The Role of Nature in Promoting Health: A Pnei Perspective

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Abstract. *The relationship between human beings and Nature is a fundamental dimension of their biological, psychological, and social experience. The human organism cannot be considered separately from the environment in which it lives, as it is in constant interaction with the stimuli and conditions of its surroundings. Yet, despite a growing body of scientific evidence indicating that contact with natural environments may help maintain health and promote psychophysical well-being, this relationship has become increasingly sporadic and discontinuous in contemporary societies. Urbanization, sedentary lifestyles, prolonged exposure to artificial stimuli, pollution, and the acceleration of everyday life have reduced opportunities for recovery and contributed to persistent stress, with possible repercussions for the balance of the nervous, endocrine, and immune systems (Bottaccioli F. & Bottaccioli A.G., 2022b).*

In this context, psychoneuroendocrinoimmunology (PNEI) offers a particularly valuable perspective for understanding the relationship between the organism and its environment. By viewing health as the result of dynamic, bidirectional interactions between psychological processes and biological systems, this approach makes it possible to understand contact with Nature not merely as a pleasant experience, but also as a potential resource for supporting psychophysiological regulation. Integrating natural environments into health-promotion initiatives may therefore represent a promising strategy for fostering well-being and contributing to a broader understanding of health (La Puma, 2023).

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Nature as a Dimension of Health

Nature is the environment in which the human species evolved, developing over millennia a relationship based on adaptation, learning, and mutual dependence. This bond continues to represent a potentially important dimension of health and well-being. Contemporary living conditions, however, have reduced opportunities for direct and sustained contact with Nature. An increasing proportion of daily activities takes place in built environments, in front of digital screens, and in response to continuous demands. Noise, crowding, pollution, a lack of accessible green spaces, sedentary behavior, and fragmented attention contribute to a daily burden of demands that is not always adequately offset by opportunities for recovery. In this context, natural environments can offer valuable opportunities for psychophysical recovery and for restoring a more balanced relationship with the rhythms of everyday life. Supporting this perspective, scientific research has documented associations between exposure to natural environments—particularly woods, forests, and settings rich in vegetation—and several indicators of physical and mental health, including perceived stress, anxiety, mood, attention, cardiovascular parameters, and autonomic and immune system activity.

A significant contribution to this field of research has come from Japan, where, since the 1980s, scientific and institutional interest in *Shinrin-yoku* has grown. The term is commonly translated as "forest bathing" (*shinrin* = forest; *yoku* = bath). The practice involves consciously immersing oneself in a forest environment through the senses and direct contact with natural elements. Studies have investigated its potential benefits and the possibility of integrating it with conventional healthcare interventions, with promising findings for the mental and physical health of participants (Hansen *et al.*, 2017).

Interest subsequently spread to other countries, encouraging the development of *Nature-Based Interventions* (NBIs). These encompass activities that vary in format, duration, setting, and aims, and are proposed for prevention, well-being promotion, and, in some contexts, as a complement to treatment pathways (Patel *et al.*, 2011; Adewuyi *et al.*, 2023).

To understand the mechanisms that may be involved, psychoneuroendocrinoimmunology (PNEI) offers an integrated perspective, viewing health as the outcome of dynamic, reciprocal interactions among the nervous, endocrine, and immune systems, psychological processes, and the environment (Bottaccioli F. &

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Bottaccioli A.G., 2017; Bottaccioli A.G. *et al.*, 2022). Emotions, the meanings attributed to experiences, behaviors, social relationships, and environmental conditions can all influence physiological processes through endocrine, autonomic, and immune pathways.

Against this background, this article provides an overview of the evidence on the role of Nature in health promotion from a PNEI perspective. After outlining stress in contemporary society, it examines research on Shinrin-yoku, the possible biological and psychological mechanisms involved, and applications of contact with Nature, including those involving virtual environments. The aim is to highlight the implications of this knowledge for prevention and the promotion of well-being.

