

Extinctions under Scenarios of Global Climate Destabilization (GCD)

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Abstract

What is the impact of Global Climate Destabilization (GCD) (better known as Global Climate Change) on biodiversity? In particular, can we point to some species that have become extinct because of the effects of climate change? While there are certain high-profile examples (e.g. Polar bears) that are evidently threatened, there are also less-well known examples. This paper addresses some lesser-known examples, and the effects that are potentially driving them extinct.

There is ferocious resistance to the notion that humans are having a negative impact on our environment. It is incumbent upon us therefore to provide evidence to support any assertions that we make, and to explain carefully the science which leads us to arrive at conclusions. As scientists, we are unfairly chastised for not being able to say things with certainty. Those who do not understand scientific theory seize on the idea that we can't "prove" our theories to assert that we don't know what we're talking about (or that controversy exists, when, in fact, there is little). I will attempt to gather and evaluate what evidence I can, in keeping with the scientific tradition.

1 Introduction

1.1 What is Global Climate Destabilization?

We begin by defining what is meant by Global Climate Destabilization (GCD), or Global Climate Change (GCC). Of course the climate changes: everyone learns something about ice ages in their youth. But these known climate changes tend to be very long ("geologic time") events, driven by the Milankovitch cycles[26]. If humans couldn't impact climate, then there would be no sense in humans fretting about the climate – like the weather, we might say "can't do anything about it, so no sense in complaining about it."

James Hansen defines "climate" as "the average weather"[18], which seems like a good starting point. In contrast, Don Blankenship, CEO of Massey coal (25 of their miners just died in the Upper Big Branch Mine), says in a talk before the Tug Valley Mining Institute that "I don't believe climate change is real"[6]; he follows that up by noting what a cold November it's been. Now there's someone who evidently doesn't believe that there's a difference between weather and climate. In the video he goes on to say that yes, the arctic is melting, but that the Antarctic is getting colder – "I believe it's a normal cycle." So he DOES believe in climate change – just in "normal cycles." Evidently the cycle is never

abnormal, and people can't provoke our climate into any abnormal cycles. That's what Don Blankenship means by GCC.

For the purpose of this paper we use Hansen's definition. Climate change, then, represents change in the average weather patterns. In Earth's history, the effects of the Milankovitch cycles have meant that we have very large changes on cycles of 100,000 years or so, with smaller changes on smaller intervals (41,000 years, 22,000 years [26]).

One question is whether climate change has historically been related to biodiversity. The answer is yes, according to Mayhew, et al.[25], who found that global biodiversity has been low during warm phases (with correspondingly higher rates of both extinction and origination of species). Hence, if humans are contributing to a rise in global temperature, then we are pushing the earth into a scenario which has traditionally implied higher extinction. The Intergovernmental Panel on Climate Change (IPCC) has concluded that "Warming of the climate system is unequivocal...", and that "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations." [22]

1.2 Extinction: Direct Effects versus Indirect Effects

Many widely respected scientists have asserted that that some extinctions have already occurred because of GCD ([17], [18], [22]). Furthermore, these same scientists assert that more – many more – extinctions are on the way, propelled by human-caused global climate change.

There are many pathways by which GCD could lead to extinction. Some are direct consequences of climate, and others are part of a chain reaction to climate change. For example, a direct effect would be too much heat – that is, a species could be living at the high end fringe of its sensitivity to temperature, and if temperature rises any more, the species may no longer be able to survive.

An indirect effect is that global warming changes a species's habitat until that habitat is no longer conducive to survival. The polar bear is subject to this effect – its ice home is rapidly disappearing. Another example of an indirect effect is related to habitat change: a pathogen may be able to survive in a habitat where it formerly didn't, leading to damage to its host species.

Peterson, et al.[30] quantify the amount of pressure species encounter as a result of habitat loss as a direct consequence of climate change scenarios. They studied fauna-level changes, and predicted few actual extinctions. However, the net effect on the species they studied were clearly in the wrong direction: under their most realistic scenario, habitable area would decrease by about 30 percent.

Another indirect effect (and a rather unusual one) is environmental sex determination (ESD): turtles, among other species, evidence ESD, which means that the ratio of male-to-female turtle young is determined by the temperature of their environment[15]. The fear is that, if warming increases too much, male offspring will no longer be produced. The ultimate cost would be extinction, of course.

