




An agent-based model of the extinction of experience: How nature availability and connectedness to nature co-evolve over time

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ABSTRACT

It has been suggested that increasing urbanization is gradually reducing opportunities for people to experience nature in their everyday lives. According to the Extinction of Experience (EoE) framework, this decline can trigger a vicious cycle: as opportunities for nature experience diminish, people may become increasingly disconnected from nature and less motivated to protect what remains—further reducing nature availability and reinforcing this vicious cycle. Despite its intuitive appeal, the EoE has largely remained a verbal theory, investigated primarily through cross-sectional studies that examine isolated relationships between its core components—nature availability, nature experience and connectedness to nature—at a single point in time. As a result, the dynamic properties of the EoE, such as feedback loops and tipping point dynamics, have not been formally tested or modelled. In this study, we seek to address this gap by using agent-based modelling (ABM) to simulate the emergence of the EoE over time. Our model centres on the interplay between nature availability, nature experience and connectedness to nature, and is parameterized using existing cross-sectional data. Through simulation, we explore how varying levels of greenspace availability influence system behaviour. Our analyses show that when greenspace coverage falls below 23 % in our ABM, a self-reinforcing feedback loop emerges, consistently leading to the EoE. Conversely, when greenspace exceeds 25 %, this vicious cycle is mitigated—or even reversed—into a virtuous cycle, where nature experience and connectedness to nature reinforce one another over time. Although exact thresholds vary depending on parameter values, the model robustly demonstrates the potential for tipping point dynamics: small reductions in greenspace can result in disproportionate, non-linear shifts toward a full EoE.

1. Introduction

Nature experiences refer to situations where individuals either actively engage with or passively experience various types of natural environments, ranging from wilderness areas to managed greenspace (Gaston & Soga, 2020; Maller et al., 2006). Experiencing such environments, whether through activities like camping in a wilderness area, picnicking in an urban park, or merely contemplating a beautiful sunset, has been shown to yield a multitude of personal and interpersonal benefits. On a personal level, contact with nature is known to enhance cognitive functioning (for a review, see Schertz & Berman, 2019) and has the potential to boost well-being by reducing stress (Ulrich et al., 1991; Yao et al., 2021), enhancing moods (McMahan & Estes, 2015) or countering ruminative thinking (Bratman et al., 2015; Lopes et al.,

2020). Engaging with natural environments is also known to confer interpersonal benefits, ranging from promoting prosocial behaviour (Goldy & Piff, 2020) to nurturing a sense of connection, not only with others but also with the natural environment itself (Mayer & Frantz, 2004; Nisbet, 2014; Passmore & Holder, 2017; Schultz et al., 2004).

While extensive research has highlighted the (inter)personal benefits of contact with nature (for a comprehensive review, see Hartig et al., 2014), contemporary demographic trends, ongoing ecosystem degradation, and particular lifestyle changes limit the opportunity and willingness of people to engage with nature on a frequent basis. Notably, the global increase in urbanization (United Nations, undated) and the simultaneous decline in biodiverse nature (Simkin et al., 2022) may contribute to a diminishing frequency and quality of nature experiences. This estrangement from nature is further compounded by specific

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modern lifestyle patterns, including heightened sedentary behaviours (Kohl et al., 2012) and, related to this, increased levels of social media use (Edwards & Larson, 2020), which may significantly reduce the frequency and quality of human-nature interactions.

Importantly, it has been hypothesised that losing opportunities to experience nature can set into motion a vicious cycle which Robert Pyle coined as the “extinction of experience” (henceforth “EoE”; Pyle, 1978; see also: Gaston & Soga, 2020; Miller, 2005; Soga & Gaston, 2016). This account introduces the idea that, as opportunities for directly experiencing nature diminish due to decreased nature availability – whether it involves having fewer nature nearby or difficult access to nature – people’s connection to the natural world may weaken. A lower connection to the natural world can, in turn, result in heightened indifference and disinterest in its preservation, ultimately leading to a further decline in nature availability and of opportunities to directly experience nature. This vicious cycle can have profound consequences, not only depriving people of chances to experience nature’s wellbeing effects (as described above), but also negatively impacting the collective commitment to environmental conservation and protection, further jeopardizing the (long-term) availability of nature.

Urbanization presents both challenges and opportunities for nature experience: while it often limits access to nature—potentially triggering or exacerbating the EoE—well-designed urban environments can also help mitigate it. Opportunities to experience (biodiverse) nature in cities can be considerable and cities are also increasingly implementing policy measures and initiatives, aimed at (re)integrating nature into or near urban settings or at facilitating citizen’s access to nature (Oh et al., 2020). Such measures and initiatives range from establishing community gardens, urban parks, green roofs, or implementing the 3-30-300 rule¹ (Konijnendijk, 2023). When accompanied by programs geared at encouraging citizens to actively engage with nature (Pocock et al., 2023), these efforts can offer an opportunity to counteract the EoE. It has even been argued that a virtuous cycle can occur, where enhanced access to urban nature can increase people’s experience with and connection to the natural world, thereby encouraging further support for greening urban spaces (Garfinkel et al., 2024).

1.1. Conceptualizing the EoE as dynamic system with tipping point dynamics

The EoE is a conceptual framework that views nature availability, experience of nature and connectedness to nature as interdependent components of a dynamic system governed by feedback loops over time. Crucially, the framework suggests that this system can evolve in two opposing directions: a vicious cycle or a virtuous cycle, depending on the state of nature availability. When nature availability drops below a critical threshold, it can set off a reinforcing loop of reduced nature experiences and connectedness to nature, further diminishing motivation to protect nature and accelerating its decline (Stroud et al., 2022). In contrast, sufficient nature availability can support ongoing nature experiences and deepen connectedness to nature, which in turn fosters conservation-oriented behaviours—creating a self-sustaining positive loop.

Importantly, at the heart of the EoE is the possibility of tipping point dynamics: the EoE implies there may be critical thresholds of nature availability where small changes in nature availability can lead to large shifts in the system’s dynamics, flipping the feedback loop from a virtuous cycle to a vicious one or vice versa (Garfinkel et al., 2024; Lenton et al., 2008, 2022). On either side of the tipping point region, the system tends to exhibit a dynamic equilibrium where it remains

¹ This rule requires that “every citizen should be able to see at least three trees from their home, have 30 percent tree canopy cover in their neighbourhood and not live more than 300 m away from the nearest park or green space” (Konijnendijk, 2022, p. 825).

relatively stable and insensitive to minor fluctuations (Meadows, 2015). However, the relationship between nature availability and connectedness to nature is non-linear—small changes in nature availability can result in disproportionately large or small shifts in connectedness to nature, depending on where the system lies relative to its tipping point (Fig. 1).

While the EoE has received growing scholarly attention within environmental and conservation research, its temporal dynamics—including feedback loops and potential tipping point dynamics—has been mainly qualitatively framed as a verbal theory and has remained largely untested. Most empirical support to date comes from cross-sectional studies that zoom in on a single relationship among the framework’s components at a specific moment in time (Colléony et al., 2020; Garfinkel et al., 2024). However, this kind of “static” research is limited in its ability to capture the core of the EoE: a dynamic process in which nature availability, nature experience and connectedness to nature interact through feedback over time. In other words, we currently lack insight into how these components function together as a *system*, governed by feedback loops and tipping point dynamics.

To address this research gap, the present study will formally model the EoE as a dynamic system in which components interact through feedback loops over time, with the aim of exploring its potential tipping point dynamics. To this end, we employ agent-based modelling (henceforth “ABM”)—a computational approach particularly well-suited for simulating the behaviours of interacting agents within complex systems and examining their emergent dynamics over time (Smith & Conrey, 2007), as detailed below.

1.2. What is agent-based modelling and why is it useful to model the EoE?

ABM is a computational tool used to simulate how agents, representing individuals, interact with one another over time within a simulated environment (Smith & Conrey, 2007). The method is considered “agent-based” because the starting point of ABM are theoretical assumptions about agents, their internal states and their behaviour (Flache & Macy, 2011). These theoretical assumptions are translated into rules that determine what agents can perceive and how they can behave. The method is computational because the agents and the behavioural rules that govern them are stated formally in a way that can be implemented in a computer programming language (Flache & Macy, 2011; Wijermans et al., 2022).

In an ABM, an agent’s decisions are based on their internal state and their environment. When agents interact with the environment and over time, a complex, dynamic system forms, whose evolution cannot be inferred by accumulating findings about individual behaviour from cross-sectional studies (Flache, 2018; Macy & Flache, 2011; Schelling, 1971). To illustrate, consider an ABM that simulates the adoption of large-scale diet change, where each agent represents an individual that can decide to become vegetarian. In such a model, each agent is influenced by the proportion of their social network that has already made the switch to vegetarianism. This creates a feedback loop: as more agents adopt vegetarianism, the visibility of this behaviour increases, which in turn influences more agents to follow suit. The ABM tracks how these interactions and observations evolve over time. Initially, the change is gradual, but as the proportion of vegetarians grows, the reinforcing effect of the feedback loop strengthens, leading to a rapid increase in adoption rates. Eventually, this process reaches a tipping point where the minority of vegetarians transforms into a majority, demonstrating how increased visibility and social influence can drive significant, non-linear shifts in collective behaviour through agent-based simulations. This example underscores that emergent system dynamics arise from repeated, time-dependent interactions of individuals, which would not become apparent when analysing isolated individual behaviour.

