PHILOSOPHICAL TRANSACTIONS B

royalsocietypublishing.org/journal/rstb

Research

Cite this article: Waring TM, Wood ZT, Szathmáry E. 2023 Characteristic processes of human evolution caused the Anthropocene and may obstruct its global solutions. *Phil. Trans. R. Soc. B* **379**: 20220259. https://doi.org/10.1098/rstb.2022.0259

Received: 22 December 2022
Accepted: 19 June 2023

One contribution of 18 to a theme issue 'Evolution and sustainability: gathering the strands for an Anthropocene synthesis'.

Subject Areas:
evolution, environmental science, theoretical biology, ecology

Keywords:
ETII, Anthropocene, evolutionary transition, cultural evolution, sustainability, human evolution

Author for correspondence:
Timothy M. Waring
e-mail: timothy.waring@maine.edu

Characteristic processes of human evolution caused the Anthropocene and may obstruct its global solutions

Timothy M. Waring[1], Zachary T. Wood[2] and Eörs Szathmáry[3,4,5]

[1]Mitchell Center for Sustainability Solutions, University of Maine, Orono, ME 04469, USA
[2]Department of Biology, Colby College, 4000 Mayflower Hill Drive, Waterville, ME 04901, USA
[3]Institute of Evolution, Centre for Ecological Research, Budapest, Hungary
[4]Center for the Conceptual Foundations of Science, Parmenides Foundation, Pöcking, Germany
[5]Plant Systematics, Ecology and Theoretical Biology, Eötvös University, Budapest, Hungary

TMW, 0000-0001-7364-1130; ZTW, 0000-0001-7369-9199; ES, 0000-0001-5227-2997

We propose that the global environmental crises of the Anthropocene are the outcome of a ratcheting process in long-term human evolution which has favoured groups of increased size and greater environmental exploitation. To explore this hypothesis, we review the changes in the human ecological niche. Evidence indicates the growth of the human niche has been facilitated by group-level cultural traits for environmental control. Following this logic, sustaining the biosphere under intense human use will probably require global cultural traits, including legal and technical systems. We investigate the conditions for the evolution of global cultural traits. We estimate that our species does not exhibit adequate population structure to evolve these traits. Our analysis suggests that characteristic patterns of human group-level cultural evolution created the Anthropocene and will work against global collective solutions to the environmental challenges it poses. We illustrate the implications of this theory with alternative evolutionary paths for humanity. We conclude that our species must alter longstanding patterns of cultural evolution to avoid environmental disaster and escalating between-group competition. We propose an applied research and policy programme with the goal of avoiding these outcomes.

This article is part of the theme issue 'Evolution and sustainability: gathering the strands for an Anthropocene synthesis'.

1. Introduction

Our species has come to dominate Earth's ecosystems. This state has been termed the 'Anthropocene' [1], a geological epoch defined by stratigraphic signatures of human activity such as concentrations of carbon dioxide and radioisotopes [2]. In this period, humans have changed global ecological processes [3] and shifted in the interactions between ecosystem processes and evolution in countless species [4].

The Anthropocene creates a novel evolutionary condition for both the biosphere and our species. Our exponential population growth, dramatic environmental modification and technological systems have created a novel evolutionary environment for humanity, which may entail existential risk for humanity [5]. Also, human environmental impacts are on course to constitute one of the larger extinction events over approximately 3.7 billion years of life [6]. However, while mass extinctions are mostly thought to be caused by violent non-biological causes, such as volcanism or impact events, the current mass extinction (i.e. [7]) appears to be a biogenic event caused by a single species.

Research on human environmental impacts has mostly overlooked the role of human evolution. Likewise, contemporary visions for environmental stewardship (e.g. [8]) are rarely informed by either human evolutionary history

THE ROYAL SOCIETY PUBLISHING

or current evolutionary mechanisms. When evolutionary theory is invoked, it is often used as a metaphorical tool rather than a useful mechanistic theory of change (e.g. [9,10]). Currently, global environmental research does not commit to an evolutionary understanding of human behaviour or integrate the evolutionary history and processes that have resulted in the global-scale impacts of human societies. Like Ehrlich & Ornstein [11], we propose that understanding human evolution is key for understanding the causes and progression of the Anthropocene as well as for the effort to design a livable future.

Research that does connect human evolution to anthropogenic environmental impacts highlights two key factors: the role of culture and the importance of group structure and cooperation [12,13]. The evolution of human culture (including language) is widely understood to be a central feature of human evolution (e.g. [14]) and is increasingly recognized as important in understanding human environmental behaviour [15]. However, the role of culture in human environmental impact is complex. On one hand, as Ehrlich & Ehrlich [16, p. 781] suggest: 'Humanity created the Anthropocene through cultural evolution'. On the other, human culture is seen as necessary to achieve sustainability through cooperative solutions [10,17,18]. Thus, adaptive cultural evolution is implicated both as a cause of global environmental decline, and the key to spread policies and solutions to mitigate anthropogenic impacts [19].

The evolution of group-level cultural traits via cultural group selection [20,21] is a central candidate mechanism to explain the evolution of human environmental exploitation [22]. Ellis proposes that the cumulative feedbacks between cultural niche construction and cultural group selection have led to the human domination of the biosphere by selecting for groups that exploit natural resources ever more efficiently and at ever greater scales [3,23]. Theoretical models have shown that cultural group selection can generate sustainable resource use behaviour in simple systems of groups under conditions of territorial resource control [24,25] and empirical research has begun to bear this out [26,27]. However, human prosociality is expansive and goes beyond simple parochial patterns of cooperation. For example, humans readily form cooperative connections and exchange cultural elements between groups [28]. Between-group cooperation can take the form of trade networks, military alliances and treaties, and may often be coupled with cultural transmission including the sharing of language and traditions. These long-distance between-group interactions may play a role in natural resource management and environmental exploitation as well [29]. Human capacity to grow new cooperative and cultural connections between groups may even result in the formation of new social units at a larger scale. Therefore, based on what we know of the evolution of human culture, cooperation and groups, it remains unclear what the prospects for global cooperation in environmental management are. This paper is a contribution to a more complete theory of how human evolution gave rise to and may unfold during the Anthropocene.

It has been proposed that human evolution can be described as an evolutionary transition in inheritance and individuality (ETII) [30]. In this paper, we develop the hypothesis that the human domination of the biosphere is a unique consequence of this ongoing human evolutionary transition and explore the implications. Our effort is in the spirit of developing the novel theory necessary for the unprecedented challenges of our time [31].

2. Human evolutionary ratchets help explain the Anthropocene

Many agree that human evolution may be partly defined by some kind of evolutionary transition [32–36]. These proposals differ on whether the transition hinges on individuality or inheritance. For example, while protolanguage may have appeared in *Homo erectus* and catalysed human evolution [37], the 'social protocell' model [36] depends on differential reproduction of cultural groups with heritable institutions [38]. For Powers *et al*. [35], the emergence of culturally determined institutions marks the central transition. Others posit that a transition in individuality is ongoing and may culminate in the future [34] or even involve an egalitarian transition joining humans with artificial intelligence [39]. The ETII hypothesis builds on these proposals. It posits that long-term human evolution is driven by a shift in the primary mechanism of evolutionary inheritance from genes to culture [30], caused by the greater adaptive power of cultural evolution in humans (e.g. [14,40–42]).

The hypothesis suggests that human evolution is dominated by a positive feedback between the adaptive capacity of human culture, which generates group-level adaptations, and the strength of human groups which employ them (figure 1*a*). This evolutionary ratchet generates two central patterns. The first is a shift in the bulk of adaptive information from genes to culture. This pattern, called *'fitness export'* [43,44], occurs as the human reliance on group-level social and technological adaptations increases, causing selection on human genes to wane. The second is a shift in human organization from individuals to groups, a defining pattern of evolutionary transitions in individuality (ETIs) generally [45]. This shift is characterized by increases in the spatial and social scale of societies and their degree of internal cooperation. Like other ETIs, the human ETII involves a positive feedback mechanism [46] which drives the emergence of a higher level of organization and individuality. Unlike other ETIs, a hypothetical ETII would conclude with the emergence of a population of *cultural superorganisms* and is therefore novel in many regards. The ETII hypothesis is supported by evidence for group-structure and cultural adaptation in human evolution [20,47–49], but raises questions about the evolution of human interaction with the environment.

We have argued that the evolutionary ratchet of the ETII helps to explain patterns of human evolution past and present [30]. Cumulative cultural evolution is believed to have strong evolutionary ratcheting effects [50,51]. Here, we explore how the same ratcheting feedbacks might additionally generate interactions between human evolution and ecology in the past, present and future. The ecological setting is crucial for the understanding of particular major transitions in general [52].

The logic connecting human domination of the biosphere to the ETII is simple. The evolution of human societies has been typified by positive feedback between the adaptive capacity of human groups and their growth and proliferation (ETII ratchet, figure 1,A). These dynamics entail positive feedback between the scale and intensity of environmental

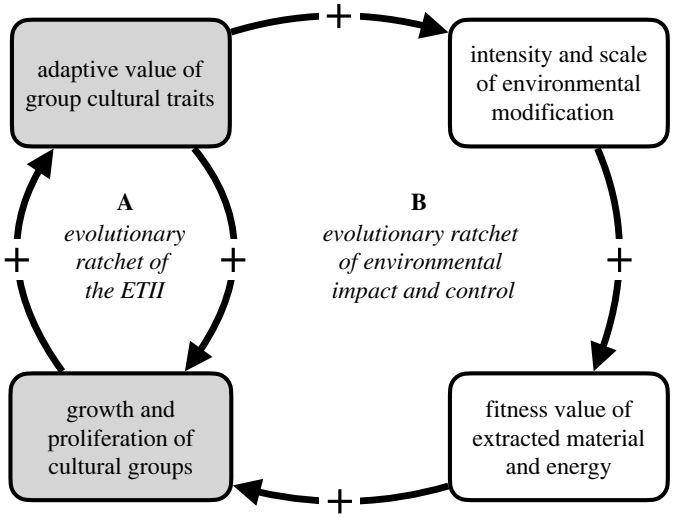

Figure 1. An evolutionary ratchet of environmental intensity. The positive feedback system of the ETII (A) entails additional positive feedback (B), in which group-level cultural innovations in environmental management tend to increase the scale and intensity of environmental modification and extraction, which in turn accelerates the proliferation of cultural groups with those innovations.

resource use and the adaptive benefits human groups extract from those resources (environmental ratchet, figure 1,B).

Proposals for the Anthropocene geological epoch have placed its onset in the mid-twentieth century [2] with the global sedimentation of novel inorganic residues. However, these recent global-scale impacts are clearly part of a larger trend in human environmental impacts and the scale of human societies with roots millions of years in the past. This trend, we propose, is the ETII.

This cumulative process extends from the emergence of cultural transmission in the *Homo* lineage and includes collective environmental practices such as cooperative hunting [53], herding [54], fishing and agriculture [55]. Ongoing iterations of growth, elaboration and expansion have resulted in both continental-scale societies of immense power and the global environmental impacts they have engendered.

3. The evolution of the human ecological niche

The relationship between organisms and their environment is typically described through the concept of the *ecological niche*. In classical niche theory, the niche is the set of abiotic and biotic conditions under which a species can survive and reproduce at a population-sustaining rate [56]. Organisms can also modify their environment to make it more favourable for themselves—this process is known as *niche construction* [57]. Humans are perhaps the ultimate niche constructors in terms of our environmental modifications. In humans, niche construction is largely the result of accumulated cultural adaptations for environmental modification and resource extraction. This has been termed *cultural niche construction* [58–60]. Over evolutionary history, the human niche has changed dramatically (table 1), growing from that of a primate omnivore to a planetary-scale niche constructor [72], affecting nearly every aspect of ecology [73], evolution [74] and eco-evolutionary dynamics [4] in the natural world.

As cultural adaptations for niche construction have accumulated over evolutionary history, the scale and intensity of human environmental impacts have grown in tandem. Prior to human cultural and linguistic abilities, human ecological impacts were not substantially different from that of other large primates. That changed when hominin species developed collective scavenging and hunting behaviours somewhat prior to 2 Ma [67–69]. A strategy of confrontational scavenging may even have predated *H. erectus* [64]. These collective strategies were probably facilitated by protolanguage and vice versa [75,76]. The global expansion of modern humans beginning approximately 200 kya [65] represented another change in the human niche. Human expansion was probably caused by improvements in culturally coordinated group behaviour and the cultural transmission of fire making methods and resulted in the extinction of numerous large mammals [77,78]. These cultural and group-level characteristics enabled a transition to cooked food with greater nutrient availability, and fewer toxins and pathogens. Increases in carnivory probably helped early humans expand their geographical niche [79]. Niche construction continued with the domestication of dogs (*ca* 23 kya, [80]) and cattle (*ca* 11 kya, [81]). Human impacts grew significantly with the advent of agriculture at the start of the Holocene *ca* 11.5 kya [82,83]. The emergence of agricultural societies with heavy local impacts including irrigated farmland, controlled pastures and cities contributed to a global transformation of land use by 3000 ya [84]. The industrial revolution marked the emergence of group-level inorganic metabolism in which human groups vastly expanded their ability to control inorganic energy and materials, giving societies more power, and greater control over the environment. Industrial technology resulted in new types of impacts including chemical pollution, ozone degradation, fishery collapse, landscape modification, groundwater depletion, anthropogenic drought, toxic pollution, radioactive waste, anthropogenic climate change and others.

A few observations can be made. First, the size of human groups have increased by eight orders of magnitude over human evolution. Second, the scale and intensity of environmental resource use and concomitant impacts have also grown dramatically over human evolution, reaching and exceeding global limits in some cases (i.e. [85]). The dramatic growth in the scale of the human ecological niche implies that evolutionary interactions between human groups have also changed. Evolutionary competition between human groups was initially low

Table 1. Changes in the ecological niche of human groups over evolution. The ETII hypothesis puts the human domination of the biosphere into a long-term evolutionary perspective, with the emergence of systems of environmental modification and control of increasing intensity and scale. Population estimates from Morris [61] and Klein Goldewijk *et al*. [62]. For additional detail, see table 3 in Ellis [3].

period	pre-transition	I	II	III	IV	V	VI		post-transition
state	most recent common human ancestor	hominin expansion	modern human expansion	global expansion	agricultural revolution	industrial revolution	the Anthropocene	…	hypothetical cultural superorganism
realized ecological niche	primate omnivore	primate omnivore and scavenger, hunter	apex omnivore	apex omnivore, ecosystem engineer	human-dominated landscapes with domesticates, organic metabolism	human-controlled landscapes with organic/inorganic metabolism	human-controlled landscapes with organic/inorganic metabolism	…	(unknown)
start of period	approximately 3 Ma [63,64]	>2 Ma–0.5 Ma	approximately 200 kya [65]	approximately 70 kya	approximately 10 kya	approximately 220 ya	present	…	(unknown)
species population	NA	NA	NA	approximately 2 000 000	approximately 4 400 000	approximately 990 000 000	approximately 8 000 000 000	…	(unknown)
population of largest city	NA	NA	NA	NA	approximately 1000	approximately 1 000 000	approximately 25 000 000	…	(unknown)
spatial scale of largest society	NA	NA	NA	local camps, <1 km^2 [66]	sub-regional	regional	continental	…	(unknown)
environmental impact intensity	equivalent to other primate species	greater than other primate species	much greater than other primate species	global expansion, megafaunal extinctions	regional driver of ecosystem function, species evolution, artificial selection	regional driver of ecosystem function, species evolution, inorganic pollution, mass extinction	global driver of ecosystem function, species evolution, gene modification, inorganic pollution, mass extinction	…	(unknown)
group-level traits of environmental control	NA	local collective hunting and scavenging [67–69]	local cooperative hunting [70], fishing and gathering, fire control [71]	territorial cooperative food provision, shelter and defence	sub-regional domestication, cities, organic fertilizer, harvesting restrictions, stone architecture, canal irrigation	regional eradication policies, national environmental law, nature preserves	continental national environmental fines and taxes, genetic modification, anti-extinction policies, global environmental law	…	(unknown)

as groups were small and sparse. Most of human evolution can therefore be characterized as an eco-evolutionary regime of *indirect resource competition* between human groups in which no group could influence the global environment or all other groups. While inter-group competition and parochial altruism are thought to have played an important role in the evolution of hunter–gatherers (e.g. [86]), societal interactions (including trade and warfare) and environmental modifications remained local or regional. After the agricultural revolution, inter-group war became larger, more structured and more important in human evolution [87]. Following the industrial revolution, societal interactions including communication, trade, war, diseases and environmental interactions became increasingly global. Also, the survival and status of human groups became globally interdependent [88,89]. This began a new eco-evolutionary regime of *direct resource competition* in which single groups can strongly influence the global environment, and potentially all other groups. This novel eco-evolutionary condition for human groups typifies the Anthropocene. Three salient examples of this interdependence are anthropogenic climate change, the COVID-19 pandemic and the proliferation of society-ending nuclear weapons. Also, while the scale and impact of human groups has increased, the finite resources of Earth have not, which suggests that human groups may not yet be well adapted to the novel conditions of the Anthropocene.