In terms of systems of species (e.g. species communities), it is important to consider another indirect effect: the timing of corresponding events. For example, if flowers begin to come out earlier, before pollinators are in place, that would be a timing crisis. Some birds no longer migrate, for example, because conditions don't merit the cost of displacement[12]. Others lay eggs earlier and earlier. "Bird communities ... will likely be torn apart." [ibid]

It seems to be very difficult to actually pin blame for any particular extinction on any particular cause. This includes the cause of global climate change. Science is notoriously cagey (and for good reason) about giving definitive answers. This is as it should be, for, as noted videographer, author, and High School science teacher Greg Craven notes in his video “The Most Terrifying Video You’ll Ever See 2”[8], the cause (of anything) could be giant mutant space hamsters. and we’re simply unaware of their role. The cause of humanity’s irrational super-exploitation in the face of limited resources and evident harm could be a virus attacking our brains and leading us to our own destruction, by our own hands. Such an attack is not without precedent: for example, a parasitic protozoa (*Toxoplasma gondii*) causes rats to crave cat urine, which leads them to be disproportionately predated by cats. The protozoan can only reproduce sexually in the feline gut[19]. What a marvelous (and terrifying) illustration of the elegant solutions of evolution.

Science moves via testable hypotheses, not asserted truths (which are the common currency of religions). Galileo tested Aristotle’s hypothesis (assertion, really) that heavier objects fall faster than lighter ones, because they “love the earth more”; for this, and for other heresies (such as declaring that the surface of the moon was not smooth, that Jupiter had moons of its own, and that the changing phases of Venus could only be explained by its orbiting the sun) Galileo was excommunicated from the Catholic Church, and spent his final years under house arrest[23].

Galileo’s story is an analogy that plays two ways under GCD, depending on one’s stance: GCD deniers can cite Galileo as the “few with the truth” against the dogma of the establishment. Just because an estimated 84% of the world’s scientists support the idea of anthropogenic climate change[2], the scientists could be wrong. Maybe the established scientific organizations have all been hoodwinked; have drunk the Kool-aid. The other analogy, however, is that science is the few, represented by Galileo, against the louder irrational establishment voices of Fox News, Rush Limbaugh, and Senators like Jim Inhofe (R-Neb). With only 28% of American adults science literate[32], scientific arguments are simply incomprehensible to the public. Furthermore, and perhaps more ominously, the effect is startlingly partisan. Republicans are significantly more likely to deny than are Democrats[2], and the public’s perception of scientific agreement on GCD is out of touch: the public perceives scientific debate and uncertainty where there is little in reality. In fact, 30% of Republicans were willing to attribute global warming to human activity, whereas 64% of Democrats thought so. Among scientists (sampled from the American Association for the Advancement of Science), 84% agreed that warming is attributable to human activity. Liberal Democrats were the group closest to the scientists, at 71%[2].

While it is often difficult to say much about particulars, scientists are generally more willing to make statements about the averages: and scientists are making thoroughly gloomy predictions about the rates of extinction due to GCD that we are likely to see in our future.

2 Extinctions and Threats of Extinction

2.1 The Monteverde Harlequin Frog (*Atelopus* sp.) and Golden Toad (*Bufo periglenes*)

Amphibians in the Costa Rican mountains are reputedly some of the first species whose disappearance have been tied to global warming. In particular, researchers at the Monteverde Cloud Forest Preserve have tied global warming to the demise of the Monteverde Harlequin Frog and the Golden Toad[31]: these researchers have concluded that GCD is behind their extinction, along with the extinction of two-thirds of the other 110 species of harlequin frog, due to a pathogenic fungus called *Batrachochytrium dendrobatidis*. The fungus was able to thrive, they contend, because of a reduction in moisture, which is a result of excessive heat in the region.

There is a dispute (of course!) about these extinctions. A recent report ([4]) suggests that the extinction has more to do with El Nino than with GCD. In a review of *Extinction in our times: global amphibian decline*[10], Matthew Fisher congratulates the authors on not wading into the GCD issue, emphasizing that, while authors have implicated global climate change [31, 7], others dispute this [33, 24]. Interestingly, Fisher is a co-author on one of those articles he cites as implicating climate change([7]). The articles he cites disputing the climate change connection are later than his, so one wonders if Fisher has had second thoughts.

