



Article

Preventing the Separation of Urban Humans from Nature: The Impact of Pet and Plant Diversity on Biodiversity Loss Belief

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Abstract: Despite the dependence of human existence on myriad ecosystem services and products, a high proportion of people feel disconnection from nature due to urbanization. This separation appears to have created an increase in the numbers of climate change and biodiversity loss denialists, thereby weakening global efforts to prevent environmental degradation and address environmental issues. The current study employs the reasoning capability of Mindsponge theory and the statistical advantages of Bayesian inference to examine whether access to in-home pet and plant diversity can increase the probability of biodiversity loss belief among urban residents. The findings from 535 Vietnamese respondents indicate that, when respondents feel comfortable at home, a higher diversity of pets is associated with a higher likelihood of believing that biodiversity loss is a real and major problem. However, the effect becomes the opposite when the respondents feel uncomfortable at home. Plant diversity has a positive impact on biodiversity loss belief regardless of comfort. Notably, the impact of plant diversity on biodiversity loss belief is more substantial among respondents who feel uncomfortable than those who feel comfortable. Following these findings, we suggest that increasing in-home biodiversity can be a promising way to raise urban residents' awareness of the occurrence and significance of biodiversity loss, which will subsequently help them build up an eco-surplus culture.

Keywords: biodiversity; urban; Bayesian Mindsponge Framework analytics; BMF; conservation



Citation: Nguyen, M.-H.; Nguyen, M.-H.T.; Jin, R.; Nguyen, Q.-L.; La, V.-P.; Le, T.-T.; Vuong, Q.-H. Preventing the Separation of Urban Humans from Nature: The Impact of Pet and Plant Diversity on Biodiversity Loss Belief. *Urban Sci.* **2023**, *7*, 46. <https://doi.org/10.3390/urbansci7020046>

Academic Editor: Jean-Claude Thill

Received: 6 March 2023

Revised: 19 April 2023

Accepted: 21 April 2023

Published: 25 April 2023



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1. Introduction

For survival, ancient peoples had to immerse themselves in nature and move across regions to take advantage of the seasonality of resources and variation in water availability. Only with the establishment of agriculture was this migration pattern broken, leading to year-round settlement [1]. However, humans still had close connections to nature through ecosystem management activities for enhancing agricultural productivity. The village farming community, which was the dominant form of settlement before the urbanization era, is a prime example of such a human–nature relationship [2,3]. Although a few cities were established around 3000 BCE, “urbanized societies”, where a high proportion of inhabitants live in cities, only developed after the Industrial Revolution, which led to economic and technological advancements and an increase in immigration from rural to urban areas [4–6].

The economies of scale produced by urbanization have driven substantial economic growth in urban areas, such that the urban population now surpasses the rural population and holds the majority of the economic power [7]. However, urbanization simultaneously results in many adverse consequences for humans and nature. One such consequence is the separation of humans from nature, more precisely described as perceptual dissociation but not actual dissociation [8,9], because the resources and services provided by natural ecosystems are the *sine qua non* of urban existence [6]. In this case, strengthening people's connection to nature is critical, as it is a crucial factor in fostering environmentally friendly attitudes and behaviors, as well as wellness [10]. In contrast, disconnected human–nature relationships will result in people's indifference to and rejection of environmental protection measures [11]. A clear reflection of such a mindset is the emergence of climate change and biodiversity loss denialists.

Climate change and biodiversity integrity are two core boundaries among the nine planetary boundaries proposed by Steffen et al. [12] to help define the “safe operating space” for human societies' development without driving the Earth system away from a Holocene-like condition. Increasing scientific evidence has suggested that climate change and biodiversity loss are approaching a tipping point [13–15]. If that is passed, they will cause irreversible long-term effects and create a less habitable environment for humans [13]. Even though many countries have formed Multilateral Environment Agreements (MEAs), such as the Paris Accords, Kyoto Protocol, Aichi Biodiversity Targets, etc., to set up policies to curtail or eradicate practices that would further damage the environment, a proportion of people still deny climate change and biodiversity loss. This leads to opposition to climate change and biodiversity loss prevention policies and programs.

A typical example of climate change and biodiversity loss denial is former president of the United States of America, Donald J. Trump, who notoriously withdrew the USA from the Paris Accords and overhauled government spending to cut programs overseen by the Environmental Protection Agency (EPA) that functioned to ensure environmental protection [16]. Dunlap and McCright [17] argue that climate change denialists' mentality, caused by complex factors, will drive them and others to spread uncertainty to undermine the environmentalist agenda. The belief differences between environmentalists and climate change denialists can be associated with their polarized behaviors that promote or undermine the environmentalist agenda.

Systematic denial of the biodiversity crisis arose following the publication of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) summary for policymakers [18]. After the report's publication, the Internet saw increased criticism of the results and questioning of the trustworthiness of the techniques employed to estimate the number of species on the brink of extinction. Lees et al. [19] classified these attempts into three main categories: literal denial (i.e., ‘species extinctions were predominantly a historical problem’), interpretive denial (i.e., ‘economic growth alone will fix the extinction crisis’), and implicatory denial (i.e., ‘technological fixes and targeted conservation interventions will overcome extinction’). They also recommended seven public communication strategies for conservation scientists to counter misinformation.

Empirically, beliefs are important factors significantly influencing individuals' thinking processes and behaviors associated with the environment [20–26]. Viewing humans' psychological processes from the information-processing perspective [27], we can consider beliefs as core values that contribute to establishing the mind's value systems and evaluating newly absorbed information during the filtering processes. In other words, beliefs help a person assess the value of particular information and decide whether to absorb or reject the given information. Understanding the determinants of beliefs regarding biodiversity loss is, therefore, imperative for improving the effectiveness of public communication and countering environmental crisis denialists.

To expand our knowledge into the determinants of belief, the current study set out to examine the following two main objectives:

- To examine whether Vietnamese urban residents' access to diversity of in-home animals and plants is associated with their belief in biodiversity loss.
- To examine whether the associations between urban residents' access to in-home biodiversity and belief in biodiversity loss are moderated by their feeling of comfort in the house.

The rationales behind these objectives are presented in Section 2.1, using the information-processing reasoning of the Mindsponge theory. Bayesian Mindsponge Framework (BMF) analytics was used to construct and verify models employing a dataset of 535 inhabitants of 35 cities across Vietnam.

2. Methodology

2.1. Theoretical Foundation

2.1.1. Mindsponge Theory Overview

The Mindsponge theory, originally proposed by Vuong and Napier [28] as the Mindsponge mechanism, explains how we came up with the two research objectives presented in the introduction [27]. The term Mindsponge was coined to describe “the mind as a sponge that squeezes out inappropriate values and absorbs new ones that fit or complement the context,” and the Mindsponge theory is a theory of information processing, constructed based on the latest evidence from brain and life sciences. It has been used in many scientific and literary works investigating psychological and behavioral issues [29–33]. Although the theory views all living systems as “minds” in the broad sense—as information collectors and processors—including organisms, biological systems, and societies, it is primarily used to examine the human mind [27].

