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RESEARCH ARTICLE

Biophobia: A Hidden Dimension of Human-Nature Relationships

The searchscape of fear: A global analysis of internet search trends for biophobias

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Abstract

1. Human relationships with nature may sometimes manifest through fear, disgust and other disease-avoidance mechanisms. While there is an evolutionary utility to these so-called 'biophobias', many people exhibit phobic responses towards organisms that pose no tangible threats, potentially leading to excessive anxiety and avoidance of interactions with nature. Understanding the drivers of the prevalence and spread of biophobias in modern societies is, therefore, a growing concern.
2. Here, we posit that online information-seeking patterns may reveal general insights into biophobias. Using a culturomics approach, we gathered temporal (2004–2022) and country-level data on the volume of internet searches for 25 biophobias, as well as 25 general phobias acting as a benchmark group. We explored temporal trends in the volume of search for each biophobias and modelled relationships between search volume for biophobias and five country-level variables.
3. We observed a steady increase in online search volume for biophobias between 2004 and 2022. Yet, there were marked differences in individual trends, with 17 biophobias showing positive, three negative and five stationary temporal trends. Arachnophobia (fear of spiders) attracted the most interest, followed by mysophobia (fear of microbes) and parasitophobia (fear of parasites).
4. The United States, the United Kingdom, Australia, Canada, Mexico and India recorded wide interest in most biophobias, whereas 49% of countries showed no search volume for any biophobia. Search patterns for biophobias were strongly associated with the percentage of urban population, urban population growth and the number of extant venomous species in a given country. Conversely, search patterns for biophobias were weakly correlated with the incidence of anxiety disorders in a country's population and the likelihood of encounters with venomous animals.
5. Our results provide quantitative support to the hypothesis that biophobias are broadly prevalent and possibly increasing as a result of widespread urbanisation and loss of experiences with nature. We suggest that people affected by biophobic

disorders may be using the Internet as a key venue to seek relevant information to appraise their condition and identify coping mechanisms. These findings have broad ramifications for understanding and mitigating human–wildlife conflicts and the prevalence of widespread biophobic sentiments in modern societies.

KEYWORDS
Arachnophobia, biophilia, Google Trends, online searches, Stress and Coping theory, urbanisation-disgust hypothesis, venomous animals, zoophobia

1 | INTRODUCTION

The renowned naturalist Edward O. Wilson (1929–2021) coined the term 'biophilia' to describe '*the connections that human beings subconsciously seek with the rest of life*' (Wilson, 1984). The biophilia hypothesis posits that humans, by sharing an evolutionary history with nature, have developed an innate affinity for the natural world (Wilson, 1984, 2013). Widespread evidence suggests that frequent exposure to nature provides various benefits to human health and well-being (Bratman et al., 2019; Keniger et al., 2013; Maes et al., 2021). At the same time, increased awareness of and connection with the natural world may be central to driving motivation towards biological conservation (Barragan-Jason et al., 2022; Simaika & Samways, 2010; Soga & Gaston, 2021; Zhang et al., 2014).

Yet, human relationships with nature are not always positive. In our ancestral past, nature was a prime source of danger—from the risk of eating a toxic fungus, through the fear of being chased by a large carnivore, to the danger of encountering a venomous animal. Therefore, it has been proposed that humans may have evolved innate behavioural and physiological responses to threat-relevant stimuli associated with nature (Gerdes et al., 2009; LoBue, 2010; Yorzinski et al., 2014). These responses often manifest through strong negative feelings such as fear, disgust and other disease-avoidance mechanisms (Davey, 2011), and can be generally referred to as 'biophobias' (Soga et al., 2023; Box 1).

