# The Effect of Global Warming on Animals & Plants

## Terry L. Root

Senior Fellow—University Faculty
Stanford University

Over the last 100 years, the average global surface temperature has warmed approximately 0.7$^{o}$C (1.4$^{o}$F) and is projected to rise at an increasing rate over the next century. This rate of warming is significantly larger than the rate of sustained global warming over the 6,000 years or so that it took for the globe to warm about 6$^{o}$C from the last ice age to our current warm interglacial period. That temperature transition, which occurred about 12,000 to 18,000 years ago, represented a warming rate of about 1$^{o}$C (1.8$^{o}$F) per thousand years. Extrapolating out the more recent warming trend to a comparable 1000 years, we see that a 7$^{o}$C/1000 years raise in temperature is some 7 times faster than in the last 18,000 years. As the planet continues to warm, the rate will continue to escalate.

A primary concern about wild species and their ecosystems is currently they are not only having to adapt to warm temperatures, but they are also having to cope with the most rapid rate of temperature increase in the last 18,000 years. Additionally, in the pre-historic past, plants and animals were not under stressed due to other human-caused problems: pollution, land-use change, invasive species, and others. Today the synergistic effects of these stresses combined with rapid warming are greatly influencing the resilience (ability to return to the same condition after a stress) of many species, communities and ecosystems. What is concerning is that very noticeable changes have been measured in species over the last 30 to 40 years during which the global temperature increased around 0.5$^{o}$C. Yet, the Summary for Policy Makers of Working Group I of the Fourth Assessment Report of the IPCC explained that the global temperature could rise as much as 6.4$^{o}$C and even beyond if we stay on the energy path we are currently traveling. It is highly likely that all but a few species and ecosystems will be able to adapt to that amount of temperature change.

By 2100 the resilience of many ecosystems is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., wildfire, insects), and other changes happening globally, such as land-use change, over exploitation of resources, invasive species, pollution (high confidence). Key ecosystem properties, (e.g. biodiversity), or regulating services, (e.g. carbon sequestration), are very likely to become impaired. When ecosystem resilience is exceeded, the response will very likely be characterized by threshold-type responses, some irreversible on time-scales relevant to human society (e.g., such as disruption of species' ecological interactions and major changes in ecosystem structure and disturbance regimes—especially wildfire and insects), and the loss of biodiversity through extinction being irreversible on any time scale.

With rapid warming, ecosystems and species are very likely to show a wide range of vulnerabilities that depend on imminence of exposure to ecosystem-specific, critical thresholds (very high confidence). The most vulnerable ecosystems include coral reefs, the sea ice biome and other high latitude ecosystems (e.g. boreal forests), mountain ecosystems and Mediterranean-climate ecosystems (high confidence). The least vulnerable ecosystems include savannas and species–poor deserts, but this assessment is especially subject to uncertainty relating to the CO2 fertilization effect and disturbance regimes such as fire (low confidence).

Since the Third Assessment Report we have many more studies analyzing the changes in the flora and fauna over longer time series. A notable number of wild animals and plants on all continents are already exhibiting discernible changes in response to regional climatic changes. This is as we expected, because temperature is central to the lives of all living organisms. Many plants and animals have and will probably continue to adjust in several ways, including: 1) shifts in the densities of populations of species either by extending their range boundaries both toward the poles (e.g., North in the US) and up in elevation, or populations numbers shifting from one portion of their range to another (e.g., the center of the abundance pattern moving up in elevation), 2), shifting in the timing (i.e., phenology) of various events occurring in spring, which is quit common, or autumn, which is less common, 3) changes in the genetic, behavioral, morphometrics (e.g., body size or egg size), or other biological parameters, and 4) local extinction or global extinction, the latter of which is irreversible at any time scale.

## **Changes In Ranges And Shifting Densities**

As the globe warms we find that species in North America are extending their ranges north and up in elevation, because habitats in these areas have now warmed sufficiently to allow colonization. The movements (dispersal) of species forced by rapidly rising temperatures, however, are frequently slowed and often blocked by numerous other human-made stresses, such as land-use changes, invasive species and pollution. Consequently, individuals that are moving north or up in elevation have to navigate around, over or across freeways, agricultural areas, industrial parks, and cities.

