colonies? There aren't exact edges to the areas occupied by the butterflies; colonies include clusters on numerous contiguous trees as well as on nearby outlying trees, so determination of the area occupied by all the butterfly-festooned trees requires judgment by the measurers. Also, because small variations in measurements from each of multiple colonies are combined, the aggregate report includes some additional imprecision.

(3) Are the colonies measured at the same time each winter? While Mexican personnel measure the colonies in mid- to late-December, the measurements take place over several days. Because of several factors – flights to find water, movement of the colonies downslope as spring approaches (Calvert & Brower, 1986), and colony reformation after storms (Brower et al., 2004) – the shape and area of the colonies change over time. Even if one were to measure the colonies on the same date in two successive winters, the form, density, and precise locations of the aggregations will differ.

(4) Is the density of monarchs within these measured colony areas constant? While we assume that the density of monarchs within the reported aggregate overwintering areas is the same, it actually varies, though by how much we do not know. A more accurate measure of colony density would require recording the number and sizes of trees with clusters and an estimate of the number of clusters per tree.

The above considerations illustrate the limits to how precisely one can estimate monarch numbers. The official reports give the aggregate colony area to hundredths of a hectare. While one may be able to calculate colony area to two decimal places, it is beyond reason to think that there is significance to such reported precision. The aggregate measurement of the 2015-16 winter is around 4 ha, but it's misleading to think that the report of 4.01 ha gives real precision. Limitations 2 through 4 described above increase the variability of the reported aggregate area but in an unbiased fashion. However, if the density of the colonies has decreased in recent years, as we think is the case, then limitation 4 means that monarch abundance is being overestimated. Furthermore, an intense storm in March, 2016, with a drop in temperature to -4.5°C, killed many of the butterflies (measurements of mortality are currently underway). If only half survived, then this winter's aggregate area may actually be closer to 2 ha. Weather events like this add further uncertainly to the annual colony measurements.

Converting area to abundance

If we knew the actual density of overwintering monarchs, we could convert annual measurements of total overwintering colony area to absolute abundance. After seeing the colonies in Mexico, Brower estimated the density of the butterflies there to be at least ten times the California density (Brower et al., 1977), which Tuskes and Brower (1978) had estimated through mark-release-recapture study to be about one million monarchs per hectare. Therefore, the first estimate in the Mexican colonies was 10 million/ha. Next, Calvert (2004) tried two methods to assess the absolute density of monarchs in Mexico. Using tree size and the weight of monarchs he measured on sample branches, he estimated 10 million monarchs/ha, though he used low estimates of tree size. Using mark-release-recapture techniques, his second method, he estimated from 7 to 61 million/ha, a wide range that reflected differences in timing, location, and analytical methods. Many assumptions went into making these estimates. Brower et al. (2004) took a different approach; following a severe storm, this group counted dead monarchs in sample plots on the forest floor (29 plots in each of two colonies) and from those measurements estimated nearly 50 million/ha.

All of these studies were conducted in dense colonies, but anecdotal reports and photographs suggest that overwintering densities may currently be less than they were when total monarch abundance was much higher. In any case, it seems reasonable to assume that overwintering colonies contain from 10 to 50 million monarchs/ha. Both the widely used figure of 30 million/ha and the estimate of 37.5 million/ha used by U.S.F.W. fall within that range, so both are reasonable choices within the range of estimated abundance. Thus, based on the total area covered by the overwintering colonies, winter-time monarch abundance peaked at around 600 million in 1996-97, fell to 35 million a year ago, and increased up to about 120 million this past winter (December, 2015), a number that is less than one-quarter of their abundance 20 years ago.

Summer monitoring

In contrast to the straight-forwardness of estimating total abundance from the area covered by dense winter aggregations, monarchs are spread widely and unevenly throughout eastern North America during the summer months. Some monitoring does take place at select areas during the summer and fall, however. This past year, a collection of seven papers presenting survey data collected during the breeding season and fall migration were published as a set in the *Annals of the Entomological Society of America*. The preface to this set (Davis & Dyer, 2015) emphasized that three of the papers pointed to lack of evidence for a summer decline. This claim was important because if no decrease were seen during the summer, then the decline in overwintering monarch numbers would have to be attributed to death or loss during the fall migration rather than due to loss of summer breeding habitat.

Several flaws invalidate the interpretation of no summer decline based on these three papers, however (see Pleasants et al., 2016). Instead, the decline of milkweeds in much of the traditional monarch breeding area remains a correlative factor (Pleasants & Oberhauser, 2013; Freese, 2015). Still, the summer and fall monitoring programs are providing valuable information about regional changes in monarch abundance. In a follow-up to this back and forth exchange about summer monitoring, Dyer & Forister (2016) emphasized the need for continuing studies of monarch population dynamics using a range of models and analytical tools.

Future assessments

The complexity of the multigenerational biology of the monarch butterfly remains a challenge to understanding what determines the numbers of monarchs that arrive in Mexico each fall. Dyer & Forister (2016) are correct that much remains to be learned of monarch population dynamics by following all stages of the life cycle. Much can be learned from citizen science projects, too, such as those run by Journey North (**www.learner.org/jnorth**) and the Monarch Larval Monitoring Project (**http://www.mlmp.org**). Summer and fall monitoring of adults takes place mostly outside the primary reproductive area of Midwestern states; if long-term monitoring could begin within that area and, even more importantly, in the migration corridor through Texas, then we would better understand the changes in summer-time abundance.

The emergence of drone technology provides a possibly more accurate way to assess the actual abundance of overwintering monarchs. If a drone provided color photos taken directly over a colony, analysis of the intensity of orange color in the images might allow one to quantify the density of monarchs more accurately. Photos taken from satellite or airplane have not provided sufficient resolution (Slayback et al., 2007), but photos from a drone would. The images could be taken in the early afternoon on sunny days, which is when sunbasking monarchs display a strong orange color that contrasts with the surrounding green forest.

This column describes what we know about the abundance of monarchs; it is another matter what one does about the well-documented long-term decline. A recent study (Semmens et al., 2016) estimates a probability of 11-57% that the migratory population of monarchs will die out during the next 20 years. The threatened species petition, which remains under review by U.S.F.W., engendered mixed opinions among lepidopterists, but whatever the outcome of that review, more people have become aware of monarchs, the decline in their overwintering numbers, and the challenges faced by these extraordinary creatures. That increased understanding has led to numerous initiatives in support of monarchs and pollinators in general (e.g., U.S.F.W., 2014; Texas Pollinator Powwow, 2016). A big concern remains on the minds of many people: how many monarchs will there be five or ten years from now?

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A monarch-draped oyamel fir bough in the Sierra Chincua colony, January, 2007. Photo by E.H. Williams.