4. Group-level cultural traits for environmental control

A general trend also emerges from table 1. *Group-level cultural traits* for direct environmental control have emerged in parallel with each new expansion in the environmental scale and intensity of human societies. These include *extractive traits* such as irrigation systems, forest harvesting machines and mechanized agricultural technology as well as *management traits* such as water quotas, forest use regulations and pesticide laws. Early human traits for environmental control are exemplified by coordinated food collection such as cooperative hunting [67–70], fishing and gathering that emerged in the Pleistocene. The emergence of agriculture in the Holocene involved more complex group-level environmental control traits including canal irrigation [90], harvesting restrictions, stone architecture, transportation and cities. Later, the industrial revolution was accompanied by even more complex traits, including continental trade and transport networks, eradication policies for nuisance species and diseases [91], agricultural subsidies, national environmental laws, natural space protections, environmental regulation, pollution fines, genetic modification, anti-extinction policies and the emergence of global environmental law [92].

Group-level environmental management traits are also evolutionarily novel, and the nature of and constraints on the evolution of these traits are poorly understood. Following our conceptual model in figure 1, novel technologies and systems for resource extraction (e.g. whaling ships) could enable the expansion of human groups. Larger groups encounter new challenges in managing the environment at the larger scale (e.g. decline of whale populations) and new opportunities (e.g. fossil fuel energy). Over time, groups may learn and evolve new traits, technologies and systems for controlling and sustaining these resources (e.g. whaling limits treaties), as well as new extractive technologies (e.g. fossil fuel combustion technology). In this hypothetical process, extractive traits emerge first, followed by societal growth. This may sometimes lead to constraints on extraction driven by an ongoing need energy and materials. So, the scale of *management traits* should often lag behind the scale of societal organization. For example, continental air quality laws can only emerge after a society has reached the continental scale.

Increasingly, policy scholars suspect that in the case of global resources such as atmospheric carbon dioxide or ocean pollution, sustainable management will require a complex set of *global cultural traits for environmental management*, including novel social, technical, and legal systems at the global scale (e.g. [93,94]). Thus, it would seem that planetary sustainability could most-readily be achieved by a global-scale cultural group with the proper group-level cultural traits. This is why Corning [95] suggests that a global superorganism may be necessary to tackle global climate change.

One early theory of global environmental sustainability is the Gaia hypothesis [96]. It suggests that Earth systems and the biosphere have evolved to become collectively self-regulating. But evidence does not support the original Gaia hypothesis [97]. In evolution, complex evolved traits necessary to maintain homeostasis emerge from long-term adaptive evolution among a population of self-organized systems rather than from self-organization alone. New versions of Gaia theory have argued that self-regulating ecological features could emerge via sequential selection for ecological persistence if communities can flexibly reassemble in a resilient biosphere [98–100]. However, global-scale reorganization would be very slow and persistence selection would probably oppose that of selection on sub-global groups. Therefore, the persistence selection mechanism would have to be strong enough to override selection on the rapidly evolving sub-global human groups, which is highly unlikely. Thus, even the newer Gaia theory does not provide a plausible route to global sustainability. Moreover, neither theory incorporates human cultural evolution.

5. The population structure problem of the human evolutionary transition

We can use this basic understanding of the evolution of group-level environmental management to explore the prospects for a sustainable or well-managed biosphere. As highlighted above, the hypothetical ETII engages an evolutionary ratchet that may have led human culture towards increasingly profound environmental impacts, at increasing spatial scale with consequences for the health of the biosphere and even the long-term survival of our species. Here, we argue that our specific evolutionary path will determine the fate of human–environment interactions and global sustainability. Our concern derives from four observations:

(i) *human evolution is driven by group-level cultural evolution in the very long term*: the ETII suggests that human evolution is driven by group-level cultural evolution [30], which requires a population of groups [21,20]. Evolutionary competition between groups is a key process in ETIs that strengthens group-level identities and solidifies group-level control of individuals and resources [45];

(ii) *global sustainability requires global cultural traits for environmental management:* the sustainable regulation of a planetary biosphere would appear to require a refined and complex set of technical and legal systems and behaviours (e.g. [94]), and would include and enforce cooperation between groups. These global cultural traits could be expressed by a single global society or global-scale individual. Such global cultural traits could evolve through adaptive cultural evolution among a population of global-scale entities;

(iii) *the scale of environmental management traits lags behind the scale of society:* extractive traits may precede the expansion of human groups. However, cultural traits for environmental management at a given scale seem to emerge most robustly within societies of that scale and therefore only evolve after those societies form. For example, strong fines for pollution are more common within nations that between them; and

(iv) *evolution in a population of sub-global groups favours the emergence of sub-global traits for environmental control*: Earth supports a population of evolving sub-global groups. Evolution among entities in a shared environment favours adaptations for resource competition and extraction (e.g. [101]). Thus, there can be limited collective action towards environmental stability in the face of evolutionary competition between groups.

Therefore, the population structure necessary for the adaptive evolution of global cultural traits for environmental regulation is in conflict with the current and historical evolutionary processes acting on human groups. Phrased another way, competition among cultural groups precludes the evolution of global systems to sustainably manage the planet. Cultural group selection could plausibly generate adaptive global cultural traits if operating among groups with sovereign control over separate planets. However, this is not likely to occur in our species in the foreseeable future, particularly before the worst effects of our global impacts (such as climate change) are felt. This idea is supported by mathematical models which show that environmental patchiness is often necessary for successful evolutionary transitions [102]. The problem is we have only one patch.

This is the *population structure problem of the human ETII*. To evolve the traits necessary to maintain a sustainable planetary environment, a population of global-scale societies is required. Short of gaining access to new livable planets, this problem appears to have no simple solution and poses mounting dangers for human survival and biosphere stability in the coming millennia.

6. Navigating human evolution in the Anthropocene

The Anthropocene and the ETII are linked by the scale of environmental control and cooperation they imply or require. The ETII operates on human cooperation over time, which global environmental challenges require. Also, the Anthropocene is defined by its global scale, a scale that human impacts have recently breached. Thus, we reason that factors and changes that influence human evolution and the ETII will have relevance for global environmental challenges, and vice versa.

Any domain of environmental management can be characterized according to two variables: the spatial scale over which the environmental resource must be sustained, and the level of cooperation necessary to benefit from the resource in a durable manner. Sustainability challenges require a minimum level of cooperation in a society of a certain minimum spatial size. For example, to solve local lake pollution, the level of cooperation needed is only that which is sufficient to stop pollution among the lakeshore residents, while to solve groundwater management, cooperation is needed among groundwater users of a watershed [103]. If these users are farmers who depend on groundwater irrigation for their livelihoods, the required level of cooperation is very high as cooperation might entail major economic loss. In this way, each environmental resource can be visualized as a *sustainability frontier* (figure 2).

Each new frontier presents an adaptive challenge that requires the development of novel social and technological arrangements (i.e. cultural traits) for environmental control at new and greater scales. Human societies have experienced many sustainability frontiers in the past, solving some (e.g. maintaining captive populations of food species, supplying nutrients for crop growth) and failing others (e.g. watershed pollution, biodiversity protection). The Anthropocene is characterized by global sustainability frontiers (disease, water, climate change, antibiotic resistance, zoonotic diseases and pandemics) which remain to be solved.

Each axis in figure 2 has a characteristic societal dynamic. The *y*-axis represents intensity of cooperation within groups. A general finding from the evolution of cooperation [45] and cultural multi-level selection in humans [20,47] is that cooperation in a group is often driven by competition between groups. Therefore, *increases in between-society competition tend to move societies along the y-axis* (i.e. [36]). For example, fierce competition between gangs of lobstermen seems to have driven the evolution of within-gang cooperation via cultural group selection [26]. The *x*-axis represents the spatial scale of resources and human groups. The spatial scale of a resource determines the spatial scale of a society capable of sustainably using it. For example, the Roman empire was among the first to build large-scale aqueduct infrastructure, because it occupied the territory necessary to control large-scale water distribution in part through the growth of political hierarchy. Therefore, *increases in hierarchical organization tend to move societies along the x-axis*.

Over human evolution, societies have grown in scale of environmental control, intensity of cooperation and in population size (figure 2, lower left). The evolutionary ratchet of the ETII hypothesis suggests that human evolution is unlikely to remain in this quadrant.

Hypothetically, a completed ETII would produce cultural superorganisms: societies with total and complete cooperation, including, presumably, the group-level reproductive centralization observed in eusocial insects. If an ETII were to complete, the transition might unfold over thousands to millions of years across this planet or many. However, the ETII may fail. Its core feedback mechanism of evolutionary competition between human groups in a shared environment could drive humanity to extinction through multiple scenarios (figure 2, top, population structure problem). By comparison, success in climate change requires a much lower level of cooperation (agreement to use certain energy sources) and could unfold relatively rapidly via cooperation between societies. However,

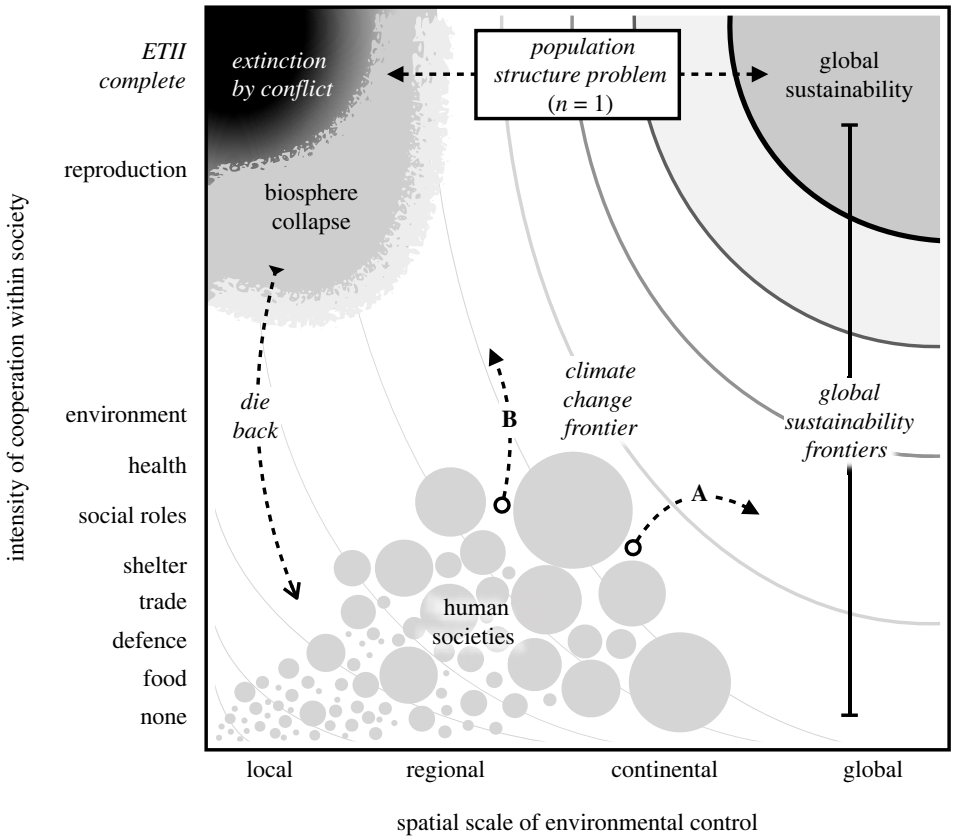

Figure 2. Dimensions of environmental management create an attractor landscape for long-term human evolution. Environmental sustainability challenges (curved frontiers) require a minimum level of cooperation in a society of a certain minimum spatial size. Alternative potential paths move humanity toward different long-term evolutionary outcomes. In path B, competition between societies over common environmental resources creates cultural selection between groups for increasingly direct competition and conflict. Path A, growing cooperation between societies facilitates the emergence of global cultural traits to preserve shared environmental benefits.

solving global climate change does require social coordination at a global scale (figure 2, right).

Using figure 2, we can evaluate potential evolutionary paths for their sustainability outcomes, existential risks and likelihoods. We focus on two contrasting paths characterized by different eco-evolutionary processes. We consider these paths equivalent to the dynamic adaptive policy pathways approach of [104]. Future evolutionary paths are unknown and inherently stochastic and reversible. Societal failures from environmental damage have occurred [105–107]. Countless paths are possible. Societies may grow and proliferate, shrink and die off. We highlight two evolutionary paths (path A and path B) which represent alternative possible futures of interest. Both paths start from our species current position and move in different directions relative to global sustainability frontiers, and to the long-term outcomes of human evolution.

(a) Path A

Growing cooperation between societies facilitates the emergence of global cultural systems of environmental control necessary to solve shared challenges such as climate change. This is the sustainable and desirable path. It relies on the bottom-up self-organization of systems of global environmental governance, and voluntary expansion of cooperation between groups and societies. Although prior societal expansion may have occurred in this mode, it is not congruent with a human ETII. Specifically, path A is not favoured by evolutionary processes for two reasons. First, selection on groups operates against cooperation between groups. Second, the population structure problem described above suggests that accumulating adaptive variation in global cultural traits is unlikely.

(b) Path B

Growing competition between societies over environmental resources accelerates the evolution of traits for direct competition and conflict. This undesirable path has significant evolutionary momentum. As we have detailed, much of recent human evolution has been characterized by between-group competition driving the growth of within-group cooperation and hierarchy [48,87,108,109]. However, path B is distinguished from prior evolutionary history because it occurs in a state in which direct environmental competition becomes increasingly unavoidable. In the short term, path B could result in major ecological collapse and human dieback as groups become more powerful but not more integrated (figure 2, left).

More problematic is that path B creates a self-reinforcing (positive) feedback system which selects for ever more competitive human groups. Positive feedbacks are probably a common feature in ETIs [46]. This competitive feedback could accelerate an ETII in humans at the sub-global scale. Feedback could progress from a mere lack of willingness to engage in between-group cooperation over global environmental regulation (indirect competition), into direct competition over environmental resources, and finally into survival competition and outright military conflict. Warfare selects for aggressive

and expansionist group-level cultural traits and destructive technologies. For example, the emergence, refinement and proliferation of nuclear weapons were driven by conflict (World War II, The Cold War) between nations. If human evolution in an ETII becomes characterized by this type of evolutionary competition, it could lead to intense global warfare among increasingly aggressive groups, and even mutual destruction and human extinction in the very distant future. To clarify, our species may not be at immediate risk of extinction. Some humans might even survive a global nuclear winter. However, our social structure and way of living is probably in near-term danger.

However, how realistic is path B? We do not yet have sufficient evidence to evaluate this question. Recent meta-analysis supports multiple causal connections between resource interactions and war [110]. In their evaluation of the global catastrophic risks (GCRs) facing humanity, Fisher & Sandberg [111] counted 15 of 18 GCRs as anthropogenic—they believe humanity may face more categories of risk from its own actions than from any external source. Thus, path B could lead to biosphere collapse in the short term or extinction in the very long term (figure 2, upper left). As Søgaard Jørgensen *et al*. [112] argue, the Anthropocene may contain evolutionary traps for humanity. If so, path B is the largest and final trap. It should be our desperate goal to avoid such a path at all costs.

7. The expansive nature of human sociality

Human sociality is uniquely expansive, and so it may be that the historical upward trajectory in the scale and intensity of cooperation can continue into the Anthropocene, avoiding the worst outcomes we have described. Human groups often cooperate and share cultural elements even in the absence of external pressures (see [29]), creating a fitness interdependence which may mitigate competitive outcomes. Perhaps the expansive quality of human sociality may mitigate this scenario.

(a) Between-group cultural transmission

The global transfer of cultural elements today is beyond that of any other era, with internet connectivity increasingly ubiquitous. Perhaps such between-group cultural transmission could facilitate the emergence of a global social identity which could support the development of necessary global sustainability traits (see [113]). However, between-group transmission may often reinforce cultural group selection [20], which is centrally implicated in the cumulative cultural evolution of extractive traits including fossil fuel technology. So, between-group cultural transmission provides no escape from the accelerating feedbacks of path B.