Thomas et al.[37], writing in 2004, cite this as the **only** concrete example of species-level extinction directly tied to climate change.

2.2 Mammalian extinction

The only mammal whose extinction has been linked to climate change is the woolly mammoth, a eold-adapted species that died out about 3600 years ago[27]. These authors conclude upon further investigation that a more likely cause was human expansion, however.

Donald Grayson, an archaeologist at the University of Washington, was cited in National Geographic News[1] to argue that climate change during the late Pleistocene (e.g. changes in weather and vegetation patterns) were the likely cause of the demise of North America's megafauna.

2.3 Invertebrate extinction

There is evidence that insects have begun responding to climate change by moving up in elevation ([20], [14]). Chen, et al.[20] show that 102 species of moths sampled in Borneo underwent a statistically significant climb of 67 meters over 42 years, which the authors attribute to climate change. Forister et al.[14] use 35 years of data on 159 species of butterflies at 10 sites at elevations of 0 to 2775 meters in the Sierra Nevada mountains to conclude that they, too, have moved to higher elevation, consistent with the predictions of global warming. Furthermore, they demonstrate a clear decline in species diversity at half of the 10 sites.

Monarch butterflies experienced a dramatic downturn in 2010, which Chip Taylor, research scientist and monarch specialist, attributed to unseasonable weather (perhaps brought on by climate change) and habitat loss[3]. Another invertebrate which has received considerable attention is coral colonies. Smith, et al.[36] suggest that corals are especially susceptible to thermal stress, and that there will be widespread mortality (even more than we've already seen), unless they adapt or acclimatize.

A final example problem related to invertibrates and GCD involves the mountain pine beetles. Marketplace (an American Public Media production) aired a radio program ([9]) that include a segment about the mountain pine beetle, and its impact on the town of Helena, Montana. Forests surrounding Helena have been devastated by the beetle. Helena Resident (Jim Robbins) and Mayor of Helena (Jim Smith) makes two points worth repeating in their interview with Sam Eaton:

Excerpt of Radio Show

JIM ROBBINS: This was all forest here. And now it's a lot of smashed pieces of wood here and pine needles and occasional patches of weed that we'll have to spray next year.

SAM: So Robbins says when people are faced with these kinds of images daily, in their own backyards, it becomes a lot harder not to believe in climate change.

ROBBINS: **There's a saying that there are no atheists in foxholes. I think there's something along that line happening here. I mean, there are still some people who refuse to believe it. But I think there's been an erosion of that disbelief and it's changed pretty dramatically.** [My emphasis]

SAM: And a lot of people don't want to call it global warming simply because it's such a politically charged term. They basically equate it with Democrats like Al Gore. People they'd never vote for.

Helena's Mayor Jim Smith definitely falls into that category. But Sarah, he told me something I'd never heard before. He said when your community is threatened, the political debate over climate change no longer matters.

SMITH: **Whether this climate change is man caused or just the natural order of things, I don't know and I don't have a lot of time to ponder that important question. We just got to deal with the situation on the ground here regardless of what the cause is.** [My emphasis]

In this case, the invertibrates are an agent of destruction, a pest promoted by GCD, which leads to further GCD. The two comments that I've highlighted above suggest two things:

1. When push comes to shove, and exceptional events are all around you, it's a lot easier to believe that something is seriously wrong with your environment – and that people may have had something to do with it. Those who believe – who predict – that we're in for some rough times will find more converts if things play out as they predict.
2. The second point is that, whatever the cause of global warming, if it's happening then we need to do something about it – whatever we can. In the end, it may make no sense to assign blame; the most important thing to do is to see what we can do to make the situation better.

Smith, et al.[36] also concludes that the outbreaks of mountain pine beetle in British Columbia are linked to GCC, and have resulted in a dramatic loss of forest biomass (which engenders another massive release of CO_2 to the atmosphere (whether in the form of decomposition or in forest fires).

2.4 Birds

One species at risk is the golden bowerbird of Australia, because its habitat is at risk of disappearing with increasing climate warming. Habitat would decrease 63 per cent with less

than 1 degree C of future warming; up to 98 per cent with 2-3 degrees C of warming; and completely disappear with between 3 and 4C of warming[12].

