Climate Change & Tipping Points: Cascading Events onto Hothouse or Stabilized Earth.

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"Nature holds the key to our aesthetic, intellectual, cognitive and even spiritual satisfaction. Destroying rainforest for economic gain is like burning a Renaissance painting to cook a meal…If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos." **Edward O. Wilson, world renowned entomologist, theorist, and naturalist.**

With climate change news all around us, it is easy to feel the "doom and gloom" around our future. We talk about a climate emergency (unlike the coronavirus calling for immediate mitigation) but it is an emergency to curb greenhouse gas emissions as a continuing and long-term goal in keeping our planet under 1.5 ^{o}C from the 1850 -1950 mean by the year 2100. The world is still consuming 34% on oil, 27% on coal and 24% on natural gas. We cannot fully remove these fossil fuels within the next three decades to zero emission by 2050 unless we adopt the ***Exponential Roadmap*** outlined below in keeping with the expectations of the UN and IPCC 2018 reports. The IEA warned that even if governments meet existing targets set by the IPCC, carbon emissions are set to rise through 2040. Global oil usage in transportation alone by vehicles, aircrafts, ships and trains amount to 6o percent; this is likely to be reduced by 2050 as renewable energy sources advance, with more electric vehicles, more efficient modes of transport and with new biofuels to replace aircraft fuel.

An **Exponential Roadmap** publication from **www.exponentialroadmap.org** website has mapped out 36 ways to reduce GHG emissions such as carbon capture and storage and planting billions of trees to reduce atmospheric carbon, to cite two examples. The lead partners of this edition of the Exponential Roadmap produced in September 2019, are Future Earth, World Wildlife Fund, Ericsson, the Royal Institute of Technology in Sweden, Potsdam Institute for Climate Impact Research, Stockholm Resilience Centre together with countless numbers of climate and

environmental scientists. The Roadmap with 36 solutions to reduce greenhouse gas emissions by 50% by 2050 focuses on these seven Sectors: Energy Supply, Industry, Buildings, Transport, Food Consumption, Nature-Based Sources and Nature-Based Sinks. The above document is lengthy but you could find a good understanding of the solutions to reduce greenhouse gas emissions to achieve zero emissions from the *Executive Summary* of the publication.

We cannot lose sight of the goals to reduce GHG emissions and to keep global temperatures around 1.5 ºC and no higher than 2 ºC by 2100. The Exponential Roadmap if adhered to, and that is a big if, would lead to a 1.5 ºC or less by 2100. An inspiring book filled with hope for the future which I recommend for your students is ***The Future We Choose: Surviving the Climate Crisis*** by Christiana Figueres & Tom Rivett-Carnac; she was the top climate diplomat for the UN, and cofounders of ***Global Optimism***. The book outlines two possible scenarios for our planet - what life on Earth will be like by 2050 if we fail to meet the Paris climate targets and what it will be like to live in a carbon neutral, regenerative world, to create a better future for all living organisms on Earth. This book makes the case for building a more just society and how we could improve our well-being as global citizens. The April 2020 issue of **National Geographic** on "How We should Save the World" & "How We Lost the Planet" gives both optimistic and pessimistic guides to Life on Earth in 2070.

Now what does a climate tipping point mean? A climate tipping point is where a small change makes a big difference in changing the state or fate of a system. Examples of potential climate and ecosystem tipping points are illustrated in Figure 1. Tipping points are more likely to occur as global average temperatures increase further, and the occurrence of one tipping point would make others more likely as cascading events even at today's global temperature increase of 1.10 ºC from 1880. "Tipping Points" by Robert McSweeney on a ***Carbon Brief*** document at **https://www.carbonbrief.org/author/robertmcsweeney** cites 9 tipping points and triggered by climate change. The risk of tipping cascades (Figure 1) would be more evident at a 2 °C temperature rise and could increase sharply beyond that point. By March 2020 the global temperature nudged to 1.10 ºC relative to relative to 1880-1922, according to GISS, NOAA and NASA; global temperatures from **the last five years have been the warmest from instrumental data.**

The **thermohaline circulation** and the Atlantic Meridional Overturning Circulation (AMOC) play a key role as a *global thermostat* and with influences global weather and climate conditions in the Arctic, Antarctic, Amazon rainforests, North America, and northern Europe (Figure 1). The recent publications on the slowing down of AMOC from a warming Arctic by rising greenhouse gas emissions is a major concern for climate changes. This complex and fundamental system of ocean currents, including the wind-driven Gulf Stream, the AMOC influences the exchange of heat between the tropics and high latitudes. Driven mainly by cold, dense water south of Greenland and the Labrador Sea, and sinking hundreds of metres in the North Atlantic Ocean, this circulation regulates the global temperature and serves as a *global thermostat*. The freshening of water from Greenland melt makes the water less dense and slows down the AMOC, affecting this giant conveyor belt and its role as a global thermostat. The Gulf Stream then becomes diverted to the east of Greenland and colder affecting the climate in northern Europe with colder winters.

