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The Biophilia Reactivity Hypothesis: biophilia as a temperament trait, or more precisely, a domain specific attraction to biodiversity

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Abstract
E.O. Wilson proposed the concept of biophilia as "the innately emotional affiliation of human beings with other living organisms." While the idea has gained traction in diverse fields, including architecture and horticulture, the few empirical tests of the biophilia hypothesis are either inconclusive or fail to provide support. This paper reviews fundamental flaws in Wilson's biophilia hypothesis and proposes "the Biophilia Reactivity Hypothesis": biophilia as a temperament trait, a theory that offers a falsifiable version of Wilson's original concept.

Keywords Biophilia · Flourishing · Nature · Temperament · Biodiversity

1 Introduction

E.O. Wilson defined biophilia as "the innate tendency to focus on life and life-like processes" (Wilson, 1984), or more specifically related to humans, "the innately emotional affiliation of human beings to other living organisms" (Wilson, 2007). Wilson defined biophilia in 1984 in the book *Biophilia: The Human Bond with Other Species* (Wilson, 1984). *Biophilia* is beautifully written: part memoir, part musing, and part theory, without a single in-text citation.

In the 40 years since its publication, biophilia has become a popular concept in fields as diverse as public health, environmental ethics, and political science—it is particularly influential in architecture, urban planning, and interior design (Yeom et al., 2022). Biophilia has been the subject of musical compositions (Björk, 2011), art exhibits (Marley, 2018), and popular books (Louv, 2008; Williams, 2017). Thousands

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of publications, both popular and scientific, refer to biophilia as though it is a hypothesis that has been rigorously tested, which to date, it has not.

This paper seeks to strengthen the original biophilia hypothesis by proposing the Biophilia Reactivity Hypothesis (BRH), where biophilia is a temperament trait, specifically, a domain-specific attraction to biodiversity.

We divide our discussion into two parts. The first part reviews the paradox that the biophilia hypothesis attempts to explain; puts biophilia in the broader context of sociobiology; highlights the errors in the original hypothesis that led to its rejection in evolutionary biology and biology; reviews the current status of the predictions of the original hypothesis, which are either unsupported, thinly supported, or difficult to falsify; and justifies the effort to strengthen the original hypothesis rather than abandoning it altogether. The second part proposes the BRH and argues that proposing biophilia as a temperament trait more accurately describes what the original hypothesis was trying to capture. It refines the definition of biophilia to refer to humans' attraction to biodiversity, instead of their attraction to "nature," a category that frequently used by researchers but one that is ambiguous and difficult to test. This paper provides a roadmap to test the hypothesis against alternative hypotheses and finally predicts the impact of the BRH on human flourishing.

We conclude that a revised hypothesis exploring biophilia is necessary, given the rise in the popularity of biophilia, which has consequences in several key areas. For example, conservation education assumes people are intrinsically motivated to maintain or increase biodiversity, when recent work has found that this Is not the case (Bowie et al., 2021). Urban planning is increasingly treating access to biophilic areas as a social justice issue, even though these areas might be harmful when treated with herbicides and pesticides (Chawla, 2015). Finally, the benefits of biophilia have mostly been explored in temperate countries in WEIRD (Western, Educated, Industrialized, Rich, and Democratic) populations, and extrapolating these studies' results to tropical developing countries might lead to a sense that these inhabitants are compensated for their economic disadvantages because of their proximity to a biophilic environment, even though their risk of parasitic and zoonotic diseases is higher due to this proximity. Testing the predictions of the BRH has implications for how we understand the impact of the natural world we have lost, how we conserve what is left, and how we can create a future in which all can flourish.

1.1 The nature paradox

For the last 50,000 years, human efforts have been focused on changing the landscape and expanding the built environment. Although modern humans, Homo sapiens, are estimated to have evolved 200,000 to 300,000 years ago (Hublin et al., 2017; McDougall et al., 2005), the cultural and technological evidence for our unique forms of cognition does not appear until 50,000 to 80,000 years ago (Hare & Woods, 2021). Shortly after this cognitive revolution, evidence emerges in the fossil record of widespread landscape alterations by humans.

These changes to the landscape likely began with fire (Wrangham, 2009). Firestick farming, the practice of deliberately burning the landscape to enhance the predictability

and yield of prey animals and edible plants, is thought to be the starting point for human landscape alteration. The oldest evidence of fire stick farming dates back 45,000 years and is attributed to the Australian Aboriginals (Turney et al., 2001). Firestick farming can enhance biodiversity by promoting certain species while suppressing others; this goal is achieved through careful management of patchwork areas, also referred to as mosaics, that create a diverse landscape (Bliege Bird et al., 2008). Once humans could predictably and sustainably manage fire, they could improve habitation, control insects and vermin, and create open landscapes for hunting and travel (Pausas & Keeley, 2009).

Until the transition to agriculture around 10,000 years ago in the Levant, or eastern Mediterranean (Kuijt, 2008), all humans lived as hunter-gatherers. Dwellings were mostly impermanent, organic structures that were abandoned as the group moved. The shift to agriculture marked the rise of sedentary societies. Throughout the Bronze Age, these sedentary societies continued to clear and burn the landscape, constructing permanent structures to such an extent that by 3,000 years ago, perhaps no terrestrial area on Earth remained unaltered by humans (Stephens et al., 2019). In 2008, the global human population turned a corner, as for the first time, more people lived in urban areas than in rural areas. By 2018, 55% of people lived in cities, and estimates project this to reach 68% by 2050 (DESA, 2018).

Not only are we an urban species, we have also become an indoor species. On average, Americans spend 87% of their time indoors and an additional 6% of their time inside cars, totaling 93% of time within the built environment (Klepeis et al., 2001). The trajectory of landscape modification that began at the dawn of our species' evolution has reached escape velocity. We now spend a fraction of our lives outdoors, and this "outdoors" is entirely designed for and constructed by humans.

