The Importance of Naturalists in Identifying Global Warming in Our Backyards

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Global warming is a major topic of scientific discussion. However, at a glance, it may appear that the world is not warming: in January of 2005 Boston received more snow than it had in any month since the city began recording snowfall, and January of 2004 was the coldest month in Boston since 1934. Are these signs of global warming? Or if the world is warming, which the numbers tell us it is, one might wonder if the warming corresponds to anything we see in any given year.

Individuals who have been carefully watching their gardens and birdfeeders over the past several decades may know better. Plants in gardens and wild habitats have been blooming earlier in the spring and dropping their leaves later in the fall. Migratory birds have been arriving earlier in the spring. Some have even stopped leaving altogether, instead opting to overwinter farther north than ever previously recorded. These naturalist observations have told a story that many thermometer-watchers may have missed. Annual temperatures in Massachusetts have risen by 0.6ºC over the past 100 years, matching the global average, and temperatures in urban areas like Boston have risen even more due to the conversion of forests to buildings, roads, and other paved surfaces (New England Regional Assessment Group 2001). However, the daytime temperatures that many of us follow have risen by only about half as much as the nighttime temperatures (Intergovernmental Panel on Climate Change 2001). While we sleep through the bulk of global warming, nature is paying very close attention to the temperature changes. It turns out that organisms like plants and birds are in many ways more responsive to these increasing nighttime temperatures than they are to warm daytime temperatures. Thus, by watching the plants and birds in our backyards, we can draw better conclusions about the changing climate than if we watch only our thermometers.

The Early Bird Arrives Even Earlier

Although spring officially arrives on the same day on the calendar each year, typical spring events like the flowering of plants and the arrival of migratory birds have been occurring anywhere from one to ten days earlier each decade. A growing number of studies provide evidence to support this observation of earlier spring events (e.g., Oglesby and Smith 1995; Sparks and Carey 1995; Bradley et al. 1999; Butler 2003; Ledneva et al. 2004; Primack et al. 2004). The reason that these events are happening earlier is fairly straightforward: many species of plants, birds, amphibians, insects, and other organisms in temperate regions rely on temperature as their primary cue to begin their spring activities. As temperatures have warmed, these species have become active earlier and earlier.

Some species are active or arriving extraordinarily earlier now than they have in the past. For example, Brown Thrashers (*Toxostoma rufum*), Field Sparrows (*Spizella* *pusilla*), and White-crowned Sparrows (*Zonotrichia leucophrys*) are now arriving in Worcester County, Massachusetts, over two months earlier than they were in the 1930s (Butler 2003). Research based on the observations of the famous American naturalist, Aldo Leopold, indicates that the first Canada Geese (*Branta canadensis*) are arriving in Wisconsin about one month earlier than they did sixty-one years ago. In England, some plant species, such as Robert geranium (*Geranium robertianum*), have flowered as much as five weeks earlier for each 1ºC increase in temperature (Bradley et al. 1999).

Although it is impossible to point to global warming as the force responsible for changes in most individual spring events, many believe that the overwhelming correlation between warming temperatures and advancing spring events provides exceptional evidence that global warming is causing many spring events to occur earlier. The validity of this logic has been vigorously debated. In 2003, two articles published in *Nature* largely settled the argument (Parmesan and Yohe 2003; Root et al. 2003). These papers used a variety of statistical techniques to analyze over 100 studies of changes in springtime events. They demonstrate two key points. First, it is exceedingly unlikely that so many biological events would occur earlier over time by chance alone. All things being equal, we would expect about half of spring events to occur earlier over time and half to occur later. To find that an overwhelming number of species worldwide are active earlier in the spring now than they were in the past suggests that *something* is causing them to be active earlier. Second, we are given a high level of confidence that global warming is responsible for the majority (67-95 percent) of earlier spring activities. This finding arises from patterns present in changes in the timing of spring events. Given what we know about global warming and the effects of temperature on spring activity, we can predict broad patterns that should exist if global warming were causing the earlier spring activity. For example, we know that areas near the poles have warmed more than areas near the equator. Thus, we would expect that spring activity would be advancing more quickly near the poles than near the equator. The data bear out this and several other predicted patterns. While individual species may be active earlier in spring for reasons other than global warming, the majority of species are in fact responding to the rise in global temperatures.