Evidence suggests that the incidence of biophobias is high, and possibly growing, in industrialised societies, even though our modern lifestyle entails only limited hazards related to wildlife. For example, while wildlife-related fatalities are extremely rare events (e.g. in the United States; Conover, 2019), animal phobias (zoophobias) have one of the highest lifetime prevalence (3.3%–5.7%) among specific phobias (Eaton et al., 2018; Wardenaar et al., 2017). Interestingly, many people exhibit phobic responses towards organisms that are not harmful or towards organisms that are geographically far, suggesting a strong cultural component to some of these phobias (Box 1).

It has been argued that the rise of biophobias in contemporary industrialised societies may be driven by a progressive disconnection with nature (Beery et al., 2023; Miller, 2005; Zsido et al., 2022), for example as a result of ongoing urbanisation (Fukano & Soga, 2021; Hand et al., 2017) or due to a growing tendency for youth and adults alike to be increasingly sedentary and bound to indoor spaces (Beyer

BOX 1 The prevalence and origin of specific phobias and biophobias

Specific phobias are anxiety disorders involving an intense, persistent and irrational fear of something that poses little or no actual threat (Eaton et al., 2018). According to a 2001–2011 cross-national survey of 22 low- to high-income countries (Wardenaar et al., 2017), the median lifetime prevalence rate of specific phobias is 7.4% (9.8% in females and 4.9% in males). Some of the most common specific phobias involve the irrational fear of heights, flying, closed spaces and different elements of the natural world (biophobias) (Eaton et al., 2018). Among the biophobias, those related to animals (zoophobias) are some of the most widespread, including arachnophobia (fear of spiders, largely considered to be the most common animal phobia; Mammola et al., 2017), entomophobia (fear of insects), ophidiophobia (fear of snakes), cynophobia (fear of dogs) and ornithophobia (fear of birds).

While the evolutionary utility of fear is widely accepted (e.g. Adolphs, 2013; Marks & Nesse, 1994), the nature of phobias is more controversial owing to their detrimental effect on human health, causing undue stress and often preceding the onset of other mental disorders (Wardenaar et al., 2017). Studies based on family and twins (e.g. Hettema et al., 2001; Shimada-Sugimoto et al., 2015) suggest a moderate to high role of genetic factors in the aetiology of phobias, whereas the role of environmental factors and information learning pathways remains more challenging to quantify [see Coelho & Purkis, 2009 for an overview of influential theories]. For example, while intuitively the fear for spiders has a clear evolutionary origin associated with the disease-avoidance disgust response (Davey, 2011; Mulkens et al., 1996), some authors have questioned its evolutionary roots based on the fact that only a small percentage of spiders actually pose a threat to humans. Indeed, diverse cultural factors and learning experiences seem to be involved in the origin and persistence of arachnophobia in modern societies (Davey, 1994; Hoffman et al., 2019; Mammola, Nanni, et al., 2020; Merckelbach et al., 1996).

Box 1 (Continued)

In pursuit of consilience, Marks (2002) conceptualised the distinct models of fear acquisition as part of a continuum. On the one end of this continuum are innate reactions that manifest with no prior traumatic experience, such as the eye-blink reflex with the fast approach of an object towards the face. On the opposite end are situations that trigger an adverse reaction after a large quantity of learning experiences has been acquired. Yet, where different biophobias stand along this continuum remains a largely open question (Soga et al., 2023).

et al., 2018; Guthold et al., 2010). This loss of human–nature interactions has been formalised as the 'extinction of experience' (Gaston & Soga, 2020; Soga & Gaston, 2016) and its causal role in the emergence of biophobias is under intense scrutiny (Soga et al., 2023; Zsido et al., 2022). Furthermore, a distorted perception of risk can be exacerbated by how wildlife is framed by different information sources, as seen, for example, for large carnivores (Bombieri et al., 2018; Nanni et al., 2020), vultures (Ballejo et al., 2021), sharks (Sabatier & Huveneers, 2018; Whitenack et al., 2022), spiders (Mammola et al., 2022a, 2022b; Mammola, Nanni, et al., 2020) and bats (López-Baucells et al., 2018; MacFarlane & Rocha, 2020; Nanni et al., 2022).

