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Changing Environments

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An independent academic psychologist, based in England, who has written extensively on different areas of psychology with an emphasis on the critical stance towards traditional ideas.

A complete listing of his writings at http://psychologywritings.synthasite.com/. See also material at https://archive.org/details/orsett-psych.

CONTENTS

1. CLIMATE CHANGE ADAPTATION

1.1. INTRODUCTION

"Climate change adaptation" refers to the response to the risks posed by climate change, and it often entails "technocratic solutions recommended by experts" (Pisor et al 2023 p1). But, Pisor et al (2023) argued, that "we know little about whether these new practices actually reduce the risks important to communities, even over the short term. What is needed are systematic data on which solutions, new or old, are effective at reducing risk for communities and persist across time. Luckily, scientists working at the intersection of climate change and culture, often in close collaboration with communities, already have evidence for what has worked — and what has not — for humans past and present" (p1).

Pisor et al (2023) introduced a special issue of journal, "Philosophical Transactions of the Royal Society B" on cultural adaptation to climate change, including the idea of "innovation and adoption, selective retention, and transmission" (IARMT).

Cultural adaptation can be viewed at three levels (Pisor et al 2023):

i) Micro (local community) - eg: "Traditional Ecological Knowledge" (TEK) [1]: "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes et al 2000 quoted in Pisor et al 2023).

For example, the tradition of sharing fish, seal and caribou ("country foods") by Indigenous people in Canada in hard times. "When asked, communities on the frontlines

[1] Also called "Indigenous ecological knowledge" (IEK).

of climate change do not always perceive the impacts measured by atmospheric scientists. This may mean that adaptations are working well" (Pisor et al 2023 p4) (appendix 1A).

ii) Meso (regional- or population-level) – eg: sharing ideas between sub-populations.

iii) Macro (multiple populations) – eg: "traditional forms of forest management" (including controlled burns and dispersing seeds).

Turner et al (2023) considered the diffusion of ideas through minority groups (eg: Indigenous groups) and majority groups (the rest of the population). Using computer simulation, they found that "adaptations diffuse throughout populations better when minority groups start out knowing an adaptation, as Indigenous populations often do, while cohesion among majority groups further promotes adaptation diffusion" (Turner et al 2023 p1).

This fits with the view that "subsistence, frequently Indigenous, populations on the margins of larger more market-integrated populations might be a source of climate adaptation" (Turner et al 2023 p8). So, it is essential that minority populations maintain cultural autonomy, argued Pisor et al (2022) (appendix 1B).

1.2. MICRO-LEVEL ADAPTATIONS

Latai-Niusulu et al (2023) challenged "the discourse of 'vulnerable Pacific Islanders' by demonstrating the adaptability of Samoans to changing socio-ecological and climatic circumstances and their ability to develop a variety of climate resilience strategies, including micro-mobilities and circular migration" (p1). The study in Samoa with forty participants in two villages showed that "micro-mobility" (ie: movements within the village and between villages) with two residences (a practice known as "fa'a- 'aigalua") helped "villagers reduce the risk of incurring physical harm from climate-related disasters, while minimising the risk of cultural harm from place detachment" (Latai-Niusulu et al 2023 p1).

"Circular mobility" (ie: "the movement of continual oscillating back and forth between homes and other places for a variety of reasons"; Latai-Niusulu et al 2023 p2) has been commonplace in the Pacific. Fa'a-'aigalua is enabled by the system of customary land rights and extended family connections, which allow Samoans to hold two or more parcels of land and diversify their places of residence and plantations . For example, many families living on the coastal parts of villages cultivate crops on other parcels of land located inland or even in another village. In this light, fa'a-'aigalua can enhance people's adaptability to changing climate and challenging situations" (Latai-Niusulu et al 2023 p3).

One study participant gave a good example of the "circular mobility" or "micro-mobility": "My older brother still lives there [previous place] but when it is close to the rainy season they come here [laughs] then afterwards they move back. He has become used to do that. I love to have him here but he doesn't want to leave there" (p6).

The research method used was "talanoa-style conversational interviews" (ie: to "talk freely"). "This method helps remove psychological distance and reduces the power differential between interviewer and interviewee and allowed the participants to share their stories in a relaxed atmosphere" (Latai-Niusulu et al 2023 p3).

The researchers concluded: "Samoans- micro-scale, circular movements like fa'a-'aigalua, enabled by customary land ownership systems and supported by family-oriented cultural practices, are simple, affordable and sustainable while providing geographically expanded opportunities for living in at-risk environments. As demonstrated in the study findings, retaining customary land ownership is important as it ensures the continuation of these flexible and spontaneous movements in response to environmental challenges. Hence, both international organisations and local governments should refrain from policies that pose a threat to customary land rights" (Latai-Niusulu et al 2023 p7).

Magargal et al (2023) described the IEK of the Diné (Navajo) People [2] and the practice of wood-hauling (ie: gathering firewood). Interviews found specific decisions in the choice of firewood, summarised by one interviewee as "we don't bother the live trees" (p5).

"All practitioners interviewed, surveyed, or who participated in focal follows reported that firewood should only be taken from dead wood, ideally from

[2] "Prior to the arrival of European explorers, and later Euro-American colonists, Diné people moved seasonally among a variety of ecological contexts ranging across arid canyons and plateaus to alpine forests, alongside numerous neighbouring Indigenous cultures. These traditional lands include large portions within the current political boundaries of Utah, Arizona, Colorado and New Mexico within the USA" (Magargal et al 2023 p2).

recently deceased trees which are frequently recently fallen, but sometimes still standing. The collection of live wood is acceptable only for specific construction and ceremonial purposes and is taboo when the use is for firewood. Despite this taboo, some Diné wood haulers shared that they have observed the harvest of live trees for firewood" (Magargal et al 2023 p5). The latter behaviour occurred when individuals had little choice - ie: few trees nearby, and/or unable to pay for coal.

Magargal et al (2023) explained that "Diné wood hauling today exists in a complex economic and political landscape that marginalises Diné communities from 'industrialised' energy sources. However, it would be inaccurate to cast this marginalisation solely in a framework of 'energy poverty' [Bednar and Reames 2020] because of the strong cultural values associated with firewood. These cultural values range across important aspects of Diné identity (without firewood, we would not be Diné) to concerns about the environmental impacts of industrialised energy sources. IEK is embedded in these cultural values and sustains a system wherein Diné cultural identity, including firewood harvest and use, can be sustained" (p7).

Put simply, the availability of plenty of trees would allow the Diné to follow traditional practices. "Decision-makers at all levels should consider how the consequences of larger trends may produce conditions that reduce the likelihood of IEK practitioners to succeed in maintaining necessary elements of human-ecological legacies" (p7), ended Magargal et al (2023).

The Inuit in the North American Arctic harvest and share local foods (country foods) as well as purchasing imported foodstuffs. "However, access to subsistence resources in Inuit communities in Canada today is strongly affected by the increasing costs of hunting activities. Harvesters are faced with the need to direct money obtained in the cash economy to buy and maintain hunting equipment including motorised boats, all-terrain vehicles (ATV) or snowmobiles, and to purchase gasoline and other supplies. The need to engage in wage labour — or, for young harvesters, formal schooling — further reduces the time available for activities on the land" (Hillemann et al 2023 p1).

Add to this changes in the weather from climate change. "For example, uncertainty in weather, such as unpredictability of the direction or strength of winds, are major concerns for hunters. Changes in sea ice cover affect access to hunting areas, as well as the behaviour, distribution and migration timing of marine mammals. Climate change also impacts access to country food through changes in the availability of key species owing to changes in population health, size or migration routes, or through wildlife management policies, such as hunting bans or quotas" (Hillemann et al 2023 p2).

Hillemann et al (2023) analysed data collected in 2013-14 on 146 Inuit households in Kangiqsujuaq in Nunavik (a mixed cash and subsistence economy). Two hundred and eighty-one foraging episodes were studied, including ice netting of fish, rifle snowmobile or canoe hunting of seal, goose, and caribou, and gathering mussels at low tide. Visiting different foraging patches involved different costs (eg: petrol for vehicle to travel long distance; purchase of rifle and ammunition).

