Evolutionary Pressures Resulting from Anthropogenic Global Climate Destabilization

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Abstract

Scientists suggest that anthropogenic (human-caused) climate change is becoming more intense, with projections of a rise in temperature of anywhere from 1.1 to 6.4 degrees Celsius by the end of the century(IPCC, 2007). Beyond the temperature changes, our planet faces changes in precipitation, albedo, ocean acidification, and general ecological changes that could see 12-39% of the planet's terrestrial surfaces experiencing "novel" climate conditions, and 10-48% suffering disappearing climates (i.e. completely different climates) by 2100. We are entering a new world, which prompted Bill McKibben to call his recent book about Global Climate Change "Eaarth"(McKibben, 2010) – because the old world, our Earth, is no more. What pressures will result from our activities forcing species into dramatic changes, and, in the worst case, extinction?

Evolutionary Pressures Resulting from Anthropogenic Global Climate Destabilization

Introduction

The title of this research paper suggests that humans are causing evolutionary changes (primarily extinctions) because of their impact on climate (global climate destabilization, or GCD). The scientific community is emphatically united behind the scientific conclusion that the cause of our current climate destabilization is human-driven ("anthropogenic") climate change: the Intergovernmental Panel on Climate Change, the American Meteorological Society, and the National Academies of Science have come out vigorously in support of the theory of anthropogenic climate change(IPCC, 2007; Council, 2007; Science, 2010b). The National Acadamy of Science reached the conclusion that "... there is a strong, credible body of evidence, based on multiple lines of research, documenting that Earth is warming. Strong evidence also indicates that recent warming is largely caused by human activities, especially the release of greenhouse gases through the burning of fossil fuels."(Science, 2010a). Furthermore, the National Academies of the nations of the G8+5 countries (Brazil, India, South Africa, Canada, Italy, United Kingdom, China, Japan, United States, France, Mexico, Russia, Germany(Committee, 2009)) have reached the same conclusion.

In order to drive home this point to our elected representatives in the United States Senate, representatives of all major scientific societies in the United States wrote a letter dated October 29, 2009 to United States Senators to inform them that "Observations throughout the world make it clear that climate change is occurring, and rigorous scientific research demonstrates that the greenhouse gases emitted by human activities are the primary driver."(AAAS, 2009)[1] In spite of evidence of this nature, the United States Senate has refused to act on climate change as of the beginning of 2011.

Unfortunately, the 2009 Climate Change Science Compendium(McMullen & Jabbour, 2009) suggests that climate change is accelerating at a much faster pace than was previously thought by scientists in the 2007 IPCC report. While we fail to act, nature continues on a destabilized climate trajectory, dictated by non-linear forces and hence highly unpredictable. What anthropogenic evolution pressures will result as a consequence of global climate destabilization? There are estimates that 40% or more of all species will go extinct with a 3.5 degree C increase in average global temperature(IPCC, 2007). At the moment, many models suggest we will likely achieve or even exceed that increase in temperature. What evidence is there for the pressures that will result based on these predictions? Which species (e.g. corals) will be the canaries in this coal mine?

"...[N]o species in Earth's history has ever been capable of standing at a pivotal moment in its evolution, analyzing its destructive behaviors, and then deciding to change course with the intent of saving itself and its fellow creatures."(Scherer, 2006) We are the first to be capable: will we be successful in changing course? Our track record is not good....

Because humans are causing the climate to change, other species have been (and will be) impacted, most negatively, by our actions: "Whether or not we have yet measured them, differential responses of interacting species to changing climate are inevitable."(Singer & Parmesan, 2010) Could the responses include extinction? It seems inevitable that the response will be this dramatic: some assert that climate-change-based extinctions have already occurred.