Here, we explored temporal and spatial patterns of internet searches related to specific biophobias, as well as to other common psychological phobias acting as a benchmark, to assess information-seeking behaviour related to nature phobic disorders. Based on the Stress and Coping theory (Lazarus & Folkman, 1984), people affected by phobic disorders may seek to appraise their condition and identify coping mechanisms by searching for relevant information online (details in Section 2.1). Therefore, we posit that online information-seeking patterns may reveal insights into the prevalence and distribution of biophobias in modern societies. Specifically, we hypothesise that internet searches for biophobias may be increasing over time and are likely to be more prevalent in countries with a higher proportion of the population living in urban environments, particularly those with a larger number of extant species that are potentially harmful to humans.

2 | MATERIALS AND METHODS

2.1 | Theoretical framework

A *phobia* is an anxiety disorder defined by a persistent and excessive fear of an object, circumstance or situation (American Psychiatric Association, 2022). A *biophobia* (Box 1) is a form of specific phobia that is driven by fear of a living organism. Phobic reactions, including those triggered by living organisms or their representations, can be characterised as stressful events caused by an external stimulus and leading to extreme reactions driven by anxiety or fear. These reactions may relate to concerns about harm from a feared object or organism, concern about embarrassment or fear of the consequences related to the exposure (American Psychiatric Association, 2022). Phobic reactions tend to have a negative impact on an individual's well-being and usually lead to the development of specific psychological, physiological or behavioural mechanisms to cope with future events. According to the Stress and Coping theory (Lazarus & Folkman, 1984), the development of coping mechanisms in reaction to a stressful event happens in two sequential stages: (i) cognitive appraisal of the situation, and (ii) assessment of coping resources. In the first stage of the process, individuals will process and categorise the event and its various facets with respect to its significance for present and future well-being. Individuals may then develop cognitive, psychological and behavioural efforts to master, reduce or tolerate the demands of a future similar stressful interaction. The theory of Stress and Coping has been widely applied, particularly in medical contexts where patients are faced with a distressing medical diagnosis or life-threatening events. Examples of the application of this theory in a medical context include patients faced with cardiac disease (Anttila et al., 2021; Holahan et al., 1997), cancer (Kang et al., 2020; Lambert et al., 2009), obesity (Ajibewa et al., 2021; Walsh et al., 2021) and particularly psychological anxiety and phobia (Liu et al., 2021; Tams et al., 2018). It has also been deployed in nonmedical contexts, including for example research focusing on coping with work (Dewe et al., 1993; Van den Brande et al., 2016) or environment-related stress (Chawla, 2020; Ojala, 2016).

Information-seeking behaviour, also referred to as monitoring, is a common approach deployed as part of coping efforts (Lazarus & Folkman, 1984). Information seeking is thought to be deployed mostly by individuals adopting problem-focused approaches to coping (handling stress by facing it head-on and taking action to resolve the underlying cause) when faced with uncertain situations (Folkman & Lazarus, 1980; van Ingen et al., 2016; van Zuuren & Wolfs, 1991). The opposite behaviour of blunting (information avoidance) is more commonly associated with emotion-focused coping (regulating feelings and emotional response to the problem instead of addressing the problem), although some authors argue otherwise (Shiloh & Orgler-Shoob, 2006). Given the widespread availability of information about a broad range of topics on the world wide web and other digital platforms, online information seeking is nowadays a common behaviour deployed by individuals seeking to develop coping strategies for stressful life events (van Ingen et al., 2016).