Household income, and gender, influenced the foraging behaviour - "while men, especially men from low-income households, often visit patches with a relatively low success probability, women and high-income hunters generally have a higher propensity to choose low-risk patches. Inland hunting, marine hunting and fishing differ in the required equipment and effort, and hunters may have to shift their subsistence activities if certain patches become less profitable or less safe owing to high costs of transportation or climate change (eg: navigate larger areas inland instead of targeting seals on the sea ice)" (Hillemann et al 2023 p1).

The impact of climate change will interact with the socio-economic position of individuals. For example, retreating sea ice increases the dependence on boats to hunt and fish, and equipment needs to be purchased. Low-income individuals will need to work in the cash economy (more) to obtain money for equipment. High-income individuals will be less affected in this scenario.

Hillemann et al (2023) ended: "While most research on climate change adaptation in the Arctic has focused on identifying behaviours or practises that harvesters could adopt in order to mitigate the effects of climate change, social and economic structures also constrain what options are feasible for actors. Inuit in Kangiqsujuaq themselves identify costs of living and of hunting equipment and supplies as major barriers to harvesting today, and our results echo their perception: socio-economic factors impact harvesting strategies and thus may constrain adaptation to climate change for some community members more than others" (p7).

1.2.1. Double Exposure

Kramer and Hackman (2023) explained: "Subsistence agriculturalists are well adapted to inter-annual climate variation. Farmers manage seasonal and annual fluctuations in food production by relying on fall-back foods, diversifying production and having well-developed alliance and exchange relationships" (p1). But climate change is part of a "double exposure" (O'Brien and Leichenko 2000) for such communities. The other element is "market integration" - "a process involving increased social and commercial interaction with non-local entities and often a blending of traditional subsistence production with the labour market (eg: wage labour, cash economy and surplus production). Because these mixed economies have a foot in two different livelihoods with different sets of risks and means to offset downturns, households must balance investments in traditional subsistence practises and social behaviours with new, unfamiliar ways of making a living" (Kramer and Hackman 2023 p1).

Kramer and Hackman (2023) interviewed Yucatec Maya maize farmers in Mexico between 2017 and 2022. In 2019, seventy-seven of 101 farmers felt that climate change had increased the frequency of bad harvests. Traditional strategies to deal with bad harvests included planting in multiple locations, planting at different times, and storing maize. Market integration in recent years (in the 21st century) meant a shift from subsistence farming to production for the market, which included purchasing "agricultural inputs" (eg: fertilisers; vehicles).

The study showed that market integration had an impact on bad harvests, specifically "a more rigid food production system that conflicts with the diversity and flexibility on which traditional strategies depend to manage climate variation" (Kramer and Hackman 2023 p1).

Households responded to market integration by intensifying their maize production, diversifying the variety of agricultural goods, or having family members work for money in non-agricultural activities. Depending on the strategy, a bad harvest was perceived and experienced differently. For example, intensifying households ranked one harvest (in 2021) as poor (because of the economic pressures), while diversifying households saw the same harvest as normal or good. This was evidence of the interaction of climate change and market integration.

1.3. MESO-LEVEL ADAPTATION

Traditionally flooded rice paddies around the world may be responsible for about one-tenth of global anthropogenic methane (CH_4) emissions per year (Lansing et al 2023). The traditional method involves flooding the soil before planting and leaving it submerged until before harvesting (approximately 100 days). Alternatives which wet and dry the soil may be better in terms of greenhouse gas (GHG) emissions.

Lansing et al (2023) reported an evaluative study in Bali, Indonesia in 2018-20. Gas measures were taken prior to the study (baseline), and subsequently farmers used the traditional method (FLD) or intermittent minimal wetting (INT) (where farmers judged when to intermittently flood).

Mitigation of GHG emissions is not straightforward. "While CH_4 emissions can be reduced by lessening the time the plants are submerged, this can trigger increased emissions of nitrous oxide (N_2O), a more potent GHG" (Lansing et al 2023 p1). Plus that there are difficulties in accurately measuring gas emissions in rice paddies. However, Lansing et al (2023) suggested that INT benefitted GHG emissions overall, while this method of irrigation clearly led to increased yield.

1.4. MACRO-LEVEL ADAPTATION

Climate change is part of "a global 'polycrisis': a series of interconnected and interacting threats — climate change and ecological disasters, rising economic inequality and political polarisation, violent conflict and more" (Hoyer et al 2023 p1). There have been polycrises in the past, and what can we learn from them?

Hoyer et al (2023) analysed 150 past societal crises from the "CrisisDatabase" (table 1.1). The researchers noted how cultural, political and economic structures at the time of the crisis were able to generate resilience and facilitate positive adaptation, or lead to unrest, violence, and societal collapse.

Hoyer et al (2023) noted three central structural pressures in societies in crisis:

i) "Popular immiseration" - ie: declining well-being and living standards for the majority of the population.

ii) "Elite over-production and conflict" - ie: too many elites competing for scarce resources.

- End of Qing Dynasty (last imperial period) in China (1644 - 1911)
- Zapotec hilltop settlement of Monte Alban (modern-day Mexico) (from 500 BCE onwards)
- Russian Romanov Dynasty (ended in early 20th century)
- Collapse of Sassanid Persian Empire (seventh century)

Table 1.1 - Example of historical crises studied by Hoyer et al (2023).

iii) "State fiscal distress and declining state function" - ie: the erosion of state legitimacy and capacity.

"Put simply, a society's evolved (or evolving) structures make them more or less vulnerable to threats arising either endogenously through the workings of the system itself or exogenously as a consequence of environmental changes (human-driven or 'natural'). In a context of high social pressure, an external stressor can exacerbate unrest and instability that was already developing. By the same token, the lower these pressures are when a threat rises, the more likely it is that the society will have the cohesion and resources to mitigate the threat's impact, maintain well-being, or the resilience to quickly rebuild critical infrastructure" (Hoyer et al 2023 p5).

What is clear from historical cases is that climate change does not inevitably lead to societal collapse. How much unhappiness exists in society beforehand and in relation to other issues is important. "For scholars, the challenge moving forward is to uncover 'leverage points' that can help shape the experience of societies facing crises away from destabilisation and violence and towards stability and even positive reform" (Hoyer et al 2023 p9).

1.4. Niche Construction

"Niche construction" is "the set of processes whereby 'organisms, through their metabolism, their activities, and their choices, define, partly create, and partly destroy their own niches' [Odling-Smee et al 1996]" (Barrett and Armstrong 2023 p2). The niche in this context is the environment. Formalised as "Niche

Construction Theory" (Odling-Smee et al 2003), it "emphasises the ability of organisms to modify their environment and, therefore, influence their own evolution and that of other species" (Scheinsohn et al 2023 p2).

Culture is important in humans' ability in niche construction [3], such that "causality of evolutionary change is not limited to selective pressures from the environment, but also includes those from constructed niches. Similarly, inheritance includes not just the genetic and cultural ones, but the so-called ecological one as well" (Scheinsohn et al 2023 p2).

"Cumulative cultural evolution" is the development of human practices, ideas, actions, and beliefs, and they have in the past and can in the future help in adaptation. Agriculture is a good example of this as seen in refinement of crop varieties, irrigation, mechanisation, and fertiliser use (Waring et al 2023).

In fact, cumulative cultural evolution is the "secret of our success" (Henrich 2017), and some would argue that that culture can be seen "to act as a kind of invisible hand that produces evolutionary optimal outcomes for cultural group members although those outcomes were not intended or foreseen by those group members" (Barrett and Armstrong 2023 p2). At its extreme, this view, which Barrett and Armstrong (2023) called a "Panglossian tendency" (after Gould and Lewontin 1979 [4]) [5], "suggests laissez-faire polices of climate intervention in which we are better off letting cultural evolution run its course in finding effective solutions to the climate crisis independently of any intentional changes in collective action or political organisation" (Barrett and Armstrong 2023 p2) [6].

Barrett and Armstrong (2023) were critical of this view because there is not an inevitable adaptation or

[3] Boyd and Richerson (1985) used the concept of the "transmitted environment".

[4] The idea of "the near omnipotence of natural selection in forging organic design and fashioning the best among possible worlds" (Gould and Lewontin 1979 p584). Gould and Lewontin (1979) criticised evolutionary thought in England and the USA in the mid-20th century for "faith in the power of natural selection as an optimising agent" (p581). This has led to a number of problems, the authors argued, including an "unwillingness to consider alternatives to adaptive stories", and a "reliance upon plausibility alone as a criterion for accepting speculative tales" (Gould and Lewontin 1979 p581).

