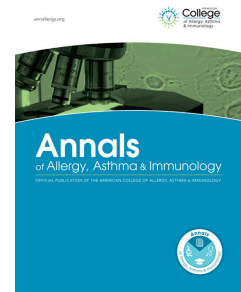


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A Butterfly Flaps its Wings: Extinction of Biological Experience and the Origins of Allergy

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Objective : The grand global challenges of the Anthropocene are interdependent with ample evidence that reduced early-life 'experience' of biodiversity primes for immune dysregulation and a higher propensity low-grade inflammation, increasing the risk of allergy many other later-onset NCDs —also now implicated in the susceptibility to acute inflammation in COVID-19 infection. The objective of this review is to explore links between biodiversity on all scales and allergic disease as a measure of immune dysregulation.

Data Sources : Were identified from PubMed and Web of Science using search terms pertaining to biodiversity, nature-relatedness, allergic disease, microbiome, NCDs, COVID-19 and associated terms.

Study Selections : Studies were selected based on relevance to human health and biodiversity.

Results : Contact with natural environments enriches the human microbiome, promotes regulated immune responses, and protects from allergy and both acute and chronic inflammatory disorders. These important links to eco-psychological constructs of the 'extinction of experience' which indicates that loss of direct, personal contact with biodiversity—wildlife and the more visible elements of the natural world—might lead to emotional apathy and irresponsible behaviors toward the environment.

Conclusion : The immune system is a useful early barometer of environmental impacts, and via the microbiome, a measure of the way in which our current experiences differ from our ancestral past. While we would benefit from further research, efforts to increase direct, personal contact with biodiversity have clear benefits for multiple aspect of physical and mental health, the skin and gut microbiome, immune function, food choices, sleep, physical activity, and promotes environmental responsibility.

Introduction:

Humanity has progressively impacted global environments and planetary systems, to such an extent that our own wellbeing is now under threat¹. In the Epoch of the Anthropocene, it is abundantly clear that all the ‘grand challenges’ are interrelated—including climate change, environmental degradation, biodiversity losses, ecosystems collapse, new infectious contagions, economic instability, social unrest and obscene inequality. For decades, human health has been under threat from a mounting ‘pandemic’ of non-communicable diseases (NCDs)^{2,3}. Although this ‘crisis in slow motion’ has been responsible for vastly more deaths and disease than infectious disease, it has unfortunately not galvanized the same coordinated global efforts for prevention, as we are currently seeing with more imminent acute infectious threats, such as COVID-19. However, given that infectious outbreaks are also inter-related to the same disruptions in planetary health, and that individuals with pre-existing NCDs are far more susceptible to infections such as COVID-19, it is imperative to take a more integrated, cross-sectoral approach to health, recognizing that immune resilience is a common factor. Ultimately, this means directing resources to remediating the underlying causes of these connected challenges, in ways that have co-benefits for the ‘health’ of people, place and planet, in the broadest sense—as also articulated recently by the *Lancet* One Health Commission⁴.

Among all NCDs, the dramatic increase in allergic diseases over the last half century has arguably been one of the most striking measures of the impact of urbanization and adoption of a westernized lifestyle on immune health^{5,6}. The very fact that asthma and allergic diseases develop so very early in life provides a unique opportunity to understand how the interconnectivity between changing environments (at macro, meso, and micro scales) impacts the human immune system from the first moments of development.

Indeed, it has been suggested that the allergy disease epidemic is a “canary in the coalmine” that exposes the impact of modern environmental change, and in particular, the specific vulnerability of the immune system—which wider significance for other aspects of health. The early-life ‘experience’ of the immune system now appears to prime for a propensity for low-grade inflammation and immune dysregulation, increasing the risk of many other later-onset NCDs. In effect, the immune system is a useful early barometer of environmental impacts, and via the microbiome (microorganisms, their genetic material and theatre of activity), a measure of the way in which our current experiences in the Anthropocene differ from our ancestral past⁷. We are also reminded that the smallest elements in our ecosystems, microorganisms, are critical to large scale systems including climate change biology, as highlighted in a recent warning by environmental scientists in *Nature Reviews*⁸.