The human mind, defined as an information-collector-cum-processor, has the following major features:

1. It reflects the natural patterns of systems in the biosphere.
2. It is a process that is dynamically balanced.
3. It involves a cost–benefit evaluation, which aims to increase the perceived benefits and reduce the perceived costs of the system.
4. It consumes energy and thus adheres to the principle of energy saving.
5. It has a goal or goals and priority, depending on the demands of the system.
6. Its fundamental purpose is to prolong the system's existence in one way or another, including survival, growth, and reproduction.

In the Mindsponge theory, mindset is a fundamental component of the mind. Conceptually, it is described as a set of highly trusted values (or information). As information is considered the most fundamental entity in the information processing approach, in many instances, the term “information” can be used interchangeably with “idea” or “value.” However, “idea” and “value” can be viewed as subjective interpretations of the information that carries them for differentiation purposes. In the mindset, there are two types of trusted values: (1) core values and (2) temporarily trusted values. Core values are beliefs (or highly trusted values) located at the “center” of a person's mindset [34]. They are commonly referred to as (but not limited to) “enduring, unquestioned ontological representations of the world” and “primary convictions about events, causes, agency, and objects that subjects use and accept as veridical” [35].

Neurologically, the mindset corresponds to an optimized adaptive memory system. The human mind stores information to generate appropriate responses, not solely to store it. Information acquired from the outside world or created internally is kept as engrams—cognitive information imprinted in a physical substance—by biochemical changes in neurons. Memory consolidation takes place in engram neurons as a result of DNA (deoxyribonucleic acid) methylation induced by inputs that cause stable structural changes [36,37]. Synaptic connections increase when signals are sent across synapses during the long-term potentiation process [38]. These dynamic information storage structures constitute the foundation of neuroplasticity, allowing the processing system to adjust flexibly [39].

The essential role of core values is to construct one's value system, from which information's value can be determined. The value system is subjective and greatly influences both the input-acquisition and output-generation processes. It determines how a person feels, thinks, chooses, and behaves in the output-generation processes. Throughout the input-acquisition process, the value system influences the multi-filtering system, which decides what information is absorbed and what is expelled [34].

Because living systems are not isolated, the mindset is not a steady information collection. It is continually updated because of the information exchange nature of cells and the plasticity of neurological systems. Due to neuroplasticity, the updating mechanisms in human minds involve "live-wiring" rather than the pervasive "hard-wiring" type in simpler systems (e.g., more reliant on predefined genetic information) [39].

Thus, beliefs are dynamically changed from related experiences, including newly obtained information and formed ideas, to adapt to changing external environments. In other words, the system's content evolves over time to better match mental representations to reality [8]. When investigating the information process of belief updating, Bayes' Theorem (given below) is useful [40]:

$$p(A|B) = \frac{p(B|A)p(A)}{p(B)}.$$

This means the posterior probability distribution is proportional to the prior probability distribution and the likelihood function. Collective evolution and individual learning are both optimization processes in which equivalence between certain evolutionary dynamics and Bayesian inference helps shed light on the progress of human cognition [41]. We also see this as one of the key reasons Bayesian statistics and Mindsponge theory are compatible, as demonstrated by the Bayesian Mindsponge Framework (BMF) analytical approach [42].

2.1.2. Environment and Biodiversity Loss Belief Formulation

Biodiversity provides various benefits to humans through multiple pathways. Clark et al. [43] contend that, besides offering necessities such as clean air and water directly associated with public physical health, biodiversity is critical for fulfilling different communities' various cultural practices, which in turn influence human mental health. Urban design incorporating green spaces and diverse wildlife improves human wellbeing by reducing stress and increasing cognitive function [44]. Such positive effects have also been corroborated by Wood et al. [45] and Bergou et al. [46]. Wood et al. [45] suggest that ecological diversity in urban green spaces (such as tree-planting and various wildlife emergence) will result in psychological restoration amongst participants from multiple ethnic groups, while Bergou et al. [46] highlight that urban dwellers' visits to green and blue spaces will result in a greater level of mental wellbeing.

Following the logic of the Mindsponge theory [27,34], people's belief in biodiversity loss is accepted and reinforced when biodiversity is subjectively deemed as beneficial, or biodiversity loss is deemed costly. Given these advantages of biodiversity, it is reasonable to assume that urban residents are more likely to consider biodiversity to be essential and absorb information relevant to biodiversity loss if they are exposed to animal or plant diversity and perceive its benefits.

However, the information on biodiversity or biodiversity loss must be available and accessible by the individual to be processed. In urban areas, especially in Vietnam, green spaces, such as public parks, are shrinking due to building construction, significantly reducing the chance for urban residents to access biodiversity-related information in public [47,48]. There are two primary ways for Vietnamese urban people to access biodiversity-related information. First is through information transmitters, like the Internet, books, videos, etc. Another way is through pet ownership and planting (including but not limited to home gardening). While the former method can hardly let the individuals experience the merits of biodiversity and the drawbacks associated with biodiversity loss, the latter

can by allowing individuals to directly interact with animals or plants and experience the services they provide.

Studies have shown that, in addition to physical health improvements, pet ownership positively correlates with favorable physical outcomes and improved mental health. Specifically, while Kruger et al. [49] found that the benefits of having a dog include increased movement, socialization, responsibility, and less stress, Wood et al. [50] suggest that having a pet helps the owner make new friends, who can then provide social support (e.g., emotional, informational, appraisal, and instrumental). However, the effects of pet diversity remain understudied. As for plants, people's wellbeing can be improved by seeing some fairly simple natural systems, such as individual trees and grass (i.e., less stress and higher satisfaction) [9,51]. The study of Raymond et al. [52] on home gardeners in Canada also observed mental benefits of home gardening for biodiversity conservation, namely: connection to nature, place attachment, attention restoration, reduced stress and anxiety, improved mood, satisfaction and pride, increased self-esteem, courage to do things differently in life, and important education or learning opportunities. Zhang et al. [53] even describe a home garden as "ecological medicine" for the mental health of urban residents during the COVID-19 pandemic as it helped promote a comfortable and natural feel. Although the review does not mention the biodiversity level of urban home gardens, it implies the benefits of those gardens in terms of an increased urban biodiversity level. Another study of German and New Zealand populations found positive associations between nature connectedness, biodiversity of private gardens, and mental wellbeing during the COVID-19 lockdown [54].

When urban residents perceive such benefits of pet ownership and plant diversity, they tend to update their mindset with more favorability towards biodiversity-related information, including that relevant to the occurrence and significance of biodiversity loss. This, as a result, facilitates the emergence and reinforcement of urban residents' beliefs in biodiversity loss. We propose two hypotheses (H) to test the assumption:

H1: *Pet diversity is positively associated with Vietnamese urban residents' belief in the existence and significance of biodiversity loss.*

H2: *Plant diversity is positively associated with Vietnamese urban residents' belief in the existence and significance of biodiversity loss.*

Nevertheless, it is acknowledged that the presence of animal and plant diversity does not always bring benefits, but can also result in costly outcomes. For example, Phillipou et al. [55]'s study discovered that, during the COVID-19 lockdown, pet owners were more likely to face greater hardship and decreased life quality. This is, perhaps, because lockdown policies changed pets' and pet owners' regular routines and social interaction patterns. Moreover, the cultural aspect should not be neglected. It is common in many Asian countries, including Vietnam, for pets to be stigmatized as unsanitary. This might require owners to put more effort and time into cleaning and tidying. When species diversity increases, conflicts might also arise. Sometimes, pet ownership can lead to conflicts with family members and/or neighbors [56]. Even for plant diversity, Raymond et al. [52] found that disagreements can occur between neighbors, gardeners, and passers-by, or between gardeners and municipal authorities, due to different expectations of the tidiness of the garden.