In an earlier paper ("Extinctions under Scenarios of Global Climate Destabilization"(Long, 2010)), I argued that evidence is strong that there are already species that have gone extinct as a consequence of Global Climate Change. In particular, it appears that amphibians are playing the role of canaries in this coal mine: the Monteverde Harlequin Frog and the Golden Toad are reputedly two species whose extinctions are a direct consequence of GCD(Pounds et al., 2006; Kolbert, 2006). The argument that the Golden Toad died out due to climatic change derives from its climatologically precarious life cycle: the toad exposed its eggs and tadpoles to a precarious life in shallow puddles, and, after a particularly dry spring, pools evaporated before the toads could emerge. A year or two later and the toads were gone, never to be seen again(Kolbert, 2006). Others, however, suggests that the extinction has more to do with El Nino than with GCD(Anchukaitisa & Evans, 2010). Undoubtedly there will be these disputes, as our biome is not quite so simple as gravity. We cannot, however, allow "the perfect to be the enemy of the good": science will never be able to prove that climate change is the culprit – the best we can expect from science is a probabilistic statement; that it is the likeliest candidate, for example.

In this paper, I want to examine the likely consequences of our climate destabilization on other species: what pressures are we exerting through anthropogenic climate change? What species are most likely to be harmed by our actions? How can we mitigate our effects?

Review of Ecological Impacts

James Lovelock provides a model for the impact of small changes in climate on biodiversity: "...when the climate changes to either hotter or colder by a small amount the first response is an increase in biodiversity. This is because the new conditions give rare species a chance to flourish while the established ones have not had time to decline."(Lovelock, 2006, p. 42)

There is compelling evidence that climate change has had impacts for millions of years before humans: non-anthropogenic climate change has had severe impacts upon species, including extinction. Ferns, for example, required wet conditions which disappeared under climate change, and so they went extinct(Nitecki, 1984). Often this is a consequence of the inevitable change in habitats: climate changes, habitats disappear, and with them disappear species which relied upon those habitats. Plants are particularly vulnerable, because they can't outrun a dramatic change in zones(Service, n.d.). The dangers are most critical to slow and "stranded" species (those which can't keep up with zonal changes, and those whose habitats simply "fall off the face of the earth" (e.g. alpine environments, or coastal environments)(Scherer, 2006; Kolbert, 2006; Smith et al., 2009). Parmesan(Parmesan, 2006) claims that polar and mountaintop species have shown "severe" range contractions and are the sentinal ecosystems in which "entire species" have already gone extinct due to climate change. The polar bear is now threatened by direct habitat loss: a reduction in ice cover has caused a reduction in hunting success and reproductive success. Mothers are finding it harder to hunt, and so both they and their cubs are not prepared for the winters (in spite of the longer hunting season). Their favorite prey are not accessible without the sea ice from which to hunt(Scherer, 2006).

Examples of species which are slow-moving, and hence unable to keep up with rapid climate change, include corals, which are a bellweather of the threats GCD pose to species, and sugar maples, which may not be able to move fast enough north by seed dispersal to keep up with zone changes. The consequences may not stop with the maples however, as other species rely on them for shelter and food(Scherer, 2006). Hence another risk is that a domino effect will cause additional extinctions – entire ecosystems and food chains at risk. Early calculations of the dangers of mid-level estimates of climate change to highly mobile species were a "mere" 15%; those of stationary species were at 37%(Kolbert, 2006).

While in Belize on a Field Expedition, I visited the Carrie Bow Cay research station. I recently reviewed their report for 2010, and discovered that several researchers identified climate change as a particular threat to species:

- N. D. Fogarty, p. 10: "...it appears that hybridization in a threatened Caribbean genus [Caribbean Acroporid corals] is evolutionarily significant with a range of possible outcomes from the benefit of novel alleles to the swamping of A. cervicornis' genome. These outcomes may hinge on the ability of the Caribbean acroporids to withstand the onslaught of threats that this genus currently faces (i.e. Allee Effect, disease, predation, increased sea temperature, ocean acidification, and increased disturbances)."(Chaves-Fonnegra et al., 2010)