Online information-seeking behaviour is also common in individuals suffering from mental and anxiety disorders (Chan et al., 2022). The dominant information needs of such individuals include additional information about their general condition and more specific details about potential treatments or coping mechanisms (Chan et al., 2022; Liebherz et al., 2015). It seems plausible that similar behaviours and needs may be observed in individuals suffering from various forms of biophobia as part of their coping strategy. For example, experimental evidence suggests arachnophobic individuals have an enhanced recall of spider-relevant information (Smith-Janik & Teachman, 2008). Based on this, we argue that people suffering from specific forms of biophobia are likely to seek information online about their anxiety to appraise their condition and identify coping or treatment mechanisms. If this is true, data from search engines should reflect this behaviour and provide insights on the temporal and spatial patterns of interest for specific biophobias that can be used to explore hypotheses about the links between urbanisation, nature exposure and the emergence and prevalence of biophobia in modern societies (Fukano & Soga, 2021; Soga et al., 2023).

2.2 | Data collection

We used a culturomics approach (Correia et al., 2021; Ladle et al., 2016) to explore information-seeking behaviour about biophobias online. Specifically, we obtained data from Google Trends (https://trends.google.com/trends/), which allows users to collect data on relative search volume data for selected terms (i.e. keywords) or topics. Topic searches are implemented using previously defined topics recognised by Google's search engine based on their semantic knowledge graph. The main advantage of topic searches compared to keyword searches are that the latter tallies only searches containing the keyword (e.g. apple, apple pie, and rotten apple), whereas the former includes also language variations of the same keyword (e.g. apple, manzana, and omena) and contextually related searches (e.g. what fruit keeps the doctor away?). Topic searches also have the advantage of helping to disentangle searches for similar keywords but referring to different topics (e.g. *Arachnophobia* the movie versus arachnophobia as a form of biophobia).

Using topic searches, we extracted data on the relative volume of worldwide searches for 25 specific biophobias and 25 other common phobias acting as a benchmark group (Table 1). We initially compiled a list of proposed biophobias from online sources (e.g. Wikipedia List of Phobias https://en.wikipedia.org/wiki/List_of_phobias; Phobia Fandom Wiki https://phobia.fandom.com/wiki/Phobia_wiki) and verified whether they were recognised by Google's knowledge graph as specific topics. For the analysis, we retained 25 specific biophobias recognised by Google's knowledge graph as topics and for which the context of searches matched the relevant biophobia (Correia, 2019). We then carried out a similar process for other phobias, selecting another 25 popular phobias ad-hoc for comparison. We obtained monthly data for the whole period of data availability, namely between January 2004 and November 2022 (i.e. 227 months).

TABLE 1 List and description of phobias considered in the analysis. A detailed description of each phobia and its associated Google Knowledge Graph topic identifier are available as Supporting Information (Table S1).

List of biophobias	List of other phobias
Acarophobia (fear of insects that cause itching)	Acrophobia (fear of heights)
Ailurophobia (fear of cats)	Aerophobia (fear of flying)
Alektorophobia (fear of chicken)	Astraphobia (fear of thunder)
Anthophobia (fear of flowers)	Atychiphobia (fear of failure)
Apiphobia (fear of bees)	Autophobia (fear of isolation)
Arachnophobia (fear of spiders)	Cancerophobia (fear of cancer)
Bovinophobia (fear of cows and bulls)	Claustrophobia (fear of closed spaces)
Chiroptophobia (fear of bats)	Coulrophobia (fear of clowns)
Cynophobia (fear of dogs)	Dentophobia (fear of dentists)
Entomophobia (fear of insects)	Dysmorphophobia (fear of body defects)
Equinophobia (fear of horses)	Emetophobia (fear of vomiting)
Herpetophobia (fear of reptiles or amphibians)	Haphephobia (fear of being touched)
Hylophobia (fear of forests)	Hemophobia (fear of blood)
Ichthyophobia (fear of fish)	Hoplophobia (fear of guns)
Musophobia (fear of rats)	Iatrophobia (fear of doctors)
Mycophobia (fear of mushrooms)	Neophobia (fear of novelty)
Myrmecophobia (fear of ants)	Nosocomephobia (fear of hospitals)
Mysophobia (fear of microbes)	Nosophobia (fear of disease)
Ophidiophobia (fear of snakes)	Nyctophobia (fear of darkness)
Ornithophobia (fear of birds)	Pediophobia (fear of dolls)
Parasitophobia (fear of parasites)	Philophobia (fear of love)
Ranidaphobia (fear of frogs)	Social phobia (fear of social situations)
Selacophobia (fear of sharks)	Technophobia (fear of technology)
Vermiphobia (fear of worms)	Trypanophobia (fear of needles)
Zoophobia (fear of animals)	Trypophobia (fear of closely packed holes)