Given the contradicting benefits and costs of owning multiple types of pets and planting multiple types of plants, we expect species diversity's effects on biodiversity loss beliefs to be conditional on home comfort, as pet and plant diversity constitutes the home environment. Comfort was assessed by respondents' self-evaluated feeling (or the experienced benefits and costs of subjects and objects existing in the house, including pets and plants). Other scholars have used this proxying strategy to measure satisfaction [57,58]. Eventually, we hypothesized:

H3: The association between pet diversity and urban residents' belief in the existence and significance of biodiversity loss is conditional on the residents' feeling of comfort at home.

H4: The association between plant diversity and urban residents' belief in the existence and significance of biodiversity loss is conditional on the residents' feeling of comfort at home.

2.2. Model Construction

2.2.1. Variable Selection and Rationale

The current study employed a dataset of urban residents' perceptions toward biodiversity–human interactions in Vietnam [59]. The dataset was generated from a systematic survey that was designed with five major steps: (i) questionnaire design, (ii) survey collection, (iii) data cleaning and validation, (iv) dataset generation, and (v) data analysis. For the questionnaire design, 38 residents of Hanoi and Ho Chi Minh City participated in in-depth interviews from 15 November to 26 December 2020. The diversity of interviewees was ensured by diversifying their age, gender, occupation, and prior experiences with nature in order to meet the “theoretical saturation” [60]. Next, the survey collection was conducted through a Web-based survey via Google Forms using the snowball sampling strategy. Before starting the survey, the participants were required to read and agree with the consent form, which ensured that respondents understood the contents and purpose of the survey.

From 18 June to 8 August 2021, responses were acquired from 581 urban residents. However, after a four-step quality check, only 535 responses were eligible. All of the low-quality responses were removed, such as those from non-urban residents, under 18, with duplicated emails, and with suspicious low-quality signals. After cleaning the dataset, 535 samples met the study requirements. The responses were then encoded and saved under a comma-separated value format. The final version of the dataset was peer-reviewed by two referees and uploaded to an open repository. The readers can find the dataset and its description details at:

- <https://direct.mit.edu/dint/article/3/4/578/107428/Multifaceted-Interactions-between-Urban-Humans-and> (accessed on 2 October 2022).

The variable *BioLossBelief* was used to measure urban residents' beliefs in the occurrence and significance of biodiversity loss. The participants were asked to provide their thoughts on biodiversity loss. Respondents reporting that biodiversity loss is real and a major problem were coded as ‘1’, whereas those reporting that biodiversity loss is not real or not a significant problem were coded as ‘0’ (see Table 1).

Table 1. Variable description.

Variable	Description	Type of Variable	Value
<i>BioLossBelief</i>	Belief in the occurrence and significance of biodiversity loss	Binary	0: Biodiversity loss is not real or not a big problem; 1: Biodiversity loss is real and a major problem.
<i>HomeComfortable</i>	The comfort of respondents in their home	Binary	0: Uncomfortable; 1: Comfortable.
<i>PlantDiversity</i>	The number of types of plants in the respondents' home	Numeric	Counted based on the number of types of plants
<i>AnimalDiversity</i>	The number of pet types that respondents own	Numeric	Counted based on the number of types of pets

To measure the in-home pet and plant diversity, we employed the self-reported number of types of pets and plants in the house of the respondents. *PlantDiversity* and *AnimalDiversity* are variables indicating in-home plant and pet diversity, respectively. Plant Diversity

was measured on a scale from 0 to 6, with ‘0’ meaning that respondents have no house plants and ‘6’ meaning that respondents have more than five types of plants in the house; ‘1’–‘5’ correspond to the number of plant types in the house. *AnimalDiversity* was measured on a scale from 0 to 3, with ‘0’ meaning respondents had no pets, ‘3’ meaning the respondents had more than two types of pets in the house, and ‘1’ and ‘2’ corresponding to the number of pet types in the house.

The comfort of respondents was measured by a binary question: ‘Do you feel comfortable when you are in the house?’ If the respondents feel comfortable, it was coded as ‘1’; otherwise, it was coded as ‘0’. In this manuscript, this is represented by the variable *HomeComfortable*.

2.2.2. Statistical Models

To test the hypotheses proposed in Section 2.1, we employed four multiple linear regression models, starting with the simplest. Specifically, we constructed Model 1 to examine Hypothesis H1:

$$BioLossBelief \sim normal(\mu, \sigma) \quad (1A)$$

$$\mu_i = \beta_0 + \beta_{AnimalDiversity} * AnimalDiversity_i + \beta_{PlantDiversity} * PlantDiversity_i \quad (1B)$$

$$\beta \sim normal(M, S) \quad (1C)$$

The probability around μ is determined by the form of the normal distribution, whose width is specified by the standard deviation σ . μ_i indicates the probability that urban resident i believes in the occurrence and significance of biodiversity loss; *AnimalDiversity_i* indicates the number of types of pet that urban resident i owns; *PlantDiversity_i* indicates the number of plant types that urban resident i owns. Model 1 has four parameters: the coefficient, $\beta_{AnimalDiversity}$ and $\beta_{PlantDiversity}$; the intercept, β_0 ; and the standard deviation of the “noise”, σ . The coefficients of the variables *AnimalDiversity_i* and *PlantDiversity_i* are distributed as a normal distribution around the mean denoted M , with the standard deviation denoted S .

We tested Hypothesis H2 by incorporating the variable *HomeComfortable_i* and its interactions with the variables *AnimalDiversity_i* and *PlantDiversity_i* into Model 1:

$$BioLossBelief \sim normal(\mu, \sigma) \quad (2A)$$

$$\begin{aligned} \mu_i = \beta_0 + \beta_{AnimalDiversity} * AnimalDiversity_i + \beta_{PlantDiversity} * PlantDiversity_i + \beta_{HomeComfortable} * HomeComfortable_i \\ + \beta_{AnimalDiversity * HomeComfortable} * AnimalDiversity_i * HomeComfortable_i + \beta_{PlantDiversity * HomeComfortable} * PlantDiversity_i * HomeComfortable_i \end{aligned} \quad (2B)$$

$$\beta \sim normal(M, S). \quad (2C)$$

HomeComfortable_i indicates whether urban resident i feels comfortable at home; $\beta_{AnimalDiversity * HomeComfortable}$ and $\beta_{PlantDiversity * HomeComfortable}$ indicate the coefficients of the nonadditive effects of *AnimalDiversity_i*, *PlantDiversity_i*, and *HomeComfortable_i* on *BioLossBelief*. If the coefficients $\beta_{AnimalDiversity * HomeComfortable}$ ’s and $\beta_{PlantDiversity * HomeComfortable}$ ’s distributions are significant, then the associations between the species diversity and biodiversity loss belief are considered conditional on a feeling of comfort. The logical network for Model 2 is presented in Figure 1.

