HUMANS: THE PLANET-ALTERING APES

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ABSTRACTS

The Sixth Mass Extinction, the Tree of Life, and the Future of Humanity

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Vitus Bering, the famous explorer, led perhaps the most ambitious scientific expedition ever in the 1730s. Commanding 10,000 people, he was in charge of exploring the vast lands of Siberia and the unknown sea between Siberia and Alaska. In 1741, he was forced to land on what would be later known as Bering Island, where he would die. In his crew was a doctor and naturalist, Georg Steller, who discovered in the calm waters close to the island a massive three-ton marine mammal, similar to a manatee, that has the name of Steller sea cow.

The new species to science is famous because it became extinct only 27 years after it was discovered. Unfortunately, hundreds of other vertebrates have become extinct because of human activities in the last five centuries.

In our recent work, we analyzed whether the rate of modern extinctions caused by human activities is higher that the normal or natural extinction rate. This is important because it would let us understand if we are causing a mass extinction.

In the history of life on Earth, there have been five mass extinctions – episodes where large numbers of species became extinct in a short period of time. All mass extinctions have been caused by natural catastrophes, such as the impact of a meteorite.

We compared the normal – also known as background – extinction rates with the modern ones. In the normal rate, derived from a thorough analysis of thousands of mammal fossil and subfossil records from the last two million years, one would expect to lose two species for every 10,000 species present every 100 years. For example, if there are 40,000 species, we would expect to see eight extinctions in a century. A rate much higher than that would indicate a mass extinction.

We compiled the list of extinct and possibly extinct species from the International Union for Conservation of Nature (IUCN), an institution that compiles these data. We found that 477 species have become extinct in the last 100 years.

Under a normal extinction rate, we would have expected to have only nine extinctions; in other words, there were 468 more extinctions than would be expected in the last century! Putting it in a different way, the species lost in the last 100 years would have become extinct in more than 10,000 years under a normal extinction rate.

Our results are dramatic and tragic. We are losing species much more rapidly now than in the last two million years! At that pace, we may lose a large proportion of vertebrates, including mammals, birds, reptiles, amphibians and fishes, in the next two to three decades.

Those species are our companions in our travel across the universe. Losing them has many consequences. Those species are essential to maintain ecosystem services, which are all the benefits that we get for free from the proper function of nature. The combination of the gases of the atmosphere, the quality and quantity of water, soil fertilization, pollination and so on are ecosystem services. By losing species, we are eroding the conditions of Earth that are essential for human well-being.

There is still time to avert the most tragic consequences of a sixth mass extinction, because this one is caused by us. We need to curb the human population growth, social inequalities and more efficient of natural resources. We need to reduce habitat loss, overfishing and overhunting, pollution and other factors that are causing the current extinction episode.

We are the only species that has the capability to save all endangered animals. Paradoxically, saving them is the only way to save humanity.

Human Introduction and Dissemination of Invasive Species

David Holway, University of California, San Diego

The introduction of species into new environments has occurred throughout human history. Over the last century, however, the rate of new introductions has exponentially increased as a function of human population growth and the globalization of trade. While most introductions fail and most of those few that establish remain environmentally innocuous, a notable minority wildly proliferates in their new ranges. These invaders disrupt ecosystems and burden economies. Environmental impacts associated with invasions are hard to predict and vary in space and time but include ecosystem-level disruptions, species extinctions, and the homogenization of biodiversity. Economic costs, while challenging to quantify, are enormous and growing. Given that established invaders are difficult to eradicate, let alone manage, stopping invasions before they start remains the most effective strategy to limit further costs resulting from invasions. Challenges to implementing this approach include regulating trade and coordinating rapid governmental responses to emerging threats.