In the present paper, we propose ABM as a particularly suitable method for exploring the system dynamics among the key components of the EoE—namely, nature availability, nature experience and

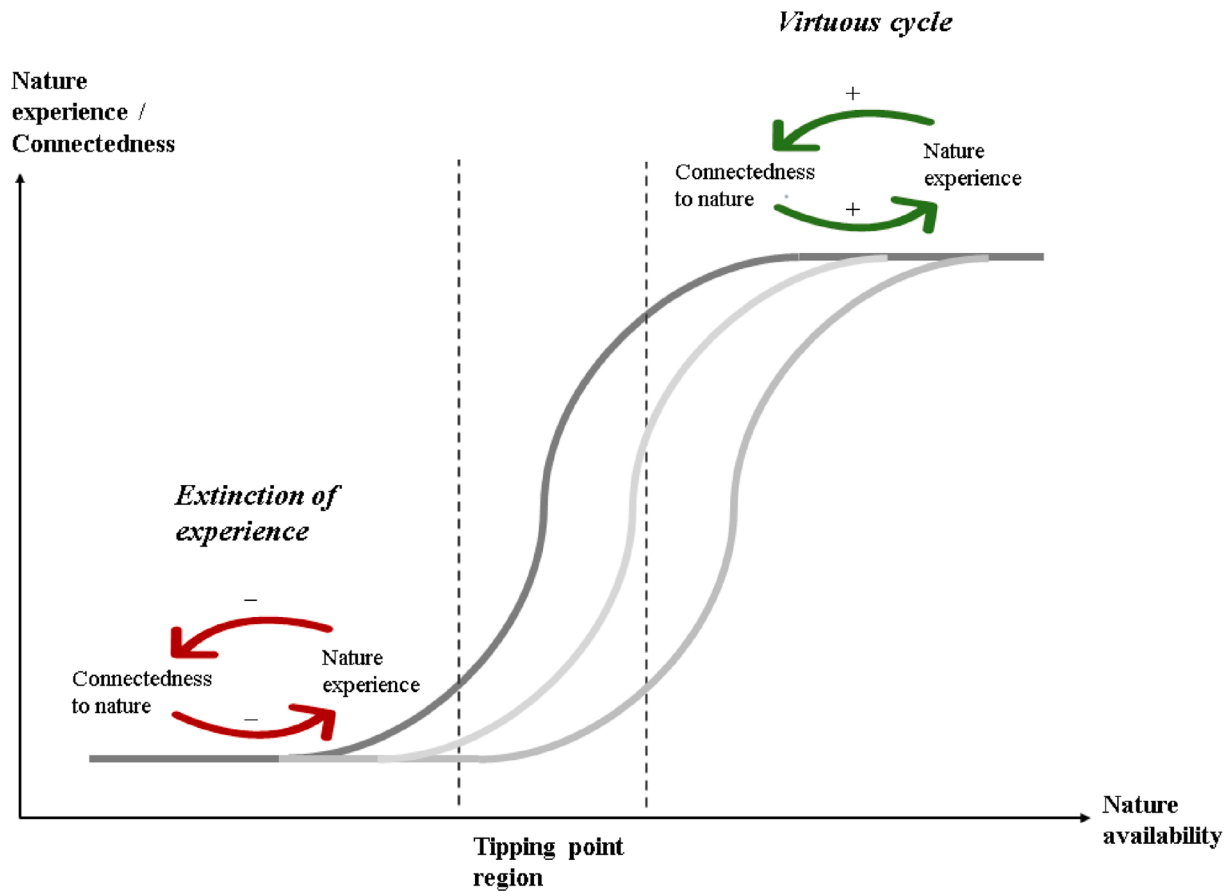


Fig. 1. Graphical representation of EoE as dynamic system with tipping point dynamics.

Note. Each of the dark to light grey lines represent a possible trajectory from EoE towards a virtuous cycle. While the specific tipping point may differ, all lines show that the relationship between nature availability and connectedness to nature is non-linear—small changes in nature availability can result in disproportionately large or small shifts in connectedness to nature.

connectedness to nature. This makes ABM a valuable complement to existing cross-sectional research on the topic (Colléony et al., 2020; Garfinkel et al., 2024). While other methods exist for analysing system dynamics (for an overview, see Bala et al., 2017), ABM’s explicit focus on agents’ interactions with the environment makes it especially well-suited for capturing the person–environment feedback loops that lie at the heart of the EoE. Moreover, ABM enables the simulation of these feedback loops over extended time periods, making it a powerful tool for modelling long-term, recurrent processes and identifying potential tipping points—moments when shifts in nature availability, nature experience and connectedness to nature may push the system into either a vicious or a virtuous cycle (Gaston & Soga, 2020; Pyle, 1978; Soga & Gaston, 2016).

1.3. An agent-based model of the EoE

Any ABM starts off with a “system map” that dictates how agents interact with their environment. Building upon earlier theorizing (Gaston & Soga, 2020; Soga & Gaston, 2016), we model the EoE by examining the dynamic interaction among three interconnected components: (a) (changes to) the availability of nature in agents’ environment, (b) agents’ experience of nature, and (c) agents’ connectedness to nature. Our system map is shown in Fig. 2a and consists of two integrated feedback loops. The primary feedback loop consists of pathways 1, 2a, and 3, and thus encompasses all three components.

Pathway 1 shows how the availability of nature in an agent’s environment affects their likelihood of experiencing nature. Cross-sectional research supports this relationship by showing that when nearby nature

is available or readily accessible to individuals, this increases their opportunities for experiencing it (e.g., Neuvonen et al., 2007; Žlender & Ward-Thompson, 2017).

Pathway 2a illustrates how nature experiences can affect agents’ connectedness to nature. Ample (cross-sectional) research supports the notion that spending time in natural environments makes people feel more connected to nature, documenting its influence across diverse forms of nature (e.g., rural and coastal areas: Wyles et al., 2019; an arboretum: Mayer et al., 2009), various types of interactions (e.g., walking

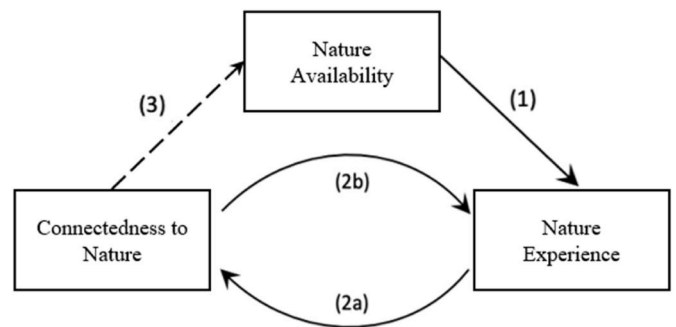


Fig. 2A. The association between (Changes in) nature availability, nature experience and connectedness to nature

Note. The arrow from connectedness to nature to nature availability is dashed to illustrate that the relationship can be direct (via pro-conservation behaviours, such as cultivating plants) as well as indirect (via pro-environmental actions, such as voting for political parties that prioritize nature conservation).

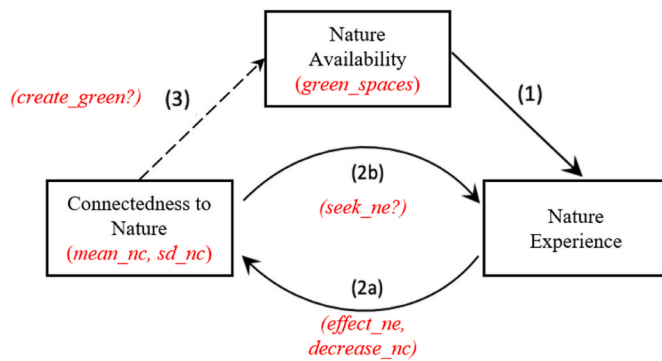


Fig. 2B. The association between (Changes in) nature availability, nature experience, and connectedness to nature and corresponding model parameters. Note. The theoretical constructs of nature availability, nature experience and connectedness to nature are written in black. The corresponding model parameters are denoted in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

barefoot; Rickard & White, 2021; imagining nature; Coughlan et al., 2022) and developmental phases (for a review, see Chawla, 2020). Of particular note is the significant research focus on how childhood experiences of nature play a pivotal role in positively shaping individuals' later-life connections to the natural world (Cleary et al., 2020; Drescher et al., 2022; Li et al., 2022; Pensini et al., 2016).

Finally, pathway 3 shows that the level of agents' connection to nature can influence the availability of nature. Research indicates this can occur in both direct and indirect ways. Directly, because individuals with a strong connection to nature are known to engage in pro-conservation behaviours, such as cultivating plants and flowers (Hughes et al., 2018) or enhancing biodiversity of urban gardens (Samus et al., 2022) that all allow them to experience nature. Connectedness to nature can also influence nature availability indirectly, because it can foster pro-environmental actions (Mackay & Schmitt, 2019; Whitburn et al., 2020), such as voting for political parties that prioritize nature conservation, or reducing traveling by plane or eating meat (Richardson et al., 2020), which in the long run contribute to mitigating the loss of nature.

Importantly, within this primary three-component system, we embed a secondary feedback loop involving nature experiences and connectedness to nature (i.e., pathway 2a and 2b). As mentioned, experiencing nature can foster a sense of connectedness to nature (pathway 2a). Conversely, a heightened connectedness to nature is also known to motivate agents to actively seek more opportunities to engage with nature (pathway 2b; Collégony et al., 2017; Hinds & Sparks, 2008; Nisbet et al., 2009).

1.4. The present research

For the present research, we translated this three-component system representation of the EoE (cf. Soga & Gaston, 2016) into an ABM, using the software *NetLogo* (version 6.2.1, Wilensky, 1999). We created a simulated environment consisting of a mix of green- and grey spaces, representing natural and built areas/spaces, respectively. As agents move through this environment over different cycles of the model, their experience of a green- (vs. grey) space will strengthen their connection to nature, in turn leading to increases in the availability of greenspace. For an impression of the model interface in *NetLogo*, please see Fig. 3. We ran different versions of this model, systematically varying the initial amount of greenspace availability. This manipulation allowed us to explore whether and at which level(s) of nature availability the system would either tip towards the EoE, remain stable, or even trigger a virtuous cycle.

2. Method

2.1. Environment and agents

The ABM comprises two key elements: a spatial environment and agents. The environment is represented by a square grid consisting of 800 square patches that are coloured either green or grey. Green patches are randomly distributed across the grid and represent greenspace, providing agents an opportunity to experience nature. Grey patches represent grey, non-natural spaces, such as streets or buildings in a real-life context. Within this spatial model, upon initialization, 100 agents are randomly positioned on either a green or grey patch, each exhibiting varying levels of baseline connectedness to nature.

2.2. Cycles of the ABM and agent-environment interactions

The model operates in discrete cycles. During each cycle, agents go through the following four phases: (1) "move", (2) "experience", (3) "connect" and (4) "change the availability of nature". First, agents *move* through the environment, representing everyday mobility of individuals. Their movement can be directed toward a green patch, or be aimless, representing all other forms of movement, which we will explain in the next section. Second, upon completing their movement, agents may end up on a green patch, allowing them to *experience* nature, or they can end up on a grey patch. In the third phase, agents' *connectedness* to nature is updated, depending on their location: connectedness slightly increases when agents end up on a green patch but decreases (to a smaller extent) on a grey patch. Fourth, depending on their level of connectedness to nature, agents can *change* the availability of nature by either removing or creating one green patch.

Through repeatedly iterating the aforementioned cycle (comprising the four phases), agent-environment interactions can lead to changes in both agents and the environment. First, an agent's level of connectedness to nature influences its tendency to seek out and experience greenspace (i.e., green patches), with higher connectedness to nature increasing the likelihood of seeking out greenspace experiences. Second, experiencing greenspace in turn affects an agent's connectedness to nature, with exposure to a green (vs. grey) patch increasing (vs. decreasing) connectedness. Third, connectedness to nature can lead to changes in the availability of greenspace. If an agent has a relatively high level of connectedness to nature, it may create one additional green patch, whereas low (er) levels of connectedness may lead to the removal of one green patch by replacing it with a grey patch. A scheme of the full decision cycle is provided in Fig. 4.

