

## EARTH OUT OF SYNC – RISING TEMPERATURES THROWING OFF SEASONAL TIMING<sup>1</sup>

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*Credit: Jack Dykinga/USDA*

A newly hatched chick waits with hungry mouth agape for a parent to deliver its first meal. A crocus peeks up through the snow. Rivers flow swiftly as ice breaks up and snows melt. Sleepy mammals emerge from hibernation, and early frog songs penetrate the night.

Spring awakening has long provided fodder for poets, artists, and almanac writers. Even for a notoriously fickle time of sunshine, rain, and temperature swings, some old-fashioned seasonal wisdom was consistent enough to be passed down through generations. The first blooming of a specific flower, for example, could traditionally signal when to find certain fish running the rivers, when to hunt for mushrooms, or when to plant crops. The timing of such seasonal events is coordinated in an intricate dance—a dance underappreciated, perhaps, until something jolts it out of step.

With global average temperatures up 0.5 degrees Celsius since the 1970s, springtime warming is coming earlier across the earth's temperate regions. A number of organisms have responded to the warming temperatures by altering the timing of key life-cycle events. The problem, however, is that not all species are adjusting at the same rate or in the same direction, thus disrupting the dance that connects predator and prey, butterfly and blossom, fish and phytoplankton, and the entire web of life.

The timing of seasonal biological events, otherwise known as phenology, has been tracked in some places for centuries. Japan's much-feted cherry tree blossoming has been carefully recorded since before 1400. The trees showed no clear trend in timing until the early 20th century, when they began to bloom earlier, with a marked advancement since around 1950.

The meticulous records of Henry David Thoreau help us gauge how spring has changed in Concord, Massachusetts, since the mid-1800s. Comparing his notes on over 500 species and subspecies of plants with modern surveys and records in between, researchers found that springtime blooming advanced by an average of one week over the past 150 years as local springtime temperatures rose.

The plant varieties that advanced their timing appear to have thrived over the years, while others declined in numbers. The varieties left behind include asters, mints, orchids, lilies, and violets. Some native plants advanced their blossoming dramatically: the highbush blueberry by three weeks and the yellow wood sorrel herb by a month. Yet these native plants may be the exception rather than the rule; on average, non-native invasive plants advanced their bloom by 11 days more than natives. With exotic invasives appearing to adapt more quickly to warming temperatures, the concern is that they could outcompete some native plants, leading to their

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disappearance.

Earlier springs and later autumns mean longer growing seasons—as long as plants do not succumb to a surprise late cold snap or wilt in the peak summer heat. In Germany, apricot and peach trees now bloom more than half a month earlier than in 1961. Apple trees in the northeastern United States moved up flowering by eight days between 1965 and 2001; apple trees require chilling time before they flower, and warmer winters have been tied to smaller harvests. Earlier spring blooming has lengthened pollen seasons in some places by weeks. Allergy sufferers beware: this trend is likely to get worse as the planet gets warmer.

A longer growing season could benefit some crops like the sugar beet. For other foods, however, including important cereals like rye, the increased early-season temperatures could hurt yields by pushing plants to devote more energy to vegetative growth than to the seed that we eat. The premature warming also elevates the risk of damage from late frosts. In 2007, for example, a warm March in prime U.S. agricultural regions pushed spring into gear early, only to be followed by unusual cold in April. The damage to the nascent crops exceeded \$2 billion.

Exactly how these changing plant communities will interact with pollinators and foragers that may or may not be changing at the same pace remains unanswered. Members of the animal kingdom are responding to warming in different ways. A quintessential early bird, the American robin, now sometimes makes an even earlier springtime debut. In the Colorado Rocky Mountains, where robin migration is not just south-to-north but also up to higher elevations, the birds have responded to warming in their wintering grounds by traveling to their high-altitude summer breeding grounds two weeks earlier in 2009 compared to the early 1980s. In some years the robins arrive long before the snow has melted—making it far more difficult for this early bird to catch the worm.



*Credit: James Leupold/USFWS*

For pied flycatchers that breed in the Netherlands, migration timing from their West African wintering grounds has not changed, but earlier spring warming has caused the birds to breed about as soon after their arrival as possible. Unfortunately, their caterpillar food has been able to respond even more strongly, advancing hatching in one woodland by an average of 15 days over two decades, while the birds only advanced by 10 days. At sites where the caterpillar populations still peak somewhat late, flycatcher populations have dropped by 10 percent, but where the caterpillars have advanced hatching the most, flycatcher populations have plummeted about 90 percent.

Across Europe as a whole, populations of birds that did not advance their migration time along with earlier spring warming have shrunk since 1990. Short-distance migrants seem to be faring better than those traveling long ways. Milder winters have even prompted growing numbers of some birds, like the Pacific brant and Canada goose, to skip migration altogether. Like the early crops, however, the birds that stay are in danger of being wiped out by a sudden cold spell.