Loss of Species, Loss of Genetic Variation, and the Future of Earth's Biota

Oliver Ryder, San Diego Zoo Wildlife Alliance

We are experiencing an accelerated rate of loss of species due to human activities. This anthropogenic phenomenon extends beyond extinction. It encompasses an expanded loss of biodiversity as the genetic diversity of species diminish, reducing gene pools to "gene puddles." One-third of all species analyzed by the International Union for the Conservation of Nature (IUCN), are estimated to be undergoing population declines. Twenty-eight percent of 134,425 species assessed by IUCN are categorized as threatened or endangered.

We know details of species extinctions events from the fossil record, historical record, and from ancient DNA studies, and that historical processes shape extinction risk. Genome sequencing of extinct species reveals in many cases trajectories of population decline and accumulation of deleterious mutations. Habitat loss and changing eco-environmental conditions, competition, and other factors produce genomic impacts, influencing extinction risk.

The legacy of past events impacts resiliency of species in the current environment in interpretable ways. Demographic trajectories reveal vulnerability to extinction. This has been accepted for recent declines, e.g., population bottlenecks, but declining effective population size is associated with risk of endangerment over many thousands of years, as revealed by new data from analyses of aligned whole genome sequences of mammals. Some species with small populations have purged deleterious mutations, portions of their "genetic load," as assessed through genomic analyses that can serve to identify species' extinction risk.

Although we are but in the initial phase of exploring genomic correlates with past and pending extinctions, comparative and population genomics analyses can provide for knowledge-based management and serve to set priorities for protections and interventions.

Remarkable advances in genomics technologies portend a deeper understanding of the evolution of life and the vulnerability of extant species to changes now taking place through human agency. The loss of genetic diversity is associated with historical and ancient extinction events. Cryopreserved cell cultures and gametes can contribute to population sustainability and mitigate extinction risk, the full extent of which is yet to be realized, but which will depend exquisitely on expansion of current efforts in conservation biobanking.

Human Transformation from Environment Managers to Ecosystem Damagers

Jessica Thompson, Yale University

Beginning with *Homo erectus* at least a million years ago, hominins have used fire to engineer the world around them. The earliest uses of fire surely included cooking, changing the energy yields of foods. Such innovations altered the course of our evolution, facilitating the evolution of species that could adapt quickly using tools and social ingenuity. After 200,000 years ago, hominins also used fire to change the material properties of stone, pigments, sap, and wood. By at least 130,000 years ago, the impacts of this regular fire use are detectable in both Africa and Eurasia as vegetation changes that cannot be explained by changing climates alone. In southern-central Africa, changes wrought by early human fire use were so profound that there was significant transformation in erosion regimes. Although these changes represent a fundamental shift in the role of humans as dominant shapers of their environments, ecosystems adjusted as early humans remained embedded within them. Then, with the advent of agriculture and pastoralism in the Holocene, the strategy that had remained stable for at least 90,000 years began to unravel. With unprecedented speed, humans transformed themselves and the world around them through domestication and changes in land use, prioritizing survival of a few species over many. Although we built our ability to bend environments to our needs on millions of years of evolution and innovation, humans are not now simply shifting to another sustainable balance. Rather, we continue to push environmental thresholds across one tipping point after the next.

Anthropogenic Global Water Insecurity

Asher Rosinger, Pennsylvania State University

Humans have adapted to meet their water needs across disparate environments over time using behavioral adaptations. Yet, as temperatures rise and freshwater sources become depleted, it is critical to understand 1) how populations modify their environments to meet their water needs, and 2) the consequences of these anthropogenic - or human caused changes - on the environment and further on human health. This talk will provide an overview of different global water challenges and focus on a couple of case studies to highlight how development projects in remote areas that provide easier access to water, which may be high in salt or other contaminants, can unintentionally worsen health outcomes and hasten water depletion.