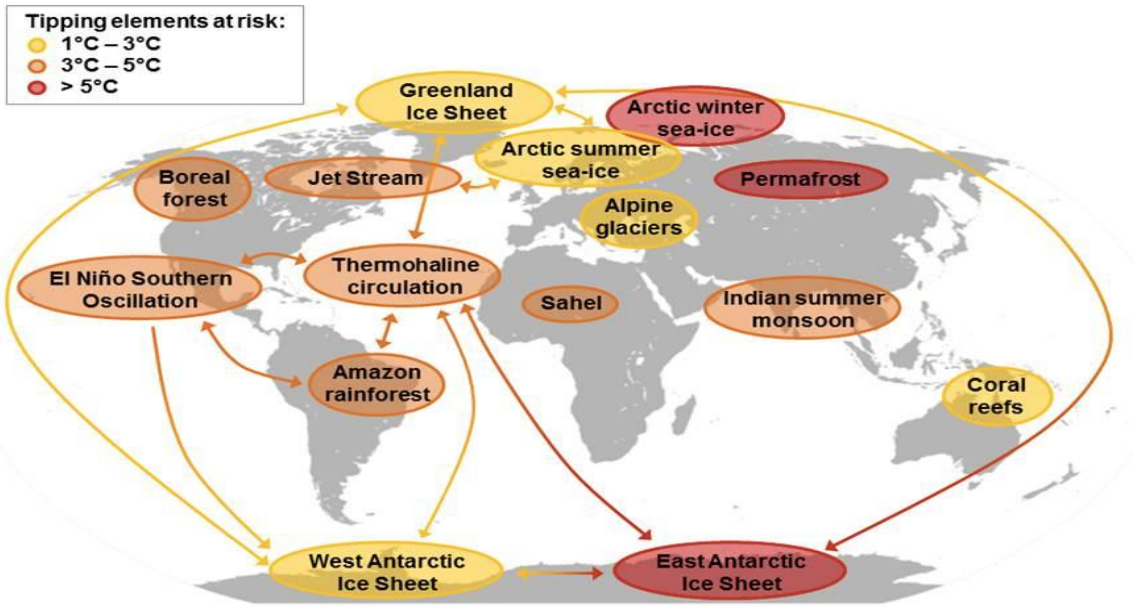

Figure 1. Tipping Points, Cascading Events or Domino Effect. Credit *Proceedings of the National Academy of Sciences* (PNAS) and *Stockholm Resilience Centre*.

Currently, the Earth System is on a Hothouse Earth pathway (Figure 1 A) driven by human emissions of greenhouse gases and biosphere degradation. The challenge that humanity faces is to create a "Stabilized Earth" pathway that has been the fairly stable climate during the Holocene epoch and to steer the Earth System away from its current trajectory toward the threshold beyond which is an impending "Hothouse Earth". This illustration (Figure 1A) appears in the scientific research paper entitled "**Trajectories of the Earth System in the Anthropocene"** in the *Proceeding of the National Academy of Sciences* by Will Steffen and eleven other climate scientists. We are at the crossroads entering the Anthropocene and needing to keep our planet from exceeding 1.5 ºC in this century. "Collective human action is required to steer the Earth System away from a potential threshold and stabilize it in a habitable interglacial-like state. Such action entails stewardship of the entire Earth System—biosphere, climate, and societies—and could include decarbonization of the global economy, enhancement of biosphere carbon sinks, behavioral changes, technological innovations, new governance arrangements, and transformed social values" according to the authors.