Now that this transformation has been achieved, a shift has occurred. People are dedicating increasing amounts of time and resources to reconnect with the nature they once sought to suppress. For example, global ecotourism, generally defined as traveling to natural areas (Fennell, 2014), was valued at US$181 billion in 2019, with projected growth to reach US$334 billion in 2027 (Statista, 2021). In addition, people are willing to pay more to live near nature. In urban areas in the U.S., individuals pay 10–30% more for a house with a view of a river or canal (Nicholls & Crompton, 2017). A study of houses in Portland revealed that people are willing to pay nearly $9000 more for a house on a tree-lined street compared to a similar house on a street without trees (Donovan & Butry, 2010). Individuals are also increasingly attempting to incorporate nature into or around their homes. The U.S. horticultural industry, encompassing nurseries, greenhouses, turfgrass producers, landscape designers, and garden centers, experienced growth from $148 billion in 2002 to $196 billion in 2013, with steady growth from 2011 to 2023 (Yue & Knuth, 2022). The total value-added contribution to the Gross Domestic Product (GDP) was $191 billion (Hall et al., 2020).

Not only do people seem to be drawn back to the natural world, there is also evidence that we are suffering without it. "Mismatch" is an evolutionary biology term used to describe a situation in which an evolved trait that was once advantageous becomes maladaptive due to changes in the environment (Li et al., 2018). For instance, our craving for sweetness was advantageous to our health while honey was the only sweetener, but the sudden access to processed sugar has been a major contributor to the obesity epidemic. Evidence for mismatch in human populations includes the rise of diseases

corresponding to increasing urbanization. Cardiovascular disease is the leading global cause of mortality. Although it has multiple causal factors, including genetics, it is also linked to sedentary lifestyles and poor diet and nutrition resulting from urban living (Thelin et al., 2009; Vorster, 2002). The second leading cause of global mortality is cancer, and while like cardiovascular disease, it has many causal factors, rapid environmental changes have led to increased exposure to environmental carcinogens, such as pollution, pesticides, and heavy metals (Belpomme et al., 2007). Respiratory disease, the third leading global cause of mortality, is often connected to pollutants and poor air quality in urban environments (Gouveia et al., 2018; Mokoena et al., 2019).

What is the source of this paradox: that we have conquered nature only to yearn for its return? Or more specifically, why is it that after spending most of our evolutionary history expanding urbanization, we now find our lives cut short because of it?

1.2 The Biophilia Hypothesis and its limitations

Although Wilson published *Biophilia* in 1984, it was not until 1992 that a symposium was convened to refine and test aspects of the biophilia hypothesis. Philosophers, biologists, psychologists, theologians, and evolutionary anthropologists presented their contributions, and the result was *The Biophilia Hypothesis* an edited volume published in 1993 (Kellert, 1995). The "biophilia hypothesis" was proposed as the answer to the urbanization paradox and laid out the argument for evolutionary mismatch.

> When humans remove themselves from the natural environment, the biophilic learning rules are not replaced by modern versions equally well adapted to artifacts. Instead, they persist from generation to generation, atrophied and fitfully manifested in the artificial new environments into which technology has catapulted humanity (Wilson, 2007, p. 32).

However, after the 1992 symposium and the subsequent publication of *The Biophilia Hypothesis*, biophilia as a concept faded from biology and evolutionary anthropology.

Due to the nature of its predictions, these disciplines should have been the theory's natural home. Instead, publications on biophilia in these disciplines flatlined, and have rarely appeared, even to the present day.

Then, around 2008, a surge of publications mentioning biophilia began appearing in satellite fields, notably in architecture and urban planning (Fig. 1). The incorporation of biophilia into these areas is likely due to the late forestry scholar Stephen Kellert, the co-editor of *The Biophilia Hypothesis*, who promoted the notion of biophilic design in several books and who became a recognized authority figure in this area (Kellert, 2012, 2018). More mysterious is the appearance of thousands of publications in the last decade mentioning biophilia in fields such as social studies, public health, philosophy, theology, tourism, and horticulture.

The evolutionary theory behind the biophilia hypothesis was neither critiqued nor tested at the time of publication, nor in the decades that followed. There are several possible reasons for this lack of scientific inquiry. First, biophilia may have been lost in the larger and louder controversy over Wilson's theory of sociobiology. Second, there were flaws in Wilson's evidence for biophilia.

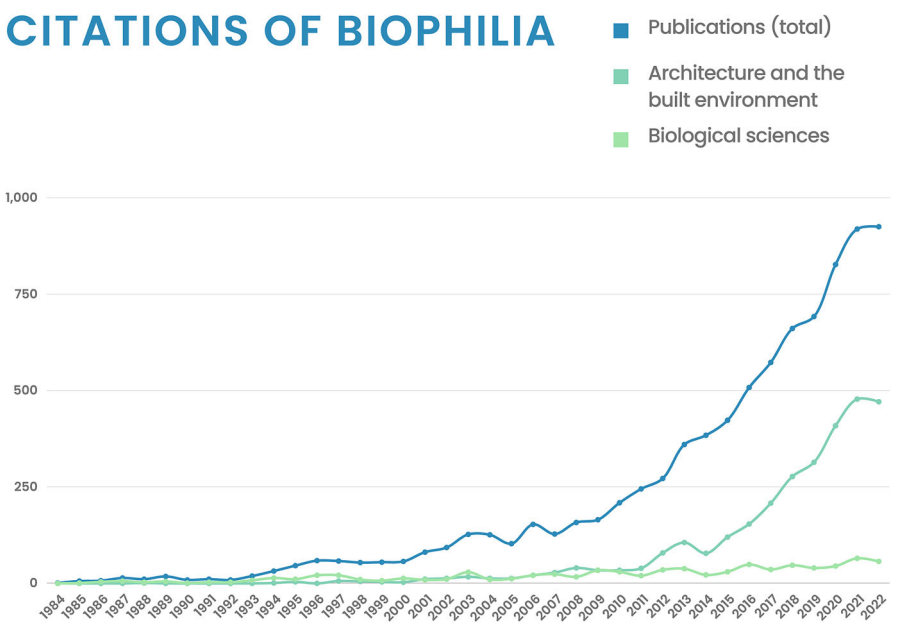

Fig. 1 Number of citations of biophilia in the academic literature 1984–2022. Citations in satellite fields and total citations have increased, but citations in the biological sciences remain few. Sourced from the research database app.dimensions.ai from 11 fields with the most peer reviewed publications and book chapters which mention biophilia