Whatever label we use for the current global burden of allergic diseases and asthma—epidemic, crisis, scourge—we can all agree that the rates are intolerably excessive. Moreover, there is consensus that genetics cannot explain the rapid shift in the burden of disease and that environmental change has played a primary role, interacting with genetic susceptibilities over time. With good reason, the initial scientific search for causation has largely focused on environmental toxins—the increasing presence of detrimental exposures. However, it is equally important to consider that the absence of protective factors could have commensurate impacts on health.

In this context, this Commentary focuses on the consequences of “biological extinction of experience” considering the evidence that the current burden of allergic disease may be, at least partially, driven by the absence of immune system “experience” with biodiversity. The “canary in the coalmine” was a useful metaphor for illuminating the once subtle concept that the rise in allergic diseases fifty years ago was a forewarning of a larger crisis of NCDs—that allergy may be an “indicator species” for the effects of ill-defined toxins on the risk of

inflammatory disease⁷. But now, there is nothing subtle about environmental change, nor the impact on human health. Indeed, the avian metaphor has become a terrible reality, with concomitant stunning real-world losses of a multitude of bird species over the same period⁹. It is time to understand the direct links between these phenomena, namely the links between biodiversity losses, on all scales, and the current rates of allergic diseases and immune dysregulation.

A Butterfly Flaps its Wings

“[Butterfly] disappearance indicates loss of life. When the last tiger is killed in India, it may hit the headlines, however, shrinkage of biodiversity also takes place in the micro-world close to us, but without notice. Preserving biodiverse life might have a preventive effect on allergy and other diseases of modern civilization”

Tari Haahtela, MD, PhD. *Allergy* 2009¹⁰

The butterfly effect is another oft-used metaphor to explain how the most minute change in local conditions can lead to massive differences in the state of wider systems—through ripple effects across a complex inter-connected web. As first postulated by Edward Lorenz as part of chaos theory, if a butterfly flaps its wings in one location, this tiny change in the atmosphere could, at least theoretically, influence weather at distant, future sites. It's rare for mathematical theories to penetrate the discourse of popular culture, but the butterfly effect has captured the imagination of the public. Perhaps because humans love both metaphors and butterflies.

Finnish physician-scientist Tari Haahtela has dedicated his career to the study of allergic diseases and allergy. He also happens to love butterflies, and as a side-passion, has traveled the globe examining these ‘flying flowers’ and their habitats (**Figure 1**). In 2009, *Allergy*

published a Commentary piece from Dr Haahtela—entitled ‘Allergy is rare where butterflies flourish in a biodiverse environment’¹⁰; for many readers it may have seemed a strange and curious outlier among critically important articles on omalizumab treatment, filaggrin mutations, gene variants, dietary carotenoids, and lipoxin A₄ generation in patients with asthma and/or allergic diseases.

Research conducted by Dr Haahtela's group and others has indicated that westernized urban environments appear to *lack* essential elements, which otherwise provide necessary exposures for the “optimal” development of tolerance against foreign proteins. Notably, these observations came to light with striking differences between immune disease between Finland and neighboring Russian Karelia. Although situated in close geographic proximity, Dr Haahtela's group had discovered strikingly different allergy prevalence in the borderlands of Finnish and Russian Karelia. The higher microbial quantity and diversity in the drinking water and house dust were among the implicated factors associated with a reduced risk of allergic disease in Russian Karelia^{11, 12}.

From his broader vantage, Dr Haahtela also noted that allergic diseases appeared to be rarer in regions where butterfly populations enjoy rich diversity. It was a generalized observation, and although it lacked detailed investigation on butterfly populations *per se*, the plausibility matched evolving knowledge derived from the ‘hygiene hypothesis’; the overarching idea of the original hypothesis¹³, and its related variants¹⁴, that the global rise in allergic disease could be related to diminished opportunity for early life exposure to microbial diversity via antibiotic overuse, smaller family sizes, excessive use of personal and household cleaning products (including detergents), lower exposure to non-pathogenic bacteria in foods (e.g. lowered consumption of fermented foods). According to the hypothesis, the mediator between these environmental changes and immune system training was proposed to be an ‘*abnormally stable microflora*’¹⁴. In essence, a “new normal” microbiome may characterize

the lived experience in urbanized, western industrial nations—reflecting a more generalized decline in biodiversity. In essence, a manifestation of wider “dysbiotic drift”¹⁵ (**Figure 2**).