A World Wildlife Federation report[12] presents a sad case of a disastrous breeding failure of seabirds in the North Sea, in 2004. Tens of thousands of long-lived, slow-breeding seabirds nesting in Britain's North Sea coastal breeding colonies failed to raise any young; in some cases starving adult birds ate those chicks that did hatch. This breeding crash has been attributed to food shortages and large-scale changes in North Sea marine ecosystems linked to ocean warming and climate change.

Furthermore, the report includes some dire warnings: "a march toward a major bird extinction may be underway," and "in the opinion of the authors many current projections of climate impacts, including those of the Intergovernmental Panel on Climate Change, are likely to be underestimates." [The authors are referring here to the "TAR", the Third Assessment of the IPCC[21].]

An expanded version[13] of the summary cited above suggests that 84% of migratory bird species are under some threat from GCC. The report is depressing reading.

2.5 Plant extinction

Parmesan[28] claims that ecological changes in the distribution of plants (and animals) are occurring in all "well-studied" ecosystems, and that the changes are "heavily biased" in agreement with the predictions from global warming models. The changes have been tied to climate change through correlations between "climate and biological variation, field and laboratory experiments, and physiological research."

An example of a plant at risk of extinction from climate change is the quiver tree (*Aloe dichotoma*) ([16],[11]). Scientists from the South African National Biodiversity Institute found quiver trees are struggling to survive in the drought conditions the area is experiencing, and that further increases in regional temperature may be too much for the plant to survive (unless they are able to adapt, effectively migrating to cooler areas). Wendy Foden, researcher at the South African National Biodiversity Institute, was quoted as saying that the quiver trees are in the early stage of a poleward (southward) range shift. "If there is no expansion in the quiver trees' range, then models forecast a 76 percent reduction in their population over the next 100 years," she said.

3 Predictions Related to Extinction

3.1 Ecosystems at Risk

The place where we might expect to see the most damage is in the habitats that are the most precarious. The two that James Hansen (and others) seized on are the Arctic and Alpine ecosystems[18]. Parmesan[28] claims that polar and mountaintop species have shown "severe" range contractions and are the sentinel ecosystems in which "entire species" have already gone extinct due to climate change. In an update to the Third Assessment of the IPCC, Smith, et al.[36] suggest that there is an increasing risk of impacts of climate change on "unique and threatened" systems, such as those at the poles and those on high mountain (alpine) environments.

In both of these ecosystems species are literally pushed off the face of the Earth – either into the sea in the arctic, or off the tops of mountains in the case of the alpine ecosystems.

The Arctic Report Card Update for 2009[35] concludes that the seven sentinel mammal species of the arctic will “almost certainly” be impacted by climate change. The health of polar bears has already been affected, with poorer body condition and lower survival as a result. Walrus have been forced to “haul out” on the shores of Alaska and Russia (rather than stay on the ice), which changes their patterns of behavior significantly, and for the worse. Less obvious consequences include seal lair collapse due to warmer temperatures (and higher mortality for pups), and higher variability in ice leading to whale entrapment in ice.

One thing about changing ecosystems: when a species is lost, another will generally rise to fill the niche. For example, speculation is that the polar bear will be replaced by killer whales as the top predator at the top of our planet[5].

3.2 Predictions of Rates of Extinction

Predictions in the IPCC Fourth Summary Report indicate that under reasonable levels of warming (e.g. 3.5 degrees C), 40% to 70% of the species will go extinct[22]. A 2009 update[36] of the IPCC “reasons for concern” suggests that things have only become more dire. In a letter to Nature, Thomas et al.[37] 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”.

One of the problems that species will have is that they are not able to keep up with the extremely rapid change in habitat, a consequence of rapidly increasing temperature. James Hansen declares in *Storms of My Grandchildren*[18] that isotherms in the U.S. are moving northward at 35 miles per decade; unfortunately, plant and animal species are only moving 4 miles per decade. They’re not keeping up, and the implied consequence is that some of these species will perish because they can’t keep up as their ecosystem gets pulled out from underneath them. This poleward movement is also validated by the IPCC report, and the shifts are attributed to recent warming with “very high confidence.”[22]

Citing Peters[29], the National Park Service reports that each 1 degree C of warming will shift temperature zones by about 160 km. Furthermore they estimate that species may equivalently move 2 m upward in elevation for every km they would migrate north, so that a 1 degree C warming globally could be combatted alternatively by moving 320 m higher up[34].