- A. Chaves-Fonnegra, pp. 10-11: "In the last three decades coral reef ecosystems have been deteriorating as a result of overfishing, pollution and climate change (Hughes et al., 2003). The most critical result of climate change is an increased frequency of coral bleaching and disease in corals.... [M]ost evidence suggests that climate change has exceeded the ability of corals to acclimate, and that reefs around the world will continue to decline (Gardner et al., 2003). Thus, reef ecosystems are facing dramatic changes."(Chaves-Fonnegra et al., 2010)

- J. L. DeBose, p. 19: "Further, initial analyses on DMSP [dimethylsulfoniopropionate] concentrations of aggregations compared to control sites show there is a significant difference between the two, paired locations. This adds to the evidence that fish aggregations may release compounds in the water that other fish find attractive. Next steps include determining specific compounds which might be driving this preference and further investigating the plankton assemblage at the heart of these aggregations. Understanding these chemically-mediated trophic cascades will inform future research into how seasonally variable plankton assemblages and associated chemical signatures drive foraging events and how a changing climate will affect the movement patterns of these important reef species as they follow the transient chemical trail."(Chaves-Fonnegra et al., 2010)

- I. C. Feller and C. E. Lovelock, p. 23: "Although mangroves provide critical ecosystem goods and services, they are threatened globally by changes in climate and nutrient over-enrichment of the coastal zone. Using latitude and tidal elevation as proxies for climate change and sea level rise, the objective of this project is to determine how excess nutrients interact with these consequences of global change to alter community structure, food webs, and patterns of herbivory in mangrove ecosystems."(Chaves-Fonnegra et al., 2010)

The timing of natural phenomena will also be disrupted by climate change, which can lead to dramatic evolutionary pressures: for example, the winter moth in Europe is out of sync with its favorite food, the oak. The caterpillers are hatching earlier than the oak trees are leafing out(Scherer, 2006). This is a bane of the winter moth, but a boon to the oak, illustrating once again that climate change may be either positive or negative from any particular specie's perspective.

Ironically it's not just CO_2 that causes climate change dangers for species: 3.5 billion years ago blue-green algae began exhaling oxygen into the atmosphere, poisoning the air with this explosive gas, causing the extinction of anaerobic bacteria(Scherer, 2006). The author argues that while modern climate change may be a bane to some, it will be a boon to others. As an example of a “bane”, he cites Costa Rica’s quetzal, which is threatened by predation from a species which has moved up in altitude, presumably in response to global warming.

How species process the primary pollutant of climate change (CO_2) will also serve as a pressure. Climate deniers focus on the role of CO_2 as a nutrient for plant growth, while forgetting “all things in moderation”. At high enough concentrations, CO_2 becomes a pollutant like any other. If I may be permitted a personal recollection, I’m reminded of a high school field trip to the toxicology lab at the Medical College of Ohio: in particular, we were visiting the toxicologist (part of a microbiology course). The toxicologist told us that everything’s a poison – it’s just a matter of the quantity[2]. One hears, for example, of long distance runners dying of excessive water during or after a race (hyponatremia(Noakes, Goodwin, Rayner, Branken, & Taylor, 2005)). Changing CO_2 levels leads to shifts in evolutionary competition: a study in the Amazon found that two of 16 trees became much more common under high CO_2, while the others became increasingly rare(Scherer, 2006). Poison ivy, meanwhile, demonstrates increased “photosynthesis, water use efficiency, growth, and population biomass”(Mohan et al., 2006). Furthermore, even as some plants take up more CO_2, their nutritional value decreases (aka “hidden hunger”) as their chemical composition changes(Scherer, 2006).