Dr. Haatela's Commentary served to underscore the potential relevancy of biodiversity at all scales to the work of both clinicians and scientists working in the field of allergy and immunology. More than ten years on, the global collapse of insect species is far more devastating than even imagined. In 2019, Australian researchers reported shocking declines in flying insect populations, and projections indicating extinction of as many as 40% of the world's insect species over the next few decades¹⁶. Butterflies are among the species experiencing devastating declines^{17, 18}. While some insect species are resilient, urbanization is detrimental to both abundance and species richness¹⁹. If these declines continue, the implications are catastrophic; insects are integral in freshwater ecosystems and the entire food web; they are food for countless larger species and perform vital roles such as pollination, pest control and nutrient recycling²⁰.

Perhaps the more relevant question for humanity now pertains to what might happen in a system “if a butterfly *doesn't* flap its wings”. In the realm of asthma and allergic diseases, Dr Haahtela was provoking our profession to consider the answer to that question. It was not his contention that butterflies have unique anti-allergic properties, but rather that this colorful, flamboyant species might be informing us about the relationship between biodiversity in general, and allergic diseases in particular.

Dr Haahtela's original Commentary in *Allergy* has since spawned a larger “Biodiversity Hypothesis” which states that contact with natural environments enriches the human microbiome, promotes immune balance and protects from allergy and inflammatory disorders. It argues that there are nested layers of biodiversity, an outer mantle including soil, water, plant and animal-associated microbiota, and an inner layer including the microbiota of

the skin, lungs and alimentary canal. The outer layer plays a large role in the colonization of the inner layer, and by extension, the operations of the immune system^{21, 22}; given the recent discoveries on the immune-nervous system interface, the natural environment and its outer mantle of biodiversity can potentially extend its reach to the brain through microbe-mediated non-sensory pathways^{15, 23}.

Extinction of Experience

“What is the extinction the condor to a child who has never seen a wren?”

Robert Pyle, PhD, *Horticulture* 1978²⁴

As experts in the field of allergy explored lifestyle factors that might contribute to the rise in allergic diseases (coincident with global urbanization), our colleagues in ecology and psychology expressed concern about the trans-generational loss of cognitive-emotional *experience* with the natural environment. Dr Robert Pyle, an ecologist who specialized in the study of butterflies, coined the term “extinction of experience.”²⁴ He and others worried that loss of direct, personal contact with biodiversity—wildlife and the more visible elements of the natural world—might lead to emotional apathy and irresponsible behaviors toward the environment²⁵.

While more research is needed on the topic of emotional disconnection from nature, several studies support the idea that adults and children in westernized, industrial, and technologically mature nations are spending more time indoors²⁶⁻²⁸ and less time in natural environments, un-tethered to screen-based devices^{29, 30}. There are also indications that losses in local biodiversity and environmental degradation are associated with greater time spent indoors³¹; in Japan, researchers have shown an age-related, cross-generational decline in childhood experiences with indicators of biodiversity³².

Psychologists have developed scales to assess individual levels of awareness of, and fascination with, the natural world; for example, the Nature Relatedness Scale (or separate Nature Connectivity, or Nature Connectedness scales) capture the degree to which subjects in research studies have an interest in making contact with nature. Higher scores on Nature Relatedness have been linked with general health and mental wellbeing^{33, 34}, as well as higher concern for the sustainability of the natural environment^{35, 36}. Intervention research involving children exposed to biodiversity-rich environments indicates that psychological wellbeing and nature relatedness can improve in tandem³⁷. Recently, psychologists have argued that available evidence supports the humans have a basic psychological need for nature relatedness³⁸.

For the most part, the work of professionals in allergic diseases has yet to intersect with the burgeoning nature relatedness and psychological extinction of experience research. But perhaps it's time for the twain to meet. The microbiome revolution may yet deliver on its many therapeutic promises^{39, 40}, but in the meantime it has already transformed how we view the human 'self' and helped erase the imaginary dividing line between the biological and psychological^{41, 42}.

Also sitting at the periphery of mainstream immunology and the study of allergic diseases is a growing body of *in vivo* research typically housed within environmental psychology or physiological anthropology. The study of *shinrin-yoku* (now generally referred to in Japanese studies as simply "forest medicine" or "forest therapy") exemplifies an intriguing line of preliminary evidence that may be of interest to our field. Loosely translated, *shinrin-yoku* means "forest-air bathing" or "absorbing the forest air" and places emphasis on the entire forest experience wherein the individual takes in all the "components emitted from the forest"⁴³. Several small short-term intervention studies (under the *shinrin-yoku* rubric) have shown that spending time in a forest environment vs. an urban built environment can influence stress

physiology, cytokines and other markers of inflammation, immune parameters (e.g. natural killer cells), blood pressure, and heart rate variability⁴⁴ (**Figure 3**).