1.2.1 Sociobiology

Biophilia was an extension of Wilson's theory of sociobiology that he described as the "systematic study of the biological basis of all social behavior" (Wilson, 2000). In 1975, Wilson published *Sociobiology; The new synthesis* (Wilson, 2000), and while most of the text was about animal behavior, the first and last chapter addressed human behavior. It is difficult to overstate the impact *Sociobiology* had in public and academic spheres. It was more than an extension of the centuries old "nurture vs nature" debate. *Sociobiology* launched an entire field of study, now called evolutionary psychology and had wide ranging impacts through fields of political science, economics, and social science.

One of the most vocal critics of sociobiology was evolutionary biologist Stephen Jay Gould. Gould critiqued sociobiology within a wider framework of adaptationism, where, for a trait (behavioral or physical) to evolve, natural selection must necessarily have acted on this trait because it conferred an evolutionary advantage (Gould & Lewontin, 1979). Biophilia was likely seen as another adaptationist invention. As for supporters of sociobiology, it is unclear why they did not extend the same support to biophilia. One possibility is that even the most fervent of Wilson's supporters in his field could not overlook several flaws within the original hypothesis and thought it best to ignore biophilia and support other aspects of sociobiology with more solid

empirical footing. The two main flaws in Wilson's argument for biophilia also happen to be his main two pieces of evidence: the savannah gestalt and the serpent myth.

1.2.2 The savanna gestalt

The savannah hypothesis roughly states that "we retain genetically based preferences for features of high-quality African savannas where our ancestors lived when their brains and bodies evolved into their modern forms" (Orians, 2016). The hypothesis is based on the 1925 discovery of *Australopithecus africanus,* a bipedal hominin who appeared to have lived in the savannas of South Africa several million years ago (Bender et al., 2012). As evidence for the savannah hypothesis, Wilson emphasized historic landscape design; "artfully spaced trees and shrubs", and the universal modern attraction to "open tree-studded land on prominences overlooking water" (Wilson, 1984, p. 110).

The savanna hypothesis is problematic for several reasons. The first is that humans did not evolve on the savanna. Subsequent to 1925, discoveries of human fossils revealed that hominids evolved in a variety of habitats. Specifically, in 1994, *Ardepithecus ramidus* was discovered, a bipedal 4.4 million year old progenitor of *Homo* that lived in a densely forested environment of what is now Ethiopia. Our species, *Homo sapiens,* evolved 200,000–300,000 years ago (Hare, 2017). Evidence for the cultural and technological revolution around 50,000–80,000 years ago allowed *Homo sapiens* to colonize almost every ecological niche including glacial tundra, temperate rainforest, coastal scrub, and everything in between (Gibbons, 2020).

Another reason the savanna hypothesis is problematic is that the evidence for contemporary human preference for savanna habitats is minimal. The most cited study for this preference is Balling and Falk (1982), who found that children prefer savanna habitats. However, within this study, the preference did not hold for older children, and the results were otherwise inconclusive. Subsequent empirical studies were unable to replicate savanna preference (Han, 2007; Hartmann & Apaolaza-Ibáñez, 2010; Kiley et al., 2017).

1.2.3 The serpent myth

The Greek word "φιλία" (philía) means affectionate friendship, and in *The Biophilia Hypothesis,* Wilson defined biophilia as "the innately emotional affiliation of human beings to other living organisms" (Wilson, 2007, p. 32).

The problem with this definition is that there are many aspects of the natural world that arouse a range of negative emotions. Even Wilson admits; "[t]he living sea is full of miniature horrors designed to reduce the visiting biologist to his constituent amino acids in quick time" (Wilson, 2007, p. 12).

To address this apparent contradiction, Wilson argues that biophobia is an extension of biophilia and uses what he describes as the universal fear and reverence of snakes as an example: "The mind is primed to react emotionally to the sight of snakes, not just to fear them but to be aroused and absorbed in their details, to weave stories about them" (Wilson, 2007, p. 86). Wilson proposes that since biophobia had already been established as phylogenetically inherited, ontogenic, and universal, the same might be

said for biophilia. However, even at the time of publication of *Biophilia*, biophobia was already a complicated phenomenon. The debate over whether the fear of snakes is a human universal has a long, complicated history, and even now, has not been resolved (Blanchette, 2006; Tipples et al., 2002).

In support of biophobia, researchers have proposed a model in which humans and primates are "prepared to learn to fear" certain stimuli. Laboratory monkeys do not innately show fear of snakes, but they quickly display fear behavior after observing wild monkeys exhibiting fear behavior towards snakes (Öhman & Mineka, 2001). However, studies of children are less clear. Children may pay attention to serpentine shapes and movement, or they may just be focusing on triangular shapes that could signal danger, such as the triangular head of a pit viper (Souchet & Aubret, 2016, although see Prokop et al., 2018). Recent studies challenge the "prepared to learn to fear" model of snakes in children (LoBue & Adolph, 2019). Cross-cultural researchers also report mixed results, with some studies finding that children who grow up around venomous snakes are more afraid of them (Ballouard et al., 2013), while others show that a lack of contact and knowledge of snakes leads to fear behavior (Makashvili et al., 2014; Özel et al., 2009). Despite decades of research and numerous publications on phobias in general, there is still no consensus on whether human fear of snakes is innate, universal, and inherited.

