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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.

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1. DOMESTICATION

"The domestication of plants and animals is considered one of the key milestones of cultural evolution, on a par with the use of lithic technology and mastery of fire. Domesticated species are — and have been — fundamental to the growth and economic success of human societies" (Gillis et al 2025 p1).

But how to define "domestication"? A wide-reaching definition is "all organisms that have had their evolutionary trajectories significantly altered by humanity... [This] definition would include everything from cats to rats and from feeder birds to body lice; the open-ended aspects demonstrate that, despite only labelling as domesticated a small sliver of the life that has existed on Earth, currently humanity is rapidly driving all life on Earth towards domestication" (Gillis et al 2025 p2). This type of definition encourages the consideration of plants and animals outside the traditional categories of domestication (eg: the opium poppy; Machado et al 2025) [1].

The definitions can be grouped into the idea of active and conscious behaviour by humans producing rapid domestication (eg: "core-area one-event model"; Gopher et al 2021), or those that "de-emphasise human innovation in favour of protracted and unconscious processes occurring along multiple parallel lineages" (Spengler et al 2025 p1) (eg: "protracted-autonomous model").

The debate on the definition of domestication was recently summarised in articles by Purugganan (2022) and Clement (2022). The former proposed a definition that "a definition that included agriculture-type mutualistic relationships between certain ants and fungi or aphids as well as certain fish and algae or shrimps (as a few examples). In doing so, he [Purugganan 2022] constructed a definition based on mutualistic relationships where one organism protected, supplied resources to, and controlled another and in turn either ate or extracted resources from the controlled member of the relationship" (Spengler et al 2025 p2). Clement (2022) emphasised any impact upon the environment by humans ("landscape domestication").

"Anti-domestication" is another idea, which "stands in direct contrast to the concept of landscape domestication, but proponents of these views seem to

[1] Plants classified as "weeds" tend not to be considered in domestication. Fuller et al (2025) proposed two pathways in the domestication of weeds - "segetal pathway (plants that originally grew as volunteer weeds within cultivation) and the ruderal pathway (plants that benefitted from anthropogenic disturbance in and around human activity areas)" (p1).

overlook the contradiction and latch onto both concepts, seemingly on ideological grounds" (Spengler et al 2025 p2). Anti-domestication suggests that humans shaping a landscape is not domestication. Anti-domestication has been linked to anti-colonialism and decolonisation positions (Spengler et al 2025).

Spengler et al (2025) proposed a number of issues related to any definition of domestication:

i) Domestication relates to heritable traits as compared to learning.

ii) Domestication occurs at a population level.

iii) Benefits to humans.

iv) Benefits to other organisms.

v) Which human behaviours cause domestication.

vi) Intentionality by humans to domesticate.

Spengler et al's (2025) own definition is "[A] change in heritable phenotypic traits in a population over time resulting from interactions with humans" (p11).

A linked issue is the distinction between "wild" and "domesticated", which "can be hard to discern in the archaeological record, and actively downplays the role of wild plant and animal species in human economic and cultural development. As scholars have been pointing out for nearly a century, the bifurcated classification of economies into foraging and farming disregards societies that managed/cultivated wild species, which had not evolved domestication traits and mixed food-procurement strategies" (Gillis et al 2025 p1).

There is another concept - "semi-domesticated" - which has been applied to reindeer, for example. The term "implies that domestication is incomplete or reaches a final stage, which does not align with current understandings of domestication" (Windle et al 2025 p2). Windle et al (2025), however, rejected this idea: "In reality, domestication is not a fixed endpoint but rather a fluid, ongoing process where humans and animals continue to influence each other's abilities and survival strategies over time. Labelling reindeer as 'semi-domesticated' therefore fails to capture this continuous

interaction and co-evolution" (p2) [2]. The ongoing nature of domestication can be seen in the practice by some reindeer herders of deliberately interbreeding wild and domesticated individuals (eg: in northeast Asia; Windle et al 2025).

Domestication "is known to produce a suite of physiological and other phenotypical changes, referred to as the 'domestication syndrome'. This includes, for example, changes in age at sexual maturity, colouration, size, fearfulness and brain composition" (Wright et al 2025 p2). Domestication also leads to changes in vocalisations. "For example, domesticated Bengalese finches have a more complex song than their wild ancestors, and domesticated cavies (guinea pigs) differ from their wild counterparts both in vocal repertoire and the structure of different vocalisations. Dogs have a considerably modified vocal repertoire compared to ancestral wolves, and foxes selected for increased tameness (as a model of domestication) use a different set of vocalisations both towards conspecifics and humans compared to unselected individuals" (Wright et al 2025 p2).

"Sheep (Ovis aries) and goats (Capra hircus) were domesticated around 10,500 years ago in the Taurus Mountains and southeastern Anatolia... from the wild mouflon (Ovis gmelini) and bezoar goat (Capra aegagrus) respectively. Their domestication marked a major shift in human history, being pivotal to the development of early agricultural societies" (Jeanjean et al 2025 p2). Archaeological evidence, however, shows differences in the evolutionary tracks of the two species. Sheep provide meat, milk and wool more than goats which could account for differences. In terms of physical development over the last 8000 years, "sheep exhibit greater variability likely reflecting selective breeding for diverse purposes. Goats, in contrast, show greater uniformity" (Jeanjean et al 2025 p1).

The reason for domestication is not just food-related. For example: "Chickens were originally thought to be domesticated primarily for sport and leisure, based

[2] Windle et al (2025) made this point: " Domestication is a continuing evolutionary process shaped by both natural and human-induced selection, where species can become genetically distinct, more dependent on humans for resources and exhibit phenotypic or behavioural changes. However, it involves not just a genetic transformation but also a co-evolutionary relationship, where humans and animals mutually influence each other through ongoing interaction, skills and knowledge. While criteria such as genetic divergence and physical traits are debated as markers of domestication, the process is understood as both a biological and a cultural adaptation" (pp1-2).

on rich archaeological findings of remains indicating that staged cockfighting was common in the societies where domestic fowl first appeared" (Wright et al 2025 p2).

Historically, manuring has been an important process in arable farming (especially in relation to rye cultivation; Schlutz et al 2025).

REFERENCES

Clement, C.R (2022) Control is not necessary in domestication Trends in Ecology and Evolution 37, 823-824

Fuller, D.Q et al (2025) Commensal domestication pathways amongst plants: Exploring segetal and ruderal crop origins Philosophical Transactions of the Royal Society B 380, 20240190

Gillis, R.E et al (2025) Unravelling domestication: Introduction to the theme issue Philosophical Transactions of the Royal Society B 380, 20240187

Gopher, A et al (2021) Breaking Ground: Plant Domestication in the Neolithic Levant: The "Core-Area One-Event" Model Tel Aviv: Emery & Claire Yass Publications in Archaeology

Jeanjean, M et al (2025) Two species, two stories: Divergent morphometric evolution of sheep and goats over the last 8000 years Philosophical Transactions of the Royal Society B 380, 20240514

Machado, R.S.R et al (2025) The origins and spread of the opium poppy (Papaver somniferum L) revealed by genomics and seed morphometrics Philosophical Transactions of the Royal Society B 380, 20240198

Purugganan, M.D (2022) What is domestication? Trends in Ecology and Evolution 37, 663-671

Spengler, R.N et al (2025) Seeking consensus on the domestication concept Philosophical Transactions of the Royal Society B 380, 20240188

Schlutz, F et al (2025) Stable isotope analyses (δ15N, δ34S, δ13C)) locate early rye cultivation in northern Europe within diverse manuring practices Philosophical Transactions of the Royal Society B 380, 20240195

Windle, M et al (2025) Multi-species entanglements and stable isotope signals (δ13C and δ15N)) in modern reindeer herding communities of boreal northeast Asia Philosophical Transactions of the Royal Society B 380, 20240203

Wright, D et al (2025) Domestication effects on crowing in chickens: Variation between wild and captive red junglefowl and domestic white Leghorn and the genetic architecture of crowing vocalisations Philosophical Transactions of the Royal Society B 380, 20240199

2. ORIGINS OF LIFE

Sole et al (2025) began with a series of questions: "Is life a rare, perhaps improbable event in the universe? Is it the outcome of a sequence of fortunate accidents tightly constrained by planetary conditions and the chemistry of its environment? Or is it an almost inevitable outcome of complex geochemistry and deep time?" (p1). These researchers continued: "These questions lie at the heart of one of the most profound frontiers of science: understanding the origins, nature and potential ubiquity of life in the cosmos" (Sole et al 2025 p1).

This is the "origin-of-life" (OOL) as a scientific problem rather than a philosophical speculation. The pursuit of answers "spans a wide range of disciplines, including geochemistry, statistical physics, systems and evolutionary biology, artificial life, synthetic biology and information theory, and reflects the inherently interdisciplinary nature of origin-of-life research" (Sole et al 2025 p1).

Sole and De Domenico (2025) observed: "The transition from non-living to living matter remains a scientific puzzle. How can we move from the first to the second, where life can be understood as a dynamic process associated with discrete, self-replicating systems? Is the origin of life one particular case study within evolutionary theory?" (p1).

Introducing a special issue of the "Philosophical Transactions of the Royal Society B" on the "origins of life: the possible and the actual", Sole et al (2025) outlined the following the issues:

i) An operational definition of life [3] - Sole et al (2025) explained that "despite our extensive knowledge of living systems, we are still far from reaching a consensus. With regard to this problem, the question arises as to how to distinguish between animate and inanimate systems when considering their change and evolution" (p3).

In terms of defining life, Benner (2010) emphasised the distinction between "the system-level concept of

[3] Stepney (2025) observed: "Study of the origin of terrestrial life is made difficult not only by the fact that the relevant processes happened billions of years ago in an environment very different from today's, but also because subsequent evolution may have wiped out evidence of early transitional stages: initial terrestrial life may have been very different from the life we see today. Furthermore, it is difficult to distinguish necessary from contingent properties given only one example: 'replaying the tape' [Gould 2000] might result in very different lifeforms" (p1).

‘life’ and the individual-level property of ‘being alive’. Conflating the two can lead to many difficulties; for example, requiring the characteristic of ‘being able to reproduce’ leads to complaints that individual animals are therefore not alive because they cannot reproduce individually: it takes two” (Stepney 2025 p2).

With particular reference to artificial life, Stepney (2025) asserted that any definition of life requires the following concepts:

a) Autopoiesis (Varela et al 1974) - Life creates and maintains itself, that is it changes, but still keeps its identity over time.

b) Agency - “A living being is an active being, rather than a mere reactive brute thing. A living being has agency: the ability to manipulate itself and its environment to achieve autonomously determined goals through purposive functional behaviours, the least of which are autopoietic self-construction and self-preservation, and possibly reproduction, although not all living beings need reproduce. The material parts of a living being (eg: cells and tissues) also arguably have agency” (Stepney 2025 p4).

c) Open-ended adaptation - “Living beings exist in a context of, and interact with, other living beings and a non-living dynamic open environment. In order for them to survive and thrive, they need to autonomously adapt to this external context. Other beings will also be adapting, and the environment will be changing, owing both to external factors and to its interactions with life, so this needs to be a continual process of adaptation. It should also be open-ended, in that the adaptive changes can demonstrate continual novelty as they respond to an open, changing environment” (Stepney 2025 p4).

Putting the requirements together, Stepney (2025) defined living beings and living systems thus: “A ‘living being’ is an autopoietic system that has agency; it interacts with its environment in the pursuit of its goals through purposeful behaviour; it adapts to changing circumstances. A ‘living system’ is a collection of living beings interacting and open-endedly co-adapting with the other living beings and a non-living environment” (p4).

ii) Is the appearance of life inevitable given the right conditions? The debate here "reflects deeper philosophical divisions about whether life is an accident or an expected outcome of physical laws" (Sole et al 2025 p3).

Also there is agency, as Kauffman and Roli (2025) explained: "Living cells not only construct themselves, but as open thermodynamic systems, they must 'eat' to survive. In general, cells can evolve to 'eat' because living cells are non-linear, dynamical systems with complex dynamical behaviour that enables living cells, receiving inputs from their environment and acting on that environment, to sense and categorise their worlds, orient to relevant features of their worlds, evaluate these as 'good or bad for me' and act based on those evaluations. This is the basis of agency and meaning. Agency and meaning are immanent in evolving life" (p9).

iii) Universal constraints on the emergence of life (eg: the need for water).

Example: "Life as we know it on Earth is encapsulated in cellular containers. This ubiquitous encapsulation profoundly shapes our conceptions of what living systems are and how they must be organised. Consequently, encapsulation is widely considered to be a fundamental feature of the origins of life" (Kempes et al 2025 p1). The origins of cellular containers is thus a key aspect of life developing.

It is generally agreed that the "last universal common ancestor" (LUCA) was "likely encapsulated in a lipid bilayer" (Kempes et al 2025 p2).

Example: The "central dogma of molecular biology", which is attributed to Crick (1958), that "information" flows from DNA to RNA to protein in one direction and cannot be reversed (Takeuchi and Kaneko 2025). Information refers to "the precise determination of sequence, either of bases in the nucleic acid or of amino acid residues in the protein", so that "the transfer of information from nucleic acid to nucleic acid, or from nucleic acid to protein may be possible, but transfer from protein to protein, or from protein to nucleic acid is impossible", and "once 'information' is passed into protein it cannot get out again" (Crick 1958 quoted in Takeuchi and Kaneko 2025). However, Takeuchi and Kaneko (2025) questioned this dogma.

Example: Thermodynamic constraints (or bounds) have been uncovered on "lifelike systems, including modern and proto-biological organisms, synthetic life, and even possible non-terrestrial lifeforms" (Kolchinsky 2025 p1). Such constraints include on Darwinian selection. "This refers to a process in which high-fitness replicators reliably outcompete low-fitness replicators. Darwinian selection can be exhibited by chemical systems, such as individual replicating molecules or networks of molecules. Synthesising such systems has been a major focus of research on the origin of life, given that the emergence of Darwinian selection is considered to be a crucial point in the transition from non-living to living matter" (Kolchinsky 2025 p1).

iv) Mapping the pathways to life.

Example: "All life as we know it is composed of carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P) and sulphur (S), as well as a suite of transition metals and metalloids, which are used for redistributing electrons and catalysing reactions in metabolic pathways" (Galloway et al 2025 p1). Emerging life had a demand for these compounds, and so the supply of them is key, for example, in terrestrial acidic hot spring systems, and deep-sea hydrothermal vents in the case of of the early Earth.

Example: Negron-Mendoza et al (2025) felt that chemical changes necessary for life to emerge will not produce life "in the absence of a genetic apparatus" (p1).

v) Beyond biological life on Earth - This includes life on other planets (exobiology or astrobiology), life created through synthetic biology (xenobiology), and "life forms that exist in virtual environments (in silico life)" (Sole et al 2025 p6) [4]. These endeavours have been summarised as the move from "life as we know it" to "life as we don;t know it" and "life as it could be" (Sole et al 2025).

Example: "The current form of life on Earth is the outcome of a series of biochemical events that led to the formation of early life with a specific molecular

[4] Stepney (2025) used the abbreviation "ALife" (artificial life).

composition encoding its many functions. However, other trajectories of events with widely different outcomes could have led to alternative forms of life with different compositions" (Hofmann et al 2025 p1). "Roads not taken" research is possible with synthetic biology (appendix 2A) to understand the alternative forms of life, like "cell-free systems" (CFS) [5]. Hofmann et al (2025) reported on CFS experiments which explored alternatives biochemical processes (eg: xeno nucleic acids; mirror-image biomolecules). The LUCA had "a unique molecular composition encoding its function" (p1), whereas alternative trajectories either failed or were outcompeted (Hofmann et al 2025).

Example: A simulation platform "Araudia" was used by Shirt-Ediss et al (2025) to explore how proto-cells might develop in different scenarios (ie: an "advanced pre-biotic scenario where those relatively simple proto-cells, which may already display some self-productive and self-reproductive capacities, should transform into increasingly elaborate and efficient metabolic systems"; p1).

EVOLVABILITY

"Evolvability" is a general term describing how "some organisms have a greater capacity to evolve than others" (Lala 2024 p27). Non-genetic inheritance seems to be important here.

"Historically, evolutionary biologists have assumed that since all organisms evolve through natural selection acting on their genes, they should all change at roughly the same rate per generation. Only in recent years has it become clear this isn't the case - some species and some traits are more evolvable than others" (Lala 2024 p27).

Lala et al (2024) outlined a number of extra-genetic processes, including:

i) Epigenetics - Chemically attached molecules (eg: methyl chemical group) to DNA that influence the gene's activity.

[5] " CFS are versatile platforms that enable biological reactions to occur outside living cells. They can be classified into protein synthesis using recombinant elements (PURE) systems and lysate-based systems. PURE systems are highly defined, consisting of purified enzymes and ribosomes for precise control, ensuring reproducibility and minimal interference. Lysate-based systems, derived from crude cellular extracts, such as from Escherichia coli cells, retain essential enzymes, metabolites and molecular machinery for gene expression" (Hofmann et al 2025 p2).

ii) Symbiotic inheritance - eg: the microbiome of animals (ie: bacteria that live on or in animals in a beneficial relationship).

iii) Culture.

Other processes include developmental plasticity (ie: variation caused by the environment), and niche construction (ie: "organisms can increase their evolvability... by modifying their environment"; Lala 2024 p29).

A key point is that "[T]hese phenomena aren't just analogous to biological evolution: they are biological evolution. They allow organisms to invade new environments, cope with change and stress, evolve new phenotypes and resist extinction until adaptive genetic mutations appear" (Lala 2024 p27). Lala (2024) continued: "The upshot of all this is that natural selection isn't something that just happens to organisms: their activities and behaviours contribute to how it happens and whether it happens at all" (p29).

APPENDIX 2A - SYNTHETIC BIOLOGY AND ETHICS

Synthetic biology can be seen as "the collision of biology and engineering" (Calvert 2021 p1). It has been important to those involved in the field, at least at the beginning, to build "a community with certain values", and to "attempt to prevent the technology being locked up by patents and other forms of intellectual property; an attempt to imagine different, more open forms of innovation" (Calvert 2024 p25).

In relation to ethics, normativity "refers to imperatives, duties, obligations, permissions, and principles which do not describe the way the world is but rather prescribe the way it ought to be" (Jun 2011 quoted in Calvert 2021). Calvert (2021) considered "multiple normativities", including "the normativity of the universal 'ought'" (ie: generalised directives), "the normativity of sharing the values embedded in design" (what Rip (2013) called "pervasive normativity"), and the "normative turn" (a political-based choice to intervene with values). She added "otherwising", which is the idea that "things could be otherwise" (ie: "recognising the plural and situated nature of knowledge claims"; p128) (Calvert 2024).

REFERENCES

Benner, S.A (2010) Defining life Astrobiology 10, 1021-1030

Calvert, J (2021) On not being a bioethicist: Normativity, otherwising and synthetic biology (Kings College London Seminar Paper, March) (unpublished)

Calvert, J (2024) A Place for Science and Technology Studies: Observation, Intervention, and Collaboration Cambridge, MA: MIT Press

Crick, F.H.C (1958) On protein synthesis Symposia of the Society for Experimental Biology 12, 138-163

Galloway, T et al (2025) Planetary sources of bio-essential nutrients on a prebiotic world Philosophical Transactions of the Royal Society B 380, 20240288

Gould, S.J (2000) Wonderful Life: The Burgess Shale and the Nature of History New York: Vintage

Hofmann, M et al (2025) Reconstituting alternative life using the test-bed of cell-free systems Philosophical Transactions of the Royal Society B 380, 20240293

Jun, N (2011) Deleuze, values and normativity. In Jun, N & Smith, D.W (eds) Deleuze and Ethics Edinburgh: Edinburgh University Press

Kauffman, S & Roli, A (2025) Is the emergence of life and of agency expected? Philosophical Transactions of the Royal Society B 380, 20240283

Kempes, C.P et al (2025) How hard is it to encapsulate life? The general constraints on encapsulation Philosophical Transactions of the Royal Society B 380, 20240297

Kolchinsky, A (2025) Thermodynamics of Darwinian selection in molecular replicators Philosophical Transactions of the Royal Society B 380, 20240436

Lala, K.N (2024) DIY evolution New Scientist 7th December, 26-29

Lala, K.N et al (2024) Evolving Evolution: The Developmental Origins of Adaptation and Biodiversity Princeton, NJ: Princeton University Press

Negron-Mendoza, A et al (2025) Can the origin of biosynthetic routes be explained by a Frankenstein's monster-like spontaneous assembly of prebiotic reactants? Philosophical Transactions of the Royal Society B 380, 20240289

Rip, A (2013) Pervasive normativity and emerging technologies. In van der Burg, S & Swierstra, T (eds) Ethics on the Laboratory Floor Basingstoke: Palgrave Macmillan

Shirt-Ediss, B et al (2025) Modelling the prebiotic origins of

regulation and agency in evolving proto-cell ecologies Philosophical Transactions of the Royal Society B 380, 20240287

Sole, R & De Domenico, M (2025) Bifurcations and phase transitions in the origins of life Philosophical Transactions of the Royal Society B 380, 20240295

Sole, R et al (2025) Origins of life: The possible and the actual Philosophical Transactions of the Royal Society B 380, 20240281

Stepney, S (2025) Towards origins of virtual artificial life: An overview Philosophical Transactions of the Royal Society B 380, 20240298

Takeuchi, N & Kaneko, K (2025) Generalising the central dogma as a cross-hierarchical principle of biology Philosophical Transactions of the Royal Society B 380, 20240296

Varela, F.G et al (1974) Autopoiesis: The organisation of living systems, its characterisation and a model Biosystems 5, 187-196

3. BEHAVIOUR SETTINGS THEORY

3.1. INTRODUCTION

McGann et al (2024) began: "In recent decades, cognitive science has come to a renewed appreciation of the role of the environment, of social and material context, in the processes of cognition and behaviour. The arising of 'embedded', 'distributed' and 'situated' approaches to cognitive science has seen a push against forms of computationalism that isolate the cognitive agent from the world around it behind a screen of interpretation and information processing" (p1).

These researchers continued that a more embedded approach "appears to unsettle long- and deeply held intuitions, particularly in what can be called Western traditions. The independence and autonomy of the mind from the world around it is fundamental to individualistic Western cultures, which have traditionally followed a strong separation between mind and body, mind and world... In contrast to these philosophical tenets, embodied, embedded and enactive cognitive science offers a wholesale reconceptualisation of life, mind and being, with sweeping implications for scientific, medical and ethical practice" (McGann et al 2024 p2).

