Global Atmospheric Change and Animal Populations

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Greenhouse gases are increasing at an unprecedented rate, due to natural sources and anthropogenic activities. Will these atmospheric contaminants endanger animal populations?

Evidence of climate change is all around us. From melting polar ice caps to home-range shifts of numerous plants and animals, the world is being altered at an alarming pace. The key factor believed to underlie climate change is increased temperature, resulting from increased levels of greenhouse gases in the atmosphere (i.e., the "greenhouse effect"; IPCC 2007; Figure 1). The greenhouse effect is a natural phenomenon permitting life to exist on our planet, however, increased levels of greenhouse gases intensify this effect resulting in increased global temperature. Over the past century, global temperature increased approximately 0.75ºC. At the current rate, global temperature may increase by 1.8–4.0ºC by the end of this century (IPCC 2007).

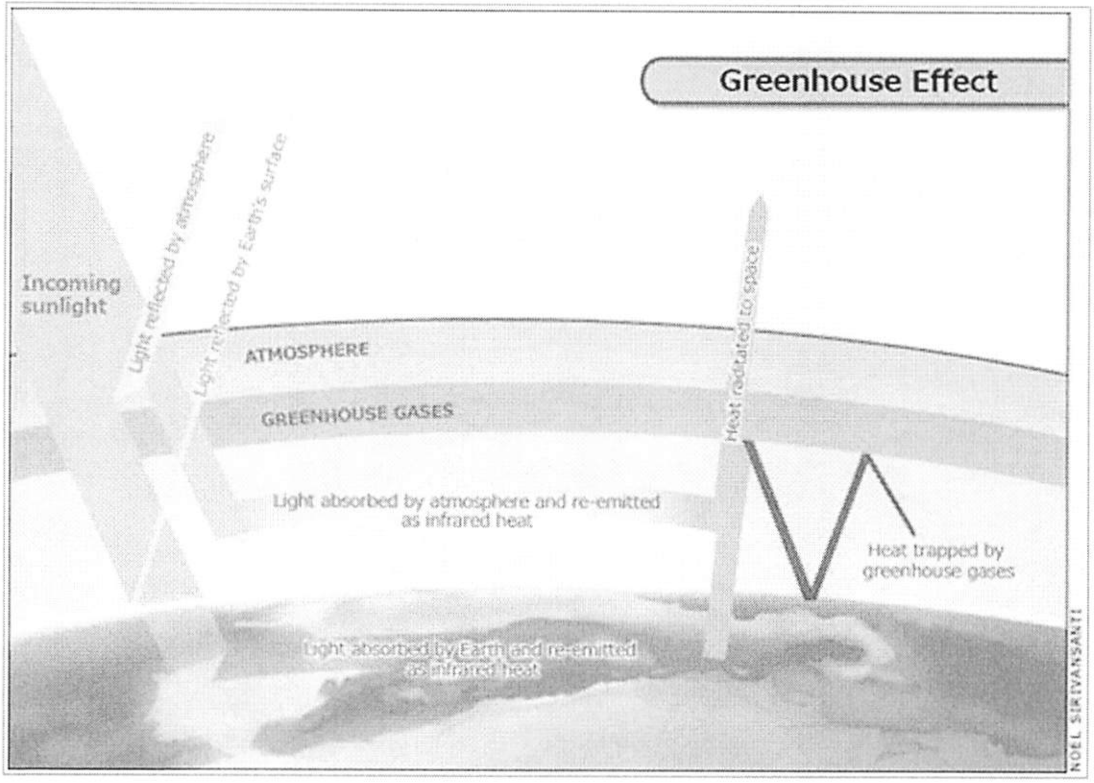

Figure 1: The "greenhouse" effect

When radiative energy becomes absorbed by atmospheric gases rather than leaving the Earthâ€™s atmosphere, this energy is re-radiated in all directions, including back to Earth, causing temperatures to increase.