Concerning other specific phobias, the paradoxical nature of human-animal relationships has been well-documented (Knight & Herzog, 2009). Following snakes, the next most common fear group comprises invertebrates, which constitute almost 80% of biodiversity and are primarily associated with aversion, disgust, dislike, and fear (Herzog & Foster, 2010), even in children (Schlegel et al., 2015). The description of humans as invertebrates (such as cockroaches or parasites) is a strategy used to dehumanize out-groups and incite violence against them (Hare & Woods, 2021). Few, if any, cultures exhibit a blend of both revulsion and awe towards slugs and cockroaches.

In summary, the two main pieces of evidence that Wilson used to support the biophilia hypothesis—the savannah gestalt and the serpent myth—have not stood the test of time. The lack of evidence for biophilia would be less significant if the predictions of the hypothesis had found support. However, to date, support has been scant and at times, contradictory.

1.3 Status of the predictions of the biophilia hypothesis

The current state of the original predictions of the biophilia hypothesis are outlined below.

1.3.1 Biophilia is inherent (that is biologically based)

Wilson's idea that biophilia has a biological basis is the prediction upon which his hypothesis hinges. It is also the prediction with the least amount of evidence. There is one study that directly investigates the heritability of biophilia (Chang et al., 2022). This study examined the responses of 2306 twins an adult twin registry in the UK and identified nature orientation as being 46% heritable. However, a question arises

concerning what precisely the term "nature orientation" encompasses. This issue will be explored in greater depth in Sect. 1.4.2.

1.3.2 Biophilia is part of our species evolutionary heritage

The prediction that biophilia is part of our species' evolutionary heritage is difficult to test. Evolutionary heritage addresses phylogeny, or the history of a behavior in related species. There is evidence that our closest genetic relatives, chimpanzees and bonobos, might exhibit abnormal behaviors such as coprophagy, fecal smearing, and repetitive rocking in non-biophilic environments, particularly in laboratory settings. In Wobber and Hare (2011), chimpanzee orphans who lived in large, forested sanctuaries displayed less aberrant behavior than chimpanzees in zoos, even though the orphans experienced the early traumatic events of being taken from their mothers at a young age and sold on the bushmeat market. The authors concluded that the rich physical and social environment of the orphan chimpanzees facilitated a return to species specific behavior.

Many animals display aberrant behavior in captive settings, particularly laboratory settings; however, whether this is because of non-biophilic, artificial stressors such as lighting, noise, and restricted movement as opposed to social stressors such as solitary confinement, abnormal social groups, or forced proximity to humans, is difficult to ascertain.

1.3.3 Biophilia is associated with human competitive advantage and genetic fitness

It is also difficult to test whether biophilia is associated with competitive advantage or genetic fitness. To test this prediction, evidence of variability in biophilia among humans would first need to be established. Next, a selective sweep analysis could be conducted to identify genes linked to individuals with biophilic tendencies. While Chang et al.'s work in 2002 offers a promising step in this direction, further investigation is needed to precisely define the relationship between nature orientation and biophilia.

In this context, refining the definition of how nature orientation aligns with the concept of biophilia becomes crucial. A more comprehensive exploration of this relationship is required for a more accurate understanding of the genetic underpinnings of biophilia.

1.3.4 Biophilia is likely to increase the possibility for achieving individual meaning and personal fulfillment

In the vast, subsequent literature on biophilia, the main prediction that is tested is the idea that biophilia can increase individual meaning and personal fulfillment (see Bratman et al., 2012; Wells & Rollings, 2012; Hartig et al., 2014; Capaldi et al., 2015; Chawla, 2015; Hall & Knuth, 2019a, 2019b, 2019c, 2020). However, for this prediction, and in some cases, for all five predictions, biophilia is defined (either directly or indirectly) as an attraction to nature. The term "nature" is often used ambiguously,

encompassing a wide range of meanings, from pristine wilderness to the broader outdoors. This general affinity for nature presents challenges for falsifiability, particularly if it also includes any potential aversions to certain aspects of nature. A more specific definition of biophilia is required and discussed in Sect. 1.4.2.

1.3.5 Biophilia is the self-interested basis for a human ethic of care and conservation of nature, most especially the diversity of life

The fifth and final, largely ignored, prediction—that biophilia could form the basis for a human ethic of care and conservation of nature—is the heart of Wilson's hypothesis. Wilson, a passionate conservationist, was searching for a conservation ethic, one that was irrefutable because it was universal. The economic, social, utilitarian benefits of conserving this natural world and its resources could be debated, but an innate need to affiliate with this natural world could not. Several researchers have engaged with the concept of biophilia as a universal conservation ethic, but most have found it either unlikely or not useful (Simaika & Samways, 2010: but see Clowney, 2013; Joye & De Block, 2011). A more extensive discussion of how and why the "diversity of life" should be factored into any test of the biophilia hypothesis will follow in Sect. 1.4.2.

Critiques of the biophilia hypothesis Critical analysis of the biophilia hypothesis is limited, compared to its overwhelming acceptance. The first critique was Diamond's chapter in *The Biophilia Hypothesis* (Diamond, 1993), in which he outlined New Guineans' cruelty to animals, their lack of fear around snakes, and evidence contrary to the savannah hypothesis. Diamond's critique was largely ignored by the other authors, and he did not comment on biophilia again. Joye and van den Berg (2011) has criticized the lack of empirical evidence and a conceptual framework, a critique that encompasses issues like the serpent myth and the savannah hypothesis. Other researchers have also raised concerns about the absence of alternative hypotheses and the overall testability of the biophilia hypothesis (Clowney, 2013; Simaika & Samways, 2010). In reviews of biophilia studies, it has been observed that the majority of research is concentrated in high latitudes, neglecting the tropics where the highest biodiversity resides and where the potential negative consequences of human interacting with nature, such as zoonotic diseases, are significant (Keniger et al., 2013).