4 Conclusions

All in all, the news looks pretty grim for species under the prevailing models of global climate changes. Habitats will be changing from underneath species, and they may well have a hard time keeping up (migration for spruce is estimated to be 1-20 km/century[34], when they may need to be moving 160 km in just a span of a few decades).

Direct impacts of climate change will lead to some species (e.g. corals) succumbing soon, because they’re at the extreme end of their adaptability to the Earth’s warming. Other species will see indirect causes snuff them out (e.g. migrating birds need to have food along their routes, and if timing events mean that their food sources don’t await them, they may die out[12]).

In general, the only logical thing to do in the face of this overwhelming onslaught of information at this time is to act, and to act as quickly as possible, to prevent biospheric losses of an unprecedented scale. Extinctions are coming: the only question seems to be the magnitude. Reasonable assumptions, however, seem to indicate that the magnitude will be very great, and the ultimate impact of this dramatic loss to our world little understood.

References

- [1] Climate change caused extinction of big ice age mammals, scientist says. http://news.nationalgeographic.com/news/2001/11/1112_overkill.html, November 2001. for National Geographic News, November 12, 2001.
- [2] Public science; scientists fault public, media. <http://people-press.org/report/?pageid=1550>, July 2009.
- [3] ABC News. *The Butterfly Effect: Where Have the Monarchs Gone*, March 2010.
- [4] K. J. Anchukaitisa and M. N. Evans. Tropical cloud forest climate variability and the demise of the monteverde golden toad. *Proceedings of the National Academy of Sciences*, 2010. doi:10.1073/pnas.0908572107.
- [5] A. Anderson. What happens to polar bears as arctic ice shrinks? National Public Radio, January 16 2010.
- [6] D. Blankenship. Speech before the tug valley mining institute. Video, November 2008.
- [7] J. Bosch, L. M. Carrascal, L. Duran, S. Walker, and M. C. Fisher. Climate change and outbreaks of amphibian chytridiomycosis in a montane area of central spain: is there a link? *Proc R Soc London*, 274:253–260, 2007.
- [8] G. Craven. The most terrifying video you’ll ever see 2. <http://www.youtube.com/watch?v=AE6Kdo1AQmY>, November 2007.
- [9] S. Eaton. Climate change in our own backyards. Marketplace Radio, October 27 2009. <http://marketplace.publicradio.org/display/web/2009/10/27/pm-climate-race-1/>.
- [10] M. C. Fisher. Silent springs: Why are all the frogs croaking? *PLoS Biology*, 7(9), September 2009. Review of Collins JP, Crump ML (2009) Extinction in our times: global amphibian decline.
- [11] I. U. for Conservation of Nature. Quiver trees and climate change desert giants feel the heat. http://cmsdata.iucn.org/downloads/fact_sheet_red_list_quivertree.pdf, 2009.
- [12] W. W. F. for Nature Australia. Bird species and climate change. Technical report, World Wildlife Federation, November 2006.
- [13] W. W. F. for Nature Australia. Bird species and climate change. Technical report, World Wildlife Federation, November 2006.