Integrated Health and the PNEI Perspective: The Role of the Environment

An integrated understanding of health, from a PNEI perspective, calls for moving beyond the traditional separation of mind and body and recognizing that psychological and biological processes are closely interconnected and influence one another. The response to a stressful situation, for example, is not exclusively a psychological event, but the outcome of a complex process involving cognitive appraisal, activation of the autonomic nervous system, hormone secretion, mobilization of energy resources, and modulation of immune functions. These processes, in turn, are not confined to the physiological domain: they can affect mood, motivation, cognitive abilities, and behavior, helping shape how a person interprets and responds to experiences. A system of reciprocal influences thus emerges, in which the perception of events, the organism's responses, and patterns of interaction with the environment continuously shape one another.

From this perspective, the environment is not merely a backdrop. The places where we live and carry out our daily activities have physical and social characteristics that can either support or hinder the recovery of psychophysical resources. A noisy, crowded, unpredictable environment, or one characterized by a high density of stimuli, may require continuous effort from attentional systems and encourage a sustained state of alertness. By contrast, a setting perceived as safe, with pleasant stimuli and fewer demands on attention, may facilitate a reduction in defensive vigilance and create conditions conducive to recovery.

This distinction does not mean, however, that an environment affects everyone in the same way or that its effects depend solely on its objective characteristics. Individual responses are also influenced by personal history, expectations, psychophysical state, and the meaning attributed to the setting. The relationship between

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individuals and their environment should therefore be understood as a dynamic process in which contextual characteristics interact with individual resources and vulnerabilities, helping shape psychological and physiological responses.

Biophilia: Our Bond with the Living World

The biophilia hypothesis suggests that human beings have an innate predisposition to seek a connection with Nature and other forms of life (Wilson, 2021). This disposition is traced to a long evolutionary history, during which the ability to recognize resources, identify signs of danger, and perceive opportunities in the environment offered an adaptive advantage. For millions of years, human survival depended on knowledge of natural cycles, the availability of water and food, the ability to interpret landscapes, and cooperation with others. Over time, these processes, together with cultural evolution, may have helped consolidate the bond with Nature and other living beings. Given that environmental conditions and behaviors can be associated with physiological changes, it is reasonable to ask whether contact with Nature might also influence the regulation of gene expression. From this perspective, one might hypothesize the involvement of molecular pathways associated with inflammation, including those regulated by the transcription factor NF-κB, with possible effects on the expression of genes involved in cytokine production. Although numerous studies have documented associations between exposure to natural environments and various physical and mental health benefits, direct evidence concerning possible epigenetic effects remains limited and requires further investigation.

Urbanization, Chronic Stress, and Allostatic Load

Urban life offers important social, cultural, and professional opportunities, but it can also expose people to a combination of demands that, when persistent and not adequately balanced by opportunities for recovery, contribute to stress. Noise, traffic, crowding, pollution, accelerated pace of life, work pressures, limited access to safe spaces for physical activity, and few opportunities to pause can increase adaptive demands and lead to repeated activation of the physiological systems involved in the stress response. This response is essential for survival: when faced with a threat or an intense demand, the organism rapidly mobilizes energy and attention, triggering a series of physiological changes that help it cope with the situation. Difficulties may arise when this mobilization becomes frequent or prolonged and opportunities for recovery are insufficient. In this context, the concept of *allostatic load* describes the cumulative physiological cost incurred by the organism as

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it adapts to repeated or persistent demands, especially when physiological systems are unable to return regularly to a state of balance.

One relevant phenomenon in this context is the *Conserved Transcriptional Response to Adversity* (CTRA), a pattern of transcriptional response associated with adversity and prolonged stress. In general terms, this profile is characterized by increased expression of genes involved in pro-inflammatory processes and reduced expression of genes involved in the antiviral response (Cole, 2019).

Cortisol, a hormone essential to the regulation of energy metabolism, circadian rhythms, and responses to environmental demands, may also contribute to these dynamics. Although it plays a vital role in adaptation, persistent dysregulation can interfere with immune balance and be associated with greater vulnerability to inflammatory conditions (Cohen *et al.*, 2012).

In this context, contact with Nature emerges as a potential resource for supporting recovery from stress and psychophysiological regulation.