Some researchers have introduced the "topophilia hypothesis" as an extension of the biophilia hypothesis, encompassing the human connection with the non-human world (Beery & Jönsson, 2015). However, this formulation, much like the biophilia hypothesis itself, poses challenges in terms of falsifiability. Others have proposed expanding biophilia to include all sentient affiliative relationships (Clowney, 2013). Such cooperation, while related, arguably delves into a different realm of biology.

There are suggestions from various researchers to either abandon the concept of biophilia altogether, revert to Eric Fromm's (1973) original definition of biophilia "the passionate love of life and all that is alive" (which omits the genetic aspect), or introduce an entirely new term (Clowney, 2013; Simaika & Samways, 2010). Joye and van den Berg (2011) has put forth the term "Phytophilic Response Module (PRM)" as a potential alternative, as it more accurately represents the restorative value of plants without necessitating the encapsulation of biophobia.

However, there are reasons to invest in further exploration of the biophilia hypothesis. Firstly, in the literal sense, the hypothesis makes sense. Anyone would prefer a space that includes life, even one as unattractive as a weed covered side of the highway, rather than a space that cannot, such as a river choked with plastic trash. Moving away from this extreme definition is likely to produce variation within individuals. For instance, certain people would not prefer the weed covered side of a highway to a pleasant indoor space. But at a fundamental level, there probably is a human universal preference for a space that supports life, even if that space is only designed to support one kind of life—humans. A series of simple preference tests would likely confirm this.

Secondly, when Peter Singer extended sociobiology into the field of ethics in 1981, he noted that Wilson had made several errors in regard to philosophical reasoning causing philosophers to largely reject and ignore Wilson's proposal for a biological basis for morality. Instead of following his peers' rejection, Singer engaged with sociobiology in a way that moved the field of ethics forward (Singer, 1984).

Biophilia resonates across disciplines and interests, which is rare for an evolutionary concept. Other evolutionary concepts that gain traction, such as "survival of the fittest", tend to be completely the opposite of their actual meaning and relevance, and have managed to do enormous damage, occasionally culminating in consequences as extreme as genocide (Hare & Woods, 2021). Biophilia, in contrast, is a lovely idea, a hopeful concept that could inspire a new relationship with the natural world, and an appreciation of its importance for human flourishing. However, to be truly powerful, it must have a more solid theoretical and empirical footing, which is what this paper seeks to address. The initial step toward achieving this goal involves establishing a precise definition of biophilia that can generate the testable predictions required by any hypothesis.

1.4 The Biophilia Reactivity Hypothesis (BRH)

1.4.1 Biophilia as a temperament trait

Biophilia, when broken into its parts is the *innate focus* on *life or lifelike processes* (Wilson, 1984). The innate piece of the definition is Wilson's main contribution. It is also the piece for which there is the least evidence. There have been substantial advances in the field of behavioral genetics and one finding that has repeated been replicated is that psychological traits show significant and substantial genetic influence (Plomin et al., 2016). However, heritability is caused by many different genes that each may have a small effect and figuring out which genes are responsible for which behavioral trait is difficult (Dietz et al., 2005). Still, in Chang et al. (2022), when examining the heritability of nature orientation of twins, found that shared environment had little influence compared to genetic influence. But as the first study in this area, it will take time for these results to be replicated.

Cognitive psychology had been slowly developing as a field in the decade before Wilson proposed biophilia, and he complained that "cognitive psychologists have been

strangely slow to address its mental consequences" (Wilson, 2007, p. 34). Wilson proposed biophilia as "complex set of learning rules that can be teased apart and analyzed individually", which mapped onto theories of cognitive psychology at the time, particularly language development. However, it was temperament psychologists whose framework better fit the biophilia hypothesis. When Wilson proposed the biophilia hypothesis, the study of temperament was a nascent field. No standardized measurements or tools existed, and it wasn't until a seminal paper in 1987, that temperament was defined by Goldsmith et al. (1987):

> Temperament consists of relatively consistent, basic dispositions inherent in the person that underlie and modulate the expression of activity, reactivity, emotionality, and sociability. Major elements of temperament are present early in life, and those elements are likely to be strongly influenced by biological factors. As development proceeds, the expression of temperament increasingly becomes more influenced by experience and context. (p. 524)

The definition of temperament has been through many iterations (Shiner et al., 2012), but at the most basic level, a temperament trait must meet at least these three criteria (Goldsmith et al., 1987). It must:

1. Have individual variability
2. Be present early in development
3. Be relatively consistent over time and in different situations

Preferably, it should also meet a fourth criteria;

4. Have physiological and neurological markers (Shiner et al., 2012)

Temperament is different from personality in that personality can change and grow but temperament is present, or begins to appear at a young age, even infancy. Temperament has a genetic component, meaning that genes influence temperament, but do not control it. Also, temperament is usually relatively consistent throughout time. As one researcher described it, personality is a symphony, and temperament is the key in which the symphony is played (Rettew, 2013).

Temperament and cognition are commonly treated as distinct processes. Temperament refers to the inherent likelihood of an individual to respond in a specific manner to particular situations. On the other hand, cognition pertains to the brain's capacity to receive, process, and apply information in problem-solving. Temperament characterizes how individuals behave when faced with emotionally charged or unfamiliar situations, such as encountering novel or unusual circumstances. Cognition, on the other hand, governs their capacity to innovate, gain insights, make decisions, and respond adaptively to resolve challenges. Nevertheless, temperament and cognition are not entirely isolated processes within the brain. Instead, they interact in intricate ways. Some traits, such as self-control, bridge the realms of temperament and cognition. Personality emerges from the interplay between temperament and cognition, shaped by how these aspects engage with the environment during an individual's development.