Large-Scale Human Modification of the Planetary Microbiome

Rob Knight, University of California, San Diego

Through the Earth Microbiome Program and complementary efforts, we have sampled a broad range of microbiomes from across the planet. All microbiomes that have been studied are impacted by human activity — the effects of industrialization on the human microbiome are best characterized, but capture of animals in zoos, domestication, modification of soils through agricultural practices, and modification of freshwater and marine microbiomes have all been well characterized. Indeed, the pervasive role of environmental microbiomes in biogeochemical cycles necessary to sustain life led to a position paper entitled "Scientists' warning to humanity: microorganisms and climate change", the title of which speaks for itself. However, there is hope. Just as there have been relatively few extinctions in the ocean ecosystem relative to terrestrial ecosystems, because the ocean is vast and connected and most species are still present somewhere (i.e. there are no mammoths but there are still blue whales), microbial ecosystems are also vast, connected, and likely harbor "seed banks" of globally rare but locally abundant microbes that can be used for re-seeding. Efforts such as the Microbiota Vault will be especially important in this respect, but also new monitoring and modeling approaches will be understand where to look globally for the best specimens and microbes to preserve.

Environmental Impacts of Human Domination of the Global Nitrogen Cycle

David Tilman, University of Minnesota and University of California, Santa Barbara

Humans now annually add more biologically available nitrogen to the Earth's land surfaces than do all natural processes. For three billion years, available nitrogen had been the major limiting currency for life on Earth. The recent human disruption of the global nitrogen cycle is causing major environmental harm, including water and air pollution, marine dead zones, 10% of global greenhouse gas emissions, and species extinctions. Three major ways to solve this nitrogen problem are (1) much more efficient global use of nitrogen fertilizers; (2) shifts to lower-meat and healthier diets; and (3) halting the conversion of food crops into biofuels, such as US corn ethanol used for transport.

Nitrogen, carbon, hydrogen and oxygen are essential elements for all forms of life on Earth. Ever since the earliest emergence of life three billion years ago, nitrogen – which is required to make proteins – has been the most limiting of these elements. However, new methods of agriculture, that began with the Green Revolution in the 1960's and have been massively expanding ever since, now add more nitrogen to terrestrial ecosystems than all natural processes combined. The resulting nitrogen pollution has highly detrimental environmental impacts.

Although nitrogen is 78% of the atmosphere, N_2 gas is an incredibly stable compound because of the amount of energy needed to break the triple bond that holds the two N molecules together. For about a billion years, lightening was the major way that this N – N bond was broken to create the biologically available forms of nitrogen that all plants require. The evolution of nitrogen-fixing cyanobacteria and the later evolution of nitrogen-fixing land plants, such as legumes, contributed to increased availability of nitrogen for land plants, thus allowing the emergence Earth's forests, grasslands and savannas. For millennia, all natural processes have tended to release a total of about 150 Tg/yr of biologically available nitrogen into Earth's land ecosystems via lightening and natural legume fixation (10 Tg/yr and 140 Tg/yr, respectively). Mainly because of the massive intensification of global agriculture since 1960, human actions now release an additional 210 Tg of available N. In particular, in 2021 global agriculture used 115 Tg of nitrogen fertilizer, added 40 Tg more from legume crops, 20 Tg more came from fossil fuel combustion and 35 Tg more from land clearing and tilling of soils.

Human domination of the global nitrogen cycle has three major environmental impacts: greenhouse gas emissions; water and air pollution; species extinctions.

- Soil microbes convert about 1% of nitrogen fertilizer into nitrous oxide, a greenhouse gas that is 300-times more potent than carbon dioxide. This agricultural emission represents about 10% of the global sum of all greenhouse gas emissions.
- Nitrate and nitrite pollution of streams, rivers, and lakes can cause blooms of often toxic cyanobacteria that have made major water supplies in numerous countries undrinkable. These algal blooms also harm freshwater fisheries and reduce the recreational value of freshwater ecosystems. Pollution of groundwaters with nitrite and nitrate from fertilized croplands can cause blue-baby syndrome and make once-healthy well waters become unsuited for human consumption.
- Runoff of available nitrogen from farms is carried to the oceans by most major rivers, and often kills all fish in huge nearshore areas, creating large marine "dead zones."
- Recent research has shown that ammonia from both nitrogen fertilization and livestock operations dissolves into the atmosphere, creating nucleating sites that generate tiny health-harming particulate matter called PM2.5. In the US alone, these agricultural air emissions cause about 20,000 excess deaths per year from lung and heart diseases.
- Agricultural nitrogen pollution is a major cause of species extinctions. For instance, for animals that live in freshwaters, including amphibians and fish, water pollution is often their greatest