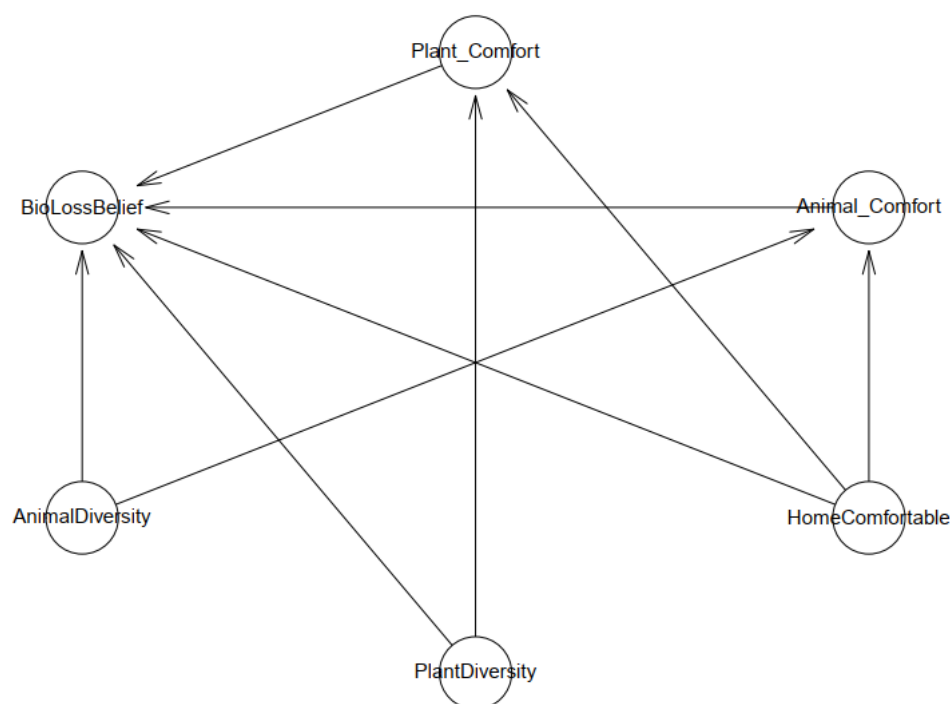


Figure 1. Model 2's logical network.

2.3. Analysis and Validation

Bayesian Mindsponge Framework (BMF) analytics was employed in the current study. The Bayesian Mindsponge Framework was applicable to the study objectives for several reasons. First, the method combines the reasoning strength of Mindsponge theory and the inference advantages of Bayesian analysis, which are highly compatible in nature [42]. Second, Bayesian inference assesses all properties probabilistically [40,61], allowing for reliable prediction with parsimonious models. However, thanks to the power of the Markov chain Monte Carlo (MCMC) technique, Bayesian methods can still fit a wide range of complex models, like the multilevel model and nonlinear regression frameworks [62]. Third, Bayesian inference has several advantages compared to its frequentist-approach counterpart; for example, it enables users to use credible intervals for result interpretation instead of the p -value [63]. Moreover, the reproducibility crisis, which has been linked to the fickleness of p -value [64], may be addressed by using Bayesian analysis.

Due to the exploratory nature of this study, models with uninformative priors or a flat prior distribution were built to provide as little prior information as possible for model estimation [65]. We also utilized the “prior-tweaking” approach to test the model’s robustness, which employs priors reflecting our disbelief in the estimated effects. If the effect patterns remain unchanged, the model’s results can be deemed robust.

Once the models were constructed, we employed the Pareto-smoothed importance sampling leave-one-out (PSIS-LOO) diagnostics to check the models’ goodness-of-fit [66,67]. LOO is computed as follows:

$$LOO = -2LPPD_{loo} = -2 \sum_{i=1}^n \log \int p(y_i|\theta) p_{post(-i)}(\theta) d\theta.$$

$p_{post(-i)}(\theta)$ is the posterior distribution based on the data minus data point i . In the “LOO” package in R, k -Pareto values are used in the PSIS method for computing leave-one-out cross-validation, which helps identify observations with a high degree of influence on the PSIS estimate. Observations with k -Pareto values greater than 0.7 are often considered influential and may be problematic for accurately estimating leave-one-out cross-validation. Commonly, a model is considered fit when the k values are below 0.5.

Then, the convergence of Markov chains can be validated statistically using the effective sample size (n_{eff}) and the Gelman–Rubin shrink factor ($Rhat$), and visually by trace plots, Gelman–Rubin–Brooks plots, and autocorrelation plots. The n_{eff} value represents the number of iterative samples that are not autocorrelated during stochastic simulation. If n_{eff} is bigger than 1000, it is generally considered that the Markov chains are convergent, and the effective samples are sufficient for reliable inference [68]. The $Rhat$ value—often referred to as the potential scale reduction factor or the Gelman–Rubin shrink factor—is used to evaluate the convergence of the Markov chains [69]. If the value exceeds 1.1, the model does not converge. Typically, the model is considered convergent if $Rhat = 1$.

Finally, the constructed model weights were compared to select the most predictive one. We employed the Widely Applicable Information Criterion (WAIC), Pseudo-Bayesian model averaging (BMA) with Bayesian bootstrap, Pseudo-BMA without Bayesian bootstrap, and Bayesian stacking for model comparison. Akaike weights help by rescaling these weights. A total weight of 1 is assigned to each model under consideration, making assessing their relative predicted accuracy simpler. The weight for a model i in a set of m models is given by [68]:

$$w_i = \frac{\exp\left(-\frac{1}{2}dWAIC_i\right)}{\sum_{j=1}^m \exp\left(-\frac{1}{2}dWAIC_j\right)},$$

where $dWAIC$ is the difference between each WAIC and the lowest WAIC. This example uses WAIC, but the calculation is the same for any other information criteria on the deviance scale. Each weight will be a number between 0 and 1, and the total of the weights will always be 1. A model with a larger weight is considered better.

The `bayesvl` R package, aided by the MCMC technique, was employed to perform Bayesian analysis because of its advantages, such as good visualization power, openness, and streamlined operation [34,70]. For transparency and cost-effectiveness [71,72], all the code and data used for this study's analysis were deposited in the Open Science Framework for public evaluation: <https://osf.io/gs3h2/> (accessed on 13 February 2023).

3. Results

We conducted the weight comparison using WAIC, Pseudo-BMA without Bayesian bootstrap, Pseudo-BMA without Bayesian bootstrap, and Bayesian stacking to find the model with the greatest predictive weight. Table 2 shows that Model 2 outweighed Model 1 in all weight categories. Hence, we chose Model 2 for the rest of the analysis.

Table 2. Model comparison and weight ranking.

Weights	WAIC	Pseudo-BMA without Bayesian Bootstrap	Pseudo-BMA with Bayesian Bootstrap	Bayesian Stacking
Model 1	0.11	0.11	0.33	0.34
Model 2	0.89	0.89	0.67	0.66
Most predictive model	Model 2	Model 2	Model 2	Model 2

Next, the PSIS-LOO approach was employed to assess whether the models fit the data. While the visual diagnosis of Model 2 is displayed in the main text, that of Model 1 is placed in the Supplementary Materials. Figure 2 demonstrates that all of the Pareto k indicators are well below 0.5, indicating a good fit between Model 2 and the data.

