

**REPLY TO ANGELO: DECLINES IN SPECIES IN THOREAU'S CONCORD
AND THE MIDDLESEX FELLS, MASSACHUSETTS, USA**

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ABSTRACT

Angelo (2014) questioned the ability of our field methods to support our previously published conclusions regarding the changing flora of Concord and the Middlesex Fells, Massachusetts (Drayton & Primack 1996; Willis et al. 2008; Primack et al. 2009). In particular, he questioned whether our five years of fieldwork is adequate to conclude that many species are declining and whether climate change is contributing to these declines. We agree with Angelo (2014) that longer searches for species will yield discoveries of more species and populations and that these searches are essential when preparing formal floras or answering some research questions. However, the intent of our work was to identify community-level patterns—trends in abundance and factors associated with those trends—and was never to create a formal flora or document the absolute abundance of individual species. Our conclusions are not particularly sensitive to whether we missed individual plants or populations during our surveys—we know we did and acknowledged as much in our previous publications. Our sampling efforts were evenly distributed across taxa and the trends in relative abundance were the most important factor in our statistical analysis. (See also a companion response by Willis and Davis in this issue, *Phytoneuron* 2014-59). We believe most of the criticisms of our work by Angelo (2014) are based on a misunderstanding of the goals, methods, and conclusions of our projects. Moreover, his criticisms do not alter the basic results of our work.

In a recent article in this journal, Angelo (2014) provides a detailed criticism of our work on the changing flora of Concord and the Middlesex Fells, Massachusetts. In particular, he makes several assertions relating to our assessments (Drayton & Primack 1996; Willis et al. 2008; Primack et al. 2009) that the population sizes of many species in Concord and Middlesex Fells are declining and that the declines in Concord are in part related to climate change. We note that Angelo (2014) does not question the validity of our much larger body of work on the impacts of climate change on the phenology and behavior of plants, birds, and butterflies of Concord and the surrounding areas of Massachusetts (reviewed in Primack & Miller-Rushing 2012; Ellwood et al. 2013)—but rather he focuses his criticisms on our findings related to changes in the abundance of plant species over time. Here we respond to each of his main assertions. We believe that most of the criticisms result from a misunderstanding or misinterpretation of the goals and conclusions of our work. Two of our collaborators agree and have written a separate and complementary response (Willis & Davis 2014).

The single biggest point that Angelo makes is that he believes our research has overstated the declines and disappearance of species from the flora of Concord, Massachusetts. He argues that we did not carry out sufficient fieldwork to comment on the flora of Concord, and that it is in fact impossible for a person or small group to accurately measure in a limited span of time the extent of a town or park flora (Angelo 2014). Overall, we agree with Angelo's point that it takes an extensive and long-term effort to comprehensively document the *absolute* presence and abundance of each individual species in a flora of a town or large park as one would do when preparing a formal flora. However, this was never the goal of our project in Concord (Primack et al. 2009). Our project was aimed at identifying *relative* changes in abundance and phenology (Primack et al. 2009), based on changes since other botanists had recorded relative abundance in the past (e.g., Hosmer 1903; Eaton 1974). For the purpose of our study, it did not particularly matter whether a species declined from common to either rare or locally extinct; it still declined in abundance.

We carried out extensive fieldwork for five years during the period 2003 through 2007, and more limited fieldwork in the seven years since. We also consulted numerous botanists, including Ray Angelo, on past and current locations in Concord of populations of less common species. This effort was more than adequate to achieve the goals of our research, even though we certainly missed individuals and populations of some species because they were very inconspicuous, very rare, or did not grow or flower in each year, as we clearly noted in our original paper (Primack et al. 2009). We were not attempting to formally document the flora of Concord, as Angelo (2014) implies.