(b) Trade

Trade is a strong type of between-group cooperation and an important force in human society and evolution. Human trade is akin to niche partitioning, in which ecological competition promotes the evolution of clearly separated niches, reducing future competition [114]. Humans have traded for possibly hundreds of millennia (e.g. [115]). However, trade is generally thought to emerge in positive-sum conditions when there are 'gains to trade.' Also, without effective regulation, trade can generate negative environmental and social externalities, particularly in industrial economies. Indeed, the success and growth of global trade appear to be a primary driver of the environmental crises of the Anthropocene. So, if trade is used as part of solutions, it must be applied with great care.

(c) Collective environmental governance

Research the on emergence of collective environmental governance, exemplified by Ostrom [103], reveals that human culture sometimes evolves to modify the conditions of resource conflict to facilitate sharing, conservation and mutually beneficial outcomes. Emergent self-governance also occurs between groups, such as in formation of international treaties, providing some hope for global environmental governance. However, the critical precondition in models of the cultural evolution of sustainable environmental governance [24,25] is the availability of locally controllable resources, which give group fitness value to cultural traits for environmental management. On the other hand, such models do not include complex cognition or foresight, so humans may solve collective challenges more readily than current models predict. However, it may be, our argument is that if human society can create similar institutions at the global level, we will need to do so not only without the assistance of adaptive group-level cultural evolution, but in spite of it.

If human sociality emerged from an evolutionary transition in inheritance and individuality as has been proposed [30], then there is nothing in its expansive nature which could offer any escape from the evolutionary challenges we have described in the Anthropocene. It remains to be seen how well the expansive nature of human sociality can counterbalance reductions in the scope for mutually beneficial environmental cooperation.

8. Research agenda

We propose a novel research agenda aimed at understanding the constraints on human evolution in a limited biosphere. Rigorous theoretical and empirical research on this topic might help humanity avoid potential catastrophes. We propose a series of research questions ranging from general and theoretical topics to pressing and applied matters:

(i) *does the human ETII hypothesis have internal validity?* Basic research on the ETII is necessary. A theoretical model of the human ETII is needed to test the internal validity of Waring & Wood's [30] theory. Such models could draw on existing models of human ETIs (e.g. [38,102,116]) and endogenous cultural group selection [24]. In addition, we might study the processes and constraints on previous ETIs in other systems. For example, it may be possible to draw useful analogies between the genetic kin selection in fraternal ETIs such as the evolution of multicellularity [102,117] and the evolution of eusocial termites approximately 150 Ma [118], and the 'cultural kin selection' expected in a human ETII;

(ii) *how strong is cultural group selection in humans?* To date, empirical evidence for adaptive group-level cultural evolution has been largely driven by case studies [20,26,119], and few quantitative studies have been performed (see [47]). However, large temporal datasets are

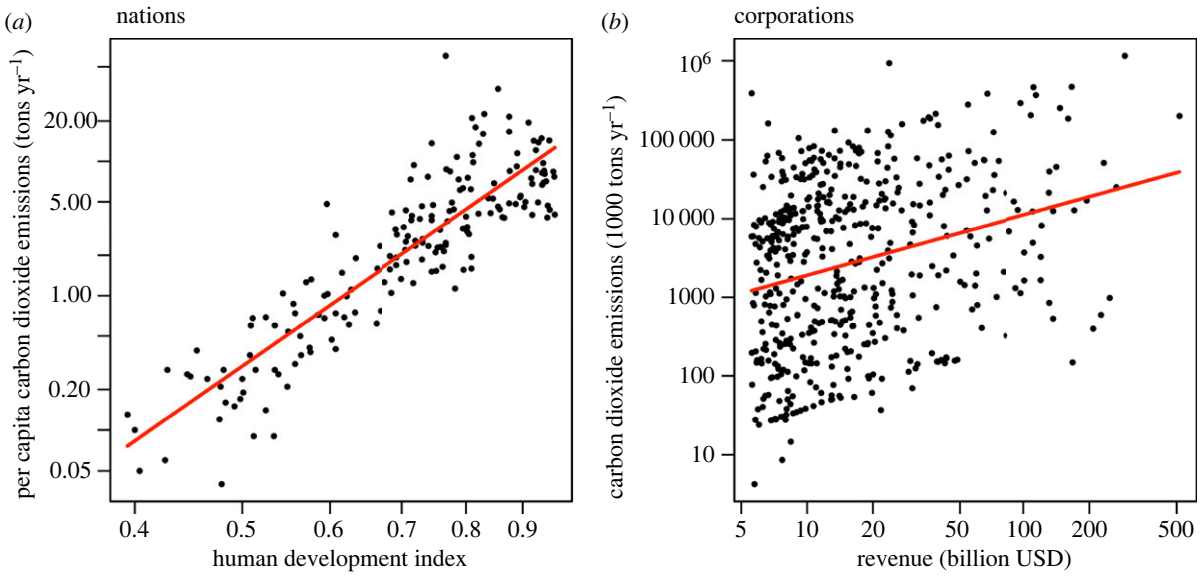

Figure 3. Environmental impact increases with proxy measures of group fitness. (*a*) Across nations, per capita carbon emissions (2021 data: [127]) are strongly correlated with the Human Development Index (2020 data: [128]). Other measures of wellbeing could also be used. (*b*) Across large corporations, total carbon emissions (2019 data: [129]) are correlated with corporate revenue (2015 data: [130]). Data do not include scope 3 emissions from the supply chain. These correlations are at least partly causal because fossil fuel consumption remains the easiest way to increase energy consumption and immediate quality of life. These relationships suggest that both types of human group are probably experiencing group-level cultural selection for increased carbon emissions. To solve anthropogenic climate change, the direction of selection needs to be reversed.

increasingly easy to construct for recent history, and approaches such as the SESHAT global history databank methodology [120] can be used for deep historical datasets, and archeological research could be employed to estimate evolution among human groupings and settlement types over large time periods of the past;

(iii) *how strong is cultural group selection for sustainable environmental traits among nations and corporations?* Synder's [121] hypothesis that humans evolved culturally (and perhaps genetically) to be unsustainable can be tested empirically. Earth only supports a small population of nations (approx. 200), with a slow generation time (approx. 250 years, see [122–124], but it houses an estimated 300 million companies [125], with an average longevity of less than 20 years [126]). Thus, we expect the rate of adaptive cultural evolution by selection and cultural learning to be dramatically faster in companies than in territorial governments. In figure 3, we demonstrate how current group populations can be studied with carbon footprint data;

(iv) *how can cultural evolution among corporations and nations be harnessed to reduce global environmental risks?* Group-level cultural evolution could be studied with an eye towards policy and intervention. However, nations and corporations probably evolve very differently. Nations are obligate and exclusive territorial groups while companies vary in their territorial claims. So, cultural group selection on countries should at least favour the maintenance of critical environmental resources within those territories. Indeed, countries do display a set of territorial resource traits including strategic energy (oil) reserves, agricultural supports and subsidies, and various environmental quality regulations. Companies, by contrast, are non-territorial groups. So cultural selection on companies should favour resource and energy acquisition regardless of external or deferred impacts. These differences may addressable through policy;

(v) *can global environmental governance emerge without an ETII?* The degree of global cooperation required for sustainable management of the global biosphere may be high (e.g. international economic and military treaties on environmental regulation), but it must be less than that required for a full ETII (e.g. group-level reproductive specialization). This suggests that an evolutionary transition is not necessary to solve near term global environmental challenges. Indeed, global environmental traits and laws have already emerged [92]. These include the Montreal Protocol, the United Nations Framework Convention on Climate Change, and the Paris Agreement. Detailed study of the conditions for the evolution of global self-governance is needed. Comparative case studies and theoretical modelling linking cultural evolution, economics and political science is needed; and

(vi) *can a human ETII be completed on a single planet, even in theory?* The population structure problem should be formally tested. New models could build on multilevel selection models with environmental resource constraints [24,131], ETI models with environmental patchiness [102,116] and cultural adaptation models with population size constraints [21,132]. These can enable new questions to be tested. For example, how could the forces and factors of cultural evolution be intentionally structured to improve the chances of the emergence of global cultural sustainability traits?

Finally, if our interpretation of the ETII hypothesis is valid, the problem of the Anthropocene is not just that humanity needs to solve collective environmental challenges at an unprecedented scale. It is that the central patterns of human evolution may prevent us from doing so. In this

light, we propose a new definition of the Anthropocene as a period in human evolution:

> the Anthropocene: *the period in which global environmental factors determine human evolutionary outcomes.*

The definition has five key features. First, it is not a geological epoch defined by stratigraphic features, but a novel period in human evolution defined by eco-evolutionary conditions. Second, this period is defined by the conditions in which individual human groups are sufficiently powerful to influence the global environment and thereby all other human groups. Third, this period entails a conflict between the scale of a society that could express the global cultural traits necessary to sustainably manage the global environment (i.e. global-scale society) and the human population structure necessary to evolve those traits (i.e. many such societies). Fourth, under the global environmental constraints of this period, the signature processes of group-level cultural evolution described by the ETII hypothesis may reduce the scope for the evolution of global environmental management traits. Fifth, the global constraint on human evolution endangers the completion of a human evolutionary transition and threatens the long-term persistence of our species.

9. Implications for policy and intervention in the Anthropocene

Our investigation leads us to suspect that the typical description of the challenges facing humanity in the Anthropocene is understated. When the patterns and processes of long-term human evolution in the environment are also considered, there is no clear and safe path through the Anthropocene. Nonetheless, our framework provides useful policy guidance to avoid near-term environmental disaster in a few ways.

First, the Anthropocene should be understood in terms of human evolution, and the ETII provides inspiration for new policy approaches and methods. We do not propose building policy solely from a new and untested theory. However, our mechanistic framework is an improvement over calls for a 'crisis discipline' of global collective behaviour [133] and GCR research [5,111], which have lacked mechanistic theory. Other theories of human evolution should be similarly explored. By integrating empirically validated and characteristic patterns of long-term human evolution with the collective behavioural requirements for global environmental sustainability, we can refine our estimation of the likelihood of catastrophic outcomes and develop useful guidance for policy exploration and inclusive sustainable solutions.

We suggest a simple and pragmatic approach: focus on solving the most pressing global environmental challenge of the moment. We do not need to solve the population structure problem of the ETII, at least not immediately. Similarly, we need not solve all the interconnected global environmental problems of the Anthropocene at once, although a sustainable global society must have that capacity. Right now, we need to solve the collective challenge of climate change. Then, we should turn to the next most pressing collective challenge and can keep solving collective global challenges for as long as we can.

Our study puts the role of cooperation and competition in human affairs in a different light than traditional economics and policy discussions. While growing global cooperation among societies may be the primary goal, cultural evolution via group competition is the evolutionary force that drives the most relevant adaptive change in human systems. This suggests, paradoxically, we must use competition among groups to build cooperation between groups. However, this may not be as far-fetched as it sounds. Perhaps we can use these two forces in careful concert to grow our collective capacity for global resource stewardship. For example, today's societies benefit from managed group-level cultural evolution in the form of peaceful competition through social systems such as markets and research grant competitions. Both generate socially valuable outputs. So, we could build intentional, peaceful and ethical systems of competitive cultural evolution to generate solutions for advancing global environmental cooperation.

For example, our study provides inspiration for solving climate change. We need to alter the direction of cultural selection on fossil fuel use among nations (via treaties) and companies (via market regulation). The means to accomplish this managed evolution are often equivalent to traditional policy approaches (e.g. carbon taxes and carbon tariffs [134]), climate clubs, investment in alternatives and bans on fossil fuel extraction and use). Evolutionary analysis simply provides an integrated theory and set of metrics. It also reminds us that these simple solutions may be the only real alternative to a spiraling pathway of increasingly direct conflict between groups.

10. Conclusion

In conclusion, connecting the Anthropocene and the ETII hypothesis has proved fruitful in both directions. The ETII helps to explain the human domination of the biosphere, from its evolutionary roots, to its current dynamics, to the shape of alternative paths we may chose. Meanwhile, the Anthropocene forces us consider if the ETII is likely to complete.

The ETII hypothesis proposes that human evolution has been dominated by feedbacks which accelerate group-level cultural adaptation and the intensity of group-level environmental control and impacts. This evolutionary ratchet has created the powerful niche-constructing groups that dominate human activity today, and the global-scale impacts they have generated. Human cultural evolution generally, and the ETII specifically, is the cause of the Anthropocene. This suggests that the sustainability and survival challenges of the Anthropocene are understated. The Anthropocene puts the processes that have steered human evolution for possibly millions of years in conflict with the evolutionary requirements for the global cultural traits we need.

Ours is a bleak reading of the possibilities of the future of environmental management and human evolution on Earth. However, it is useful because it is bleak. Worst-case scenarios are an indispensable planning tool (e.g. [5]). So, it may be on the intentional processes in cultural evolution, including innovation, foresight, planning and collective action, must be where we make our stand [135,136], by building global governance for the Anthropocene [94] even though it is against the interests of existing groups. It is our hope that this perspective can contribute to that collective effort, expanding the considerations of society today to help better select long-term paths in future.

We have suggested that humanity might be poorly adapted to survive a new evolutionary relationship to the biosphere. Even if this proposition is only slightly likely, or

partially true, it deserves sharp attention. We hope that our raising the issue strikes new alarms and helps to motivate greater efforts at collective action.

Ethics. This work did not require ethical approval from a human subject or animal welfare committee.

Data accessibility. This article has no additional data.

Authors' contributions. T.M.W.: conceptualization, funding acquisition, project administration, visualization, writing—original draft, writing—review and editing; Z.T.W.: conceptualization, investigation, writing—original draft, writing—review and editing; E.S.: writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

Funding. This work was supported in part by research grants to T.M.W. from the US National Science Foundation (grant no. EPS-2019470) and the US Department of Agriculture (grant no. NIFA-ME022008) and by grant (grant no. KKP_19_129848) to E.S. from the Hungarian National Research, Development, and Innovation Office.

Acknowledgements. We would like to thank two excellent reviewers, as well as inspirational evolutionary theorists who have influenced us, especially Peter Richerson, Richard McElreath, Mike Kinnison, Eva Jablonka and John Maynard Smith.