These '*shinrin-yoku*' studies are limited by small sample sizes and short duration; moreover, given that potential allergens are among the "components emitted" from trees and flowering plants, they cannot be used to make arbitrary decisions about public policy (e.g. planting certain trees or flowers) that might otherwise influence millions of allergy sufferers. Immense planting of new growth cedar (*sugi*) trees in post-war Japan is still considered to be a factor in '*sugi-pollinosis*', considered now to be a national affliction⁴⁵.

On the other hand, the emerging research on psychological extinction of experience and nature relatedness is of importance to the Biodiversity Hypothesis; in particular, inclusion of validated Nature Relatedness scores (identifying personal connection to nature, or lack thereof) might provide further insight into existing epidemiological work. For example, early life familial pet ownership has been linked with reduction in allergic disease^{46, 47}, yet we know little about the psychological underpinnings that might drive pet ownership (such as Nature Relatedness) in the first place. These psychological constructs might be associated with several differing lifestyle variables, differences that might explain the conflicting findings on pet ownership and allergic diseases⁴⁸⁻⁵⁰.

Consider also the several large-scale studies using satellite technology and land use data to link geographic greenness (as a surrogate of trees, shrubs, plant-based biodiversity) with lower rates of wheezing, asthma, respiratory disorders and allergic diseases^{51, 52}. Like pet ownership, the results are conflicting, with some research indicating that living near coniferous forests (and unspecified green space) is associated with worse outcomes in asthma and allergic diseases^{53, 54}. Several studies have found relationships between residential proximity to farms, arable lands, exposure to farm-associated microbiota, and protection

194 against allergic diseases and asthma^{55, 56}. Yet, all farms cannot be painted with the same
195 brush, and efforts to bring protective soil/farm-associated microbiota to clinicians and
196 patients awaits lengthy translation⁵⁷. In the meantime, it may be helpful to know more about
197 the psychological antecedents (beyond the oft-discussed term ‘stress’) that might influence
198 risk, and the cognitive-emotional drivers of the behavior that might place one in contact with
199 biodiversity.

200 Loss of contact with biodiversity can also be imagined in the form of wholesale changes to
201 dietary patterns; it has been argued that for children in westernized nations, the loss of whole
202 plant foods (relatively unprocessed, high in fiber and phytochemicals) from the diet,
203 coincident and the massive encroachment of the “invasive species” known as ultra-processed
204 foods^{58, 59} (which now dominate the nutritional landscape, like weeds, displacing nutrient-
205 dense foods) is also an “extinction of experience”⁶⁰. Displacement of relatively unprocessed
206 foods with ultra-processed foods is another contemporary “disconnection” from nature and
207 the products of biodiversity with direct implications for the gut microbiome⁶¹. Ironically, it
208 appears that animal studies exploring environmental determinants of immune resilience may
209 more accurately resemble human immune responses if they are reared in more natural
210 environments⁶².

211 Ongoing research is currently evaluating strategies to promote nature relatedness in preschool
212 children, and how this may improve dietary habits and exercise among parents and children
213 in the same household⁶³, as well as effect on the microbiome and immune function. Green
214 prescriptions, also known as also known as nature-based solutions, may have significant co-
215 benefits for individuals, community and the wider environment⁶⁴ (**Figure 3**). Similarly,
216 microbiome-inspired green infrastructure provide ecological solutions that promote personal
217 biodiversity through healthier, more biodiverse cities and urban environments⁶⁵. These

place-based environmental strategies will also provide opportunities to study the impact on immune function, especially in children.

In sum, the psychological constructs of extinction of experience and nature relatedness are highly relevant to the work of professionals in our field of allergic diseases; it can be argued that up to now, work within the Biodiversity Hypothesis rubric has involved searching for clues in the ‘immunological extinction of experience’ (e.g. missing microbes) and that such work will be bolstered by looking more deeply at the upstream drivers of behaviors that otherwise put us in contact with biodiversity.