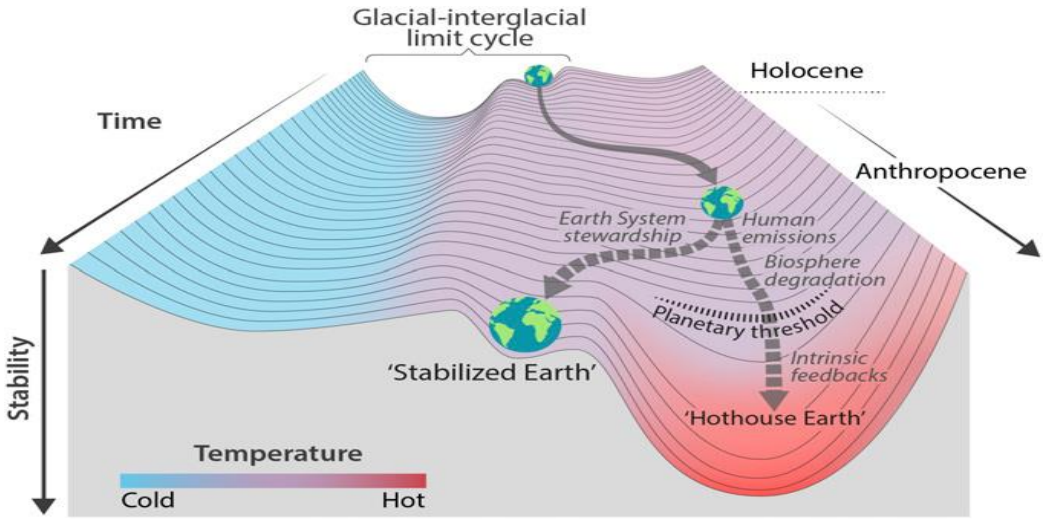

Figure 1 A. Pathway of the Earth System out of the Holocene into the Anthropocene for 'Hothouse Earth' or 'Stabilized Earth'.

"Maximizing the chances of avoiding a Hothouse Earth requires not only reduction of carbon dioxide and other greenhouse gas emissions but also enhancement and/or creation of new biological carbon stores, for example,

through improved forest, agricultural and soil management; biodiversity conservation; and technologies that remove carbon dioxide from the atmosphere and store it underground" to maintain an interglacial system or one similar to the Holocene as noted by co-author Johan Rockström, former executive director of the Stockholm Resilience Centre (www.stockholmresilience.org).

The global surface temperature has risen to 1.10 ºC since 1850 with some regions experiencing higher surface land and ocean temperatures. Northern Canada's average temperature has risen to 2.3 ºC since 1948, more than twice the global mean; Alaska and the entire Arctic region are more than double the global average temperature; the Gulf of Alaska and Gulf of Maine are warmer than in previous decades. Tipping points are more likely to be generated from higher temperatures and the evidence is already abundantly clear. "If damaging tipping cascades or domino effect as indicated in Figure 1 can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. We need to change our approach to the climate problem" says Timothy Lenton, director of the Global Systems Institute at the University of Exeter in England. For example, part of the reason that **Greenland** has an ice sheet today is that it has had that ice sheet for hundreds of thousands of years. "If the Greenland ice sheet were to pass a tipping point that led to its disintegration, simply reducing emissions and lowering global temperatures to pre-industrial levels would not bring it back again. It would probably require another ice age to achieve that" according to Lenton. Both polar regions are presently being impacted by higher atmospheric and oceanic temperatures.

The loss and thinning of Arctic sea ice, glacial retreat and ice sheets decline at both polar regions, and from all mountain glaciers are evidence of a warming planet from increasing greenhouse gas emissions. The warming of all oceans (NE Pacific, Gulf of Alaska, Gulf of Maine, Indian Ocean, Tasman Sea, Southern Ocean) experience increasing marine heatwaves; the slowing down of the Atlantic Meridional Overturning Circulation (AMOC) is having profound climatic changes in Europe and northeast US, Canada, and the Sahel in Africa. **Positive feedback** including loss of albedo, permafrost melt with escape of CO_2 and CH_4 exacerbate Arctic warming, changes to the polar jetstream, loss of sea ice, loss of ice sheets and glacial retreats, mainly from Greenland and Nunavut.