References

1. Steffen W, Crutzen PJ, McNeill JR. 2007 The Anthropocene: are humans now overwhelming the great forces of nature. *J. Hum. Environ.* **36**, 614–621. (doi:10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2)
2. Waters CN *et al.* 2016 The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* **351**, aad2622. (doi:10.1126/science.aad2622)
3. Ellis EC. 2015 Ecology in an anthropogenic biosphere. *Ecol. Monogr.* **85**, 287–331. (doi:10.1890/14-2274.1)
4. Wood ZT, Palkovacs EP, Olsen BJ, Kinnison MT. 2021 The importance of eco-evolutionary potential in the Anthropocene. *BioScience* **71**, 805–819. (doi:10.1093/biosci/biab010)
5. Kemp L *et al.* 2022 Climate endgame: exploring catastrophic climate change scenarios. *Proc. Natl Acad. Sci. USA* **119**, e2108146119. (doi:10.1073/pnas.2108146119)
6. Ceballos G, Ehrlich PR, Dirzo R. 2017 Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proc. Natl Acad. Sci. USA* **114**, E6089–E6096. (doi:10.1073/pnas.1704949114)
7. Barnosky AD *et al.* 2011 Has the Earth's sixth mass extinction already arrived? *Nature* **471**, Article 7336. (doi:10.1038/nature09678)
8. Chapin FS *et al.* 2022 Earth stewardship: shaping a sustainable future through interacting policy and norm shifts. *Ambio* **51**, 1907–1920. (doi:10.1007/s13280-022-01721-3)
9. Levin SA *et al.* 2022 Governance in the face of extreme events: lessons from evolutionary processes for structuring interventions, and the need to go beyond. *Ecosystems* **25**, 697–711. (doi:10.1007/s10021-021-00680-2)
10. Beddoe R *et al.* 2009 Overcoming systemic roadblocks to sustainability: the evolutionary redesign of worldviews, institutions, and technologies. *Proc. Natl Acad. Sci. USA* **106**, 2483–2489. (doi:10.1073/pnas.0812570106)
11. Ehrlich PR, Ornstein RE. 2010 *Humanity on a tightrope: thoughts on empathy, family, and big changes for a viable future*. New York, NY: Rowman & Littlefield Publishers.
12. Van Den Bergh JC. 2018 *Human evolution beyond biology and culture: evolutionary social, environmental and policy sciences*. Cambridge, UK: Cambridge University Press.
13. Waring T, Kline M, Brooks J, Goff S, Gowdy J, Janssen M, Smaldino P, Jacquet J. 2015 A multilevel evolutionary framework for sustainability analysis. *Ecol. Soc.* **20**, 34. (doi:10.5751/ES-07634-200234)
14. Richerson PJ, Boyd R. 2005 *Not by genes alone: how culture transformed human evolution*. Chicago, IL: University of Chicago Press.
15. Schill C *et al.* 2019 A more dynamic understanding of human behaviour for the Anthropocene. *Nat. Sustain.* **2**, 12. (doi:10.1038/s41893-019-0419-7)
16. Ehrlich PR, Ehrlich AH. 2022 Returning to 'Normal'? Evolutionary roots of the human prospect. *BioScience* **72**, 778–788. (doi:10.1093/biosci/biac044)
17. Wilson RS, Herziger A, Hamilton M, Brooks JS. 2020 From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. *Nat. Clim. Change* **10**, 200–208. (doi:10.1038/s41558-020-0691-6)
18. Adger WN, Barnett J, Brown K, Marshall N, O'Brien K. 2013 Cultural dimensions of climate change impacts and adaptation. *Nat. Clim. Change* **3**, 2. (doi:10.1038/nclimate1666)
19. Kaaronen RO, Borgerhoff Mulder M, Waring TM. 2022 *Applying cultural evolution to address climate and environmental challenges*. OSF Preprints. (doi:10.31219/osf.io/u7hvj)
20. Richerson P *et al.* 2016 Cultural group selection plays an essential role in explaining human cooperation: a sketch of the evidence. *Behav. Brain Sci.* **39**, e30 (19 pages). (doi:10.1017/S0140525X1400106X)
21. Henrich J. 2004 Demography and cultural evolution: how adaptive cultural processes can produce maladaptive losses—the Tasmanian Case. *Am. Antiquity* **69**, 197–214. (doi:10.2307/4128416)
22. Safarzyńska K, Frenken K, Van Den Bergh JC. 2012 Evolutionary theorizing and modeling of sustainability transitions. *Evol. Hum. Behav.* **41**, 1011–1024. (doi:10.1016/j.respol.2011.10.014)
23. Ellis EC, Magliocca NR, Stevens CJ, Fuller DQ. 2018 Evolving the Anthropocene: linking multi-level selection with long-term social–ecological change. *Sustainability Sci.* **13**, 119–128. (doi:10.1007/s11625-017-0513-6)
24. Waring TM, Goff SH, Smaldino PE. 2017 The coevolution of economic institutions and sustainable consumption via cultural group selection. *Ecol. Econ.* **131**, 524–532. (doi:10.1016/j.ecolecon.2016.09.022)
25. Safarzyńska K. 2013 Evolutionary-economic policies for sustainable consumption. *Ecol. Econ.* **90**, 187–195. (doi:10.1016/j.ecolecon.2013.03.020)
26. Waring T, Acheson J. 2018 Evidence of cultural group selection in territorial lobstering in Maine. *Sustainability Sci.* **13**, 21–34. (doi:10.1007/s11625-017-0501-x)
27. Andrews J, Borgerhoff Mulder M. 2018 Cultural group selection and the design of REDD+: insights from Pemba. *Sustainability Sci.* **13**, 93–107. (doi:10.1007/s11625-017-0489-2)
28. Pisor AC, Surbeck M. 2019 The evolution of intergroup tolerance in nonhuman primates and humans. *Evol. Anthropol.* **28**, 210–223. (doi:10.1002/evan.21793)
29. Pisor AC, Borgerhoff Mulder M, Smith KM. 2023 Long-distance social relationships can both undercut and promote natural resource management. *Phil. Trans. R. Soc. B* **378**, 20220269. (doi:10.1098/rstb.2022.0269)
30. Waring TM, Wood ZT. 2021 Long-term gene–culture coevolution and the human evolutionary transition. *Proc. R. Soc. B* **288**, 20210538. (doi:10.1098/rspb.2021.0538)
31. Currie TE, Borgerhoff Mulder M, Fogarty L, Schlüter M, Haider LJ, Tavoni A, Jansen R, Folke C, Waring TM. 2023 Integrating evolutionary theory and social-ecological systems research to address the sustainability challenges of the Anthropocene. *Phil. Trans. R. Soc. B* **378**, 20220262. (doi:10.1098.2022.0262)
32. Maynard Smith J, Szathmáry E. 1995 *The major transitions in evolution*. Oxford, UK: Oxford University Press.
33. Maynard Smith J, Szathmáry E. 2000 *The origins of life: from the birth of life to the origin of language*. Oxford, UK: Oxford University Press.
34. Stearns SC. 2007 Are we stalled part way through a major evolutionary transition from individual to group? *Evolution* **61**, 2275–2280. (doi:10.1111/j.1558-5646.2007.00202.x)
35. Powers ST, van Schaik CP, Lehmann L. 2016 How institutions shaped the last major evolutionary transition to large-scale human societies. *Phil.*

Trans. R. Soc. B **371**, 20150098. (doi:10.1098/rstb.2015.0098)

36. Andersson C, Törnberg P. 2018 Toward a macroevolutionary theory of human evolution: the social protocell. *Biol. Theory* **14**, 86–102. (doi:10.1007/s13752-018-0313-y)
37. Bickerton D. 2009 *Adam's tongue: how humans made language, how language made humans*. New York, NY: Macmillan.
38. Andersson C, Czárán T. 2023 The transition from animal to human culture—simulating the social protocell hypothesis. *Phil. Trans. R. Soc. B* **378**, 20210416. (doi:10.1098/rstb.2021.0416)
39. Rainey PB. 2023 Major evolutionary transitions in individuality between humans and AI. *Phil. Trans. R. Soc. B* **378**, 20210408. (doi:10.1098/rstb.2021.0408)
40. Jablonka E. 1994 Inheritance Systems and the Evolution of New Levels of Individuality. *J. Theoretical Biol.* **170**, 301–309. (doi:10.1006/jtbi.1994.1191)
41. Perreault C. 2012 The pace of cultural evolution. *PLoS ONE* **7**, e45150. (doi:10.1371/journal.pone.0045150)
42. Mathew S, Perreault C. 2015 Behavioural variation in 172 small-scale societies indicates that social learning is the main mode of human adaptation. *Proc. R. Soc. B* **282**, 20150061. (doi:10.1098/rspb.2015.0061)
43. Michod RE. 2005 On the transfer of fitness from the cell to the multicellularorganism. *Biol. Phil.* **20**, 967–987. (doi:10.1007/s10539-005-9018-2)
44. Davison D, Andersson C, Michod R, Kuhn S. 2021 Did human culture emerge in a cultural evolutionary transition in individuality? *Biol. Theory* **16**, 213–236. (doi:10.1007/s13752-021-00382-x)
45. Okasha S. 2006 *Evolution and the levels of selection*. Oxford, UK: Oxford University Press.
46. Crespi BJ. 2004 Vicious circles: positive feedback in major evolutionary and ecological transitions. *Trends Ecol. Evol.* **19**, 627–633. (doi:10.1016/j.tree.2004.10.001)
47. Francois P, Fujiwara T, van Ypersele T. 2018 The origins of human prosociality: cultural group selection in the workplace and the laboratory. *Sci. Adv.* **4**, eaat2201. (doi:10.1126/sciadv.aat2201)
48. Handley C, Mathew S. 2020 Human large-scale cooperation as a product of competition between cultural groups. *Nat. Commun.* **11**, 702. (doi:10.1038/s41467-020-14416-8)
49. Carmel Y. 2023 Human societal development: is it an evolutionary transition in individuality? *Phil. Trans. R. Soc. B* **378**, 20210409. (doi:10.1098/rstb.2021.0409)
50. Tennie C, Call J, Tomasello M. 2009 Ratcheting up the ratchet: on the evolution of cumulative culture. *Phil. Trans. R. Soc. B* **364**, 2405–2415. (doi:10.1098/rstb.2009.0052)
51. Tomasello M, Kruger AC, Ratner HH. 1993 Cultural learning. *Behav. Brain Sci.* **16**, 495–511. (doi:10.1017/S0140525X0003123X)
52. van Gestel J, Tarnita CE. 2017 On the origin of biological construction, with a focus on multicellularity. *Proc. Natl Acad. Sci. USA* **114**, 11 018–11 026. (doi:10.1073/pnas.1704631114)
53. Hawkes K, O'Connell JF, Blurton Jones NG, Oftedal OT, Blumenschine RJ, Widdowson EM, Whiten A, Bone Q. 1991 Hunting income patterns among the Hadza: big game, common goods, foraging goals and the evolution of the human diet. *Phil. Trans. R. Soc. Lond. B* **334**, 243–251. (doi:10.1098/rstb.1991.0113)
54. Næss MW. 2020 Cultural group selection and the evolution of reindeer herding in Norway. *Hum. Ecol.* **48**, 279–291. (doi:10.1007/s10745-020-00158-0)
55. Altman A, Mesoudi A. 2019 Understanding agriculture within the frameworks of cumulative cultural evolution, gene-culture co-evolution, and cultural niche construction. *Hum. Ecol.* **47**, 483–497. (doi:10.1007/s10745-019-00090-y)
56. Chase JM, Leibold MA. 2003 *Ecological niches: linking classical and contemporary approaches*. Chicago, IL: University of Chicago Press. See https://press.uchicago.edu/ucp/books/book/chicago/E/bo3638660.html.
57. Odling-Smee J, Erwin DH, Palkovacs EP, Feldman MW, Laland KN. 2013 Niche construction theory: a practical guide for ecologists. *Q. Rev. Biol.* **88**, 3–28. (doi:10.1086/669266)
58. Laland KN, Odling-Smee J, Feldman MW. 2000 Niche construction, biological evolution, and cultural change. *Behav. Brain Sci.* **23**, 131–146. (doi:10.1017/S0140525X00002417)
59. Laland KN, Odling-Smee J, Feldman MW. 2001 Cultural niche construction and human evolution. *J. Evol. Biol.* **14**, 22–33. (doi:10.1046/j.1420-9101.2001.00262.x)
60. Laland KN, O'Brien MJ. 2011 Cultural niche construction: an introduction. *Biol. Theory* **6**, 191–202. (doi:10.1007/s13752-012-0026-6)
61. Morris I. 2010 *Why the west rules–for now: the patterns of history, and what they reveal about the future*. New York: NY: Farrar, Straus and Giroux.
62. Klein Goldewijk K, Beusen A, Doelman J, & SE. 2017 Anthropogenic land use estimates for the Holocene – HYDE 3.2. *Earth Syst. Sci. Data* **9**, 927–953. (doi:10.5194/essd-9-927-2017)
63. Mongle CS, Strait DS, Grine FE. 2023 An updated analysis of hominin phylogeny with an emphasis on re-evaluating the phylogenetic relationships of *Australopithecus sediba*. *J. Hum. Evol.* **175**, 103311. (doi:10.1016/j.jhevol.2022.103311)
64. Plummer TW *et al.* 2023 Expanded geographic distribution and dietary strategies of the earliest Oldowan hominins and Paranthropus. *Science* **379**, 561–566. (doi:10.1126/science.abo7452)
65. Hershkovitz I *et al.* 2018 The earliest modern humans outside Africa. *Science* **359**, 456–459. (doi:10.1126/science.aap8369)
66. Lobo J, Whitelaw T, Bettencourt LMA, Wiessner P, Smith ME, Ortman S. 2022 Scaling of hunter-gatherer camp size and human sociality. *Curr. Anthropol.* **63**, 68–94. (doi:10.1086/719234)
67. Ferraro JV *et al.* 2013 Earliest archaeological evidence of persistent hominin carnivory. *PLoS ONE* **8**, e62174. (doi:10.1371/journal.pone.0062174)
68. Pobiner BL. 2020 The zooarchaeology and paleoecology of early hominin scavenging. *Evol. Anthropol.* **29**, 68–82. (doi:10.1002/evan.21824)
69. Thompson JC, Carvalho S, Marean CW, Alemseged Z. 2019 Origins of the human predatory pattern: the transition to large-animal exploitation by early hominins. *Curr. Anthropol.* **60**, 1–23. (doi:10.1086/701477)
70. Stiner MC, Barkai R, Gopher A. 2009 Cooperative hunting and meat sharing 400–200 kya at Qesem Cave, Israel. *Proc. Natl Acad. Sci. USA* **106**, 13 207–13 212. (doi:10.1073/pnas.0900564106)
71. Goren-Inbar N, Alperson N, Kislev ME, Simchoni O, Melamed Y, Ben-Nun A, Werker E. 2004 Evidence of hominin control of fire at Gesher Benot Yàaqov, Israel. *Science* **304**, 725–727. (doi:10.1126/science.1095443)
72. Zeder MA. 2017 Domestication as a model system for the extended evolutionary synthesis. *Interface Focus* **7**, 20160133. (doi:10.1098/rsfs.2016.0133)
73. Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997 Human domination of Earth's ecosystems. *Science* **277**, 494–499. (doi:10.1126/science.277.5325.494)
74. Palumbi SR. 2001 Humans as the World's greatest evolutionary force. *Science* **293**, 1786–1790. (doi:10.1126/science.293.5536.1786)
75. Bickerton D, Szathmáry E. 2011 Confrontational scavenging as a possible source for language and cooperation. *BMC Evol. Biol.* **11**, 261. (doi:10.1186/1471-2148-11-261)
76. Szilágyi A, Kovács VP, Czárán T, Szathmáry E. 2023 Evolutionary ecology of language origins through confrontational scavenging. *Phil. Trans. R. Soc. B* **378**, 20210411. (doi:10.1098/rstb.2021.0411)
77. Andermann T, Faurby S, Turvey ST, Antonelli A, Silvestro D. 2020 The past and future human impact on mammalian diversity. *Sci. Adv.* **6**, eabb2313. (doi:10.1126/sciadv.abb2313)
78. Barnosky AD. 2008 Megafauna biomass tradeoff as a driver of Quaternary and future extinctions. *Proc. Natl Acad. Sci. USA* **105**(Suppl. 1), 11 543–11 548. (doi:10.1073/pnas.0801918105)
79. Stiner MC. 2002 Carnivory, coevolution, and the geographic spread of the genus *Homo*. *J. Archaeol. Res.* **10**, 1–63. (doi:10.1023/A:1014588307174)
80. Perri AR, Feuerborn TR, Frantz LAF, Larson G, Malhi RS, Meltzer DJ, Witt KE. 2021 Dog domestication and the dual dispersal of people and dogs into the Americas. *Proc. Natl Acad. Sci. USA* **118**, e2010083118. (doi:10.1073/pnas.2010083118)
81. Clutton-Brock J. 1999 *A review of the natural history of domesticated mammals*. London, UK: Natural History Museum.
82. Zeder MA. 2011 The origins of agriculture in the near east. *Curr. Anthropol.* **52**, S221–S235. (doi:10.1086/659307)
83. Zohary D, Hopf M. 2000 *Domestication of plants in the Old world: the origin and spread of cultivated plants in west Asia, Europe and the Nile valley*, 3rd edn. Oxford, UK: Oxford University Press. See https://www.cabdirect.org/cabdirect/abstract/20013014838
84. Stephens L *et al.* 2019 Archaeological assessment reveals Earth's early transformation through land use. *Science* **365**, 897–902. (doi:10.1126/science.aax1192)
85. Rockström J *et al.* 2009 Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.* **14**, 1–33. (doi:10.5751/ES-03180-140232)

