

- 1 Classification: Biological sciences, Ecology
- 2 Title: Monarch butterfly trends reported in Boyle et al. (2019) are sensitive to unexamined
- 3 changes in museum collections over time
- 4 Author affiliation:
- 5 Tyson Wepprich
- 6 <https://orcid.org/0000-0002-6875-092X>
- 7 Department of Botany and Plant Pathology
- 8 Oregon State University
- 9 2082 Cordley Hall
- 10 Corvallis, OR, USA 97331-2902
- 11 Corresponding author:
- 12 Tyson Wepprich
- 13 Department of Botany and Plant Pathology
- 14 Oregon State University
- 15 2082 Cordley Hall
- 16 Corvallis, OR, USA 97331-2902
- 17 +1 636-373-7790
- 18 [tyson.wepprich@oregonstate.edu](mailto:tyson.wepprich@oregonstate.edu)

19 Abstract

20 Museum records can document long-term changes in phenology, species interactions, and trait  
21 evolution. However, these data have spatial and temporal biases in sampling which may limit  
22 their use for tracking abundance. Often museum records are the only historical data available,  
23 and Boyle and colleagues make long-term abundance estimates for the Eastern North American  
24 Monarch butterfly (*Danaus plexippus*) and its milkweed hostplant (*Asclepias* spp.) using 1,191  
25 and 31,510 records from 1900-2016, respectively. They conclude that Monarch and milkweed  
26 abundance started to decline in the mid-20<sup>th</sup> century, before the adoption of herbicide-resistant  
27 crops that are often blamed for losses of Monarch hostplants. Using the same data, I argue that  
28 the Monarch trend changes with the choice of taxa used to standardize Monarch records. The  
29 abundance trend after dividing Monarch records by butterfly (Rhopalocera) or Nymphalidae  
30 records, instead of by Lepidoptera as in Boyle et al. (2019), shows no mid-century peak  
31 corresponding to the milkweed trends. One reason the Monarch trend reported by Boyle and  
32 colleagues changes when standardized by other taxa is the declining proportion of butterflies  
33 within Lepidoptera records from a peak of 40% in the mid-20<sup>th</sup> century to less than 10%. This  
34 reanalysis shows that changes over time within the taxa used to standardize records matter, in  
35 addition to potential sampling biases in the species of interest.

36

37 Museum records can document long-term changes in phenology, species interactions, and trait  
38 evolution (1). However, these data have spatial and temporal biases in sampling which may limit  
39 their use for tracking abundance (2). Often museum records are the only historical data available,  
40 and Boyle and colleagues make long-term abundance estimates for the Eastern North American  
41 Monarch butterfly (*Danaus plexippus*) and its milkweed hostplant (*Asclepias* spp.) using 1,191

42 and 31,510 records from 1900-2016, respectively (3). They conclude that Monarch and  
43 milkweed abundance started to decline in the mid-20<sup>th</sup> century, before the adoption of herbicide-  
44 resistant crops that are often blamed for losses of Monarch hostplants (4). Using the same data, I  
45 argue that the Monarch trend is sensitive to the method of standardization and appears less robust  
46 than the milkweed trend.

47 Boyle and colleagues recognize that museum records must be standardized by collection effort to  
48 estimate an index of annual relative abundance (2, 3, 5). They divide the number of Monarch  
49 records by the number of Lepidoptera records in each year. Their abundance index peaks mid-  
50 20<sup>th</sup> century before a long-term decline (reproduced in the top row of Figure 1A). However, this  
51 trend changes with the choice of taxa used to standardize Monarch records. The abundance trend  
52 after dividing Monarch records by butterfly (Rhopalocera) or Nymphalidae records shows no  
53 mid-century peak corresponding to the milkweed trends (Figure 1A). I also show similar results  
54 from generalized linear models with linear and quadratic effects of year that account for the  
55 annual number of museum records with weights (5), a feature which the approach in (3) lacks  
56 (Figure 1B).

57 Collection effort that does not target the species of interest should be excluded when possible in  
58 these standardizations. Within the Lepidoptera, moths and butterflies would be most frequently  
59 sampled by nighttime light traps and daytime netting, respectively. One reason the Monarch  
60 trend reported in (3) changes when standardized by other taxa is the declining proportion of  
61 butterflies within Lepidoptera from a peak of 40% to less than 10% (Figures 1C & 1D),  
62 potentially due to increasing use of light traps around the mid-20<sup>th</sup> century (6). In reference to  
63 museum records, Boyle and colleagues note that “the most concerning possible biases are those

64 that change over time within a species” (3). This reanalysis shows that changes over time within  
65 the taxa used to standardize records also matter.