Will Steffen and eleven of the world's top climate scientists (*Science,* Vol. 347, Feb. 13, 2015) stated**:** "We explore potential future trajectories of the Earth System by addressing the following questions:

1) **Is there a planetary threshold in the trajectory of the Earth System that, if crossed, could prevent stabilization in a range of intermediate temperature rises?**
2) **Given our understanding of geophysical and biosphere feedbacks intrinsic to the Earth System, where might such a threshold be?**
3) **If a threshold is crossed, what are the implications, especially for the well-being of human societies?**
4) **What human actions could create a pathway that would steer the Earth System away from the potential threshold and toward the maintenance of interglacial-like conditions?"**

The individual tipping elements are color-coded in Figure 1 according to estimated thresholds for global average surface temperature. As mentioned, the Arctic region is more than twice the global mean so "tipping elements at risk" for 1- 3 ^{o}C is already undergoing changes in a major way. **Arrows show the potential interactions among the tipping elements which could generate cascades**. **If current national pledges (Paris Agreement) to reduce greenhouse-gas emissions are implemented — and that's a big 'if' — they are likely to result in at least 3 °C rise by 2100 according to the *UNEP 2019 Gap Emissions Report.*** This is despite the goal of the 2015 Paris Agreement to limit warming to well below 2 °C and time will tell. **Warming must be limited to 1.5 °C to avoid a climate emergency according to** the 2018 IPCC publication of *Global Warming of 1.5 ^{o}C.* **To further complicate the climate crisis the IPCC stated that "after 2000 years the atmosphere will still hold 15-40% of the initial CO_2 released and 50% of any added atmospheric CO_2 removed after 200 years."**

Degraded Ecosystems are well known in the Great Barrier Reef and the Amazon rainforest; deforested regions now show **CO_2 as a source, not as the normal carbon sink,** further changing the climate and ecosystem**. NASAs Orbiting Carbon Observatories (OCO-2 & 3) found additional carbon loss (7 billion tonnes of CO_2 in 2016) from the Amazon as well as from central Africa and**

SE Asia. Warming in the Arctic and Antarctic, SE Asia and Australia, the latter two regions having been recently degraded from droughts and fires even without an El Nino event. The ice shelves and glaciers from Greenland, Western Antarctic and the Peninsula continue to lose hundreds of billions of tonnes of ice each year. Tipping points and cascading events are looking more likely as some regional temperatures are higher than the global mean - from northern Canada, Alaska and throughout Arctic. The updates from various sources (Environment Canada and Climate Change & NOAA) noted that Canada's mean temperature in 2019 from 1948-2018 was 1.7 °C while Northern Canada was 2.3 °C, 1.9 ºC in British Columbia, all above the global mean. According to NOAA, the Arctic temperature averaged 3.0 °C, and since 1900 Continental US mean temperature increased to ~2.0 °C. Recent forest fires and the devastation from the pine beetle are evidence of a changing climate in British Columbia. Warming must be limited to 1.5 °C as the optimum goal for this century. **This requires an emergency response for developed countries as well as India and China. "**Avoiding this threshold by creating a ***Stabilized Earth Pathway*** can only be achieved and maintained by a coordinated, deliberate effort by human societies to manage our relationship with the rest of the Earth System, recognizing that humanity is an integral, interacting component of the system" as stated by Will Steffen and eleven other climate scientists in the June 2018 edition of the *Proceedings of the National Academy of Sciences*.

Tipping elements, such as loss of the Greenland ice sheet and Arctic sea ice **(B)** and those indicated in **Figure 2** from **A to J** experience impacts and increasing each year. These tipping elements, along with some of the non-tipping element feedbacks (e.g. gradual weakening of land and ocean physiological carbon sinks, permafrost melt), could push the global average temperature even higher, inducing tipping in mid- and higher temperature clusters. "For example, tipping (loss) of the Greenland ice sheet could trigger a critical transition in the Atlantic Meridional Ocean Circulation (AMOC), which could together, by causing sea-level rise and Southern Ocean heat accumulation, accelerate ice loss from the East Antarctic Ice Sheet on timescales of centuries" according to Timothy Lenton and others in the November 28, 2019 *Nature* journal (Figure 2).