86. Choi JK, Bowles S. 2007 The coevolution of parochial altruism and war. *Science* **318**, 636–640. (doi:10.1126/science.1144237)
87. Turchin P. 2016 *Ultrasociety: how 10,000 years of war made humans the greatest cooperators on earth*. Chaplin, CT: Beresta Books.
88. Makan A. 2007 Island nations plan for rising seas, mass migration. *Reuters*. See https://www.reuters.com/article/idUSSP277709
89. UNESCAP. 2022 Pacific climate change and migration project. (Project report). See https://www.unescap.org/subregional-office/pacific/pacific-climate-change-and-migration-project.
90. Thomas AR, Fulkerson GM. 2021 *City and country: the historical evolution of urban-rural systems*. Lanham, MD: Rowman & Littlefield.
91. Henderson DA. 2012 A history of eradication—successes, failures, and controversies. *The Lancet* **379**, 884–885. (doi:10.1016/S0140-6736(12)60381-X)
92. Yang T, Percival RV. 2009 The emergence of global environmental law. *Ecol. Law Q.* **36**, 615–664.
93. Kotzé L. 2019 A global environmental constitution for the Anthropocene? *Trans. Environ. Law* **8**, 11–33. (doi:10.1017/S2047102518000274)
94. Woolley O, Harrington C. 2022 Law and governance in the Anthropocene. *Glob. Policy* **13**, 5–10. (doi:10.1111/1758-5899.13168)
95. Corning PA. 2022 Politics in evolution: the first 5 million years, and the next 100. In *Biopolitics at 50 years*, vol. 13 (eds T Wohlers, A Fletcher), pp. 27–45. Bingley, UK: Emerald Publishing Limited.
96. Lovelock JE, Margulis L. 1974 Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis. *Tellus* **26**, 2–10. (doi:10.1111/j.2153-3490.1974.tb01946.x)
97. Tyrrell T. 2013 *On Gaia: a critical investigation of the relationship between life and earth*. Princeton, NJ: Princeton University Press.
98. Lenton TM. 2004 Clarifying Gaia: regulation with or without natural selection. In *Scientists debate Gaia: the next century* (eds SH Schneider, JR Miller, E Crist, PJ Boston). Cambridge, MA: The MIT Press.
99. Doolittle WE. 2014 Natural selection through survival alone, and the possibility of Gaia. *Biol. Phil.* **29**, 415–423. (doi:10.1007/s10539-013-9384-0)
100. Doolittle WF. 2019 Making evolutionary sense of Gaia. *Trends Ecol. Evol.* **34**, 889–894. (doi:10.1016/j.tree.2019.05.001)
101. Bernhardt JR, Kratina P, Pereira AL, Tamminen M, Thomas MK, Narwani A. 2020 The evolution of competitive ability for essential resources. *Phil. Trans. R. Soc. B* **375**, 20190247. (doi:10.1098/rstb.2019.0247)
102. Black AJ, Bourrat P, Rainey PB. 2020 Ecological scaffolding and the evolution of individuality. *Nat. Ecol. Evol.* **4**, Article 3. (doi:10.1038/s41559-019-1086-9)
103. Ostrom E. 1990 *Governing the commons: the evolution of institutions for collective action*. Cambridge, UK: Cambridge University Press.
104. Haasnoot M, Kwakkel JH, Walker WE, ter Maat J. 2013 Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Change* **23**, 485–498. (doi:10.1016/j.gloenvcha.2012.12.006)
105. Diamond J. 2011 *Collapse: how societies choose to fail or succeed: revised edition*. Harmondsworth, UK: Penguin.
106. Tainter JA. 1996 Complexity, problem solving, and sustainable societies. In *Getting Down to Earth: Practical Applications of Ecological Economics* (eds R Costanza, O Segura, J Martinez-Alier), pp. 61–76. Washington, DC: Island Press.
107. Tainter J. 1988 *The collapse of complex societies*. Cambridge, UK: Cambridge University Press.
108. Zefferman MR, Mathew S. 2015 An evolutionary theory of large-scale human warfare: group-structured cultural selection. *Evol. Anthropol.* **24**, 50–61. (doi:10.1002/evan.21439)
109. Turchin P *et al.* 2022 Disentangling the evolutionary drivers of social complexity: a comprehensive test of hypotheses. *Sci. Adv.* **8**, eabn3517. (doi:10.1126/sciadv.abn3517)
110. Vesco P, Dasgupta S, De Cian E, Carraro C. 2020 Natural resources and conflict: a meta-analysis of the empirical literature. *Ecol. Econ.* **172**, 106633. (doi:10.1016/j.ecolecon.2020.106633)
111. Fisher L, Sandberg A. 2022 A safe governance space for humanity: necessary conditions for the governance of global catastrophic risks. *Glob. Policy* **13**, 792–807. (doi:10.1111/1758-5899.13030)
112. Søgaard Jørgensen P *et al*. 2023 Evolutionary traps for humanity in the Anthropocene and the pursuit of global sustainability. *Phil. Trans. R. Soc. B* **378**, 20220261. (doi:10.1098/rstb.2022.0261)
113. Zhang RJ, Liu JH, Lee M, Lin M, Xie T. 2023 Continuities and discontinuities in the cultural evolution of global consciousness. *Phil. Trans. R. Soc. B* **378**, 20220263. (doi:10.1098/rstb.2022.0263)
114. Hardin G. 1960 The competitive exclusion principle. *Science* **131**, 1292–1297. (doi:10.1126/science.131.3409.1292)
115. Blegen N. 2017 The earliest long-distance obsidian transport: evidence from the ~200 ka Middle Stone Age Sibilo School Road Site, Baringo, Kenya. *J. Human Evol.* **103**, 1–19. (doi:10.1016/j.jhevol.2016.11.002)
116. Nitschke MC, Black AJ, Bourrat P, Rainey PB. 2023 The effect of bottleneck size on evolution in nested Darwinian populations. *J. Theoret. Biol.* **561**, 111414. (doi:10.1016/j.jtbi.2023.111414)
117. Michod RE. 2007 Evolution of individuality during the transition from unicellular to multicellular life. *Proc. Natl Acad. Sci. USA* **104**(Suppl. 1), 8613–8618. (doi:10.1073/pnas.0701489104)
118. Chouvenc T, Šobotník J, Engel MS, Bourguignon T. 2021 Termite evolution: mutualistic associations, key innovations, and the rise of Termitidae. *Cell. Mol. Life Sci.* **78**, 2749–2769. (doi:10.1007/s00018-020-03728-z)
119. Waring T, Lange T, Chakraborty S. 2021 Institutional adaptation in the evolution of the 'co-operative principles.' *J. Evol. Economics*. (doi:10.1007/s00191-021-00738-3)
120. Turchin P *et al.* 2015 *Seshat: The Global History Databank*. See http://uhra.herts.ac.uk/handle/2299/16139.
121. Snyder BF. 2020 The genetic and cultural evolution of unsustainability. *Sustainability Science* **15**, 1087–1099. (doi:10.1007/s11625-020-00803-z)
122. Kemp L. 2019 Are we on the road to civilisation collapse? *BBC Future*. See https://www.bbc.com/future/article/20190218-are-we-on-the-road-to-civilisation-collapse.
123. Taagepera R. 1979 Size and duration of empires: growth-decline curves, 600 B.C. to 600 A.D. *Soc. Sci. Hist.* **3**, 115–138. (doi:10.2307/1170959)
124. Taagepera R. 1978 Size and duration of empires growth-decline curves, 3000 to 600 b.c. *Soc. Sci. Res.* **7**, 180–196. (doi:10.1016/0049-089X(78)90010-8)
125. Dun & Bradstreet. 2017 *The Dun & Bradstreet D-U-N-S® Number The Universal Standard for Business Identification*. 2.
126. Hillenbrand P, Kiewell D, Miller-Cheevers R, Ostojic I, Springer G. 2019 *Traditional company, new businesses: the pairing that can ensure an incumbent's survival*, p. 11. New York, NY: McKinsey & Company.
127. Crippa M *et al*. 2022 *CO2 emissions of all world countries*, EUR 31182 EN. Luxembourg: Publications Office of the European Union. (doi:10.2760/730164)
128. UNDP. 2022 Human Development Report 2021–22. New York, NY: United Nations. See https://hdr.undp.org/content/human-development-report-2021-22.
129. Barbato A, Kenny E, Weiner PM, Pringle T, Vollmer ME, Fagerlin D, Bailey J. 2021 Fortune 500 Emissions Report FY2019 (Fortune 500 Companies Greenhouse Gas Emissions). Recapture. See https://www.recapturecarbon.com/fortune-500-emissions-report-2019.
130. Largest US Corporations: Fortune Five Hundred. (15 June 2015). *Fortune*, F1–F22.
131. Safarzynska K, Smaldino PE. 2023 Reducing global inequality increases cooperation: a simple model of group selection with a global externality. *Phil. Trans. R. Soc. B* **378**, 20220267. (doi:10.1098/rstb.2022.0267)
132. Lake MW, Crema ER. 2012 The cultural evolution of adaptive-trait diversity when resources are uncertain and finite. *Adv. Complex Syst.* **15**, 1150013. (doi:10.1142/S0219525911003323)
133. Bak-Coleman JB *et al.* 2021 Stewardship of global collective behavior. *Proc. Natl Acad. Sci. USA* **118**, e2025764118. (doi:10.1073/pnas.2025764118)
134. Abnett K. 2022 EU strikes deal on world-first carbon border tariff. *Reuters*. See https://www.reuters.com/markets/carbon/eu-strikes-deal-world-first-carbon-border-tariff-2022-12-13/.
135. Richerson PJ, Boyd R, Efferson C. 2023 Agentic processes in cultural evolution: relevance to Anthropocene sustainability. *Phil. Trans. R. Soc. B* **378**, 20220252. (doi:10.1098/rstb.2022.0252)
136. Lenton TM, Latour B. 2018 Gaia 2.0. *Science* **361**, 1066–1068. (doi:10.1126/science.aau0427)

Science Progress
2023, Vol. 106(3) 1–22

DOI: 10.1177/00368504231201372
journals.sagepub.com/home/sci
Sage

World scientists' warning: The behavioural crisis driving ecological overshoot

Joseph J Merz[1,2], Phoebe Barnard[2,3,4], William E Rees[5], Dane Smith[6], Mat Maroni[1], Christopher J Rhodes[7], Julia H Dederer[1,2,8], Nandita Bajaj[2,9,10], Michael K Joy[1,11], Thomas Wiedmann[12] and Rory Sutherland[6]

[1]Merz Institute, Whitianga, New Zealand
[2]Stable Planet Alliance, Calabasas, USA
[3]University of Washington, Seattle, WA, USA
[4]African Climate and Development Initiative and FitzPatrick Institute, University of Cape Town, Rondebosch, South Africa
[5]University of British Columbia, Vancouver, Canada
[6]Ogilvy, London, UK
[7]Fresh-lands Environmental Actions, Reading, UK
[8]Foundation for Climate Restoration, Los Altos, CA, USA
[9]Antioch University, Yellow Springs, OH, USA
[10]Population Balance, Saint Paul, MN, USA
[11]Victoria University, Wellington, New Zealand
[12]Sustainability Assessment Program, School of Civil and Environmental Engineering, UNSW Sydney, Sydney, Australia

Abstract

Previously, anthropogenic ecological overshoot has been identified as a fundamental cause of the myriad symptoms we see around the globe today from biodiversity loss and ocean acidification to the disturbing rise in novel entities and climate change. In the present paper, we have examined this more deeply, and explore the behavioural drivers of overshoot, providing evidence that overshoot is itself a symptom of a deeper, more subversive modern crisis of human behaviour. We work to name and frame this crisis as 'the Human Behavioural Crisis' and propose the crisis be recognised globally as a critical intervention point for tackling ecological overshoot. We demonstrate how current interventions are largely physical, resource intensive, slow-moving and focused on addressing the symptoms of ecological overshoot (such as climate change) rather than the

Corresponding author:
Joseph Merz, Merz Institute, Whitianga, 3510, New Zealand.
Email: joseph@merzinstitute.org

distal cause (maladaptive behaviours). We argue that even in the best-case scenarios, symptom-level interventions are unlikely to avoid catastrophe or achieve more than ephemeral progress. We explore three drivers of the behavioural crisis in depth: economic growth; marketing; and pronatalism. These three drivers directly impact the three 'levers' of overshoot: consumption, waste and population. We demonstrate how the maladaptive behaviours of overshoot stemming from these three drivers have been catalysed and perpetuated by the intentional exploitation of previously adaptive human impulses. In the final sections of this paper, we propose an interdisciplinary emergency response to the behavioural crisis by, amongst other things, the shifting of social norms relating to reproduction, consumption and waste. We seek to highlight a critical disconnect that is an ongoing societal gulf in communication between those that know such as scientists working within limits to growth, and those members of the citizenry, largely influenced by social scientists and industry, that must act.

Keywords
behaviour, ecological overshoot, scientists warning, pronatalism, marketing, psychology, ecology, economics, population, consumption

For Will Steffen (1947–2023), one of the kindest advocates for our planet in a time of crisis.

'The conscious and intelligent manipulation of the organized habits and opinions of the masses is an important element in democratic society. Those who manipulate this unseen mechanism of society constitute an invisible government which is the true ruling power of our country. We are governed, our minds are molded, our tastes formed, our ideas suggested, largely by men we have never heard of'.

– Edward Bernays, *Propaganda*, 1928

'A species causing the extinction of 150 species per day doesn't need more energy to do more of what it does'.

– Hart Hagan, Environmental journalist

Introduction

Modern humans and millions of other species face an unprecedented number of existential threats due to anthropogenic impacts exceeding our planet's boundaries.[1] We are in dangerous territory with instability in the known realms of biosphere integrity, land system change and novel entities such as plastics and synthetic toxins, climate change, freshwater change and biogeochemical flows.

Considering the dynamic, closed and interconnected nature of Earth's systems together, these threats pose an increasingly catastrophic risk to all complex life on Earth. Many scientists privately believe it to be already too late to avoid the tipping points that will trigger devastating and irreversible feedback loops.[2]

It is increasingly acknowledged that all of these threats are symptoms of anthropogenic ecological overshoot. Overshoot is defined as the human consumption of natural

resources at rates faster than they can be replenished, and entropic waste production in excess of the Earth's assimilative and processing capacity.[3–7]

In this paper, we explore the behavioural drivers of overshoot, providing evidence that overshoot is itself a symptom of a deeper, more subversive modern crisis of human behaviour. We work to name and frame this crisis as 'the Human Behavioural Crisis' and propose the crisis be recognised globally as a critical intervention point for tackling ecological overshoot. We demonstrate how current interventions are largely physical, resource intensive, slow-moving and focused on addressing the symptoms of ecological overshoot (such as climate change) rather than the distal cause (maladaptive behaviours). We argue that even in the best-case scenarios, symptom-level interventions are unlikely to avoid catastrophe or achieve more than ephemeral progress.

In the final sections of this paper, we propose an interdisciplinary emergency response to the behavioural crisis by, amongst other things, the shifting of social norms relating to reproduction, consumption and waste. We seek to highlight a critical disconnect that is an ongoing societal gulf in communication between those that know such as scientists working within limits to growth, and those members of the citizenry, largely influenced by social scientists and industry, that must act.

Scientists working in limits to growth must join forces with social scientists not only in academia but critically with the non-academic practitioners of applied social and behavioural science. Not only are such practitioners demonstrated masters in the theory of driving behaviour change but crucially also masters of the practical implementation of that theory in the real world.

Lastly, we will provide a possible frame through which to view our species' ability to consciously drive large-scale behavioural change as an opportunity unavailable to most other species. An implementation of such a framework limiting widespread maladaptive behavioural manipulation may ensure human appetites remain within planetary boundaries, and be key in unlocking a truly prosperous and sustainable future for *H. sapiens* on Earth.

This paper is not intended to be an exhaustive roadmap to address the behavioural crisis, instead it should be taken as a call to action for interdisciplinary collaboration to achieve just that.

Scope

In this paper, aside from reproductive behaviours which we mention below, our focus is largely confined to socially constructed attitudes, values and behaviours that encourage unnecessary personal consumption, and which have led the world into a state of overshoot.

This focus is critical because, to date, a mere quarter of humanity – the wealthy quarter – is responsible for 74% of excess energy and material use.[8] This, when taken alone, is sufficient to propel the human enterprise into overshoot.

Meanwhile, the quarter of the global population who live below the USD $3.65 poverty line, and the almost half, 47%, who live below the USD $6.85 poverty line[9] aspire to achieve equivalent high-end lifestyles, encouraged, in part, by the constant barrage of advertising. To achieve this would certainly increase greenhouse gas

emissions, deplete many essential renewable resources from fish-stocks to arable soils and strain global life-support to breaking point, including the risk of triggering runaway hothouse Earth conditions.[10]

We acknowledge that there are many other relevant behaviours and considerations, including genetic pre-dispositions to consume, the role of temporal, spatial and social discounting, socio-political factors (e.g. status hierarchies) and even addiction to conspicuous consumption.

Repeated rewarding experiences help shape the synaptic circuits of the developing brain, predisposing the individual to seek out similar experiences that reinforce the already preformed circuits and to deny or reject contrary inclinations or information.[11]

We also acknowledge that part of our focus, on media and marketing manipulation, is just one example of how intentional behavioural manipulation undermines planetary and social health. There certainly are other examples – such as how firms and governments limit more sustainable options either by design or consequence. In essence, power dynamics in society underlie the manipulation of needs, wants and desires. This is crucial for understanding how our human predisposition for potentially maladaptive behaviours has been twisted to become actually maladaptive. While we humans are fully capable of regulating ourselves, power dynamics in societies often overcome this. Better understanding this within different societies, and how it perpetuates our 'poly-crises', will help us move into a wiser and more sustainable civilisation.

In regards to reproductive behaviours, population growth plays, and will continue to play, a significant role in ecological overshoot. Across the globe, the middle class is the fastest-growing segment of the population, projected to grow another billion to reach 5 billion by 2030.[12] Over the coming decades, the majority of projected population growth will be concentrated in the developing world,[13] where the average standard of living must be raised through increases in per-capita consumption. As a result, however, their ecological footprints are likely to increase towards those of the Global North.