Put simply, there is a "mutuality of embodied agent and environment" (p2), and McGann et al (2024) proposed "four bodies of extant literature" that are relevant:

i) Behavioural ecology.

ii) Anthropology.

iii) Ecological psychology (eg: Gibson 1986).

iv) Behaviour settings theory (BST) - "studying patterns of behaviour within a physical and social milieu" (McGann et al 2024 p3). The ideas came from observations of children in a small town in Kansas, USA, in the 1950s (eg: Barker 1968), and have subsequently

been developed more widely [6].

McGann et al (2024) introduced a special issue of the "Philosophical Transactions of the Royal Society B" on "behaviour settings theory in the 21st century" with three broad themes:

a) The challenge of research in the field which is far more informative than laboratory studies.

b) The use of technology in BST research.

c) The relationship between settings and individual human beings (eg: are they active or passive?).

These authors divided the articles in the special issue under the headings of key concepts, contemporary concerns, and novel empirical work.

3.2. KEY CONCEPTS

Heft (2024) observed: "Barker's claim that emergent eco-psychological structures (behaviour settings) are generated in the course of everyday life in communities was surely seen as exotic when it was first proposed in the 1950s and 1960s. Following developments over recent decades in dynamical systems and complexity theory this should no longer be the case. The notion of novel emergent structures that have properties not to be found in the constituents that give rise to them is now nearly commonplace
among the natural sciences" (p4).

Heft (2024) outlined the key elements of BST:

a) "Behaviour settings as emergent dynamic structures" - "Over the course of their daily activities, individuals often come together intentionally in a certain location, in conjunction with certain affordances and for a particular duration of time, and in doing so, give rise to and/or sustain a behaviour setting. Such collective actions can generate dynamic eco-psychological entities such as a class session in a school, a game of soccer or a neighbourhood store during hours of operation. Behaviour settings arise from more than merely

[6] For example, Robert Sommer (eg: 1969) who developed the theory with more emphasis on the physical environment.

an assemblage of individuals, but from a particular set of functional interdependencies among those individuals that sustain their actions with the support of material features (eg: affordances) present" (Heft 2024 p5).

b) The co-ordination of individual behaviour behaviour to the setting - ie: the mechanisms that lead individuals in a classroom, say, to manifest "classroom behaviour".

c) "The development of skilled 'behaviour setting-specific' actions" - Socialisation is the process of children learning how to act in different situations. "To learn about and ultimately comprehend what a particular behaviour setting is, most fundamentally is to develop skilled actions and practices normatively suited to that setting" (Heft 2024 p7).

There is a parallel to Bourdieu's (1990) concept of "habitus" (defined as "embodied 'dispositions durably inculcated by the possibilities and impossibilities, freedoms and necessities, opportunities and prohibitions inscribed in objective [ie: perceivable] conditions'" (quoted in Heft 2024).

d) "Congruence across adjacent nested levels of structure" - Different levels of analysis can be applied from behaviours in society to brain functioning [7].

The key concepts in behaviour settings analysis are (Aunger et al 2024):

i) Physical objects - "physical attributes of the place where the setting takes place, including its layout (the 'stage' for action), objects and infrastructure (eg: architectural features)" (Aunger et al 2024 p2).

ii) Social agents - "the individuals or groups present within the setting, with a focus on their roles and relationships. These roles influence how individuals behave, communicate and relate to one another within the environment" (Aunger et al 2024 p2).

iii) Psychological rules - eg: norms and

[7] Van Orden et al (2012) proposed the idea that "the brain does a great deal of work in the service of behavior that is controlled by the body, a blue-collar role compared to the white-collar control exercised by the body" (p1). This is contrary to the traditional view that the brain controls the body. These authors explained that "the brain is primarily about maintaining presence of mind. In our meaning, 'presence of mind' includes the present configuration of the body as it is currently entwined in meaningful relations with the present configuration of the world" (Van Orden et al 2012 p7).

expectations of the situation.

iv) Temporal aspects - "the temporal aspect refers to such factors as the duration of the setting, and the timing and sequencing of activities by role-players, summarised as the setting 'routine' (which Barker called a 'standing pattern'). The temporal aspects can influence the pace, organisation and co-ordination of activities within the behaviour setting" (Aunger et al 2024 p2).

3.2.1. Interdependence

BST offers "an empirically verifiable unit of study that (i) was not created by the researcher, (ii) was restricted neither to the individual alone nor to the environment alone, but that (iii) included both at once in a manner that was interdependent (ie: organism and environment as co-constituting) rather than merely transactional (ie: organism and environment as separate entities that give/receive inputs and outputs). Behaviour settings theory thus challenges the old dualisms of organism and environment, individual and society, and biology and culture" (Avram et al 2024 p2). The interdependence was described by the term "synomorphic" by Barker (1968).

For example, a softball game is "a standing pattern of behaviour that organises the actions of all who participate, from players to coaches to spectators. It is bounded physically in that the game is interdependent with the structure and layout of the playing field, as well as the objects its occupants are using (eg: bats, balls and mitts for the players; seats and hot dogs for the spectators). It is also bounded temporally in that the game has both a beginning and an end, outside of which the behaviour setting no longer exists (though some behaviour settings can be 'open' 24 hours). Elements of the behaviour setting 'softball game' are not only interdependent with one another, but also independent from elements of neighbouring settings. For instance, the leaders of the softball game (eg: coaches and umpires) are not the same personnel in charge of the library beside the playing field, and behaviours that begin in the library are unlikely to be completed in the softball game. Librarians do not shelve books at third base, and while an errant ball could smash through a library window, the game tends not to spill into the library" (Avram et al 2024 p2).

Barker (1968) developed a set of criteria (called

"K-21") (or methodology [8]) for understanding the interdependence with five elements - (i) a standing pattern of behaviour, (ii) anchored to a particular milieu complex, (iii) bound to a particular time and space, and (iv) the behaviour is synomorphic with the milieu, and (v) the milieu complex surrounds the behaviour (Avram et al 2024) [9].

The interdependence can be seen in that the rules for appropriate conduct are "out there" in the practices and situations (ie: behaviour settings) rather than in the heads of individuals, argued Di Rienzo et al (2024). These authors quoted their case study of a science laboratory where learning to use a prosthetic hand was done with virtual reality. The researchers commented: "In our observations, we were hard-pressed to find but one activity that was not shaped by the normative demands of the situation. Indeed, most possibilities for action in human life are like that. If this is so, then we need the research tools to make such normativity visible" (Di Rienzo et al 2024 p10).

Avram et al (2024) found 279 academic articles on BST in research in psychology, but these researchers felt that many of them were "missing the mark" (p11). Avram et al (2024) explained with "the parable of the coffee": "Imagine you are being tested for your skill at making a cup of coffee. Say there are five steps involved (eg: fetch the coffee, fetch the water, add the coffee to the machine, add the water to the machine and switch on the machine), each of which earns you a certain number of percentage points if you complete them satisfactorily. If you correctly follow the steps needed to gain a score of 90%, you may congratulate yourself on an excellent result. If, however, the 10% that you neglected was adding the coffee to the machine, then what you will not have is a cup of coffee. Many empirical behaviour settings papers, it seems, have forgotten the coffee" (p11).

These authors offered four reasons for this:

i) No behaviour settings (ie: too broad or too narrow in their research focus).

ii) No use of Barker's method (ie: K-21).

iii) Inconsistent use of Barker's method.

[8] Schoggen (1989) developed the methodology.

[9] Lucas (2024) applied Barker's method to observations at a university art gallery in Canada.

iv) Barker's method unexplained.

Avram et al (2024) concluded that "Barker's emphasis on the interdependence of the physical and the social, the organism and the environment, has failed to retain its prominence in the empirical work that followed his initial insights" (p13).

3.3. CONTEMPORARY CONCERNS

"Behaviour settings emerge in the interplay among the activities of different agents and the material, social and normative constraints imposed by specific environments and contexts. These settings range from dyadic conversations to scientific meetings, in-person reunions to social media platforms and so on" (Gastelum-Vargas et al 2024 p1).

Behaviour settings can enable or constrain the type of reasoning, through the roles of participants, the communication patterns, and the social norms, for instance. They are "places for reasoning" (Gastelum-Vargas et al 2024).

Reasoning can be viewed as "a set of habits", where a habit is "a regulated behavioural pattern formed through past experiences. Habits can be learned on purpose but many times, it is the repeated interactions with some material (such as clay) that turn into a particular habit. The rules of reasoning can be understood as established patterns within the collective activities that shape particular behavioural settings. These reasoning habits position us in relation to the information provided by the environment through affordances, empowering us to make various inferences about the environment and our interactions with it. Habits are ways of using and incorporating the environment norms and patterns of thinking or action" (Gastelum-Vargas et al 2024 pp2-3).

The emphasis in BST on field-based investigations is an antidote to the criticism of psychology as "overly reliant on artificial laboratory-based activities" (Baggs and Sanches de Oliveira 2024 p1). For example, Roger Barker's work involved entire communities in Kansas, for example, and was a clear rejection of psychological research based on undergraduates, which was the norm at the time (if not still now) (Baggs and Sances de Oliveira

2024) [10].

Barker (1947 in Barker and Associates 1978) wrote: "Although we know a great deal about how children behave under relatively controlled, standardised conditions, such as intelligence- and personality-testing situations, we know little about the nature of the situations that actually confront children in their daily lives and how they react to them. Preoccupation by investigators with behaviour under controlled conditions has crowded out concern with naturally occurring situations and with the interrelations between them and behaviour. We do not know in concrete detail how parents, teachers, and other adults and children behave toward children, we do not know what pressures and demands are made upon children, we do not know how they respond: what successes, failures, frustrations, and happinesses children actually experience" (quoted in Baggs and Sanches de Oliveira 2024).

McGann (2024) commented: "Psychological phenomena occur across a wide range of scales, ranging from small, quick events of neurology and biology, to broader, more prolonged unfoldings typical of extended cultural practices. Although theories deployed by psychologists of different stripes have tended to incorporate these different scales, this is typically done in a manner that is implicit, and often unsystematic. That is, typical psychological research is conducted in a manner that is 'scale-blind'" (p1). This author argued that scale-blindness limits understanding of phenomena, and so the solution is "to be explicit about the scale at which we are working at all times" (McGann 2024 p7). It is argued that BST "provides a good start" (McGann 2024 p7).

BST has been adapted over time, and Sepulveda-Perdo and Mojica's (2024) work is an example with their "enactive approach". They explained that "the focus of ecological theories on how individual agents attune their actions to the pre-established order of behaviour settings neglects the agents' active role in sustaining or motivating transformations in this order" (Sepulveda-Perdo and Mojica 2024 p1). The enactive approach, thus, tries to explain agency in situations/behaviour settings.

In this theory, agency has different aspects (eg: autonomy and adaptivity). "Autonomy and adaptivity are inter-related. The autonomy or identity of an individual

[10] Hutchins (eg: 1995) aimed to take cognitive psychology out of the laboratory into the field (Baggs and Sanches de Oliveira 2024).

is not guaranteed. Adaptive behaviour is needed to sustain this identity, and an agent's repertoire of regular adaptive responses is part of its identity. Adaptivity, on the other hand, is guided by the norms that establish what is right or wrong to sustain the identity of an autonomous system. Agents' behaviour primarily responds to norms that maintain their identity. At the biological level, agents intend to keep themselves alive. At the sensorimotor level, they intend to sustain their regular patterns of interaction with the environment, and at the social level, they intend to interact in coordination with others. We can therefore make sense of our world based on multiple dimensions of interaction with the environment, based on different normative criteria. However, these multiple normative dimensions are not mutually excluded. They are deeply entangled or enmeshed since they are often mutually supported but sometimes involve a series of tensions and conflicts" (Sepulveda-Perdo and Mojica 2024 p4). Put very simply, we follow situational norms as much as they conflict with individual survival. We follow the greeting ritual in a situation, say, but autonomy is required if we fall during the process (ie: we change our behaviour from the greeting ritual).

3.4. NOVEL EMPIRICAL WORK

Aunger et al (2024) argued that BST can help in understanding people in virtual contexts (eg: playing computer games; online shopping) because the theory is "couched neither at the level of the individual nor the population, but in-between — as a description of relatively short-term activity by a relatively small group of interacting people in a circumscribed space. It is highly predictive of human behaviour without referring to complex psychological traits" (p1).

Awamleh (2024) applied BST to the architectural design process ("behaviour setting transformation methodology"; BSTM); specifically, the recognition that behaviour is "profoundly influenced by the spaces they [humans] inhabit" (p2).

Kalis et al (2024) applied BST to "the science of self-control". "Self-control is the ability of individuals to pursue goals they value in the face of conflicting motivations... [and] that this ability should be understood as a set of skills by which individuals

modulate their relation to their environment, more specifically the behaviour settings they inhabit" (Kalis et al 2024 p1). This is a challenge to the traditional focus on "self-control mechanisms" in the brain. Kalis et al (2024) asserted that "self-control should be understood as a quite general ability that can only be meaningfully ascribed to persons-in-context, and not to specific mechanisms happening inside their brains" (p2).

This is a "results" account of self-control (Sripada 2021). Kalis et al (2024) explained: "Against 'process' views of self-control, which assume that only some cognitive processes count as self-control processes, we call an individual's activity an exercise of self-control in so far as the agent thereby pursues goals they value in the face of conflicting motivations. In consonance with this view, we propose to understand self-control as a set of skills... These skills can vary in kind, depending on the specific self-control problem at hand and the context in which the individual finds herself, which implies that being skilled at self-control requires knowing what strategies would work best in a specific context, and knowing how to employ them (in recent social-psychological literature this is referred to as 'polyregulation' [eg: Hofmann 2025]). For example, someone wanting to quit smoking might engage in different strategies for reaching her goal. She might gradually reduce the number of cigarettes smoked in a day, or build a routine of going to the office without taking her cigarettes with her" (pp2-3). The crucial point is that self-control is a "situational capacity" and its study "requires us to investigate individuals in their contexts" (Kalis et al 2024 p3).

Kalis et al (2024) took the classic example of the "marshmallow test" (eg: Mischel 2014). A child is presented with a marshmallow (or sweet or treat) and told that if they wait without eating it (say, for ten minutes), they will receive two. Not only are researchers interested in whether the child eats the marshmallow, but the strategies of resistance of temptation/self-control they use. Kalis et al (2024) proposed that cultural differences in this study show the situational context and support BST, as in Lamm et al (2018), who compared German middle-class children and Nso children in Cameroon. Kalis et al (2024) explained that "while German children enacted many motor strategies (eg: turning around so as to not face the temptation, walking around the room or even leaving the room), Nso children engaged in little motor activity if at all. This, according to the authors, reflects the different cultural frameworks

in which the children grew up: German children feel a conflict between their powerlessness in waiting and their self-perception of a free individual; Nso children are strongly educated from a young age to follow demands within a hierarchical structure, to the point that they do not even seem to experience a motivational conflict at all" (p4).

BST here can be summed up by this quote from Barker and Associates (1978) (quoted in Kalis et al 2024): "We found that we could predict many aspects of children's behaviour more adequately from knowledge of the behaviour characteristics of the drug stores, arithmetic classes, and basketball games that they inhabited than from knowledge of the behaviour tendencies of the particular children". The marshmallow test is an experiment, and it is not the same as real-life situations of self-control. For example, "in a 'real' context, children might be more or less motivated to engage in self-control, given a range of all other contextual factors at play (maybe they are in a rush to go play with a friend so that the preferred response is to eat the first marshmallow and leave)" (Kalis et al 2024 p4).

Pedersen and Nielsen (2024) provided a case study of a new day centre for homeless people in Denmark. "Rather than merely offering a place 'to be', the day centre aims to support users' development of agency, in the sense of expanding their life-space or action capabilities" (a "place-for-being" to a "place-for-being-doing-acting") (Pedersen and Nielsen 2024 p1). BST helped to understand the designing of "enabling spaces" to achieve this.

Zielinski and Raczaszek-Leonardi (2024) applied BST to "the analysis of situations and communicative needs of persons after larynx removal surgery (laryngectomy)" (p1). The researchers explained further: "This surgery limits possibilities for natural verbal interaction, forcing the affected person to rely on substitutive voice generation mechanisms and compensatory techniques. While studying speech aid designs, we were surprised at the low versatility of the solutions proposed: the current technological research on new speech aids is mainly driven by the 'clarity of signal transmission' goal, while speech intelligibility and naturalness is measured in listening tests performed in an acoustic laboratory setting — only one of the various possible settings and entirely non-typical. What seemed to be missing is the consideration that communication occurs in multiple environments and multiple interpersonal contexts, each

with its specific requirements for voice quality beyond simple 'intelligibility'. People need to be quiet and tender, sometimes blend with the acoustic environment and have voice dynamics adapted to a particular situation. This variety of complex and nuanced needs of a person using a device in interaction with others remains unidentified. Their identification requires the study of particular interactions in their real settings, with a proper methodology and a humane, qualitative reflection, as well as a framework that could help recognise the classes of contexts and their specific properties and requirements for voice characteristics" (Zielinski and Raczaszek-Leonardi 2024 p2).

3.5. REFERENCES

Aunger, R et al (2024) Applying the Barker school concept of "behaviour settings" to virtual contexts Philosophical Transactions of the Royal Society B 379, 20230291

Avram, C.M et al (2024) Reclaiming behaviour settings: Reviewing empirical applications of Barker's behaviour settings theory Philosophical Transactions of the Royal Society B 379, 20230283

Awamleh, Z (2024) Behaviour setting transformation method, filling in the gaps of the conventional architectural design process Philosophical Transactions of the Royal Society B 379, 20230292

Baggs, E & Sanches de Oliveira, G (2024) Rewilding psychology Philosophical Transactions of the Royal Society B 379, 20230287

Barker, R.G (1968) Ecological Psychology: Concepts and Methods for Studying the Environment of Human Behaviour Stanford, CA: Stanford University Press

Barker, R.G & Associates (1978) Environments, Habitats, and Human Behaviour: Studies in Ecological Psychology and Eco-Behavioural Science from the Midwest Psychological Field Station, 1947-1972 San Francisco: Jossey-Bass

Bourdieu, P (1990) The Logic of Practice Stanford, CA: Stanford University Press

Di Rienzo, G et al (2024) Navigating the normativity of behaviour settings: An observational case study Philosophical Transactions of the Royal Society B 379, 20230295

Gastelum-Vargas, M et al (2024) Places for reasoning Philosophical Transactions of the Royal Society B 379, 20230294

Gibson, J.J (1986) The Ecological Approach to Visual Perception Hove: Psychology Press

Heft, H (2024) Behaviour settings, situated action and

complexity theory Philosophical Transactions of the Royal Society B 379, 20230284

Hofmann, W (2025) Self-control. In Gilbert, D et al (eds) The Handbook of Social Psychology (6th ed) Princeton, NJ: Situational Press

Hutchins, E (1995) Cognition in the Wild Cambridge, MA: MIT Press

Kalis, A et al (2024) Running away from the marshmallow: The relevance of behaviour settings for a situated science of self-control Philosophical Transactions of the Royal Society B 379, 20230289

Lamm, B et al (2018) Waiting for the second treat: Developing culture-specific modes of self-regulation Child Development 89, 3, e261-e277

Lucas, M (2024) A practitioner's field guide to the behaviour settings method Philosophical Transactions of the Royal Society B 379, 20230285

McGann, M (2024) Reorienting psychological science Philosophical Transactions of the Royal Society B 379, 20230288

McGann, M et al (2024) People, places, things and communities: Expanding behaviour settings theory Philosophical Transactions of the Royal Society B 379, 20230282

Mischel, W (2014) The Marshmallow Test: Understanding Self-Control and How to Master It New York: Random House

Pedersen, S & Nielsen, E (2024) Enabling spaces for (varied) co-existence Philosophical Transactions of the Royal Society B 379, 20230293

Sepulveda-Pedro, M.A & Mojica, L (2024) Enactive behaviour settings: Situating agency, normativity and transformation Philosophical Transactions of the Royal Society B 379, 20230286

Schoggen, P (1989) Behaviour Settings: A Revision and Extenion of Roger G Barker's Ecological Psychology Stanford, CA: Stanford University Press

Sommer, R (1969) Personal Space: The Behavioural Basis of Design Englewood Cliffs, NJ: Prentice Hall

Sripada, C (2021) The atoms of self-control Nous 55, 800-824

Van Orden, G et al (2012) The blue-collar brain Frontiers in Physiology 3, article 207

Zielinski, K & Raczaszek-Leonardi, J (2024) Behaviour settings as a way to order types of situations for the study of speech aids Philosophical Transactions of the Royal Society B 379, 20230290

4. PREGNANCY AT HIGH ALTITUDES

4.1. INTRODUCTION

Murray et al (2025) outlined the situation: "With ascent to high altitude, barometric pressure falls decreasing the partial pressure of inspired O_2 ($_{pi}O_2$). This impedes oxygen delivery to the tissues, giving rise to tissue hypoxia and the accompanying challenge of maintaining cellular metabolic and redox homeostasis. Physiological responses to hypoxic challenge include those that mitigate the fall in convective oxygen delivery through, eg: increased ventilation, cardiac output, angiogenesis and oxygen carriage capacity (ie: red blood cell mass). This increase in haematocrit offsets the fall in haemoglobin O_2 saturation at altitude, effectively maintaining arterial oxygen content (C_aO_2) even up to 7000 m. However, arterial oxygen pressure ($_pO_2$) remains low, limiting oxygen diffusion and necessitating metabolic responses that alter cellular oxygen demand" (p1).

Burton et al (2025) began with these points: "It is estimated that over 81 million people worldwide live at altitudes higher than 2500 m [11], the level at which normal physiological adaptations are unable to fully compensate for the reduced oxygen availability in the atmosphere [12]. Exposure to hypobaric hypoxia [13] has particularly profound effects on reproduction. This is especially true for recent migrants to high altitude, who may suffer infertility, have low-birthweight babies, and have a significantly higher risk of complications of pregnancy. By contrast, indigenous populations who have lived at elevation for many generations are protected to some extent by genetic and physiological adaptations" (p1).