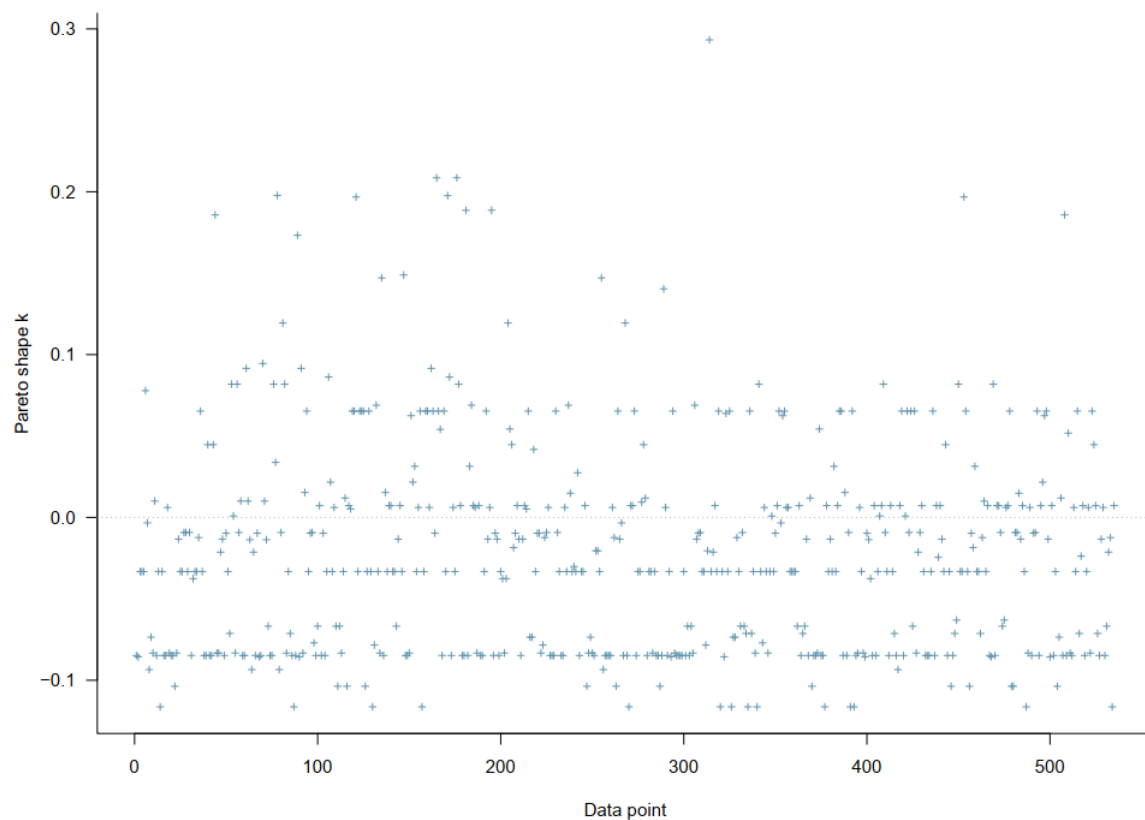


Figure 2. Model 2's PSIS-LOO diagnosis plots with uninformative priors.

The simulation of Models 1 and 2 can be considered to converge well based on the convergent indicators. Specifically, the effective sample size (n_{eff}) values of all models' parameters were above the standard threshold of 1000, and all $Rhat$ values were equal to 1 (see Table 3 for Model 2 and Table S1 for Model 1). Since the main model of the current study is Model 2, we only display Model 2's estimated diagnostic statistics and visualizations in the main text. The convergence diagnosis plots of Model 1 are presented in Figure 3 (for trace plots), Figure 4 (for Gelman–Rubin–Brooks plots), and Figure 5 (for autocorrelation plots).

Table 3. Results of Model 2.

Parameters	Uninformative Priors				Informative Priors			
	Mean	SD	n_{eff}	$Rhat$	Mean	SD	n_{eff}	$Rhat$
<i>Constant</i>	0.59	0.09	3976	1	1.28	0.48	3968	1
<i>HomeComfortable</i>	1.19	0.83	4044	1	0.32	0.42	3949	1
<i>PlantDiversity</i>	0.41	0.20	3744	1	0.16	0.13	3857	1
<i>Plant*Comfort</i>	−0.29	0.21	3855	1	0.00	0.13	3958	1
<i>AnimalDiversity</i>	−0.55	0.37	4658	1	−0.22	0.25	3736	1
<i>Animal*Comfort</i>	0.85	0.43	4684	1	0.47	0.28	3835	1

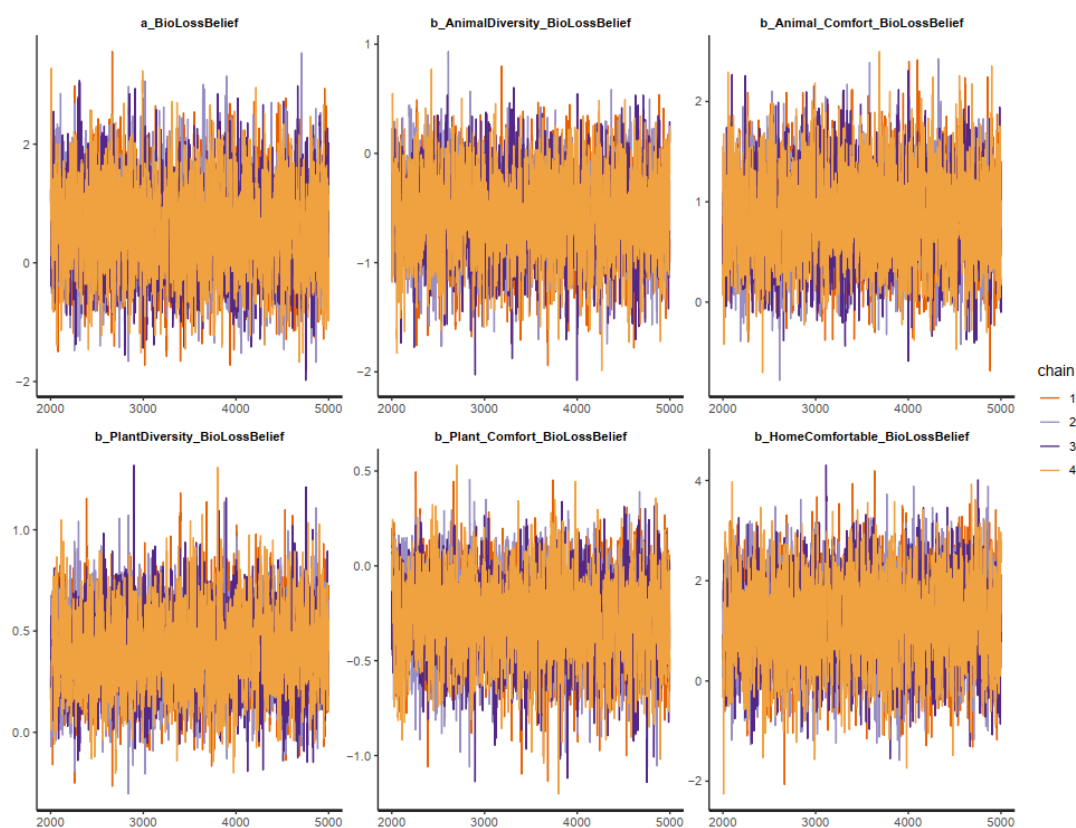


Figure 3. Model 2's trace plots with uninformative priors.