An Exposome Perspective

“[The physician] must master a new science focused on the effects that the total environment exerts on the human condition...knowledge of environmental biology must therefore become one of the essential bases of medical science and practice”

Rene Dubos, 1967⁶⁶.

The complexity of the Biodiversity Hypothesis underscores the need to examine intertwined temporal exposures, including those which at first glance, may seem unrelated to the microbiome-immune system interface. For this reason, many in our field are adopting an exposome perspective. The exposome refers to the study of accumulated “exposures” (that is, physical, sensory, and positive/negative emotional experiences) and their interaction with genes over time. The exposome vantage takes the position that genes alone cannot explain disparities in allergic diseases and asthma, and underscores that individual exposures we have been measuring over the previous decades (e.g., airborne particulate matter, farm-associated microbes, pollen allergenicity, etc.) does not occur independent of the total environment⁶⁷.

The dysbiotic effects of ‘grey space’ in urban environments are multidimensional, from the displacement of greenspace and biodiversity on all scales, to the aggregate effects of inequalities in income, education, social cohesion which differentially affect choices and behaviors that contribute to NCDs⁶⁸. Living in Westernised urban environments has been clearly associated with lower biodiversity in the human gut microbiome^{69, 70}. Moreover, migration to more urbanized regions, such as the USA, is associated with immediate loss of microbiome diversity and function, with displacement of native strains (such as *Prevotella* strains) with US-associated strains (such as *Bacteroides* strains)⁷¹. These effects increase over time and across generations and are compounded by obesity.

Again, there are direct implications for immune resilience and the predisposition for inflammation—not only for the chronic inflammation of NCDs, but also acutely as demonstrated with adverse outcomes with inflammatory responses to the SARS-Cov-2 virus, causing COVID-19⁷². Around 79% of people requiring intensive care for COVID-19 in the USA and 86% of deaths in New York State, as elsewhere around the world, have occurred in those with comorbid NCDs⁷³. There is also speculation that perturbations in the gut microbiome, which are well characterised in many NCDs, may be implicated in the susceptibility to COVID-19⁷⁴. Indeed, even in normal individuals, there is preliminary evidence that difference in the gut microbiome may be associated with proteomic biomarkers and inflammatory cytokines which predict the progression to severe COVID-19⁷⁵. There are now calls to consider the role of lifestyle, diet and the microbiome and the wider exposome in susceptibility and resilience to COVID-19⁷⁶, notably as expression of angiotensin converting enzyme 2 (ACE2), the receptor for entry of the SARS-CoV-2 spike protein, is modulated by environmental and lifestyle factors⁷⁷. This underscores the importance of ecological approaches to environmental and lifestyle health that promote resilience to inflammation across the life course—particularly when the foundations of health are laid⁷⁸. Indeed, for

decades the field of allergic disease has been at the forefront of efforts to underscore the importance of early life ecology for life-long immune health.

While the desire for such an approach has been advocated by experts in allergic diseases for decades⁷⁹, the new era of 'omics' technologies (the ability to simultaneously measure large numbers of biomolecules representing genes, genes expressions, proteins, and metabolites) provides optimism that researchers can identify biological markers of relevance to the total lived experience of individuals (including experiences of parents and grandparents) and entire populations⁸⁰⁻⁸². Such technologies, leveraged by the microbiome revolution, can help us pick apart the influences of dietary choices, stress, sleep, exercise, and psychological drivers of biological outcomes over time. It may finally be possible to reconcile various aspects of total lifestyle, vis à vis disease risk, and place them into the context of larger mediators of Anthropocene-associated 'dis-ease'⁸³. This cannot be achieved without also addressing the value systems that drive the attitudes and actions of individuals and whole societies^{84, 85}.

There is little doubt that in the Anthropocene, conversations concerning medicine, science, and health (at all scales) are political discussions. There is ample evidence that authoritarianism is detrimental to health at all scales. Hence, experts in planetary health have advocated for a broad introduction of political science into medical and health-related graduate programs. This is described in detail elsewhere, but a part of this must be in understanding the corporate and commercial determinants of health⁸⁶⁻⁸⁸.

In addition to numerous important well-established top-down public health and environmental initiatives, solutions will increasingly depend on grass-roots strategies that improve the health of people and places. This empowers communities, engenders optimism, and encourages collaboration between different sectors of government, industry, science and

288 the public ⁸⁹. It also increases opportunities for people to engage in change—personally and
289 collectively.