Species near the poleward side of continents (e. g., South Africa’s fynbos) will have no habitats into which they can disperse as their habitat warms. The same is true for species living near the tops of mountains. Additionally, species living in these areas will be further stressed by species from farther inland or farther down the mountain moving into their habitats. Because of the heat stress and the new species with which they must interact, many species currently on islands, on the poleward side of continents and near the tops of mountains could go extinct unless humans move them to another location and make sure they survive there.

The need for species to track certain temperatures could cause wildlife managers to face a number of novel challenges over the next several decades. To date, preservation practices are generally ill prepared to deal with the challenges of rapid climate change and effective adaptation responses are likely to be costly to implement. For example, at least some managed species or species of concern will need to move as the globe warms. This could easily mean that many species currently protected in wildlife refuges or national parks could easily need to disperse to new habitats on less protected lands. These new habitats occupied by these previously managed species and species of concern may not be conducive to protecting species. This is certainly a very likely problem that needs some advance thought and planning.

Throughout pre-historic and more recent times, species have been found to move independently from other species in their community or ecosystem; species move at different rates and directions, depending on their unique metabolic, physiological and other requirements. This independent movement, will probably become increasingly evident the higher the temperature becomes. Such differential movement could result in a disruption of the connectedness among many species in current communities. This could cause a tearing apart of communities, which could disrupt biotic interactions such as predator-prey relationships. For example, if the range of a predator shifts and the range of its prey does not, a population balance becomes disrupted—a perceived benefit if the prey is an endangered species. If, however, the prey is a food-crop pest, then humans could certainly see the increase in its population as detrimental.

Disruption of biotic interactions could jeopardize the sustainability of ecosystem services on which we rely and could also lead to numerous extinctions. Substantial changes in the structure and functioning of terrestrial and marine ecosystems are very likely to occur with warming of 2 to 3°C above pre-industrial levels and associated increased atmospheric CO2 (high confidence). Major biome changes, such as emergence of novel biomes, and changes in species' ecological interactions, with predominantly negative consequences for goods and services, are very likely by, and virtually certain beyond those temperature increases.

Progressive acidification of oceans due to increasing atmospheric carbon dioxide is expected to have negative impacts on marine shell-forming organisms (e.g., corals) and their dependent species. Indeed, by 2100 ocean pH is very likely to be lower than during the last 20 million years.

## Changes in Timing

Another change that has been already seen occurring in species on every continent is shifting in the timing (i.e., phenology) of various events primarily occurring in spring but also to some extent in the autumn, such as frogs breeding earlier, cherry blossoms blooming earlier and leaves turning color later. Over the last 30 years, around 115 species (plants and animals together) from locations around the globe were found to be changing the timing of a spring event earlier by around 5 days per decade. Only 6 out of the 115 species (~5%) showed a later change in timing of their spring events (Fig 1).