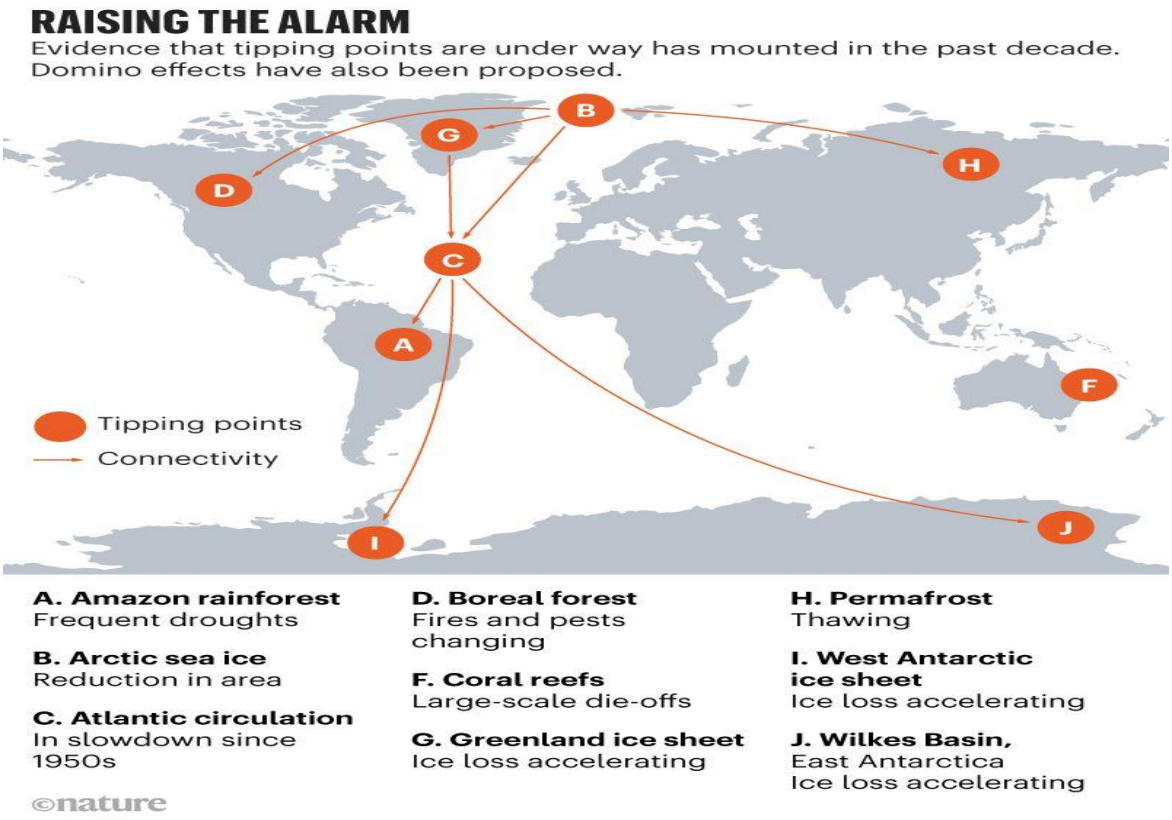

Figure 2. "Climate tipping points — too risky to bet against"- Timothy M. Lenton et al. *Nature*, Vol 575, Issue 7784, Nov. 28, 2019.

Although 2019 was not the worst year for fires or deforestation in the Amazon unlike in Australia, it was the year when the extent of fires and deforestation in the region garnered full global attention. The loss of forest cover leads to staggering losses of biodiversity, carbon sink, and, in turn, human well-being. In addition, although deforestation anywhere in the Amazon diminishes hydrological cycles, what happens in the Brazilian Amazon is particularly important because of the sensitivity of that part of the forest to incremental and cumulative impacts of vegetative decline from dieback. Current deforestation is substantial and frightening: 17% across the entire Amazon basin and approaching 20% in the Brazilian Amazon. Brazil's National Institute for Space Research recorded more than 74,000 fires by August 2019 in Amazonia. The years 2016-2018 saw extreme drought and forest fires in Fort McMurray, Alberta and vast regions in British Columbia. California, SE Asia and Australia with extensive bush fires in 2019 and continuing into 2020. All 'fire regions' saw a loss of carbon sink,

biodiversity loss of millions of species, extensive property damage and loss of human lives.

Dry seasons in Amazonian regions, SE Asia, Australia, western Canada and the southwest US are already hotter and becoming longer. “The increasing frequency of unprecedented droughts in 2005, 2010, and 2015/16 is signaling that the tipping point is at hand. Deforestation and other fast-moving changes in the Amazon threaten to turn parts of the rainforest into savanna, devastate wildlife and release billions of tons carbon into the atmosphere” as a warning from Brazilian climate scientists and cited in “Amazon Tipping Point: Last Chance for Action” by Thomas E. Lovejoy in *Science Advances* (Vol. 5, no. 12. Dec. 20, 2019).