66 I do not think that this reanalysis presents the true Monarch trend, since it contrasts with recent  
67 declines (7). Rather, I think analysis of abundance from biological records needs more data and  
68 methodological advances to approach the value of systematic monitoring (2). The estimates for  
69 milkweed trends may be more robust with thirty times the number of herbarium records  
70 compared to Monarch specimens (3). Boyle and colleagues verify their method for herbarium  
71 records by correctly estimating increasing trends in four invasive plants over the 20<sup>th</sup> century. A  
72 similar approach with invasive insects would be a valuable test to verify if museum records can  
73 estimate long-term trends in highly variable insect populations.

74

## 75 References

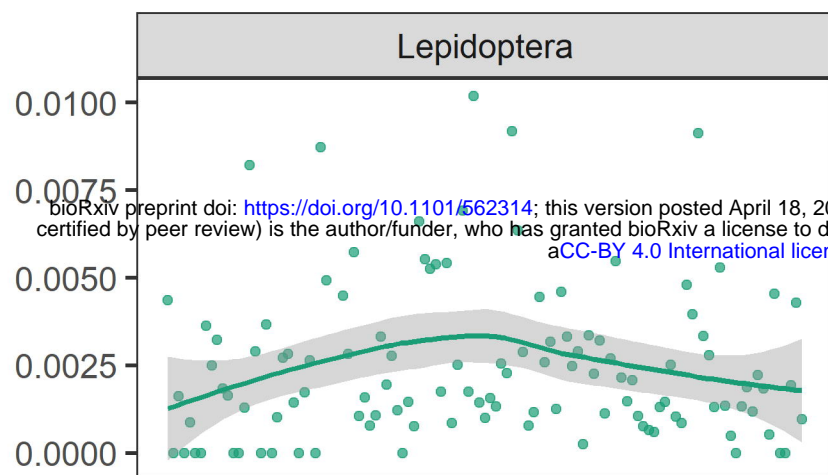
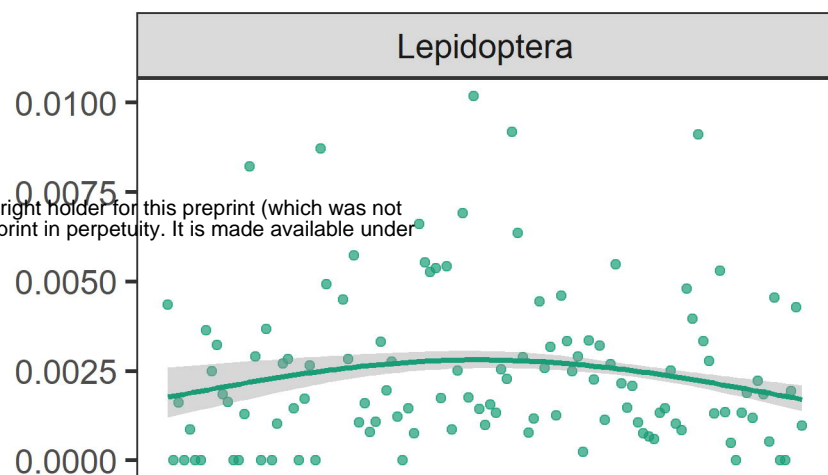