2.3. Parameters governing agents, the environment and their interactions

For our ABM to be operationable, we formalized (characteristics of) agents, environments and their interactions. In Table 1, we provide all simulation parameters and their default values. In the following, we describe each parameter and explain the origin of the parameter values and how they relate to the pathways from Fig. 2a. While the parameters *green_spaces* (*gs*), *n_agents* (*N*), *mean_nc* (*M*) and *sd_nc* (*SD*) define specific constructs, the parameters *effect_ne* (*a*), *decrease_nc* (*b*), *seek_ne?* and *create_green?* specify the relationships between these constructs (please note Fig. 2b). The parameter *max_n_cycles* (*s*) is needed for the model to operate, which we elaborate on in the following.

max_n_cycles (*s*). This parameter sets the number of cycles at which the model stops and therefore determines the length of simulations runs. The more cycles, the longer the simulations run. The default value is 10,000 as with this number of cycles there is enough time for the dynamics between nature availability, nature experience and connectedness to nature to give rise to either the EoE or a virtuous cycle.

green_spaces (*gs*). The parameter *green_spaces* describes the percentage of green vs. grey patches in the simulated environment. It can range from 0% (i.e., no green patches) to 40%, with a default value of

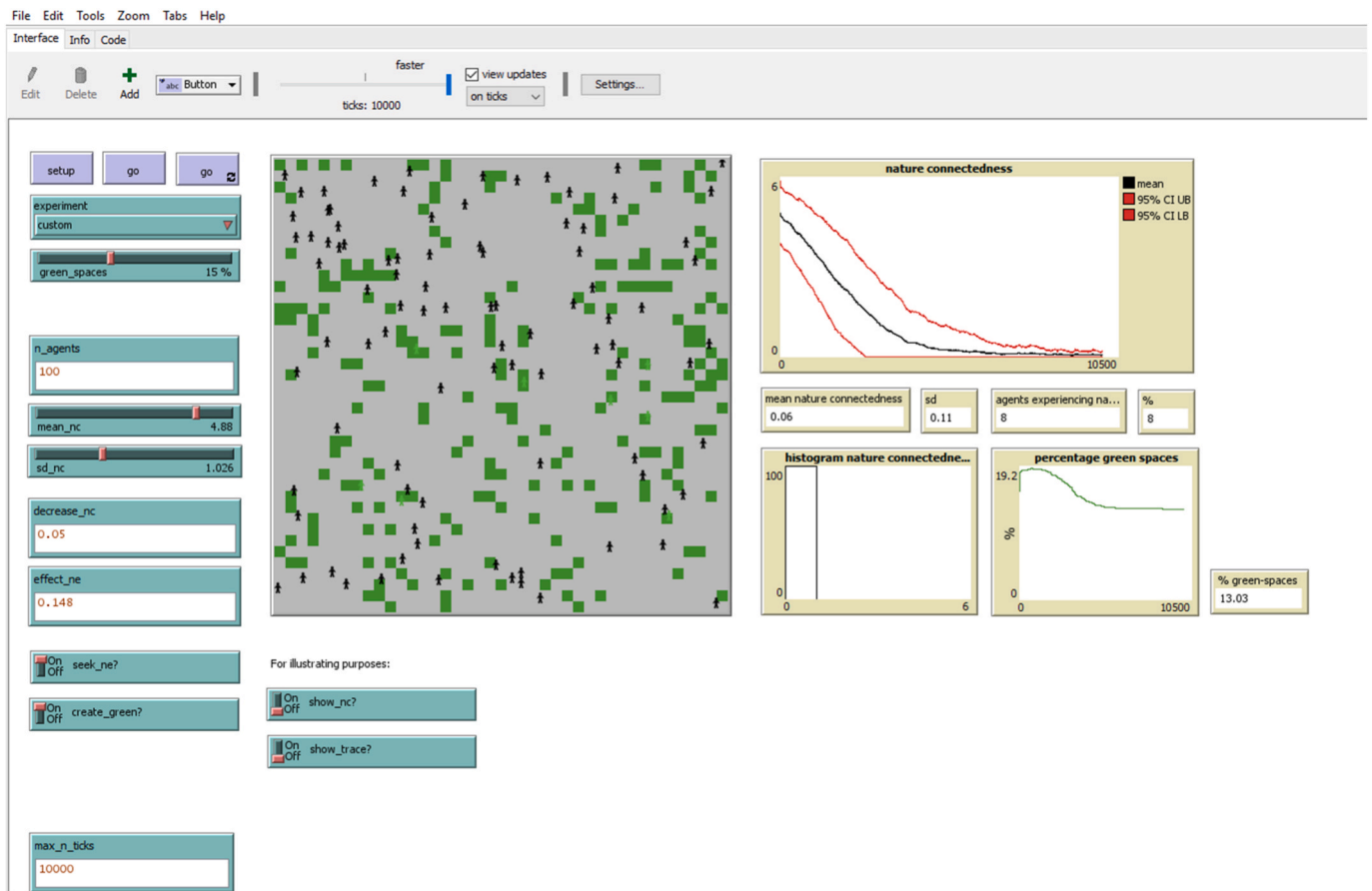


Fig. 3. Model interface in NetLogo.

25 %. This default was chosen as a midpoint estimate informed by global data: Urban greenspace averages around 17 %, while average urban tree canopy cover is approximately 26 % (HUGSI, 2021). The parameter `green_spaces` (`gs`) is essential for **pathway 1**. As agents move around in the simulated environment, the higher the percentage of greenspace in the environment, the more likely agents are to land on a green patch.

n_agents (N). The parameter `n_agents` defines the size of the population of agents and has a default value of 100. We chose this default value to ensure sufficient variation within the population while maintaining manageability.

mean_nc (M) and sd_nc (SD). These parameters determine the initial mean and standard deviation of connectedness to nature (`nc`) in the population of agents. A key challenge in modelling connectedness to nature at the population level is the lack of large-scale, cross-national datasets that directly measure this construct. To address this, we turned to a related and available proxy for which cross-national data exist: green self-image. This measure reflects the extent to which looking after the environment is important for individuals and the extent to which individuals strongly believe that people should care for nature (Welsch & Kühling, 2018). While not identical to connectedness to nature, Brügger et al. (2011) show that the scales for green self-image and connectedness to nature converge (correlations between measures: $r = 0.66$), supporting its use as a proxy. We used cross-national data on green self-image from the European Social Survey (Welsch & Kühling, 2018), which includes 228,390 observations across 35 countries. Based on this dataset, we set the initial parameter values for `mean_nc` and `sd_nc` to $M = 4.88$ and $SD = 1.026$, respectively. Upon model initialization, every agent draws a value from a normalised distribution with a mean of 4.88 and standard deviation of 1.026 on a scale from 0 to 6, where higher values indicate higher connectedness to nature. Hence, agents differ from each other in terms of their initial connectedness to nature.

effect_ne (a). Based on the theoretical background outlined in the Introduction, we expect that experiencing nature promotes peoples' connectedness to nature. The parameter `effect_ne` (`a`) defines the amount by which connectedness to nature increases upon experiencing nature and is therefore relevant for **pathway 2a**. We parameterized this part of our model based on the study by Alcock et al. (2020) where they quantified the relationships between neighbourhood greenspace, recreational nature visits and appreciation of the natural world (i.e., connectedness to nature). We used their estimates from the structural equation model as a proxy to define our parameter. Specifically, in their results the covariance between nature visits and nature appreciation is 0.148 (95 % CI: 0.140, 0.157) which we used to express that people's connectedness to nature can increase by 0.148 when they are on a green patch.²

However, we deem it unlikely that peoples' connectedness to nature increases every single time they encounter greenspace. Hence, instead of modelling that an agent landing on a green patch will always lead to an increase in connectedness to nature by 0.148, we modelled that for agents landing on a green patch there would be a likelihood of 10 % that their connectedness to nature will be increased by 0.148. The likelihood of 10 % is derived from Alcock et al. (2020), who found that 10 % of the variance in individuals' connectedness to nature is accounted for by the availability of nature in their neighbourhood. We used this explained variance statistic as a proxy to express the chance of updating connectedness to nature based on nature experience.

² Because the translation from cross-sectional, sample based statistics to causal relationships on the agent level is arguable, we conducted sensitivity analyses exploring the impact of different parameter values on the dynamics (please see appendix).

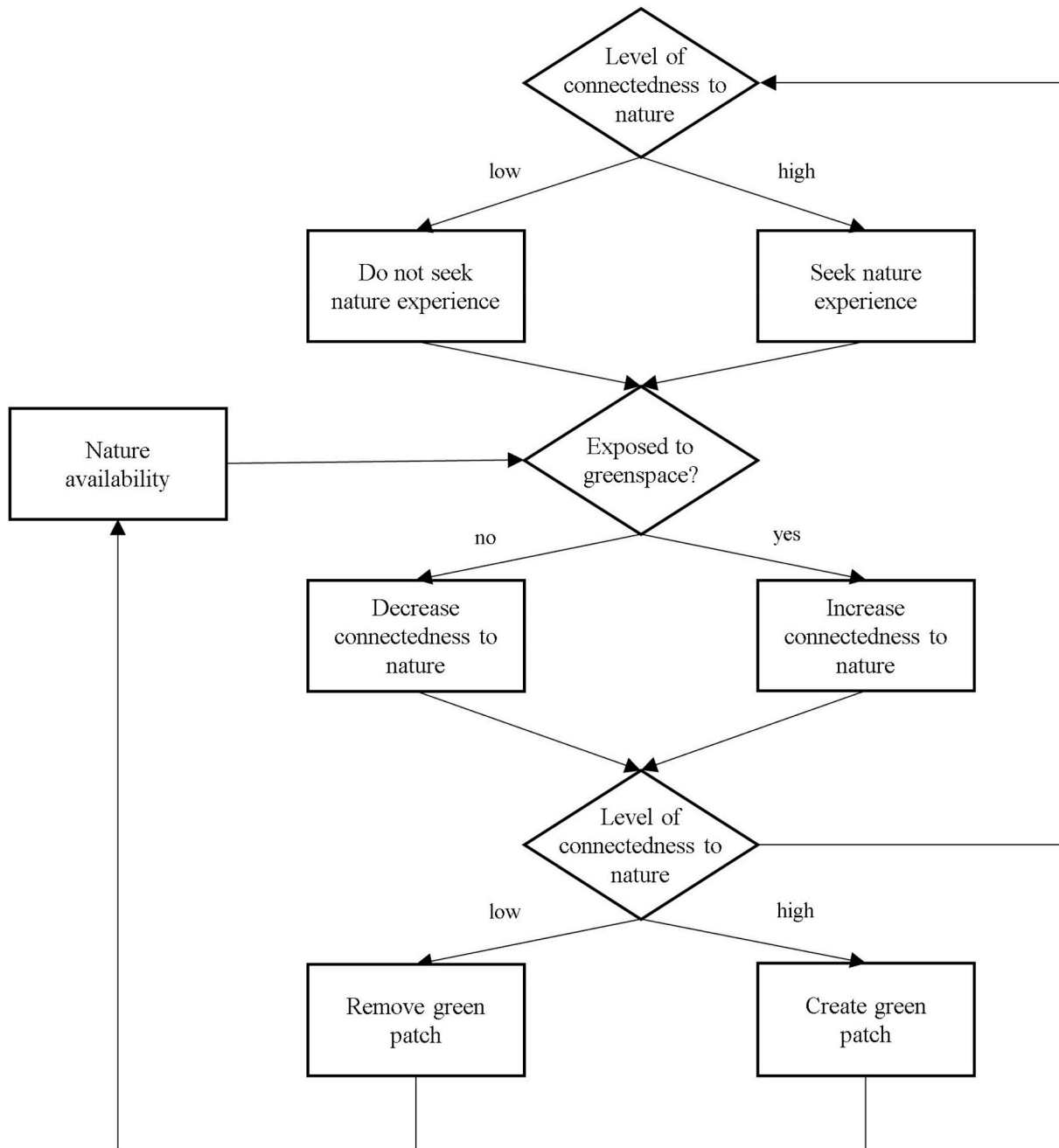


Fig. 4. Flowchart describing the decision cycle of agents.