[5] After Dr Pangloss in "Candide" by Voltaire.

[6] Barrett and Armstrong (2023) quoted these examples from Lomborg (2020) as "Panglossian to the point of absurdity" (p7): "At its simplest, adaptation means that people react sensibly to challenges — in our case, to a changing climate. As it gets warmer, more people will adapt by turning on their air conditioners (and fewer will use their heaters). If they don't yet have an air conditioner, more people will buy one (and more people will be able to buy one as global prosperity increases). Similarly, tourists will adapt to a warming world by changing their travel destinations. Warm places like Sri Lanka will host fewer tourists. On the other hand, more visitors will choose Finland and Canada for their next holiday, while fewer Finns and Canadians will travel abroad".

niche construction through cumulative cultural evolution. In the same way that natural selection can lead to extinction if certain costly traits come to dominate, so cultural norms and practices can spread though they may not be beneficial. Barrett and Armstrong (2023) explained: "Cultural practices that perpetuate harmful environmental effects such as excessive emission of greenhouse gases could be a self-reinforcing stable equilibrium in which all actors are doing what is 'best' for them, or perceived as best, given their set of choices. In such cases, the cost for individuals or cultural groups to unilaterally defect from their current policy of actions can seem to outweigh the benefits associated with any alternative courses of action" (p4).

The problem is this: "Anthropogenic climate change is the result of cumulative cultural practices of human niche construction" (Barrett and Armstrong 2023 p4). It derives from "patterns of cultural evolution gone bad" or "the back of the invisible hand of culture" (Barrett and Armstrong 2023 p4).

1.5. APPENDIX 1A - ETHNOBIOLOGY

"Classically, ethnobiology has been defined as the study of the interactions of people and the environment. This sometimes makes it appear that the term is associated with human ecology and ethnoecology. Darrell Posey (1987 quoted in Albuquerque and Alves 2016), one of the greats of ethnobiology, sees it as the study of knowledge and concepts developed by any culture on biology" (Albuquerque and Alves 2016 p3). There are two traditional approaches in ethnobiology - cognitive, and economic (Albuquerque and Alves 2016). "For its cognitive approach, ethnobiology is concerned with know [sic] how cultures perceive and know the biological world; in its economic focus, it considers how these cultures convert biological resources into useful products" (Albuquerque and Alves 2016 p4).

One area of interest is understanding "traditional knowledge" (also called "local knowledge", "indigenous knowledge", or "ethnoscience") (Albuquerque and Alves 2016). "The knowledge of local people has long been underestimated by most scientists, who seemed to neglect other knowledge systems" (Albuquerque and Alves 2016 p6). But Donovan and Puri (2004), for example, showed local knowledge of certain plants in Indonesian Borneo was common in many aspects to academic scientific records. While Warren et al (2003) showed that farmers in Nigeria had a better overview of the general harm of soil erosion than technicians and scientists (Albuquerque and Alves 2016).

1.6. APPENDIX 1B - RESEARCH TOOLKIT

Local, rural Indigenous and descendant (LID) communities are, and will be further, disproportionately impacted by climate change. How can conservation and developmental practitioners help such groups, specifically with community empowerment? "A community may identify a common need (eg: infra-structural improvements, alternative sources of income, reliable health care etc), agree on actionable steps for a project addressing this need, and have stakeholders willing and able to lead those steps. However, they may still face barriers (ie: difficulty securing funding, sourcing materials) that constrain their ability to realise their goal" (Buffa et al 2023 p3).

Buffa et al (2023) presented "a context-adaptable toolkit to assess community agency, identify barriers to adaptation, and survey perceptions of behaviour change around natural resource conservation and alternative food acquisition strategies. This tool draws on public health and ecology methods to facilitate conversations between community members, practitioners and scientists" (p1). There are four underlying constructs (Buffa et al 2023):

a) Openness - "one's perception of the project idea as positive and acceptable to the community and that one can be open to an idea without being willing or able to act upon it" (Buffa et al 2023 p3).

b) Willingness - determination to take the necessary steps to achieve the goal.

c) Access - "one's ability to use and make decisions about the spaces, resources and outputs relevant to the project" (Buffa et al 2023 p3).

d) Empowerment - the perception of the ability to carry the decisions made through.

The toolkit was piloted in southwestern Madagascar with Vezo fishing communities with focus groups and surveys. The central question was: "What do you wish that conservationists and scientists asked you before suggesting changes for your community as you confront climate change and biodiversity loss?" (Buffa et al 2023 p4).

The main concern was depletion of marine resources, and alternatives for the community included a duck husbandry project. The survey listed 41 potential barriers to members of the local community successfully participating in the project (eg: initial purchase of ducks; veterinary services; housing of ducks; transport to market). Most barriers were perceived as "small".

Community involvement in projects to help LID groups adapt to climate change is crucial. The toolkit proposed by Buffa et al (2023) includes "focus group discussions and an individual survey to facilitate community-led project development at two junctures: (1) to guide idea generation around solutions for a community-identified problem; or (2) to refine an ongoing project to integrate community feedback. It provides a template for scientists and practitioners to engage with local experts and co-produce development solutions that respect local histories and knowledge. Much like any development project, policy should be produced in conversation with communities" (Buffa et al 2023 p10).

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2. ANTHROPOCENE SYNTHESIS

2.1. INTRODUCTION

"Globally connected industrialised societies are now the main driver of change in the Earth system, a time period that has come to be known as the Anthropocene. On the one hand, this ecological dominance of humans could be seen as the ultimate evolutionary success of a species. On the other hand, the overlapping systemic and global risks that mark the Anthropocene hardly seem like a success. Human activities are threatening the stability of the Earth's climate, the survival of many co-inhabitants, and indeed the basis for the stability of human civilisation" (Sogaard Jorgensen et al 2023a p1).

How did we get here, what is happening, and where are we going are three questions that Sogaard Jorgensen et al (2023a) attempt to answer with "an Anthropocene synthesis" (ie: a diversity of approaches from different areas of science).

1. The past: the evolution of the Anthropocene - eg: population growth; resource use; technological developments.

2. The present: the dynamics of the Anthropocene

3. The future: the transition to sustainability

2.2. THE PAST

2.2.1. Population Growth

"The overall trajectory for the human-environment interaction has been punctuated by demographic boom-and-bust cycles, phases of growth/overshooting as well as of expansion/contraction in productivity" (Gayo et al 2023 p1).

Gayo et al (2023) used the case study of populations in the Atacama Desert (South America), who began agriculture there as early as 1500 BC. Population sizes grew and contracted over time, and the researchers modelled data for the last 1200 years, including climate change, and warfare. A key variable was co-operation-competition between the peoples, along with the ability for problem-solving.

Lima et al (2023) asserted that "technological innovations modify the environment and the energy fluxes from the environment, which affects human population growth" (p2). Put simply, large population increases go hand in hand with greater ability to produce energy via cultural and technological innovations. For example, the "Neolithic demographic transition" (10-11 000 years ago) was a rapid increase in population density as agriculture was adopted in the Levant area of the Mediterranean, or a rapid population growth three hundred years ago at the time of the "Industrial Revolution" (Lima et al 2023).

Put into the language of ecology and evolution, "population, co-operation, and cultural trajectories are structured in a feedback relationship that impacts the evolution of the socio-cultural human niche. According to models of niche cultural construction, humans of one generation 'build' new environments that are inherited by the following generation, which in turn modify it again (in the same direction) for the next generation. This leads to a coupled dynamic between niche construction and ecological inheritance. Therefore, environmental modifications tend to improve the average living conditions of individuals, increasing population growth rates and population density. The combination of innovation, social complexity, and ecosystem engineering capacity is an explosive 'cocktail' responsible for the human population expansion and the impact on the planet's surface" (Lima et al 2023 p7).

2.2.2. Cumulative Cultural Evolution

Trying to explain the "rise of humans" involves different models and theories. One key idea is "cumulative cultural evolution" (CCE) - put simply, the accumulation of knowledge [7]. "Each individual contributes a small addition to the accumulating whole, while aggregate knowledge can reach levels far beyond what any individual could produce or master on her own. Social learning, in short, allows the population to retain the past insights of others while individuals build on these insights little by little. The result is cumulative cultural evolution. First come traditional varieties of corn, rice, wheat and potatoes. Then come modern high-yield varieties built on decades of scientific research" (Efferson et al 2023 p1).