For some taxa, the nature of the relationship between spring activity and temperature is obvious. Many species of frogs begin their reproductive season immediately following ice-out on small ponds. Several species of plants, such as marsh marigold (*Caltha palustris*) and spicebush (*Lindera benzoin*), flower immediately after the ground has thawed. For other taxa, such as migratory birds and several species of plants, the relationship between springtime activity and temperature is less clear. Temperature probably plays an important role in regulating spring activity, but other factors, such as day length, precipitation, and wind direction, probably play important roles too.

Examining the connection between seasonal biological phenomena and these types of environmental factors forms the core of the study of phenology. In light of the recognition of global warming as an important change for biological systems, a growing number of biologists are addressing phenological questions such as, "Just how important is temperature in determining when birds migrate?" Recent studies have demonstrated that temperature is the most important indication of spring for many bird and plant species, but several species seem to rely much more heavily on other cues. Exactly how the phenologies of these somewhat temperature-independent species will change as the world warms is largely uncertain.

Movin' On Up

In addition to advancing spring events, global warming has induced many species in the Northern Hemisphere to shift their ranges northward, or up mountainsides. Species are following the warming climate. Species ranges will probably shift faster than one might have initially expected based on changes in average temperatures.

Recall that nighttime temperatures are warming much faster than are daytime temperatures; studies show that the minimum temperature that a species can withstand largely determines its distribution (Root 1988; Woodward 1992). Thus, from the perspective of species range shifts, a 0.6ºC increase in average temperature does not matter all that much. What matters is how much the minimum temperature has increased. Consider the example of Manomet, Massachusetts, on the coast just north of Cape Cod. Manomet's average temperature has risen by 1.6ºC since 1969 (Fig. 1). Over the same time period, though, the minimum temperature has risen by 4.3ºC (Fig. 1); this increase in minimum temperatures is the change that will most affect the ability of many species to shift their ranges.

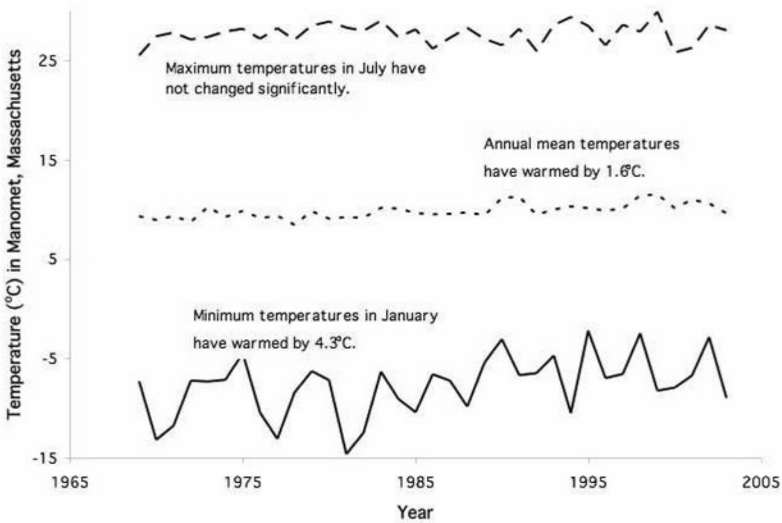

Figure 1: Mean annual (finely dashed line), maximum July (coarsely dashed line), and minimum January (solid line) temperatures in Manomet, Massachusetts, USA from 1969 to 2003. Temperatures were averaged from five weather stations within twenty-five kilometers of Manomet in order to minimize any local anomalies that might be present at a single station. Data was taken from the National Climatic Data Center.

Evidence for current shifts in species ranges is relatively limited, but new studies are appearing all the time. Studies of butterflies provide the best examples of warming-dependent range shifts. In both the western United States and in Europe, butterfly population extinctions are increasing in southern areas as conditions become too warm for species to persist, while new populations are forming in northern areas as conditions there become more favorable. It appears that the extinctions and expansions are related to physiological limitations of the species. Changes in land use do not appear to be causing the range shifts, since land use is changing equally in the northern and southern range limits.