extinction risk. Atmospheric deposition of biologically available nitrogen of agricultural origin onto terrestrial ecosystems a major threat to plant species. Most plant species have a series of evolved traits that make them good competitors for soil nitrogen. However, when nitrogen deposition make a different soil nutrient, such as calcium or phosphate become limiting, plants are nitrogen-efficient lose out in competition and can be driven locally extinct by the few species that are strong competitors for calcium or phosphate.

How to Feed 10 Billion People

Walter Willett, Harvard T.H. Chan School of Public Health

The world is facing a health crisis due to increasing rates of obesity and diabetes, and the consequences of this pandemic will accumulate over the coming decades. Simultaneously, climate change is accelerating and is already having devastating effects that will undermine our ability to feed the world's growing population. In turn, our food systems contribute importantly to greenhouse gas emissions, water and land use, and multiple forms of pollution. Thus, a solution to feeding what will be about 10 billion people by 2050 diets that are both healthy and environmentally sustainable presents an opportunity to mitigate many global challenges. The EAT-Lancet commission addressed this challenge stepwise by defining healthy diets quantitatively, determining whether these can be produced within planetary boundaries for greenhouse gas emissions and other environmental factors, and identifying strategies to achieve these goals. Any solution must assume that we rapidly shift from fossil fuels to green energy. The commission found that global adoption of a flexitarian dietary pattern that could include up to about two servings per day of animal sourced foods, together with improvements in agricultural practices and reductions in food waste, would have major benefits for human health and allow us to stay within planetary boundaries. Achieving this will require the engagement of governments at all levels, civil society, and individuals.

Humans vs. Humankind: Are Human-made Chemical Pollutants Impacting Global Fertility?

Patricia Hunt, Washington State University

Human-made chemicals with the unexpected ability to interfere with our body's endocrine system have become prominent contaminants in daily life. Because the hormones produced by our endocrine system create complex signaling networks that control our growth, maturation, fertility, immunity, behavior, and sleep, these *endocrine disrupting chemicals*, or *EDCs*, can exert powerful biological effects. Declines in human fertility evidenced by falling sperm counts and increases in the incidence of infertility raise concern that daily exposure to EDC contaminants already is impacting human fertility. By design, all species are responsive to their environment. In humans, this responsiveness means that changes in our environment can affect the production of eggs and sperm, the growth and development of the fetus, and adult susceptibility to disease. While data from experimental studies link EDC exposures to effects on all of these, some exposure effects exhibit the remarkable ability to affect not only the exposed individual but also subsequent generations of unexposed descendants. Thus, in a 21st century world characterized by environmental crises, EDCs represent a planetary health problem with the potential to affect future generations.

Accumulating Space Debris and the Risk of Kessler Syndrome

Alice Gorman, Flinders University

In 1957, the USSR launched Sputnik 1, the first human object to leave Earth. In the 65 years since then the region of Earth orbit has become filled with satellites and space junk. The proliferation of debris has led to the prediction of Kessler Syndrome, a state where a never-ending cascade of collisions between orbital objects renders parts of space unusable for human purposes. However, there are many different ways to look at the space junk surrounding Earth. For example, it is also an archaeological record of humanity's first steps into outer space, a cultural landscape created by the combined effects of natural and cultural processes, and a technological signature of the same kind that SETI (Search for Extraterrestrial Intelligence) researchers are looking for around exoplanets in other solar systems. It's unclear when or whether the tipping point into Kessler Syndrome might be reached, but if humanity is confined to Earth in the future, what will this mean?