Proponents of 'green growth' may argue that there is a way to avoid this, however, 'the burden of proof rests on decoupling advocates'.[14]

To avoid ecological breakdown 'incrementalist propositions along the lines of green growth and green consumerism are inadequate. The ideals of sufficiency, material thresholds and economic equality that underpin the current modelling are incompatible with the economic norms of the present, where unemployment and vast inequalities are systematic requirements, waste is often considered economically efficient (due to brand-protection, planned obsolescence, etc.) and the indefinite pursuit of economic growth is necessary for political and economic stability'.[15]

Even the relatively conservative IPCC views population growth as a significant factor in climate change (a single symptom of ecological overshoot).[16] Additionally, a recent paper found that population growth has cancelled out most climate gains from renewables and efficiency from the last three decades.[17] For these reasons and more, we have not gone into detail on certain aspects of population dynamics. Instead, we have rooted this paper in ecological economics where population – at any level – plays an important role.

We call for additional research to develop a full understanding of the many dimensions of the behavioural crisis and how we can best address it.

Previous scientists' warnings

The initial 'World Scientists' Warning to Humanity' was published in 1992,[18] starkly emphasising the collision between human demands and the regenerative capacity of the biosphere. It was followed by a further report, 'World Scientists' Warning to Humanity: A Second Notice'[19] which confirmed that the intervening 25 years had merely accelerated environmental destruction driven by a global population increasing by more than 40% – some 2 billion humans. The 'World Scientists' Warning of a Climate Emergency' report,[20] so far endorsed by 14,859 scientists from 158 countries, proposed a range of measures for restoring and protecting natural ecosystems, conserving energy, reducing pollutants, reducing food waste, adopting more plant-based diets, stabilising population and reforming the global economy.

Subsequent warnings from the scientific community have added to the evidence of overshoot including insect extinctions,[21] the impact of climate change on microorganisms,[22] the freshwater biodiversity crisis,[23] endangered food webs,[24] invasive alien species,[25] the degradation of large lakes,[26] the illegal/unsustainable wildlife trade,[27] the role of affluence,[28] tree extinctions,[29] an imperilled ocean,[30] and population growth as a specific driver.[31] These papers are gathered on the Alliance of World Scientists website.

Despite so many warnings, there has been a marked lack of action, driving several of us to co-author a 'World Scientists' Warnings into Action, Local to Global' paper,[32] so far endorsed by over 3,000 scientists from more than 110 nations, to set out a framework for concrete action to curb our hyperconsumption of resources. This paper focused on the same six key issues (energy, pollutants, nature, food systems, population and the economy, plus governance and leadership), and on three timelines to 2026, 2030 and 2050. None of the key issues identified by the authors are isolated problems; they are all symptoms of human ecological overshoot.

In the present paper, we contend that an underlying behavioural crisis lies at the root of 'overshoot' and probe the implications for humanity if we are to retain a habitable planet and civilisation. While human behaviours were implicit in the various world scientists' warnings, we believe they need explicit attention and concerted emergency action in order to avoid a ghastly future.[33]

Human behaviour drives overshoot

The main drivers of anthropogenic ecological overshoot are human behaviours and cultures relating to consumption[8,28] and population dynamics.[31,34] These two factors are mathematically, though certainly not linearly, related. Like other species, *H. sapiens* is capable of exponential population growth (positive feedback) but until recently, major expansions of the human enterprise, including increases in consumption and waste, were held in check by negative feedback – e.g. resource shortages, competition and disease – which naturally curbed continued population growth.[7]

H. sapiens took around 250,000 years to reach a global population of 1 billion in 1820, and just over 200 years to go from 1 billion to 8 billion. This was largely made possible by our species' access to cheap, easy, exosomatic energy, mainly fossil fuels. Fossil fuels

enabled us to reduce negative feedback (e.g. food shortages) and thus delay and evade the consequences of surpassing natural limits. In that same 200 year period, fossil energy (FF) use increased 1300-fold, fueling a 100-fold increase in real gross world product, i.e. consumption, and the human enterprise is still expanding exponentially.[7] We are arguably in the late boom phase of a one-off boom-bust cycle that is driving us rapidly beyond the safe harbour of planetary boundaries towards chaotic collapse and worse (Figure 1).[5,7]

In this paper, we use the term 'behavioural crisis' specifically to mean the consequences of the innate suite of human behaviours that were once adaptive in early hominid evolution, but have now been exploited to serve the global industrial economy. This exploitation has accumulated financial capital – sometimes to absurd levels – for investors and shareholders, and generated manufactured capital ('human-made mass') that now exceeds the biomass of all living things on Earth.[35] Significantly manipulated by the marketing industry, which several of us represent, these behaviours have now brought humanity to the point where their sheer scale – through our numbers, appetites and technologies – is driving ecological overshoot and threatening the fabric of complex life on earth.

These behaviours are related to our previously highly adaptive, but now self-defeating, impulses to:

- seek pleasure and avoid pain;
- acquire, amass and defend resources from competitors;

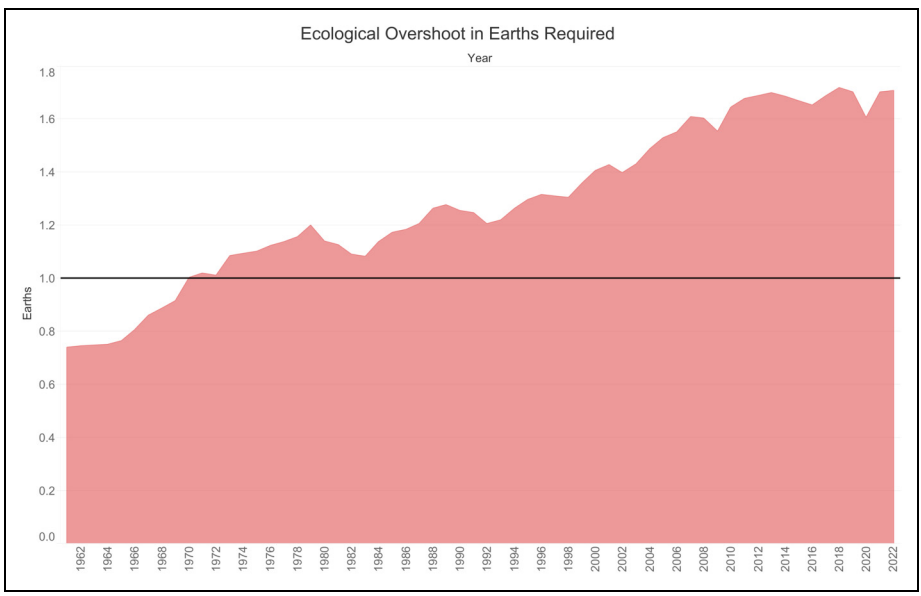

Figure 1. Ecological overshoot in number of Earths required. Data from Global Footprint Network – June 2023.

- display dominance, status or sex appeal through size, beauty, physicality, aggression and/or ornamentation;
- procrastinate rather than act whenever action does not have an immediate survival benefit particularly for ourselves, close relatives and our home territories (humans are innate temporal, social and spatial discounters).

Many of our continuing environmental and societal challenges arise from these hijacked impulses. In a global economy that strives to create and meet burgeoning demand, rather than fairly and judiciously apportioning supply, these behaviours are collectively highly maladaptive, even suicidal for humanity.[1]

Drivers of overshoot behaviour

The evolutionary drive to acquire resources is by no means exclusive to the human animal. In *H. sapiens* however, the behaviours of overshoot are now actively promoted and exacerbated by social, economic and political norms largely through the intentional, almost completely unimpeded exploitation of human psychological predispositions and biases. Here, we explore what we consider to be three critical drivers in the creation and continuation of the human behavioural crisis.

Economic growth

Economists define the 'economy' as all those organised activities and behaviours associated with the production, allocation, exchange and consumption of the valuable (scarce) goods and services required to meet the needs and wants of the participating population. But this is a simplistic, limited definition. An ecologist might describe the economy as that set of behaviours and activities by which humans interact with their biophysical environment (the ecosphere) to acquire the material resources required for life, and to dispose of the waste materials that result from both our biological and industrial metabolisms. Economic accounts should therefore record all the energy and material 'throughput' from the natural world through the human subsystem and back into nature; they should even account for those produced goods that do not enter formal markets, as these add to gross material consumption. In other words, human economic behaviour helps define the human ecological niche, the role *H. sapiens* plays in interacting with, and altering the structure, function and species composition of, the ecosystems of which we are a part. From this perspective, economics really should be human ecology. But it is not.

Today's dominant neoliberal economics conceives of the economy as a self-generating 'circular-flow of exchange (monetary) value' that operates separately from, and essentially independent of, the natural environment.[36] We generally measure the scale of economic activity in terms of gross national product, i.e. the abstract monetary value of final goods and services produced in a country in a specified time period. Physical natural resources (i.e. 'the environment') are seen as merely one of several interchangeable 'factors of production;' should a particular resource become scarce, we need

only increase the input of other factors (capital, labour, knowledge) or depend on rising prices to stimulate some engineer to find a substitute.[37,38]

The same simplistic thinking conceives of humans as self-interested utility maximisers (i.e. 'consumers') with unlimited material demands and no attachment to family or community. It was easy for modern techno-industrial society to make the leap from believing that the economy is untethered from nature, people essentially insatiable and human ingenuity unbounded, to accepting the notion of unlimited economic growth fostered by continuous technological progress. This helps explain why real gross world product has ballooned 100-fold, and average per capita income (consumption) has increased by a factor of 14 (twice that in wealthy countries) since the early 1800s.[39]

Interestingly, most people seem unaware that this explosion was made possible not only by improving population health but, more importantly, through technologies that use fossil fuels – coal, oil and natural gas. Fossil energy is still the dominant means – 81% of primary energy in 2022 – by which humans acquire sufficient food and other resources to grow and maintain the human enterprise. Between 1800 and 2021, global FF use increased by a factor of 1,402, from just 97 TWh to 136,018 TWh.[39] The average world citizen today uses 175 times as much FF as his/her counterpart in 1800. Remarkably, we humans have burned half the FFs ever consumed and emitted half our total fossil carbon wastes in just the past 30 years.[40]

Marketing

Up until the early twentieth century, marketers focused on functional differentiation. The effectiveness of their work was largely contingent on its ability to 'spotlight' functional reasons to buy specific products when people needed them.[41] In essence, the role of marketing was to connect functionally differentiated products with willing buyers. As markets matured, however, competition intensified, and businesses looked to find better ways to differentiate themselves beyond the purely functional.

Around this time, Sigmund Freud's nephew, Edward Bernays, began experimenting with his uncle's psychoanalysis work to develop techniques for widespread behavioural manipulation. Bernays later termed this The Engineering of Consent, describing it as the 'use of an engineering approach – that is, action based only on thorough knowledge of the situation and on the application of scientific principles and tried practices to the task of getting people to support ideas and programs'.[42] Bernays successfully commercialised his work and is commonly regarded as one of the founders of the public relations industry. This novel approach, along with others developed in advertising agencies around the globe, proved highly influential on the way products were marketed and sold to consumers.

Suddenly, marketing effectiveness was no longer determined by its ability to 'raise awareness' or harvest existing demand but by its ability to deepen and diversify the needs and wants that could be met through personal consumption.[43] This paradigm shift meant that business growth was no longer constrained by people's mere biological requirements, it could instead be unlocked by attaching greater meaning to an effectively infinite number of market offerings.

In this brave new world of unchecked business growth, multinationals were no longer marketing hygienic toothpaste, but a mint-flavoured confidence boost – a maintenance purchase was suddenly something that could make you feel more attractive. Cars were no longer being sold based on their functional superiority (i.e. space, speed, comfort, price), but by what they suggested about you as a person (i.e. status, sexiness, rebelliousness, appetite for adventure).

In an era saturated by brands and marketing, consumption has become less reflective of our physical needs and more reflective of our runaway psychology. For example, we may buy to boost our mood, reinforce our identity[44] or elevate our social status above others.[45]

The targeting of consumers has become increasingly effective through the collection and use of data and analytics. The collection and sale of individuals' personal data is rampant. Unsurprisingly, tech giants like Google and Facebook are amongst the most active in this space. These companies track and sell not only what consumers view online but also their real-world locations through what is known as RTB (Real-Time Bidding).

In the US, users' personal online data is tracked and shared 294 billion times each day (for your average American, that's 747 times per day). In Europe, that figure was found to be 197 billion times (Google alone shares this personal data about its German users 19.6 million times per minute). Combined that's 178 trillion times per annum.[46] All this leads to incredibly detailed data about individual user behaviours and preferences. In fact, a 2017 report found that by the time a US child reaches 13 years old, Ad Tech companies hold an average of 72 million data points on that child.[47]

The subsequent egregious overconsumption, which in combination with the resulting creation of waste, disproportionately multiplied by population, gives the wealthy a far greater negative environmental impact than the poor.[8] Individuals with incomes in the top 10% are now responsible for 25–43% of environmental impact and 47% of CO_2 emissions, while the bottom 10% contribute just 3–5% of environmental impact,[28] and the bottom 50% contribute only 10% of CO_2 emissions.[48] A recent report found the top 20 wealthiest individuals on Earth produce 8000 times the carbon emissions of the poorest billion people.[49]

For sustainability, reductions in FF and material consumption between 40% and 90% are necessary.[50,51] This may seem unattainable without a proportionate loss in living standards; however, affluent countries exist far beyond sufficiency. In fact, 'the drastic increases in societies' energy use seen in recent decades have, beyond a certain point, had no benefit for the well-being of their populations – social returns on energy consumption per capita become increasingly marginal'.[15] As such, multiple studies now demonstrate per-capita energy consumption in many affluent countries could be decreased substantially and quality living standards still maintained.[15,52–54]

Pronatalism

Reproductive decision-making is assumed to be a largely personal choice, free from the constraints of cultural and institutional norms. As a result, discussion of reproduction as it relates to environmental degradation and ecological overshoot is often met with concern

regarding impingement of people's personal desires, rights and actions. However, human reproductive behaviours, like most other behaviours, are greatly influenced by cultural norms and institutional policies and deserve to be investigated critically.[55,56]

Pronatalism is a set of social and institutional pressures placed on people to have children, often driven by forces such as patriarchy, religion, nationalism, militarism and capitalism.[57] Pronatalism exerts enormous influence on people and their choices.

- Positive feedback is often expressed through glorification of motherhood and large families, financial incentives and subsidies for childbearing, including through assisted reproductive technologies.
- Negative feedback is expressed through stigmatisation of use of contraceptives, abortion and lifepaths that do not fit dominant cultural narratives, such as single adults, childless and childfree people, LGBTQIA+ people, adoptive families, those who regret parenthood or those who do not have the 'right' number of children.[58]

Depending on the degree of patriarchal and institutional control in a given culture, stigma can take the form of physical and emotional abuse, divorce, economic marginalisation and social ostracisation.[56] The degree of policing individual parenting choices strongly determines the degree of conformity by individuals in a culture or community. This explains why women's stated preferences for number and timing of children vary in accordance with the norms of the community in which they reside.[55]

Anthropological studies of later hunter-gathering societies as well as evidence of very early agricultural groups show that the shift to settlement societies led to a systematic diminution of female status, as women went from being active gatherers of food to being relegated to the home sphere, as males dominated the fields. The subsequent rise in population, cities and tribal conflict over land and power created the need for more laborers and warriors, which raised the value of women as child bearers to the exclusion of other roles, thereby underpinning the beginnings of pronatalism.[59]

Due to the dangers associated with pregnancy and childbirth, as well as the laborious process of child-rearing, certain 'social devices' had to be employed to make reproduction appear more desirable, thereby population increase would offset the wastage of war and disease.[60] Social devices including the institutions of law, religion, media, education and medicine were used to promote and reinforce the universal idealisation of pregnancy and motherhood.

Over the last 200 years, improvements in public health, medicine, disease control and sanitation – all of which occurred on the back of fossil-fuelled industrialisation – significantly lowered the risk of dying, especially amongst children, leading to unprecedented growth in the human population. Pronatalism remains deeply embedded within institutional policies and norms that glorify and reward reproduction to serve external demographic goals – capitalism, religion, ethnocentrism and militarism amongst others.