Several studies have reported that bird range limits are also changing (e.g., Thomas and Lennon 1999; Valiela and Bowen 2003; Austin and Rehfisch 2005). It is difficult to say what is causing the range shifts in each particular case, whether it is land use change, invasive plant species, or warming. However, the large number of birds that are breeding and overwintering north of their normal ranges suggests that global warming is probably a major cause of shifts in bird breeding and overwintering ranges.

Do These Changes Matter?

Many people may be inclined to ask, "What does it matter that spring is getting earlier, and that species are shifting their ranges?" Both earlier spring activity and shifts in geographic ranges will, in all likelihood, have major impacts on ecosystems. Each species responds to warming differently. Some species now appear much earlier in the spring than they did 100 years ago. Other species appear at the same time now as they did 100 years ago. Similarly, species are changing their ranges (or will change their ranges) at different rates. Thus, biological communities will be shaken up, and we are only beginning to understand how the shake-up will play out.

Many species have evolved time-sensitive relationships. For example, specialist pollinators have evolved to emerge in the spring at the same time that their preferred plant species flower. If the plant and the pollinator respond differently to warming, the two may lose their synchrony, potentially to the detriment of each. In Europe male bees of certain species emerge just as orchid species are flowering. The bees attempt to mate with the bee-like flowers, and in the process, the plants are pollinated. A few days later, the female bees emerge and mate with the male bees. If a warming climate caused the male and female bees to emerge several days earlier, perhaps the male bees would not be interested in the flowers, and the orchids would remain unpollinated.

Other examples of time-sensitive relationships may include the current situations with Great Tits (*Parus major*) in the Netherlands and American Robins (*Turdus migratorius*) in the Rocky Mountains. In the Netherlands, Great Tits are not changing their breeding time in response to warming. However, caterpillars, their primary food source, have been appearing earlier each spring (Visser et al. 1998). Thus, Great Tit reproduction is mistimed with its food source, probably causing populations to decline or at least change food sources. In the Rocky Mountains, American Robins are arriving earlier each spring in response to warming, but the snow on the mountains is not melting any earlier (Inouye et al. 2000). Robins therefore are arriving before their food is available. Of course, robins can easily fly to an area where food is available, but the point is that as the climate warms, time-sensitive relationships will change. Other ecological relationships will change as a result, probably in ways we will be unable to predict.

At the same time that these time-sensitive relationships are changing, other species are also shifting their ranges, each at its own rate. Species will coexist where they have not previously. Resident species will face new pressures from competition with newly arriving species. Some species will thrive in new areas, while others will become increasingly rare. The implications of changing communities for individual species are difficult to predict; however, some broad trends are already apparent. For example, as the climate has warmed, pests and pathogens have already migrated northwards and upwards and have encountered new host species. A particularly well documented example is the expansion of mosquito-borne diseases to higher elevations in Asia, Africa, and Latin America (Epstein et al. 1998). In the Pacific Northwest, the mountain pine beetle (*Dendroctonus ponderosae*) has expanded its range northward in response to warming, and it has caused abnormally high mortality among most pine species in the area (Logan and Powell 2001). The negative impact that new pests and pathogens will have on plant species, like the pines in the Pacific Northwest, will be exacerbated because many plants will be growing under conditions of heat-related stress. Evidence also suggests that warming benefits many invasive species and may even allow some horticultural plant species to become invasive (Dukes and Mooney 1999; Walther 2000). Other plant species will probably be endangered because they cannot migrate fast enough to keep up with climate change; they will either adapt or face extinction (Miller-Rushing and Primack 2004). Among bird species, the ecological implications of shifting species ranges are difficult to predict, but it is clear that their ecological relationships will change. Undoubtedly, many rare and declining bird species will be further threatened with extinction by these ecological changes.

The Importance of Naturalists

Observations of earlier spring events and changes in species ranges have provided key pieces of evidence that global warming is indeed occurring and that nature is already responding to it. Most of the first studies examining the historical response of organisms to warming conditions turned to the long-term records of botanical gardens, scientists, and professional naturalists. For example, several botanical gardens in Europe kept close track of when plants were flowering on their grounds. In the United States, a network of botanists monitored when lilac and honeysuckle cultivars flowered in various locations. In addition, several individuals, such as Robert Marsham in the United Kingdom and Aldo Leopold in the United States, kept records of when plants were flowering and when birds were arriving on their properties or study plots.