Physiological Responses: The Autonomic Nervous System and Stress Axes

The spread of *Shinrin-yoku* ("forest bathing") has helped establish contact with Nature as a potential complementary resource for health promotion. Among the most frequently reported findings in studies of this practice are changes in physiological indicators associated with stress. In several studies comparing exposure to forest and urban environments, time spent in forests has been associated with lower heart rate and blood pressure, lower cortisol concentrations, and increased heart rate variability (HRV), indicating greater parasympathetic activity alongside reduced sympathetic activity (Park *et al.*, 2010; Tsunetsugu *et al.*, 2007; Li *et al.*, 2016).

To understand these findings, it is useful to consider the role of the autonomic nervous system, which helps regulate the body's involuntary functions and adapt them to changing demands. Its sympathetic and parasympathetic branches contribute to the modulation of physiological arousal through complementary mechanisms: the former supports the mobilization of resources needed to meet demands, while the latter contributes to rest, digestion, and recovery. The changes observed during exposure to natural environments therefore suggest that such settings may influence the dynamic balance between activation and recovery.

Another system involved in the stress response is the hypothalamic–pituitary–adrenal (HPA) axis, which coordinates a fundamental part of the neuroendocrine response to stressors. When a situation is perceived as stressful, the hypothalamus initiates a sequence of signals involving the pituitary gland and the adrenal cortex, culminating in cortisol secretion. Changes in cortisol levels can provide infor-

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mation about HPA-axis activity, particularly in response to immersion in green environments.

Particularly interesting is the observation that some favorable physiological changes have been found not only after immersive walks in forests, but also after simply viewing forest landscapes. This suggests that physical movement, although it may contribute to the overall benefits, is not the only factor involved. Visual perception of the natural environment may also help modulate psychophysiological responses, indicating that the relationship between Nature and health can develop through different forms of exposure and sensory engagement.

Nature and the Immune Response

Prolonged exposure to high cortisol levels is known to interfere with the regulation of the immune response, affecting the number and functioning of Natural Killer (NK) cells, which are key components of innate immunity. These cells share some characteristics with Cytotoxic T Lymphocytes, which belong to the adaptive immune system, including the ability to recognize and eliminate virus-infected cells and cells that have undergone malignant transformation (Bottaccioli F. & Bottaccioli A.G., 2022a).

In this context, some studies suggest that walks in natural environments may be associated not only with an increase in the number and activity of NK cells, but also with greater expression or activity of cytotoxic proteins, including perforin, granzymes, and granulysin (Li *et al.*, 2007). These molecules are stored in granules within NK cells and Cytotoxic T Lymphocytes and are released through a process known as *degranulation*, which enables target cells to be damaged and eliminated. Some studies have also reported that certain changes in NK-cell activity may persist for days or weeks after exposure to forest environments, in some cases for up to approximately 30 days. This finding is noteworthy but should be interpreted cautiously: the duration of effects may vary according to the exposure protocol and individual characteristics.

A Calmer Mind in Nature

Another interesting finding from studies conducted in Japanese forests concerns changes in prefrontal cortex activity. In particular, a reduction in total hemoglobin concentration (t-Hb) in this brain region has been observed both while viewing forest landscapes and while walking in natural environments, compared with measurements taken while viewing or walking through urban settings (Park *et al.*, 2007). This parameter, used to assess cerebral hemodynamic changes, can

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provide indirect information about changes in neuronal activity. The reduction in t-Hb has been interpreted as a possible sign of lower prefrontal cortex activation, in a region involved in cognitive control, planning, and attentional regulation. This finding suggests that contact with natural environments may promote a state requiring less cognitive effort and allowing greater mental relaxation, potentially accompanied by reduced rumination—the tendency to keep attention anchored to worries and thereby sustain emotional distress (Bratman, 2015).

Nature and the Regulation of Emotional States

Walks in forests and green spaces have been associated with reduced anxiety and improved mood (Kotera *et al.*, 2022). These effects may occur after relatively brief periods of exposure, ranging from 15 minutes to several hours, and have been linked to changes in autonomic nervous system activity, including increased parasympathetic activation, consistent with a state of relaxation and calm (Song *et al.*, 2018).