290 Research shows that most people have clear preference for a more caring and responsible
291 society where progress does not erode warmth and social cohesion, with opportunities to
292 participate and make a difference ^{90, 91}. Optimism promotes engagement, and change is more
293 likely and more meaningful when there are tangible pathways for people to engage, and when
294 we believe that our actions can make a meaningful difference ⁸⁹. At the community level,
295 researchers have found that the mere greening of vacant lots can improve mental health ⁹²;
296 when the topic of environmental factors and a healthy diet is approached from a food justice
297 and power inequity issue, young adults are more engaged and motivated for nutritional
298 change ⁹³. Thus, finding solutions to complex, interconnected problems will require research-
299 based collaboration between academia and the communities they serve.

300 Recent events with COVID-19 have shown how a subcellular molecular event on one side of
301 the planet can have rapid and far-reaching cascading effects across the entire globe. This has
302 heightened the awareness of the connections between personal and planetary health. It has
303 also demonstrated the capacity for a galvanizing coordinated response to an acute threat, with
304 rapid changes to personal and collective behavior for mutual benefit. The same level of effort
305 is now needed to address the NCD pandemic in the post-COVID-19 world, from the first
306 moments of life, when many of these conditions have their origins ⁷⁸. Although the NCD
307 pandemic has occurred on a much slower time frame and seemingly more insidious, the
308 devastated large scale personal, economic and societal impact of these chronic diseases is
309 arguably far more significant and long-lasting—and no less important. Without the same
310 coordinated large-scale efforts to address these conditions, the burden on our societies and
311 our health care systems is unsustainable. This is also ultimately rooted in the way we live—
312 our behaviours, our attitudes and our relationship with the environment that sustains us.

Conclusion

Experts working in the field of allergy should be proud of a progressive legacy of scientific research into the effects of the total environment on human health. Many of our early findings on environmental toxins and microbes have influenced virtually every branch of science and medicine; for example, research in the early days of ‘microflora’ and the immune system/allergy set the table for the burgeoning gut-brain-microbiome field⁹⁴.

However, the interrelated challenges of the Anthropocene, including those directly and indirectly associated with allergic disease, demand interdisciplinary work; in order to truly explore the merits of the Biodiversity Hypothesis, the closed silo system is untenable; our colleagues in psychology, ecology and other fields can help us with a more fine-grained understanding of *how* the disappearance of the Monarch butterfly might be connected, not only to allergic disease, but the myriad of noncommunicable and communicable threats that we face today.

As we reflect on the “butterfly effect” we are again reminded that small changes can have large effects (**Figure 4**), and that we should not underestimate the importance of our contribution as individuals to much-needed global change for greater good.

Figure legends:

Figure 1: Every ecosystem depends on the health of its smaller parts: “A swallowtail butterfly wondering where to go” inspired by a photograph taken by Dr. Tari Haahtela in Portugal on the Atlantic coast (personal communication). Artwork created by Dr. Susan Prescott.

Figure 2: Time is of the essence in addressing ‘dysbiotic drift’: Decades of macroscale biodiversity loss reflected in microscale ecology with direct impact on physical and mental well-being (many mediated via effects on immune health). The longer we delay addressing this, the more we risk irreversible loss of ecosystems.

Figure 3: Multi-dimensional health benefits of nature-based solutions (green prescriptions): Decades of research show health benefits across all domains including mental health (improved mood and sleep, reduce depression, anxiety, PTSD), performance (improved concentration, cognitive performance), reduced inflammation, reduced cortisol/stress responses, reduced asthma and allergies, lower BP, HR, oxidative stress, reduces and buffers NCDs. There is also evidence that increasing urban greenspaces can reduce health inequalities due to social disadvantage. (Artwork created by Dr. Susan Prescott).

Figure 4: Small changes can have large effects. Recent events have shown how small changes in one part of the planet can have global ripple effects as a result of human behavior. We can apply the same principles to affect positive change.