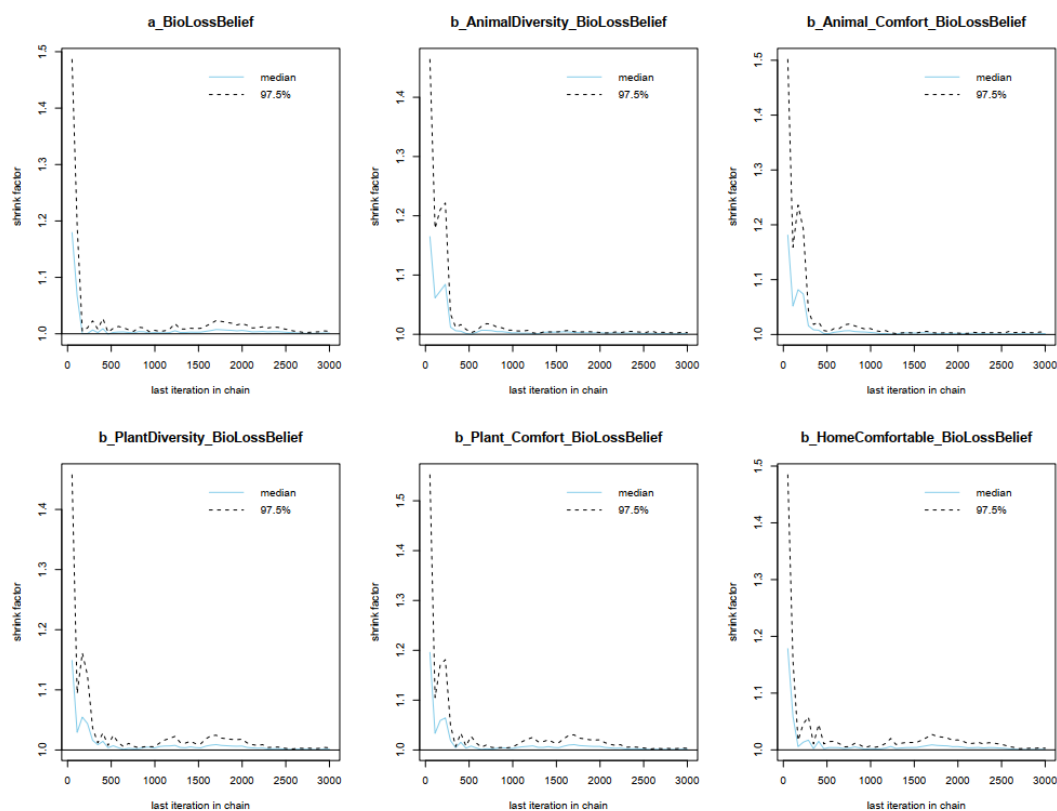


Figure 4. Model 2's Gelman–Rubin–Brooks plots with uninformative priors.

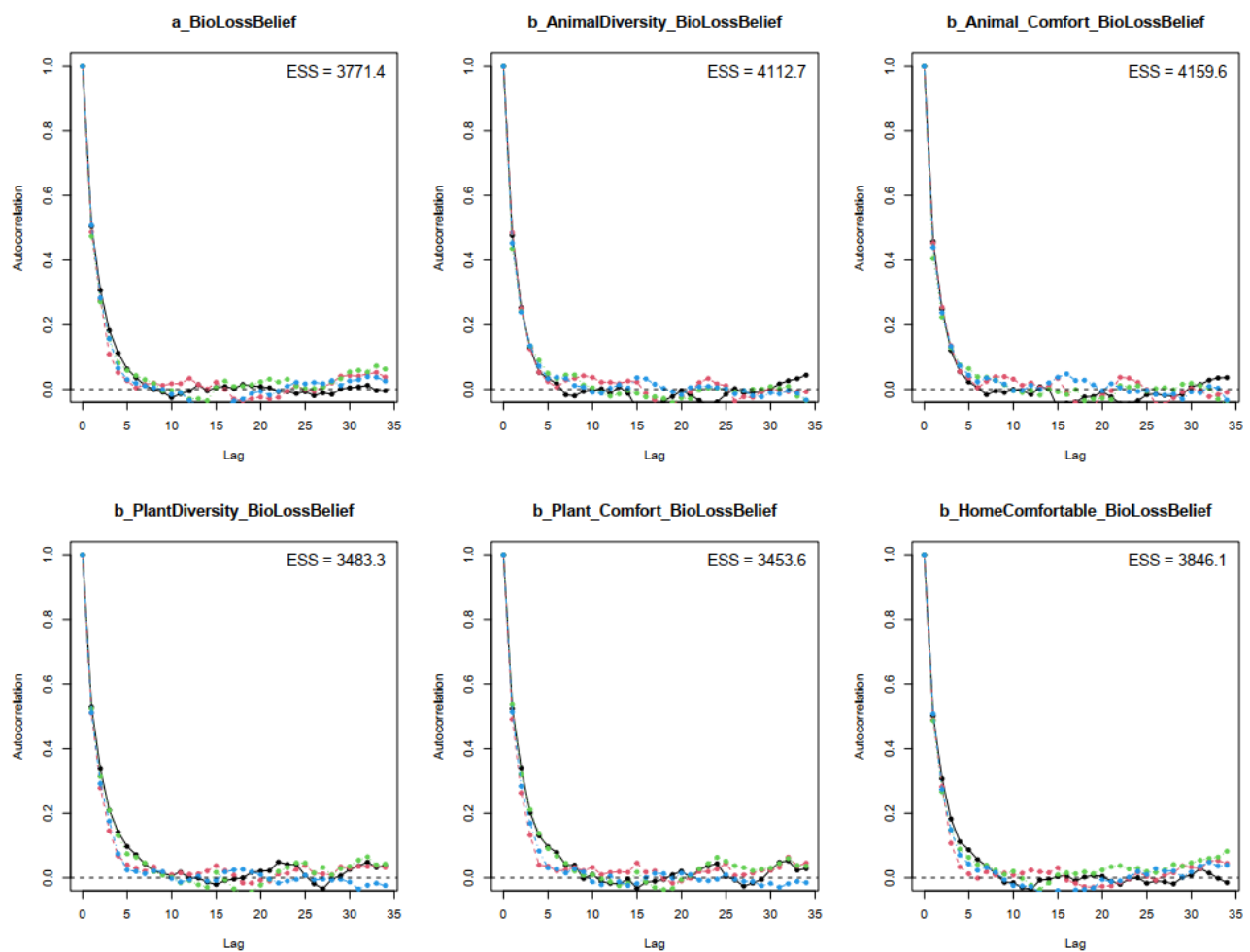


Figure 5. Model 2's autocorrelation plots with uninformative priors.