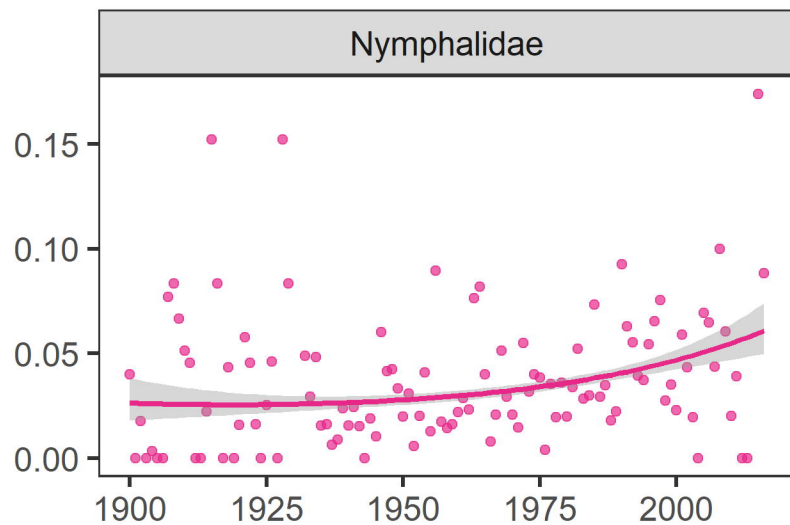
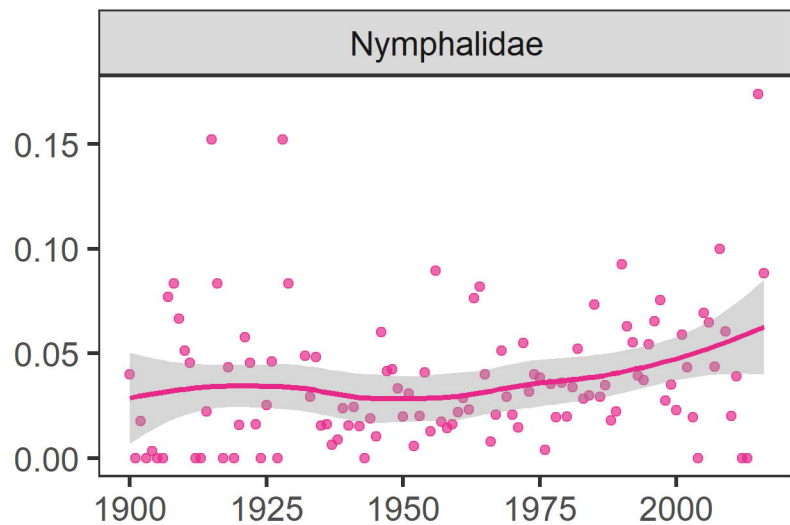
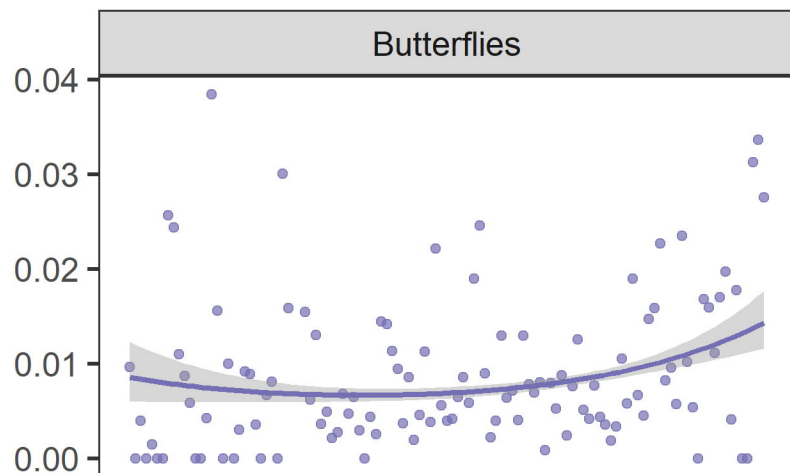
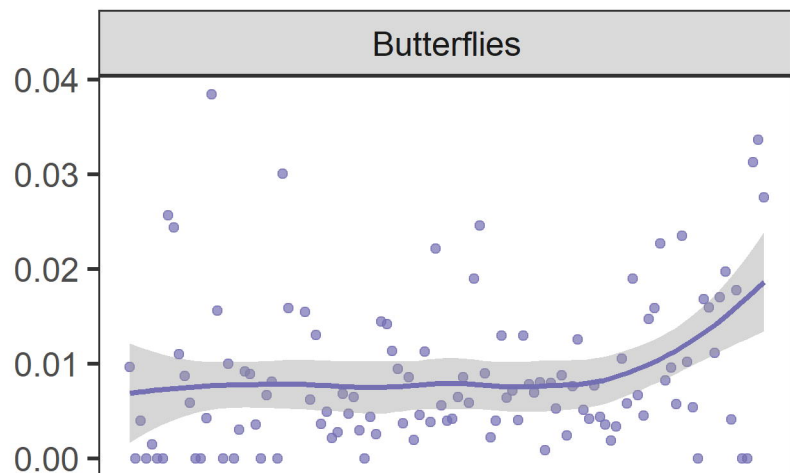
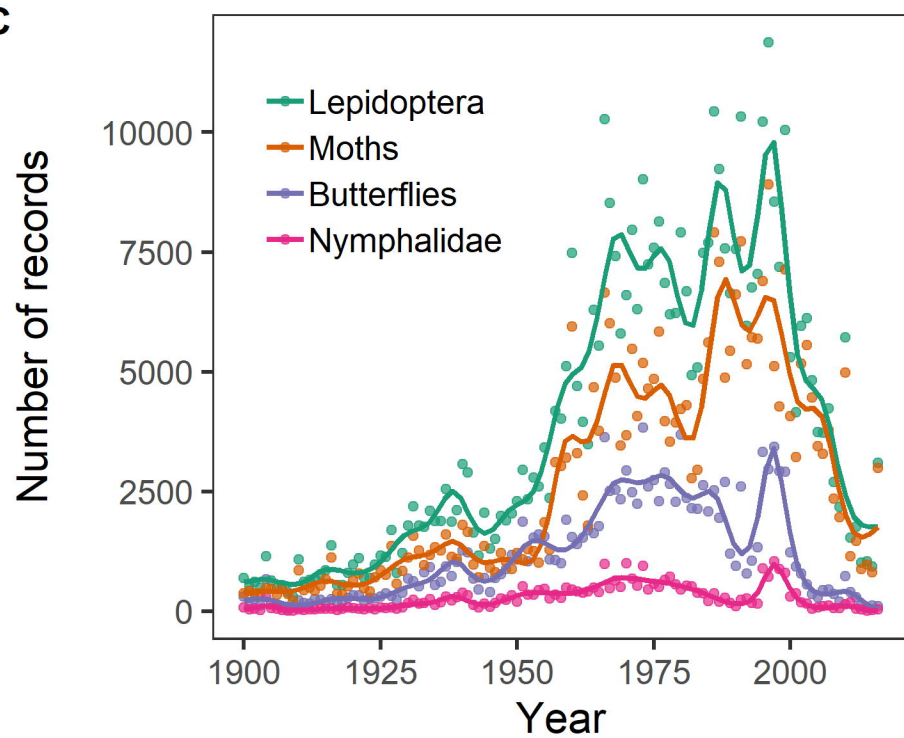
- 76 1. Meineke EK, Davies TJ, Daru BH, Davis CC (2019) Biological collections for  
77 understanding biodiversity in the Anthropocene. *Philosophical Transactions of the Royal*  
78 *Society B: Biological Sciences* 374(1763):20170386.
- 79 2. Isaac NJB, Pocock MJO (2015) Bias and information in biological records: Bias and  
80 information in biological records. *Biological Journal of the Linnean Society* 115(3):522–  
81 531.
- 82 3. Boyle JH, Dalglish HJ, Puzey JR (2019) Monarch butterfly and milkweed declines  
83 substantially predate the use of genetically modified crops. *Proceedings of the National*  
84 *Academy of Sciences*:201811437.