Greenhouse gases are naturally produced (Withgott & Brennan 2009; Bloom 2010). For example, volcanic activity generates large amounts of carbon dioxide (CO_2). Limestone (calcium carbonate, $CaCO_3$) and other sedimentary rocks store enormous amounts of carbon. When these rocks are broken down, such as by adverse weather conditions, CO_2 is released into the atmosphere. Fires, which are increasing in frequency, also produce large amounts of greenhouse gases (e.g., CO_2; methane, CH_4).

Anthropogenic activities are also considerably increasing the levels of atmospheric contaminants. In the mid 1800s, with the advent of the industrial revolution, greenhouse gas levels started to increase dramatically (Withgott & Brennan, 2009; Figure 2). Burning of fossil fuels, such as coal, gasoline, and oil, produces both primary pollutants (those directly produced from fossil fuel combustion; e.g., nitrogen dioxide, NO_2; carbon monoxide, CO; carbon dioxide, CO_2) and secondary pollutants (compounds produced from fossil fuel combustion that undergo secondary chemical reactions to form pollutants; e.g., ozone, O_3) (Withgott & Brennan 2009; Bloom 2010). Primary and secondary atmospheric pollutants are compounds that contribute to global climate change.

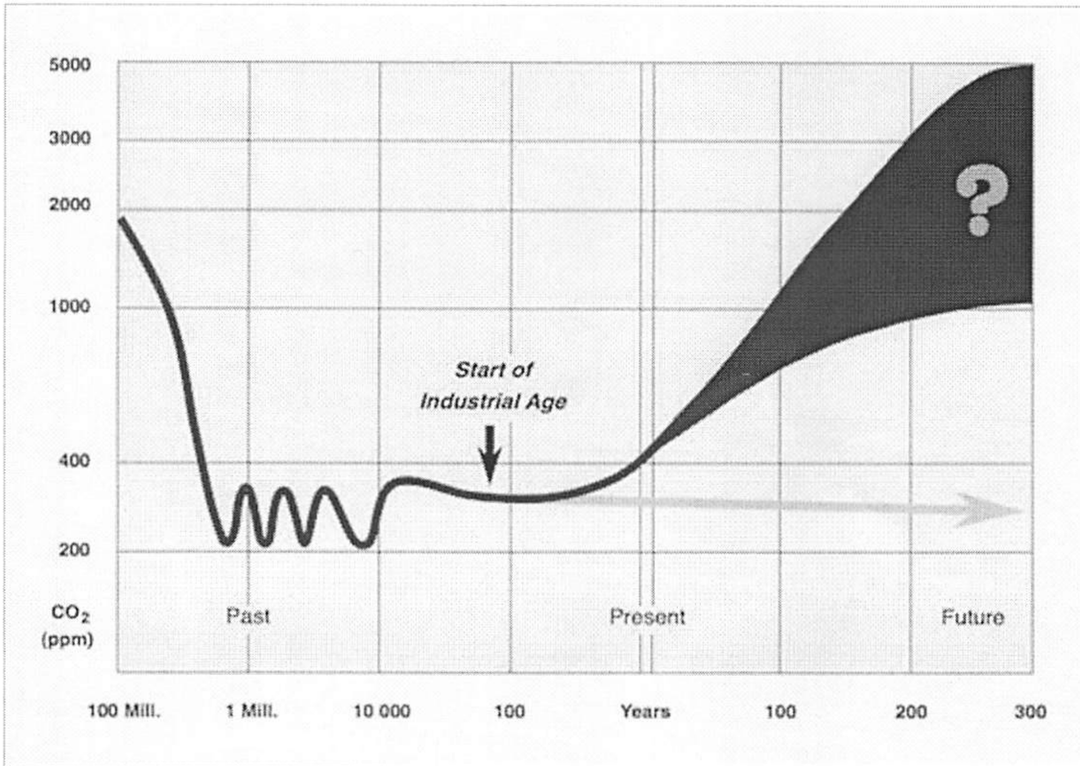

Figure 2: Carbon dioxide levels through geologic time

A cyclical phenomenon w ithin a narrow range over the past million years, CO2 level has increased unabated since the beginning of the industrial age. (Courtesy of Hannes Grobe)