Most of our understanding of how species respond to global warming still comes from these professionally collected data sets. Because high quality, long-term records of this sort are rare, we know how only a few species have responded to warming, and that in just a select number of locations. Now many scientists, we among them,

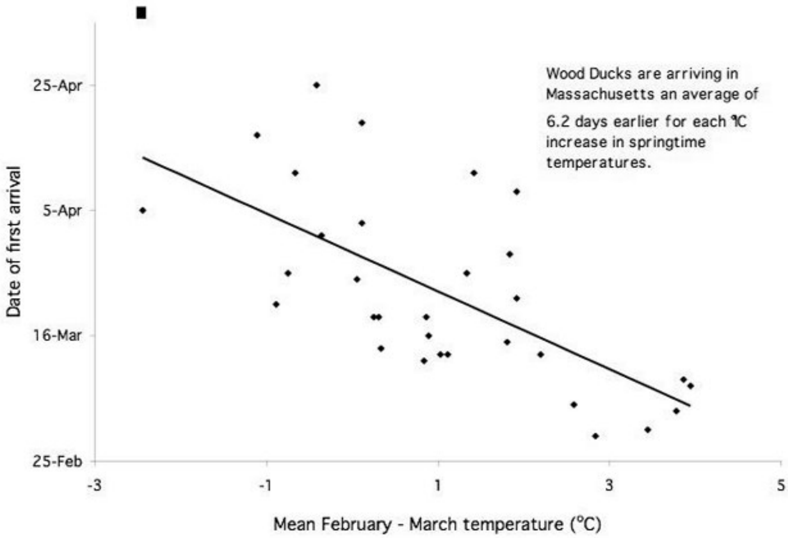

Figure 2: Wood Duck (*Aix sponsa*) arrival dates in Middleborough, Massachusetts, USA for the period 1970–2002 in relation to mean springtime (February–March) temperatures. Line represents best-fit using regression analysis. Figure taken from Ledneva et al. (2004).

are working to uncover untapped sources of data; we are finding that naturalists, both trained and amateur, are one of the most important. Many individuals — birders, gardeners, hunters, and fishermen among them—notice biological phenomena when they happen, and a large number keep very good records of what they see.

The northeastern United States provides a great case study for how naturalists have provided descriptions of biological responses to global warming that would not have been available otherwise. For example, for the past fifty-four years Kathleen Anderson, a well-known naturalist in Massachusetts, has been keeping records of the birds, flowering plants, butterflies, and amphibian choruses that she hears or sees on her farm in Middleborough. Her records provide an outstanding record of changes in the timing of spring activity on her farm. Many bird species are arriving at her farm earlier now than they did in the past, largely due to a warming climate (Ledneva et al. 2004). Wood Ducks in particular are now appearing on her pond thirty days earlier than they did thirty years ago (Fig. 2). They arrive earlier in eastern Massachusetts, but only arrive at her pond once the ice melts. The earlier appearance of the Wood Ducks is then related to the earlier melting of the ice.

Similarly, the Worcester County Ornithological Society has published records of migratory bird sightings since 1932, and the Cayuga Bird Club in Ithaca, New York, has recorded the first spring sightings of migratory birds since 1903. Analyses of these records have yielded important information regarding how migratory birds have responded to global warming (Oglesby and Smith 1995; Butler 2003). In addition to finding that birds are migrating earlier now than in the past, these analyses revealed that the migration times of short-distance migrants, such as Brown Thrashers (*Toxostoma rufum*) and Field Sparrows (*Spizella pusilla*), are much more sensitive to global warming than are those of long-distance migrants, such as Least Flycatchers (*Empidonax minimus*) and Blackpoll Warblers (*Dendroica striata*) (Fig. 3). Short-distance migrants seem to depend primarily on temperature cues to set their migration times, while long-distance migrants seem to rely on other cues, such as day length. Currently, researchers are analyzing several more collections of naturalists' observations of gardens, forest plants, and migratory birds in the northeastern U.S.