Introducing a special issue of the "Philosophical Transactions of the Royal Society B" on pregnancy at high altitude, Burton et al (2025) emphasised the importance

[11] Key areas in the world are the Andean Altiplano in South America, the Tibetan plateau, Asia, and in the Africa, the Highlands of Ethiopia (Murray et al 2025).
[12] Over fourteen million people live at extreme altitude, defined as 3500 m and above (Giussani 2025).
[13] Reduced oxygen at high altitudes due to low atmospheric pressure.

of understanding the consequences for the foetus of hypoxia as well as the long-term impact for lifelong human health. Evidence from both human and non-human animal studies were classed as relevant.

4.2. HEALTH RISKS

Chronic foetal hypoxia is a risk that produces foetal growth restrictions, and high-altitude pregnancy leads to lower birth weight compared to sea level [14], but not in individuals with highland ancestry. Low birth weight is a risk factor for adult cardiovascular disease (Giussani 2025).

Bolivia is an interesting country to study with the city of La Paz in the Andes mountains (4000 m above sea level), but other cities like Santa Cruz are close to sea level. Vargas et al (2007) compared over 25 000 birth records taken from both these cities. Average birth weight was 2.7 kg in La Paz and 3.6 kg in Santa Cruz (Giussani 2025). Simple comparisons of different cities, however, is limited by confounders: "For one, as populations at high altitude are highly impoverished and have a high ethnic admixture, the partial contributions of chronic hypoxia, nutrition or genetics on foetal growth and development really remain quite unclear. In addition, since the mother, placenta and foetus are all exposed to the influence of the chronic hypobaric hypoxia of pregnancy at high altitude, the partial contributions between the effects of high-altitude hypoxia on the mother, placenta and/or fetus are difficult to disentangle" (Giussani 2025 p2).

Animal experiments are thus attractive because of the ability to control variables. The chicken embryo is "the ideal animal model to determine the direct effects of any environmental influence on foetal growth and development, independent of effects on the maternal and/or placental physiology, as the embryo develops in complete isolation within its own eggshell. The model offers several other important advantages. Compared with rats and mice, which are born highly immature, cardiovascular development is near-complete pre-hatching in the chicken, and the temporal profile of these 'pre-natal' cardiovascular developmental milestones is more similar between humans and chickens, compared with between humans and rats or mice" (Giussani 2025 p2).

[14] Birth weight is reduced by around 100 g for each 1000 m higher in elevation during pregnancy, and pregnancy complications increase with altitude (Murray et al 2025).

For example, Giussani et al (2007) studied eggs from chickens in Santa Cruz and La Paz, either fertilised and laid in the same area or moved between fertilisation and laying. Giussani (2025) outlined the findings: "The data showed that eggs laid by sea-level hens and incubated at high altitude were significantly growth-restricted relative to eggs laid by sea-level hens and incubated at sea level. This resembled the detrimental effect of high altitude on birth weight in babies from European mothers undergoing pregnancy in La Paz relative to those in Santa Cruz. When eggs laid by highland hens were incubated at high altitude, they also showed significant growth restriction relative to eggs laid by sea-level hens and incubated at sea level. However, these embryos were significantly heavier than embryos from eggs laid by sea-level hens and incubated at high altitude. This resembled the protective effect on birth weight in babies from mothers of Andean ancestry relative to those of European ancestry undergoing pregnancy in La Paz. Fascinatingly, eggs laid by highland hens, which usually show growth restriction when incubated at high altitude, not only recovered their growth but also grew larger when incubated back at sea level relative to eggs laid by sea-level hens and incubated at sea level. Finally, eggs laid by sea-level hens and incubated at high altitude in La Paz with oxygen supplementation to equate sea-level partial pressures of oxygen did not show the restrictive effect of highland incubation on embryo weight. This final group highlighted that the detrimental effect of high altitude slowing fetal growth is due to the hypoxia, rather than the hypobaria [low atmospheric pressure alone], of life at high altitude" (p4).

Hillman and Dolmaa (2025) reported two years of data (2017-2019) from Leh, Ladakh, India, in the Himalayas (and a comparison population in low-altitude South India). Of the 318 pregnant women in Leh who delivered at full term, the average birth weight was 3.05 kg, with children of mothers of Tibetan ancestry (ie: adapted to high altitude [15]) having heavier birth weights. This was also found in the low altitude sample. Stillbirths in Leh were significantly higher than the national average (25.2 vs 9.7 per 1000 births [16]), however, but it was not clear to the researchers if this was due to altitude or other factors (eg: malnutrition).

[15] Genome analysis by Hillman and Dolma (2025) confirmed adaptation by highland ancestry.

[16] The figure is 5.2 per 1000 births in the UK in the same period (Hillman and Dolma 2025).

Pre-natal hypoxia's impact upon the body has to be seen in the context of post-natal lifestyle choices. One example is salt intake in the diet, which Baba et al (2025) studied in rats. Male rats gestated in normal or reduced oxygen environments were given normal or high salt diets after birth. Blood pressure at eighteen weeks old was the main outcome measure. Individually, hypoxic pregnancy (ie: low oxygen/normal salt group), and high-salt diet (ie: normal oxygen/high salt group) rats showed similar effects. "Rats from hypoxic pregnancies had signs of pulmonary hypertension and right ventricular thickening, whereas rats fed a post-natal high-salt diet had systemic hypertension, left ventricular wall thickening and impaired relaxation" (Baba et al 2025 p1). Meanwhile low oxygen/high salt rats showed a combination of both effects, but not evidence of an interaction. "Results suggest a poor post-natal diet can put additional strain on the cardiovascular system of offspring from hypoxic pregnancies, which can have significant implications for disease management" (Baba et al 2025 p1).

4.3. PRE-ECLAMPSIA

Pre-eclampsia is associated with up to 8% of global pregnancies, and it is linked to maternal hypertension, age, and low socio-economic status, but altitude is hypothesised as a risk factor also (Mitchell-Sparke et al 2025).

The evidence, however, is mixed. For example, Bailey et al (2022) found a one-third increased risk among mothers living above 2500 m compared to below that altitude in Colorado, USA, while data from Ecuador (2015-2017) showed a decreased risk at 1500-3500 m altitude, but an increased risk of pre-eclampsia for those living above 3500 m (Tejera et al 2021). "These mixed findings suggest that the effect of altitude on pre-eclampsia risk may (i) not be linear and/or (ii) depend on context-specific factors" (Mitchell-Sparke et al 2025 p2).

Mitchell-Sparke et al (2025) developed on the last study, analysing data from all hospital discharges in Ecuador for 2021-2023. Adjustment was made for maternal age, ethnicity, healthcare access and type, and urban/rural residence. No significant relationship was found between altitude and pre-eclampsia, but "increased risk was noted at the extremes of maternal age ($p < 0.001$) and among women with publicly funded care ($p < 0.001$). Ethnicity was also a risk determinant, but no interaction

with altitude was found" (Mitchell-Sparke et al 2025 p1). Note that overall less than 5% of pregnancies were diagnosed with pre-eclampsia.

The researchers accepted that less than 4% of their sample lived above 3000 m, and that information on body mass index was not available.

Comparison between studies is limited because "different studies may have classified pre-eclampsia using varying criteria, particularly over time..." (Mitchell-Sparke et al 2025 p8).

4.4. PHYSIOLOGICAL ASPECTS

There is interest in understanding the mechanism of adaptation of highland groups that limit the reduction in birth weight. Proposals include adaptation in uterine blood flow, or placental metabolism [17], and specific genes (eg: PRKAA1 or EPAS1) (Giussani 2025). "Genetic high-altitude adaptations influence a dynamic network of traits such as haematological, breathing, and vascular responses as well as metabolic regulation. The interplay among these factors probably determines how well individuals cope with hypoxia, with the presence or absence of key adaptations potentially tipping the balance between resilience and risk, which is particularly important in pregnancy, where O_2 supply is critical for foetal development" (Gu et al 2025 p6).

Foetuses in situations of long-term hypoxia show adaptations including lower oxygen consumption rates, and increased glucose and lactate production. These are seen as adaptations that allow the foetus faced with foetal growth restriction (FGR) due to hypoxia to "defend its rate, albeit lower, of oxidative metabolism" (Kyllo and Wesolowski 2025 p1). Most data here comes from the sheep model (Kyllo and Wesolowski 2025).

Infants born with FGR have an increased risk of metabolic diseases later in life (Kyllo and Wesolowski 2025).

The llama is studied as it shows adaptations to low oxygen levels of the Andean Altiplanto (>4000 m above sea level). It is believed that "llamas possess specific genes enabling them to cope efficiently with hypoxia, having evolved in an environment with low oxygen levels in the Andean Altiplano for at least 2 million years"

[17] Eg: placental mitochondria (Murray et al 2025).

(Llanos et al 2025 p1).

Lowland sheep foetuses, for example, taken to high altitudes show increased cerebral blood flow and reduced peripheral vasoconstriction to compensate and reduce the risk of brain injury, but llama foetuses do not have this response to hypoxia. Other physiological changes protect against brain injury due to lack of oxygen. This is an example of the adaptations in llamas (Llanos et al 2025).

Anti-oxidants (eg: in vitamin C, melatonin, and statins) have the potential as a means of preventing cardiovascular disease in hypoxic pregnancies (Botting-Lawford et al 2025).

A major detrimental effect of hypoxia is oxidative stress for the foetus; specifically reactive oxygen species (ROS) production in cells [18]. Excessive ROS production is damaging, but ROS production is important in regulating blood flow when there are short-term episodes of hypoxia. "Short-term acute episodes occur during labour owing to uterine contractions or umbilical cord compression. In response, the foetus prioritises oxygen and nutrient delivery to the brain, heart and adrenal glands at the expense of other organs, a mechanism known as the foetal brain-sparing response" (Botting-Lawford et al 2025 p1). Thus, there are concerns around the use of anti-oxidants (Botting-Lawford et al 2025).

4.5. REFERENCES

Baba, H et al (2025) Effects of a post-natal high-salt diet on cardiac function in offspring from hypoxic pregnancies Philosophical Transactions of the Royal Society B 380, 20240184

Bailey, B et al (2022) High-altitude residence alters blood pressure course and increases hypertensive disorders of pregnancy Journal of Maternal-Fetal and Neonatal Medicine 35, 7, 1264-1271

Botting-Lawford, K.J et al (2025) Anti-oxidants: Powering the fight against foetal hypoxia Philosophical Transactions of the Royal Society B 380, 20240183

Burton, G.J et al (2025) Pregnancy at high altitude: The challenge of hypoxia Philosophical Transactions of the Royal Society B 380, 20240167

Giussani, D.A (2025) Foetal growth and congenital heart disease at high altitude Philosophical Transactions of the Royal Society B 380, 20240177

[18] First studied in sheep; Thakar et al 2010).

Giussani, D.A et al (2007) The role of oxygen in pre-natal growth: Studies in the chick embryo Journal of Physiology 585, 911-917

Gu, W et al (2025) Genetic adaptations shaping survival, pregnancy, and life at high altitude and sea level Philosophical Transactions of the Royal Society B 380, 20240170

Hillman, S.L & Dolma, P (2025) High-altitude pregnancy adaptations: Evidence from a Himalayan population in Leh Philosophical Transactions of the Royal Society B 380, 20240396

Kyllo, H.M & Wesolowski, S.R (2025) Foetal nutrient flux and oxidative metabolism during hypoxia: Adaptive responses to defend foetal growth Philosophical Transactions of the Royal Society B 380, 20240176

Llanos, A.J et al (2025) The perinatal llama immersed in the thin oxygen of the Andean Altiplano Philosophical Transactions of the Royal Society B 380, 20240180

Thakor, A.S et al (2010) Redox modulation of the foetal cardiovascular defence to hypoxaemia Journal of Physiology 588, 4235-4247

Mitchell-Sparke, E et al (2025) Altitude and risk of pre-eclampsia: Insights from a large-scale epidemiological study in Ecuador Philosophical Transactions of the Royal Society B 380, 20240169

Murray, A et al (2025) Placental mitochondria in high-altitude pregnancy: Metabolic adaptations and a toolkit for respiratory assessment Philosophical Transactions of the Royal Society B 380, 20240175

Tejera, E et al (2021) A population-based study of pre-eclampsia and eclampsia in Ecuador: Ethnic, geographical and altitude differences BMC Pregnancy and Childbirth 21, article 116

Vargas, M et al (2007) Determinants of blood oxygenation during pregnancy in Andean and European residents of high altitude American Journal of Physiology: Regulatory, Integrative and Comparative Physiology 293, 3, R1303-R1312

5. ENDOSOMAL PATHWAY

The endosomal pathway is a cellular process that involves integral proteins and their associative proteins and lipids (collectively called "cargo") (Cullen et al 2024).

Defects in this pathway could be implicated in neurodegeneration. Cullen et al (2024) asked a number of key questions: "why is the brain particularly vulnerable to endosomal pathway defects? How do endosomal pathway defects lead to disease? How is it that subtly different defects in the endosomal pathway lead to one type of neurodegenerative disease or the other?
Can endosomal pathway defects be targeted therapeutically?" (p1).

Different proteins in endo-lysosomal dysfunction have been linked to different neurodegenerative disorders (eg: beta-amyloid and tau in Alzheimer's disease; mutant Huntington protein (mHTT) in Huntington's disease; TAR DNA-binding protein-43 (TDR-43) in fronto-temporal dementia) (Herman et al 2024).

Concentrating on Alzheimer's disease, post-mortem brain tissue studies (eg: Cataldo et al 2000) have identified dysfunction of the endo-lysosomal pathway (eg: "endosomal trafficking defects"; Herman et al 2024). Genetic studies have found an increased risk of Alzheimer's disease with gene variants that lead to the endosomal trafficking defects (Herman et al 2024).

Different cell types in the brain have different requirements of the endosomal pathway, and so dysfunction of this will have varied impacts (ie: cell type-specific vulnerabilities) (Maninger et al 2024).

Another neurodegenerative disorder is Parkinson's disease (PD), which was first described by James Parkinson in the early 19th century, and it is characterised by "motor symptoms, such as resting tremor, slowness of movement (bradykinesia), postural instability, gait impairment and limb rigidity. There are also substantial non-motor symptoms, including memory and cognitive impairment, apathy, anhedonia, insomnia, fatigue, urogenital issues, dysfunction of the autonomic nervous system and loss of facial expressions. Some of the non-motor symptoms, such as constipation, depression, rapid eye movement sleep behaviour disorder (RBD) and loss of smell (hyposmia), can emerge well before the motor symptoms" (Bhore et al 2024 p1).

The loss of dopamine neurons, particularly in

certain areas of the brain, accounts for the symptoms, though there is "a remarkable heterogeneity in the aetiology and pathogenesis of the disorder. The heterogeneity can manifest as variation in age of onset, disease progression, clinical phenotypes, cellular pathways, neurotransmitter systems, epigenetics and underlying genetic risks" (Bhore et al 2024 p1).

Knowledge about the genes, and the cellular pathways has grown in recent years. For example, a specific monogenic (single gene) rarer version of PD has been linked to endo-lyosomal dysfunction. Polygenic (multiple gene) versions are the common forms of PD (eg: over 90% of cases) (Bhora et al 2024).

A rare endo-lysosomal-related condition is Niemann-Pick type C (NPC) disease, which includes cognitive decline as well as psychosis, epileptic seizures, and dystonia among varied symptoms. "Although first symptoms can be revealed at any age from the neonatal period to the sixth decade of life, the most common manifestation is at childhood age, which often leads to premature death. Notably, the age at neurological onset is largely predictive of disease severity" (Malara et al 2024 p1).

Almost all cases are caused by a mutation in the NPC1 gene, which, put simply, leads to a build up of lipid within cells (Malara et al 2024).

REFERENCES

Bhore, N et al (2024) Common genetic risk for Parkinson's disease and dysfunction of the endo-lyosomal system Philosophical Transactions of the Royal Society B 379, 20220517

Cataldo, A.M et al (2000) Endocytic pathway abnormalities precede amyloid beta deposition in sporadic Alzheimer's disease and Down syndrome: Differential effects of APOE genotype and presenilin mutations American Journal of Pathology 157, 277-286

Cullen, P.J et al (2024) Understanding the endo-lysosomal network in degeneration Philosophical Transactions of the Royal Society B 379, 20220372

Herman, M et al (2024) Endo-lysomal dysfunction in neurodegenerative diseases: Opinion on current progress and future direction in the use of exosomes as biomarkers Philosophical Transactions of the Royal Society B 379, 20220387

Malara, M et al (2024) Endo-lysosomal dysfunction and neuronal-glial crosstalk in Neumann-Pick type C disease Philosophical Transactions of the Royal Society B 379, 20220388

Maninger, J-K et al (2024) Cell type-specific functions of Alzheimer's disease endocytic risk genes Philosophical Transactions of the Royal Society B 379, 20220378

6. SOCIAL AGEING

6.1. INTRODUCTION

"Social ageing" can be defined as "changes in individuals' social connections that occur as they age" (Firth et al 2024 p2). This includes "alterations in social behaviour, social roles, types of interactions and opportunities to interact, as well as the overall structure of social networks individuals are embedded within, and across all life stages from early development to later-life" (Firth et al 2024 p2) [19].

Firth et al (2024) introduced a special issue of the journal "Philosophical Transactions of the Royal Society B" which integrated ecology, evolutionary biology, behaviour, and demography to understand "age and society using natural populations".

There are a number of issues relevant to this topic (Firth et al 2024):

i) The mechanisms of age related patterns of social behaviour - For example, "older individuals may become more central in social networks due to their accumulated knowledge, acting as repositories of information and potentially being a more attractive social associate" (Firth et al 2024 p3). While physiological mechanisms include cognitive ability, body size, and immune function. "Such factors may influence how individuals interact as they grow older, potentially affecting their social standing or overall behaviour" (Firth et al 2024 p3) [20].

ii) Consequences for the group of individual ageing - "For example, older individuals might lack the energy

[19] Referring to insects, but making a relevant general point, Harrison et al (2024) noted that "sociality is not a fixed set of social behaviours, but rather a spectrum covering simple to complex sets of social interactions. At the simplest level, social interactions can refer to any interaction between conspecific individuals. At the other end of the sociality spectrum lie the eusocial insects, where kin selection has resulted in the evolution of complex social interactions occurring within a related social group" (p1).

[20] For example, as male lions age, they move from their natal pride into small coalitions with other males, and this alters their social associations (Packer and Pusey 1982).

to actively invest in others to the same extent and so may take more and reciprocate less, so social networks in aged populations may be skewed away from co-operation which will influence their functioning" (Firth et al 2024 p4) [21].

Age has an impact on a population in terms of the age structure of that population. For example, an older population with less individuals reproducing will mean a slower population growth than a younger population with more reproducing individuals.

Death of individuals in a population of a certain age will influence more the overall population size. Charlesworth (eg: 1972) used the term "critical age group" to describe these individuals. The "critical age group might, for example, be composed of all individuals of reproductive age, or of newborn individuals, depending on the biology of the population" (Charlesworth 1973 quoted in Gamelon et al 2024).

iii) Ageing and evolutionary fitness - For example, ageing causes a decrease in the amount of social associates that an individual has, and so "the social ageing of an individual may not just alter their own survival or reproductive success, but also that of their associates" (Firth et al 2024 p5).

There is a concept called the "selection shadow" (eg: Medawar 1952), which "refers to the decline in the force of natural selection with increasing age. As individuals age, their probability of survival decreases, and they contribute less to future generations, leading to weaker selection pressures against deleterious mutations that manifest later in life. In this context, this weakening of natural selection may allow social senescence effects to persist in older individuals, and in species where social networks span multiple generations this phenomenon may influence the evolution of social ageing traits in even more complex ways" (Firth et al 2024 p5).

"Studies in humans show a variety of impacts that social interactions may have on ageing patterns. Generally, negative social experiences, such as weak social connectedness, negatively correlate with health and mortality risk. However, this is not the case for all dimensions of health. For instance, the quality of social interactions (ie: strength of the relationship) and an

[21] Key areas to understand in terms of ageing and social relationships include social choice and preferences, breeding behaviour, co-operation, and competition (Woodman et al 2024).

individual's perception of their connectedness within a social network seem to be key indicators of cognitive function in older adults rather than just the frequency of social interactions" (Harrison et al 2024 p2).

Social interactions within the group can work both ways - positive and negative in relation to ageing. For example, co-operative living improves survival chances (or compared to living alone), but a larger group can mean increased competition for resources (and stress) which reduces survival chances.

"Living in groups offers social animals the significant advantage of accessing collective wisdom and enhanced information processing, enabling more accurate decisions related to foraging, navigation and habitat selection. Preserving group membership is crucial for sustaining access to collective wisdom, incentivising animals to prioritise group cohesion. However, when individuals encounter divergent information about the quality of various options, this can create a conflict between pursuing immediate rewards and the maintenance of group membership to improve access to future pay-offs" (Mann 2024 p1). Improved information can benefit survival, while conflict can have a negative impact on it. Also individuals may compromise on one decision to remain in the group. So, Mann (2024) argued, "patterns of sociality should be interpreted in the context of the life history of an individual and its peers, rather than through the lens of an isolated decision" (p1) [22].

However, "sociality is multi-faceted" (p2), and "[S]pecies are more than just social or not social" (Salguero-Gomez 2024 p12). This led this author to propose "a continuum of animal sociality to examine whether sociality, the way individual organisms organise themselves within a population and interact, shape their demography" (Salguero-Gomez 2024 p2) with five categories:

a) Solitary - Individuals only meet to breed (eg: tiger).

b) Gregarious - Individuals spend time in groups but with limited social interactions (eg: zebra).

c) Communal - Closer group living than (ii), but no

[22] Nunez et al (2015) found that feral horse foals with more associations had greater survival after a catastrophic event causing large population loss than those with fewer associations.

co-operative breeding (collective care for offspring) (eg: purple martin).

d) Colonial - Common nesting area (eg: nesting birds).

e) Social - in this case "individuals live in close proximity and form stable, organised groups, engaging in social behaviours such as co-operative breeding and hierarchical structures" (Salguero-Gomez 2024 p2) (eg: African elephants).

Applying these categories to 152 species from thirteen taxonomic classes, Salguero-Gomez (2024) noted the following patterns - "more social species live longer, postpone maturity, have longer generation time and greater probability of achieving reproduction than solitary, gregarious, communal or colonial species" (p1) - but not "reproductive or actuarial senescence rates" (ie: aspects of ageing).

Only a small number of species were studied, and the findings were associations - ie: it is not possible "to disentangle the direction of causality between sociality and demography" (Salguero-Gomez 2024 p11).