In some research protocols, immersion in forest environments has also been associated with a reduction in unpleasant emotional states, such as anger, hostility, confusion, and dejection, alongside an increase in positive emotions (Bielinis *et al.*, 2019). Positive emotions are not merely a pleasant aspect of experience; they may contribute to psychophysical well-being and be associated with favorable long-term health outcomes (Fredrickson, 2003; Cohen *et al.*, 2006). Possible biological correlates of these emotional states include changes in inflammatory processes: some studies have found associations between positive emotions and lower levels of pro-inflammatory cytokines, including interleukin-6 (IL-6) (Stellar *et al.*, 2015).

Nature and Cognitive Function: Restoring Attention

Contact with Nature may help restore attentional resources and improve certain cognitive functions. According to *Attention Restoration Theory* (Kaplan, 1995; Berto, 2005), natural environments facilitate the recovery of directed attention, a form of voluntary attention that requires sustained cognitive control and may become depleted after prolonged exposure to demanding stimuli, such as those typical of many urban settings. Natural environments, by contrast, can capture attention spontaneously through inherently fascinating stimuli, reducing the need for voluntary attentional control and thereby offering an opportunity for mental recovery.

Supporting this perspective, Berman *et al.* (2008) found that a walk of approximately 50 minutes in an urban park was associated with improvements in short-

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term memory and attentional and executive abilities compared with a walk in a more chaotic urban environment. These cognitive benefits have been observed not only in healthy individuals but also in clinical populations, particularly people experiencing depressive symptoms. In this group, brief contact with Nature was associated with both improved mood and better cognitive performance (Berman *et al.*, 2012).

Favorable effects have also been observed in educational and workplace settings. Among students at different educational levels, exposure to natural environments has been associated with improvements in working memory and selective attention (Mason *et al.*, 2022). Similarly, workplace interventions involving contact with Nature have been associated with reduced perceived stress and improvements in some aspects of cognitive performance, particularly visual processing speed and selective attention (Daniels *et al.*, 2022).

Overall, these findings suggest that natural environments may be a useful resource for supporting cognitive functioning in different areas of life, although the magnitude and duration of the benefits may vary according to the characteristics of the interventions and the people involved.

Well-Being and Eudaimonia: Beyond Immediate Pleasure

An active and engaged connection with Nature can foster not only well-being associated with immediate, fleeting pleasure—known as *hedonic* well-being—but also well-being associated with a deeper and more enduring form of fulfillment, known as *eudaimonic* well-being (Passmore & Howell, 2014). Several experimental and correlational studies have assessed the effects of contact with Nature on key indicators of psychological well-being associated with eudaimonia, drawing on the decades of research conducted by American researcher Carol Ryff. Throughout her career, Ryff has sought to identify and study the dimensions of well-being that underpin personal fulfillment. The dimensions she identified include *autonomy, personal growth, self-acceptance, purpose in life, environmental mastery, and positive relationships with others* (Ryff, 1989). In addition to these, experimental and correlational studies have also examined *vitality*, which is often described in the literature as an aspect of eudaimonic well-being (Ryan & Deci, 2001).

These studies suggest that the more people engage with Nature, the more their sense of connection is associated with a range of indicators of eudaimonic well-being, including *meaning and purpose in life, autonomy, personal growth, vitality, authenticity, and life satisfaction* (Cervinka *et al.*, 2012; Pritchard *et al.*, 2020).

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Potential Mechanisms: Phytoncides, Color, Air, and Sensory Stimuli

The psychophysical effects attributed to Nature may arise from several interacting mechanisms:

Phytoncides and Plant-Derived Organic Compounds. Plants and trees release volatile organic compounds into the atmosphere, including the *terpenes* α-pinene, β-pinene, tricyclene, camphene, and limonene. These are components of phytoncides, volatile substances involved in plant defense against insects, parasites, and other potentially harmful agents. Experimental studies have investigated the possible biological effects of these compounds, including antioxidant, antimicrobial, and anti-inflammatory properties, as well as effects on Natural Killer (NK) cell activity and the expression of cytotoxic proteins (Li *et al.*, 2006, 2009).