When Markov chains are convergent in the trace plot, they are well-mixing and stationary around an equilibrium. Figure 3 depicts a healthy variation of Model 2's Markov chains around a central equilibrium, which is a favorable indicator of convergence. The decrease in shrink factors to one after the warm-up periods further confirms the convergence (see Figure 4).

The autocorrelation charts in Figure 5 also contribute to the validation of Markov chain convergence. The rapid reduction of autocorrelation levels to zero after a specific number of lags implies that iterative samples in the stochastic simulation process are memoryless, representing a strong indication of convergence.

We performed the model fitting using R version 4.2.0 ("Vigorous Calisthenics") on 4 March 2023, with the elapsed time being 102.34 s. The MCMC setups for fitting were 5000 iterations, including 2000 warm-up iterations, four cores, and four Markov chains.

Table 3 displays the estimated posterior distributions of Model 2, and Figure 6 illustrates them. Because Model 2 is sophisticated, it is necessary to visualize the findings before interpreting them. Before interpreting the results, they need to be evaluated concerning reliability and robustness.

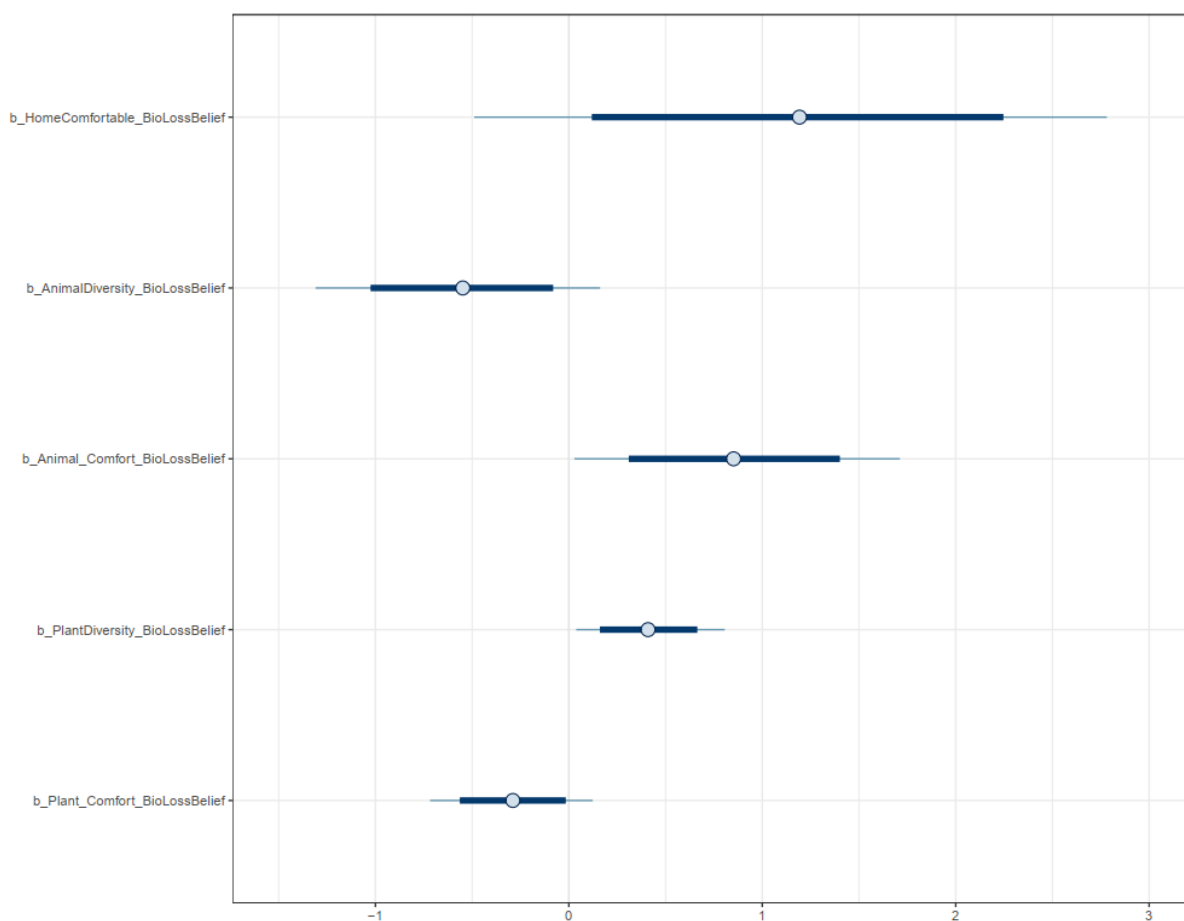


Figure 6. Model 2's posterior distributions with uninformative priors.

Figure 6 illustrates the posterior distributions of Model 2 on an interval plot. The thin blue lines reflect the probability mass outside of the highest credible zone, whereas the thick blue lines show the probability mass within the 89% Highest Posterior Density Intervals (HPDI). As seen in Figure 6, the 89% HPDI of all posterior distributions is completely on either the positive or negative side of the axis. This suggests that the estimated results are highly reliable. Even when we used the “prior-tweaking” approach, the parameter magnitudes only altered marginally, but their trends remained stable. As a result, the estimated results are robust.

Employing Equation (2.2) and the estimated mean values of parameters in Table 3, we calculated the probability that an urban resident will believe in the occurrence and significance of biodiversity loss. The calculated numbers are plotted in Figure 7A,B. To elaborate on the results, when urban residents feel comfortable in their home, a greater diversity of pets in the house is associated with a higher probability of biodiversity loss belief. However, if they feel uncomfortable at home, there is a likelihood that a higher level of pet diversity will be associated with a lower probability of biodiversity loss belief. As for plants, the positive effect of diversity on biodiversity loss belief is consistent in respondents feeling comfortable or uncomfortable at home. However, the impact of plant diversity is more substantial among urban residents who do not feel comfortable than those who do.

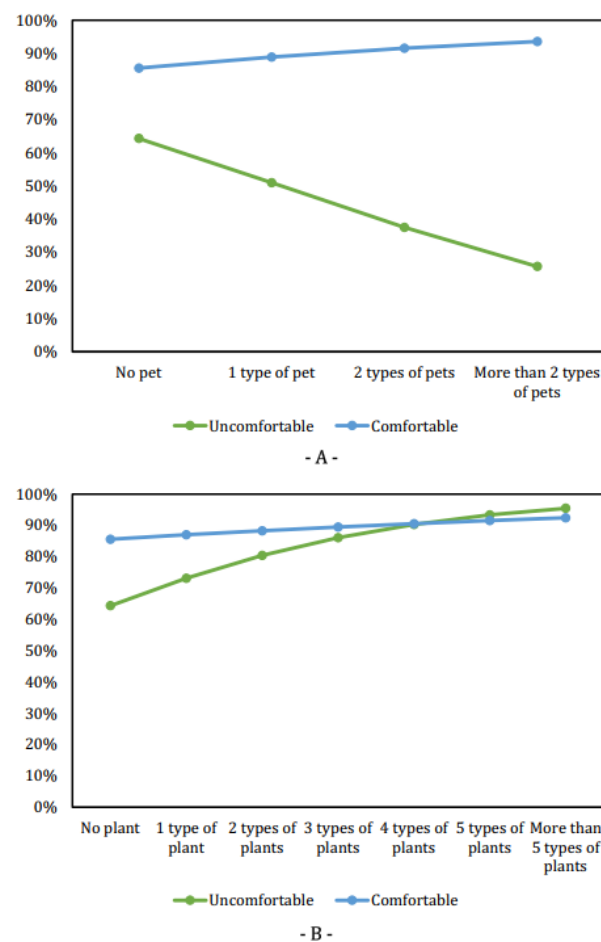


Figure 7. Probability of belief in biodiversity loss for (A) urban residents who own a pet or pets but not a plant, and (B) urban residents who own a plant or plants but not a pet.