In terms of establishing causality, Moiron and Bouwhuis (2024) commented: "As an example, older birds often breed earlier in the season than younger birds, which may lead to them experiencing a reduced density, which in turn may reduce their (opportunity for) social interaction" (p2).

Moiron and Bouwhuis (2024) analysed 29 years of data (1993-2021) collected on a breeding colony of common terns on the German North Sea coast. The number of neighbours during breeding was used as a proxy measure of social environment experienced. In total, there were 4710 observations from 878 individual females of known age and laying date, and the number of active neighbours ranged from 0 to 37 (mean 6.7). There was evidence of age-specific declines in the number of neighbours during breeding.

Woodman et al (2024) stated: "Much previous research has studied ageing in laboratory settings, particularly using insects and other short-lived animals as models However, studies on captive animals may lead to conclusions that cannot be generalised to natural ecological contexts. Therefore, the importance of studying ageing in wild populations is widely acknowledged" (pp1-2).

6.2. RESEARCH WITH PRIMATES

Physiological changes associated with ageing influence social behaviours. For example, reduced energy leads to more time resting and fewer energetically demanding behaviours, which impact social interactions. Older individuals have less energy through food intake due to less foraging.

Siracusa et al (2022) stated that "energetic deficiencies are expected to restrict an individual's movement and therefore their ability to socially engage or the likelihood of others coming into social contact, leading to reductions in the quality and quantity of social relationships" (quoted in Furtbauer et al 2024). This is the "energetic deficiencies hypothesis".

Furtbauer et al (2024) tested this with data on wild chacma baboons in South Africa. Sixteen adults in a well-studied troop wore bio-logging collars which provided details of movement, while social grooming and interactions were observed, and faecal samples gave information about diet, and hormones. Faecal triiodothyronine (fT3) was used as a proxy for energy availability.

"Higher (individual mean-centred) fT3 was associated with increased residency time (ie: remaining in the same area longer), which, in turn, was positively related to social opportunities (ie: close physical proximity). Individuals with more frequent social opportunities received more grooming, whereas for grooming given, fT3 moderated this effect, suggesting an energetic cost of giving grooming" (Furtbauer et al 2024 p1).

Lower-energy individuals showed the use of strategies to maintain their energy. The researchers concluded that "future work should consider whether age-related declines in sociality may be a by-product of a strategy to conserve energy" (Furtbauer et al 2024 p1). Reduced energy could be described as a mechanism of age-related changes in sociality.

The findings suggested "a more subtle energy–movement–sociality mechanism" (Furtbauer et al 2024 p8) than proposed by the "energetic deficiencies hypothesis".

Social interactions carry the risk of infectious disease transmission. It is proposed that this risk impacts social ageing "because immunosenescence often means that individuals are less able to fight infections as they age and so suffer greater morbidity to infectious diseases, age-based reductions in individual social network connectedness can help mitigate disease costs in

older individuals. By being socially selective (ie: reducing their number of social partners while socialising for longer with their closest associates), older individuals may be able to reduce their risk of infection while maintaining the benefits of social relationships" (Siracusa et al 2024 p2).

Siracusa et al (2024) provided data for this idea from the well-studied rhesus macaques on Cayo Santiago, Puerto Rico. Data on adults, collected by observations between 2010 and 2022, were analysed for social networks (eg: grooming bouts), and compared with models of respiratory virus spread.

Reducing the number of social partners with was beneficial for pathogens with high transmissibility, and/or when the infection was more severe (in impact and/or duration).

There was support for the idea that reduced social connectedness in old age protects against infectious disease.

Also using Cayo Santiago data, Patterson et al (2024) explored the impact of early life adversity on later life of rhesus macaques. Overall, more early life adversity was associated with earlier death (both as infant and as an adult). However, there were differences between individuals depending on the type of adversity, timing, and social context. Maternal death in the first four years of an individual's life was the strongest variable, while social support was a positive one.

Other forms of adversity included high temperatures, low rainfall, high group size at birth, and early hurricane exposure. There were sex differences in that male survival was more strongly impacted by adversity (especially maternal loss).

Campos et al (2024) made the case for white-faced capuchins as "a promising new model system for ageing research" (p1). There are a number of long-running studies of natural populations (eg: Santa Rosa, Costa Rica, since 1983). Capuchins are highly social primates, which is important because social interactions are believed to be key in "one of the most enduring questions in public health... why some individuals remain healthy and high functioning well into old age, while others experience physical or cognitive deficits, chronic disease and premature mortality" (Campos et al 2024 pp1-2).

6.3. MAMMAL RESEARCH

Changes in infection by parasites can vary over the lifespan of an animal, and behaviour could drive these changes. "For example, individuals could alter their feeding locations as they age, which could move them into areas that are more or less likely to support environmental parasites, or it could result in lower-quality resource intake, driving weaker immunity and therefore greater susceptibility to infection. Similarly, ageing individuals could become more socially isolated, potentially driving decreased exposure to directly transmitted parasites" (Albery et al 2024 p2). Physiological changes (eg: in relation to the immune system) also play a role.

Albery et al (2024) investigated these ideas using data on a well-studied population of red deer on the Isle of Rum, Scotland. Different parasite counts were available from faecal samples collected between 2016 and 2021. Data on social networks and interactions were based on census observations.

Age-related changes in parasite count of different parasites were found (eg: decreases in liver fluke, but increase in strongyle nematode counts with age). The changes, however, could not be accounted for by changes in social behaviour with ageing alone. The researchers concluded that "age-related changes in infection can vary substantially within the same system, and likely depend on a complex combination of immune, behavioural, and demographic processes" (Albery et al 2024 p8).

6.4. RESEARCH WITH INSECTS

Harrison et al (2024) reviewed the evidence of the impact of social environment on ageing in "non-social" insects. For example, group size as seen in resource competition in early life can influence the individual's allocation of resources to now (reproduction) or the future (lifespan). Stressful early life conditions lead to swifter development to sexual maturity and to reproduction at the expense of of living longer, while favourable early conditions result in longer lifespan [23]. The latter has been called the "silver spoon effect" (Grafen 1988). This idea has been tested experimentally (eg: crickets; Gutierrez et al 2020).

[23] Note that there is a difference between lifespan and "health span" (ie: healthy part of the lifespan) (Harrison et al 2024).

The presence of same-sex or opposite-sex individuals has also been studied in experiments. Male lifespan is more sensitive to the presence of same-sex individuals more than females (eg: more injury from male-male contests reduces lifespan). Females exposed to many males have reduced lifespan compared to those living alone or with females. "This may be owing to sex-specific costs of reproduction, whereby the energetic demands of reproduction for females are generally greater than, or different from, those of males" (Harrison et al 2024 p5).

Age of social partners is another variable (ie: the age of same-sex "friend"). "The studies in... [fruit flies] that alter social partner age generally find a negative trend between social partners' age and longevity, ie: young same-sex partners are beneficial but older partners deleterious to lifespan" (Harrison et al 2024 p5).

6.5. BIRDS

Using six years of data on house sparrows on an island in Devon, UK, Schroeder et al (2024) found that social networks decreased with age. Video recordings of colour-ringed birds at a feeder and their interactions were analysed.

Thirty-five social networks were created from over 1600 observations of individual interactions between over 600 adults. Less older individuals were observed (eg: 3 at age 7 years vs 528 at age 1 year), which may explain in part less social interactions by older adults (ie: "the fewer birds in the same peer age group, the lower their sociality was"; Schroeder et al 2024 p5).

6.6. REFERENCES

Albery, G.F et al (2024) Divergent age-related changes in parasite infection occur independently of behaviour and demography in a wild ungulate Philosophical Transactions of the Royal Society B 379, 20220508

Campos, F.A et al (2024) Wild capuchin monkeys as a model system for investigating the social and ecological determinants of ageing Philosophical Transactions of the Royal Society B 379, 20230482

Charlesworth, B (1972) Selection in populations with overlapping generations. III: Conditions for genetic equilibrium Theoretical Population Biology 3, 4, 377-395

Charlesworth, B (1973) Selection in populations with

overlapping generations. V: Natural selection and life histories American Naturalist 107, 303-311

Firth, J.A et al (2024) Understanding age and society using natural populations Philosophical Transactions of the Royal Society B 379, 20220469

Furtbauer, I et al (2024) Linking energy availability, movement and sociality in a wild primate (Papio ursinus) Philosophical Transactions of the Royal Society B 379, 20220466

Gamelon, M et al (2024) The concept of critical age group for density dependence: Bridging the gap between demographers, evolutionary biologists and behavioural ecologists Philosophical Transactions of the Royal Society B 379, 20220457

Grafen, A (1988) On the uses of data on lifetime reproductive success. In Clutton-Brock, T (ed) Reproductive Success Chicago: University of Chicago Press

Gutierrez, Y et al (2020) Diet composition and social environment determine food consumption, phenotype and fecundity in an omnivorous insect Royal Society Open Science 7, 200100

Harrison, L.M et al (2024) Ageing effects of social environments in "non-social" insects Philosophical Transactions of the Royal Society B 379, 20220463

Mann, R.P (2024) Agents seeking long-term access to the wisdom of the crowd reduce immediate decision-making accuracy Philosophical Transactions of the Royal Society B 379, 20220467

Medawar, P.B (1952) An Unsolved Problem of Biology London: H.K Lewis & Co

Moiron, M & Bouwhuis, S (2024) Age-dependent shaping of the social environment in a long-lived seabird: A quantitative genetic approach Philosophical Transactions of the Royal Society B 379, 20220465

Nunez, C.M.V et al (2015) Sociality increases juvenile survival after a catastrophic event in the feral horse (Equus caballus) Behavioural Ecology 26, 138-147

Packer, C & Pusey, A.E (1982) Co-operation and competition within coalitions of male lions: Kin selection game theory Nature 296, 740-742

Patterson, S.K et al (2024) Early life adversity has sex-dependent effects on survival across the lifespan in rhesus macaques Philosophical Transactions of the Royal Society B 379, 20220456

Salguero-Gomez, R (2024) More social species live longer, have longer generation times and longer reproductive windows Philosophical Transactions of the Royal Society B 379, 20220459

Schroeder, J et al (2024) Not so social in old age: Demography as one driver of decreasing sociality Philosophical Transactions of the Royal Society B 379, 20220458

Siracusa, E.R et al (2022) Social ageing: Exploring the drivers of late-life changes in social behaviour in mammals Biology Letters 18, 20210643

Siracusa, E.R et al (2024) Social ageing can protect against infectious disease in a group-living primate Philosophical Transactions of the Royal Society B 379, 20220462

Woodman, J.P et al (2024) The ecology of ageing in wild societies: Linking age structure and social behaviour Philosophical Transactions of the Royal Society B 379, 20220464

7. TRANSFORMING FOOD SYSTEMS

7.1. INTRODUCTION

Global food systems are placing unsustainable burdens on humans, societies, and the planet. "A wide spectrum of evidence documents the long-term unsustainability of how we produce food, how it is processed and the negative health consequences of our diets. This includes: data on child malnutrition and the consequences for brain development; the negative impact of diet-related disease on labour productivity and premature deaths; the destruction of natural resources required to support food production; the high contributions to greenhouse gas emissions; and predictions of the increasing difficulty of maintaining food supplies at the scale to feed the world's population amidst socio-economic, political and environmental challenges" (Horton et al 2025 p1).

Transforming food systems for the better includes agriculture as well as many other disciplines like nutrition science, genetic engineering, and economics (Horton et al 2025). "Transforming the UK Food System for Healthy People and a Healthy Environment" (TUKFS), for example, was set up to achieve change in the UK (Horton et al 2025) [24].

Horton et al (2025) outlined some key issues related to transforming the global food system, including:

i) The development of novel approaches.

[24] The term "agrifood systems" is used by the "Food and Agriculture Organisation of the United Nations" (FAO) to describe "the journey of food from farm to table. The systems also encompass non-food products that constitute livelihoods and all of the people, as well as the activities, investments and choices, that play a part in getting us these food and agricultural products" (De Matteis et al 2025 p1).

ii) How to make dietary changes.

iii) What is grown, how and where it is grown, and how it is processed (table 7.1).

- Finding new sources of food or adapting existing sources are possible avenues for change. For example, grass. "Despite the high nutritional content of grass, humans cannot digest the grass's lignocellulosic structure and instead rely on animals to convert grass into digestible nutrient-rich foods such as meat and milk. This is an inefficient process, as cattle need up to 125 kg of fresh grass (20% dry weight) to produce 1 kg of edible meat or 5 kg of milk solids [6–9]. Grasses already contain relatively high amounts of protein, comprising approximately 15% in fresh grass and between 11 and 15% in silage. If 20 M tonnes of grass was directly repurposed for human food, then this would equate to approximately 3 M tonnes of protein, approximately double the UK's total protein consumption" (Kurhan et al 2025 p2).

- Kurhan et al (2025) reported experiments "coupling targeted mechanochemical processing and novel biotechnology to convert silage into edible protein and lipid fractions. To this end, the water-soluble protein and vitamins were extracted from silage using a twin-screw extruder at room temperature. The extrusion of the silage was optimised in water with no additional chemicals. Under optimal conditions, 22 wt% of the silage was solubilised, with this fraction containing 52% of the protein present from the original material. The protein contained key essential amino acids with a profile similar to soy protein. Vitamins B1, B2, B3 (nicotinamide and nicotinic acid) and B6 (pyridoxine, pyridoxal and pyridoxamine) were also extracted" (p1).

Table 7.1 - Eating grass.

iv) The social implications of the interventions in food production.

v) Taking a global perspective (appendix 7A).

vi) From research to policy. Horton et al (2025) described the barriers here thus: "Public sector decision makers are often unwilling to use coercive instruments owing to anticipated public backlash. Since almost all agricultural and food policies are likely to redistribute economic advantages and disadvantages along the food supply chain, politicians charged with making such decisions are subject to lobbying and pressure from interest groups. Policy choices thus consider both economic and political evidence in addition to scientific evidence. This may lead to the dilution or dismissal of

key scientific evidence such as the need to take a systems approach to the agrifood sector" (p3).

7.2. SOCIAL INNOVATIONS

The social innovations needed to transform the global food systems should be, Lyon et al (2025) argued, "place-based initiatives such as community hubs, cafes and therapeutic growing space; supply chains and food access for social justice and sustainability; and food behaviour change activities that alter consumption and purchasing" (p1). These authors placed great emphasis on collaborative partnerships.

Also "cross-cutting and boundary-spanning nature of food requires an understanding of the breadth of issues, with innovation coming from organisations that may not in themselves be focused on food, but create space for people to engage in discussions and learning about food in ways that traditional public health or environmental education models may not be able to reach" (Lyon et al 2025 p6) (eg: "Nursery Chef"). The "London Early Years Foundation" set up the "Nursery Chef" initiative to not only provide "good" food for children, but to encourage the whole family to eat better by giving children "homework" (eg: recipe cards), for instance.

Lyon et al (2025) stated three key questions for social innovations to provide the answers to:

i) "What are the dimensions and processes of social innovation practice with intent for transforming food systems?".

ii) "What are the challenges to overcome in developing those innovations?".

iii) "How can social innovations be amplified and lead to future transformations?".

7.2.1. Barriers To Change

Food systems "remain largely intransigent to change" (Sawyer et al 2025 p1). They are "complex adaptive systems": "A generalisable characteristic of complex adaptive systems is self-organisation, which allows a system to restore a level of (spontaneous) order following disruption, so that it continues to achieve its

embedded goals. This reversion to order means there is in-built resistance to long-term system change. Consequently, there is debate about how system transformation might be achieved" (Sawyer et al 2025 p2).

Barriers to change emerging from a research project in the city of Birmingham in central England involve the five sub-systems of food systems - supply chain and wholesaling, grocery retail (eg: supermarkets), institutional catering (eg: canteens; schools), out-of-home retailing (eg: restaurants), and community food support services (eg: "food banks") (Sawyer et al 2025). The motivations of the different parties was one barrier to change (eg: emphasise on profit); what Sawyer et al (2025) described as "the epistemic, social, symbolic, spatial and temporal differences between stakeholders" (p1).

Suggestions for interventions included healthier and more sustainable takeaway outlets, swapping products in convenience stores in socio-economically deprived areas, and dealing with food waste.

7.3. TUKFS

Bridle et al (2025) asserted that the "UK food system is a driver of the public health crisis of non-communicable disease, is linked to the cost-of-living crisis, and contributes to climate change, biodiversity loss and soil degradation. The economy relies strongly on the health of its people and food businesses, while also impacting the livelihoods of food system actors" (p1). TUKFS is an attempt to deal with such issues involving the government and researchers in academia. The five main areas of focus are (Bridle et al 2025):

i) "Disrupting towards a regenerative food production system" - eg: "regenerative agriculture".

ii) "Innovating in manufacturing and the supply chain" - eg: shorter domestic food supply chains; food and drink manufacturing that is sustainable.

iii) "Transforming food environments for healthy and sustainable food" - eg: encourage supermarkets to promote healthy food options and downplay unhealthy ones; simplify health and environmental labelling on food; change menus to healthier options in hospitals.

iv) "Empowering communities" - eg: rewarding

community and locally produced food sources.

v) "Transforming policy and governance" - eg: food policies that inform all government policies; cross-government and citizen bodies.

Bridle et al (2025) ended: "The need for change comes at a time when food producers are facing financial pressures and uncertainties, with farmers operating at marginal gains or at a loss, while shouldering much of the risk from increasing extreme weather events. Meanwhile, geopolitical instability threatens sourcing of inputs and ingredients and increasing prices, large food manufacturers and retailers are demonstrating significant economic growth, and citizens face a cost-of-living crisis. Structural changes and increased support can enable businesses to make decisions more aligned with a transformed system, through advice and financial support for farmers and businesses, or enabling the redistribution of surplus food to those in need" (p10).

7.4. SYSTEMS APPROACH

De Matteis et al (2025) outlined five case studies from around the world involving the FAO and transforming the global food systems:

i) Morocco - In 2024 the "National Committee for Food Systems Transformations" (CNTSA) was launched with responsibility for "providing shared strategic direction, co-ordinating efforts, monitoring the implementation of the national roadmap, and identifying investment opportunities to drive forward the agrifood systems transformation agenda" (De Matteis et al 2025 p3).

ii) Albania - Policies to reduce the rural-urban economic gap as the rural areas had declined with young people leaving (eg: "agritourism").

iii) Costa Rica - Moving away from the dependence on coffee exports.

iv) Pacific Islands (Fiji, the Solomon Islands, and Vanuatu) - Policies to deal with the high incidence of obesity-related problems.

v) Rwanda - Policies to address persistent food insecurity and malnutrition.

For De Matteis et al (2025) the case studies showed that "some countries are gradually moving away from linear and siloed ways of thinking and working towards embracing elements of a systems approach, intentionally steering ongoing food systems transformations towards greater social, economic and environmental goals" (p6). A systems approach involves many different parties in the agrifood system working together and at different levels. It is more than just farmers working alone or governments imposing changes alone.

The actual process, however, will vary between countries. "Different countries must overcome different challenges and find different solutions" (Horton et al 2025 p2).

7.5. REGENERATIVE AGRICULTURE

"Regenerative agriculture" is a farmer-led approach "to produce food while simultaneously improving soil health, supporting biodiversity, reducing input costs and enhancing climate resilience" (Berthon et al 2025 p1). There are five main principles - reduce the soil disturbance, keep the soil covered, maintain living roots of crops, increase crop diversity, and integrate the livestock with the arable (Berthon et al 2025).

"While multiple practices are associated with delivering these principles, there remains considerable uncertainty in our understanding of the potential contribution regenerative agriculture can make to socio-economic and environmental outcomes across different farming systems and pedo-climates. The uncertainty stems partly from the loose definition of regenerative agriculture, which allows farmers to adopt a spectrum of practices under the umbrella term, and makes it hard for those in other parts of the food system to be sure which farms are really 'regenerative'" (Berthon et al 2025 p2).

Evidence to support regenerative agriculture is not straightforward to find. "Several previous studies demonstrate a systems-based approach using agricultural field experiments, where the cropping system at plot or field scale is the unit of study, and the performance of different cropping systems is compared using multiple outcomes. Performance can be compared statistically based on either single or multiple outcomes, as long as sufficient replication at the system level is included in the design" (Berthon et al 2025 p2).

Berthon et al (2025) compared two research projects in the UK - "FixOurFood" (seven different farming

techniques compared in 21 plots of land), and "H3" ("Healthy Soil, Healthy Food, Healthy People") (blocks of land in one of three farming systems). A number of issues were noted including "challenges defining regenerative agriculture; co-design and maximising knowledge exchange; generalising results beyond study sites, when practices and outcomes are context-dependent; the need for interdisciplinarity; and generating evidence on long-term transitions with time lags between system change and outcomes, in an environment of short-term funding" (Berthon et al 2025 p1).

7.6. CHANGING MENUS AND DIETS

In "controlled situations" like worker canteens or hospitals, the menus can be changed to offer food options that are healthier and/or reduce carbon emissions in their production. For example, Flynn et al (2025a) reported a proof-of-concept study in a university hall of residence with 300 students, where the weekday evening meals were changed "for the better". Reductions in the carbon footprint of meals, and in saturated fatty acid (SFA) intake of 31% and 6% respectively were found (Flynn et al 2025b).

Flynn et al (2025b) analysed weekly menu data from eleven UK hospitals and modelled the benefits of changed menus. The carbon footprint of meals could be reduced by end to 30% (estimated range of 9.1% to 29.3%), and the intake of SFA by a similar amount (estimated range of 5.0% to 26.5%) depending on the ingredients changed. Strategically swapping menu items is the way the policy could be introduced.

More widely, "BeanMeals" was "aimed at transforming institutional catering and home-cooking by using UK-grown beans as healthier ingredients, and by changing public procurement practices to use more local products" (Ingram et al 2025 pp1-2). The project took place in Leicestershire in the English Midlands, and was an example of a "fork-to-farm" approach (as opposed to the conventional "farm-to-fork" approach). "The 'fork' represents the end point of what a variety of stakeholders want in terms of health, economic and environmental outcomes. 'Fork to farm' should not be misinterpreted as a consumption-driven system in the usual business sense — starting with the desires of potential customers and then tailoring products to meet them. A range of health, economic and environmental

outcomes need to be considered, whether or not any given set of consumers values or is even aware of them" (Ingram et al 2025 p2).

Practically, three scenarios were developed around increasing average daily consumption of 8.5 g of beans to either 17, 34, or 50 g. For example, the introduction of new bean-based recipes into six school menus in early 2023, and bean-focused classroom activities for 9-10 year-olds (including lessons on growing, cooking, and exploring different bean types).