We carried out the data extraction following a procedure that allows for relative search volume to be comparable between topics (Adamo et al., 2022; Davies et al., 2018; Mammola, Riccardi, et al., 2020). Google Trends returns data with values between 0 and 100 as an indicator of relative search volume. For the sampled period, the maximum value of 100 represents the highest proportion of searches observed during any month and all other monthly values are rescaled relative to this maximum. Search volumes are therefore only comparable if rescaled to the same maximum value, and each search allows up to five topics simultaneously. To ensure the comparability of relative search volumes between phobias after the first search, each search retained always one phobia in common with earlier searches. We rescaled the values between searches using the coefficient of a linear regression between the monthly values of the phobia present in both searches. We selected the phobia retained between searches iteratively, starting with the most searched phobia (Social phobia). This selection process considered only phobias where the regression between the values obtained in both searches returned an R^2 value above 0.95, and among those fitting this criterion, we selected the phobia with the most nonzero values in both searches. This process ensures that a minimum amount of noise is introduced by the scaling process. We rescaled relative search values for general searches and also searches classified under the Health category by Google.

2.3 | Data analysis

We carried out all statistical analyses in R v4.2.2 (R Core Team, 2022). First, we explored the relationship between general and health-related searches for biophobias and other phobias. We calculated the average relative search volume over the 227 months of sampled data and calculated the Spearman's rank-order correlation between the average search volume of each phobia associated with general and health-related searches. Given the strong correlation between the results of both searches (see Section 3), we restricted subsequent analyses to the results obtained from general searches as they include a broader range of information-seeking interests.

Second, we explored temporal trends in search interest for biophobias and other phobias. We used nonparametric Mann–Kendall tests to detect the existence of significant temporal trends in the time series of relative search volume for the period sampled and Sen's slope to assess the direction of the observed trend. We calculated Mann–Kendall tests through the 'MannKendall' function in package Kendall v.2.2.1 (McLeod, 2011) and Sen's slopes using the function 'sens.slope' from package trend v.1.1.4 (Pohlert, 2020). We calculated these tests for each phobia separately, and also for the sum of interest in biophobias, other common phobias (i.e. benchmark group), and for the ratio between the two.

Finally, we assessed the presence of search interest for each biophobia independently at the country level. Data available from Google Trends currently allows only the comparison of search volume for multiple topics within a country or for a single topic between countries; therefore, we focused this analysis on whether search interest for individual phobias was recorded in each country. Using regression analysis, we tested whether individual differences among the search volume for different countries could be related to five explanatory variables: (i) percentage of urban population, (ii) urban population growth, (iii) incidence of contact with venomous animals per 100,000 individuals, (iv) percentage of population with an anxiety disorder and (v) extant venomous species. We sourced data on the percentage of human population and urban population growth from the World Bank Database using the function 'wb_data' from package wbstats v.1.0.1 (Piburn, 2020). We collected data on the incidence of contact with venomous animals and the percentage of the population with anxiety disorders from the Global Burden of Disease Network (2021) via Our World in Data (https://ourworldindata.org). We obtained data on extant venomous species per country from the Living Hazards Database (https://www.acq.osd.mil/eie/afpmb/livinghazards.html). We centred explanatory variables to zero based on the arithmetic mean and standardised them (z-transformed) to one standard deviation (Schielzeth, 2010). We modelled the relationship between the number of biophobias searched for in each country and the five predictors above with a generalised linear model. Prior to model fitting, we carried out data exploration (Zuur et al., 2010) by visually checking the distribution of response and predictor variables and by confirming no major collinearity among predictors via pairwise Pearson's r correlations based on a threshold of $|r| < 0.7$ (Figure S1). Considering that our dependent variable cannot assume negative values, but was highly zero-inflated (49% of the countries showed no search volume for any biophobia), we specified a hurdle negative binomial model with the R package glmmTMB v.1.1.5 (Brooks et al., 2017). A hurdle model is a two-component mixture model consisting of a zero mass component and a positive observations component following a truncated count distribution (Feng, 2021); we specified a negative binomial model for the count model because there was overdispersion in the positive counts. Note that the output of our hurdle model is composed of two parts: (i) the estimates for a binary model that explains how the predictors affect the presence/absence of country-level searches for biophobias; and (ii) the estimates for a positive count model that investigates how the predictors explain differences in the volume of search across countries. We validated the model by inspecting residuals and fitted values using functions in the R package performance v.0.10.2 (Lüdecke et al., 2021).