A direct consequence of global warming effect is that plants respond differently to CO_2, creating either a three-carbon acid (C_3), a four-carbon acid (C_4), or storing CO_2 at night and assimilating it in the daylight (CAM). Each responds differently to higher temperatures and excess CO_2. Increasing temperatures will favor corn over wheat (C_4 over C_3); drought will favor CAM(Gates, 1993). Each such change represents a change in niche, or habitat, which will drive changes in animal species which rely on these plants for food.

That being said, Walker(Walker, 1991) asserts that “vegetation will change more as a result of rare and extreme events than in response to a change in average conditions.” Examples he cites include changes in plant composition in response to severe droughts, El Nino events, excessive rainfall, etc.

Another direct effect of global warming is environmental sex determination (ESD): turtles, New Zealand’s tuatara, and other species exhibit ESD, which means that the ratio of male-to-female of their young is determined by the temperature of their environment(warming.com, n.d.; Scherer, 2006). Warming increases the proportion of males in some species: a drop in female offspring means fewer individuals to reproduce, and the ultimate cost could be extinction.

An indirect consequence of GCD is to exacerbate other problems: for example, global warming may be worsening air pollution(Scherer, 2006), which has obvious consequences for our species (but for many others, as well). Alternatively, the problem of human-caused habitat fragmentation is heightened by climate change, which forces animals to move across fragmented landscapes without the benefit of corridors (Kolbert, 2006).

Overall, the predictions offered in the IPCC Fourth Summary Report are bleak: under reasonable projected levels of warming (e.g. 3.5 degrees C), 40% to 70% of the species will go extinct(IPCC, 2007). A 2009 update(Smith et al., 2009) of the IPCC “reasons for concern” suggests that things have only become more dire: Thomas et al.(Thomas et al., 2004) estimate that under “mid-range” predictions of climate warming for 2050, 15 to 37 percent of the species in their sample of regions and taxa will be “committed to extinction”.

Likely Targets of Evolutionary Impact

So which species are most vulnerable? What are their characteristics? Here are several characteristics (the first seven of which are from Gates(Gates, 1993)):

1. Species at the contracting edge of a species range;

2. Geographically localized species in small areas (potential victims of human-driven habitat loss);

3. Very specialized species (e.g. those whose habitats are very tightly defined, or which rely exclusively on other species which are likely to vanish or be severely impacted(Gates, 1993));

4. Poor dispersers ("sluggish" trees, for example);

5. Montane and alpine species (which may see their habitats literally pushed off the tops of their mountains);

6. Arctic communities (especially those dependent upon ice);

7. Coastal communities (subject to fiercer storms and rising sea levels);

8. Those species especially sensitive to temperature (e.g. corals, which undergo bleaching with high temperatures(Burke et al., 2004), or those species whose sex is determined by temperature(warming.com, n.d.; Scherer, 2006).

9. Ocean creatures sensitive to increasing acidification.

As a specific example, consider the Kirtland's warbler, which nests on dry ground. The only tree under which it nests is the jack pine, which live currently in sandy soils. If climate change forces the jack pine north into moister soils, the warbler may no longer be able to nest successfully. According to (Gates, 1993), "some scientists believe the Kirtland's warbler may be the first species casualty of greenhouse warming." That was in 1993, and the good news is that the warbler is making a recovery of sorts(Fish & Service, 2008).

Conclusion

I find that I am in close alignment with James Lovelock, creator of the notion of Gaia, brilliant scientist, and author: "Evolution is iterative, mistakes are made, blunders committed; but in time that great eraser and corrector, natural selection, usually keeps a neat and tidy world." ((Lovelock, 2006), p. 145)

"Until recently we accepted that the evolution of organisms takes place according to Darwin's vision, and the evolution of the material world of rocks, air and ocean according to textbook geology. But Gaia theory sees these two previously separated evolutions as part of a single Earth history, where life and its physical environment evolve as a single entity. I find it helpful to think that what evolves are the niches, and organisms negotiate for their occupancy."((Lovelock, 2006), p. 35)

Here is a summary of the important impacts of anthropogenic climate change considered here:

1. Predation by species which have moved into a new zone.
2. Loss of habitat, reducing hunting and reproductive success.
3. Change in climate requiring a displacement to a new, perhaps inferior, zone.
4. A ripple effect: sugar maples die off, then white-breasted nuthatches could follow....
5. Disrupting nature's timing (e.g. food sources aren't available when expected)
6. Change in sex ratios, because of temperature dependent sex assignment.
7. Spread of disease will impact species (some positively, some negatively).
8. Ocean acidification threatens shell-forming creatures.
9. CO_2 poisoning (and "hidden hunger" – a reduction in nutrition value, in spite of increased growth) will become an issue.
10. A compounding effect: storms may cause sewer systems to overflow, which causes

water pollution, which kills fish.

Appendix

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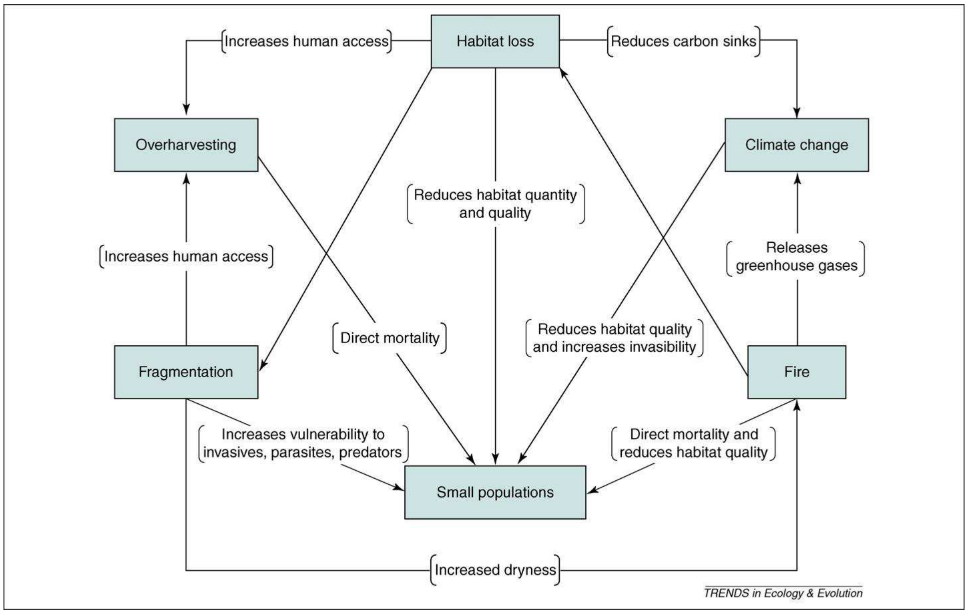
Footnotes

[1] The organizations included the following: American Association for the Advancement of Science, American Chemical Society, American Geophysical Union, American Institute of Biological Sciences, American Meteorological Society, American Society of Agronomy, American Society of Plant Biologists, American Statistical Association, Association of Ecosystem Research Centers, Botanical Society of America, Crop Science Society of America, Ecological Society of America, Natural Science Collections Alliance, Organization of Biological Field Stations, Society for Industrial and Applied Mathematics, Society of Systematic Biologists, Soil Science Society of America, and the University Corporation for Atmospheric Research.

[2] I have since learned that this is known as the dictum of Paracelsus(Lovelock, 2006), p. 95

Figure Captions

Figure 1. From 1231212312: "An example of the synergistic feedbacks which threaten species in disturbed tropical rain forests."


Habitat loss
Increases human access
Reduces carbon sinks
Overharvesting
Climate change
Reduces habitat quantity and quality
Increases human access
Releases greenhouse gases
Direct mortality
Reduces habitat quality and increases invasibility
Fragmentation
Fire
Increases vulnerability to invasives, parasites, predators
Direct mortality and reduces habitat quality
Small populations
Increased dryness
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