Ingram et al (2025) summed up: "The BeanMeals analysis has focused on the UK bean system, revealing where opportunities arise and where potential stumbling blocks and stakeholder push-back might come from. Potential clearly exists for increased demand to be triggered, and a more coherent governmental policy direction. Future systemic innovations within the food system could involve making beans available in easy-to-use, sustainable and low-cost formats that are appealing to children and families (eg: beans incorporated into familiar and well liked foods). Also, innovations that bypass the need for soaking and/or boiling within the kitchen would be welcome: even though these bean varieties need less soaking from dried than many others, the pre-preparation and time required for this was noted by some of the schools and families as a barrier to regular use. Potential also exists for increased production, albeit from a very low baseline, if benefits to farmers can be made clear. But this will also need investment in supply infrastructure, depending on how demand develops (whole beans, dried/canned, processed composite products, protein-based products etc)" (p9).

To help consumers to change their food choices a scoring system that rates the food's nutritive value, and environmental impact is needed. The "Sus-Health Index" is such a system. "The index is a product of existing nutrition and environmental indices, using a composite indicator methodology, and can be presented quantitatively as a numeric value or qualitatively on a categorised, colour coded, scale 'A (best)–E (worst)'" (Grigoriadis et al 2025 p1).

The food part of the Index was based on seven nutrients and food components - energy, saturated fat, total sugar, sodium, percentage of vegetables, fruit or nuts, fibre, and protein - while the "European Food Environmental Footprint Single Index" (EFSI) (Ramos et al 2022) with thirteen categories of impact was the basis of the environmental side of the Sus-Health Index.

Twenty-nine foods were tested with the Index (eg: tuna, cod, milk, lentil, orange), and four hone-cooked meals. Among the individual foods, fifteen received an "A" score (eg: pea, lentil, carrot), none an "E" score, but five were rated as "D" (eg: tuna, beef). The best meal was vegetable curry ("A" rating), and the worst was spaghetti carbonara ("C" rating) with beef stew "C" and chicken curry "B".

The researchers admitted that a wider selection of foods needed to be used. They also noted that it is important "not to neglect economic trade-offs of improving Sus-Health scores such as the impacts of dietary transitions on employment in the agrifood sector, and on the affordability of food" (Grigoriades et al 2025 p9).

7.6.1. Dietary Fibre

Dietary fibre consumption in the UK, for example, could be improved. "Dietary fibre is present predominantly in plant-based foods and is not digested or absorbed in the upper gastrointestinal tract, passing to the colon where it may be fermented by the gut microbiota. Types, contents and properties (notably solubility, viscosity and fermentability) of fibre vary considerably between food sources, which may result in different effects on human physiology. There is strong evidence for the benefits of dietary fibre, particularly cereal fibre and wholegrain, in reducing the risk of cardio-metabolic diseases and colorectal cancer by increasing faecal mass, fermentation to short-chain fatty acids, lowering blood lipids and improving glycaemic control" (Lovegrove et al 2025 p1).

How to increase consumption? Possible strategies include better nutritional data, public health messaging, more informative food labelling, and food reformulation and fortification (Lovegrove et al 2025). Ultimately, palatable and affordable fibre-rich foods are required. For example, "Raising the Pulse" is a project in the UK to increase the fibre content of white bread by the use of higher fibre ingredients like pulse flour from faba beans (Lovegrove et al 2025) (table 7.2).

More widely, changes in agricultural practices may be required if there is an growing demand for fibre-rich foods. "An increased use of, for example, beans as a break crop, or under-sowing of beans, could be part of a strategy to increase bean production. This strategy also

- It is often believed that children will only eat white bread and this is a barrier to change.

- Wilkinson et al (2025) described small-scale projects to replace white bread with higher fibre breads in UK school breakfast clubs (eg: in East Liverpool and Leeds).

- "A key outcome was that child preferences were not a major barrier. When provided with higher fibre foods, children ate and enjoyed them. This suggests that simple food policy levers could significantly reduce the approximately 6 g average 'fibre gap' in UK school children's intake, for example by mandating that all bread served in schools be at least a 'source of fibre'" (Wilkinson et al 2025 p1).

Table 7.2 - School Breakfast Clubs

improves soil health, reduces disease pressure and may reduce nitrogen input requirements for the subsequent cereal crops. These approaches are becoming increasingly attractive since the production of oilseed rape — the dominant break crop used in rotation with wheat over the past few decades — has decreased owing to restrictions in pesticide use. To increase the fibre content of bread, it will be necessary to ensure an adequate supply of raw materials (improved varieties of wheat and 'new' ingredients such as beans), which may require farmers to be financially incentivised. New baking and production methods should also be explored to ensure that these new or improved ingredients can be used on a commercial scale without prohibitive cost increases. In this sense, a whole food chain approach needs to be taken to ensure demands are met and the rollout of any strategic programme is effective" (Lovegrove et al 2025 p8).

7.6.1. Inequalities

"The food system is a multi-faceted complex web of actors and organisations that are necessary for the production, transformation, distribution and retailing of food to the consumer across the food chain. While the global food system produces enough calories to feed everyone on the planet there are disparities in access (physically and economically) that impact overall diet quality within and between social groups in society. There is clear evidence of a socio-economic gradient in health and that diet is a modifiable risk factor for the development of non-communicable diet-related disease" (Wagstaff et al 2025 p2).

Any transformation of global food systems must take account of deprived groups. Firstly, listening to what such individuals want is often overlooked in studies. Wagstaff et al (2025) reported the lessons learned from two multi-method action research projects in four areas of high deprivation in England - "Food Systems Equality" (FoodSEqual) and "Food Systems Equality-Health" (FoodSEqual-Health) (including individual interviews, focus groups, and workshops).

Building trust and relationships with local community organisations was key, as well as cultural sensitivity and understanding, and tailoring research and programmes to the local area.

For example, in the case of improving fruit and vegetable consumption, three quotes from workshop participants highlighted the reality - "It's good to be eating healthy and it would be nice if you can go to a shop and afford all those nice, healthy looking vegetables... buy that good quality stuff. I wouldn't be able to afford to do it"; "You need 5 a-day, don't you? [BUT] you've got to have the [FUNDS] money-wise to buy the stuff, yes"; and "If you've got like two quid and you're going into Morrisons, you're going to grab something like something to snack on for lunch or whatever, you're going to grab some biscuits and a pack of crisps. You buy a cheap snack. A pack of strawberries is your £2 gone" (p12). One solution was "Fresh Street" [25] which provided consumers with vouchers for use in local providers of fruit and vegetables (eg: market stalls; independent grocers). In two areas with the intervention, after twelve months, average consumption increased by one portion per day compared to baseline. "What is perhaps more striking is the value of the community cohesion aspect of the intervention: neighbours who were 'strangers at the till' now visit the stall together; requests for culturally appropriate vegetables to be available have led to the engagement of a wider ethnic diversity making use of the co-located healthcare, social care and café facilities" (Wagstaff et al 2025 p12).

Wagstaff et al (2025) ended: "Systemic change, at national and local authority level, is required to place food strategy and action plans at the heart of tackling dietary determinants of health inequalities. Food Partnerships should be supported to develop locally agile solutions that enable producers, manufacturers, retailers and residents to achieve a healthy, economically viable and accessible food system in each area" (p14).

[25] See https://www.freshstreet.uk/.

Affordability came out as most important, followed by access to the food. As one workshop participant stated: "I would snack on strawberries if they were the price of a pack of biscuits" (p14).

7.7. SOCIAL IMPACTS OF INNOVATIONS

Indoor vertical farming (VF) is a possible solution to improve food security and safety for urban populations. Indoor VF is a form of controlled environment agriculture (CEA). By operating in controlled environments, vertical farms can potentially mitigate the risks posed by climate variability, pests and pollution and offer a healthier setting for crop growth. VF, which utilises vertical space through columnar structures or stacked layers, has the potential to improve resource efficiency and reduce the environmental impact of food production. As such, it may offer a more sustainable and resilient approach to urban food security, providing stable, year-round food production" (Kluczkovski et al 2025 p2).

Kluczkovski et al (2025) distinguished four types of VF - building-based (ie: specific building), shipping-container-based, in-store (at retail places), and "appliance farms" (mobile farms integrated into homes or offices).

Kluczkovski et al (2025) reviewed the literature on urban VF and assessed the impact in a number of ways, including:

i) Urban food security - eg: stability of food supply all year round and provision of fresh, high quality food, but this may be too expensive for low-income groups. Also property prices may increase with demand for buildings for VF.

ii) Inclusive urban economy - eg: "green jobs" in VF, and food distribution and retail, but these may be low-paid.

iii) Urban civic life - eg: community-building, but limited evidence here and risk of perpetuating social inequalities.

Despite the potential of VF for urban populations, Kluczkovski et al (2025) highlighted "the need to consider the role of pre-established socio-economic structures, policy contexts and the wider FS [food

system] when seeking to understand the social impact of VF, especially beyond the individual level to wider community benefits. This requires examining VF as a socio-technical intervention, as well as considering the broader political economy and particular urban context in which vertical farms are implemented. Much VF literature to date reflects a technocratic, productionist perspective typical of mainstream FS analysis, where power dynamics and institutional frameworks are taken as given, rather than socially constructed. VF may form part of wider efforts to transform FS, but as Anderson and Leach [2019] reflect, rather than technical transitions, the need is for 'deeper transformations' for global FS and for sustainability and equity more broadly. Such transformation is inevitably profoundly political, requiring power and political economy 'to be addressed head-on'" (p8).

7.8. APPENDIX 7A - SINGAPORE

Certain countries, like Singapore, import most of their food, and so are especially vulnerable to change in international trade. Food security, defined as "when all people at all times have access to sufficient, safe and nutritious food that meets the dietary needs and food preferences for a productive and healthy life" (McGuire et al 2015 quoted in Li et al 2025), is thus an issue.

Put into numbers, the population requires nearly 2400 million eggs, over 600 000 tonnes of vegetables, and 375 000 tonnes of meat, for example, per year, of which 90% of these are imported (Li et al 2025). This situation led the Singapore government in 2019 to a policy of "30 by 30" - ie: the goal of producing 30% of total nutritional needs for the population at home by 2030. This involves encouraging innovation (eg: "alternative proteins" like "cultured meat" and insect protein), having flexible regulations (to support innovation), and developing collaborative partnerships (eg: government and private companies). "Key factors for success include strategic leadership, robust investments in research and development, the nurturing of a skilled workforce and a focus on sustainable practices and market acceptance" (Li et al 2025 p1).

7.9. REFERENCES

Anderson, M & Leach, M (2019) Transforming food systems: The

potential of engaged political economy IDS Bulletin 50, 2, 131-146

Berthon, K et al (2025) Measuring the socio-economic and environmental outcomes of regenerative agriculture across spatio-temporal scales Philosophical Transactions of the Royal Society B 380, 20240157

Bridle, S et al (2025) Key action areas for transforming the UK food system: Insights from the Transforming UK Food Systems (TUKFS) Programme project portfolio Philosophical Transactions of the Royal Society B 380, 20240166

De Matteis, L et al (2025) International experiences of systems approaches: Re-thinking policies and governance to transform agrifood systems Philosophical Transactions of the Royal Society B 380, 20240159

Flynn, A.N et al (2025a) Dish swap across a weekly menu can deliver health and sustainability gains Nature Food 6, 843-847

Flynn, A.N et al (2025b) Strategic menu optimisation could reduce carbon emissions and saturated fat consumption: A simulation modelling study of UK hospital inpatient meals Philosophical Transactions of the Royal Society B 380, 20240152

Grigoriadis, V et al (2025) Developing the SuS-Health Index: A combined measure for describing environmental impact and nutritive value of foods and meals Philosophical Transactions of the Royal Society B 380, 20240160

Horton, P et al (2025) Food systems transformation: Rationale and methodologies Philosophical Transactions of the Royal Society B 380, 20240146

Ingram, J et al (2025) Fork to farm: Reverse engineering a food system Philosophical Transactions of the Royal Society B 380, 20240158

Kluczkovski, A et al (2025) Urban vertical farming: Innovation for food security and social impact? Philosophical Transactions of the Royal Society B 380, 20240154

Kurhan, S et al (2025) The development of a silage-based biorefinery to deliver the maximum nutritional benefit for human consumption from UK grasslands Philosophical Transactions of the Royal Society B 380, 20240161

Li, A.Z et al (2025) Safeguarding sustenance: Singapore's strategic commitment to enhancing food security through advancing food research and innovation Philosophical Transactions of the Royal Society B 380, 20240164

Lovegrove, J.A et al (2025) Importance of dietary fibre, strategies for increasing intake and maintenance of the supply chain in the UK Philosophical Transactions of the Royal Society B 380, 20240148

Lyon, F et al (2025) Exploring social innovations for transforming food systems Philosophical Transactions of the Royal

Society B 380, 20240156

McGuire, S et al (2015) The state of food insecurity in the world 2015: Meeting the 2015 international hunger targets: Taking stock of uneven progress, Rome: FAO, 2015 Advances in Nutrition 6, 5, 623-624

Ramos, S et al (2022) Enviroscore: Normalisation, weighting, and categorisation algorithm to evaluate the relative impact of food and drink products npj Science of Food 6, article 54

Sawyer, A et al (2025) Towards a collaborative interdisciplinary system approach to urban food system transformation: A case study from the Mandala research consortium Philosophical Transactions of the Royal Society B 380, 20240155

Wagstaff, C et al (2025) Addressing food system determinants of health inequalities in urban environments: Learning from the FoodSEqual and FoodSEual-Health projects Philosophical Transactions of the Royal Society B 380, 20240150

Wilkinson, N et al (2025) The children may not be the problem: Evidence of acceptance and enjoyment of higher fibre breads from choice architecture studies in school breakfast clubs Philosophical Transactions of the Royal Society B 380, 20240151

8. BIODIVERSITY LOSS AND THE FUTURE

8.1. INTRODUCTION

Bridle et al (2025) began by stating the stark reality: "Preventing catastrophic biodiversity loss is one of the defining challenges of the twenty-first century. The destruction of millions of years of evolutionary history risks devastating consequences - not only for biodiversity itself - but also for human health and well-being, food production, climate regulation and for ecological resilience to climate change" (p1).

The idea of "bending the curve" of biodiversity loss [26] (eg: Mace et al 2018) is to find ways "so that the ecosystems on which humanity depends remain productive in the face of rapid global change" (Bridle et al 2025 p1) [27].

But there is much we do not know, including, Bridle et al (2025) explained, "how accelerating threats to biodiversity interact, hampering our ability to mitigate their impacts. In addition, we still do not know how biodiversity within and among species shapes ecological resilience and interacts with socio-economic systems, or when and where critical rates of biodiversity loss and

[26] "Global biodiversity is in steep decline, driven largely by land-use change, human exploitation and invasive species. These losses are impacting human societies, compromising prosperity, health and sustainability. A major challenge for the coming years is to halt and reverse this decline, to 'bend the curve on biodiversity loss' to an upward trajectory" (Williamson et al 2025 p1). Williamson et al (2025) emphasised the non-linear nature of biodiversity loss because of the non-uniform distribution of biodiversity.

[27] In tropical forests, with a drying and warming climate change, it is expected that there will be an increase in species with drought-tolerance traits (eg: increased leaf photosynthetic capacity and decreases in leaf area and thickness in deciduous trees) (Aguirre-Gutierrez et al 2025). But Aguirre-Gutierrez et al (2025) found that in the Amaericas such change is "at a rate that is fundamentally insufficient to track climate change" (p1).

environmental change are exceeded" (p1).

Georgina Mace's work is important here (eg: Mace 2014), and Bridle et al (2025) introduced a special issue of the "Philosophical Transactions of the Royal Society B" on this topic. They identified four relevant themes in Mace's work:

i) "Understanding the processes that determine ecological diversity and biological resilience to changing environments" - Measurement, recognition of patterns, and understanding of causes of ecological resilience.

ii) "Measuring the state of biodiversity to determine conservation priorities" - There are clear agreed metrics related to climate change (eg: atmospheric CO_2 concentration), but "there is no comparable standardised unit of biodiversity loss. Instead, the many biodiversity metrics available measure different aspects of natural systems, each of which may respond differently to anthropogenic pressures. In addition, the effects of a given amount of biodiversity loss, although wide-reaching, may be different at different locations and in different biomes" (Bridle et al 2025 p3).

iii) "Biodiversity and the natural capital it provides to human society" - Understanding the relationship between biodiversity loss and human well-being is important.

iv) "Future scenarios for nature: using science to guide political action" - "The costs of biodiversity loss are unevenly and inequitably distributed, such that those least responsible for its destruction are often the most affected. Addressing these inequities is key to building a sustainable future. National and global economies remain shaped by subsidies and recent history to empower a minority to profit hugely from environmental destruction. In contrast, those who are the most impacted by biodiversity loss — such as the world's marginalised communities, those still at school or those not yet born — have little economic power to effect political change or affect policy" (Bridle et al 2025 p4).

8.2. UNDERSTANDING THE PROCESSES

"Biogeographic regionalisation" involves dividing the surface of the world into regions based on shared

characteristics (ecological and evolutionary) of the species therein. "Understanding biogeographic regions is crucial across the fields of ecology, evolutionary biology and conservation because it allows the investigation of factors driving biodiversity patterns and ecosystem dynamics across ecological scales, and the possible changes in these factors in the past and into the future. Thus, delineating biogeographic regions can enable the identification of the underlying processes that shape species composition, community structure and ecosystem functioning as well as enable the prediction of how contemporary factors such as habitat loss and climate change may alter these regions, and delineate areas and species for conservation priority" (Gross et al 2025 p1).

Alfred Russell Wallace (1876) performed an early version of this process, which Holt et al (2013) updated much later as twenty regions nested into eleven larger realms (mostly for vertebrates and plants) (Gross et al 2025).

Gross et al (2025) applied biogeographic regionalisation to butterflies (of which there are approximately 19 000 current species worldwide) using data for over 10 000 species (in a database created by Daru 2024). Nineteen phylogenetic regions ("phyloregions") were delineated, nested within six realms:

- 1. Holarctic (North American, Eurasian, Tibetan, Japanese regions).
- 2. Indo-Malayan (Hengduan–Himalayan, Chinese, Indian, Novozelandic).
- 3. African (Afrotropical, Maghrebi, Madagascan).
- 4. Nusantaran (Malesian, Papuasian).
- 5. Australian.
- 6. Neotropical (Mesoamerican, Caribbean, Amazonian, Pampeo-Andean, Valdivian).

The boundaries between regions were linked to temperature seasonality and precipitation (ie: "when regional climates shifted from relatively consistent year-round to those with more pronounced seasonal variation"; Gross et al 2025 p9).

Understanding about the genes of species will help in knowing about the possibilities of adaptation and plasticity in a changing world. The limits of adaptation were viewed by Georgina Mace as "both a key driver of broad macro-ecological scaling laws and a determinant of

which life-history traits and taxonomies are most associated with high extinction" (Chevin and Bridle 2025 p2).

A current species has evolved to survive in a particular environment (niche) in the main. But some species have flexibility within that context, and predicting that ability will help in understanding which species may become extinct.

"Evolutionary Rescue" (Gomulkiewicz and Holt 1995) describes a population that is able to avoid extinction through evolution. Researchers have attempted to model this phenomenon, but most studies involve single cell or simple organisms (Chevin and Bridle 2025).

One traditional argument for the conservation of biodiversity is that it is a "good" and nature is "something we like" (Rodrigues 2025). Two concepts are key - "option value" and "insurance value". The former is "the idea that the diversity of life is valuable because we cannot predict which elements will provide uses or benefits in the future" while 'insurance value' describes that "diversity is valuable because we cannot predict which elements will help maintain system stability or integrity in the face of future changes" (Rodrigues 2025 pp1-2).

Put another way, conservation of everything is necessary, not just the species that appear useful and/or popular because the ecosystem is made up of interconnections between all species. Barrie (2024) gave an example of the human focus on certain species and not others: "When a humpback whale arrived in the seas off Mexico last year, the scientific world sat up in wonder. And with good reason, because the whale... had just finished an 11 000 kilometre journey... Ants, however, are rarely on the lips of those discussing nature's best pilots" (p21).

Not only are the ants' navigational abilities extraordinary, but there is a lack of interest in that and their dwindling numbers (Barrie 2024). For example, wood ants use visual cues to navigate through cluttered undergrowth, and an ant in the Sahara uses an internal "step counter" in barren terrain (Barrie 2024). "Perhaps thinking of insects as individual animals, rather than their collective species, is a start" (Barrie 2024 p21).

8.3. MEASURING

The "International Union for Conservation of Nature

(IUCN) "Red List of Threatened Species" (Red List) has its origins earlier in the 20th century, but the first comprehensive assessment was published for birds in 1988 (Butchart et al 2025).

The categories used today (since 1994) are "Least Concern", "Near Threatened", "Vulnerable", "Endangered", "Critically Endangered", "Extinct in the Wild", and "Extinct". The idea of "Threatened" covers the categories of Vulnerable, Endangered, and Critically Endangered (Butchart et al 2025).

The "Red List Index" (RLI) is a measure of the "average extinction risk of groups of species" (p1), and it is based on the number of species in each category of the Red List (Butchart et al 2025).

The Red List and RLI depend upon the data available (eg: reported observations of an animal), and there can be a time-lag between reports and categorisation. "The RLI is based on data for a very high proportion of species in each of the taxonomic groups included, so its trends should be largely representative of those for the entire set of species in these groups. This representativeness builds from the strengths of the Red List process, which is an effective way to make meaningful inferences from imprecise or incomplete data, enabling the RLI to incorporate information even from species that are rare, localised or difficult to survey" (Butchart et al 2025 p8).

"Georgina Mace played a pivotal role throughout the process of developing and applying the Red List criteria, bringing the rigour of population biology to the practical challenges of assessing extinction risk consistently across different groups of species and types of life histories. She also played an important role in promoting the taxonomic expansion of the Red List, strengthening the requirements for documenting assessments and contributing to the development of the Red List Index" (Butchart et al 2025 p2).

Eyres et al (2025) introduced a new metric called "Land-cover change Impacts on Future Extinctions" (LIFE), which aimed to map anthropogenic-caused extinctions based on loss or gain of natural habitat ("Area of Habitat"; AOH). It was developed from Duran et al's (2020) persistence score.