decrease_nc (b). This parameter defines the amount by which connectedness to nature decreases when *not* experiencing nature (i.e. when the agent does not end up on a green patch). To consider that connectedness to nature is relatively stable across time, even though nature experiences may decrease (Clayton et al., 2018; Kaiser et al., 2014), the default value of the parameter expressing the decrease in connectedness over time (when agents are on grey patches) is chosen to be smaller ($b = 0.05$) compared to the increase in connectedness (when agents land on a green patch, $a = 0.148$). When agents land on a grey patch they have, similar to the effect_ne parameter, a 10 % chance that their connectedness to nature decreases by 0.05 (Alcock et al., 2020).

seek_ne? The parameter seek_ne? Is decisive for **pathway 2b**. Setting this parameter to “yes” enables agents to actively seek nature experiences. Whether or not agents seek nature experiences depends on their connectedness to nature. Based on the theoretical background

outlined in the Introduction, we expected that the higher agents’ connectedness to nature, the more likely they would be to actively seek nature experiences. We operationalised this by increasing the probability of an agent seeking nature proportionally with their connectedness to nature (nc), following $P(\text{seek nature}) = nc/6$. For $nc = 1$, the probability $P(\text{seek nature})$ is $1/6$ ($\approx 16.7\%$), increasing linearly up to $nc = 6$, where the probability is $6/6$ ($=100\%$).

In addition, independent of agents’ connectedness to nature, we assumed that people would encounter various reasons that would prevent them from seeking nature experiences (e.g., no available nature nearby). Therefore, we incorporate an additional probability condition: Agents have a 16 % chance of moving toward the closest green patch; otherwise, agents will move in a random direction. The likelihood of 16 % is based on Alcock et al. (2020) who found that 16 % of the variance in individuals’ nature visit frequency was accounted for by availability of

Table 1
Simulation parameters.

Name	Symbol	Range	Default	Source	Description
green_spaces	gs	(0, 40)	25	HUGSI (2021)	Proportion of green vs. grey patches, expressed in percentages.
n_agents	<i>N</i>	\mathbb{N}	100		Size of the population of agents.
mean_nc	<i>M</i>	(0, 6)	4.88	Welsch & Kühling (2018)	Initial mean connectedness to nature in the population of agents.
sd_nc	<i>SD</i>	(0, 3)	1.026	Welsch & Kühling (2018)	Initial standard deviation of connectedness to nature in the population of agents.
decrease_nc	<i>b</i>	\mathbb{Q}^+	0.05	Kaiser et al. (2014); Clayton et al. (2018)	The amount by which connectedness to nature decreases when not experiencing nature.
effect_ne	<i>a</i>	\mathbb{Q}^+	0.148	Alcock et al. (2020)	The amount by which connectedness to nature increases upon experiencing nature.
seek_ne?		yes/no	Yes		Whether or not agents can actively seek nature.
create_green?		yes/no	Yes	Clayton et al. (2018)	Whether or not agents have the ability to create and remove a green patch, respectively.
max_n_cycles	<i>s</i>	\mathbb{N}	100 000		Number of cycles at which the model stops.

nature in their neighbourhood. We used the explained variance statistic as a proxy to express the chance of seeking nature experiences. Thus, only if both probability conditions are met, agents will move towards the closest green patch (i.e., seek nature experience).

create_green? This parameter is decisive for **pathway 3**. Setting this parameter to “yes” enables agents to create and remove a green patch once, respectively, per simulation run. This mirrors our reasoning that individuals’ connectedness to nature can influence nature availability directly (via pro-conservation behaviours) as well as indirectly (via pro-environmental actions, such as voting for political parties that prioritize nature conservation).

We incorporated only the direct pathway into our model, assuming that individuals with a strong connection to nature are more likely to engage in pro-conservation behaviours, such as cultivating plants and flowers or enhancing urban garden biodiversity. Conversely, we assume that individuals with low connectedness to nature are less likely to engage in such behaviours and may (for example) even replace plants with paving. Translated into the model, if an agent has a high connectedness to nature ($nc > 5$) and is on a grey patch, it can turn the patch into a green one with a likelihood of 38.6 %. This probability is based on Clayton’s et al. (2018) findings that 38.6 % of adults create gardens. If the agent is on a green patch, but has a low connectedness to nature ($nc = 0$), it can turn the patch into a grey one with a likelihood of 38.6 %.

2.4. Simulation experiments

We used NetLogo’s *BehaviourSpace* feature to run simulation experiments, setting the runtime at 10,000 cycles. To explore the potential tipping point where the dynamics of nature availability and connectedness to nature might lead to either the EoE or to a virtuous cycle, we systematically varied the percentage of green patches (see variable *green_spaces*). Six greenspace conditions were created: 5 %, 10 %, 15 %, 20 %, 25 % and 30 % of greenspace, with all other parameters kept at their default values. For each greenspace condition, we conducted thirty independent simulations, resulting in a total of 180 simulation runs.

We analysed the data produced by these simulations using a separate R script (*RStudio* version 2022.02.2 + 492, the model, data and R script can be found in the supplementary materials). To explore the emergence of the EoE or a virtuous cycle, we investigated connectedness to nature and percentage of greenspace over time and conditions using time series analyses. To assess the effect of greenspace condition on connectedness to nature and on the percentage of greenspace at the end of simulation runs, we conducted analyses of variance. We used two-tailed independent samples *t*-tests with Welch’s correction of unequal variances to compare the six greenspace conditions (cf. Mittal et al., 2019). Furthermore, we investigated potential tipping points by examining how small changes in the percentage of greenspace could lead to non-linear effects on connectedness to nature. To further explore how different values for each parameter would impact the dynamics of nature availability, nature experience and connectedness to nature, we performed sensitivity analyses.

3. Results

3.1. Time effects

Fig. 5 shows the change in agents’ mean connectedness to nature (Fig. 5a) and percentage of greenspace (Fig. 5b), averaged across the 30 simulation runs for each of the six greenspace conditions. Means and standard deviations of both measures at beginning and at the end of the simulation runs by condition are mentioned in Table 2. Inspection of the graphs shows that across all conditions and for both connectedness to nature and percentage of greenspace, there are no fluctuations of connectedness to nature over time (i.e., no drops followed by increases, or vice versa). These resulting system states are stable, indicating that once the system has moved towards either the EoE or to a virtuous cycle, it remains on that trajectory, with little possibility of reversal. For both measures, connectedness to nature and percentage of greenspace, conditions 1 to 3 quickly settle into a stable state, stabilizing after the first quarter of simulation runs.

Examining connectedness to nature, in most conditions there is a decline in connectedness over time. The exception is greenspace condition 6 (i.e., 30 % initial greenspace), where connectedness to nature is slightly higher at the end of the simulation ($M = 5.61$, $SD = 0.09$) than at the beginning ($M = 4.89$, $SD = 0.10$).

The pattern for the evolution of greenspace percentage over time is more complex. Initially, there is a slight and very brief increase across all six greenspace conditions, followed by a drop below initial levels in conditions 1 through 4. In other words, we document the EoE: when the initial greenspace area is 15 % or lower (conditions 1–3), there is a vicious cycle where nature availability shrinks over time. Nevertheless, in condition 4 (i.e., 20 % initial greenspace), the percentage of greenspace remains substantial with a value of 18.79 ($SD = 1.72$) at the end of the simulation, even though connectedness to nature nearly drops to zero in this condition ($M = 0.46$, $SD = 0.28$). Conversely, an overall increase in the percentage of greenspace (i.e. a virtuous cycle) is observed in conditions 5 (i.e., 25 % of initial greenspace, final percentage of greenspace $M = 29.97$, $SD = 2.07$) and 6 (i.e., 30 % of initial greenspace, final percentage of greenspace $M = 35.95$, $SD = 1.32$).