Efferson et al (2023) also emphasised the use of two types of technology by humans over the years: "Consumption technology affects the rate at which humans can extract resources. Production technology controls how effectively humans convert labour into new resources. The dynamics of both types of technology are subject to cumulative cultural evolutionary processes that allow both technological progress and regress" (p1).

Explaining the CCE that produced the Anthropocene needs to include non-agentic and agentic forces. The former "just happen" and are akin to random mutations in genetic evolution, while the latter is "agentic in the sense that decisions of the organisms involved play an active role" (Richerson et al 2023 p1) (eg: learning).

Richerson et al (2023) pinpointed two key parts in the origin of CCE: "One part is the increasing millennial and sub-millennial scale climate variation that favours adaptation by learning and social learning. The other part is the ape and Australopithecine preadaptations of large societies and hands that could be specialised for toolmaking, uncompromised by the use of the forelimbs for locomotion. The large economic pay-offs to using tools to acquire difficult resources and deploying co-operation for subsistence practices meant that only humans could take massive advantage of the cultural niche" (p4).

Waring et al (2023) favoured two key factors to

[7] The application of the principles of evolutionary theory to non-genetic systems is known as "extended evolutionary synthesis" (EES) (Pigliucci and Muller 2010). "In humans, for example, information affecting behaviour is predominantly transmitted culturally through social learning. This results in cultural evolution in which behaviours, language, institutions and technology are modified and spread between people and groups" (Currie et al 2023 p3)

explain the human impact on the environment - "the role of culture and the importance of group structure and co-operation" (p2). These authors concentrated particularly on the latter. Specifically, the "evolution of group-level cultural traits via cultural group selection" (Waring et al 2023 p2). The ability to co-operate taken further than within small groups leads to trade networks, military alliances and treaties. Co-operation at such a large scale is key in the exploitation of the environment, a major element of the Anthropocene.

Waring et al (2023) outlined two possible paths for the future from these ideas:

- Path A - "Growing co-operation 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" (p7).

- 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" (Waring et al 2023 p7).

Sadly, they concluded that "humanity might be poorly adapted to survive a new evolutionary relationship to the biosphere" (Waring et al 2023 p10).

2.2.3. Other Theories

Lenton and Scheffer (2023) sought to answer the question: "What propelled the human 'revolutions' that started the Anthropocene?" (p1). They asserted that the key factors were fire use, agriculture development, state formation, labour specialisation, and industrial investments. Reinforcing feedback cycles based on these changes propelled humanity forward abruptly and irreversibly. The only solution, they argued, "to escape a bleak Anthropocene will require abruptly shifting from existing unsustainable 'vicious cycles', to alternative sustainable 'virtuous cycles' that can outspread and outpersist them. This will need to be complemented by a revolutionary cultural shift from maximising growth to maximising persistence (sustainability)" (Lenton and Scheffer 2023 p1).

Lenton and Scheffer's (2023) explanation of the development of humans is described as a "survival of the systems" framework (Lenton et al 2021), and it tries to combine other explanations based on cultural evolution, complex adaptive systems, and long-run economic growth. Put simply, each "innovation" or "revolution" in the past two million years built on previous ones and reinforced its importance.

Take the example of the intentional use of fire ("the first human revolution"; Lenton and Scheffer 2023). Fire use changed the food consumed, produced warmth and protection, and control over the environment (eg: burning of grasslands). The first two allowed movement to new areas, while the last one prepared the way for the next development - agriculture, and so on. Later industrial development is based on the use of fire in manufacturing, for instance. Each development allows for larger populations of humans.

Human techno-cultural development has occurred much faster than the evolutionary time-scales, and than ecological systems can adapt. This has been called a “greedy strategy” in systems analysis (Weinberger et al 2023).

2.3. THE PRESENT

2.3.1. Socio-Technical Evolution

Kempe and van Lente (2023) viewed innovation as "an evolutionary process" - ie: "the creation and uptake of innovations (new products and production technologies) resembles a process of variation, selection and retention" (p1).

However, socio-technical evolution is dissimilar to natural evolution in being less random (with directed research and development, for example), and that the selection processes are mostly man-made (eg: from shareholders and profit) (Kempe and van Lente 2023).

The concept of "co-evolution" is key here, which Kempe and van Lente (2023) defined as !a condition in which two or more processes with evolutionary elements of variation, selection and retention influence each other through selection pressures and resourcing" (p2). They continued: "An example of selection pressure is climate policies coercing business to reduce greenhouse gas emissions; an example of resourcing is the provision of subsidies and informational support. The evolution of business is thus directly connected to the evolution of government policies. As all societal sectors (including the government sector, finance and science) show interdependency, within those sectors and between sectors, any sector co-evolves with other sectors. Also the wider institutional order (trade regimes, democracies, and rights and obligations for citizens and business) is subject to co-evolutionary dynamics and meta-governance (the governance of governance [Jessop 2003])" (Kempe and van Lente 2023 p2).

The processes of co-evolution have myopically caught producers, consumers, governments, and scientists, argued Kempe and van Lente (2023), in short-term aims when longer term ones are needed. They stated: "Actors are myopically caught in processes of co-evolution, not because they are short-sighted and stupid but because 'unsustainability is the accumulated result of the improvement processes of many, intertwined, smart actors combined' [Diepenmaat 2020]" (Kempe and van Lente 2023 p5).

Kempe and van Lente (2023) ended with this plaintive thought: "A new consciousness of the Anthropocene may evoke fundamental changes in science and the economy, but only when they are sufficiently carried by institutional changes and new practices" (p6). That could be "global consciousness".

2.3.2. Global Consciousness

Zhang et al (2023) observed: "As humanity moves into the Anthropocene epoch, it is apparent that 'industry as usual' is unsustainable" (p7). "Global consciousness" (GC) could be an important behaviour here, but it varies between individuals. Zhang et al (2023) described GC as "encompassing cosmopolitan orientation, global orientations (ie: openness to multi-cultural experiences) and identification with all humanity,...that is strongly associated with pro-environmental attitudes and behaviours, less ingroup favouritism and prejudice, and greater pandemic prevention safety behaviours" (p1).

More specifically, Liu and McDonald (2016) defined GC as "a knowledge of both the interconnectedness and difference of humankind, and a will to take moral actions in a reflexive manner on its behalf" (quoted in Zhang et al 2023), while McFarland et al (2019) explored the idea of "Global Harm Identification and Citizenship".

Individuals high in GC are more co-operative, but not automatically more pro-social. For example: "Older adults are typically oriented towards significant others, with whom the older person has formed a meaningful and enduring attachment. A study of over 67 000 individuals across 67 countries [Cutler et al 2021] found that donations overall — and specifically to a national charity — increased with age, but donations to an international charity decreased with age. GC would appear to require specific socialisation experiences rather than age-based maturation, as previous research has shown it to be positively correlated to religiosity, higher education and socio-economic status" (Zhang et al 2023).

Zhang et al (2023) reported data from surveys in China, Hong Kong, Malaysia, Singapore, Taiwan, and the USA in 2020 (n = 1449 respondents). Measures were taken of a variety of characteristics (eg: cosmopolitan orientation), and fifteen life experience changes (eg: moved to a new location; someone close to you died).

Certain life experiences were found to increase GC, particularly getting married, and welcoming a new child to the world, which were empathy-building and network-enhancing, but also receiving a promotion or getting a better job. "Less intuitively, death of a close-other enhanced rather than reduced GC. Perhaps this was achieved through the ritualised management of meaning where a sense of the smallness of self is associated with growth of empathy for the human condition..." (Zhang et al 2023 p1).

2.3.3. Niche Construction

The industrial development of humans over recent centuries (or "industrial niche construction" to use ecological terminology [8]) has produced three types of injustice (Dorninger et al 2023):

i) Inter-species - "through niche construction processes humans appropriate or destroy an unproportionally large share of the trophic energy from ecosystems over other species..." (Dorninger et al 2023 p6).

ii) Intra-generational - unbalanced trade relations between humans around the world.

iii) Inter-generational - the impact on future

[8] "Clearly, no niche construction process can be classified as exclusively destructive or regenerative, because there will always be winners and losers, ie:. species that thrive and reproduce in the course of presumably destructive industrial niche construction or the global spread of domesticated animals and plants, while other wild animals and plants are decimated" (Dorninger et al 2023 p7).

generations of the behaviour of past and current humans.