Despite great advances in gender equality and opportunities for women in education and the economy over the last several decades, pronatalism remains a strong pillar in many societies. Most religious traditions have strong pronatalist teachings and scriptural mandates to 'be fruitful and multiply', further buttressed through misinformation about contraceptives

and abortion, and proscriptions on their use.[57,58] Economists, political leaders and corporate elites regularly argue that keeping fertility high ensures a steady supply of workers, consumers and taxpayers, while generating a larger pool of potential inventors.[58]

Neoliberal economic interests are also enacted through popular media and culture that perpetuate pronatalist narratives. From product advertising and women's magazines glorifying motherhood, and celebrity gossip fixation on the 'biological clock' and 'baby bump', to popular movies and television programmes that use pregnancy to 'complete' the character arc of a protagonist. The marketing, media and entertainment industries exert an enormous influence on people's reproductive decision-making.[61]

Meanwhile, neoliberal feminism – feminism of the privileged colonised by neoliberal ideology – seeks to advance political goals and enhance market value and has only reinforced the mandatory-motherhood narrative by advocating for women to 'have it all', a goal unattainable for the majority of women around the world. This new form of feminism has conveniently been exploited by the assisted reproductive technology industry, growing annually by 9%, with projected growth to a global $41 billion industry by 2026 to market medically dubious technologies such as egg freezing to increasingly younger women.[62–64]

Concerns about overpopulation in this century led authorities and advocates to institute campaigns and policies to reduce fertility rates. The majority of these policies, which employed measures to combat pronatalism by providing women the means to control their own fertility through access to education and family planning, proved extremely effective. Countries as diverse as Thailand, Indonesia and Iran saw their fertility rates drop from over six to under two in a matter of decades.[65] On the other hand, coercive policies such as China's one-child policy, and forced abortion and sterilisation campaigns in Puerto Rico and India, not only led to egregious violations of human and reproductive rights but they also backfired. They created the disastrous legacy of tainting all family-planning campaigns – including the majority that have focused on liberating women – with the blemish of coercion.[34,65,66] These draconian measures not only led to widespread suspicion of any efforts towards population reduction and stabilisation but they also had the opposite effect of strengthening and legitimising the centuries-old form of reproductive control: pronatalism.[56] Currently, half of all pregnancies globally are unintended and 257 million women are unable to manage their own fertility due to oppressive pronatalist norms within their communities.[67]

Given that the number of children that women desire is largely a social construct within a hegemonic framework of pronatalism, we must create a new cultural landscape that illuminates the fertility levels that women anywhere in the world might truly desire outside this construct. Fertility trends in every geography where women have greater reproductive autonomy point towards a tendency for smaller families – a choice that has been described as women's 'latent desire' for no or few children.[66,68]

Addressing population growth, and the pronatalism that drives it, must become central to norm-shifting efforts in order to elevate reproductive rights while also promoting planetary health.

Tackling the behavioural crisis

Current interventions at the symptom-level often do more to maintain the status quo than to address the drivers of ecological overshoot. Accepted approaches are generally

technological interventions requiring immense amounts of raw materials and generating proportional ecological damage. For example, the much-hyped wholesale transition of our energy systems from fossil fuels to renewables would require daunting levels of raw material and fossil fuels in a futile struggle to meet humanity's ever-growing demands.[69–72] Even if successful – which is not likely[73] – the energy transition would address only a single symptom of ecological overshoot, likely worsening other symptoms significantly in the process. As noted earlier, it is humanity's access to cheap, convenient energy that has allowed us to overshoot many planetary boundaries.[7,74] Would anything else change simply because we substitute one form of energy for another?

Conversely, interventions addressing the behavioural crisis shift the focus from treating symptoms to treating the core cultural causes. Prioritising psycho-behavioural change over technological interventions may also have greater potential to relieve anthropogenic pressures on Earth. It would certainly greatly reduce the fossil fuels and material extraction required to maintain the human enterprise. An example of an intervention at this level could be the intentional creation of new social norms for self-identity to change human behaviours relating to consumption, population and waste.

Paradoxically, the marketing, media and entertainment industries complicit in the creation and exacerbation of the behavioural crisis, may just be our best chance at avoiding ecological catastrophe. Storytelling shapes appetites and norms: in this paper, we focus largely on the marketing industry, but we believe it important to highlight the potential of the media and entertainment industries for addressing the behavioural crisis also. Modelling behaviour through entertainment can be an extremely powerful way of driving behavioural change.[75] A real-world example of this can be seen through the telenovelas created by the Population Media Centre. PMC's broadcasts have been remarkably successful in changing reproductive behaviours in many countries through the role modelling of small family norms, delaying marriage until adulthood, female education and the use of family planning. In Ethiopia, pre and post-broadcast quantitative surveys found that listeners were 5.4 times more likely than non-listeners to know at least three family planning methods. Married women who were listeners increased current use of modern family planning methods from 14% to 40%, while use amongst non-listeners increased less than half of that.[76]

It is also worth noting that when it comes to addressing maladaptive behaviours in the current paradigm, there appears to be a focus on raising awareness and education under the arguable assumption that this will lead to the desired behavioural changes. While awareness and education certainly have important roles to play in combating ecological overshoot, they are relatively ineffective at driving behavioural change.[77] Can the same behavioural mechanisms that built and fuelled our immense appetites bring them back within planetary limits to growth?

Lessons from the marketing industry

For more than 100 years, marketers, and recently behavioural scientists, have become proficient at influencing human desires, particularly consumer behaviour. The frameworks of persuasion they have developed could help bring humanity, and countless other species, back to safe harbour by reducing per capita consumption through the

celebration of lives of sufficiency, and setting healthy reproductive norms, all without triggering feelings of loss or regret in the general populace.

Though good marketing may seem like black magic, and the exclusive domain of a select number of creative 'gurus', it is actually an accessible and highly replicable system of proven practices and principles crafted to influence behaviour.

Broadly speaking, marketers strive to influence individuals' felt wants and purchasing patterns in one of two key ways: by changing an individual's perceptions of a product or by changing the social context in which specific forms of consumption take place. It follows that the same strategies can be put to use to redirect consumers' behaviour rather than reinforcing the present consumption-based crisis. An individual's belief about a product or service's value relies heavily on how it is 'framed'.

Tversky and Kahneman[78] have extensively demonstrated this framing effect, showing that people's choices can be predictably shifted, not through changing the choices themselves, but by changing what consumers perceive as the salient qualities of available choices. For instance, advertising a yoghurt as 98% Fat Free is much more compelling than promoting the same product as containing only 2% milk-fat. Similarly, people who would be turned off by the promotion of a vegan diet may be completely receptive to the same regime when it is advertised as a plant-based or cholesterol-free diet.[79]

Of the many ways to frame a new behavioural choice, the most successful will offer a clear and relevant benefit to switching. It is not, for instance, as effective to sell nicotine patches merely as a means to quit smoking as it is to promote them in terms of concrete personal benefits (e.g. better relationships, improved health, longer life, etc.). In short, if we were to effectively address the crisis of human behaviour, the desirable alternative behaviours (e.g. flying less, driving less, wasting less, having fewer children) must be creatively framed in ways that accentuate the benefits to the individual rather than highlight their personal sacrifices.

Human behaviour – like that of many other animals – is not driven merely by individual perceptions and values but also by the social context and system in which it occurs. In regards to the former, we act in ways that advertise our wealth, sexual prowess or social status.[80] Much like the peacock with its ornate tail or the stotting Springbok, humans have developed species-specific signals to demonstrate particular attributes or qualities to others.

While the intent of these signals remains largely the same across cultures and over time (i.e. to establish status, attractiveness, dominance, trustworthiness, etc.) the physical means of expression is constantly changing (e.g. from precious gold, silk or ivory in pre-industrial times to the prestige automobiles and expensive sound equipment in the 1980s, to the high-end computers, iPhones and understated Airpods of the 2000s). By better understanding what values and qualities people are trying to signal about themselves, we can design alternative perceptual framing that results in dramatically altered behaviour. For example, in one highly successful Australian road safety campaign, a team of marketers was able to effectively reframe the meaning of dangerous high-speed driving from signalling 'masculine bravery' to signalling 'masculine insecurity'.[81] Similarly, between 1979 and 2012, strategic efforts were made to reduce the practice of driving while under the influence of alcohol in the UK. Through decades of targeted marketing, community advocacy and police enforcement, the dangerous behaviour was

successfully transformed from exceptionally commonplace (i.e. performed by over half the male driving population) to exceptionally rare (i.e. viewed as unacceptable by 92% of the population).[82]

This idea of signalling becomes particularly significant in light of the disproportionately negative impact that wealthy people have on the ecosphere through 'conspicuous consumption'. While wasteful excess has historically been a reliable cross-cultural signal of social status, there is now promising evidence that this too is amenable to change in response to increasing eco-consciousness. Recent studies have pointed to a counter-signalling effect amongst wealthier populations, wherein more status is actually conferred to those who consciously try to impress by consuming less (e.g. driving modest cars, taking transit, wearing clothes from the thrift store, etc.).[83] By developing ways to positively socialise responsible behaviour, we can help people maintain their sense of self-worth and social status while reducing their contribution to ecological overshoot.

Although social norms may be shifting slightly in the right direction amongst the wealthy, such a values revolution is unlikely to occur in a time frame rapid enough to restore humanity to a survivable limits to growth scenario. In order to effect the rapid changes necessary to secure our long-term survival, we must consider how marketing, behavioural science and other direct instruments of social influence, including but not limited to the media and entertainment industries, might be used in an emergency response to accelerate the process. At the same time, we must find ways to support the billions of individuals who are greatly in need of increases in consumption to do so without inducing further planetary harm.

While the stigmatisation of 'driving under the influence' took decades, recent developments in social networks theory have shown that comparable changes are possible within a timescale of years. With a concerted, multidisciplinary effort by the aforementioned industries, radical change would likely be possible even sooner. The concept of the social 'tipping point' shows that as a belief or value spreads through a population, there is a catalytic threshold beyond which there is accelerated widespread adoption of that belief. Evidence suggests that this 'tipping point' can occur after just 25% of a study population has accepted the belief as a new norm.[84] This finding may be highly relevant to negate our behavioural crisis in an effective time frame.

Conceivably, there may be a 'tipping point' in social acceptance of the values associated with degrowth, where they are likely to become positively reinforced through various forms of media and entertainment without conscious participation. We urgently call for an emergency, concerted, multidisciplinary effort to target the populations and value levers most likely to produce the threshold effect, and catalyse rapid global adoption of new consumption, reproduction and waste norms congruent with the survival of complex life on Earth.

Directing and policing widespread behaviour manipulation

Behavioural manipulation has been intentionally used for nefarious purposes before, and as we've just explored, has played a critical role in the creation of the behavioural crisis and consequential ecological overshoot. Eco-centric behaviour is the heart of any

sustainable future humanity might wish to achieve. Moreover, we are at a crossroads, with three paths ahead:

- We can choose to continue using behavioural manipulation to deepen our dilemma,
- We can choose to ignore it and leave it to chance, or
- We can use an opportunity that almost no other species has had and consciously steer our collective behaviours to conform to the natural laws that bind all life on Earth.

This raises ethical questions, for example, who is worthy of wielding such power? At present, the answer is anyone with the necessary influence or financial means to exploit it. However, we should not entrust this to any individual human, company, government or industry. Instead, any continued use of widespread behavioural manipulation should be firmly bound by, and anchored within a framework built upon the laws of the natural world, as well as the science on limits to growth.

We urgently call for increased interdisciplinary work to be carried out in directing, understanding and policing widespread behaviour manipulation.

Conclusion

In summary, the evidence indicates that anthropogenic ecological overshoot stems from a crisis of maladaptive human behaviours. While the behaviours generating overshoot were once adaptive for *H. sapiens*, they have been distorted and extended to the point where they now threaten the fabric of complex life on Earth. Simply, we are trapped in a system built to encourage growth and appetites that will end us.

The current emphasis for overshoot intervention is resource intensive (e.g. the global transition to renewable energy) and single-symptom focused. Indeed, most mainstream attention and investment is directed towards mitigating and adapting to climate change. Even if this narrow intervention is successful, it will not resolve the meta-crisis of ecological overshoot, in fact, with many of the current resource-intensive interventions, it is likely to make matters worse. Psychological interventions are likely to prove far less resource-intensive and more effective than physical ones.

- We call for increased attention on the behavioural crisis as a critical intervention point for addressing overshoot and its myriad symptoms.
- We advocate increased interdisciplinary collaboration between the social and behavioural science theorists and practitioners, advised by scientists working on limits to growth and planetary boundaries.
- We call for additional research to develop a full understanding of the many dimensions of the behavioural crisis (including the overwhelming influence of power structures) and how we can best address it.
- We call for an emergency, concerted, multidisciplinary effort to target the populations and value levers most likely to produce rapid global adoption of new

consumption, reproduction and waste norms congruent with the survival of complex life on Earth.
- We call for increased interdisciplinary work to be carried out in directing, understanding and policing widespread behaviour manipulation.

The clock is ticking not only because the health of the natural systems upon which we are utterly dependent is deteriorating but also because broadscale interventions are only possible when a society holds together and is capable of coherent action. As the effects of overshoot worsen, the likelihood of societal breakdown increases. We still have an opportunity to be proactive and utilise the intact systems we have in place to deliver a framework for shifting social norms and other necessities for addressing the behavioural crisis. However, the day may come when societal breakdown will make intervention impossible, locking the planet into an unguided recovery that may salvage much of 'nature' but be inhospitable to human life.

Acknowledgements

The authors thank the following for their constructive and insightful suggestions on the manuscript: Alexandra Ellen Appel, EdD, Bridget Doran, Bill Ryerson, Kris White, Linda Chang and Eileen Crist.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Joseph J. Merz https://orcid.org/0000-0002-1808-6477
Christopher J. Rhodes https://orcid.org/0000-0002-2929-4466
Nandita Bajaj https://orcid.org/0000-0002-0300-1573

Note

1. We are aware that the term 'behavioural crisis' may be misunderstood by those familiar with government health department terminology, in which behavioural health is often specifically applied to addiction and mental health crises and disorders such as substance abuse, eating disorders and self-injury (University of Massachusetts Global undated). But this is not our usage of the term.

References

1. Rockström J, Steffen W, Noone K, et al. Planetary boundaries: exploring the safe operating space for humanity. *Ecol Soc* 2009; 14: art32.

2. Lenton TM, Rockström J, Gaffney O, et al. Climate tipping points – too risky to bet against. *Nature* 2019; 575: 592–595.
3. Catton WR. *Overshoot: The ecological basis of revolutionary change*. Illinois, USA: University of Illinois Press, https://www.jstor.org/stable/10.5406/j.ctt1hfr0mh (1980, accessed 20 June 2023).
4. Victor PA. *Escape from overshoot: Economics for a planet in peril*. British Columbia, Canada: New Society Publishers, Limited, 2023.
5. Rees WE. Ecological economics for humanity's plague phase. *Ecol Econ* 2020; 169: 106519.
6. Rees W. Overshoot: cognitive obsolescence and the population conundrum. *J Popul Sustain* 2023; 7: 15–38.
7. Rees WE. The human eco-predicament: Overshoot and the population conundrum. *Vienna Yearb Popul Res* 2023; 21. doi:10.1553/p-eznb-ekgc
8. Hickel J, O'Neill DW, Fanning AL, et al. National responsibility for ecological breakdown: a fair-shares assessment of resource use, 1970–2017. *Lancet Planet Health* 2022; 6: e342–e349.
9. Schoch M, Kofi Tetteh Baah S, Lakner C, et al. Half of the global population lives on less than US$6.85 per person per day. World Bank, https://blogs.worldbank.org/developmenttalk/half-global-population-lives-less-us685-person-day (2022, accessed 20 June 2023).
10. Steffen W, Rockström J, Richardson K, et al. Trajectories of the earth system in the anthropocene. *Proc Natl Acad Sci U S A* 2018; 115: 8252–8259.
11. Wexler BE. *Brain and culture: Neurobiology, ideology, and social change*. Massachusetts, USA: MIT Press, 2006. doi:10.7551/mitpress/1658.001.0001.
12. Kharas H. The unprecedented expansion of the global middle class. Published online 2017.
13. UN World Population Prospects (2022) https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf (accessed 22 August 2023).
14. Decoupling-Debunked.pdf, https://eeb.org/wp-content/uploads/2019/07/Decoupling-Debunked.pdf (accessed 22 August 2023).
15. Millward-Hopkins J, Steinberger JK, Rao ND, et al. Providing decent living with minimum energy: a global scenario. *Glob Environ Change* 2020; 65: 102168.
16. Shukla PR, Skea J and Slade R. Working group III contribution to the sixth assessment report of the intergovernmental panel on climate change.
17. Chaurasia A. Population effects of increase in world energy use and CO_2 emissions: 1990–2019. *J Popul Sustain* 2020; 5: 87–125.
18. World Scientists' Warning to Humanity. https://www.ucsusa.org/sites/default/files/attach/2017/11/World%2520Scientists%2527%2520Warning%2520to%2520Humanity%25201992.pdf (accessed 20 June 2023).
19. Ripple W, Wolf C, Newsome T, et al. World Scientists' warning to humanity: a second notice. *BioScience* 2017; 67: 1026–1028.
20. Ripple WJ, Wolf C, Newsome TM, et al. World Scientists' warning of a climate emergency. *BioScience* 2020; 70: 8–12.
21. Cardoso P, Barton PS, Birkhofer K, et al. Scientists' warning to humanity on insect extinctions. *Biol Conserv* 2020; 242: 108426.
22. Cavicchioli R, Ripple WJ, Timmis KN, et al. Scientists' warning to humanity: microorganisms and climate change. *Nat Rev Microbiol* 2019; 17: 569–586.
23. Albert JS, Destouni G, Duke-Sylvester SM, et al. Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio* 2021; 50: 85–94.
24. Heleno RH, Ripple WJ and Traveset A. Scientists' warning on endangered food webs. *Web Ecol* 2020; 20: 1–10.
25. Pyšek P, Hulme PE, Simberloff D, et al. Scientists' warning on invasive alien species. *Biol Rev* 2020; 95: 1511–1534.

