Long-Term Trends in Eastern North American Monarch Butterflies: A Collection of Studies Focusing on Spring, Summer, and Fall Dynamics

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The monarch butterfly, *Danaus plexippus* (Nymphalidae, Danainae), is one of the most familiar and appreciated insects in North America and is an iconic symbol of insect conservation (Gustafsson et al. 2015); attention on this charismatic species has increased since declines of their Mexican overwintering colonies were reported (Brower et al. 2012). These declines are alarming, yet they may or may not be representative of the patterns for other phases of this species' ontogeny or its phenology. The collection of articles in this special feature was produced by researchers associated with a variety of nation-wide citizen science projects that have been tracking monarchs for many years, with the overarching goal of identifying long-term trends in their abundance or distribution outside of the wintering period. The articles in this feature include: 1) a study that reports patterns of spring recolonization within the breeding range (Howard and Davis); 2) two articles that examined long-term changes in reproductive output (Stenoien et al., Nail et al.); 3) a paper that analyzes censuses of summer adult monarchs from two butterfly monitoring programs (Ries et al.); 4) two studies focusing on fall migration censuses (Badgett and Davis, Crewe and McCracken); and 5) a paper examining 18 yr of migration tagging and recovery data from one site (Steffy). The collective results of these studies should have a significant impact on our current understanding of eastern monarch population dynamics. For example, despite dramatic reductions in overwintering size, there has been no detectable change in the recolonization of the overall breeding range of monarchs in the past 18 yr (Howard and Davis), and at least one model suggests that a large breeding range is essential for preventing extinction of eastern monarchs (Yakubu et al. 2004). Furthermore, two decades of censuses of adult monarchs in the summer from two separate butterfly monitoring programs show no significant reductions in numbers (Ries et al.), and censuses of migrating monarchs at a site in Michigan also show no evidence of decline (Badgett and Davis). These patterns, combined with similar results indicating no declines from other programs that monitor adult monarchs in summer and fall (Davis 2012, Ries et al. 2015), have profound implications, as the patterns documented are the opposite of the published long-term trends at the overwintering sites. On the other hand, two of the articles in this feature focus on immature stages of monarchs, and both of these have uncovered some ongoing and enigmatic problems. One shows recent declines (within the past 7 yr) in regional egg densities (Stenoien et al.) and the other shows more long-term, gradual declines in larval survival (Nail et al.) within the core breeding range. It is not clear what factors are causing these losses.

Beyond the obvious value of monarchs as a model system for conservation and ecological research, there is an additional focal area of this special feature that distinguishes these studies as an important collection of articles: their effective utilization of citizen science. Because some of the results reported in this special feature are not completely consistent with current paradigms about monarch declines, one might be tempted to ask about the utility of citizen science databases. Are such databases subject to higher error variance and should they be trusted when the consequences affect policy, such as considerations for listing a species as endangered? Large-scale studies have demonstrated that there are no statistical differences when comparing lepidopteran feeding pattern data from citizen science databases versus some of the largest professionally collected lepidopteran larval databases in existence (Dyer et al. 2012). The growing impact of citizen science is clear, and this special feature comprises an important example of such a positive contribution to science and education.

Despite the fact that the articles in this special feature include disparate data sets for monarchs at different stages, as well as the fact that different protocols

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and citizen science databases were used, there are obvious consistencies across these studies. The most visible example is the high level of year-to-year variation documented for most variables, including fall migration indices, spring recolonization rates, regional egg densities, larval survival rates, and summer counts of adults. Such variation is predicted by models (Yakubu et al. 2004), and it clearly demonstrates that long-term trends are inherently difficult to detect without many years of data. Several studies in this collection also provide evidence that long-term trends are not always linear. In one case, the number of migrants at Long Point, Ontario, increased in the first 10 yr, and then declined thereafter (Crewe and McCraken). Similarly, egg densities in the Midwest increased from 1997 to 2006, but have declined for the past 7 yr (Stenoien et al.).

The collective results from this special feature will help guide future conservation and research efforts. Given the lack of declines in numbers of breeding adults, but clear declines in overwintering colonies, an immediate task will be to identify factors that affect or limit fall migration success. Examination of monarch tagging data, as utilized by Steffy in this feature, is a good start, although more studies like this one are needed (Davis 2015). Steffy's analyses showed that early migrants tend to be more successful at reaching the wintering grounds, which is consistent with other results showing that early migrants are better-adapted for long-distance flight (Satterfield and Davis 2014). Another important contribution of the Steffy paper is the first-ever comparison of Mexico recovery rates from wild monarchs versus those reared indoors (and subsequently tagged) over many years. This exercise showed that while a select few reared monarchs were capable of reaching the overwintering site, the success rate was extremely low compared with wild monarchs. With the growing popularity of rearing monarchs in homes and for commercial releases, this result implies that such practices create monarchs that are not well-suited for release, at least into the migratory cohort.

What is missing from this collection is research on the potential effects of climate change on monarch populations, and this is research that is urgently needed. Warming temperatures are expected to shift the monarch breeding range northward (Batalden et al. 2007, Lemoine 2015), which could result in longer travel distances to the overwintering sites (and by extension, greater migratory mortality). There are already early signs of this – the earliest sightings of fall roosts are coming from farther north (Howard and Davis 2015), and monarch arrival to overwintering sites is starting to show signs of delay, at least in the past 2 yr (E. Howard, personal communication). Moreover, if the core breeding range expands northward, sites that used to be in the core (i.e. the Midwest) will one day become peripheral, which may affect recruitment (i.e. egg densities and larval survival) in these areas. A growing number of studies also suggest that climate change predictions outside of an appropriate community ecology context cannot accurately predict species' response to climate change parameters – for example, changes in plant chemistry and parasitism can greatly modify predicted shifts in a species' range or its population dynamics (Tylianakis and Binzer 2014), thus more studies on immature stages, their host chemistry, their potential competitors, and their natural enemies should also contribute to understanding the future ecology and conservation of monarchs.

Finally, the conservation of any species requires knowledge of its population size. For many years, the status of the monarch population in eastern North America has been judged solely on the size of overwintering cohort in Mexico, largely because of convenience and a lack of other options. Comparable data sets from other long-term monitoring programs had not been analyzed and made available, until now. The collection of papers in this special feature help make it clear that the long-term trajectory of the eastern monarch population depends on what stage of the life cycle is examined, and the next steps should be to determine which stages are most critical, carefully calculate model parameters such as fecundity and parasitism rates, and utilize established mathematical approaches to estimating population parameters and modeling population dynamics.

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