As evidenced by the caterpillars in the Netherlands, short-lived insects have some of the fastest life-cycle responses to global warming. In Central Europe, where almost every summer since 1980 has been hotter than the long-term average, warming has allowed some species of butterflies and moths to become active earlier and actually add an extra generation in the year—

something not seen among those species in records dating back to the 1850s. If predation does not increase, a population explosion could overstress the plants that the butterfly and moth caterpillars eat.



*Credit: Ryan Hagerty/USFWS*

High-altitude mountain pine beetles in western North America present a similar case. In warmer weather they can complete their life cycles in one year instead of two. Insects that once were active for just two weeks a year now can be found flying for up to six months, leaving devastated forests in their wake. Earlier springs and milder winters are also linked to an increased incidence of tick-borne encephalitis and other diseases spread by insects that do well in the warmer conditions.

In addition to or instead of adjusting life-cycle timing, some organisms have responded to warming temperatures by shifting their geographical ranges, often poleward or upward. Bird and butterfly range shifts averaging 6 kilometers per decade have already been observed, with some species moving quite faster. There are, of course, limitations to all these adaptations. Even more-mobile species can gain only so much altitude before running out of mountain or can travel only so far before becoming blocked by pervasive human development.

Some wildlife take their timing cues from environmental factors other than temperature. The snowshoe hare, for instance, appears to rely on changes in day length to signal when to transform its coat color from winter white to summer brown. While day-length patterns are the same from year to year, snow in the hare's Montana wilderness habitat now melts up to a month early. If hares are not able to speed up their coat change, they will be in trouble: a stark white hare on bare ground is a remarkably easy target. And as go the hares, so go the lynxes that feed almost exclusively on them.

Tinkering with an incredibly complex and interconnected system is fraught with risk. These mismatches are just some examples of how a hotter world is a world unlike any we have known. It is still too early in this global experiment to tell which creatures will be the climate winners and losers, but the signs indicate that the losers will be the majority. Turning down the global thermostat by cutting greenhouse gas emissions is the only way to avoid the risk of throwing nature further out of sync.

<b>Phenology Trends Observed in Selected Species</b>			
<b>Location</b>	<b>Period</b>	<b>Indicator</b>	<b>Observed Change</b>
<b>MAMMALS</b>			
Arctic regions	1993-2006	Caribou and wild reindeer ( <i>Rangifer tarandus</i> ) calving; plant growing season	Caribou spring migration is cued by day length, and typically matches up with the emergence of nutritious plants important for birthing and nursing mothers; however, with warming of 4.6 degrees Celsius, the growing season in Greenland has advanced in recent years by 2 weeks while caribou births have not changed timing. The mismatch of peak nutritious food and calving has been associated with declining offspring production and early deaths of calves.
Scotland - Outer Hebrides Islands	1986-2006	Soay sheep body size; plant growing season	Milder winters and longer growing seasons have made it possible for smaller sheep, which would otherwise succumb to harsher conditions, to survive, decreasing average body size in the overall population by about 5 percent over the two decades.
Canada - Yukon	1989-1998	North American red squirrel ( <i>Tamiasciurus hudsonicus</i> ) births; white spruce ( <i>Picea glauca</i> ) cone abundance	As average spring temperature increased by 2 degrees Celsius and precipitation decreased since 1975, red squirrels have advanced the date they gave birth by an average of 18 days, a change of 6 days per generation. Their primary food source, white spruce cones, has become more abundant over the same period. Early breeders had increased fitness, suspected to be related to higher food availability.
United States - Colorado Rocky Mountains	1975-2009	Yellow-bellied marmot ( <i>Marmota flaviventris</i> ) emergence from hibernation	As temperature has risen, marmots have moved their emergence from hibernation up by more than a month. In years when snowmelt comes later, there is a long lag time before the marmots can easily access food, which compromises litter size and frequency of reproduction.
<b>BIRDS</b>			
Europe	1947-2007	Migration synchrony of cuckoo birds ( <i>Cuculus canorus</i> ) and other migrants	The cuckoo bird is a parasite that lays its egg in other birds' nests; when the cuckoo chick hatches, it pushes the host bird's eggs out of the nest. Cuckoos now arrive at their European breeding grounds 5 days earlier than they did 40 years ago, close to the average advancement for other migrants flying in from sub-Saharan Africa. However, shorter distance migrants arrive more than 14 days earlier, making it easier for them to escape cuckoo bird parasitism while the pressure mounts on the long-distance flyers.
Denmark	1971-2005	Barn swallow ( <i>Hirundo rustica</i> ) breeding	With mean April temperature up 2.2 degrees Celsius, barn swallows have been able to lay their first group of eggs earlier, giving them a longer interval before their second laying of the season. Longer intervals between layings were associated with increased reproductive success.