3 | RESULTS

Our results suggest that the world wide web is indeed used as a source of information for people seeking knowledge about phobias as we recorded search interest for all of the 50 phobias explored (Figure 1). Social phobia (also known as social anxiety disorder) attracted by far the most interest among the phobias explored in this study, independently of the search context. Other frequent specific phobias such as trypophobia (fear or disgust of closely packed holes)

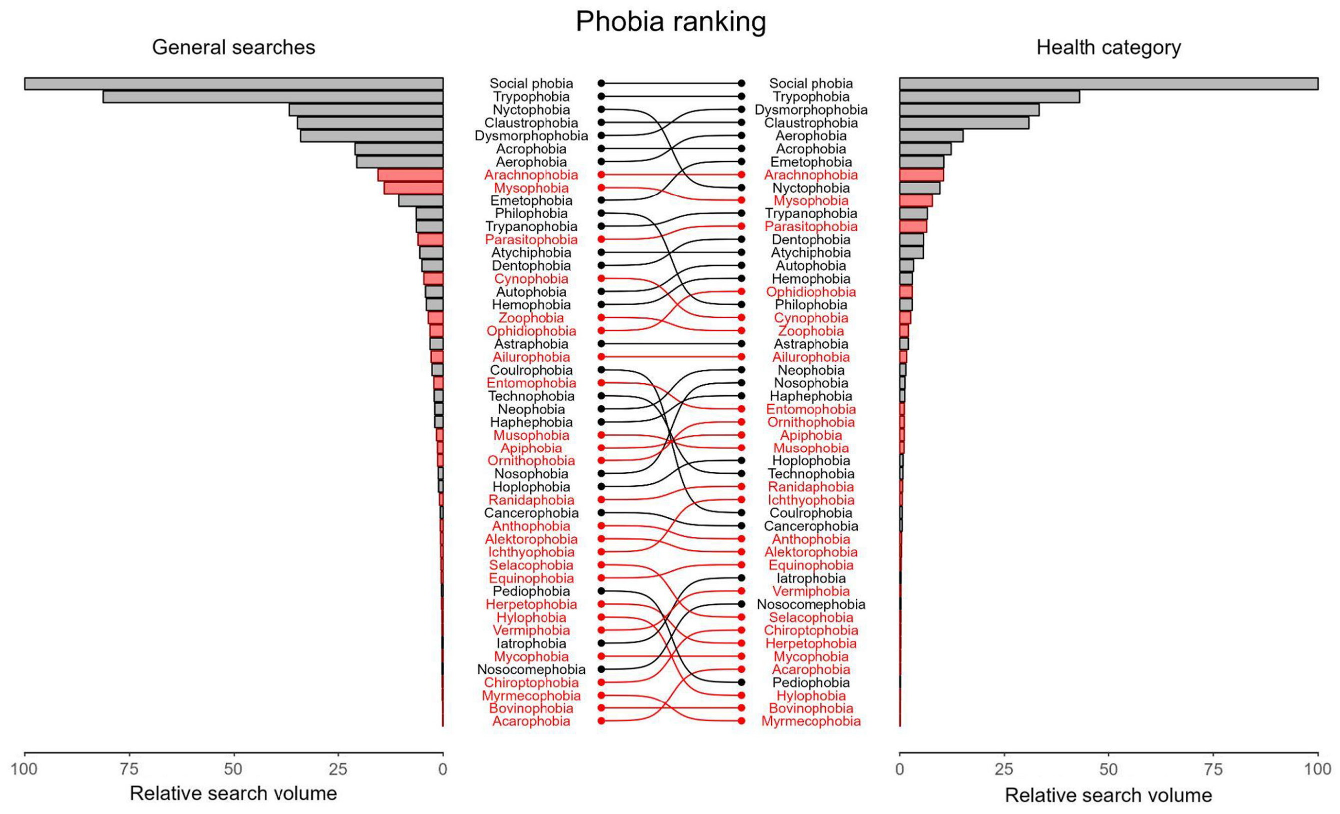

FIGURE 1 Ranking of common psychological phobias based on relative search volume in the context of general (left panel) and health-related searches (right panel). Psychological phobias associated with elements of nature (biophobias) are highlighted in red.

and nyctophobia (fear of the dark) featured among those gathering the most search interest. Within the biophobias, arachnophobia (fear of spiders) attracted the most interest, followed by mysophobia (fear of microbes) and parasitophobia (fear of parasites). Searches for biophobias were generally less frequent than for other common phobias, even though search volumes for the most common biophobias were comparable to other common specific phobias, such as trypanophobia (fear of needles) or emetophobia (fear of vomiting). While the relative volume of searches differed slightly between the general and health-related searches (Figure 1), there was a high, significant correlation between the two contexts (Spearman's rho = 0.965, p-value < 0.001), suggesting that some phobias dominate public attention across different search contexts.

We observed a positive trend associated with increasing search volume for general searches of both biophobias (Mann–Kendall's tau = 0.336; p-value < 0.001) and other common psychological phobias (Mann–Kendall's tau = 0.503; p-value < 0.001) between 2004 and 2022, although the trend was stronger for the latter (Figure 2a,b). As a result, the proportion of searches associated with biophobias in relation to those