4. Discussion and Conclusions

The current study employed the Mindsponge theory to conceptualize models to examine the effects of in-home biodiversity on urban residents' belief in biodiversity loss and whether such effects are conditional on residents' comfort at home. The Bayesian Mindsponge Framework (BMF) analytics was utilized to verify the conceptualized models on a dataset of 535 Vietnamese urban residents. The research found positive effects of urban residents' connections to in-home plant and animal diversity on their belief in biodiversity loss. Moreover, these effects are conditional on residents' comfort at home.

Specifically, when the respondents feel comfortable at home, a higher diversity of pets is associated with a higher likelihood of believing that biodiversity loss is a real and major problem. In contrast, a higher diversity of pets is associated with a lower likelihood of believing that biodiversity loss is a real and major problem if respondents feel uncomfortable at home.

The effects of in-home animal diversity on biodiversity loss belief in two comfort scenarios validate the Mindsponge theory's reasoning: information is absorbed and reinforced in urban residents' mindsets when it is perceived as beneficial, but rejected if it is perceived as costly. When the number of types of pets increases, it will likely uninclude out-of-the-ordinary animals other than dogs and cats. Keeping exotic pets, species "without a long history of captivity and ... likely to have been sourced directly or within a few generations from wild populations" [73], can help owners satisfy their personal interests and need for entertainment and companionship [74]. However, when the number of types of pets increases, pet care also becomes more complex and demanding. Pet diversity can adversely affect a house's cleanliness and tidiness without adequate management. Suppose

the owners are comfortable with the house having a wide variety of pets. In that case, they might enjoy the advantages of having more types of pets, which might make it more likely for them to integrate information related to biodiversity loss. On the contrary, if they are uncomfortable with the house having so many pets, the higher diversity might feel like a burden, therefore driving them to question the value of wildlife diversity and reject information relevant to biodiversity loss.

Regarding plant diversity, it generally positively affects the biodiversity loss belief. The consistently positive effect of plant diversity on biodiversity loss belief might be explained by the fact that domesticated plants are generally good for human health. According to [75], many studies show that plant diversity in urban green spaces, residential neighborhoods, parks, and gardens is associated with better human physiological and psychological wellbeing.

The effect of plant diversity on biodiversity loss belief is stronger among respondents who feel uncomfortable at home than those who feel comfortable, thereby increasing the likelihood that the biodiversity loss belief of respondents with different levels of comfort will converge when the plant diversity is high. This pattern might be explained by humans' innate tendency to seek connections with nature [76,77]. Hypothetically, biophilia exists in people's mindsets or has been reinforced, like genetic information, over thousands of years of surviving and evolving within the natural environment [8,78]. Thus, information from the biophilic environment can be easily integrated into the human mind, while information from the nonbiophilic environment is more likely to be differentiated for thorough evaluation [27,34]. Differentiation is a stressful process as it consumes more energy and involves many cognitive functions, possibly leading to poor information exchange with the surrounding environment and negative impacts on human health, such as high blood pressure, poorer short-term memory, and negative emotions [79]. Following this logic, it is reasonable to anticipate that respondents living in uncomfortable environments tend to have clearer perceptions of plant diversity's benefits than those in comfortable ones. Thus, they might view planting more types of plants as an adaptive strategy to turn their living environment into a more comfortable place [78], thus reinforcing the value of biodiversity and, eventually, the belief in existence and significance of biodiversity loss. It should also be noted that plant species planted in urban areas are mostly domesticated and selective, so they pose minimal risks to humans (e.g., poisonous or bearing thorns).

Based on the results above, increasing in-home biodiversity can be a promising way to raise urban residents' awareness of the occurrence and significance of biodiversity loss. When urban residents perceive the costs of biodiversity loss, they will be more likely to adopt the values of the eco-surplus culture [80], which can help reduce environmentally damaging behaviors and generate funds for conservation [30,31]. Notably, in most situations, the likelihood of biodiversity loss belief rises when biodiversity increases, except when a respondent feels uncomfortable in an environment of high pet diversity. This suggests that promoting the ownership of diverse types of pets at home can be a contentious approach to promoting urban residents' belief in biodiversity loss. With the exception of common domesticated species such as dogs and cats, increasing the diversity of pets might lead to rising demand for exotic pets, such as birds, reptiles, and mammals, exacerbating illegal wildlife trade problems [73].

The current study is not without limitations [71]. First, as the diversity of pets and plants is self-reported, it was not possible to know the level of taxonomy the respondents were referring to when reporting results. Second, the convenient sampling strategy was employed because of social distancing during COVID-19, which might lead to selection bias. The findings should thus be considered with caution. By applying a Bayesian analysis, we could produce exact estimates based on the data at hand, which can later be compared with studies analyzing random sampling. However, considering the variety of residences and backgrounds of participants (from cities around Vietnam), we believe that our results are fairly representative.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/urbansci7020046/s1>, Table S1: Results of Model 1 with uninformative priors; Figure S1: Model 1's PSIS-LOO diagnosis plots with uninformative priors; Figure S2: Model 1's trace plots with uninformative priors; Figure S3: Model 1's Gelman–Rubin–Brooks plots with uninformative priors; Figure S4: Model 1's autocorrelation plots with uninformative priors; Figure S5: Model 1's posterior distributions with uninformative priors.

Author Contributions: Conceptualization, M.-H.N.; methodology, M.-H.N., Q.-L.N. and V.-P.L.; software, Q.-L.N. and V.-P.L.; validation, Q.-H.V. and T.-T.L.; formal analysis, R.J., Q.-L.N. and V.-P.L.; investigation, M.-H.T.N., R.J. and T.-T.L.; resources, M.-H.N.; data curation, M.-H.N.; writing—original draft preparation, M.-H.N., M.-H.T.N. and R.J.; writing—review and editing, M.-H.N. and R.J.; visualization, Q.-H.V.; supervision, Q.-H.V.; project administration, Q.-H.V.; funding acquisition, Q.-H.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: For transparency and cost-effectiveness, all the code and data used for this study's analysis have been deposited in the Open Science Framework for public evaluation: <https://osf.io/gs3h2/> (accessed on 13 February 2023).

Conflicts of Interest: The authors declare no conflict of interest.

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