The conditions differ in terms of speed by which the model reaches

a) Connectedness to Nature over Time

b) Percentage of Greenspace over Time

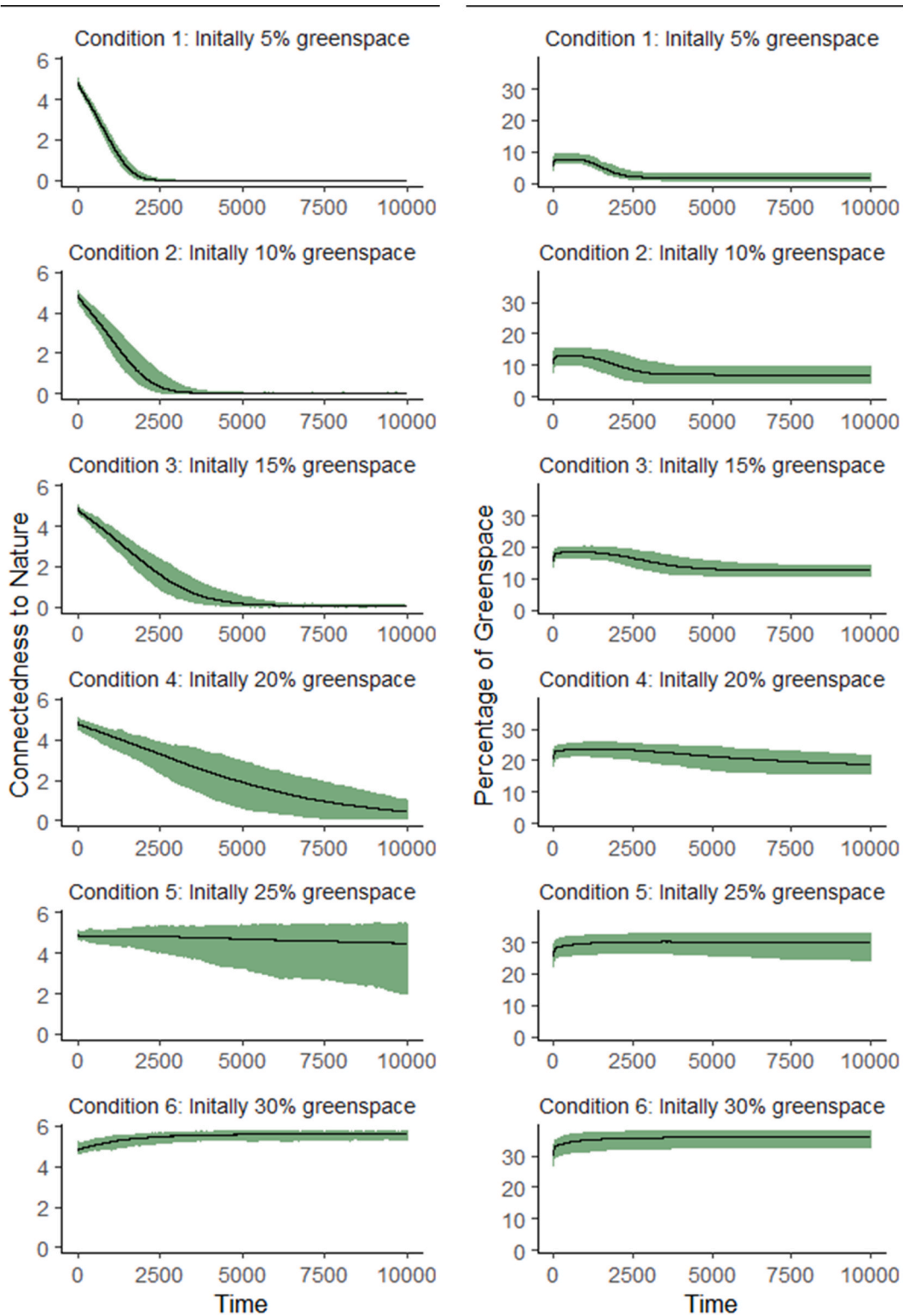


Fig. 5. A) Connectedness to Nature over Time b) Percentage of Greenspace over Time
Note. Green lines refer to a) connectedness to nature or b) percentage of greenspace for each simulation run per condition, black lines denote the average a) connectedness to nature or b) percentage of greenspace across 30 simulation runs per condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2

Means and standard deviations of the connectedness to nature and percentage of greenspace at the beginning and the end of simulation runs by condition.

	Connectedness to nature		Percentage of greenspace	
	Beginning	End	Beginning	End
Condition 1	4.84 (0.08)	0.01 (0.01)	5.03 (0.50)	1.80 (0.54)
Condition 2	4.87 (0.11)	0.03 (0.01)	9.98 (0.88)	7.04 (1.10)
Condition 3	4.87 (0.07)	0.08 (0.01)	15.23 (0.78)	12.67 (0.87)
Condition 4	4.85 (0.13)	0.46 (0.28)	20.00 (0.97)	18.79 (1.72)
Condition 5	4.88 (0.12)	4.47 (0.80)	25.27 (1.18)	29.97 (2.07)
Condition 6	4.89 (0.10)	5.61 (0.09)	30.04 (1.28)	35.95 (1.32)

Note. Standard deviations are in parentheses.

its new equilibrium (i.e. a stable system state). For the conditions generating the EoE (i.e., condition 1–4), we observe that the lower the initial percentage of greenspace, the quicker the model stabilizes at a lower level of connectedness to nature and percentage of greenspace.

3.2. Effect of nature availability on connectedness to nature

In addition to looking at the time evolution of our dependent measures, we examined the effect of the initial percentage of greenspace (i.e., nature availability) on connectedness to nature and percentage of greenspace at the end of simulation runs. Two ANOVAs were conducted, revealing a statistically significant effect of greenspace condition on both measures (final connectedness to nature: $F(1, 178) = 513.13, p < 0.01$; final percentage of greenspace: $F(1, 794.59) = 6062.3, p < 0.01$). The results suggest that a 5 % increase in initial greenspace coverage leads to significant differences in both mean connectedness to nature and percentage of greenspace at the end of simulations (see Table 3 for contrasts between all conditions).

3.3. tipping point dynamics

The time-series graphs show a transition from a decline to an increase in connectedness to nature over time that emerges between greenspace condition 4 (i.e., 20 % of initial greenspace) and 6 (i.e., 30 % of initial greenspace). To zoom in on these shifting dynamics further, we reran the simulation, adjusting the initial greenspace percentage from 20 % to 30 % in 1 % increments, with 30 simulations per condition.

Fig. 6 shows the mean connectedness to nature at the end of the simulation runs as a function of the initial percentage of greenspace, illustrating an s-shaped transition and a tipping point region towards either the EoE or a virtuous cycle. At 15–18 % of initial greenspace, the model consistently results in an EoE with low variance: in all simulations, connectedness to nature reduces almost to zero. Between 19 and 21 %, this outcome persists, but increasing variance of the final mean connectedness to nature signals that the system becomes less stable. A sharp increase in connectedness to nature occurs as the initial prevalence of greenspace is increased to 22–24 %, indicating a system shift and a tipping point. Beyond 24 %, connectedness to nature continues to rise but at a slower rate, with decreasing variance. Thus, the model identifies a tipping point between 22 % and 24 % greenspace coverage, beyond which the system consistently settles in either a vicious or a virtuous cycle.

Table 3

Significant differences between conditions for connectedness to nature and percentage of greenspace, respectively, at the end of simulation runs.

	Initial percentage of greenspace					
	5 %	10 %	15 %	20 %	25 %	30 %
Connectedness to nature	0.01 _a (0.01)	0.03 _b (0.01)	0.08 _c (0.01)	0.46 _d (0.28)	4.47 _e (0.80)	5.61 _f (0.09)
Percentage of greenspace	1.80 _a (0.54)	7.04 _b (1.10)	12.67 _c (0.87)	18.79 _d (1.72)	29.97 _e (2.07)	35.95 _f (1.32)

Note. Standard deviations are in parentheses. Means that do not share subscripts differ by $p < 0.01$ according to unpaired two-sample two-tailed t-test with Welch's correction of unequal variances.

3.4. Sensitivity analysis

The previous results show that small changes in nature availability can be decisive in shifting the entire system from the EoE to a virtuous cycle or vice versa. However, the exact percentage of greenspace at which this tipping point occurs depends on the model parameters. We conducted a sensitivity analysis to check the robustness of the non-linear relationship between nature availability and connectedness to nature and to explore where the tipping point lies for different parameter configurations.

Here, we will showcase how the model reacts to different parameter values for decrease_nc. Specifically, we study the impact of different parameter values for decrease_nc on mean connectedness to nature for different levels of initial greenspace percentage. The appendix provides a comprehensive description of further sensitivity analyses, where we explore how the model reacts to different parameter values for mean_nc, sd_nc, effect_ne, seek_ne? create_green?

Fig. 7 shows a heat map visualizing mean connectedness to nature at the end of the simulation runs separated per level of greenspace on the x-axis (ranging from 4 % to 40 %) and different parameter values for decrease_nc on the y-axis (ranging from $b = 0.03$ to $b = 0.07$). The colour intensity represents the mean connectedness to nature at the end of the simulation runs: red, indicating low connectedness to nature ($nc < 2$; i.e., emergence of the EoE - a vicious cycle), green, which indicates high connectedness to nature ($nc > 4$, i.e., emergence of a virtuous cycle).

Examining each row in the heat map, we observe that final connectedness to nature does not increase gradually with rising nature availability. Instead, the EoE persists up to a certain threshold of initial greenspace, beyond which the system undergoes a shift and gives rise to a virtuous cycle. Testifying to the robustness of our earlier results, this shows again that nature availability has a non-linear influence on connectedness to nature, which generates tipping points beyond which the system stabilizes into a dynamic equilibrium (either into a vicious or a virtuous cycle).

Comparing across rows in the heat map, it becomes clear that the higher the decrease_nc parameter (thus, the stronger connectedness to nature decreases without nature experience) the more initial greenspace is needed to prevent the EoE. With $b = 0.03$, 12 % of initial greenspace is needed to sustain a virtuous cycle; whereas with $b = 0.07$, 40 % of greenspace is not enough to prevent the EoE. The broad range of tipping point values indicates that the model is highly sensitive to this parameter value. Still, the dynamics between nature availability, nature experience and connectedness to nature are independent of specific parameter values and we can reliably detect tipping point dynamics across different scenarios.

4. Discussion

The EoE framework is sometimes used to issue a cautionary warning to policymakers: when nature availability falls below a critical threshold—a tipping point—even a small additional loss could, in theory, trigger a cascade of further reductions, with limited potential for reversal. Until now, the EoE has remained a verbal theory, lacking formal models that capture its systemic structure. Moreover, there has been no attempt to simulate the EoE as a system of interacting components that allow for feedback mechanisms. As a result, it remains unclear

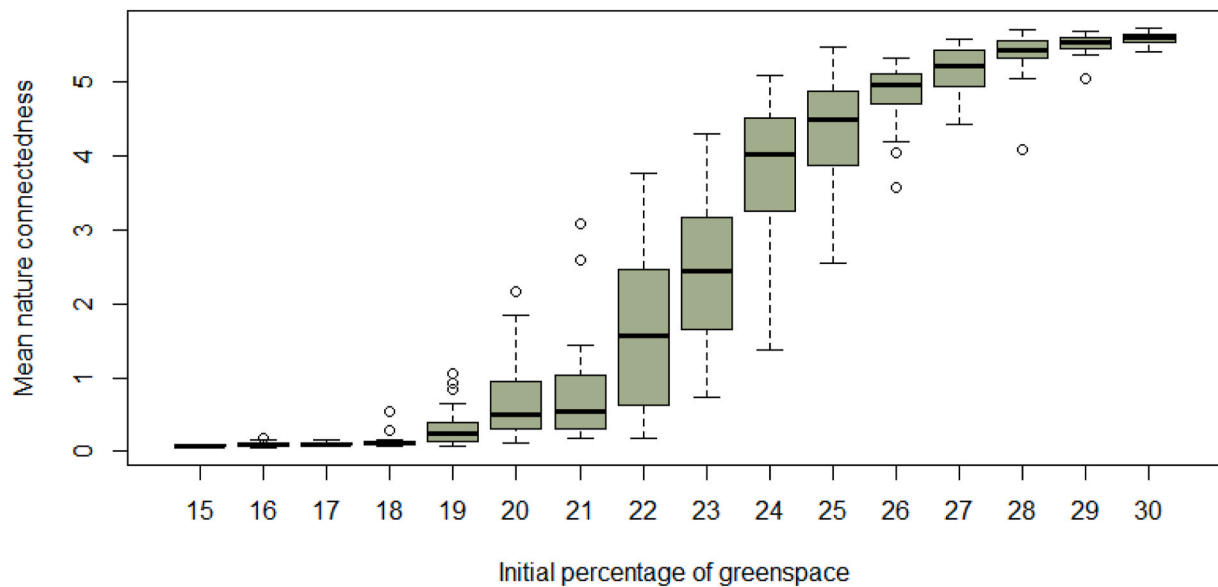


Fig. 6. Boxplots of the mean connectedness to nature at the end of simulation runs per level of greenspace.