Dorninger et al (2023) observed that "it will be essential to learn from newly evolving research on 'collectively defined self-limitation' [Brand et al 2021], 'sufficiency' instead of efficiency only [Sandberg 2021], 'degrowth' [D'Alisa et al 2014], 'restraining the present' [Lazarus 2008], 'maximising persistence' [Lenton and Scheffer 2023], or a 'steady-state economy' [Daly 1973], which all provide practical examples that — if implemented — could potentially go beyond current destructive human niche construction processes..." (pp7-8).

2.3.4. Remanufactured Products

Reuse of scarce resources is crucial, and the "circular economy" is based upon this principle. Remanufacturing is a specific example here - "this is done by converting a product that is nearing the end of its life and is no longer supported by the manufacturer into a new product that carries the same warranty as the original... In the remanufacturing process, the returned product is disassembled, the parts are cleaned and sorted properly, the parts are refurbished, and some new parts may be procured and finally reassembled and tested for quality" (Alyahya et al 2023 p1).

But is there a market for such products? In other words, how do consumers view remanufactured products?

Research suggests a lower quality perception compared to brand new goods, and so price discounts are needed to encourage purchase (eg: between 15-40% depending on the product) (Alyahya et al 2023).

Other variables include ethical ideology, product knowledge (eg: that a remanufactured version of a product is as good as a brand new one), and demographic factors (eg: age; education; income) (Alyahya et al 2023).

Much research is based on stated future intentions, which are not necessarily the same as actual behaviour. Alyahya et al (2023) surveyed consumers who had purchased remanufactured products in the previous six months. An online survey was completed by 420 such consumers in Saudi Arabia in mid-2022. Items on the questionnaire included "I feel that I have played a great part in helping the environment when I bought remanufactured products"; "I have a moral obligation to treat others fairly" (moral obligation); and "I am afraid that the performance of remanufactured products is inferior to performance of new products" (perceived risk).

Willingness to purchase remanufactured products was predicted by variables like high moral/ethical ideology, low perceived risk, and high product knowledge.

2.3.5. Cities

Cities are a future of the Anthropocene. "Increasing evidence shows that cities are changing the genetic and cultural makeup of many populations, including animals, plants, fungi and micro-organisms, which might have significant effects on socially relevant ecosystem functions such as nutrient cycling, pollination, water and air purification and food production both locally and globally" (Alberti 2023 pp1-2).

Evolution occurs faster in cities compared to the surrounding countryside (eg: meta-analysis of more than 1600 changes; Alberti et al 2017). There are multiple selection processes driving this pattern, including habitat modification by humans, pollution, and introductions and invasive species (Alberti 2023). Specifically, the speed of evolution may be increased by the "urban heat island" effect, and the density of interactions, while "high environmental variability, both spatially (eg: differences between a park and a parking lot) and temporally (eg: changes in noise or light pollution throughout the day), can lead to stronger selective pressures, potentially catalysing faster evolution" (Alberti 2023 p5).

2.3.6. Long-Distance Relationships

Pisor et al (2023) concentrated on "common-pool resources" (CPRs) - ie: "natural resources like forests, fisheries and watersheds that can be depleted and from which it is difficult to exclude users — especially when the CPR can be accessed by multiple communities. Each of these resources poses a 'sustainability frontier' requiring social mechanisms of environmental control" (p1).

Long-distance social relationships spanning communal boundaries can play both a positive and a negative role in natural resource management (NRM) of CPRs. On the positive side, kin relationships, business or trade relationships, and friendships can promote norms of sustainability through interdependence. On the other hand, such relationships can facilitate and transmit norms of overharvesting (Pisor et al 2023).

The solution is polycentric management of resources involving multiple communities in long-distance relationships, argued Pisor et al (2023), not ignoring the costs of such relationships. "Human social relationships can be an asset, not just a hindrance to local NRM in the Anthropocene" (Pisor et al 2023 p9).

Pisor et al (2023) presented two case studies from Tanzania - forest management in Pemba (a Zanziberi archipelago island), and Tanga region fishing communities. Though long-distance relationships could increase private harvesting, there were many benefits to such relationships including information-sharing.

2.3.7. Polycrisis

The Anthropocene could be classed as a "polycrisis" - "multiple interacting crises spanning the ecological, social, economic and technological domains" (Sogaard Jorgensen et al 2023b p1). Sogaard Jorgensen et al (2023b) asked: "Could the current Anthropocene trajectory be a trap that modern industrialised societies are naive to, not unlike seabirds feeding on deadly marine plastics, lacking the capacity to distinguish them from nutritious marine plankton?" (pp1-2).

In answer, these authors proposed fourteen traps (divided into three categories) for humanity with its increasing complexity (table 2.1).

For humans to escape these traps, Sogaard Jorgensen et al (2023b) outlined five behaviours:

i) Recognising traps.

ii) Measuring accurately the threats.

iii) Reorganising and innovating.

iv) "Being prepared for the unknown" (or for "unknown unknowns").

v) Navigating conflict, and co-operation at a global level.

CATEGORY	TRAPS
Global	1. Simplification ("increasing specialisation produces simplified sub-systems that are vulnerable to shocks"; p4). 2. Growth-for-growth (pursuit of economic growth at expense of human well-being). 3. Overshoot (economic growth overshoots the Earth's tipping point). 4. Division (co-operation between certain groups leads to global conflict). 5. Contagion (increased connectivity increases the speed of spread of diseases, and ideas).
Technological	6. Infra-structure lock-in (complex infra-structures that are maladaptive, and refusal to change). 7. Chemical pollution. 8. Existential technology (technology that threats the existence of humans as a whole; eg: nuclear weapons). 9. Technological autonomy (reliance on technology that is misaligned with human needs). 10. Dis- and misinformation.
Structural	11. Short-termism. 12. Overconsumption. 13. Biosphere disconnect (separation of humans from nature). 14. Local social capital loss ("digitalisation can lead to loss of local social capital through reduced interaction and echo chambers"; p4).

(Source: table 1 Sogaard Jorgensen et al 2023b)

Table 2.1 - Three categories of traps for humanity.

2.4. THE FUTURE

"Social-ecological systems" (SES) research is a sub-field of sustainability science that "recognises that humans and nature are deeply intertwined and aims to enable changes in governance, technology and behaviour that ensure a sustainable liveable planet for future generations. SES research provides a useful toolkit of theories and methods for understanding how these systems work, and how we might aim them towards long-term health and resilience" (Currie et al 2023 p2).

SES research is action-oriented "aiming not just to understand how a system functions but to act to improve the sustainability or resilience of the system" (Currie et al 2023 p2).

Ellis (2023) talked of "the power of human aspirations" as "Earth's most disruptive force of nature", and "a better future for both people and planet will depend on guiding this..." (p1).

Put simply, the power of human aspirations is manifest in the changes that humans have produced in the environment from fire to clear land, to domestication of species and agriculture, to industrial food systems (both beneficial and harmful).

But aspirations can be harnessed for good with "shared aspirations for a better future" (Ellis 2023 p8). Storytelling and cultural narratives have an important role to play here, including in terms of relationships towards each other as well as to the planet. Ellis (2023) ended: "The way people treat each other shapes the way people treat the rest of nature, and the other way around" (p8).

2.4.1. Co-Operation

Co-operative behaviour within a local group is crucial for changing behaviour, and particularly, for Safarzynska and Smaldino (2023), how wider events, like climate change, impact the co-operation.

Co-operation can be studied in "public good games". For example, a group of four players can contribute any amount of their stake to a common pool. The total amount is doubled, say, and then divided by four. If all players co-operate (ie: put all their stake in the pool), everybody benefits equally. But if some players do not co-operate (ie: put in less money), these individuals benefit at the expense of everybody else.

Safarzynska and Smaldino (2023) simulated such games, but varied the consequences of non-co-operation between evenly distributed among all players, or having a stronger impact on the rich or the poor. Co-operation was found to be strongest "if it either disproportionately benefits the poor or disproportionately reduces the payoffs of the rich" (Safarzynska and Smaldino 2023 p1) (appendix 2A).