Angelo (2014) specifically cites the examples of the Liliaceae and Orchidaceae. We found that species within these families tended to experience disproportionate declines in abundance in Concord (Primack et al. 2009), but Angelo suggests that species in these families did not actually experience particularly dramatic declines in abundance. For the Liliaceae, Angelo (2014) lists 5 species that were rare or occasional in Thoreau's time, many of which are likely extinct today in Concord, and 11 species that were formerly common, of which Angelo considers 6 or 7 likely to be still common. However, based on our fieldwork, one of the seven species Angelo considers to be common is now rare (we have only seen two very small populations of *Hypoxis hirsuta*) and we have never seen another species (*Clintonia borealis*) in the field in Concord. Thus, of 16 species in the Liliaceae, five were rare or occasional and have likely disappeared from the Concord flora, and six were formerly common and have now become rare or locally extinct, and five are still common or occasional. It is worth noting that two *Lilium* species were formerly reported as common (Eaton 1974); we only saw one plant of *L. canadensis* in one year and we never saw the other species (*L. philadelphicum*); these are very conspicuous plants and hard to miss. We also found only one population of *Trillium cernuum*, which we witnessed gradually decline in abundance over the past 10 years to the point where the remaining plants no longer flower. By our estimate, the Liliaceae family is in sharp decline in Concord.

For the Orchidaceae, of 22 species historically found in Concord, Angelo (2014) lists 11 species as formerly rare or occasional, with most of them likely no longer present in Concord. Of 11 formerly common orchid species, Angelo has apparently only seen five of them in Concord. Out of this list of five common species, we agree with Angelo (2014) that two (*Cypripedium acaule* and *Goodyeara pubescens*) are still somewhat common in Concord today, though even *Cypripedium* is not nearly as abundant as it was 12 years ago. Angelo (2014) lists three other orchid species as having been common in 1974. However, of these three, we found only a single plant of *Platanthera psycodes* in one year, only one population *Pogonia ophioglossoides* in a single bog, and only a few plants of *Spiranthes cernua* in a lawn. Thus, of the 22 orchid species historically found in Concord, 11 were rare or occasional and may have disappeared from the Concord flora, 9 were formerly common and are now rare or locally extinct, and 2 are still somewhat common. We believe this represents a rather dramatic decline of the Orchidaceae in the Concord flora. Angelo (2014) focuses on just on these two families, but there are many other groups of plants, such bladderworts

(*Utricularia*) and mountain mints (*Pycnanthemum*), that have similarly declined in abundance in Concord.

Angelo (2014) also asserts that the declines in the abundance of many plant species in Concord are likely not related to climate change, contradicting our previous finding (Willis et al. 2008). We give a short response to this assertion here. Willis and Davis (2014) give a more thorough response in a companion article in this issue.

Angelo (2014) uses various arguments in different parts of his paper to suggest that climate change is not related to species declines in Concord: (1) warming in Concord has not exceeded the year-to-year fluctuations in temperature, (2) particular declining species still occur in locations farther south that are warmer than Concord, (3) many other aspects of the environment—e.g., reforestation, development, and the spread of non-native plants—have changed, and (4) the data on changes in abundance used in Willis et al. (2008) are unreliable. Angelo's assertions (1) and (2) have some validity, although it does not follow from these points that warming temperatures are not related to declines in abundance. In fact, warming temperatures and changes in phenology have been related to declines in abundance or performance of species in various locations within their ranges (examples reviewed in Cleland et al. 2012; Cahill et al. 2013). These declines could be caused by a range of factors associated with climate change—e.g., extreme temperatures and precipitation events (Ellwood et al. 2013; Melillo et al. 2014); local adaptation that has genetically altered heat or drought tolerance of local populations relative to southern populations; or temporal mismatches with pollinators, herbivores, or other physical or biological resources (Cahill et al. 2013).

It is also important to recognize that we found that declines in the abundance of particular species were correlated with phenology (specifically, the ability of flowering times to shift and to track interannual changes in winter and spring temperatures) and species ranges (species with northern distributions tended to decline in abundance more than species with more southern ranges). The relationships between declines in abundance and phenology and species ranges were determined by an analysis of changes in all of the wildflowers we observed, not particular species. There are certainly cases where individual species disappeared because of loss of habitat, pollution, forest succession, invasive species, or deer herbivory, as we acknowledged in our original papers (Willis et al. 2008; Primack et al. 2009). However, when we considered the full set of plant species, and considered a range of factors—including habitat, status as native or introduced, and deer preference—that might be associated with declines in abundance, phenology and species ranges explained some of the variation between species that declined in abundance and those that did not, thereby implicating climate change as contributing to the declines in abundance of many plant species in Concord (Willis et al. 2008, 2009). It is worth repeating that from a statistical point of view, the difference between whether a formerly common species substantially declined in abundance or has disappeared entirely would have a negligible, if any, effect on our results. In addition, many the rare species that currently exist in Concord consist of just a few remaining individuals and will likely disappear from Concord in coming decades. And finally, although Angelo (2014) questions our use of Hosmer's (1903) records of abundance to determine the decline and loss of species, these patterns are similar to what we found using observations derived from the journals of Thoreau and Eaton's (1974) flora of Concord (Primack et al. 2008).

