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FORUM

Opinion: conservation of monarch butterflies (*Danaus plexippus*) could be enhanced with analyses and publication of citizen science tagging data

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Abstract. 1. Recent declines in the size of overwintering colonies of monarch butterflies (*Danaus plexippus*) in eastern North America have stimulated calls for greater conservation efforts of the migratory phenomenon. Conservation decisions, however, should be guided by sound science, and the migratory phase of this population is the least-studied part of its life cycle.

2. Data from large-scale citizen science programs can help address this knowledge gap. For over 20 years, volunteers have been tagging migrating monarchs with numbered stickers from MonarchWatch (www.monarchwatch.org), who oversees the management of tagging and recovery records. These data have the potential to vastly improve scientific understanding of the migratory phase (such as identifying spatial and temporal trends in mortality) and help target conservation efforts, but this potential has not yet been fully realised, based on a review of published studies in the last 20 years.

3. Since citizen science programs are often understaffed and operate on minimal budgets, data analysis may not be a high priority for project staff. To stimulate scientific investigations using tagging data, there are alternative solutions that could be implemented including making data publicly available or soliciting assistance from external scientists. Such efforts would not only benefit research into monarch biology, but would lend scientific credibility to tagging activities.

4. Tagging monarchs is a popular activity with clear educational value. In my opinion these data could be, however, better utilised to improve the conservation of the migratory phenomenon itself.

Key words. Conservation, *Danaus plexippus*, migration, monarch butterflies, monarch tagging.

Recent public and scientific alarm followed from reports of declines in the size of overwintering colonies of monarch butterflies, *Danaus plexippus*, in central Mexico (Brower *et al*., 2013). These declines are thought to stem from loss of overwintering habitat (Brower *et al*., 2002; Vidal *et al*., 2013) and reductions in milkweed in agricultural regions of the United States (Pleasants & Oberhauser, 2013). A less-frequently discussed explanation is that adult mortality during migration may be increasing, perhaps because of loss of stopover habitats, reduced nectar resources or more frequent encounters with man-made obstacles (McKenna *et al*., 2001). This could explain the discrepancy between long-term patterns of overwintering colony size and the lack of declines in counts of migrating monarchs at northern locations (Davis, 2012). Regardless of the relative contribution of different causes, these patterns emphasise the importance of the migratory journey to the biology and population dynamics of eastern monarchs, since migrating monarchs move long distances across diverse habitats. To better understand complex mechanisms driving monarch declines, there is now an urgent need to identify sources of mortality during migration, and to better understand the dynamics of the migration itself, including the relative contribution of monarchs from different regions of the flyway to the overwintering population in Mexico.

The large-scale (continental) nature of the monarch migration is inherently difficult to study by scientists working alone. This phase, however, can be effectively

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researched through large-scale citizen science programs (Howard & Davis, 2009; Howard & Davis, In Press; Davis *et al*., 2012). One program in particular that has the potential to vastly improve scientific understanding of this phenomenon is MonarchWatch (www.monarchwatch.org), which solicits volunteers in North America to capture and tag migrating monarchs with numbered stickers (Fig. 1). Thousands of monarchs are tagged each fall, and if tagged monarchs are recovered along the flyway or at the overwintering sites, this provides valuable information such as the routes of travel (although this assumes a straight line of travel), flight durations, stopover site locations, and tag recovery rates. This program therefore functions in much the same way as does bird-banding, which has a long history of pursuit by amateur and professional ornithologists, and which provides scientists with valuable data for studying bird migration (e.g. Calvert *et al*., 2013; Macdonald *et al*., 2013; Garrettson *et al*., 2014). Unlike bird-banding programs, however, the data from monarch tagging efforts remains largely unexplored by scientists.

To see the scientific potential of monarch tagging data, we need to look no further than the original tagging program started by Fred Urquhart in the 1950s, who solicited volunteers to tag migrating monarchs to help pinpoint the overwintering site of the eastern North American population. After many years of tagging and plotting recovery locations, Urquhart determined that monarchs in eastern North America were migrating to somewhere in central Mexico. He then solicited the help of people familiar with the region to look for the actual sites, and they were eventually found (by Kenneth and Catalina Brugger) in 1975 (Urquhart, 1976). This discovery remains as the greatest scientific advancement in monarch biology in the last 40 years, and 'one of the great events in the history of lepidopterology' (Brower, 1995). Importantly, Dr. Urquhart went on to publish a number of additional papers on monarch migration that were based on the tagging data, including studies that elucidated the migration flyways (Urquhart & Urquhart, 1978), identified important roosting locations (Urquhart & Urquhart, 1979b) and reported on the Atlantic flyway patterns (Urquhart & Urquhart, 1979a). These studies, plus relevant contributions by other citizen scientists, are reviewed further in Brower (1995). While the Urquhart studies have limitations (including a lack of statistical rigor and objectivity), they are still valuable for validating patterns found with other citizen science data (Howard & Davis, 2009), and they do add to the collective knowledge of this phase of the life cycle.