- 85 4. Pleasants JM, Oberhauser KS (2013) Milkweed loss in agricultural fields because of  
86 herbicide use: effect on the monarch butterfly population: *Herbicide use and monarch*  
87 *butterflies. Insect Conservation and Diversity* 6(2):135–144.
- 88 5. Bartomeus I, et al. (2013) Historical changes in northeastern US bee pollinators related to  
89 shared ecological traits. *Proceedings of the National Academy of Sciences* 110(12):4656–  
90 4660.
- 91 6. Southwood TRE (1978) *Ecological Methods: With Particular Reference to the Study of*  
92 *Insect Populations* (Springer Netherlands: Imprint: Springer, Dordrecht) Available at:  
93 <http://public.eblib.com/choice/publicfullrecord.aspx?p=3107803> [Accessed February 28,  
94 2019].
- 95 7. Vidal O, Rendón-Salinas E (2014) Dynamics and trends of overwintering colonies of the  
96 monarch butterfly in Mexico. *Biological Conservation* 180:165–175.
- 97 8. Boyle J, Dalglish H, Puzey J (2019) *Data from: Monarch butterfly and milkweed declines*  
98 *substantially predate the use of genetically modified crops* (Dryad Digital Repository)  
99 doi:10.5061/dryad.sk37gd2.
- 100 9. Wickham H (2016) *ggplot2: Elegant Graphics for Data Analysis* (Springer-Verlag New  
101 York) Available at: <http://ggplot2.org>.

102

103 **Figure 1: Trends in Eastern North American Monarch butterfly museum records change**  
104 **with the choice of standardization.** All data came from (8) and span 1900-2015 and the Eastern  
105 USA. **A.** I reproduce Figure 1A in (3) with their standardization by Lepidoptera records and

106 present two alternative standardizations (Rhopalocera and Nymphalidae). I similarly use the  
107 default LOESS smooth in the *ggplot2* R package for visualizing trends and 95% confidence  
108 intervals (9). **B.** The relative abundance of the three standardizations are alternatively modeled  
109 with a binomial generalized linear model, weighted by the annual number of records, predicting  
110 relative abundance with linear and quadratic year covariates. **C.** Total number of records of  
111 Lepidoptera, moths, butterflies, and Nymphalidae each year with splines showing trends. **D.** The  
112 proportion of butterfly records to all Lepidoptera records shows a strong temporal trend that  
113 influences the mid-20<sup>th</sup> century peak of Monarch abundance reported in (3) and shown in the top  
114 row of **A** and **B**.

**A****B**Monarch records /  
total recordsMonarch records /  
total records**C****D**