Angelo (2014) also cites resurveys (Hamlin et al. 2012; Kittredge 2013) of one of our projects documenting the loss of plant species from the Middlesex Fells (Drayton & Primack 1996). Angelo (2014) uses these resurveys to argue that bigger teams of researchers and more years of fieldwork allow teams to find more species, which is certainly true. The Drayton and Primack (1996) study was done largely by one person working for 300 hours over two field seasons, and the latter Hamlin et al. (2012) study was done by a team of botanists working for 2000 hours over nine years—so it is not surprising that Hamlin et al. (2012) found many species that Drayton and Primack (1996) could not locate. Importantly, though, Hamlin et al. (2012) confirm the main conclusions of Drayton

and Primack (1996). First, the Hamlin et al. (2012) study was unable to locate 22 % of the historical flora of the Middlesex Fells—so both studies concluded that numerous species have been lost. Second, Hamlin et al. (2012) and Drayton and Primack (1996) both found that the most of the species that disappeared were rare in 1896. Third, both studies reported a substantial increase in the proportion of the flora that was non-native. Fourth, both studies reported that certain groups, such as orchids, were especially prone to decline and local extinction. The main difference between the two studies is that Drayton and Primack (1996) found that the number of native species in the Middlesex Fells had declined over time, while Hamlin et al. (2012) found that the total number of native species had stayed the same, although the species composition had changed (Hamlin and Kittredge 2013 supply additional data). This difference between the two studies is almost certainly due to Hamlin et al. (2012) surveying the area more intensively than did Deane (1896) in the original survey, and finding more of the persistent rare species that were likely present in the past and that Deane (1896) had simply missed. For example, for the Poaceae, Hamlin et al. (2012), report finding 20 new native grasses not recorded by Deane (1896) but not being able to find 15 previously reported species, for a net increase of 5 native grass species. Thus while we undersampled the original flora documented by Deane (1896), Hamlin et al. (2012) almost certainly oversampled it relative to Deane (1896).

Despite the critiques of Angelo (2014), our core findings do not need to be altered—in fact Angelo (2014), Hamlin et al. (2012), and Kittredge (2013) all agree that the floras of Concord and the Middlesex Fells are changing substantially and that these changes appear to be related to human influences. Although spending more time searching an area for species allows a research team to find more populations of rare and occasional species, which appears to be the main point of Angelo (2014), shorter and less complete searches can allow a study to make fruitful inferences about community-wide changes that are taking place, such as we did (Drayton & Primack 1996; Willis et al. 2008; Primack et al. 2009) and as has been done elsewhere by numerous other research teams exploring changes in ecological communities (e.g., Robinson et al. 1994; Leach & Givnish 1996; Lavergne et al. 2006). Other botanists working in Massachusetts have similarly found changes in local floras over the past century (for example, Bertin 2002; Standley 2003). An additional point is that surveys like ours in Concord and the Fells can energize people to undertake a more comprehensive flora, increase local awareness, and maybe even promote conservation. This is in fact exactly the outcome that has occurred for the Middlesex Fells and what may yet happen in Concord if botanists decide to undertake a new town flora.

We admire the work and expertise of botanists and others who aim to fully document the floras of particular areas—ecological research, and our work specifically, relies on these types of surveys and experts (e.g., Hosmer 1903; Eaton 1974). During the course of our study, we greatly benefitted from the advice given to us by many Concord botanists, especially Ray Angelo, on where to find rare species. Ray Angelo was also able to help us identify some of the new plants that have recently arrived in Concord. His knowledge of the flora of Concord is outstanding and we respect his opinion. We believe some of the points that he makes in his paper have merit, but also believe his main points reflect a misunderstanding of the intent of our research—his critiques do not alter the conclusions of our work.

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