2.4.2. Greenwashing

Companies need to change to sustainable production, but there is a risk of cheating in the form of "greenwashing". This includes claims that the stages of the supply chain are sustainable (when they are not necessarily so), particularly with the use of "in-house" or self-certification.

"Many consumers may be willing to pay a premium for sustainably produced goods, but they cannot or will not invest the substantial time and energy necessary to verify that the goods in question were in fact sustainably produced. This is where certification schemes enter the picture. Product labels based on such certification schemes are meant to help consumers make informed buying decisions. However, it might often be difficult for consumers to verify the information provided by labels" (von Flue et al 2023 p2).

How consumers view certification is important. If they overestimate the reliability of self-certification, then produces are incentivised to "greenwash", but underestimating reliability can lead to a distrust of independent/third-party certification as well. There is a role for an independent party that provides accurate information to consumers (von Flue et al 2023) [9].

2.5. APPENDIX 2A - Counting and Pro-Social Behaviour

Two aspects of pro-social behaviour - sharing (of resources), and instrumental helping (ie: offering to help) - have been theorised as "distinct behaviours, each with differentiated underlying mechanisms, developmental trajectories, ans neural substrates" (Sohail et al 2022 p291). For example, in the first two years of life, "early helping appears to be intrinsically motivated, requiring little explicit encouragement..., whereas sharing, relies more heavily on cueing..., and appears more difficult to motivate even when the recipient's desires are clear" (Sohail et al 2022 p291).

The development of these two abilities may be linked to specific cognitive abilities. Sohail et al (2022) investigated numerical cognition (or counting proficiency) with 85 pre-schoolers in the USA.

In a repeated measures design, the children performed a sharing task and a helping task in a randomised order. In the former, children could share

[9] For example, "Ethical Consumer" in the UK (https://www.ethicalconsumer.org/ethical-consumer-magazine).

their ten stickers with a sad puppet who had none. There was no direct encouragement of sharing by the experimenter. In the helping task, the children could aid a puppet completing a sticker task by using their stickers. Numerical cognition of 1-6 was tested with a pile of plastic ducks, and six questions like, "can you give me one duck?". "Proficient counters" got six correct answers.

"Basic" pro-social behaviour (defined as giving at least one sticker) was shown by 94% of children in the helping condition and 96% in the sharing condition. But "precise" or "equal" pro-social behaviour (defined as giving five stickers) was 13% and 34% respectively.

Numerical cognition was found to predict sharing, but not helping behaviour: "That is, compared with children who were not yet proficient counters, children who were proficient counters were more likely to share resources equally during the sharing task, but were no more likely to exhibit preciseness in helping behaviour" (Sohail et al 2022 p297). Sohail et al's (2022) conclusion was that "numerical cognition does not support pro-social behaviour in general, but rather that number cognition is uniquely recruited to resolve the competing demands (self versus other) of sharing" (p298).

This was a laboratory-based experiment with specifically created games to measure behaviours.

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3. ENDOCRINE RESPONSES AND ENVIRONMENT

3.1. INTRODUCTION

"Endocrine signalling regulates almost all biological processes, and the action of many hormones is closely linked to environmental signals. Hormones are therefore at the core of animal responses to environmental variation. Endocrine systems are relevant ecologically through integrating environmental signals with fundamental biological responses that underpin individual fitness and the function of ecosystems" (Little and Seebacher 2024 p1). For example, thyroid hormones in amphibians regulate development, and align physiological responses to the environmental changes of the seasons (Little and Seebacher 2024).

Little and Seebacher (2024) outlined three key issues:

i) The measurement of endocrine responses - For example, measuring circulating levels of hormones, like glucocorticoid (released during stress) in blood samples. "However, there is not always a clear correspondence between hormone concentrations and hormone signalling, because the latter may depend on receptor characteristics and densities rather than on circulating hormone levels alone" (Little and Seebacher 2024 p2).

ii) Endocrine flexibility - This is "hormones as information carriers, which are deployed to effect within-individual rapid and reversible changes in physiological regulation in response to unpredictable challenges" (Little and Seebacher 2024 p3).

iii) Endocrine responses to anthropogenic impacts -

Anthropogenic endocrine disruption is a challenge, as seen in endocrine disrupting chemicals (EDCs) (appendix 3A), artificial light-at-night (ALAN), and human-induced climate change (appendix 3B) [10].

For example, ALAN disrupts biological clocks (regulated by melatonin and thyroid hormone), while EDCs "interact with nuclear receptors such as thyroid and glucocorticoid receptors to activate or block endocrine signals. EDCs thereby impair essential biological functions across a broad range of taxa and have the potential to disrupt ecosystems, particularly in aquatic environments" (Little and Seebacher 2024 p3).

Increasing temperature and climate change can interact with endocrine signals to alter the body size and shape of different animals (Little and Seebacher 2024).

3.2. THYROID HORMONES

"Environmental variability can modify phenotypes during the lifetime of an organism and across generations via epigenetic modifications. Importantly, endocrine signalling can be linked to epigenetic processes such as DNA methylation, which together can alter physiology, behaviour and ecology of animals. Epigenetic processes modify gene expression programmes without altering respective DNA sequences but by the addition (or removal) of functional groups (eg: methyl groups) to DNA or histone molecules" (Seebacher and Little 2024 p1). Thyroid hormone is a good example here.

Light and temperature act on the thyroid hormone, which in turn acts on epigenetic processes. "Thyroid hormone production and release are controlled via the hypothalamic–pituitary–thyroid axis through the sequential actions of thyroid-releasing hormone and thyroid-stimulating hormone" (Seebacher and Little 2024 p2).

Thyroid hormones (TH) regulate development in amphibians and fish, for example, including metamorphosis (where it occurs). "Climate change alters mean temperatures and temperature variability, both of which can impact thyroid hormone signalling and hence DNA methylation. For example, unusually warm winters cause a mismatch between seasonal light cycles and temperature cycles that impacted thyroid hormone signalling in mosquitofish (Gambusia holbrooki) and caused physiological dysfunction in mice" (Seebacher and Little

[10] Sihs (2013) used the term "human-induced rapid environmental change" (HIREC).

2024 p5). Pollution (eg: EDCs like bisphenols, found in various plastics) and ALAN also impact TH signalling.

Zwahlen et al (2024) summarised five ecological functions of TH across the animal world:

i) Metabolic regulation.

ii) Regulation of body temperature (thermogenesis).

iii) Salinity acclimation in coastal fishes that move between marine (high saline) and freshwater (low saline) areas.

iv) Seasonal adaptation - eg: body changes for the annual mating season.

v) Metamorphosis - "It involves changes in internal and external body features, diet, and behaviour, which allow the organism to survive the transition from its larval to its juvenile environment. The classic example is the transformation of an aquatic tadpole to a terrestrial frog. In fishes, especially marine fishes, larvae are typically planktonic, growing and dispersing in the open ocean. Metamorphosis enables juveniles to live in a different environment such as shallow coastal areas and reefs" (Zwahlen et al 2024 p7).

All these functions involve TH interacting with other hormones and body systems.

3.3. GLUCOCORTICOIDS

Habitat loss is stressful to organisms. Glucocorticoid hormones (GCs) are released during stress, and so are a good indicator of an individual's level of stress.

"GCs are released from the adrenal gland via the hypothalamic–pituitary–adrenal (HPA) axis and regulate blood glucose levels and mobilise energy reserves. At baseline levels, GCs fluctuate daily and seasonally, reflecting the cumulative energetic demands required to maintain internal homeostasis across changing conditions. For example, baseline GCs can vary during energetically demanding life-history stages such as breeding and migration, weather events or periods of resource limitation. In response to acute or unpredicted challenges, GCs rise quickly and promote immediate survival, eg: by facilitating predator escape behaviour, territory defence behaviour or mounting of an immune response" (Alaasam et al 2024 pp1-2).

Alaasam et al (2024) investigated the relationship between GCs in different species of birds and their habitats using publicly available data. The GC data came from "HormoneBase" [11], a database containing published and unpublished records of GCs collected from adult, free-living vertebrates. The researchers concentrated on the USA from 1969 to 2015, and 51 species of birds. Data on land use were taken from the US Geological Survey's "National Land Cover Database" (NLCD) [12].