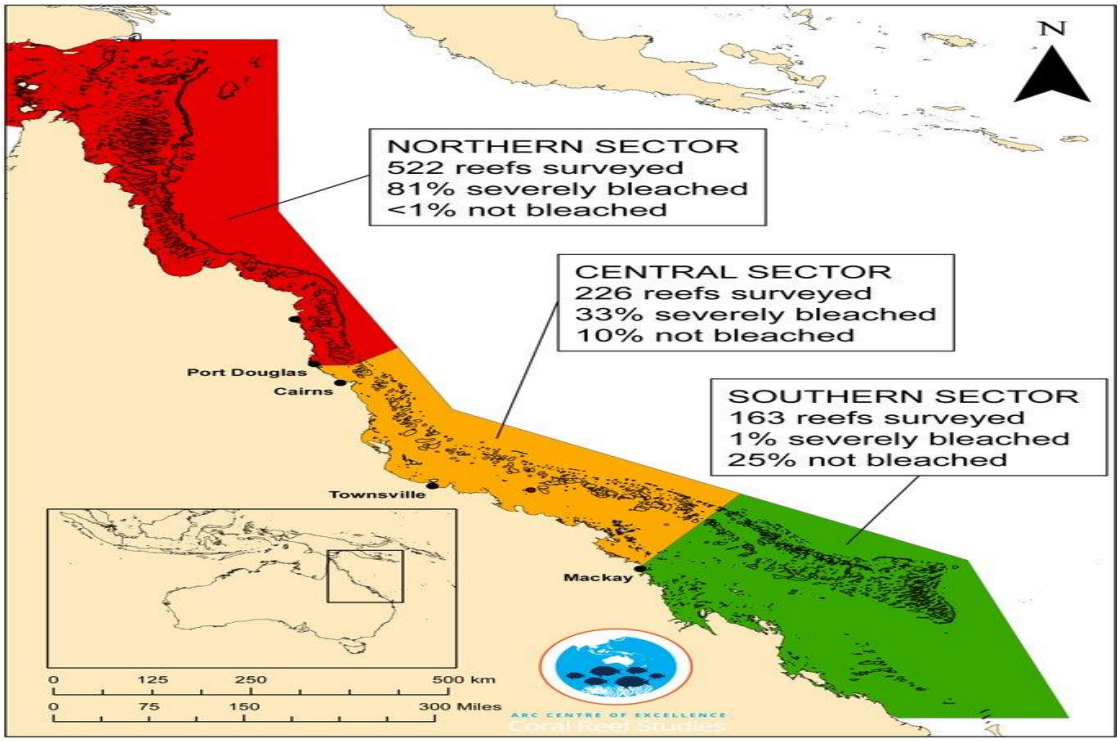

Figure 3. Great Barrier Reef Impacts. Credit Professor Terry Hughes

A global die-off of coral reefs in 2016 and 2017, which included the loss of nearly half of the **Great Barrier Reef**, shocked scientists (Figure 3). “Compared to coral bleaching in 1998 and 2002, the 2016 event (an El Nino year) was much more extreme - hotter, far more extensive, and deadlier,” says Professor Terry Hughes,

an expert on the reef and director of the Centre of Excellence for Coral Reef Studies at James Cook University in Australia. **The reef has changed forever. Extreme heat in 2016** damaged Australia's Great Barrier Reef much more substantially than initial surveys indicated, according to ongoing studies that have tracked the health of the coral treasure. Coral bleaching occurs when excessive heat kills or expels algae called **zooxanthellae,** which have a symbiotic relationship with reef-building corals. The algae provide the corals with energy and nutrients from photosynthesis; without them, the corals often die. "This drastically changed the species composition of almost one-third of the 3,863 individual reefs that comprise the Great Barrier Reef" according to Hughes.