The probability of extinction of a species is calculated over 100 years, and the loss of habitat is assumed to be cumulative and non-linear, "with the effect of losing a given quantity of habitat increasing as the

remaining habitat diminishes and hence also dependent on habitat changes in the more distant past" (Eyres et al 2025 p3).

LIFE scores were calculated for over 30 000 species of terrestrial vertebrates (using IUCN extinction threat categories) based on changes in the environment, either converting the remaining natural vegetation to agriculture (negative impact) or restoring farmland to natural habitat (positive impact). For example, "habitat restoration would be particularly valuable per unit area in endemic-rich regions that have undergone extensive habitat clearance already (such as the Atlantic Forest, eastern Madagascar and the Ethiopian Highlands). Habitat retention, on the other hand, would have most impact in mitigating extinction in these regions too, but also in endemic as well as species-rich regions where there has been less marked conversion to date (such as the Guyana Shield, southeast Amazon Basin, Cameroon, eastern Congo, Greater Sundas and northern Australia)" (Eyres et al 2025 p10).

The researchers accepted that an understanding on the link between reduced AOH and extinction is limited, and LIFE assumed that all habitats were of equal value to species.

Another metric is the "Living Planet Index" (LPI), which is "a leading global indicator of biodiversity change. It measures the average rate of change in monitored vertebrate populations from a large and growing database of population time series — the Living Planet Database (LPD) — sourced from published literature, grey literature, open databases and contributed data. The LPI was conceived as an indicator for biodiversity in 1997 by WWF International" (McRae et al 2025 p1). Academic use of the LPI was first reported by Loh et al (2005) (McRae et al 2025).

McRae et al (2025) commented on the limitations of the LPI and other such metrics: "Ledger et al [2023] have previously summarised some of the main challenges to the use or adoption of biodiversity indicators, including the LPI, such as the sensitivity of the method to extreme trends, data availability, and the way they are communicated. Some technical limitations are common to multi-species indices, such as the sensitivity of the geometric mean to outliers, zero values and rare species. Furthermore, uncertainty from both measurement of the population and stochasticity within a population tends to bias a geometric mean downwards, and this is especially pronounced when population trends co-vary" (p5).

8.4. NATURAL CAPITAL

Georgina Mace is attributed with the "natural capital approach(es)" (eg: Bateman and Mace 2020), which provides "a universally applicable framework that incorporates any or all elements of the natural environment within conventional economic decision-making" (Binner et al 2025 p1). The idea is that nature underpins all human economies (eg: non-renewable energy sources; self-renewable food sources). The upshot is that conservation and biodiversity renewal will benefits economies (and ultimately human well-being) [28].

"The natural capital framework provides a highly flexible and comprehensive approach to bringing the natural environment into conventional economic decision-making. It embraces the diversity of nature's capital and sets this alongside the manufactured, human and other capital types that dominate policy, showing how the services provided by all combine to generate the goods upon which human well-being rests. The framework also sets out how both private, market-priced and non-market social costs and benefits can be incorporated into analyses and viewed from either an individual/business or public perspective, allowing decision makers to understand the likely private response to changes in public policy and hence refine the latter" (Binner et al 2025 p11).

But natural capital approaches are not just about the economic valuation of nature, as Mace (2019) pointed out: they should "not be simply a means to place a monetary value on the natural environment so that it is taken more seriously in decision-making. Rather, [they] should be the means by which governments, corporations, and individuals can take proper responsibility for the essential components of natural capital that underpin society and a good life (the assets), record the condition of these assets and how this is changing over time, and ensure that provision is made when they fall below critical levels" (quoted in Fairbrass et al 2025).

Biodiversity has links to human health, "mostly indirect (eg: pollination contributing to food security), occur at scales ranging from the microbial to the planetary, and are mediated by numerous social and environmental forces that vary over space and time" (Gibb et al 2025 p1). Infectious diseases, particularly

[28] Natural capital refers to the stock of environmental assets that supports a flow of ecosystem services that benefit society" (Fairbrass et al 2025 p2).

zoonotic (from animals to humans) and vector-borne (transmitted by arthropods) ones, are the particular focus of Gibb et al (2025) in the biodiversity-health link.

"The emerging consensus in disease ecology is that anthropogenic ecosystem degradation and resulting ecological community changes — arising, for example, through habitat fragmentation, land use and climate change — on average tend to increase local pathogen transmission and disease in wildlife (Gibb et al 2025 p2). These authors continued: "Zoonotic and vector-borne disease systems are inherently socio-ecological in nature: modifications of landscapes for agriculture, industry and cities construct new niches and stressors for hosts, vectors and their pathogens, so shaping infection hazards; social factors such as gender, wealth, livelihoods and nutrition influence human–wildlife contact and exposure to pathogens, susceptibility to disease and access to healthcare. What these processes look like varies widely across different regions and socioeconomic settings worldwide, and may depend more on political–economic and historical than proximate ecological circumstances" (Gibb et al 2025 p2).

One approach is described as "One Health" or "people and nature" [29], where humans are seen as embedded in nature, and so what is good for nature is good for humans [30]. Put simply, maintaining and improving biodiversity benefits humans.

Gibb et al (2025) outlined three issues around biodiversity and health:

i) The anthropogenic impact on nature creates new niches for infectious disease - "Compared to minimally disturbed ecosystems, anthropogenic habitats often show markedly different — and in many cases more extreme — environmental variability over time, such as seasonal fluctuations in water availability (eg: transient versus year-round), vegetation and food resources (eg: cropping cycles) and local climates (eg: heat island effects). Many zoonotic and vector-borne diseases are climate sensitive, with temperature, rainfall and humidity impacting host and vector population dynamics, physiology and body condition, behaviour and host–pathogen interactions, as well as pathogen persistence in the

[29] As opposed to "nature despite people" or "nature for people" (Gibb et al 2025).

[30] The "people and nature" framework of Mace (2014) is the "two way dynamic relationships between people and nature", which is the basis of science, policy and practice today (Reyers and Bennett 2025). Reyers and Bennett (2025) developed this idea as "people with nature" - "an inextricably intertwined perspective on people-nature relationships" (p2).

external environment" (Gibb et al 2025 p4).

ii) The relationship between disease, biodiversity, and social disadvantage - eg: mosquito- and water-borne infections "tend to cluster in poorer and peripheral neighbourhoods of tropical cities" (Gibb et al 2025 p6).

iii) "Spillback" (or zooanthroponosis) (human-to-animal pathogen transmission) - eg: respiratory virus spillback to some primates. "The consequences of spillback can include the establishment of reservoirs within new hosts and geographic locations: for example, multiple introductions of SARS-CoV-2 have established endemic circulation in white-tailed deer in North America, which could ultimately serve as a source of novel variants to re-emerge in humans" (Gibb et al 2025 p7).

The solution for Gibb et al (2025) is effective intervention strategies, which "address proximal drivers of specific diseases, focusing variously on lowering pathogen prevalence within host populations (eg: land use policies, ecological restoration, host or vector control, wildlife vaccination), interrupting human exposure pathways (eg: reducing hunting or trade of high-risk species, improving water and sanitation infrastructure), reducing human susceptibility to disease (eg: vaccination, improving food security, better prevention and treatment of co-morbidities) or ensuring prompt diagnosis and treatment following infection (eg: by improving health systems infrastructure and accessibility)" (p7). The answer is "people and nature" in relation to infectious disease (Gibb et al 2025).

Gibb et al (2025) presented infectious disease transmission as based on hazard (pathogen diversity and prevalence), exposure (drivers of contact and transmission), and vulnerability (susceptibility to disease). The human behaviours that produce biodiversity loss impact each of these factors.

Fairbrass et al (2025) concentrated on the marine environment: "Coastal and marine ecosystems... play a crucial role in supporting biodiversity and providing essential goods and services to humans. These ecosystems encompass a variety of habitats, including seagrass beds, salt marshes and estuaries, which are home to numerous species of plants and animals. In addition to their ecological significance, coastal and marine ecosystems contribute significantly to... [an] economy through

activities such as tourism, fisheries and renewable energy production" (p2).

Locatelli et al (2025) stated: "Adaptation to climate change is a social–ecological process: it is not solely a result of natural processes or human decisions but emerges from multiple relations within social systems, within ecological systems and between them" (p1). This view led these researchers to propose "a novel analytical framework to evaluate social–ecological relations in nature-based adaptation, encompassing social (people–people) [eg: institutions; diversity; people's capacity], ecological (nature–nature) [eg: taxonomic diversity; landscape connectivity] and social–ecological (people–nature) [eg: moral concerns; spirituality; ecosystem management] relations" (Locatelli et al 2025 p1). Using 25 case studies, they found that people-nature relations are most effective, though all three are intertwined.

8.5. FUTURE SCENARIOS

Balmford et al (2025) began: "The scale and speed of the extinction crisis demand innovative thinking and bold responses. More than 50 years after recognising the problem, and despite dozens of international agreements, near-daily calls to action and billions of dollars invested in conservation interventions, we are still collectively failing to bend the curve of biodiversity's decline. Continued business-as-usual conservation will not turn things around, and we are fast running out of time to change how we do things" (p1).

Food policy/farming was the focus of these researchers, and their innovation thinking was "high-yield farming" (ie: greater yield per acre). This means using less land for farming, and being less environmentally harmful than "industrial agriculture". Note that, according to the IUCN Red List, agriculture impacts between half and three-quarters of all threatened and near-threatened amphibians, reptiles, mammals, and birds (Balmford et al 2025).

Balmford et al (2025) commented on change: "Perhaps the broadest conclusion is that there are often substantial opportunities to improve yields simply through adopting existing best practices. African smallholders, for example, commonly achieve dramatic increases in yields of staple crops when given access to improved seed varieties, modest amounts of inorganic

fertiliser, and advice on how to improve soil fertility and structure" (p8).

High-yield farming would use less land ("land-sparing"), but, if successful, it may lead to falling food prices and this may produce a rebound where more land is farmed to maintain profits for farmers. Strategies to combat this risk include support for farmers, and strict land-use zoning (Balmford et al 2025).

At the same time, other policies need to reduce the demand for higher footprint foods (eg: meat) and food waste (Balmford et al 2025).

"Africa's biodiversity is exceptional. The continent is home to over 70 000 plant species (about a sixth of all plant species globally), 1100 species of mammals (about 17% of the planet's mammals), 2500 birds, 950 amphibians, about 2000 reptiles and 5000 freshwater fish species, not to mention the myriads of invertebrates. Additionally, Africa is home to 8 of the 36 recognised global biodiversity hotspots, 373 wetlands of international importance (Ramsar sites), over 1255 Important Bird and Biodiversity Areas and 1966 Key Biodiversity Areas (KBAs. Africa hosts 20% of the world's rainforest areas, especially the Congo Basin, a 240-million-hectare rainforest spanning eight African countries and supporting the livelihoods of 100 million people in the region" (Bezeng et al 2025 p2).

Bezeng et al (2025) described an African perspective on biodiversity conservation. This continent has the fastest growing human population, and so reaching "30 by 30" (30% of land and ocean protected by 2030) will be a challenge (with less than 20% protected at the moment).

Bezeng et al (2025) offered five recommendations:

i) Accelerate data collection, sharing, and analysis to inform decision-making (appendix 8A).

ii) Capacity build for future generations (eg: training conservation workers).

iii) Expand protected areas.

iv) Improve funding for conservation (eg: private funding).

v) Integrate indigenous and local knowledge into conservation strategies (eg: Community Resource Management Area (CREMA) initiative in Ghana with Murugu

and Mognori communities) (appendix 8B).

Beseng et al (2025) ended on a positive note: "The journey is long and will take time. However, with Africa's abundance of ambitious, young, tech-savvy individuals, the future holds great promise" (p9).

McKenzie et al (2025) stated their concern: "Action by businesses and financial institutions, alongside governments, inter-governmental organisations, civil society and communities, will be vital to halting and reversing biodiversity loss" (p2). They continued: "Businesses and financial institutions have dependencies and impacts on nature that create risks and opportunities to their organisations, including physical, transition and systemic risks" (McKenzie et al 2025 p2).

McKenzie et al (2025) outlined four critical science and technical advances that would help businesses to halt and reverse biodiversity loss:

a) Consensus on metrics to measure change in ecosystems.

b) Regular updated publicly available data on the state of nature.

c) Accounting systems that "structure data, support risk management and create accountability at corporate, ecosystem and national levels" (McKenzie et al 2025 p1). (Also known as "natural capital accounting).

d) Risk assessment approaches that include nature-related risks (appendix 8C).

Purvis (2025) talked of a "satnav" for nature to help in reducing biodiversity loss. "The twin pillars of such a satnav are (i) models to predict expected future outcomes of today's choices; and (ii) rapid feedback from monitoring to enable course corrections and model improvement" (Purvis 2025 p1).

The satnav helps society to find its way to goals that are set around reducing biodiversity loss. "Without a satnav, society will effectively have to try to find its way to the outcome goals by looking in the rear-view mirror that the current headline indicators provide" (Purvis 2025 p1).

Purvis (2025) accepted, however, that "biodiversity change is harder to model than climate change" (p4). Reasons for this include that agreement on key variables

of biodiversity change, and their measurement, are harder. Put simply, climate change targets can be focused on emissions of greenhouse gases, but what is the equivalent for biodiversity loss? Historical time-series data are relatively lacking for biodiversity loss also.

Purvis (2025) ended: "It is often said that we can only manage what we can measure. However, it would be more accurate to say that we can only manage what we can both measure and model. By itself, measurement can tell us that something needs to be done; but deciding what that something is requires an additional ability to project future consequences of alternative choices. A true satnav for nature will further require ongoing monitoring to check that the choice made has the consequences that were expected. While having a satnav is not enough to guarantee reaching the desired destination (as slow progress on climate mitigation makes all too clear), not having one makes it impossible to get there efficiently" (p7).

8.6. APPENDIX 8A - MISINFORMATION ABOUT WIND FARMS

Wind power will be an important part of the transition away from fossil fuels. This will mean more construction of wind farms on- and offshore. Public acceptance and resistance are key.

Winter et al (2024) investigated the belief in scientific misinformation around wind farms. Scientific misinformation was defined as "publicly available information that is misleading or deceptive when compared to the best available scientific evidence and that runs contrary to any scientific consensus or the claims of acknowledged experts in the domain. Defining misinformation as contrarian claims allows for the possibility that there may be grains of truth in some of the claims, that in a philosophical sense objective truth is often unknowable, and that some claims are not falsifiable" (Winter et al 2024 p1).

In particular, four types of misinformation were used in this research - "(1) that decision-makers conspire to mask wind farms' dangers and exaggerate their benefits; (2) that wind farms are detrimental to human health; (3) that they are ineffective; and (4) that they are harmful to the natural environment" (Winter et al 2024 p1).

Over 6000 adults from the USA, the UK, and Australia were presented with sixteen contrarian/misinformation statements (table 8.1), and around one-quarter agreed

with at least half of the claims. These individuals were more likely to have a "conspiracy worldview" (ie: powerful actors secretly acting in the world), and less likely to be pro-environmental.

- The government withholds important information that speaks against the extension of wind energy.
- Contrary to official claims, wind energy is very expensive compared to other energy sources.
- Due to the massive extension of wind energy, hardly any building material is available for housing and only at very high prices.
- The disposal of wind turbines releases more CO2 than is saved by their operation, since many parts cannot be recycled but must be incinerated.

Table 8.1 - Examples of misinformation statements.

8.7. APPENDIX 8B - CONSERVATION GOVERNANCE

The creation of protected and conservation areas (PCAs) around the world has often been imposed on Indigenous Peoples and local communities including their displacement and eviction. "Additionally, its management practices, including militarised enforcement and reliance on Western scientific ontologies, have been criticised for perpetuating colonial and racist legacies... Beyond the moral implications of such social justice concerns, increasing evidence supports the instrumental argument for equitably governing natural resources as a means of ensuring management effectiveness and ecological outcomes of conservation measures" (Dehmel et al 2025 p2).

Equity in this context can be seen as having three dimensions - distribution, procedure, and recognition (Dehmel et al 2025). These dimensions have been operationalised in different ways, and one of these is the "Site-level Assessment of Governance and Equity" (SAGE) tool. This is "a tool for site-level stakeholders and rightsholders to self-assess equitable governance in conservation areas of any governance type and to identify, plan, and implement actions for improvement... It allows different site-level actors to discuss and document their diverging perceptions and opinions of a set of principles covering multiple dimensions of social equity" (Dehmel et al 2025 p3). It is based on multiple-choice questions, and ten principles (eg: "respect for

resource rights and human rights of community members" (recognition dimension); "effective mitigation of negative impacts on community members" (distribution); "fair and effective law enforcement" (procedure)).

Dehmel et al (2025) analysed 37 SAGE assessments from nineteen countries, and found "a large variation in assessment results across the sites" (p2). Overall, "equity assessments tended to be slightly more positive for PCAs governed by and with Indigenous Peoples and local communities than those governed purely by government agencies" (Dehmel et al 2025 p2). Mitigating the impacts on local communities was the biggest challenge. Different actors (eg: decision-makers; users) had different views on the positiveness of PCAs (eg: "conservationists value wildlife more than humans and their property"; "some actors feel only invited when their participation is of interest to protected and conserved area staff"; p10).

The researchers accepted that "because SAGE is conducted only in areas without overt conflict and the sites self-selected to join this study, our findings relate to comparatively uncontentious PCAs. They do not reflect contexts with deep-rooted, overt, or violent conflicts" (Dehmel et al 2025 p13).

8.8. APPENDIX 8C - RISKS

8.8.1. The Dark Side of Resource Subsidies

"Through their movements and migrations, many animals transport resources across ecosystem boundaries and thus fulfil crucial ecological roles by enabling flows of energy and nutrients to different communities" (Subalusky and Twining 2024 p783). There is also a "dark side" to "resource subsidies" (Walters et al 2008) in that migratory animals can transport contaminants in their bodies.

Brandt et al (2024) explored this in a study of the migration of five Pacific salmon species to North America between 1976 and 2015. The movements of Pacific salmon shape ecosystems. "These fish hatch in fresh water and later migrate to the ocean where they gain more than 95% of their biomass. As they return to their place of birth to spawn and die, salmon can carry resources from the ocean hundreds of kilometres inland, where nutrients of marine origin ultimately nourish freshwater and terrestrial food webs, and provide key food sources for Indigenous communities" (Subalusky and Twining 2024

pp783-784). But the salmon also contain contaminants like mercury and chemical compounds in industrial products which came through the marine food web (Subalusky and Twining 2024).

Brandt et al (2024) analysed records from fisheries across Alaska, the Bering Sea and the Pacific Northwest. An average of 119 million salmon per year migrated transporting 14 000 tons of nutrients and contaminants. Higher salmon returns during the study period were estimated to have increased salmon-derived nutrients into the freshwater by 30%, and contaminants by 20%. "These increases were dominated by pink salmon, which are short-lived, feed lower in marine food webs than other salmon species, and had the highest nutrient-to-contaminant ratios. As a result, the delivery of nutrients increased at a greater rate than the delivery of contaminants, and salmon inputs became more ecologically beneficial over time. Even still, contaminant loadings may represent exposure concerns for some salmon predators" (Brandt et al 2024 p875).

For example, bald eagles, and if they consumed the mercury from just 1% of the salmon, "concentrations in their body would just exceed those anticipated to have adverse health effects" (Subalusky and Twining 2024 p784).

8.8.2. Gene Drives To Control Invasive Species

"Invasive mammalian pests are among the greatest threats to global biodiversity and have constituted an unprecedented form of global change. Commensal rodents, including house mice (Mus musculus), have spread throughout the globe, causing significant environmental damage and loss of agricultural productivity. Islands are biodiversity hotspots and are particularly susceptible to the impact of invasive rodents, where they contribute to widespread extinction and endangerment, particularly of migratory bird species, reptiles, and plant stocks that have not evolved with rodents. Current control methods rely principally on the widespread distribution of anti-coagulant rodenticides, an approach that is costly to apply at scale, carries ethical concerns regarding the mechanism of toxicity, and is not species specific, rendering its application feasible only on islands without significant human population, livestock, or sensitive off-target species" (Gierus et al 2022 p1).

Genetic biocontrol technologies, like "gene drives"

(eg: Burt 2003), are a possibility. Gene drives are genetic elements (natural or synthetic) that spread through a population rapidly. For example, faulty copies of female fertility genes could be used with mice (Gerius et al 2022). By altering a gene in the male sperm, say, it will have a greater spread through the population as males mate with multiple females.

However, Gerius et al (2022) commented: "Although genetic biocontrol strategies including gene drives have considerable potential, their development must proceed with utmost caution; be informed by comprehensive risk assessments; have phased testing with a step-by-step approach; and have respectful engagement with stakeholders, publics, and the general community, as well as with regulatory authorities" (p8).

8.8.3. Do Invasive Species Succeed?

There are two main hypotheses predicting if an invasive species will succeed developed from Charles Darwin's ideas on natural selection (Perez-Navarro et al 2025):

i) "Pre-adaptation hypothesis" - Invasive species similar to native species will succeed more than dissimilar invaders due to "shared advantageous characteristics".

ii) "Limiting similarity hypothesis" - Invasive species similar to natives will be less successful than dissimilar invaders due to "competitive exclusion" by natives.

Using thirty-three years of data from a survey of plants in "Cedar Creek Ecosystem Science Reserve", Minnesota, in the USA, Perez-Navarro et al (2025) found support for both hypotheses depending on how similarity is measured.