Key Greenhouse Gasses

Carbon Dioxide (CO_2)

A direct result of fossil fuel combustion, CO_2 is arguably the most important greenhouse gas, on the basis of both the amounts produced and its effects on the climate (Bloom 2010). The majority of CO_2 produced by human activities stays in the atmosphere, while some also enters aquatic ecosystems. Carbon dioxide levels are approximately 380 ppm (parts per million), but are expected to reach 535–983 ppm by 2100 (IPCC 2007). (Approximate contribution to global warming: 33%; Hansen & Sato 2001).

Methane (CH_4)

Under oxygen-poor (anaerobic) conditions, microorganisms frequently produce CH_4. Methane is also produced by: the imperfect combustion of wood products (clearing land for agriculture), animals (digestive by-products of cattle, goats, sheep), and natural gas operations (natural gas is primarily CH_4) (Bloom 2010). Methane levels are approximately 1.8 ppm, but future levels are predicted to be from 1.46–3.39 ppm by 2100 (IPCC 2007). (Approximate contribution to global warming: 15%; Hansen & Sato 2001).

Ozone (O_3)

Tropospheric ozone, as opposed to stratospheric ozone (i.e., the “ozone layer”), is a secondary pollutant. One of the main components of photochemical smog, it is generated through complex chemical reactions that involve sunlight, nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) (Bloom 2010). All of these compounds are produced through by fossil fuel combustion. Tropospheric ozone levels may increase by 40–60% by 2100 (IPCC, 2007). (Approximate contribution to global warming: 13%; Hansen & Sato 2001).

Chlorofluorocarbons (CFCs)

Molecules of carbon atoms bound to chlorine and fluorine atoms. These compounds are used in diverse ways such as refrigerants, spray can propellants, cleaners, and in the production of Styrofoam (Bloom 2010). These compounds break down the ozone layer; chlorine atoms can break down multiple ozone molecules (Withgott & Brennan 2009). While tremendous progress has been made to reduce the production of these compounds, they have a lifespan in the atmosphere of 20–100 years, and the potential to increase global warming 1000-times more than a similar mass of CO_2 molecules (IPCC 2007; Bloom 2010). (Approximate contribution to global warming: 7%; Hansen & Sato, 2001).

Nitrous Oxide (N_2O)

Most nitrous oxide is produced by microorganisms undergoing anaerobic respiration (denitrification). Large fertilizer additions, a common agricultural practice, increase these emissions (Bloom, 2010). Nitrous oxide levels are approximately 0.32 ppm, but future levels are predicted to be 0.36–0.46 ppm by 2100 (IPCC 2007). (Approximate contribution to global warming: 6%; Hoffman *et al.* 2006).

Effects of Greenhouse Gases Are Not Just from Global Warming

Greenhouse gases can influence animal populations through mechanisms other than global warming. These gases can enter terrestrial and aquatic food webs, and alter ecosystem functioning. Atmospheric contaminants commonly do this in two ways: 1. bottom-up and 2. top-down pathways (Percy *et al.* 2002). In bottom-up effects, these contaminants directly alter plant anatomy and physiology, and hence indirectly change the behavior and life history patterns of animals that rely on these plants for food or shelter. In contrast, in top-down effects, greenhouse gases influence natural enemy (i.e., parasitoid or predator) behavior or life history patterns, resulting in altered population dynamics for their prey. Two greenhouse gases believed to most strongly influence animal population dynamics are carbon dioxide and tropospheric ozone.