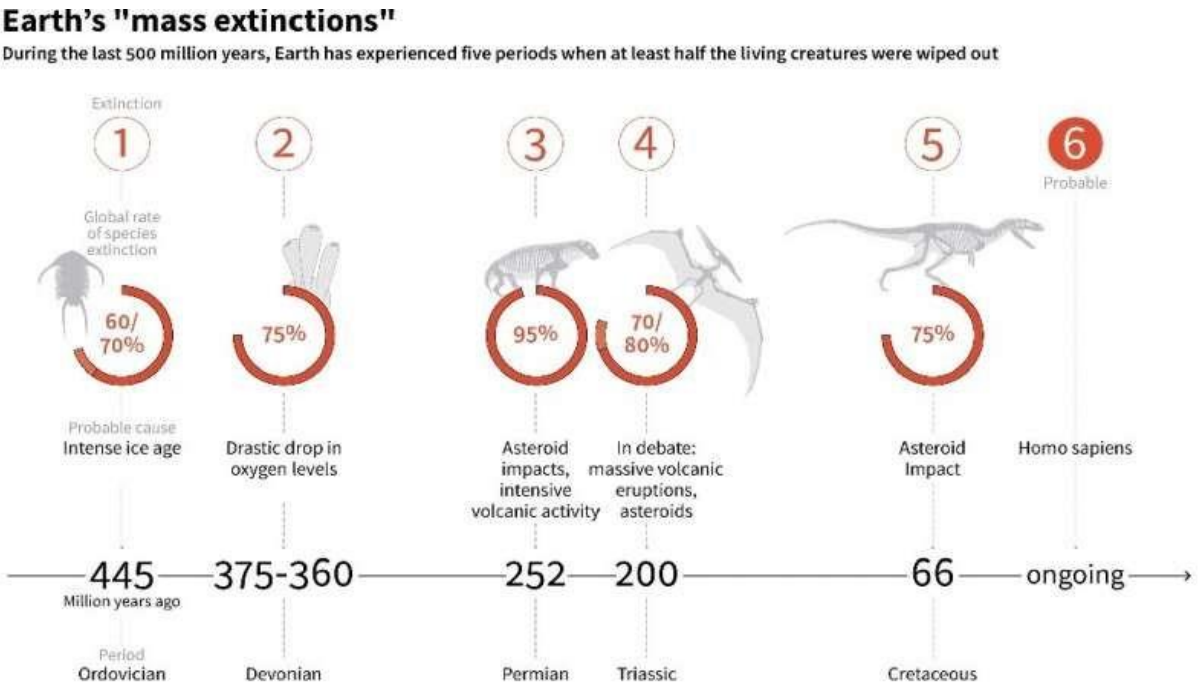

Figure 4. Earth's Mass Extinctions and ongoing *Homo Sapiens* engagement on a 'sixth mass extinction' today. Credit PNAS.

The published article **"Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines"** in *Proceedings of the National Academy of Sciences* (PNAS, July 10, 2017) noted that the "the population extinction pulse we describe shows, from a quantitative viewpoint, that **Earth's sixth mass extinction** is more severe than perceived when

looking exclusively at species extinctions. Therefore, humanity needs to address anthropogenic population extirpation and decimation immediately. That conclusion is based on analyses of a sample of 27,600 vertebrate species, and on a more detailed analysis documenting the population extinctions between 1900 and 2015 in 177 mammal species." **The scientists found billions of populations of mammals, birds, reptiles and amphibians have been lost all over the planet, leading them to say a sixth mass extinction has already progressed further than was thought.**