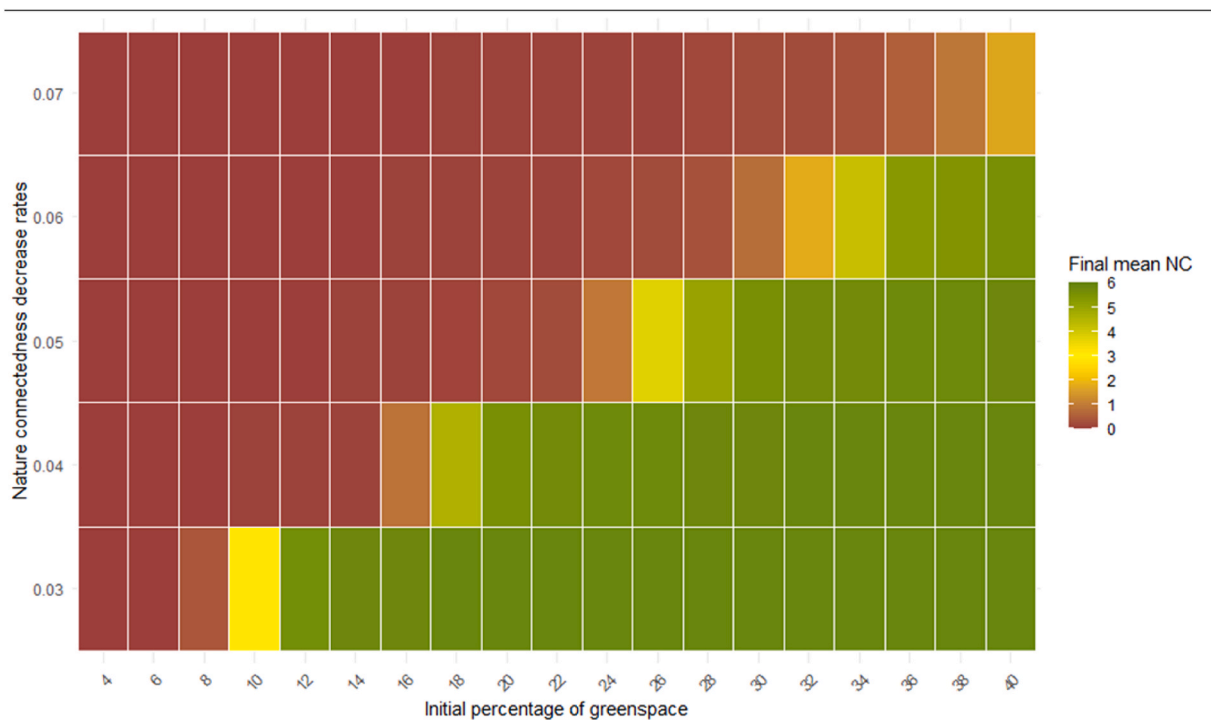


Fig. 7. Mean connectedness to nature at the end of simulation runs with different parameter values for the decrease rate of connectedness to nature. Note. The default value for decrease_nc that was used in the main analysis is $b = 0.05$.

whether the EoE truly implies tipping point dynamics, where small changes in nature availability can lead to a qualitatively different system state. In this study, we used ABM to formalize the EoE framework and simulate its dynamics over time, involving feedback loops and tipping point dynamics.

In our simulations, we varied the initial percentage of greenspace and examined how these variations affected long term patterns of nature availability and connectedness to nature. The results indicate that staying above a minimal threshold of greenspace is crucial for sustaining a dynamic equilibrium. When greenspace covers less than 23 % of the environment, a self-reinforcing feedback loop sets in: the EoE becomes inevitable and accelerates as the initial amount of greenspace decreases.

Conversely, when greenspace exceeds 25 %, this vicious cycle is mitigated or even reversed into a virtuous one, where both connectedness to nature and nature availability mutually reinforce each other. The model thus identifies a tipping point between 23 % and 25 % greenspace coverage, below which the system triggers a vicious cycle of declining nature availability. The resulting system states are stable, meaning that once the system shifts towards either EoE or its virtuous counterpart, it remains on that trajectory, with little possibility of reversal.

The findings suggest that relatively high levels of nature availability in an individual’s environment can positively influence their connectedness to nature, potentially counteracting the EoE. While some scholars have argued that simply increasing nature availability may not

significantly affect connectedness to nature (Kaiser et al., 2014; Nisbet et al., 2009), our results highlight an important nuance. Specifically, not all increases in greenspace are equally effective: a meaningful shift requires surpassing a critical threshold. Once this tipping point is approached, even a small increase—as small as 1 %—can shift the system away from extinction and towards sustained high levels of nature availability and connectedness to nature.

4.1. Limitations and ideas for future research

The present work is of course not without limitations. One important issue is that for some variables we lacked appropriate data to calibrate and validate the ABM, which is common for empirically parameterized ABMs (Jager & Ernst, 2017). Specifically, we had no empirical basis to determine the extent to which connectedness to nature decreases when agents are deprived of nature experiences. This is important, as our sensitivity analyses showed that the percentage of greenspace needed to sustain a virtuous cycle strongly depend on the specific parameter value for this decrease rate. We therefore caution against interpreting our results as evidence for the fact that there is an absolute tipping point (i.e. 23–25 %) below which the EoE sets in real life. However, our simulations consistently show the possibility of tipping points *dynamics*: across different parameter values, we reliably find that the relationships between nature availability, nature experience and connectedness to nature are non-linear such that a small change in nature availability can trigger large and irreversible changes in connectedness to nature. Thus, with our ABM, we address a broader gap in the literature: much of the current research on connectedness to nature and nature experience relies heavily on cross-sectional data, limiting our capacity to model dynamic feedback loops and long-term effects.

Scholars have acknowledged the limited empirical documentation of the EoE (Gaston et al., 2020), particularly with regard to establishing causal relationships between nature experience and connectedness to nature. Ideally, agent-based models such as ours—designed to capture dynamic interactions—should be validated against longitudinal or time-series data that reflect how these variables evolve over time. Unfortunately, such datasets remain scarce. In this context, we view our model not only as a theoretical advancement, but also as a call to action—urging researchers to design and implement studies that track nature experience and connectedness to nature over time. Such efforts would provide critical data for more robust model calibration and empirical validation.

Our model necessarily abstracts from a far more complex reality—one that includes diverse forms of nature, multiple ways of interacting with natural environments, social influence and the bidirectional relationship between these interactions and connectedness to nature. However, our primary objective was not to capture every possible predictor of nature experience or connectedness to nature. Instead, we translated the verbal account proposed by Pyle into an ABM, allowing us to test whether the model's components actually would lead to feedback loops and tipping point dynamics. To that end, we included only the core conceptual building blocks of Pyle's account. This level of simplification, which is common in variable-based psychological modelling, does not suggest that other factors are unimportant, but rather that they fall outside the current scope of the model. Yet, despite its simplicity, the model reveals tipping point dynamics: beyond a certain threshold, self-reinforcing feedback loops are triggered, ultimately leading to the onset of the EoE or its virtuous counterpart.

To enrich our model, future research could develop more sophisticated frameworks that better capture inter- and intra-individual differences in the effects of nature experiences. Some individuals may feel more connected to nature following nature experiences than others, and this effect can vary across the lifespan. Prior research indicates that nature experiences during childhood are particularly influential in shaping connectedness to nature (Rosa et al., 2018), a developmental factor that future models should consider. Moreover, integrating social

interactions between agents and broader socio-cultural factors—such as prevailing cultural attitudes toward nature or environmental education policies—could offer a valuable direction for future research aiming to reflect the complex, population-level dynamics of connectedness to nature. Finally, our model treated all greenspaces as identical, assuming a uniform influence on agents. Yet, some natural environments—such as forests—may offer richer and more immersive experiences than others, like grass fields (Hartig et al., 2014). Advanced models could thus incorporate greenspaces with qualitatively distinct characteristics, including variations in size, biodiversity and structural complexity, which may differentially impact connectedness to nature.

4.2. Theoretical and practical implications

On a theoretical level, our primary contribution lies in moving the EoE from a verbal conceptual framework into a formal ABM, offering insights into the temporal dynamics underlying the EoE. While cross-sectional studies provide valuable snapshots of associations between variables, they are limited in capturing feedback loops, non-linear dynamics such as tipping points and emergent system-level behaviours. In contrast, ABM enables the modelling of these processes over time, allowing for a more comprehensive understanding of how individual-level mechanisms—such as reduced nature experience or connectedness to nature—mutually reinforce one another and scale up to shape population-level trends.

Regarding practical implications, the model may serve as a valuable tool for visualizing and raising awareness about the dynamic interplay between nature availability, nature experiences and connectedness to nature, as well as their broader consequences at both individual and societal levels. It can be used to effectively communicate these dynamics to researchers, urban planners and other stakeholders. When well calibrated and validated (Rand & Rust, 2011) with empirical data, the model also offers a basis for designing and testing targeted interventions to promote nature availability and foster connectedness to nature—for example, in neighbourhoods where surveys assess residents' nature experiences and connectedness to nature and spatial data are used to gauge local nature availability. Based on such data, recommendations can be made about the minimum amount or quality of nature (often: greenspace) required to prevent a downward spiral toward the EoE. Furthermore, the findings suggest that investing in greenspace yields benefits beyond individual well-being by helping sustain a virtuous cycle in which nature experience, nature availability and connectedness to nature reinforce each other over time.

Although individual action is valuable, an important responsibility rests with policymakers to ensure that sufficient, publicly accessible greenspace is available to meet people's needs for connectedness to nature. In this regard, a key takeaway for practitioners from our simulations is to recognise that even small increases or losses in greenspace/nature could have disproportionate effects—either fostering beneficial environmental engagement or accelerating the EoE. Near tipping points, seemingly minor changes could be decisive in shifting the entire system toward a positive feedback loop or conversely, a vicious cycle of disaffection.

5. Conclusion

This study contributes to the growing body of research identifying the decline in human nature experiences and connectedness to nature as fundamental barriers to societal transitions toward sustainability. Using an ABM approach, we explored the complex and dynamic interplay between nature availability, nature experience and connectedness to nature. Crucially, our findings reveal tipping point dynamics, where small changes in nature availability trigger disproportionate shifts in connectedness to nature. Recognizing these thresholds is vital for designing timely and effective interventions that foster a virtuous cycle of human–nature interaction and advance a more sustainable future.

Beyond this, ABM provides a powerful framework for integrating psychological insights with broader environmental and societal challenges. Investigating sustainability through such a formalized and dynamic perspective is essential for advancing theory, shaping policy and helping to safeguard the future of our planet.