Key Messages:

1. The once subtle effects of urbanisation have escalated into large-scale biodiversity loss which is echoed on the micro-ecological scale with changes in personal and environmental microbial ecosystems. This is directly implicated in the epidemic of allergy and many other noncommunicable diseases (NCDs)
2. Modernity has also been associated with human behavioural changes, with significantly more time indoors, progressively less contact with biodiversity in natural environments, and evidence that reduced early-life ‘experience’ of biodiversity primes for immune dysregulation and a higher propensity low-grade inflammation
3. Efforts to increase direct, personal contact with biodiversity have clear benefits for multiple aspect of physical and mental health, the skin and gut microbiome and immune function. There are also beneficial effects on health behaviours—such as food choices, sleep, and physical activity—that also favourably impact immune function.
4. Increasing nature connectedness is also important for promoting environmental responsibility and value systems that are geared to restoring and preserving biodiversity.

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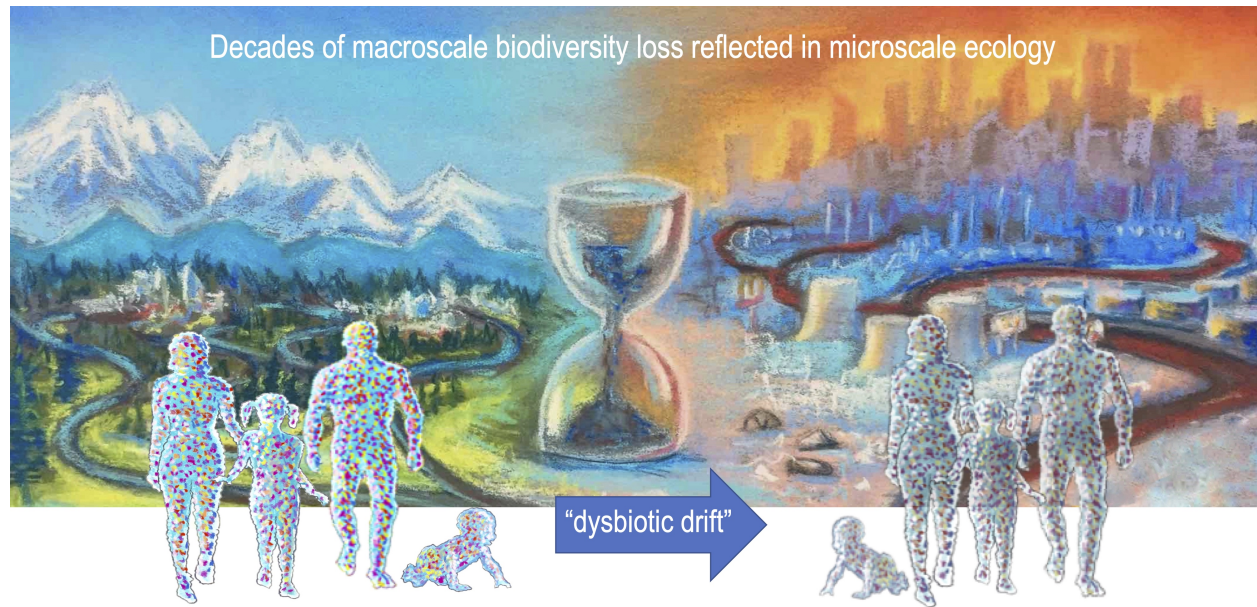
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Ecological extinction: disappearing microbes in westernized populations
Direct impact on physical and mental well-being (via effects on immune health)





Figure legends:

Figure 1: Every ecosystem depends on the health of its smaller parts: “A swallowtail butterfly wondering where to go” inspired by a photograph taken by Dr. Tari Haahtela in Portugal on the Atlantic coast (personal communication). Artwork created by Dr. Susan Prescott.

Figure 2: Time is of the essence in addressing ‘dysbiotic drift’: Decades of macroscale biodiversity loss reflected in microscale ecology with direct impact on physical and mental well-being (many mediated via effects on immune health). The longer we delay addressing this, the more we risk irreversible loss of ecosystems.

Figure 3: Multi-dimensional health benefits of nature-based solutions (green prescriptions): Decades of research show health benefits across all domains including mental health (improved mood and sleep, reduce depression, anxiety, PTSD), performance (improved concentration, cognitive performance), reduced inflammation, reduced cortisol/stress responses, reduced asthma and allergies, lower BP, HR, oxidative stress, reduces and buffers NCDs. There is also evidence that increasing urban greenspaces can reduce health inequalities due to social disadvantage. (Artwork created by Dr. Susan Prescott).

Figure 4: Small changes can have large effects. Recent events have shown how small changes in one part of the planet can have global ripple effects as a result of human behavior. We can apply the same principles to affect positive change.