Matters of Life and Death:
Change Beyond Planetary Homeostasis

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Physiology is the “science of life” and, as physiologists, we are interested in the function and survival of diverse lifeforms including humans. The Physiological Society’s recent “Extreme Environmental Physiology” meeting addressed the impact of the external environment on human physiology – fascinating papers from this event will appear in *Experimental Physiology* in the coming weeks. But at the meeting we also “flipped the ecological coin” to discuss the impact of humans on the environment. These two aspects are, of course, intimately related: humans impact on the environment and survival of the biosphere, and the changed environment impacts on the health and survival of humans.

From the cell to the complex organism, all life responds to (internal and external) environmental change, to remain within defined physiological boundaries. Breaching these bounds is fatal - and survival thus depends upon the ability to sense and respond to changes in that environment. Change is detected by sensors, the signal from many of which (such as those which detect change in skin temperature) relates to the scale but also speed of change: rapid change generally evokes a greater response, whilst very slow changes may evoke no response at all (Keatinge *et al.* 1986). Afferent sensory input, in turn, drives mitigation (physiological or behavioural [*e.g.* sweat, seek shade]) or adaptation (short or long-term processes which enhance the ability to tolerate the ‘new normal’). If the change is great or fast enough, it may exceed the speed of (or capacity to) correct or adapt to the change, and death results.

Do the planet, and human awareness, follow the same principles? Can our planet and its ecosystem cope with small, slow environmental change but not with rapid large scale change? And for humans, are the fastest global changes just too slow to reach consciousness and provoke a response?

It took over 3.5 billion years for multi-celled life to evolve from the most primitive organisms on Earth, and 4.2 billion years for humans to appear, with their populations reaching 1 billion in number by 1823. Small, slow change. But then, with the advent of the agricultural and industrial revolutions, our numbers grew: by another billion in only 123 years, then 33 years, and then every 12-14 years since.

Large, fast change. And the speed and scale of the growth in humanity's industry - and use of natural resources - has greatly exceeded that of its population.

Effectively unlimited resources – like sunlight or the forces of tides – can be used without restraint. Otherwise, resource use can only be sustained if their rate of replication (animals, plants) or replenishment (soil, water) matches or exceeds their rate of consumption. For living organisms, their habitats and ecosystems must be preserved. All other inanimate or non-breeding source materials have to be recycled.

But humanity has ignored such simple logic. We have mined and polluted, killed for food and razed habitat, destroyed diversity and created monocultures. The land surface area grazed by cattle now exceeds that of the whole of the continent of Africa. Over 70 % of all birds on the planet are now farmed poultry. Between 2014-2018 the world lost an area the size of Britain in trees, and the annual rate of tree loss increased by 43 % (Rowling, 2019). *Every second*, we destroy half a soccer pitch area of rainforest. In the same second we throw away 16,600 plastic bottles and 127,000 plastic bags (Euromonitor International, 2018; Elmore, 2019). The world loses 24 billion tonnes of topsoil each year (UN, 2017), and may have run out of topsoil, on which today's food is grown, in a matter of decades (Marler & Wallin, 2006). Worldwide, we use up to 2,500 km^3 of water for crop irrigation, and overuse of groundwater or finite resources (such as fossil aquifers) makes this unsustainable. Consider, too, chemical and nanoparticle pollution.

The result of our actions? The number of vertebrates on the planet has fallen by 60 % since 1970 (WWF & ZSL, 2018) and, according to the United Nations Convention on Biological Diversity, six species were becoming extinct every hour even 12 years ago (Djoghla, 2007). At this moment, 1 million species are threatened with extinction (UN, 2019). Big change. Fast change.

And now, on top of this, comes climate change. It took some 350 million years to draw down atmospheric carbon dioxide (CO_2) into plants and animals which locked the carbon below ground in the form of fossil fuels. We only started burning these a little over 160 years ago, and especially in the last 50 years. In *every second* of 2018, we burned a quarter of a million kilograms of coal, 116 million litres of gas, and

used 7 million litres of oil (Sadamori, 2018). In the space of 50 years, atmospheric CO_2 emissions have reached the highest concentrations in over 3 *million* years. The consequent trapping of longwave radiation has led to energy gain (1750-2011) at a rate of 2.8 $W.m^{-2}$ of the Earth's surface (Myhre & Shindell, 2018), the equivalent of four Hiroshima Bombs *each second* (Cook, 2014). Polar ice is melting, sea levels are rising, and add energy to an atmosphere, you get weather - more of it, and ever more extreme.

Our impacts on our planet have been too great and too fast. Our ecosystems cannot mitigate these impacts, and the speed and scale of change has been too fast for them to adapt. Sadly, when measured in terms of a human life, the scale of change is harder to detect. Perhaps this is why humans, sitting atop a teetering ecosystem pyramid, seem intent on continuing to hack at its base. The rate of change is too slow in human terms to provoke an appropriate reaction in most. This, despite warnings that change is the greatest threat to human health of this century (Costello *et al.* 2009).

But some people *are* noticing. This year alone has seen a Climate Emergency declared by groups as disparate as the Australian Medical Association and the UK Government. Greta Thunberg has led school strikes. Extinction Rebellion has taken to the streets. So the sensors of some have begun to fire - but fire late. We cannot now adapt to survive; we have to mitigate, to stop doing the damage: our shopping, transport, fuel and dietary choices have to change, and change fast. To achieve the best catastrophe we can, each of us must reduce our greenhouse gas emissions by nearly 8 % next year - and then every year thereafter.

We need to sense the change that is occurring around us and respond to that change with the requisite speed and at the requisite scale. Our physiology, and therefore our survival, depend upon it.

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