It was found that stress-induced, but not baseline, GC levels positively correlated with usable land. This relationship, Alaasam et al (2024) explained, "is consistent with the traditional view that a robust GC stress response is an adaptive mechanism critical to the maintenance of homeostasis and may be indicative of population health" (p6). But, they continued: "it is becoming increasingly evident that the benefits of a robust response may depend on the efficacy of recovery to baseline levels, ie: the rate at which individual GC levels return to baseline after a disturbance" (Alaasam et al 2024 pp6-7).

The researchers found differences between and within species, and so warned: "While our results show that land use can affect physiology on a population level, the magnitude and direction of the effect should be carefully interpreted on a case-by-case basis" (Alaasam et al 2024 p7).

The findings could show that species in sub-optimal habitats have a reduced stress response because species in such environments invest in reproduction not survival, or habituation to chronic stress, or a maladaptive response due to long-term stress ("maternal effects"). "For example, nutritionally restricted maternal environments can lead to decreased responsiveness of the hypothalamic-pituitary-adrenal axis in fledglings" (Alaasam et al 2024 p7).

Using publicly available data, the study was dependent on the accuracy and system of categorisations employed by the databases. This led the researchers to certain definitions, like classifying "land cover types as 'usable' for a population if the species had any record of inhabiting the type of land cover at the

[11] https://hormonebase.org/.

[12] https://www.usgs.gov/centers/eros/science/national-land-cover-database.

appropriate time of year/life-history stage, without attempting to estimate differences in the quality or preference, likely over-estimating the area that a population could realistically exploit" (Alaasam et al 2024 p8).

Alaasam et al (2024) added a general warning that "conservation practitioners should be cautious in using one-time plasma samples of GCs to make long-term judgements about populations" (p8).

Note that the idea that higher GC levels are "a proxy of poorer physiological state" (p1) has been challenged as "an overly simplistic interpretation of the complexity of the GC function" (Jimeno and Rubalcaba 2024 p2). "Endocrine flexibility" (appendix 3C) is becoming a key concept. The capacity of the individual to adjust GC response patterns to their environment (Jimeno and Rubalcaba 2024).

3.4. MELATONIN

Hormones are linked to biological clocks, and melatonin and light and dark is a prime example. This is produced by the lineal gland, and shows a daily rhythm of high concentrations at night and low concentrations during the day (Helm et al 2024). "The encoding of night length through melatonin generates seasonal information, which in temperate-zone mammals can organise or modulate a host of seasonally changing processes (eg: reproductive condition, immune function, aggressive behaviour, metabolism)" (Helm et al 2024 p6).

The process is slightly different for birds, but the rapidly increasing ALAN has an impact. "When exposed to ALAN, birds are highly vulnerable to disruption of behavioural rhythms and of physiological systems under rhythmic control. Several studies suggest that melatonin is likely a key mediator for a broad range of effects" (Helm et al 2024 p1).

Melatonin manipulation experiments have been undertaken (eg: great tits; Greives et al 2012), and this hormone has been shown to be involved in clutch initiation as well as daily/diel activity. "The melatonin-induced delay in clutch initiation differed between two study years, being greater in the colder and wetter year. The data suggest that melatonin indeed influences physiological systems regulating timing of clutch initiation, and may influence how these systems balance inhibitory (eg: signals of short days) and stimulatory (eg: temperature) cues. As the climate is changing, spring weather is becoming more unpredictable, and birds that breed in response to cues of a 'false-spring' suffer fitness costs" (Helm et al 2024 p6).

The same research with males (Greives et al 2015) found that "the melatonin-induced delay in diel behaviour was fitness-relevant, as late-rising males lost paternity in the clutches of their female mates" (Helm et al 2024 p6).

Melatonin biosynthesising in the pineal gland has been observed in embryos (eg: chickens) (Helm et al 2024). In one experiment (Gwinner et al 1997) starling eggs were kept in incubators that varied the light-dark cycles, and the melatonin levels in newly hatched birds had aligned to the particular cycle of their incubator (Helm et al 2024).

It is clear then that light/dark impacts melatonin, and so ALAN will have a consequence. This was observed from the early days of electric street lighting in the 1930s (eg: starlings in London; Rowan 1937). "The most consistent observation is advanced diel activity onset under ALAN" (Helm et al 2024 p7).

ALAN also impacts nocturnally migrating birds that use the stars for navigation. "Birds may be attracted or repelled by ALAN. On close distance, many lose orientation and suffer fatal collisions with human infrastructure. ALAN has also major ecological effects on birds, such as changes in prey availability, in predation risk and in complex ecosystem functions" (Helm et al 2024 p7).

Birds are sensitive to relatively low levels of light (below 1 lux [13]), the impact is dose-dependent, and wave length-dependent (eg: blue light has a greater affect) (Helm et al 2024).

3.5. BODY SIZE AND SHAPE

Body size and shape are influenced by hormones, and in turn by climate change. Some studies suggest a shrinking body size in recent years - for example, in males of 105 terrestrial bird species - while bill surface area and wing length have increased in others (eg: 129 North and South American bird species) (Names et al 2024).

This fits with "Bergmann's Rule" (proposed in 1847) which asserts that animals in colder latitudes are

[13] Equivalent to moonlight on a clear night (https://www.seratechnologies.com/what-is-lux-and-what-level-should-it-be/; accessed 1st March 2024).

larger, while "Allen's Rule" (proposed in 1877) describes a pattern of shorter appendages in latitudes further from the equator (Names et al 2024). So, "smaller body size and longer appendages are favoured in lower latitudes because they increase surface area to body volume ratios" (Names et al 2024 p2).

But climate change is not just increasing temperatures, it also involves changes in weather patterns that will influence food supply, competition, disease prevalence, and predation, and these impact body size. So, climate change will not inevitably produce smaller body size across the board (Names et al 2024).

In part, the changes in hormones will explain this. Endocrine mechanisms are complex, and work in the body in actions with genes, in different concentration levels, receptor densities, and at multiple sites/tissues in the body. "Body size is a polygenic trait, and several hormones are known to regulate variation in body size, including (but not limited to) members of the growth axis (IGF-1 [insulin-like growth factor], IGF-2 and growth hormone), thyroid hormones and glucocorticoids" (Names et al 2024 p4).

As an example, Names et al (2024) concentrated on IGF, which is involved in growth (eg: IGF-1 and bone growth), and longevity (eg: lower IGF-1 and greater longevity). "Recent comparative studies in mammals and birds also reported that species with higher IGF-1 have a 'faster pace of life' characterised by more rapid growth, higher reproductive output and reduced lifespans. These studies suggest that, within and among species, hormones and life-history traits can evolve in unison and changes in hormone levels, such as IGF-1 can result in co-ordinated changes in suites of traits, including body size" (Names et al 2024 p7).

Complex interactions in the body make it difficult to predict the impact of climate change on body size and shape. The lizard species, the brown anole is a well-studied example of growth (Cox et al 2017). Males and females are born the same size, but adult males are up to three times heavier than adult females. The larger growth of males is triggered by testosterone, but other hormones are involved also (eg: IGF; growth hormone) (Names et al 2024).

3.6. FOOD INTAKE

Food intake is regulated by processes in the body that include specific hormones (eg: orexin; neuropeptide

Y (NPY)) as well as general ones (eg: reproductive hormones). Changes in the environment can produce changes in food availability, which impact the processes in the body.

Concentrating on fish, Volkoff (2024) described the different environmental factors and examples of research studies:

i) Temperature of the water - Generally, increasing temperature leads to increased foraging behaviour and food intake to compensate for higher metabolic demands. In experiments, higher temperature leads to increased orexin and lower appetite inhibiting hormones, for example.

ii) Acidity of the water - eg: goldfishes have been found to reduce feeding in low-pH (high acidity) water, and this was due to hormonal changes (eg: peptide YY).

iii) Oxygen levels in the water - eg: low oxygen levels produce a stress response in rainbow trout, which decreases feeding.

iv) Salinity of the water - eg: high salinity (salt concentration) decreases food intake, and expression of NPY in Nile tilapia (a cichlid fish).

v) Turbulence of the water - eg: increased food intake in turbulent waters, and a decrease in certain hormone in goldfish.

vi) Light - eg: changes in orexin in ornate wrasse in experiments that varied the light conditions (eg: length of darkness).

vii) Contaminants - eg: higher levels of cadmium in the water increased food intake in Prussian carp and levels of NPY.

viii) Sound - Exposure to noise generally reduces food intake.