Fig 1. Monarch butterfly with a uniquely numbered tag (sticker) placed on its hindwing, which if recaptured, will provide information about the route of travel, and other data useful for conserving the migratory population. Photo credit: Tracy Batchelder.

In 1992, the coordination of monarch tagging was taken over by MonarchWatch (www.monarchwatch.org), based at the University of Kansas. In the 20+ years since, this organisation has made great strides in recruiting new volunteers, developing new tagging protocols, and now the practice of tagging monarch during their fall migration is a popular activity at schools, nature centres and with interested citizens. In fact, the number of monarchs tagged each year by these volunteers ranges from 50 000 to 100 000 (O. R. Taylor, pers comm.), which means that the total number of monarchs tagged in the past 20 years is now over one million (perhaps two). Despite this monumental effort and expense (volunteers must purchase tags from MonarchWatch), there have been very few peer-reviewed studies that have used MonarchWatch tagging data to address scientific and conservation goals. A search of published studies in Google Scholar yielded only 7 publications (where tagging data were the focus) since 1992, and 5 of these were written wholly or in part by the current author using personal data retained by taggers (i.e. retained after submitting their original data to MonarchWatch), and focusing only on site-level patterns (Garland & Davis, 2002; Davis & Garland, 2004; Brindza *et al*., 2008; McCord & Davis, 2010, 2012). The most recent study examined a subset of tag recovery data taken (without permission) from the MonarchWatch website (i.e. the searchable tag recovery database) in an attempt to elucidate the navigation ability of monarchs (Mouritsen *et al*., 2013). The conclusions from that study have since been questioned (Oberhauser *et al*., 2013), and the manner in which the data were obtained was certainly inappropriate, and as a result of this incident the tag recovery database was taken offline.

The educational value of monarch tagging is without question. These activities are a superb way to engage the general public and to bring awareness of the plight of the monarch. Still, calling it a citizen science program implies that science is the core element of the program, and based on my review of the scientific literature, this has not been the case. Moreover, with the amount of effort put into gathering these data over the past two decades, both by the volunteers and MonarchWatch personnel, the failure to analyse and publish results of the data is extremely unfortunate, and it certainly is not advancing the cause of monarch biology and conservation.

To better conserve the migratory generation of monarchs, there are a number of urgent questions that need to be addressed, and these could only be answered using tagging and recovery data. First, and most importantly, we must identify the greatest sources of mortality (both natural and man-made) along the migratory flyway. Rates of tag recoveries (in Mexico), although not directly assessing mortality, could serve as a useful surrogate of migratory mortality, and these could be compared across geographic regions. It is also extremely imperative that we determine whether the overall rate of mortality during migration is increasing over time (i.e. over the years since the program began). If so, this may help to explain the discrepancy between population trends obtained from migration censuses from northern regions and overwintering counts (Brower *et al*., 2012; Davis, 2012); if the number of monarchs that begin the migration each year has not changed (Davis, 2012), but the number that finish has (Brower *et al*., 2012), then the missing piece of the puzzle must lie in the migratory journey itself. Tag recovery data could also be used to assess the impact of extreme weather events, such as drought, on migration success (Brower *et al*., In Press). In this scenario, recovery rates from the drought year(s) could be compared to those from non-drought years, or, one could compare recovery rates between flyway regions that differ in climatic conditions. Finally, there are a variety of additional scientific questions that could be addressed using the original data from tagged monarchs (i.e. not necessarily those that were recovered), that would improve our understanding of the migration itself. These could include elucidating the increasingly male-biased sex ratio in migrating monarchs (Davis & Rendon-Salinas, 2010), identifying within-season flight patterns (Satterfield & Davis, 2014), or clarifying the 'aberrant' migration flyway of Atlantic coast migrants, as first described by Urquhart (Urquhart & Urquhart, 1979a).

A call for action

The precarious nature of the eastern migration should serve as a stimulus for MonarchWatch to commence legitimate analysis of the tagging data to address the questions raised above, and most importantly, publish their results in peer-reviewed scientific journals. If this is not possible because of time constraints of MonarchWatch personnel, or funding, there are other possible ways to make this happen, including making the data (i.e. all data from both tagging and recovery sites) publically available on the MonarchWatch website, which would facilitate scientific investigation by researchers. Another approach would be to enlist the help of non-MonarchWatch scientists to analyse and publish the data. There are a number of active scientists and graduate students studying monarch biology in North America and elsewhere (as evidenced by the many contributors of recent books about monarch biology, Oberhauser *et al*., In Press; Oberhauser & Solensky, 2004) who would be well qualified to contribute to this effort.

Conclusion

As scientists, it is our responsibility to see that research data are effectively used to address the questions we ask about the natural world, and to ensure that results become part of the publically accessible scientific literature. For data gathered by citizen scientists, this goal should be even more paramount, both to allow the volunteers to witness the fruits of their efforts, and to lend scientific validation to their activities. The discovery of the overwintering sites in Mexico is a profound reminder of what can be achieved from effective use of monarch tagging data. MonarchWatch has been overseeing tagging efforts in North America for 20 + years, but the data from this program has yet to be fully tapped by scientists. In my opinion these data are vital for informing conservation efforts, which are needed now more than ever.

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