- [14] M. L. Forister, A. C. McCall, N. J. Sanders, J. A. Fordyce, J. H. Thorne, J. O'Brien, D. P. Waetjen, , and A. M. Shapiro. Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *Proc. Natl. Acad. Sci. USA*, 107(5):2088–2092, 2010.
- [15] global-greenhouse warming.com. Climate change and sea turtles. <http://www.global-greenhouse-warming.com/climate-change-and-sea-turtles.html>. Accessed 4/23/2010.
- [16] global-greenhouse warming.com. Quiver tree. <http://www.global-greenhouse-warming.com/quiver-tree.html>. Accessed 4/23/2010.
- [17] L. Hannah, G. F. Midgley, T. Lovejoy, W. J. Bond, M. Bush, J. C. Lovett, D. Scott, and F. I. Woodward. Conservation of biodiversity in a changing climate. *Conservation Biology*, 16(1):264–268, February 2002.
- [18] J. Hansen. *Storms of My Grandchildren*. Bloomsbury USA, 2009.
- [19] B. Harder. Parasite 'brainwashes' rats into craving cat urine, study finds. <http://news.nationalgeographic.com/news/2007/04/070403-cats-rats.html>, April 2007. for National Geographic News, April 3, 2007.
- [20] S. B. J. D. H. V. K. C. H. S. B. J. K. H. I-Ching Chen, Hau-Jie Shiu and C. D. Thomas. Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proc Natl Acad Sci USA*, 106:1479–1483, 2009.
- [21] IPCC. Climate change 2001: Ipcc third assessment report. Technical report, Intergovernmental Panel on Climate Change, 2001. http://www.grida.no/publications/other/ipcc_tar/, accessed 4/23/2010.
- [22] IPCC. Summary for policymakers, climate change: Synthesis report. fourth assessment report. Technical report, Intergovernmental Panel on Climate Change, 2007. http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html, accessed 4/23/2010.
- [23] G. Keillor. His wife. <http://writersalmanac.publicradio.org/index.php?date=2010/04/12>, April 2010.
- [24] K. R. Lips, J. Diffendorfer, J. R. M. III, and M. W. Sears. Riding the wave: reconciling the roles of disease and climate change in amphibian declines. *PLoS Biology*, 6(3), March 2008.
- [25] P. J. Mayhew, G. B. Jenkins, and T. G. Benton. A long-term association between global temperature and biodiversity, origination and extinction in the fossil record. *Proc. R. Soc. B*, 275(1630):47–53, January 2008.
- [26] NOAA. Astronomical theory of climate change. <http://www.ncdc.noaa.gov/paleo/milankovitch.html>, April 2009. Accessed 4/20/2010.

- [27] D. Nogues-Bravo, J. Rodriguez, J. Hortal, P. Batra, and M. B. Araujo. Climate change, humans, and the extinction of the woolly mammoth. *PLoS Biology* 6(4): e79. doi:10.1371/journal.pbio.0060079, 6(4), April 2008.
- [28] C. Parmesan. Ecological and evolutionary responses to recent climate change.
- [29] R. Peters. *The challenge of Global Warming*, chapter Effects of global warming on biological diversity, pages 82–95. Island Press, Washington, DC., 1989.
- [30] A. T. Peterson, M. A. Ortega-Huerta, J. Bartley, V. Sanchez-Cordero, J. Soberonk, R. H. Buddemeier, and D. R. B. Stockwell. Future projections for mexican faunas under global climate change scenarios. *Nature*, pages 626–629, April 2002.
- [31] J. A. Pounds, M. R. Bustamante, L. A. Coloma, J. A. Consuegra, M. P. L. Fogden, P. N. Foster, E. L. Marca, K. L. Masters, A. Merino-Viteri, R. Puschendorf, S. R. Ron, G. A. Sannnnchez-Azofeifa, C. J. Still, and B. E. Young. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, 439:161–167, January 2006.
- [32] J. Raloff. Science literacy: U.s. college courses really count. *Science News*, 177(6):13, March 2010. http://www.sciencenews.org/view/generic/id/56517/title/Science_literacy_U.S._college_courses_really
- [33] J. R. Rohra, T. R. Raffela, J. M. Romansica, H. McCallumb, and P. J. Hudson. Evaluating the links between climate, disease spread, and amphibian declines. *PNAS*, 105(45):17436–17441, November 2008.
- [34] N. P. Service. Biodiversity. <http://www.nps.gov/archive/glac/resources/bio7.htm>.
- [35] M. Simpkins. Arctic report card update for 2009 (marine mammals). <http://www.arctic.noaa.gov/reportcard/marine-mammals.html>, October 2009. NOAA Fisheries Service; October 19, 2009.
- [36] J. B. Smith, S. H. Schneiderb, M. Oppenheimer, G. W. Yohee, W. Hare, M. D. Mastandrea, A. Patwardhan, I. Burton, J. Corfee-Morlot, C. H. D. Magadza, H.-M. Fussel, A. B. Pittock, A. Rahman, A. Suarez, , and J.-P. van Ypersele. Assessing dangerous climate change through an update of the intergovernmental panel on climate change (ipcc) 'reasons for concern'. *PNAS*, 106(11):4133–4137, March 2009.
- [37] C. D. Thomas, A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. Extinction risk from climate change. *Nature*, 427:145–148, January 2004.