Netherlands	1985-2005 (caterpillars and birds), 1988-2005 (trees)	Spring timing across 4 levels in a food chain: oaks, caterpillars, small passerine birds (tits and pied flycatchers), and predatory raptors (sparrowhawks)	Oak tree budburst hardly advanced, but the caterpillars that eat the emergent leaves are hatching two weeks earlier. The small birds (tits and flycatchers) that eat the caterpillars also advanced their hatching, but only about half as much. For flycatchers, this mismatch has been associated with population declines. At the top of the food chain, sparrowhawks that prey on the small bird fledglings did not hatch any earlier, though they are the least timing-dependent species in the food chain because they have a diverse diet.
Northern Canada - Hudson Bay	1988-2007	Egg-laying date for Arctic seabird, Thick-billed Murres ( <i>Uria lomvia</i> )	Sea ice break up advanced by 17 days, as did the peak bird population, indicative of peak food supplies. Yet median egg-laying date only advanced by 5 days, creating a gap between when eggs hatch and when the maximum number of adult birds are present. This gap is correlated with a reduction in nestling growth.
<b>MARINE</b>			
North Sea	1958-2002	Phenological changes at different trophic levels in marine pelagic communities	Timing of blooms and peak abundance at various levels of the food chain have shifted at different rates with warming. These timing mismatches among plankton, diatoms, and fish larvae are an additional source of pressure on cod fish populations declining from overfishing.
<b>AMPHIBIANS</b>			
United Kingdom - England	1978-2006	Common frog ( <i>Rana temporaria</i> ) and water frog ( <i>Rana lessonae/esculenta</i> ) spawning; newt ( <i>Triturus</i> spp.) arrival	Common frogs exhibited no change in breeding timing over the thirty years, while water frogs advanced by nearly 3 weeks between 1978-1990 and 1991-2006. Newts advanced their arrival time to the studied ponds by a month or more. Newts will eat frog eggs, but not enough data is available to tell if the timing changes affected predation.
North America - United States and Canada	early 1980s-late 1990s	Spawning of western toads ( <i>Bufo boreas</i> ), Cascades frogs ( <i>Rana cascadae</i> ), spring peepers ( <i>Pseudacris crucifer</i> ), and Fowler's toad ( <i>Bufo fowleri</i> )	Western toads at one Oregon site bred earlier, though not significantly; at the other sites they did not. None of the other three species of frogs and toads exhibited a significant trend toward earlier breeding. If the amphibians rely on insects that have adjusted timing with warming, there could be a potential mismatch.
<b>INSECTS</b>			
Japan - Nagano	1953-2002	Flowering of four cherry and apricot tree species ( <i>Prunus</i> spp.) and appearance of butterfly ( <i>Pieris rapae</i> )	Flowering advanced over the last three decades while butterfly appearance was delayed. Temperature increases varied at different times of the year: during the time when plants got their flowering cues, temperatures increased sharply, whereas when the butterflies were cued, temperatures did not change significantly. This could portend a possible disruption in pollination.

Finland	1993-2002	Parasitoid wasp ( <i>Cotesia melitaeorum</i> ) and butterfly host ( <i>Melitaea cinxia</i> ) timing	Warmer temperatures in springtime led to earlier emergence of adult parasitoid wasps, putting them more in synch with their host butterfly, allowing for higher rates of parasitic colonization. Because most butterfly males pupate earlier than the females, a change in timing of the parasitoid could influence butterfly sex ratios.
<b>PLANTS</b>			
Germany	1961-2005	Fruit tree blossoming	Fruit trees advanced their blossoming by the following number of days: apricot - 17.2, peach - 15.7, plum - 14.1, pear - 13.7, apple - 12.5, sweet cherry - 9.6, sour cherry - 9.6. Earlier flowering puts trees at higher risk of damage from late frosts.
Italy - Western Liguria	1981-2007	Pollen season	With warming temperatures, pollen season for common allergenic plants has started significantly earlier: by 83 days for Parietaria plants, 46 for olive, 27 for birch, 26 for grass, and 9 for cypress. Total pollen counts increased for all but grass. At the same time the share of people sensitized (often correlated with allergy symptoms) to all pollen types except for grass also increased, while sensitization to dust mites did not change.
United States - Washington, DC metro area	1970-1999	Flowering dates of 100 plant species	In 89 of 100 species, average blossoming advanced by 4.5 days. Significant correlations were found between earlier blooming and changes in temperature, with nighttime temperatures increasing by 0.2-1.2 degrees Celsius. Only 11 species were flowering later. Plants advancing included false strawberry weed (unpopular with gardeners) by 46 days, and cherry trees (popular with tourists attending the annual festival) by 6-7 days.
United States - New England	1963-2003	Maple syrup season	Syruping season has shifted to start 8 days earlier and end 11 days earlier, resulting in shortening by 10 percent. Cold temperatures allow sap to form and warm temperatures allow it to flow; when nights warm earlier, trees begin to bud and sap is no longer usable for syrup.
<b>Source:</b> compiled by Janet Larsen, <b>Earth Policy Institute</b> , March 2010.			