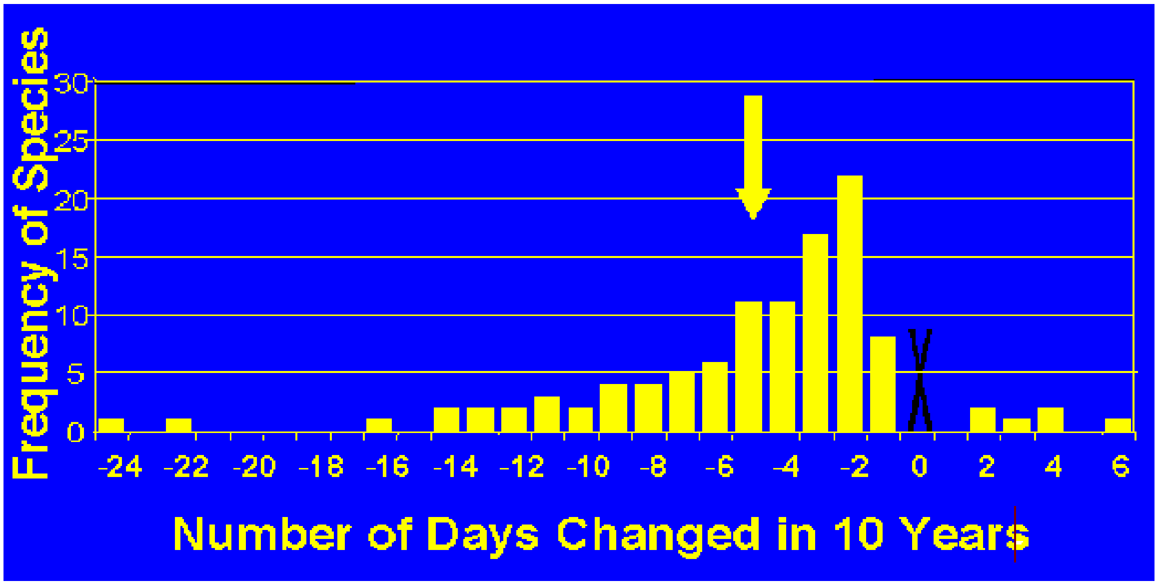

Figure 1 The number of species (both plants and animals) from around the globe with a spring trait changing by number of days per decade. Positive numbers mean the trait is happening later over the years, while negative numbers are for traits happening earlier. The “X” indicates species showing no change were not considered. The average number of days changed per decade is 5.1 (the arrow).

Rapid phenological changes of species could be problematic. For example, farmers may need to respond to warming by changing the timing of their planting and even the type of crop grown. Either of these changes could allow an insect, which was previously limited by the availability of food, the ability to grow in population size. If the insect feeds on the nectar from the flowers of the crop, then the farmer could benefit from the crops being pollinated. If, however, the insect feeds on the tissue of the crop plant, then the larger insect population could be a detriment.

## Changes in Genetics, Behavior, and Other Traits

Studies investigating how rapidly warming temperatures are affecting genetics, behavior and other species’ traits are relatively uncommon thus far, but the findings are significant. For example, a behavioral change associated with global warming is the foraging habits of polar bears. As the globe has warmed, these bears are increasingly foraging by necessity in garbage dumps. Bears normally hunt seals, but capturing seals requires bears to be standing on sea ice. With global warming the ice is thinning and melting earlier in the spring and freezing later in the fall. Both the type of food and quantity are no longer sufficient to sustain the previous number of bears. Hence, the population size of these bears has dropped. Additionally, other animals that depend on the polar bear as a keystone species (e.g., arctic fox and ivory gull) may also be in significant trouble as the bears catch fewer seals, leaving fewer carcasses on the ice for these other scavengers.

Another example is a North American mosquito. When the days become a certain length, it goes into dormancy. But what determines the length of the day that triggers the dormancy is genetically controlled. With global warming the habitats where this mosquito is found are staying warmer longer in the fall, which means shorter day are warmer. Now the genetic control of the day-length trigger has changed to a shorter day length.

## Extirpation and Extinction

The escalating rise in average global temperatures over the past century has put numerous species in danger of extinction. "Functionally extinct" species, or species we can anticipate to be very highly likely to go extinct, include those that cannot move to a different location as the temperature increases due to either lack of available habitat or the inability to access it. Without human assistance the probability of extinction is quite high. For example, pikas are currently living in the Rocky Mountains where the ambient temperature is quite close to the maximum this small mammal can endure. Moving up in elevation to cooler regions is not possible because the stony habitat needed by pikas is generally not available higher up on mountains. Another example is a subspecies of a checkerspot butterfly in Baja California. It will probably go extinct in the near future because it too has a low tolerance to hot temperatures, but cannot shift in to cooler regions because Tijuana and San Diego are blocking its way.

Money, land, personnel, or political will are not available for such endeavors to occur, and also absent is the long-term commitment to translocate even half of the functionally extinct species we know of today. Consequently, many scientists predict that we are standing at the brink of a mass extinction that would be caused by one very careless species.

Roughly 20-30% (varying among regional biotas from 1% to 80%) of species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction if global mean temperatures exceed 2-3°C above pre-industrial temperatures (1.3-2.3$^{o}$ C above current) (medium confidence). For example, with warming of 2.8°C above pre-industrial, sea ice declines according to some projections causing polar bears to face a high risk of extinction in the wild, which could increase the risk extinction of species relying on polar bears (e.g., Ross gull eating seal-kill leftovers). Other ice-dependent species, not only in the Arctic but also in the Antarctic, are facing similar situations. Given that there are around 1.7 million identified species on the globe, somewhere between 340,000 and 570,000 species could go extinct primarily due to our negligence. Extinctions are virtually certain to reduce societal options for adaptation responses.