As plants are primary producers, and CO_2 is converted into sugars through photosynthesis, CO_2 is essential for plant growth. It would seem intuitive, then, that increased CO_2 levels would benefit both the plants and the animals that utilize them. But how do animals respond to plants grown under increased CO_2 levels? In general, increased CO_2 levels decrease leaf nitrogen levels, a vital nutrient for herbivorous animals (Ehleringer *et al.* 2005). Similarly, plants frequently increase the production of secondary compounds (antifeedants, toxins) under elevated CO_2 atmospheres (Ehleringer *et al.* 2005). As a result, herbivores may increase feeding rates on enriched plants to compensate for decreased nitrogen availability, but still exhibit decreased growth rates and higher mortality (Percy *et al.* 2002).

In comparison, the effects of tropospheric O_3 may be even more detrimental to ecosystem functioning. Ozone, a highly unstable greenhouse gas, damages organisms at the cellular level (Menzel 1984). When ozone breaks down, free radicals are produced; free radicals directly damage both lipids and proteins (Halliwell & Gutteridge 1999). In plants, O_3 directly interferes with photosynthesis; plants become weakened and susceptible to herbivory, plant pathogens, and diseases. It is not yet possible to generalize how animal populations will be influenced by elevated tropospheric O_3 levels; both positive and negative effects have been reported (Percy *et al.* 2002).

Scientists have contemplated the long-term effects of increased atmospheric pollutants on animal populations. It is believed that atmospheric contaminants will alter animal populations by: 1. increasing extinction rates, and/or 2. reducing genetic diversity (Mondor *et al.* 2005). As organisms are faced with challenges at an unprecedented scale and rate, species extinctions may increase and become widespread as these organisms are unable to cope with these challenges. Others argue that most populations have sufficient genetic variation to survive almost any environmental changes. Species may persist, but with reduced genetic variance, they may become more susceptible to other environmental challenges (e.g., diseases).

Examples

Ocean Life

Approximately one-third of the anthropogenically produced CO_2 dissolves in the oceans, causing seawater to become more acidic ("ocean acidification"). Ocean acidification, however, is not the only way that CO_2 will shape ocean life. Due to rapidly increasing CO_2 levels, low O_2 "dead zones" will become more prevalent (Brewer & Peltzer 2009). As increased amounts of CO_2 dissolve from the atmosphere into the ocean, marine animals require ever higher levels of O_2 to respire normally. That is, higher CO_2 levels make it more difficult for marine organisms to breathe, and consequently find food, avoid predators, etc. The most severe effects are predicted to be in "oxygen minimum zones", ocean depths of 300–1,000 m, where oxygen is already present at very low concentrations and only specialized marine life, such as the Owlfish (*Bathylagus milleri*) thrives (Brewer & Peltzer 2009; Figure 3).

Figure 3: An Owlfish, Bathylagus sp.
Inhabitants of the deep ocean, increasing CO2 levels may increase respiratory demands in already low O2 environments, putting such species at risk. (Courtesy of Griffiths)

Insect Behavior

As greenhouse gases alter plant developmental trajectories, insects colonizing those plants may also differ behaviorally and physiologically. Research conducted at the Aspen Free-Air CO_2 Enrichment (Aspen FACE) site on insects that colonize plants growing under increased CO_2 and/or O_3 levels shows some striking results. Poplar aphids (*Chaitophorus stevensis*) colonizing Trembling aspen (*Populus tremuloides*) trees grown under high CO_2 conditions are behaviorally different than those colonizing trees grown under elevated O_3 (Mondor *et al.* 2004; Figure 4). When exposed to alarm pheromone, aphids in high CO_2 environments disperse at a lower rate, while those growing in high O_3 environments disperse at a higher rate, from the plant than those living at ambient CO_2 and O_3 levels (Mondor *et al.* 2004). It is unknown whether this effect results from altered host plant quality or is a result of altered production/reception of alarm pheromone. This experiment does suggest, however, that behavioral responses to pheromones (such as are often used for pest management) may be altered under future atmospheric conditions.