26. Jenny JP, Anneville O, Arnaud F, et al. Scientists' warning to humanity: rapid degradation of the world's large lakes. *J Gt Lakes Res* 2020; 46: 686–702.
27. Cardoso P, Amponsah-Mensah K, Barreiros JP, et al. Scientists' warning to humanity on illegal or unsustainable wildlife trade. *Biol Conserv* 2021; 263: 109341.
28. Wiedmann T, Lenzen M, Keyßer LT, et al. Scientists' warning on affluence. *Nat Commun* 2020; 11: 3107.
29. Rivers M, Newton AC, Oldfield S, et al. Scientists' warning to humanity on tree extinctions. *Plants People Planet* 2023; 5: 466–482.
30. Georgian S, Hameed S, Morgan L, et al. Scientists' warning of an imperiled ocean. *Biol Conserv* 2022; 272: 109595.
31. Crist E, Ripple WJ, Ehrlich PR, et al. Scientists' warning on population. *Sci Total Environ* 2022; 845: 157166.
32. Barnard P, Moomaw WR, Fioramonti L, et al. World scientists' warnings into action, local to global. *Sci Prog* 2021; 104: 368504211056290.
33. Bradshaw CJA, Ehrlich PR, Beattie A, et al. Underestimating the challenges of avoiding a ghastly future. *Front Conserv Sci* 2021; 1.
34. Tucker C. Bending the curve by 2030: on the path to a population safe harbour. *J Popul Sustain* 2022; 6: 51–61.
35. Elhacham E, Ben-Uri L, Grozovski J, et al. Global human-made mass exceeds all living biomass. *Nature* 2020; 588: 442–444.
36. Daly HE. The circular flow of exchange value and the linear throughput of matter-energy: a case of misplaced concreteness. *Rev Soc Econ* 1985; 43: 279–297.
37. Solow RM. The economics of resources or the resources of economics. *Am Econ Rev* 1974; 64: 1–14.
38. Dasgupta PS and Heal GM. *Economic theory and exhaustible resources*. Cambridge, UK: Cambridge University Press, 1980. doi:10.1017/CBO9780511628375.
39. Ritchie H, Roser M and Rosado P. Energy. *Our World Data*. https://ourworldindata.org/fossil-fuels (2022, accessed 20 June 20).
40. Stainforth T and Brzezinski B. More than half of all CO_2 emissions since 1751 emitted in the last 30 years – IEEP AISBL, https://ieep.eu/news/more-than-half-of-all-co2-emissions-since-1751-emitted-in-the-last-30-years/ (2020, accessed 20 June 2023).
41. Kotler P. *Marketing management: Analysis, planning, implementation, and control*. New Jersey, USA: Prentice Hall, 1997.
42. Bernays EL. The engineering of consent. *Ann Am Acad Pol Soc Sci* 1947; 250: 113–120.
43. McGee LW and Spiro RL. The marketing concept in perspective. *Bus Horiz* 1988; 31: 40–45.
44. Sirgy MJ. Self-Concept in consumer behavior: a critical review. *J Consum Res* 1982; 9: 287–300.
45. Belk RW. Possessions and the extended self. *J Consum Res* 1988; 15: 139–168.
46. The Biggest Data Breach. https://www.iccl.ie/wp-content/uploads/2022/05/Mass-data-breach-of-Europe-and-US-data-1.pdf (accessed 20 June 2023).
47. SuperAwesome launches Kid-Safe Filter to prevent online ads from stealing children's personal data. SuperAwesome, https://www.superawesome.com/superawesome-launches-kid-safe-filter-to-prevent-online-ads-from-stealing-childrens-personal-data/ (2018, accessed 20 June 2023).
48. Bruckner B, Hubacek K, Shan Y, et al. Impacts of poverty alleviation on national and global carbon emissions. *Nat Sustain* 2022; 5: 311–320.
49. Ahmed N, Marriott A, Dabi N, et al. *Inequality kills: The unparalleled action needed to combat unprecedented inequality in the wake of COVID-19*. Oxford, UK: Oxfam, 2022. doi:10.21201/2022.8465.
50. Bringezu S. Possible target corridor for sustainable use of global material resources. *Resources* 2015; 4: 25–54.

51. Akenji L, Lettenmeier M, Koide R, et al. *1.5-Degree lifestyles: targets and options for reducing lifestyle carbon footprints*. Espoo, Finland: Institute for Global Environmental Strategies, Aalto University, D-mat Ltd., 2019. doi:10.57405/iges-6719.
52. Trainer T. Remaking settlements for sustainability: the simpler way. *J Polit Ecol* 2019; 26: 219–221. doi:10.2458/v26i1.22972
53. Lockyer J. Community, commons, and degrowth at dancing rabbit ecovillage. *J Polit Ecol* 2017; 24: 519. doi:10.2458/v24i1.20890
54. Rao ND, Min J and Mastrucci A. Energy requirements for decent living in India, Brazil and South Africa. *Nat Energy* 2019; 4: 1025–1032. doi:10.1038/s41560-019-0497-9
55. Dasgupta A and Dasgupta P. Socially embedded preferences, environmental externalities, and reproductive rights. *Popul Dev Rev* 2017; 43(3): 405–441. doi:10.1111/padr.12090
56. Bajaj N and Stade K. Challenging pronatalism is key to advancing reproductive rights and a sustainable population. *J Popul Sustain* 2023; 7: 39–70.
57. Carroll L. *The baby matrix*. California, USA: Laura Carroll, 2012.
58. Bajaj N. Abortion bans are a natural outgrowth of coercive pronatalism. Ms. Magazine, https://msmagazine.com/2022/06/07/abortion-bans-coercive-pronatalism-forced-birth/ (2022, accessed 20 June 2023).
59. Engelman R. *More: Population, nature, and what women want*. Chicago, USA: Bibliovault OAI Repos Univ Chic Press, 2010.
60. Hollingworth LS. Social devices for impelling women to bear and rear children. *Am J Sociol* 1916; 22: 19–29.
61. Kaklamanidou BD. The voluntarily childless heroine: a postfeminist television oddity. *Telev New Media* 2019; 20: 275–293.
62. Rottenberg C. Neoliberal feminism and the future of human capital. *Signs J Women Cult Soc* 2017; 42: 329–348.
63. Tsigdinos PM. An IVF survivor unravels 'fertility' industry narratives. *J Mark Manag* 2022; 38: 443–459.
64. Patrizio P, Albertini DF, Gleicher N, et al. The changing world of IVF: the pros and cons of new business models offering assisted reproductive technologies. *J Assist Reprod Genet* 2022; 39: 305–313.
65. Weisman A. Countdown. Our last, best hope for a future on earth?, https://www.hachettebookgroup.com/titles/alan-weisman/countdown/9780316236508/ (2013, accessed 20 June 2023).
66. Tucker C. It's time to revisit the Cairo consensus. *J Popul Sustain* 2021; 5: 63–73.
67. Nearly half of all pregnancies are unintended – a global crisis, says new UNFPA report. United Nations Population Fund, https://www.unfpa.org/press/nearly-half-all-pregnancies-are-unintended-global-crisis-says-new-unfpa-report (2022, accessed 20 June 2023).
68. Campbell M and Bedford K. The theoretical and political framing of the population factor in development. *Philos Trans R Soc B Biol Sci* 2009; 364: 3101–3113.
69. Michaux SP. The mining of minerals and the limits to Growth, https://tupa.gtk.fi/raportti/arkisto/16_2021.pdf (2021).
70. Michaux SP, Vadén T, Korhonen JM, et al. Assessment of the scope of tasks to completely phase out fossil fuels in Finland.
71. Michaux S. Review of 4 papers in context of work done affiliations, 2023.
72. Kalt G, Thunshirn P, Krausmann F, et al. Material requirements of global electricity sector pathways to 2050 and associated greenhouse gas emissions. *J Clean Prod* 2022; 358: 132014.
73. Nikiforuk A. The rising chorus of renewable energy skeptics. The Tyee, https://thetyee.ca/Analysis/2023/04/07/Rising-Chorus-Renewable-Energy-Skeptics/ (2023, accessed 20 June 2023).

74. Gowdy J. Our hunter-gatherer future: climate change, agriculture and uncivilization. *Futures* 2020; 115: 102488.
75. La Ferrara E, Chong A and Duryea S. Soap operas and fertility: evidence from Brazil. *Am Econ J Appl Econ* 2012; 4: 1–31.
76. Negussie T. Hearing is believing. *Commun World* Published online April 2008.
77. Bergquist M, Thiel M, Goldberg MH, et al. Field interventions for climate change mitigation behaviors: a second-order meta-analysis. *Proc Natl Acad Sci U S A* 2023; 120: e2214851120.
78. Tversky A and Kahneman D. The framing of decisions and the psychology of choice. *Science* 1981; 211: 453–458.
79. Anderson J. What to call plant-based meat alternatives: A labeling study. Faunalytics, https://faunalytics.org/what-to-call-plant-based-meat-alternatives-a-labelling-study/ (2019, accessed 20 June 2023).
80. Poças Ribeiro A, Harmsen R, Rosales Carreón J, et al. What influences consumption? Consumers and beyond: purposes, contexts, agents and history. *J Clean Prod* 2019; 209: 200–215.
81. The success of the "Pinkie" campaign, https://acrs.org.au/files/papers/33%20Watsford%20The%20success%20of%20the%20pinkie%20campaign.pdf (accessed 20 June 2023).
82. 92% of people feel ashamed to drink and drive as 50th anniversary THINK! campaign is launched. GOV.UK, https://www.gov.uk/government/news/92-of-people-feel-ashamed-to-drink-and-drive-as-50th-anniversary-think-campaign-is-launched (2014, accessed 20 June 2023).
83. Eckhardt GM, Belk RW and Wilson JAJ. The rise of inconspicuous consumption. *J Mark Manag* 2015; 31: 807–826.
84. Centola D, Becker J, Brackbill D, et al. Experimental evidence for tipping points in social convention. *Science* 2018; 360: 1116–1119.

Author biographies

Joseph J Merz is the Co-founder of a number of organisations. He is the Founder and Chairman of the Merz Institute - a research institute largely focused on addressing ecological overshoot at a behavioural level. Joseph serves on the Executive Committee of the Stable Planet Alliance, and is also a Senior Fellow of the Global EverGreening Alliance.

Phoebe Barnard (PhD) is full professor of environmental and societal futures and global change science at University of Washington, climate vulnerability research associate at University of Cape Town, CEO of the global coalition Stable Planet Alliance, and cofounder of the Global Restoration Collaborative, a young process to drive and reframe our economy and civilization to regenerative alternatives. Working for 34 years in Namibia at its independence from colonial rule, and South Africa at its transition to post-apartheid democracy, she brings the "What is, to what if?" frames that these countries considered at their historical crossroads to the challenges now faced by humanity as a whole. Working with youth, women and indigenous networks for transformative change, she was granted a Fulbright Fellowship, a Society for Conservation Biology Distinguished Service Award (with Sir David Attenborough and Dame Prof Georgina Mace) and Forbes Distinguished Achievement Award.

William E Rees is a human ecologist, ecological economist, former Director and Professor Emeritus of the University of British Columbia's School of Community and Regional Planning in

Vancouver, Canada. His research focuses on the ecological requirements for sustainable development and on the behavioural and socio-cultural barriers to change. Best known as originator and co-developer with his PhD students of 'ecological footprint analysis', Prof Rees has authored almost 200 peer-reviewed and numerous popular articles on sustainability policy. His work is widely awarded internationally.

Dane Smith, BPsych(Hons), is an applied Behavioural Scientist who has spent the past decade working in the advertising industry. He currently leads Ogilvy Australia's Behavioural Science Practice and services a mixture of government and private sector clients across APAC as the company's Regional Consulting Partner.

Mat Maroni is Strategic Lead at Merz Institute's Overshoot Behaviour Lab. His primary role is Chief Strategy Officer Asia Pacific for one of the largest global advertising networks. He has been at the forefront of communication strategy across Europe and Asia Pacific for the last 20 years, advising brands both within agencies and directly as consultant. Across this time he has delivered globally recognised, multi-award winning campaigns and authored for a range of industry media and the World Advertising Research Center.

Christopher J Rhodes is Director of the consultancy, Fresh-lands Environmental Actions, and a Board member of Scientists Warning Europe. He became a full professor in physical chemistry in his early 30s, and has published over 250 peer reviewed academic papers and an extensive online collection of essays and journalism. He has advised on low-carbon energy for the European Commission. Chris holds Fellowships of the Royal Society of Chemistry, the Linnean Society of London, and the Royal Society of Arts. He is Chair of Transition Town Reading (U.K.). He has also published a novel, a collection of poetry and a series of children's picture books.

Julia H Dederer has delivered transformational leadership programs nationally and internationally for over four decades. During this time she co-led programs for the Global Women's Leadership Network as well as serving as Chief of Staff for climate restoration not-for-profit, Methane Action. Julia is dedicated to empowering individuals and organizations across climate and ecosystem restoration. She currently serves on the boards of the Merz Institute and the Foundation for Climate Restoration, and is an Executive Committee member of the Stable Planet Alliance.

Nandita Bajaj is the Executive Director of the Population Balance, a US nonprofit that works to inspire behavioral and system change towards a smaller human footprint that embraces planetary boundaries. She is an adjunct lecturer at the Institute for Humane Education at Antioch University, where she teaches about the combined impacts of pronatalism and human expansionism on reproductive, ecological, and intergenerational justice. In addition to a number of peer-reviewed papers and forthcoming book chapters, her work has appeared in major news outlets including Canadian Broadcasting Corporation, The Washington Post, The Guardian, Newsweek, Ms. Magazine, The Globe and Mail, and National Post. Nandita has an MEd. (Humane Education) from Antioch University, a BEng. (Aerospace Engineering) from Toronto Metropolitan University, and a BEd. from University of Toronto.

Michael K Joy (PhD) has been working for three decades at the interface of science and policy in New Zealand. He has published scientific papers in many fields from artificial intelligence and data mining, freshwater fish ecology, freshwater bioassessment to the freshwater ecology of sub-Antarctic islands. As a senior researcher at Victoria University of Wellington he now works on

improving the connection between science, policy, and real outcomes to address the multiple environmental issues facing New Zealand. Mike serves on the board of the Merz Institute, a not-for-profit largely focused on addressing ecological overshoot at a behavioural level. He has received multiple awards for this work including the 2013 Royal Society of New Zealand Charles Fleming Award for protection of the New Zealand environment, the Morgan Foundation inaugural River Voice Award and the inaugural New Zealand Universities Critic and Conscience award.

Thomas Wiedmann is Professor of sustainability research at UNSW Sydney, Australia. He has long-standing expertise in integrated, quantitative sustainability assessment, industrial ecology and environmental footprint analysis and has published 140 journal papers and 123 other scientific publications. His recent research is focusing on sustainable transformations towards post-growth economies.

Rory Sutherland has worked at Ogilvy since 1988 and is currently its Vice Chairman. He is the author of two books, one essentially on the phenomenology of marketing (Alchemy: The surprising Power of Ideas that Don't Make Sense) and (co-authored with Pete Dyson) Transport for Humans on the psychology of transportation. He has an Honorary Doctorate from Brunel University and is a Honorary Professor at the University of Warwick. He has been elected a fellow of The Marketing Society, The Institute of Practitioners in Advertising, the British Interactive Marketing Association and the Institute of Direct Marketing. He has written a fortnightly column for The Spectator since 2008, along with occasional pieces for Wired, The Telegraph and The Times. He has spoken at TED, TEDxAthens, and at countless industry events.