Volkoff (2024) summed up: "Food intake is ultimately regulated by feeding centres of the brain, which receive and process information from endocrine signals from both brain and peripheral tissues such as the gastro-intestinal tract. These endocrine signals stimulate or inhibit food intake, and interact with each other to maintain energy homeostasis. Changes in environmental conditions might change feeding habits and rates, thus affecting levels of energy stores, and the expression of endocrine appetite regulators" (p1).

In terms of the research evidence available, Volkoff (2024) comments on its variety: "There is a wide variation in the results from different studies, which can be owing to species-specific differences but also to different ranges in the parameters examined and different experimental protocols, highlighting a need for some type of standardisation in the experimental protocols. In addition, many studies report changes in feeding behaviour and growth, but information is lacking on the role of the endocrine system mediating these effects" (p6).

3.7. APPENDIX 3A - ENDOCRINE DISRUPTING CHEMICALS

An EDC is defined by the "International Programme on Chemical Safety" (of World Health Organisation; WHO) as "an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub-)populations" and a "potential endocrine disruptor is an exogenous substance or mixture that possesses properties that might be expected to lead to endocrine disruption in an intact organism, or its progeny, or (sub-)populations" (Kloas et al 2024 p2). EDCs are part of human chemical pollution of the environment.

Fishes and amphibians are particularly vulnerable to EDCs. The original idea, known as the "oestrogen hypothesis" (eg: Purdom et al 1994), proposed that reproduction is altered by oestrogen in water.

Two key aspects of reproductive biology are impacted - the reproductive functioning of adults, and the sexual differentiation of developing offspring (including sex reversal). The zebrafish, three-spined stickleback, and the tropical clawed frog are well studied here (Kloas et al 2024).

EDCs are categorised into EATS ((o)estrogenic, androgenic, thyroidal, steroidogenic) modalities (ie: the hormone types impacted) (Kloas et al 2024).

Miglioli et al (2024) described the action of EDCs during early development in Mediterranean mussels.

3.7.1. Xenobiotics

Wild (2005) proposed the concept of the "exposome" to cover environmental exposures and their biological impacts. There are two dimensions here: "(i) the exposome covers a variety of exposures including chemical, physical, biological, psychological, social and behavioural exposures; (ii) the exposome spans the life-course, including critical periods of vulnerability such as the pre-natal period, newborns, puberty, the elderly" (Tomkiewicz et al 2024 p1).

"Xenobiotics" is a term used to cover exogenous chemicals like contaminants, pollutants, and drugs, as well as dietary components, and microbial metabolites that assault the body (Tomkiewicz et al 2024).

"In mammals, xenobiotics or their metabolites are excreted by the kidney or through the bile; they can be metabolised primarily in the liver as well as in other organs and for some of them by the gut microbiota. The major pathways involved in the short-term response to chemical stress is the inducible elimination and detoxication of xenobiotics which is carried out by xenobiotics metabolising enzymes (XMEs) and transporters" (Tomkiewicz et al 2024 p2). This describes the short-term response to xenobiotics, whereas long-term adaptation involves genetic and epigenetic changes, and can be linked to evolution (Tomkiewicz et al 2024).

The interaction of exogenous chemicals and the gut microbiome (GM) has gained interest in recent years. The latter is "clearly involved in the degradation of xenobiotics (drugs, contaminants) and, considering the large diversity of enzymatic activities present in the GM, this activity could contribute to the elimination of xenobiotics. However, in some cases, microbial metabolism leads to degradation products that are more toxic than the parent compound. For example, melamine which was added to infant formula to artificially boost nitrogen content (a proxy for protein), is degraded by the GM into a highly toxic metabolite leading to severe human renal toxicity" (Tomkiewicz et al 2024 p7).

There are also nanomaterials and nanoplastics, which are "new entities" (Richardson et al 2023) that challenge the body (Tomkiewicz et al 2024).

3.8. APPENDIX 3B - WARMING PLANET

Warming oceans are impacting reproduction among fish species through the effect on hormone regulation. Over seventy species are known to have "temperature-dependent sex determination" (TSD), where the water temperature determines the sex of the developing offspring (Lema et al 2024).

"By far the most observed type of TSD in fishes is gonadal masculinisation at elevated temperatures. Genetic females in many species are sensitive to high temperatures and can undergo a process known as 'sex reversal', whereby temperature overrides processes of sex determination and differentiation, inhibits the endogenous female programme, and drives testicular development" (Lema et al 2024 p2). There are few instances of alternatives in the form of masculinisation in low temperatures or feminisation in high temperatures, which means the possible male skewing of sex ratios in warming waters of the future (Lema et al 2024).

The temperature effects occur during a particular period of larval development known as the "sexually labile period", and the hypothalamic-pituitary-inter-renal gland (HPI) is the mechanism (ie: a stress reaction to the heat). "The first response of the neuroendocrine system to environmental stress is an increase in hypothalamic corticotropin-releasing hormone (Crh). Crh then stimulates the secretion of adrenocorticotropic hormone (Acth) from the pituitary gland, which in turn regulates cortisol levels from the inter-renal glands" (Lema et al 2024 p3).

3.9. APPENDIX 3C - FLEXIBILITY

Survival for the organism requires the ability to respond and cope with unpredictable changes in the environment. "In vertebrates, one hormonal system is exceptionally important to such adjustments, the hypothalamic–pituitary–adrenal (HPA) axis. The HPA axis enables organisms to respond to many factors but especially stressors (ie: unpredictable or uncontrollable stimuli in the external and internal environments that threaten homeostasis), primarily via glucocorticoids (GCs). Circulating GCs mediate homeostasis and stress responses via a two-tiered receptor system. Moderate daily and seasonally rhythmic variations in concentrations (ie: baseline variation) are associated with changes in energy metabolism and behavioural activity and regulated largely by mineralocorticoid receptors (MRs). By contrast, rapid (ie: within minutes) and larger increases in concentrations (ie: stress responses), usually coincident with exposure to stressors, are regulated by glucocorticoid receptors (GRs). Surges like these are quickly (within minutes to hours) followed by decreases to pre-stressor concentrations (ie: via negative feedback of the hormones on central GRs), an equally critical change, as sustained elevations of GCs can diminish health and fitness" (Zimmer et al 2024 p1).

"Endocrine or HPA flexibility" is the "ability of an individual to maintain and recover homoeostasis" or the "capacity of an individual to modify its HPA axis in response to stressors across multiple contexts" (Zimmer et al 2024 p2).

The fittest individuals "should be those that can most appropriately use their hormones to adjust the phenotype when the need arises, not those with high or low concentrations at various points in time" (Zimmer et al 2024 p2).

3.9.1. Endocrine Flexibility

"Endocrine flexibility" is key to coping with the temperature extremes and variability of climate change. It is defined as "reversible changes in endocrine responses systems. Endocrine flexibility might occur through changes in various components of endocrine systems, such as receptor density in different tissues or production and clearance of hormones" (Taff et al 2024 pp2-3).

There will be individual differences (or among-individual variation) in endocrine flexibility based on three aspects - average hormone concentrations, degree of hormonal change, and their co-variation (Taff et al 2024).

"Some insight comes from work in poultry: in chickens, embryonic exposure to heat produces chicks that mount a weaker corticosterone response to a subsequent heat challenge. Exposure to acute cold shortly after hatching also causes chicks to later mount a shorter corticosterone response to a cold challenge (ie: have stronger negative feedback). Several studies in wild birds also show that thermal challenges early in development can affect the strength of the corticosterone response to a standardised stressor later in the juvenile period, and even into adulthood" (Taff et al 2024 pp4-5).

Endocrine flexibility is assumed to be beneficial, but it may also constrain coping with changing temperature, or even be unimportant (Taff et al 2024).

Taff et al (2024) outlined five possible patterns of endocrine flexibility:

i) Large individual differences in flexibility, which leads to this "trait" evolving in the population in time. Flexible individuals survive and mate, while non-flexible ones do not.

ii) Low among-individual variation in flexibility, but high population average flexibility allows coping. The norm of the population is high flexibility.

iii) Low or no flexibility of individuals or population. High risk of extinction.

iv) Some individual differences in flexibility and flexibility at population level, but variation is inadequate to cope with changing environment. Population vulnerable to extinction.

v) Very high flexibility at population level, but some individual differences leads to risk of "overshoot" (ie: too much evolutionary change and population vulnerable to extinction).

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