Figure 4: A poplar aphid, Chaitophorus stevensis, colony feeding on a trembling aspen, Populus tremuloides, leaf

Note the leaf damage resulting from increased O3 exposure. (Courtesy of Michelle Tremblay)

Bird Foraging

Birds may be imperiled by global climate change, as distributions and ranges may be altered considerably by increasing temperatures. Bird populations may be influenced in a much more direct manner, such as through altered food availability. When Black-capped chickadees (*Poecile atricapillus*) were offered a choice between caterpillars higher v. lower in tannins (such as would occur when fed foliage grown under high and low CO_2 conditions, respectively), the birds consistently chose to eat larvae low in secondary compounds (Muller *et al.* 2006; Figure 5). Thus increased CO_2 levels may alter bird populations through altering their food sources.

Figure 5: A Black-capped Chickadee, Poecile atricapillus

As greenhouse gases alter plant chemistry, these birds may become more selective in choosing which caterpillars to feed upon. (Courtesy of Mdf)

Summary

Animal populations face rapid and long-lasting challenges as a result of atmospheric changes. Some of these challenges will result from atmospherically induced increases in global temperature. Greenhouse gases such as CO_2 and tropospheric O_3, however, have already been documented, and will continue to alter animal population dynamics through altered ecosystem functioning. Organisms may express both behavioral and physiological changes to atmospheric composition, resulting in large-scale and long-term responses of animal populations ranging from reduced genetic variation to increased rates of extinction.

References and Recommended Reading

Bloom, A. J. *Global Climate Change: Convergence of Disciplines*. 1st ed. Sunderland, MA: Sinauer & Associates, 2010.

Brewer, P. G. & Peltzer, E. T. Limits to marine life. *Science* **324**, 347-348 (2009).

Ehleringer, J. R., Cerling, T. E. *et al.* eds. *A History of Atmospheric CO_2 and its Effects on Plants, Animals, and Ecosystems*. New York, NY: Springer, 2005.

Halliwell, B. & Gutteridge, J. M. C. *Free Radicals in Biology and Medicine*, 3rd ed. New York, NY: Oxford University Press 1999.

Hansen, J. E. & Sato, M. Trends of measured climate forcing agents. *Proceedings of the National Academy of Sciences of the United States of America* **98**, 14778-14783 (2001).

Hoffman, D. J., Butler, J. H. *et al.*, The role of carbon dioxide in climate forcing from 1979 to 2004: introduction of the Annual Greenhouse Gas Index. *Tellus Series B - Chemical and Physical Meterology* **58**, 614-619 (2006).

Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2007: Synthesis Report*. Geneva: IPCC Secretariat, 2007.

Menzel, D. B. Ozone: An overview of its toxicity in man and animals. *Journal of Toxicology and Environmental Health, Part A: Current Issues* **13**, 181-204 (1984).

Mondor, E. B., Tremblay, M. N. *et al.*, Divergent pheromone-mediated insect behaviour under global atmospheric change. *Global Change Biology* **10**, 1820-1824 (2004).

Mondor, E. B., Tremblay, M. N. *et al.*, Altered genotypic and phenotypic frequencies of aphid populations under enriched CO_2 and O_3 atmospheres. *Global Change Biology* **11**, 1990-1996 (2005).

Muller, M., McWilliams, S. R. *et al.*, Tri-trophic direct and indirect effects of plant defenses: Black-capped chickadees choose to eat gypsy moth caterpillars based on host leaf chemistry. *Oikos* **114**, 507-517 (2006).

Percy, K. E., Awmack, C. S. *et al.*, Altered performance of forest pests under atmospheres enriched by CO_2 and O_3. Nature **420**, 403-407 (2002).

Withgott, J. H., & Brennan, S. *Essential Environment: The Science Behind the Stories*, 3rd ed. San Francisco, CA: Pearson, 2009.