8.9. REFERENCES

Aguirre-Gutierrez, J et al (2025) Tropical forests in the Americas are changing too slowly to track climate change Science 387, p1057 & eadl5414

Balmford, A et al (2025) Sustainable high-yield farming is essential for bending the curve of biodiversity loss Philosophical Transactions of the Royal Society B 380, 20230216

Barrie, R (2024) Consider the ant New Scientist 27th July, p21

Bateman, I.J & Mace, G.M (2020) The natural capital framework for sustainably efficient and equitable decision making Nature Sustainability 3, 776-783

Bezeng, B.S et al (2025) An African perspective to biodiversity conservation in the twenty-first century Philosophical Transactions of the Royal Society B 380, 20230443

Binner, A.R et al (2025) Using the natural capital framework to integrate biodiversity into sustainable, efficient and equitable environmental decision-making Philosophical Transactions of the Royal Society B 380, 20230215

Brandt, J.E et al (2024) Continental-scale nutrient and contaminant delivery by Pacific salmon Nature 634, 875-882

Bridle, J et al (2025) How should we bend the curve of biodiversity loss to build a just and sustainable future? Philosophical Transactions of the Royal Society B 380, 20230205

Burt, A (2003) Site-specific selfish genes as tools for the control and genetic engineering of natural populations Proceedings of the Royal Society B 270, 921-928

Butchart, S.H.M et al (2025) Measuring trends in extinction risk: A review of two decades of development and application of the Red List Index Philosophical Transactions of the Royal Society B 380, 20230206

Chevin, L-M & Bridle, J (2025) Impacts of limits to adaptation on population and community persistence in a changing environment Philosophical Transactions of the Royal Society B 380, 20230322

Daru, B.H (2024) A global database of butterfly species native distribution Ecology 106, 1, article e4462

Dehmel, N et al (2025) Insights from equitable governance assessments in conservation areas around the world Conservation Biology (https://conbio.onlinelibrary.wiley.com/doi/10.1111/cobi.70101)

Duran, A.P et al (2020) A practical approach to measuring the biodiversity impacts of land conversion Methods in Ecology and Evolution 11, 8, 910-921

Eyres, A et al (2025) LIFE: A metric for mapping the impact of land-cover change on global extinctions Philosophical Transactions of the Royal Society B 380, 20230327

Fairbrass, A.J et al (2025) Recording gaps in marine evidence with a natural capital lens Philosophical Transactions of the Royal Society B 380, 20230214

Gibb, R et al (2025) Towards a “people and nature” paradigm for biodiversity and infectious disease Philosophical Transactions of the Royal Society B 380, 20230259

Gierus, L et al (2022) Leveraging a natural murine meiotic drive to suppress invasive populations Proceedings of the National Academy of Sciences, USA 119, 46, e2213308119

Gomulkiewicz, R & Holt, R.D (1995) When does evolution by natural selection prevent extinction? Evolution 49, 201-207

Gross, C.P et al (2025) A global biogeographic regionalisation for butterflies Philosophical Transactions of the Royal Society B 380, 20230211

Holt, B.G et al (2013) An update of Wallace's zoogeographic regions of the world Science 339, 74-78

Ledger, S.E.H et al (2023) Past, present and future of the Living Planet Index NPJ Biodiversity 2, article 12

Locatelli, B et al (2025) Intertwined people-nature relations are central to nature-based adaptation to climate change Philosophical Transactions of the Royal Society B 380, 20230213

Loh, J et al (2005) The Living Planet Index: Using species population time series to track trends in biodiversity Philosophical Transactions of the Royal Society B 360, 289-295

Mace, G.M (2014) Whose conservation? Science 345, 1558-1560

Mace, G.M et al (2018) Aiming higher to bend the curve of biodiversity loss Nature Sustainability 1, 448-451

Mace, G.M (2019) The ecology of natural capital accounting Oxford Review of Economic Policy 35, 1, 54-67

McKenzie, E.J et al (2025) Science and technical priorities for private sector action to address biodiversity loss Philosophical Transactions of the Royal Society B 380, 20230208

McRae, L et al (2025) The utility of the Living Planet Index as a policy tool and for measuring nature recovery Philosophical Transactions of the Royal Society B 380, 20230207

Perez-Navarro, M.A et al (2025) Evidence for environmental filtering and limiting similarity depends on spatial scale and dissimilarity score Ecology 106, e70244

Purvis, A (2025) Bending the curve of biodiversity loss requires a "satnav" for nature Philosophical Transactions of the Royal Society B 380, 20230210

Reyers, B & Bennett, E.M (2025) Whose conservation, revisited: How a focus on people-nature relationships spotlights new directions for conservation science Philosophical Transactions of the Royal Society B 380, 20230320

Rodrigues, A.S.L (2025) Accounting for functionality in the identification of global conservation priorities: Promises and pitfalls Philosophical Transactions of the Royal Society B 380, 20230209

Subalusky, A.L & Twining, C (2024) Salmon's moveable feast of food and contaminants Nature 634, 783-784

Wallace, A.R (1876) The Geographical Distribution of Animals Cambridge: Cambridge University Press

Walters, D.M et al (2008) The dark side of subsidies: Adult stream insects export organic contaminants to riparian predators Ecological Applications 18, 8, 1835-1841

Williamson, J et al (2025) Clustered warming tolerances and the non-linear risks of biodiversity loss on a warming planet Philosophical Transactions of the Royal Society B 380, 20230321

Winter, K et al (2024) Public agreement with misinformation about wind farms Nature Communications 15, article 8888

9. FIRE REGIME CHANGES

9.1. INTRODUCTION

Wildfire patterns are changing in recent years with more extreme cases in high-latitude Northern Hemisphere areas (eg: North America), but less fire activity in traditional fire-prone areas (eg: Brazil) ("a trend largely attributable to anthropogenic modifications of land use patterns and fire management practices"; Shen et al 2025 p1).

Shen et al (2025) asserted: "For the first time in Earth's history, human activity may rival or surpass natural forces as the primary driver of wildfire dynamics at global scales. The anthropogenic influence manifests not only through altered fire regimes but also more fundamentally through the restructuring of spatio-temporal patterns of biodiversity responses and driving feedbacks at species and ecosystem levels" (pp1-2).

"Fire regime" refers to temporal patterns (eg: how long the fire burns or frequency of fires or fire-burning season), intensities (eg: the average and maximum temperatures), and spatial extents (eg: how many acres affected or new areas vulnerable) (Shen et al 2025).

Fire regime changes (FRC) are crucial to understand as they "may drive responses in ecosystem structure and function across spatio-temporal scales, posing significant challenges to socio-economic adaptation and mitigation capacities" (Shen et al 2025 p1) [31].

The drivers of FRC can be divided into (Shen et al 2025):

a) Climate change - eg: global warming; altered precipitation patterns and drought; lightning occurrence change.

b) Human activity - eg: human ignition; deforestation and expansion of agriculture; fire

[31] Novel or new fire regimes are defined as "deviations from historical fire patterns" (Puig-Girones et al 2025 p2).

suppression policy.

An example of the impact of human land use can be seen in the Eurasian steppes (over 4000 km of grasslands stretching from Eastern Ukraine to the Altai mountains). "Political and economic turmoil following the break-up of the Soviet Union in 1991 triggered abrupt land abandonment over millions of hectares and a collapse of livestock populations. The build-up of vegetation as fuel, rural depopulation and deteriorating fire control led to a rapid increase in fire size, area burned and fire frequency. Fire regimes were also driven by drought, but likely only after fuel had accumulated. Increased fire disturbance resulted in grass encroachment, vegetation homogenisation and decreasing plant species diversity" (Kamp et al 2025 p2).

Puig-Girones et al (2025) observed: "While the causes and consequences of novel fire regimes are contentious, there is a consensus that multiple drivers are in play, including climate change, land use, biotic mixing and their underlying societal causes" (p2).

The type of landscape is a variable. For example, in savannahs flammable grasses encourage frequency fires, while in forests "the closed canopy of fire-sensitive trees provide shade that inhibits flammable grasses and maintains conditions that preclude fires (high moisture and low wind). Under extreme weather conditions, severe fires percolate into forests, inducing a shift to an open state; conversely, long fire-free intervals permit the establishment of trees in the savanna and ultimately the development of a closed forest" (Ramirez et al 2025 p2).

Not only historically wildfire-prone areas getting worse (eg: USA), but new and emerging wildfire-prone areas (eg: UK) is an issue. Little et al (2025b) addressed these situations in workshops in 2023 with wildfire science researchers in the USA and the UK. Three themes emerged as priorities:

i) Understanding and predicting fire behaviour and impacts - eg: fire danger rating systems are based on data from the 1970s, and so may be out of date.

ii) Increasing resilience to fire (both human and ecosystems).

iii) Understanding the impacts of fire on the atmosphere, climate, and human health.

Historical data can help in understanding changes in fire regimes. For example, Segura-Garcia et al (2025) reported data on the Brazilian Cerrado region between 1985 and 2020. This is "a heterogeneous region of open ecosystems adapted to fire intermingled with patches of woody growth-forms, with high levels of biodiversity and endemism. In recent decades, land conversion and human activities have proliferated across the Cerrado, losing about half of its original area. These changes, coupled with climate change, are altering its fire regimes with uncertain, but possibly adverse, consequences for Cerrado ecosystems" (Segura-Garcia et al 2025 p1). Comparing the periods of 1985-1993 to 2012-2020, fire activity in the southern areas had "substantially decreased", while in the centre and north it had "increased or remained high over time" (p1). The whole area was divided into 30 km grid cells for analysis purposes.

Two forces worked in tension over the study period - human activity (eg: deforestation; agriculture) and reduced fire activity, while climate change increased fire sizes and frequency in areas of remaining vegetation.

9.2. DRIVERS

Gan (2025) noted: "Alleviating wildfire effects requires in-depth understanding of what propels them, which informs better assessment of risks and consequential societal impacts" (p22). The ignition and behaviour of a fire, and its effects on the burned area are key measures (Gan 2025).

Historical fire data allow the development of predictive models of the effects, particularly in locations where there is not history of such fires.

Wang, W et al (2025) developed a model for Canada based around three categories of drivers - weather, topography, and fuel. "For example, the fuel category included indicators for vegetation type, biomass, crown closure (blocking of sunlight from reaching the forest ground), tree height, and coniferous species coverage. Each indicator showed varying degrees of association with burn severity. Among all the factors, fuel aridity, which reflects the abundance and moisture content of flammable vegetative fuels, was determined to be the primary driver for most Canadian forest fires between 1981 and 2020" (Gan 2025 p23). There were differences in drivers in different parts of Canada. For example, "a large increase in burn severity in northern Canada compared with other

regions in Canada. This trend was more notable in years after 2001. Whereas weather condition was the dominant driver of the effect of wildfires in northern Canada, fuel aridity and vegetation type were key drivers of wildfires in southern areas" (Gan 2025 p23).

Jones et al's (2024) analysis of fires in non-tropical regions of the world found that vegetation dynamics (plant growth based on weather and soil conditions), and weather were key drivers in the 21st century. "This is in contrast to their identification of human activities — such as deforestation and land fragmentation — as the primary drivers of fire carbon emission in the tropical and sub-tropical regions" (Gan 2025 p23).

From US data, Balch et al (2024) highlighted "fire growth rate" as important - ie: "fast fires" (burning more than 1620 hectares per day; Gan 2025), though rare, cause most infra-structure damage. It was found that "weather and vegetation type dictated the fire growth rate, although human factors, such as arson and downed power lines, may also have contributed to fast fires. A single factor could also cause various effects over time. For example, an increase in precipitation or atmospheric moisture decreased immediate fire risk but could stimulate vegetation growth and accumulate fuel that, if ignited, could yield a more severe fire in the future" (Gan 2025 p23).

Little et al (2025a) found that "persistent positive anomalies" (PPAs) were upper-air circulation patterns associated with wildfires in Europe in the 21st century (2001-2021).

"In the Northern Hemisphere mid-latitudes, surface weather is driven by the west-to-east progression of synoptic-scale weather systems. Synoptic scale refers to atmospheric circulation conditions operating over time periods of approximately 2–10 days and spatial scales from hundreds to thousands of kilometres. Anti-cyclonic blocking highs and ridges are areas of high pressure that are near stationary and disrupt the usual zonal airflow for an extended period, leading to hot, dry surface weather. Where these systems persist, they can lead to extreme events such as heatwaves and drought. Persistent positive anomalies (PPAs) in 500 hPa [hectopascal] geopotential heights are associated with a range of blocking patterns, characterised by weakened or reversed zonal flow and persistent, large positive anticyclonic anomalies. Warming and drying of descending air parcels during PPAs result in extreme surface temperatures, which

may be amplified by land–atmosphere feedbacks including soil moisture deficits and snow cover changes" (Little et al 2025a pp1-2).

PPAs link to wildfires specifically in the creation of dry fuel with extreme surface temperatures as well as impacting the fire once started (eg: descending warm, dry air trapping smoke at the surface and leading to poor surface air quality).

Little et al (2025a) found that the area burned was highest up to one week following PPA presence, and wildfires were 2-3 times more likely overall within a PPA. In summary: "PPAs are significant drivers of extreme fire weather and wildfire activity across Europe and their importance relative to other processes increases latitudinally from Southern to Northern Europe. Europe-wide, all regions were more likely to experience extreme fire weather and enhanced wildfire activity for all months between March and October for the years between 2001 and 2021, inclusive (except Eastern Europe wildfires in April)" (Little et al 2025a p7).

Attempts have been made to characterise "fire weather" (eg: temperature, humidity, precipitation, wind speed) and fire activity (eg: "Canadian Fire Weather Index System", "McArthur Forest Fire Danger Index" in Australia, "National Fire Danger Rating System" in the USA). But even with such indices, "a direct statistical or mathematical relationship between a specific fire weather measurement and fire activity is rarely found (Wang, X et al 2025 p1).

The concept of "spread day" (eg: Podur and Wotton 2011) is another possible predictor. "Fires burn most of their areas within a few days of extreme fire weather conditions, regardless of how long the actual fire durations were, and such days are called the spread days. A power law relationship exists between fire duration and size only when the duration is measured as the number of spread days, and the potential maximum number of spread days also shows the prediction power of annual area burned and fire frequency. However, there is still no common standard for how to identify a spread day during the lifetime of a fire. Two aspects of identifying a spread day are critical to both academic research and fire management practice: one is the actual fire growth and the second is the fire weather thresholds to separate a spread day from a non-spread day" (Wang, X et al 2025 p2).

Wang, X et al (2025) applied spread day to data from forested areas of Canada between 2001 and 2021. The aim

was to establish how extreme fire weather needs to be for a spread day to occur. There were differences depending on the season, and the type of ecozone. Fire weather conditions did not have to be "very extreme" for a spread day to occur (ie: median fire weather conditions).

Pausas et al (2025) applied an evolutionary framework to understanding the drivers of fires - ie: bottom-up or top-down. This is "whether species determine the environment (bottom-up) or if environments shape plant traits (top-down)... Many forests are subject to either frequent low-intensity surface fires or less frequent but high-intensity crown fires. What are the ultimate factors controlling these fire regimes? The top-down model proposes that environmental factors controlling productivity and ignitions shape fire regimes; the bottom-up model attributes them to different plant assemblies" (Pausas et al 2025 p1). Analysis of different tree species in Europe and North America by these researchers suggested a top-down model - ie: "the ultimate cause of divergent fire regimes between continents is the difference in environmental conditions that generate different evolutionary dynamics rather than the difference in assemblies due to biogeographical history" (Pausas et al 2025 p4).

9.3. PEOPLE

The selective media coverage of extreme wildfires "has led to a widespread but mistaken belief that wildfires are universally and increasingly directly exacerbated by human activities" (Harrison et al 2025 p1). But Harrison et al (2025) argued that a historical perspective of wildfires provides "a more nuanced picture of the influence of people in fire regimes" (p2). These researchers used palaeo-environment evidence (eg: sediment records) as well as direct observation of current fire events, and modelling. They stated: "Statistical and modelling analyses show no discernible impact of hunter–gatherer communities, and even the time-transgressive introduction of agriculture during the Neolithic had no impact on fire regimes at a regional scale. The post-industrial expansion of agriculture was an important influence on fires, but since the late 19th century, the overwhelming influence of humans has been to reduce fire through progressive landscape fragmentation rather than through influencing ignitions" (Harrison et al 2025 p1).

In terms of recent fires and other studies, Balch et al (2017), for instance, estimated that over 80% of the total number of fires in the USA between 1992 and 2012 were ignited by people. But these accounted for less than half of the total burnt area (Harrison et al 2025).

Known ignition causes is not always the case. In California between 2012 and 2018, for example, half of known ignitions were caused by lightning and half by people, and the former caused a greater burnt area (Hantson et al 2022).

It must be remembered that humans benefit from fires. "Some fire users, including Indigenous and local Peoples, burn to meet small-scale livelihood objectives and/or for related cultural reasons (eg: for hunting, pastoralism, cropping, fuel management or ceremony). Larger landowners and commercial enterprises also use fire (eg: in land clearance for industrial agriculture, forestry or cattle ranching). Some state agencies and non-governmental organisations (NGOs) also conduct prescribed burning (eg: for ecosystem or fuel management)" (Smith et al 2025 pp1-2).

The "Global Fire Use Survey" (GFUS) questioned individuals involved in fire management (Smith et al 2025). The online survey in 2022-2023 recruited 311 respondents involved in researching or working with/on fire. It found that more widespread burning is done by local people than commercial land users, state agencies, and NGOs. "While ecological outcomes, wildfire risk and greenhouse gas emissions are usually central in global fire assessments, the GFUS makes clear that policymakers cannot ignore the economic and cultural benefits of fire use to rural populations globally" (Smith et al 2025 p9).

In terms of controlled burning, "[R]egulatory restrictions are the most common policy interventions targeting fire use but are ineffective in achieving their aims in regions with higher burned area. While community-led governance of burning is rarer, it was deemed more effective than restrictive policy interventions, particularly in regions with higher burned area" (Smith et al 2025 p1).

Nearly three-quarters of the GFUS sample were researchers, and the highest response was in North America. The researchers admitted that the GFUS was "strongly limited in its geographical scope and in the voices it represents. Survey responses clustered in regions of the Global North with significant fire management challenges, but regions of the world with the most burned area, particularly in sub-Saharan Africa,

were under-represented. Researchers dominated among respondents, and those fire practitioners that responded tended to work for state agencies or companies, rather than using fire within small-scale livelihoods or for cultural reasons" (Smith et al 2025 p9). But it was the "first global effort" to collect data on current fire use and "expert knowledge" (Smith et al 2025).

9.4. PLANT-ANIMAL INTERACTIONS

Some plants and animals have evolved in ecosystems with regular natural fire events. "In fire-prone ecosystems, plant population dynamics are influenced by morphological traits such as flammability, branch retention or shedding, and bark thickness; by reproductive traits including post-fire reproductive mode, post-fire flowering and serotiny; and by life history parameters including survival and recruitment rates. For animals, key factors influencing fire-related population dynamics include survival, habitat requirements, movement, dispersal and behaviour (eg: taking refuge in burrows or rock fissures)" (Charles et al 2025 p2).

How will the changes in fire regimes impact plants and animals, and particularly their interactions? The answer to this question will depend upon an understanding of specialised plant-animal interactions and fire.

Charles et al (2025) performed a literature review on this topic (finding 25 relevant articles). Fifty-two cases where fire influenced specialised plant-interactions were found, which could be categorised as:

i) Mutualisms - eg: pollination; dispersal; food provision.

For example, sap beetles that live in the stem of dwarf palms in the shrublands of Spain are protected from fire, and are pollinators of the palms.

ii) Commensal interactions - eg: habitat provision.

For example, Australian birds dependent on certain types of trees for habitat may be absent from an area after a fire depending on how long the trees take to regrow. Increasing fires would mean the absence of the birds from an area for longer periods, if not entirely.

iii) Antagonistic interactions - eg: seed predation; parasitism.

For example, squirrels that survive on nuts are at

risk if the tree takes an long time to produce nuts after a fire.

9.5. FIRE MANAGEMENT AND BIODIVERSITY

"Understanding fire regimes and how they are changing is important because they modulate biodiversity across scales — from species to whole ecosystems. In forests and woodlands with frequent high-intensity fires, plants have evolved fire-adaptive traits such as serotiny (retention of seeds on mature plants), smoke-induced germination and post-fire resprouting. Fire regimes in these habitats can maintain open-canopy habitats, promoting diverse grass species favoured by sunlight and, in turn, a variety of insects, land snails and birds that thrive in fire-created niches. Fire patterns can also contribute to maintaining a diversity of ecosystems; for example, reduced fire frequency can transform open tropical savannas into closed forests" (Puig-Girones et al 2025 p2).

The concern is primarily with more frequent fires, but less frequent fires or fire suppression can lead to fuel accumulation, and so when wildfires do occur they are more intense and severe (Puig-Girones et al 2025).

Puig-Girones et al (2025) outlined two main fire management practices in fire-prone landscapes. One approach is to re-establish historical (pre-industrial) practices, and those of Indigenous groups. "However, re-establishing historical fire patterns in changing landscapes and climates without historical analogues is challenging" (Puig-Girones et al 2025 p2).

Alternatively, fire regimes are defined based on the type of landscape - ie: context-dependent - "varying with ecosystem type, historical fire regime, land management, conservation goals, and societal objectives and constraints" (Puig-Girones et al 2025 p2).

Both these practices make use of two types of planned burning: "(i) broadcast burning, applied more uniformly over large areas (from hundreds to thousands of hectares) and emphasising high coverage of burnt areas across the landscape; and (ii) patch-mosaic burning, conducted more heterogeneously at smaller scales (from less than a hectare to hundreds of hectares) and emphasising the creation of patchiness and variation in burnt areas" (Puig-Girones et al 2025 p3).

Fire management in relation to biodiversity

conservation has four main challenges, according to Puig-Girones et al (2025):

i) Setting objectives - "Effectively protecting biodiversity under novel fire regimes demands knowledge of ecosystems, as well as societal needs. Policymakers and practitioners often use a range of information to formulate fire management objectives, including spatial planning tools, such as habitat and species distribution maps, conservation plans, local knowledge about forest management and historical fire records. Indigenous and traditional fire knowledge, as well as Indigenous-led initiatives, are also increasingly recognised. Engaging a wide range of community stakeholders provides valuable perspectives and helps clarify ambiguities for policymakers on the potential implications of their decisions" (Puig-Girones et al 2025 p4).

ii) The complexity of fire-biodiversity relationships - "Setting ecological burn objectives is challenging due to the need to consider all species involved, not just a select few. A meta-analysis on the effects of prescribed burning effects on biodiversity found difficulties in detecting consistent relationships due to study heterogeneity and insufficient comparability and reporting across studies. Limited information often leads to burning practices that prioritise more easily measured taxa, such as plants, while animals and their habitats are often neglected" (Puig-Girones et al 2025 p3).

iii) Uncertainty about past fire patterns and also future ones - Issues include too frequent or not frequent enough fires for wildlife, the "right" kind of fire, and the timing of fires.

iv) Creating landscape types that meet biodiversity goals - "Generating adequate fire mosaics, including variation in patch size, connectivity and time-since-fire distribution, is also difficult due to insufficient understanding of the ecological effects of different mosaics, contributing to management strategies that may not be fit for purpose" (Puig-Girones et al 2025 p4).