## Future Projection for Wild Plants and Animals

A primary adaptation strategy to climate change and even current climate variability available to managers is to reduce and manage other stresses on species and ecosystems, such as habitat fragmentation and destruction, overexploitation, eutrophication, desertification and acidification. Significant disturbances to wild habitats, including extractive use and fragmentation, are very likely to impair species' adaptation.

Given our observations of what has happened to species under different external pressures, whether they are natural or human caused, we are able to predict what might happen to species under a variety of changes. Indeed, predicting the ecological consequences of species based on pressures that actually happened may validate these forecasts. Reliable forecasting of responses of species can be invaluable to managers and policy makers, because it could help prevent negative surprises in one of two main ways. The first is by indicating which change is most likely to occur, thereby indicating what management practice(s) are needed to help avert negative surprises. The second is for those changes that cannot be managed effectively be well understood, making us better prepared for the incipient changes.

## The Cause of the Rapid Warming

Species can be used to help understand what may be causing the climate to change so dramatically. Many studies have been done showing that several species are shifting the timing of various spring events. These trends have been associated with the trend in observed temperatures around the location where the species were studied. These two trends can be correlated with each other to quantify the strength of the relationship.

To determine if humans are having a measurable influence in the increasing temperatures, models need to be used. For the same locations and the same time periods that the species data were collected, temperatures were modeled (using HADGM3) in three different ways. First, only natural factors that cause the climate to change (e.g., sunspots, volcanic eruptions) are included in the model. Second only human factors that influence the climate are included (e.g., greenhouse gases, particulates). Finally, the model is run with both of these types of factors combined. These three different types of modeled temperatures are determined for all the species recorded at various locations around the northern hemisphere (southern hemisphere studies of species trends are rare) for the same years of each of the particular studies.

The trends for each species at each location are compared separately to the trends of the observed temperatures, the trends of modeled temperatures with only natural forcings, the trends of modeled temperatures with only human forcings, and the trends of modeled temperatures with the combined forcings. With each comparison a correlation coefficient may be calculated. There are ~145 correlation coefficients derived for the species data compared to each of the three modeled temperatures. Only ~86 correlation coefficients were calculated for the observed temperatures and species trends (observed temperature data were only available for 86 species). The number of similar correlation coefficients is counted and the counts plotted.

Figure 2 shows the plots of these sums. The purpose is to compare the associations of the different modeled data with that of the observed data. Consequently, the plot or histogram of the observed data is plotted in all three panels. The top panel shows the comparison between the observed histogram and the natural-forced histogram. The agreement is not very good. The next panel shows the comparison between the observed histogram and the human-forced histogram. The agreement is better. The bottom panel shows the comparison between the observed histogram and the combined histogram. The agreement is quite good and statistical analyses show that the last agreement is statistically significant. Certainly a study such as this one needs to be done using more than one model, but certainly these results suggest that species are changing in response to regional temperature changes, and the regional temperature changes are being measurably influenced by human forcings (e.g., greenhouse gases). This indicates that humans, directly through emission of greenhouse gases into the atmosphere, are causing significant ecological consequences that could be detrimental in the future, not only to other species but also to us.

Figure 2. Plotted are the frequencies of the correlation coefficients between the timing of changes in traits (e.g., earlier egg-laying) of 145 species and modeled (HADCM3) spring temperatures for the grid-boxes in which each species was examined. At each location, all of which are in the Northern Hemisphere, the changing species' trait is compared with modeled temperatures driven by: (a) Natural forcings (maroon bars), (b) anthropogenic (i.e., human) forcings (orange bars), and (c) combined natural and anthropogenic forcings (yellow bars). In addition, on each panel the frequencies of the correlation coefficients between the actual temperatures recorded during each study and changes in the traits of 83 species, the only ones of the 145 with reported local-temperature trends, are shown (blue bars). On average the number of years species were examined is about 28 with average starting and endings years of 1960 to 1998. Note that the correspondence: a) between the natural and actual plots is weaker ($K=60.16$; $p>0.05$) than b) between the anthropogenic and actual ($K=35.15$; $p>0.05$), which in turn is weaker than c) the agreement between combined and actual ($K=3.65$; $p<0.01$). Taken together, these plots show that a measurable portion of the

warming regional temperatures to which species are reacting can be attributed to humans, therefore showing joint attribution (After Root et al. 2005).