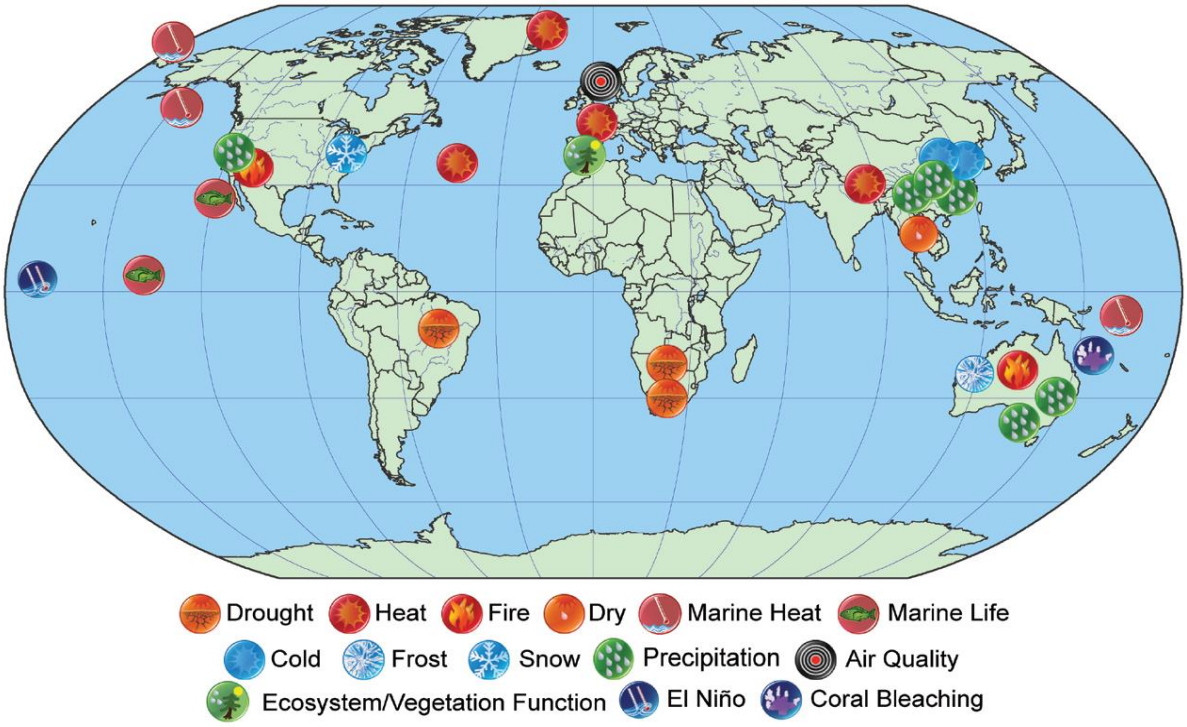

Figure 5. Extreme Climate Events & Impacts. For details access: ***Bulletin American Meteorological Society*** **(BAMS), Special Supplement** – Volume 99, No.1, January 2018

Regarding extreme and frequent weather/climate events (Figure 5), and as an important guide to tipping points, access the above from my book at **https://teachbcdb.bctf.ca/permalink/resource629. "Extreme weather and climate change"** section is carried on pages 145 – 167 for global impacts; the section **"The Alarm Has Been Sounded"** from pages 339 – 354 gives the reader a global overview on tipping events and the impact of hothouse earth. **Carbon Brief (https://www.carbonbrief.org) provides an excellent**

summary of attribution of extreme weather to climate change with an interactive global map of extreme events. "Our new analysis reveals that 69% of the 355 extreme weather events and trends included in the map were found to have been made more likely or more severe by human-caused climate change. Heatwaves account for 47% of such events, while droughts and heavy rainfall or floods each make up 15%" according to the *Carbon Brief* document.

Biosphere tipping points across a range of ecosystems from the Arctic to the Antarctic are increasing and interconnected across different biophysical systems. Those highly likely tipping points have already been cited; the cryosphere is an obvious visual climate system component with loss of ice sheets and glacial retreats and collapse leading to increase in sea level rise. Ocean heatwaves have led to mass coral bleaching at the Great Barrier Reefs and in Caribbean and Pacific equatorial regions with loss of marine biodiversity and food chains, further impacting on human livelihood. Deforestation in the Amazon and in SE Asia is creating droughts and savannas, loss of millions of species, affecting the lives of indigenous people, reducing the carbon sink and increasing carbon loss as noted by NASAs Orbiting Carbon Observatories. With increasing droughts and less rainfall, those ecosystems are now being impacted by forest fires originating from settlers for cattle ranching and agricultural crops like soybean. "Raising the Alarm" in Figure 2 illustrate the interconnectedness at risks of impending tipping points. Lenton and colleagues stated that the "clearest emergency would be if we were approaching a global cascade of tipping points that led to a new, less habitable, 'hothouse' climate state. Interactions could happen through ocean and atmospheric circulation or through feedbacks that increase greenhouse-gas levels and global temperature."

If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us. We need to change our approach to the climate problem. To sum up, this quote from Edward Wilson, the world's renowned entomologist and naturalist, in addition to reducing greenhouse gas emissions, preserving nature is key to our salvation: ***"Humanity is a biological species, living in a biological environment, because like all species, we are exquisitely adapted in everything: from our behavior, to our genetics, to our physiology, to that***

particular environment in which we live. The earth is our home. Unless we preserve the rest of life, as a sacred duty, we will be endangering ourselves by destroying the home in which we evolved, and on which we completely depend."

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BC Teacher Magazine – 2019 September/October Issue. Resources for Teachers on "Climate Crisis and Conserving Nature" pp. 24-25 by Harold Gopaul. www.bctf.ca.