The Color Green and Visual Experience. Observing the different shades of green found in Nature may have not only visual but also emotional effects: green can promote a sense of calm, mindful presence, and connection with oneself and the environment. Perception of and responses to these shades may also vary according to culture, individual sensitivity, and visual habits, making the experience of green subjective and personal.

The effects of viewing greenery have also been investigated in relation to brain activity. Some studies have examined changes in electroencephalographic activity, identifying possible changes in *beta* rhythms, associated with alertness and attention, and *theta and delta* rhythms, involved in different states of relaxation (Khadir *et al.*, 2023). These findings suggest that exposure to greenery may promote a state of *relaxed alertness*, in which attention and ease coexist. Green stimulates without agitating; it calms without draining energy.

Atmospheric Ions and Air Quality. *Negative air ions* are particles carrying a negative electrical charge that, according to some scientific evidence, may have beneficial effects on human health (Yamada *et al.*, 2006). Natural environments such as forests, mountains, and areas near flowing water are characterized by relatively high concentrations of these particles, suggesting that they may contribute to the biological effects associated with contact with Nature.

Another relevant factor is *air quality*: forest environments have significantly lower concentrations of certain air pollutants than urban areas. Exposure to pollutants is associated with harmful effects on the respiratory system and with inflammatory processes, as the smallest particles can penetrate deep into the respira-

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tory tract. Air pollution can also disrupt immune regulation, impairing some defense mechanisms against viruses and tumors while promoting pro-inflammatory responses (Bottaccioli F. & Bottaccioli A.G., 2017, 2022b).

Real Nature vs. Virtual Nature: A Possible Comparison

Evidence supporting the psychological and biological benefits of exposure to virtual Nature through state-of-the-art equipment is growing rapidly (Browning *et al.*, 2020). Such benefits may be particularly relevant for people who cannot physically access natural environments because of mobility limitations, health conditions, geographical distance, caregiving responsibilities, financial constraints, or a lack of available green spaces.

Exposure to a variety of virtual natural environments has been found to produce a significant increase in subjective vitality, restore physical and psychological resources depleted by the ongoing effort to meet everyday demands, reduce anxiety and stress, and improve mood (Clemente *et al.*, 2024; Yin *et al.*, 2020; Mattila *et al.*, 2020). This sense of energy and restoration has been found to be similar to that experienced when physically immersed in a natural environment (Theodorou *et al.*, 2023).

Although virtual immersion in Nature may benefit the mind and body across a range of populations, both clinical and non-clinical, these experiences also have limitations and challenges. Further research is certainly needed to improve the effectiveness of this type of experience. Above all, however, virtual simulations of natural environments should ideally be integrated with actual immersion in Nature, as part of an integrated approach to well-being and health.

Conclusions: Reconnecting with a Relationship That Supports Health

The evidence reviewed suggests that contact with natural environments may be associated with benefits across several domains: physiological, emotional, cognitive, and relational. The PNEI perspective makes it possible to place these findings within an integrated view of health, understood as a dynamic process in which body, mind, and environment influence one another. Nature does not act like a drug, with uniform doses and effects for everyone; rather, it offers a range of conditions that may support recovery from stress, physical activity, physiological regulation, restoration of attention, and connection with oneself and the environment.

The value of Nature, however, extends beyond the benefits it may offer to human health. It also lies in the opportunity to recognize ourselves as part of a wider

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network of relationships on which our well-being and quality of life depend. Health is closely linked to the quality of the environments in which we live and to the availability of spaces that support rest, movement, and social connection.

In light of these considerations, making Nature accessible is an individual and collective responsibility. Discussing its benefits also means addressing equity: not everyone has the same opportunities to access safe parks, gardens, trails, or environments with clean air. Responsibility cannot fall exclusively on individuals, who are asked to change their habits without addressing the conditions that often make such changes difficult. Urban policies are needed to protect and expand public green spaces, create safe walking and cycling routes, improve connections between neighborhoods and parks, promote biodiversity, and reduce exposure to pollutants. Only through shared commitment will it be possible to integrate Nature meaningfully into health and well-being promotion.

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