Wilson proposed biophilia as a cognitive trait, but his description of biophilia was more aligned with a temperament trait, with the exception of individual variability:

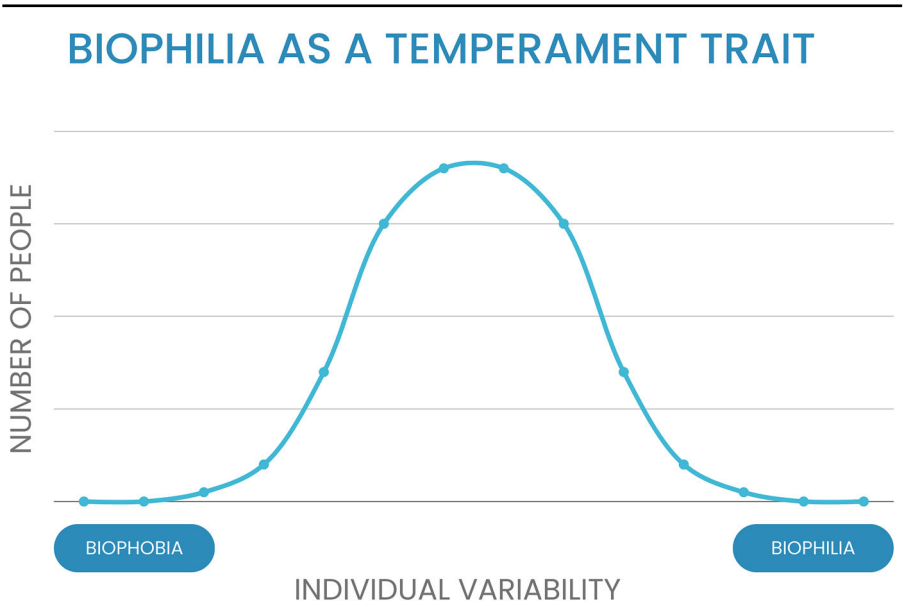

Fig. 2 Biophilia as a temperament trait

> [Biophilia] unfolds in the predictable fantasies and responses of individuals from early childhood onward. It cascades into repetitive patterns of culture across most or all societies, a consistency often noted in the literature of anthropology. These processes appear to be part of the programs of the brain. (Wilson, 1984, p. 85)

Wilson defined biophilia as a human universal, as part of "ultimate human nature" (Wilson, 1984, p. 32). Ironically, if Wilson had acknowledged individual variability of biophilia, it would have solved a weakness in his hypothesis. Instead of performing theoretical somersaults to wrap biophobia into biophilia, as a temperament trait, biophobia and biophilia would be on opposite ends of the spectrum (Fig. 2).

The other advantage of biophilia as a temperament trait is that, with a little more clarification, it becomes testable. Firstly, biophilia must meet the criteria of a temperament trait. Secondly, it must be domain specific, or not completely overlapping with a domain general temperament trait. For example, high biophilia should not just be an extension of the temperament trait of sociability (the tendency to prefer the presence of others), and low biophilia, or biophobia, should not just be an extension of emotionality (the tendency to get easily distressed or upset) (Zentner & Bates, 2008). Biophilia may overlap with these temperament traits, but should be distinct, or domain specific, so that someone high in biophilia can also be low in sociability and vice versa.

Biophilia, as a temperament trait, is an innate attraction to "life or life-like processes." It is this last phrase, "life of life-like processes", which is the real challenge of the definition.

1.4.2 An ambiguous nature

In the majority of the literature mentioning biophilia, including most contributing authors to *The Biophilia Hypothesis* "life or lifelike processes" is used interchangeably with nature. Nature can be as broadly defined as "areas containing elements of living systems that include plants and nonhuman animals across a range of scales and degrees of human management, from a small urban park through to "pristine wilderness" (Bratman et al., 2012).

There are several challenges with a definition of nature that spans everything from pristine wilderness to the general outdoors. The first is that the hypothesis becomes difficult to test, especially when it comes to the "innate" part of the definition, upon which the entire hypothesis hinges.

For instance, in Chang et al. (2022), an analysis of longitudinal surveys from an adult twin registry revealed that nature orientation demonstrated a heritability of 46%. Additionally, the survey encompassed measurements of nature experience. The findings indicated a heritability of 48% for the frequency of public nature space visits, 34% for the frequency of garden visits, and 38% for the duration of garden visits. However, beyond the moderately significant results that suggest environmental influences play a substantial role in the variability of these traits, the study prompts the question of whether these measurements accurately capture biophilia. What kind of "nature" people are drawn to and how is this attraction manifested through the frequency and duration of garden visits?

Genetic evidence for a trait requires that the trait can be measured. Even human height, which is easy to measure, is a polygenic trait that involves over 400 gene regions (Wood et al., 2014). The attraction to anything from green spaces to remote wilderness outposts is difficult to measure and therefore difficult to connect with any genetic component.

The second problem with an ambiguous definition of nature is that biophilia is found in nature but not all nature is biophilic. To encourage people to spend time outside in nature, many areas are treated with herbicides and pesticides. In the U.S., of the 40 most common household pesticides, 39 are toxic to fish and other aquatic organisms vital to the ecosystem, 33 are toxic to bees, 18 are toxic to mammals, and 28 are toxic to birds (Beyond Pesticides, 2021). Many of these pesticides negatively affect human health and wellbeing. Of these same 40 pesticides, 26 are linked to cancer or carcinogenicity, 12 are linked to birth defects, 21 to reproductive effects, 32 to liver or kidney damage, 24 to neurotoxicity, and 24 to disruption of the endocrine (hormonal) system (Beyond Pesticides, 2021).

Studies that explore the benefits of connecting with nature and scales that measure people's connectedness to nature (e.g. Richardson et al., 2019) often neglect to address these concerns, even though various health agencies have issued warnings regarding the potential adverse health effects of exposure to these agents, particularly among children (Chawla, 2015).

