Monarch butterfly declines reported in Boyle et al. (2019) are biased by unexamined changes in museum collections over time

Abstract

Museum records provide an underutilized source of information for documenting long-term changes in phenology, species interactions, and trait evolution. However, non-systematic collection data must be treated carefully if they are to approximate abundance, as trends may be confounded with spatial or temporal changes in sampling effort. Boyle et al. (2019b) argue that the relative abundance of Eastern North American Monarch butterflies (*Danaus plexippus*) has been in a long-term decline since the mid-20th century, following a similar decline in milkweed (*Asclepias* spp.) herbarium records. I demonstrate that this reported abundance trend is biased by the choice to standardize Monarch records as a proportion of all Lepidoptera collected. The sampling of Lepidoptera has changed systematically over time to favor moths, causing the apparent trend in Monarch records. With the data standardized more appropriately, I show that the trend in Monarch records shows no mid-century decline and increases over recent decades. As the trend in Monarch museum specimens contradicts the recent trend in Monarch abundance documented from systematic population monitoring, I argue that these records are unreliable for abundance estimates. The conclusion in Boyle et al. (2019b) that Monarch declines started in the mid-20th century is unwarranted both because the trend is biased by sampling changes in museum records and because the trend in Monarch records, when corrected, does not correspond with real-world population abundance.

Museum records provide a wealth of information for documenting long-term changes in phenology, species interactions, and trait evolution (Meineke et al. 2019). However, these data have spatial and temporal biases in sampling which may be confounded with apparent trends in relative abundance (Kharouba et al. 2019). Often museum records are the only historical data available, and Boyle et al. (2019b) make the first abundance estimates spanning more than a century for the Eastern North American Monarch butterfly (*Danaus plexippus*) and its milkweed hostplant (*Asclepias* spp.) using 1,191 and 31,510 records from 1900-2016, respectively. They conclude that Monarch abundance started to decline around 1955, before the introduction of herbicide-resistant, genetically-modified crops that are held culpable for losses of Monarch hostplants (Pleasants and Oberhauser 2013). Using the same data as Boyle and colleagues, I demonstrate that Monarch records show neither a robust abundance trend nor a specific time when the population decline started.

Boyle and colleagues recognize that museum records, due to their unstructured sampling, must be standardized by collection effort to estimate an index of annual relative abundance (Bartomeus et al. 2013). They chose to divide the number of Monarch records by the number of all Lepidoptera collected each year. Their reported abundance index peaks mid-century before a long-term decline (reproduced in Figure 1A), which provides the foundation for Boyle and colleagues' attribution of environmental causes to explain the Monarch decline. However, this trend is an artifact of the choice to standardize by all Lepidoptera records. Within the Lepidoptera, moths and butterflies have different collection methods, such as nighttime light traps and daytime netting, respectively. I present the Monarch abundance trend derived by dividing Monarch records by butterfly (Rhopalocera) records, arguably a more appropriate choice for standardization. When standardized as a proportion of butterfly records, the relative

abundance of Monarch records is level between 1900 and 1980 and then increases over recent years (Figure 1B). The discrepancy results from the fact that the proportion of butterflies within Lepidoptera records changes over time (Figures 1C & 1D), potentially due to the growing availability of light traps in the 1950s (Leather 2015). This change in sampling, unexplored in Boyle et al. (2019b), explains the shape of their reported trend rather than any underlying change in Monarch abundance.

Does this mean that Monarch abundance is increasing (Figure 1B)? I argue that these data are insufficient to model abundance, as the trend in museum specimens contradicts the evidence, from systematic monitoring, of a decline in the summer range (Pleasants et al. 2017) and the wintering grounds (Vidal and Rendón-Salinas 2014). The estimates for milkweed trends in Boyle et al. (2019b) may be more robust with thirty times the number of herbarium records compared to Monarch specimens. The density of museum records needed to produce reliable estimates of abundance is untested. As the Monarch abundance trends are unreliable even with the proper standardization, these data do not support the key argument in Boyle et al. (2019b) that the Monarch decline started in the mid-20th century.

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Figure 1: Trends in Eastern North American Monarch butterfly museum records change with choice of standardization methods. All data came from Boyle et al. (2019a) and I similarly use the default LOESS smooth in the *ggplot2* R package for visualizing trends and 95% confidence intervals (Wickham 2016). **A.** Reproduction of Figure 1A in Boyle et al. (2019b), showing the trend in relative abundance when Monarch records are divided by all Lepidoptera records. **B.** The trend in relative abundance when Monarch records are divided by butterfly records does not match Figure 1A or Boyle et al. (2019b). **C.** Total number of records of Lepidoptera, moths, and butterflies in the Eastern USA each year with splines to show trends. **D.** The proportion of butterfly records to all Lepidoptera records shows a strong temporal trend that biases the Monarch trend reported in Boyle et al. (2019b).