CRedit authorship contribution statement

Fernanda M. Reintgen Kamphuisen: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration,

Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yannick Joye:** Writing – review & editing, Supervision, Project administration, Methodology, Data curation, Conceptualization. **Jan Willem Bolderdijk:** Writing – review & editing, Supervision, Methodology.

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Appendix

Sensitivity Analysis

We conducted six sensitivity analyses to 1) investigate the robustness of our main finding - that small changes in nature availability can be decisive in shifting the entire system from the EoE to a virtuous cycle or vice versa and 2) explore where this tipping point lies for different parameter configurations. In each sensitivity analysis we focus on one parameter and explore how different parameter values impact the mean connectedness to nature at the end of simulation runs. We study the impact of different parameter values on mean connectedness to nature for different levels of initial greenspace percentage. A high mean connectedness to nature at the end of simulation runs represents the emergence of a virtuous cycle, a low mean connectedness to nature at the end of the simulation runs represents the emergence of the EoE. An overview of parameters that we varied in the context of the sensitivity analyses can be found in Table A1. For all sensitivity analyses we varied the level of greenspace from 4 % to 40 % in steps of 2, all other parameters are kept at their default values. Further, we conducted 10 simulation runs for each parameter value per greenspace condition. To reduce computing load and because the main analysis shows that there are no fluctuations of connectedness to nature over time (i.e., no drops followed by increases, or vice versa) we reduced the runtime from 10,000 to 5000 cycles.

In the following we show per sensitivity analysis one heat map. The heat maps visualise the relationship between the parameter under investigation and the percentage of initial greenspace (ranging from 4 % to 40 %). The colour intensity represents the mean connectedness to nature at the end of simulation runs (i.e., final mean connectedness to nature). The colour gradient ranges from red, indicating low connectedness to nature values ($nc < 2$) and thus, emergence of the EoE/a vicious cycle, to green, which indicates high connectedness to nature values ($nc > 4$) and thus, the emergence of a virtuous cycle. Hence, graphs highlight how mean connectedness to nature values vary across different parameter values and greenspace percentages. By this, graphs can help identify if small changes in nature availability can be decisive in shifting the entire system from the EoE to a virtuous cycle and where this tipping point lies for different parameter configurations.

Table A1
Overview of Parameter Values and Range of Initial Greenspace in the Sensitivity Analyses

Number	Parameter	Description	Parameter range	Results
1	mean_nc	Initial mean connectedness to nature in the population.	$M = \{2, 3, 4, \mathbf{4.88}\}$	Figure A1
2	sd_nc	Initial standard deviation of connectedness to nature in the population.	$SD = \{0.05, \mathbf{1.026}, 1.5, 2\}$	Figure A2
3	decrease_nc	The amount by which connectedness to nature decreases when not experiencing nature.	$b = \{0.03, 0.04, \mathbf{0.05}, 0.06, 0.07\}$	Figure A3
4	effect_ne	The amount by which connectedness to nature increases upon experiencing nature.	$a = \{0.1, \mathbf{0.148}, 0.2\}$	Figure A4
5	seek_ne?	Whether or not agents can actively seek nature.	yes, no	Figure A5
6	create_green?	Whether or not agents have the ability to create and remove a green patch, respectively.	yes vs. no	Figure A6

Note. Default parameters are marked in bold.

Figures A1- A6 report the final mean connectedness to nature separated per level of green space on the x-axis and different parameter values for mean_nc, sd_nc, decrease_nc, effect_ne, seek_ne? And, create_green? On the y-axis. Overall, the model appears robust in supporting our main conclusion: Small changes in nature availability can be decisive in shifting the entire system from the EoE to a virtuous cycle or vice versa. Put differently, nature availability has a non-linear effect on connectedness to nature and therefore, produces tipping points beyond which the system consistently sets in. This shows from the heat maps, where the final connectedness to nature does not increase gradually with increasing nature availability. Instead, the EoE consistently emerges up to a certain amount of initial green space after which the system shifts and a virtuous cycle consistently emerges. Hence, the sensitivity analyses depict that the dynamics between nature availability, nature experience and connectedness to nature are independent of specific parameter values and we can reliably detect tipping point dynamics across different scenarios.

However, the region of these tipping points shifts depending on parameter settings. When the initial connectedness to nature is lower, a higher amount of greenspace is required to prevent the EoE (see Figure A1). When agents' connectedness to nature at the beginning of the simulation runs is on average $M = 2$, more than 30 % of initial greenspace is needed to prevent the EoE, compared to the default value of $M = 4.88$, where more than 26 % of initial greenspace is needed to prevent the EoE. Yet, the standard deviation of the initial connectedness to nature does not impact the tipping point location (see Figure A2). Across all four parameter values, the tipping point always remains around 26 % of initial greenspace. Figure A3 shows that the stronger nature connectedness decreases without nature experience, the more initial greenspace is needed to prevent the EoE. The broad range of tipping points (for $b = 0.03$ the tipping point lies around 10 % of initial greenspace, whereas for $b = 0.07$, 40 % of greenspace is not enough to prevent the EoE) indicates that the specific tipping point is highly sensitive to this parameter value. Likewise Figure A4 shows that the percentage of initial greenspace needed to prevent the EoE strongly depends on the parameter value for effect_ne. Deviating circa 0.05 from the default value of $a = 0.148$ shifts the tipping point from 26 % to either 16 % of initial greenspace (for $a = 0.2$) or above 40 % (for $a = 0.1$). Thus, the larger the impact of nature experience on connectedness the less green space is needed to foster a virtuous cycle. Further, enabling agents to actively seek nature and to create and remove greenspace, both promotes a virtuous cycle at a lower level of initial greenspace compared to deactivating these parameters (see Figure A5 and A6). To conclude, the specific tipping point depends on parameter values that we initialize the model with, and is especially sensitive to the parameters

decrease_nc (*b*) and effect_ne (*a*). Yet, the dynamics between nature availability, nature experience and connectedness to nature are independent of specific parameter values and reliably show non-linear effects of nature availability on connectedness to nature.

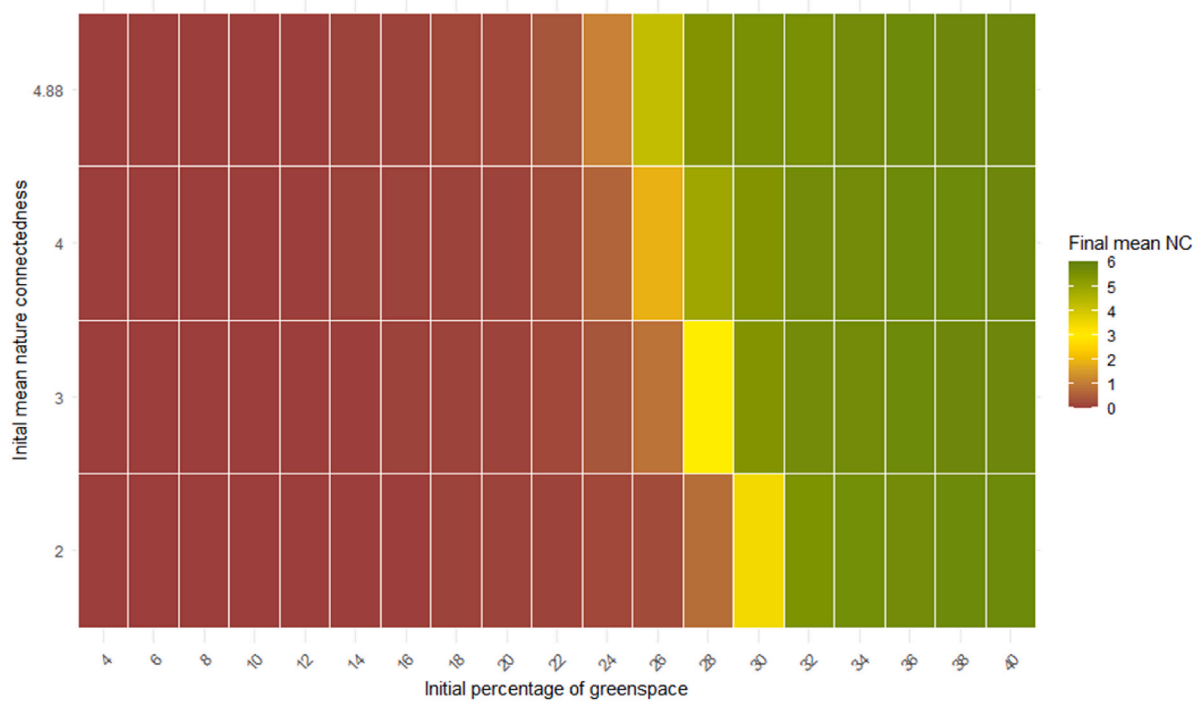


Fig. A1. Final Mean Connectedness to Nature with Different Parameter Values for the Mean of the Initial Nature Connectedness Distribution
Note. The default value for mean_nc that was used in the main analysis is $M = 4.88$.

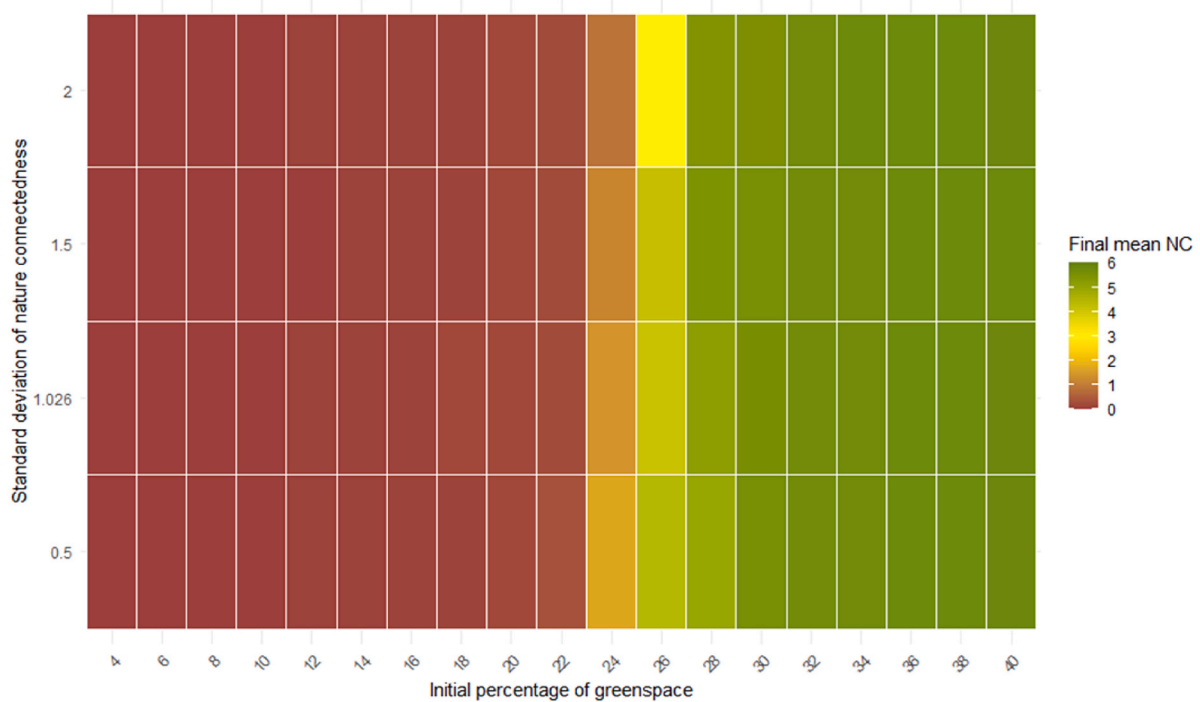


Fig. A2. Final Mean Connectedness to Nature with Different Parameter Values for the Standard Deviations of the Initial Nature Connectedness Distribution
Note. The default value for sd_nc that was used in the main analysis is $SD = 1.026$.