1.4.3 An argument for biodiversity

Placing the original definition in the context of Wilson's writings and works, it is clear that the closest interchangeable term with "life" is not "nature" but biodiversity.

The subtitle of Wilson's original *Biophilia* is "the human bond with other species." Almost every text Wilson wrote after *Biophilia* addresses the importance of biodiversity, and the imminent threat of its loss.

Therefore, this paper proposes the Biophilia Reactivity Hypothesis (BRH), where biophilia is defined as a temperament trait, specifically a domain-specific attraction to biodiversity.

Studies of biophilia rarely focus on biodiversity (Keniger et al., 2013). The reason for this is partly a definition debate. The word "biodiversity" was shortened from "biological diversity" by biologists in the 1980s (Novacek, 2008; Sarkar, 2021), and there are variations in how different researchers and fields define biodiversity (Swingland, 2001). In its simplest form, biodiversity is the variety of life (DeLong Jr, 1996). For ease of measurement, most studies focus on species number and richness.

One question for the measurement of human attraction to biodiversity is is whether non-biologists can distinguish between high and low biodiverse environments. In one study, people correctly identified grasslands as environment with high species richness, and they preferred these environments (Lindemann-Matthies et al., 2010). A Finnish study found that national parks with higher rates of biodiversity attracted more visitors (Siikamäki et al., 2015). In an Australian study, researchers found mixed preference for high and low biodiverse home gardens, although preference was significantly higher for gardeners who belonged to native plant societies (Kurz & Baudains, 2012).

Other studies have found that people's ability to assess biodiversity is inconsistent (Clergeau et al., 2001; van Riper et al., 2017). For example, people noticed an increase of plant diversity in a public park but underestimated bird and insect diversity (Shwartz et al., 2014). Another study found that children do not prefer biodiverse spaces, but instead prefer yards and gardens (Hand et al., 2017). A study in Spain found that people only value some elements of biodiversity (charismatic megafauna and trees) and have a negative or neutral association with other elements (invertebrates, microorganisms); they are rarely willing to pay to preserve any elements of biodiversity (although willingness to pay increases slightly with positive affect) (Martín-López et al., 2007). Various studies have found no preference, or minimal preferences for landscapes of different levels of biodiversity (Qiu et al., 2013; Williams & Cary, 2002).

An essential part of testing the biophilia hypothesis will be building on previous research to see if people can distinguish between high and low biodiversity and whether attraction or aversion towards biodiversity is implicit or explicit.

1.5 BRH: a roadmap

The BRH predicts that biophilia will meet three requirements outlined by Goldsmith et al (1987), and should preferably meet the fourth requirement. To test this prediction, this paper proposes the development of a Biophilic Quotient (BQ).

1.5.1 Individual variability

The initial prediction posits that BQ will exhibit variability across individuals in a distribution resembling a normal curve. This suggests that BQ will not display an upper or lower limit effect, nor will it manifest a bias towards positive or negative values. Additionally, a negative correlation is anticipated between biophilia and biophobia within each individual.

The BQ will measure attraction to biodiversity in two ways. The first is through self-reported survey data. Survey questionnaires remain one of the main measurements of temperament, and with careful study design and analysis, have found to be reliable assessments of temperament traits (Rettew, 2013, p. 33). The second is behavioral observation pioneered by Kagan et al. (2007) who followed infants longitudinally into adulthood. Coded behaviors included approach and avoidance, distress signals, and engagement towards novel objects. These variables were correlated with outcomes later on in life. Similar behavior could be coded in the context of attraction towards biodiverse versus non biodiverse environments.

Concurrently, the ability to distinguish high and low biodiversity should be assessed in participants. The BRH predicts that people who can identify environments with high biodiversity may be more attracted towards biodiversity. An alternative hypothesis is that the ability to distinguish biodiversity is independent of the attraction towards biodiversity.

1.5.2 Early emerging

Once the BQ has been developed and validated for adults, the next step will test whether the same individual variability present in adults is also present in children.

Although some temperament traits appear later on in life, facilitated by events such as puberty or menopause, biophilia is expected to appear early in childhood, perhaps even infancy. As a *domain specific* temperament trait, biophilia may overlap with (but not map onto) traits such as extraversion, novelty seeking, and surgency, all of which appear early in life.

Similar to the work of Rothbart and colleagues (Capaldi & Rothbart, 1992; Derryberry & Rothbart, 1988; Rothbart et al., 2001), once a reliable survey instrument is designed to assess BQ in adults, the same survey should be adapted to apply to infants and children so that it can be filled out by their caregivers. This new instrument will have to be validated, and also show a normal distribution among individuals. Once coded behaviors that express attraction to biodiversity have been identified in adults, these should be used with children, and adapted where necessary.

1.5.3 Remain relatively consistent over time

Although environmental factors, such as exposure and experience, almost certainly influence BQ, as a trait, BQ should remain relatively consistent over time (Goldsmith et al., 1987). A child who is attracted to the outdoors, animals, and insects will be expected to retain this attraction into adulthood, even in the face of negative experiences (being stung or bitten). A child who is averse or frightened of biodiversity might be

expected to gravitate towards more lifeless or less biodiverse environments, such as cities or indoor activities. Support for this prediction will require longitudinal data. The BQ developed for different age groups will be applied within individuals, from infancy to adulthood.

1.5.4 Physiological and neurological markers

The fourth prediction, which will provide further evidence for biophilia as a temperament trait is that there will be physiological and neurological markers. Not all temperament traits have physiological markers that can be reliably measured. However, these physiological markers, along with survey instruments and coding of behavior, can strengthen the argument for biophilia as a temperament trait. For example, someone with high BQ might respond with lowered cortisol in a biodiverse environment. Heart rate variability could also be measured, both in laboratory settings and the field. In laboratory settings, facial recognition software and eye tracking could measure pupil dilation and facial expressions in response to different images. Once physiological markers are established in adults, subsequent efforts should focus on different age groups, both between and within individuals.