One way to view the objectives of fire management is via a series of trade-offs. For example, reducing the risk of wildfires to human communities versus suppression of natural fire regimes, or benefit grazing animals by removing certain shrubs versus help the spread of

invasive species (Puig-Girones et al 2025).

Puig-Girones et al (2025) ended: "Effective fire management under novel fire regimes requires an evidence-based approach. Biodiversity-focused fire management must recognise fire's ecological role, adapting strategies to mimic natural or historical fire regimes while accounting for novel conditions driven by rapid environmental changes" (p8).

9.6. REFERENCES

Balch, J.K et al (2017) Human-started wildfires expand the fire niche across the United States Proceedings of the National Academy of Sciences, USA 114, 2946-2951

Balch, J.K et al (2024) The fastest-growing and most destructive fires in the US (2001 to 2020) Science 386, 425-431

Charles, F.E et al (2025) The influence of changing fire regimes on specialised plant-animal interactions Philosophical Transactions of the Royal Society B 380, 20230448

Gan, J (2025) Disentangling the drivers of wildfires Science 387, 22-23

Hantson, S et al (2022) Human-ignited fires result in more extreme fire behaviour and ecosystem impacts Nature Communications 13, article 2717

Harrison, S.P et al (2025) Climate, vegetation, people: Disentangling the controls of fire at different timescales Philosophical Transactions of the Royal Society B 380, 20230464

Jones, M.W et al (2024) Global rise in forest fire emissions linked to climate change in the extra-tropics Science 386, eadl5889

Kamp, J et al (2025) Collapse and recovery of livestock systems shape fire regimes on the Eurasian steppe: A review of ecosystem and biodiversity implications Philosophical Transactions of the Royal Society B 380, 20240062

Little, K et al (2025a) Persistent positive anomalies in geopotential heights drive enhanced wildfire activity across Europe Philosophical Transactions of the Royal Society B 380, 20230455

Little, K et al (2025b) Priority research directions for wildlife science: Views from a historically fire-prone and an emerging fire-prone country Philosophical Transactions of the Royal Society B 380, 20240001

Pausas, J.G et al (2025) Are fire regimes the result of top-down or bottom-up drivers? Philosophical Transactions of the Royal Society B 380, 20230447

Podur, J & Wotton, B.M (2011) Defining fire spread event days for fire-growth modelling International Journal of Wildlife Fire 20,

4, 497-507

Puig-Girones, R et al (2025) The use of fire to preserve biodiversity under novel fire regimes Philosophical Transactions of the Royal Society B 380, 20230449

Ramirez, D.P et al (2025) Fire-driven alternative vegetation states across the temperate Andes Philosophical Transactions of the Royal Society B 380, 20230509

Segura-Garcia, C et al (2025) The fire regimes of the Cerrado and their changes through time Philosophical Transactions of the Royal Society B 380, 20230460

Shen, Z et al (2025) Novel wildfire regimes under climate change and human activity: Patterns, driving mechanisms and ecological impacts Philosophical Transactions of the Royal Society B 380, 20230446

Smith, C et al (2025) A global expert elicitation on present-day human-fire interactions Philosophical Transactions of the Royal Society B 380, 20230463

Wang, W et al (2025) Canadian forests are more conducive to high-severity fires in recent decades Science 387, 91-97

Wang, X et al (2025) When is fire weather extreme enough for active fire spread in Canada? Philosophical Transactions of the Royal Society B 380, 20230465

10. ACOUSTIC MONITORING OF BIODIVERSITY

10.1. INTRODUCTION

Martinez-Medina et al (2025) began: "Tropical ecosystems are the most biologically diverse regions on the planet, serving as natural laboratories where scientists have long posed and evaluated fundamental questions in ecology and evolution. However, these ecosystems are increasingly threatened with habitat loss, conversion and climate change, leading to unprecedented rates of biodiversity loss, including extinction of species that are still undescribed" (p1). One tool for understanding such ecosystems is acoustic monitoring.

"Initially developed for marine environments, passive acoustic techniques have since been adapted for terrestrial and freshwater ecosystems, allowing researchers to detect species' presence, analyse animal behaviour and assess ecological questions through soundscapes. Animal-generated sounds provide invaluable insights into communication, social structures and ecological interactions that might otherwise be difficult to observe, particularly in the dense vegetation and towering canopies of tropical forests" (Martinez-Medina et al 2025 p1). Add on top the use of machine learning to analyse the data, and so large-scale monitoring programmes are possible.

"Furthermore, the increasing accessibility of acoustic monitoring tools in tropical countries has encouraged broader participation from local researchers, conservation practitioners and even participatory scientists, fostering more inclusive and regionally driven conservation efforts. The involvement of local communities in data collection and interpretation not only enhances conservation initiatives but also strengthens the connection between science and traditional ecological knowledge" (Martinez-Medina et al 2025 p1).

Martinez-Medina et al (2025) introduced a special issue of the journal "Philosophical Transactions of the Royal Society B" on acoustic monitoring of tropical ecosystems.

10.2. EXAMPLES OF RESEARCH

Passive acoustic monitoring (PAM) "involves deploying autonomous acoustic sensors or recording devices to capture sounds produced by vocal animals, natural events or anthropogenic activities. By studying these sounds, researchers can identify specific species, monitor biodiversity, study animal behaviour and assess environmental changes without the need for human observers. PAM is a valuable tool for monitoring species that use sound for communication, particularly avian species. It offers significant advantages over visual surveys for studying loud yet elusive species that are rare and difficult to observe visually, as these species can be identified over long distances using sound" (Nguyen Chi et al 2025 p1).

It can be used to study all animals or specific ones in an area. For example, Howells et et al (2025) used PAM to record all insects calling in an area in the eastern Brazilian Amazon over two years. This was classed as "an ecoacoustic approach to survey biodiversity" (Howells et al 2025 p1) [32]. Continuous recording at three sites was made during 2018 and 2019 (a total of 3972 hours of recordings).

It was found that insect calling activity showed both seasonal and daily cycles. Peak acoustic activity was between July and September (the dry season), and daily between 20.00 and 05.00 hours (ie: darkness).

In the water environment, Barroso et al (2025) used PAM and AI to classify fish sounds at rocky reefs in Arraial do Cabo, Rio de Janeiro, Brazil.

In relation to birds, Ramesh et al (2025) found that vocal activity in the Western Ghats, India, was significantly higher at dawn than dusk using PAM. Specifically, vocal activity was higher among bird species that were highly territorial, and that were omnivores (table 10.1). Acoustic data were collected at 43 sites in the rainforest in the Valparai plateau between June and October 2020.

An example of PAM and a particular species is Nguyen Chi et al's (2025) continuous recordings in a nature reserve in Vietnam for 4-5 days at forty different times in 2021 and thirty times in 2023. The objective was to record the calls of the crested argus, which is a

[32] Riede and Balakrishnan (2025) discussed more generally the ecoacoustic approach with tropical insect conservation.

- "Acoustic transmission hypothesis" - air quality and conditions more favourable for calling earlier in the day.

- "Inefficient foraging hypothesis" - calling when light levels low (dawn and dusk) as foraging not possible at these times.

- "Territorial defence hypothesis" - "dawn song is a form of 'extra vigorous keep-out signal' that serves to defend and advertise their territories to prospective males after a period of inactivity at night" (Ramesh et al 2025 p3).

- "Social dynamics hypothesis" - the dawn chorus serves to adjust social relationships between neighbours.

(Source: Ramesh et al 2025 table 1 p3)

Table 10.1 - Four theories for calling at dawn and dusk.

critically endangered bird. "The crested argus is very rare and sensitive to human presence; therefore, surveying using visual observations might not be possible" (Nguyen Chi et al 2025 p2). Machine learning was applied to the acoustic data [33].

Peak calling activity was found at dawn and dusk, and during March and April.

In the case of a critically endangered species, Chirino et al (2025) used PAM in the Veragua Rainforest in Costa Rica over eighteen months to study the calling activity of the lemur leaf frog. Recordings were made between 18.00 and 0.500 hours every day between July 2019 and February 2021 in an area with five experimental ponds. The microphones were placed at two metres above the ground, and seven metres from the ponds. Machine learning was subsequent applied to the data. It was found that weather conditions impacted calling activity. For example, "higher activity of the lemur leaf frog was triggered by increasing humidity independently of temperature, and by accumulated rainfall within the preceding 24 h and by decreased moonlight" (Chirino et al 2025 p1).

Verahrami et al (2025) used PAM in the Nouabale-Ndoki National Park, Congo, to assess the impact of gun hunting on forest elephants. There was evidence of changes in calling activity in areas of gun hunting (eg: increased nighttime calling), and movement away from an area for eight days after gunshots.

[33] Training of machine learning algorithms is a key aspect of their use. Williams et al (2025), for example, used 57 000 reef sounds and fifty times more bird sounds in their training programme.

wa Maina and Njoroge (2025) showed the value of "citizen science" data (compared to PAM and point counts by researchers) in the Mount Kenya ecosystem for monitoring biodiversity (eg: birds, bats and butterflies). However, the researchers admitted "even with the use of multiple methods, our survey still misses rare species known to occur in the Mount Kenya ecosystem, indicating that even the use of multiple methods is not exhaustive" (wa Maina and Njoroge 2025 p1).

10.3. REFERENCES

Barroso, V.R et al (2025) Optimal feature selection and model explanation for reef fish sound classification Philosophical Transactions of the Royal Society B 380, 20240055

Chirino, F et al (2025) Environmental drivers of calling activity in the critically endangered lemur leaf frog, Agalychnis lemur (Hylidae: Phyllomedusinae) Philosophical Transactions of the Royal Society B 380, 20240050

Howells, N et al (2025) Temporal patterns of Amazonian insect acoustic activity Philosophical Transactions of the Royal Society B 380, 20240337

Martinez-Medina, D et al (2025) Tuning into nature: The sonic boost transforming tropical biodiversity research Philosophical Transactions of the Royal Society B 380, 20240044

Nguyen Chi, T et al (2025) Circadian rhythms and the use of transfer learning for critically endangered crested argus Rheinardia ocellata in the Central Highlands of Vietnam: The implications for conservation Philosophical Transactions of the Royal Society B 380, 20240056

Ramesh, V et al (2025) Why is the early bird early? An evaluation of hypotheses for avian dawn-biased vocal activity Philosophical Transactions of the Royal Society B 380, 20240054

Riede, K & Balakrishnan, R (2025) Acoustic monitoring for tropical insect conservation Philosophical Transactions of the Royal Society B 380, 20240046

Verahrami, A et al (2025) Forest elephants modulate their behaviour to adapt to sounds of danger Philosophical Transactions of the Royal Society B 380, 20240051

wa Maina, C & Njoroge, P (2025) Comparing point counts, passive acoustic monitoring, citizen science and machine learning for bird species monitoring in the Mount Kenya ecosystem Philosophical Transactions of the Royal Society B 380, 20240057

Williams, B et al (2025) Using tropical reef, bird and unrelated sounds for superior transfer learning in marine bioacoustics Philosophical Transactions of the Royal Society B 380, 20240280

11. SHIFTING SEAS

"The influences of the ocean on humanity are manifold and complex. While our impacts on the ocean are similarly diverse, one stressor emerges consistently across the globe — extractive harvest. Generalising the impact of people on the oceans across ecosystems and human cultures is difficult, but early hunter-gatherer-fisher populations are understood to have had limited large-scale impacts on marine ecosystems compared to subsequent human periods" (Holman et al 2025a p2). This impact has grown with subsequent generations until the huge pressures on the oceans of modern times.

"Human impacts on marine ecosystems in recent decades have been global and substantial in magnitude. In addition to the peak in fishing pressure, invasive species introductions, habitat alterations and some forms of pollution have all increased or plateaued. Alongside these stressors, human-driven climate change has emerged as a ubiquitous threat. The effects of climate change on ecosystems and biodiversity are increasingly common across marine ecosystems, and interactions between climate change and other stressors, for example, overfishing or eutrophication, are likely to further degrade ecosystems" (Holman et al 2025a p3).

Roberts et al (2025) explained: "Analyses of the past offer benchmarks from different points in time, inform us of the consequences of particular activities and set the health of our current ecosystems within the context of past ecological and societal changes. They offer insights as to how past societies interacted with and managed ocean resources and their ecological outcomes" (p2).

The situation can be summed up thus: "Never before have the seas faced as much pressure as they are today" (Holman et al 2025a p3). On the positive side, human understanding of past marine biodiversity is "unprecedented", and Holman et al (2025a) introduced a special issue of the "Philosophical Transactions of the Royal Society B" on the topic of "shifting seas". The articles were divided into three groupings:

i) "Marine biogenic archives" - information gained from bones and shells of animals.

Example: Genelt-Yanovskiy et al (2025) performed isotope analysis on specimens of baleen whales and seals collected between 1843 and 1951 in the South Atlantic and around Antarctica, and preserved at a London museum, to

understand the impact of industrial-scale whaling. From the late 1700s to the early 1900s whaling and sealing were major activities. Isotope analysis can give a picture of the nutrients in the bones (ie: what prey was eaten).

Example: Reynolds et al (2025) used growth increments within the shells of a long-lived marine bivalve (Arctica icelandica; common name: ocean quahog) in the North Sea/North Atlantic to cover 600 years up to the present (live and dead-collected specimens used). The variability in the width of the annually formed growth rings in the shells is sensitive to environmental changes (eg: seawater temperature; salinity; atmospheric circulation patterns). Sclerochronologies were constructed, which are "the marine counterpart" to dendrochronologies from tree growth rings.

Example: Schone et al (2025) used periwinkle shells collected from archaeological sites on Orkney, Scotland, and reconstructed water temperatures between the 14th and 19th centuries. Shell oxygen isotope data were analysed.

Example: Yamoah et al (2025) analysed isotopes in 150 bones of cod from northeast Scotland to provide insight about the North Sea over 1500 years. The period 500 to 1800 was stable for cod populations, but the last 200 years have seen overfishing along with stress and changes in diet quality leading to "a restructuring of the North Sea food web" (Yamoah et al 2025 p1).

ii) "Human chronicles of the changing sea" - historical human sources of information (eg: written records).

Example: del Valle et al (2025) reviewed 543 peer-reviewed articles from the field of "historical marine ecology" (HME), covering texts from Roman times to the 20th century. The vast majority of articles (85%) found declines in the studied marine animal populations over time, while only 3% of articles reported increases only (and the remainder a mixture of increases and decreases). But there was a bias in the research towards commercially important species (eg: fishes), and to the Global North in the articles. "For instance, nearly as much research focused on the California Current as the entire Indian Ocean, and 74% of first authors worked in North America and Europe" (del Valle et al 2025 p1).

Historical research is important to establish a "baseline" state of an ecosystem in order to compare the current situation. "Understanding declines is complicated by the 'shifting baseline syndrome' [eg: Pauly 1995] — assessment errors that occur when a modern system is compared against previous reference points that are assumed to represent the 'natural' or 'baseline' state of the system, when in fact, these baselines are also altered states" (del Valle et al 2025 p1).

Example: McClenachan et al (2025) reconstructed Pacific cod catches across the Bering Sea, Aleutian Islands, and Gulf of Alaska for the period 1864 to 1950 from commercial fisheries data. A catch decline in the 1920s and 1930s was noted [34].

Three drivers of the decline were assessed with different types of data - social changes (eg: changes in demand for cod to eat) (eg: from articles in the "Pacific Fisherman" magazine), overfishing (eg: from US government reports), and climate (eg: 2 °C higher temperature) (eg: from open source ocean temperature data). McClenachan et al (2025) argued for "the importance of understanding long-term drivers of fisheries productivity and the value of linking fisheries and climate histories" (p1).

Example: Hayes et al (2025) used commercial fisheries documents, and information from First Nation people to describe commercial clam fishing's impact on "ancestral sea gardens" in British Columbia between 1882 and 1985. Settler-controlled commercial clam fisheries began in 1882, while Indigenous communities continued with traditional practices. There was "a rapid change in clam tending, harvesting and processing that relied on Indigenous land, knowledge, labour and skill being directed away from traditional harvesting and towards unsustainable catches for commercial gain" (Hayes et al 2025 p1).

"Historical insights can play a crucial role in restoration efforts by identifying ecological baselines and helping support the Indigenous reclamation of ocean spaces and the responsibility to tend them" (p1), argued Hayes et al (2025).

Example: Walther Mendoza et al (2025) used written (table 11.1) and verbal sources on bivalve species along

[34] "In many ways, the collapse of the Pacific cod fishery in the 1930s provides an ocean analogue to the Dust Bowl. This well-known phenomenon in environmental history was a complex social and ecological event, associated with warming in the 1930s. This same warming existed in the ocean, with the 1930s and 1940s as a period of warming around the world" (MClenachan et al 2025 p9).

the coast of the Baja peninsula, Mexico. For centuries Californio Indigenous groups were sustained by the shellfish reefs, and then the arrival of European travellers and colonists and overexploitation concerns as early as the mid-18th century.

- "At this place fish of all kinds were found in such abundance that boats could be loaded with very little labour, and pearl oysters strewed the shores in such unaccountable quantities as to make the beach appear like an immense pavement of brilliant mosaics" (written in 1596).

- "The richest pearl fisheries in the Americas at the present time are those of the Gulf of California, centring around La Paz, and along the outer coast of Lower California, in Mexico" (written in 1911).

- "If all these islands, which contain immense resources in excellent harbours, in minerals, in fisheries, and in pearl-oyster banks, were joined together, they would make a district of country 100 miles long by 80 miles broad, and at a rough estimate they would make one-fifteenth of the superficies of the peninsula" (written in 1868).

(Source: table 1 p7 Walther Mendoza et al 2025)

Table 11.1 - Examples of quotes from written sources used by Walther Mendoza et al (2025).

iii) Sediment records - eg: ancient environmental DNA (eDNA).

The methodology here can be called "deep time approaches" (Roberts et al 2025).

Roberts et al (2025) asked a number of relevant questions (and tried to answer them):

a) "Can we tell from past remains whether animals were more abundant than today?" (eg: "how many fish did the ocean support in the past?").

b) "When did significant, detectable, human influence on the ocean begin, what forms did it take and how has it developed over time?".

c) "What can be learned about the past from the historical observations?".

Example: Sedimentary ancient DNA (sedaDNA) [35]

[35] "SedaDNA forms through the gradual accumulation and preservation of genetic material from

analysis was used by Campbell et al (2025) to understand ecological changes in coastal Australia (specifically, Kelly Hill Cave, Kangaroo Island, South Australia). "This approach holds great potential for investigating shifts in resource and land-use changes, the introduction of non-native species and distinguishing between human and natural impacts on biodiversity" (Campbell et al 2025 p1).

Compared to analysis of ancient pollen and (macro)fossils, sedaDNA's "primary advantage is high taxonomic resolution, allowing the detection of a wider range of species, including those not typically preserved in the fossil record. This improves vegetation reconstructions, particularly where macro-fossils are scarce. Additionally, sedaDNA captures genetic information from diverse organisms such as bacteria, phytoplankton and zooplankton, aiding in reconstructing past ecosystems and biodiversity changes. Challenges include potential contamination from modern DNA complicating results interpretation, and preservation issues influenced by taphonomic processes affecting DNA quality and quantity" (Campbell et al 2025 p2).

Example: Holman et al (2025b) analysed two sediment cores from northern Icelandic shelf seas for ancient eDNA for three millennia (1315 BCE to 1785 CE), and combined this source with local climate and population records, and archaeological data. Despite the growth of the human population in Iceland, there appeared to be a limited impact on marine biodiversity (and specifically, cod and herring).

The researchers accepted an "important caveat in understanding past ecosystem dynamics is that our knowledge of a contemporary ecosystem may not reflect how the ecosystem worked in the past" (Holman et al 2025b p9).

Understanding the oceans in the past can help with future human behaviours (eg: marine restoration initiatives) (Holman et al 2025a).

REFERENCES

Campbell, M.A et al (2025) Using sedimentary ancient DNA in coastal and marine contexts to explore past human-environmental

various organisms, including plants, animals and micro-organisms. These organisms shed cellular debris, faeces, pollen and other biological remnants into their environment over time, which then become integrated into sediment layers" (Campbell et al 2025 p2).

interactions in Australia Philosophical Transactions of the Royal Society B 380, 20240032

del Valle, E et al (2025) Systematic review of global historical marine ecology reveals geographical and taxonomic research gaps nd biases Philosophical Transactions of the Royal Society B 380, 20240279

Genelt-Yanovskiy, E.A et al (2025) Stable isotopic composition of Antarctic and Patagonian marine mammals collected before and during industrial-scale whaling: Assessing the baseline for long-term changes in the marine ecosystem Philosophical Transactions of the Royal Society B 380, 20240227

Hayes, P et al (2025) Ecological legacy of Indigenous dispossession: Disruption of ancestral sea gardens by commercial clam fisheries in British Columbia, 1882-1985 Philosophical Transactions of the Royal Society B 380, 20240277

Holman, L.E et al (2025a) Shifting seas: Understanding deep-time human impacts on marine ecosystems Philosophical Transactions of the Royal Society B 380, 20240026

Holman, L.E et al (2025b) Ancient environmental DNA indicates limited human impact on marine biodiversity in pre-industrial Iceland Philosophical Transactions of the Royal Society B 380, 20240031

McClenachan, L et al (2025) "The fish that stop": Drivers of historical decline for Pacific cod and implications for modern management in an era of rapidly changing climate Philosophical Transactions of the Royal Society B 380, 20240278

Pauly, D (1995) Anecdotes and the shifting baseline syndrome of fisheries Trends in Ecology and Evolution 10, 10, p430

Reynolds, D et al (2025) A sclerochronology defined 600-year baseline of marine dynamics in the North Sea Philosophical Transactions of the Royal Society B 380, 20240036

Roberts, C.M et al (2025) Bones, skulls and baselines - how the past can inform modern marine management, protection and restoration Philosophical Transactions of the Royal Society B 380, 20240043

Schone, B.R et al (2025) Shells of Littorina littorea (Gastropoda) - an archive for palaeoclimate and seasonal shellfish collection in medieval and early Orkney? Philosophical Transactions of the Royal Society B 380, 20240039

Walther Mendoza, M et al (2025) A window to the past and future aquaculture in the Gulf of California: The abundant times of "Meyibo" Philosophical Transactions of the Royal Society B 380, 20240041

Yamoah, A.K.K et al (2025) Investigating long-term trophic stability in North Atlantic cod (Gadus morhua) through nitrogen stable isotope analysis of amino acids Philosophical Transactions of the Royal Society B 380, 20240028