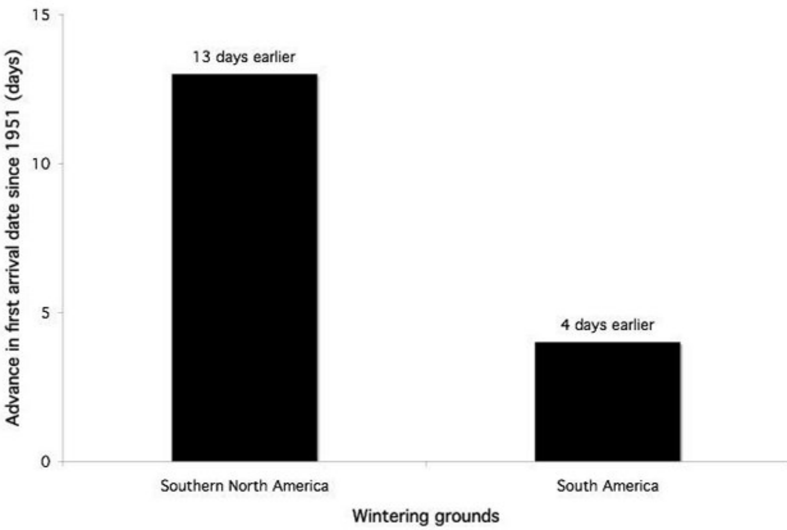

Figure 3: Difference in change in migration time between migratory bird species that over-winter in southern North America and those that over-winter in South America. Data was taken from Butler (2003).

Of course, data on bird sightings come with caveats. The main concern arises from variability in sampling effort. If sampling effort varies significantly over time, it can affect trends in the data. For example, it is easy to imagine that twenty people looking for the first Blue Jay to arrive would probably find it before one person would alone. Thus, if more and more people began looking for the first Blue Jay over successive years, we would expect the first Blue Jay to be sighted earlier and earlier, even if the first Blue Jay is actually arriving at the same time each year.

A similar phenomenon could occur if observers spend more time looking for the first Blue Jay. A person who spends twenty hours per week looking for the first Blue Jay would probably see a Blue Jay before a person who spends two hours per week. If someone spent more and more time looking for the first Blue Jay each year, we would again expect the first Blue Jay to be seen earlier over time, even if it is arriving at the same time each year. Even if sampling effort has not remained constant, if the types of fluctuations are known, researchers may be able to correct the data for sampling effort. Using such corrections, they should be able find out how much earlier or later the Blue Jay really is arriving over time. If sampling effort fluctuated a lot in ways that are not known, then the record may still provide some information, but it will be limited. Because of the impact that sampling effort has on trends present in long-term collections of observations, the best information comes from records for which the sampling effort has remained relatively constant over time. Such has been the case at Manomet Center for Conservation Sciences, where researchers have been using the same methods and sampling effort since 1970. We are currently analyzing these records to quantify the effect of changes of population sizes and sampling effort on observations.

Despite any caveats, naturalist records are gaining attention as a critical source of information on how species respond to climate change. We believe that this attention is well deserved. As scientists examine more naturalist records, we will expand the range of locations where we understand how global warming is altering biological phenomena. Probably more importantly, naturalists can help educate others about how species in their hometowns are changing as a result of global warming, with the result that more people will recognize that global warming is already having an impact on local flora and fauna. Naturalists, thus, serve a double purpose in the study of biological responses to global warming—as researchers and educators. In this dual role, we expect that naturalists will continue to contribute to our understanding of how global warming is affecting biological systems in backyards around the world.

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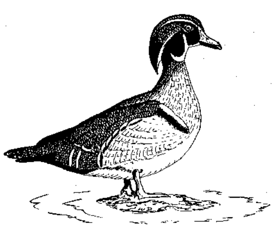
Editor's Note: *The subject of global warming has generated a number of recent sources for further reading, including the Spring 2005 issue of* Sanctuary*, the Journal of the Massachusetts Audubon Society, and a report from The Wildlife Society (Technical Review 04-2) entitled* Global Climate Change and Wildlife in North America. *This report can be obtained at:* <http://iis-db.stanford.edu/pubs/20784/climate_change_technical_review.pdf>.

Abraham J. Miller-Rushing *and* ***Richard B. Primack*** *work in Massachusetts at Boston University. They are examining the impacts of climate change on bird migration and plant flowering times. If you have long-term records of biological phenomena that you would like to contribute, please feel free to contact Dr. Primack at primack@bu.edu.*



WOOD DUCK BY WILLIAM E. DAVIS, JR.