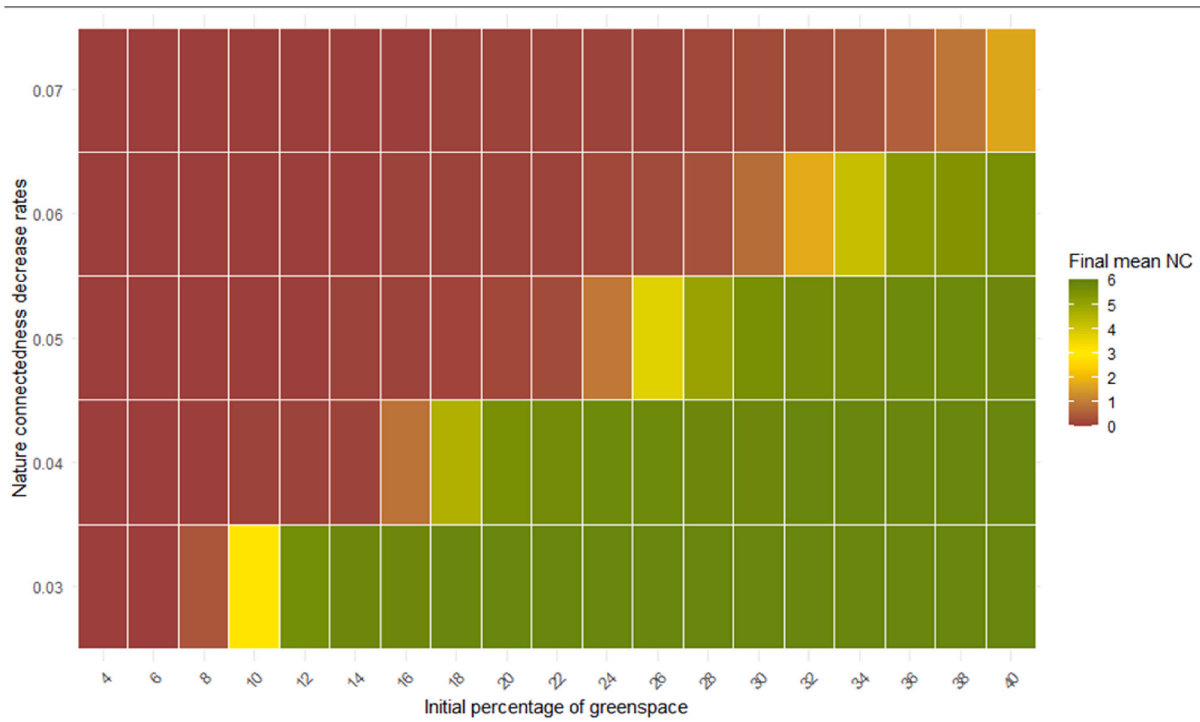


Fig. A3. Final Mean Connectedness to Nature with Different Parameter Values for the Decrease Rate of Nature Connectedness
Note. The default value for decrease_nc that was used in the main analysis is $b = 0.05$.

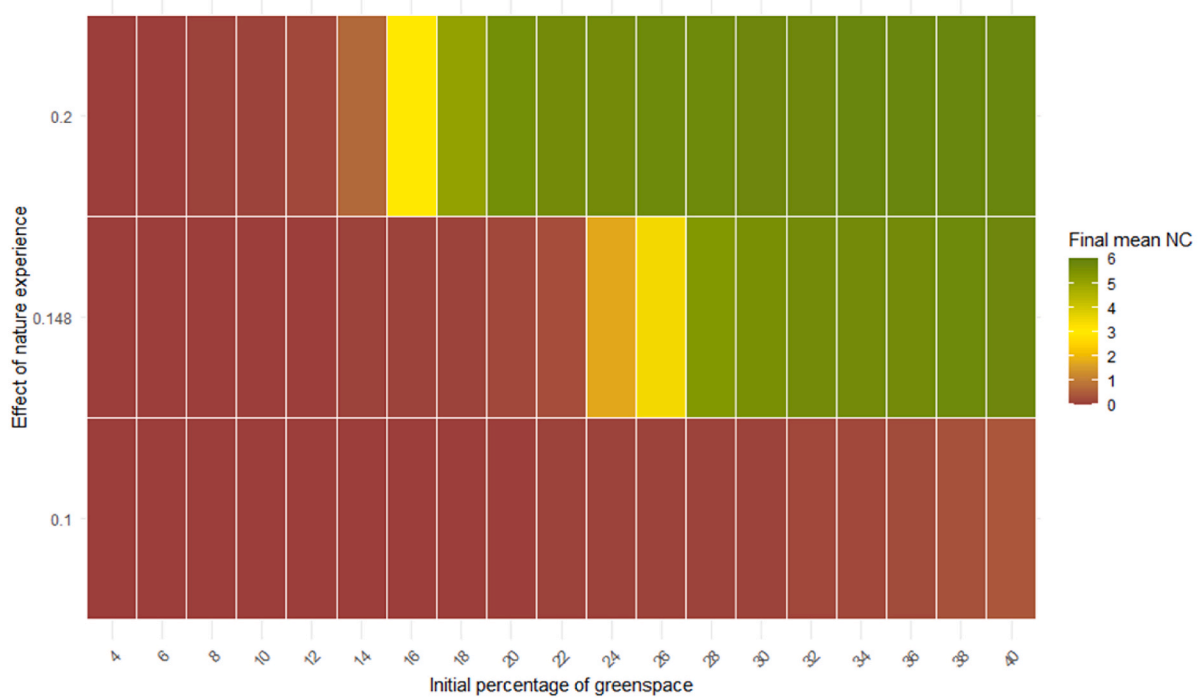


Fig. A4. Final Mean Connectedness to Nature with Different Parameter Values for the Effect of Nature Experience
Note. The default value for effect_ne that was used in the main analysis is $\alpha = 1.026$.

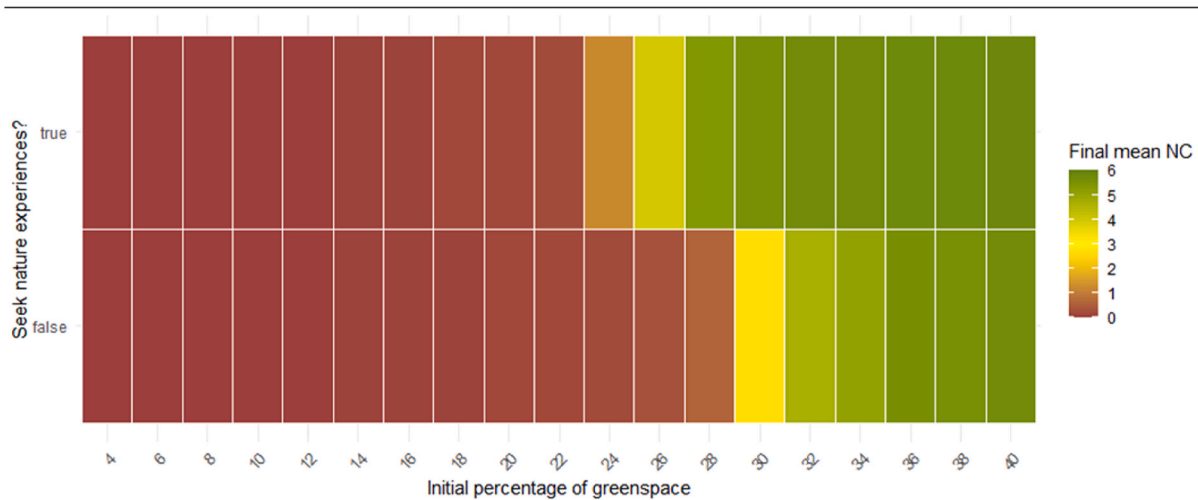


Fig. A5. Final Mean Connectedness to Nature for Whether or Not Agents Can Actively Seek Nature
 Note. The default setting for seek_ne? That was used in the main analysis is “true”.

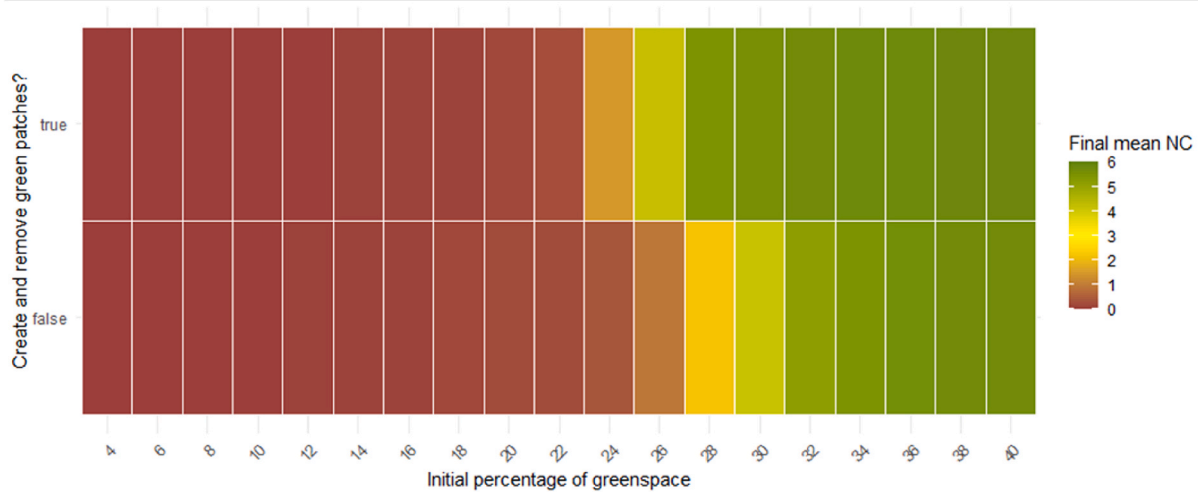


Fig. A6. Final Mean Connectedness to Nature for Whether or Not Agents Can Actively Shape Nature
 Note. The default setting for create green? That was used in the main analysis is “true”.

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