Alternative hypotheses If there is sufficient evidence for BRH, it is possible to propose alternative hypotheses. that explain human attraction to biodiverse environments. The null is the Anthrophilia Hypothesis (AH), which proposes that humans evolved innate prosocial behavior towards other humans, primarily kin, ingroup members, and strangers, but not towards abstract categories like future generations or forests. In the AH, attraction or willing to act positively towards biodiverse environments is an accidental byproduct of our prosocial behavior towards humans that has been flexibly co-opted to apply to other non-human categories.

An attraction towards other humans is well established in the literature as a temperament trait, also known as sociability (Rettew, 2013). Bowie et al (2021) directly tested the AH against Wilson's biophilia hypothesis. In a cross-cultural study of 1088 children in Congo, China and the US, researchers found no evidence for an intrinsic motivation in children to save forests. Even children in a conservation summer camp in the US would not donate tokens to save a forest unless they were extrinsically rewarded (in candy) for doing so or punished (with a time delay) for not doing so.

The second alternative hypothesis is the Diversity Hypothesis (DH), a domain general trait where humans are attracted to all kinds of diversity (defined as novelty and variability) rather than biodiversity. Reactivity towards novelty has been well established as a temperament trait (Kagan et al., 2007), and has been linked with the personality trait of extraversion, where extraversion is the "tendency to engage the world and other people" (Rettew, 2013, p. 25). Rothbart listed High Intensity Pleasure as a sub factor of Extraversion: "Pleasure related to situations involving high stimulus intensity, rate, complexity, novelty, and incongruity" (Derryberry & Rothbart, 1988).

The DH predicts that BQ would simply map onto high intensity pleasure or novelty seeking, rather than emerge as a domain specific trait.

If the two alternative hypotheses have been ruled out, then support becomes stronger for the BRH.

1.6 The intersection of biophilia and human flourishing

The BRH predicts that individuals with a high BQ should respond positively to biodiverse environments. The field of positive psychology did not exist until Seligman and Csikszentmihalyi (2000) called for a new era of study of the "positive features that make life worth living".

Flourishing is "a construct that encompasses the increase of positive emotion, engagement, meaning, positive relationships and accomplishment, involving an existence provided of a greater meaning" (Scorsolini-Comin et al., 2013). Without any conceptual framework of positive psychology, Wilson perfectly captured the concept of flourishing decades before the field had been proposed.

> In a twist my mind came free and I was aware of the hard workings of the natural world beyond the periphery of ordinary attention, where passions lose their meaning and history is in another digestion, without people, and great events pass without record or judgment. I was a transient of no consequence in this familiar yet deeply alien world that I had come to love (Wilson, 1984, p. 10).

There are thousands of studies that explore the link between nature and flourishing, including those that mention biophilia. Instead of flourishing, these studies might use terms such as well-being, happiness, or positive affect, and there are several survey instruments that measure an affinity towards nature, although most of these scales measure a single underlying factor (Tam, 2013), with the exception of Nisbet et al. (2009).

There are few studies which examine the effect of biodiversity on flourishing. In the literature that exists, one study found that people visiting natural areas with a high level of biodiversity had higher well-being, particularly in urban versus semi-urban settings (Carrus et al., 2015). Another study found that although people could not correctly assess biodiversity, their sense of well-being improved once biodiversity was increased (Shwartz et al., 2014). In contrast, Dallimer et al. (2012) found no evidence for a link between species richness and well-being; however, if people perceived the biodiversity to be higher, there was a slight positive effect.

The BRH predicts that people with a high BQ are more likely to flourish in biodiverse environments. It is essential to validate these results in non-WERID populations in biodiversity hotspots, such as tropical latitudes where risk of zoonotic disease transfer is higher. Keniger et al (2013) noted that most research examining the intersection between natural spaces and flourishing occur in Western, temperate climates. For example, one preliminary study found that Meru rural pastoralists in Kenya have a more negative perception of nature than their more urban counterparts (Marczak & Sorokowski, 2018). More studies of this kind are critical since extrapolating benefits of biophilia to non-WEIRD societies could have unintended consequences. For example, living in or near biophilic environments, such as the developing world in tropical regions, could be seen as providing benefits to wellness, health and longevity, where in fact, none exist.

2 Conclusion

It is not surprising that the biophilia hypothesis has struck a chord with researchers in a broad range of disciplines. Mounting evidence of catastrophic climate change, deforestation, and species extinction has us confronting the costs of continuing to expand the urban environment and retreat indoors. The biophilia hypothesis an articulation of anxiety and loss. Many of us intuit, as did Wilson, that the natural world is fundamentally important. However, intuition is not enough. A true hypothesis is falsifiable. Currently, the biophilia hypothesis is not.

This lack of scientific precision would not be a matter of urgency, or even importance, except that thousands of publications are basing policy decisions, urban planning, and building theory on the biophilia hypothesis as though it has been tested. Access to biophilic environments has been argued to be a social justice issue, conferring an unfair advantage to children of higher socioeconomic status, even though "access to nature" is poorly defined, and when treated with carcinogenic chemicals, creates potential harm. Conservationists might be putting misguided faith in biophilia as a human universal, when perhaps, only some people flourish in the natural world, and some prefer a beautiful lifeless indoor space. Perhaps these preferences shift when nature becomes uncomfortable and exposes people to zoonotic and parasitic diseases.

The Biophilia Reactivity Hypothesis proposes biophilia as a temperament trait, specifically, a domain specific attraction to biodiversity. This definition generates testable predictions which allows the hypothesis to be falsified. Whether or not the predictions of the hypothesis will be supported, or whether biophilia is a more domain general trait, has important implications for conservation, how we build our new environments, and how we can best flourish.

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Declarations

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