associated with other phobias actually decreased over the sampled period (Mann–Kendall's tau = −0.428; p-value < 0.001; Figure 2c). We also observed marked differences in the trends associated with different forms of biophobia. From the set of 25 biophobias assessed, 17 showed a positive trend, three showed a negative trend and five a nonsignificant trend between 2004 and 2022 (Figure 3; Table S2).

The number of biophobias with recorded search interest varied greatly between countries and showed a skewed distribution, with a few countries recording search interest for various biophobias and a large number of countries showing no search volume for any biophobia (123 of 250; 49%; Figure 4b). The United States and the United Kingdom showed the highest number of biophobias with recorded search interest (24 of 25 biophobias assessed), followed by Australia (23), Canada, Mexico and India (22) (Figure 4a). At the country level, both the presence of search interest for biophobias and the number of biophobias with recorded search volume were strongly associated with the percentage of urban population, urban population growth and the number of extant venomous species (Figure 5; model estimates in Table S3). Conversely, the incidence of anxiety disorders in a country's population and encounters with venomous animals were only weakly related to either of the response variables. More in detail, countries with a higher number of extant venomous species had a higher probability to register search interest for biophobias (estimate ± std. error: 1.419 ± 0.304, p-value < 0.001), and showed search interest for more biophobias (estimate ± std. error: 0.378 ± 0.070, p-value < 0.001). A similar pattern was observed for the proportion of urban population, whereby countries with a larger share of the population living in urban environments were more likely (estimate ± std. error: 0.564 ± 0.203, p-value < 0.01) to show interest in biophobias and to search for more biophobias (estimate ± std. error: 0.265 ± 0.108, p-value < 0.05). Urban

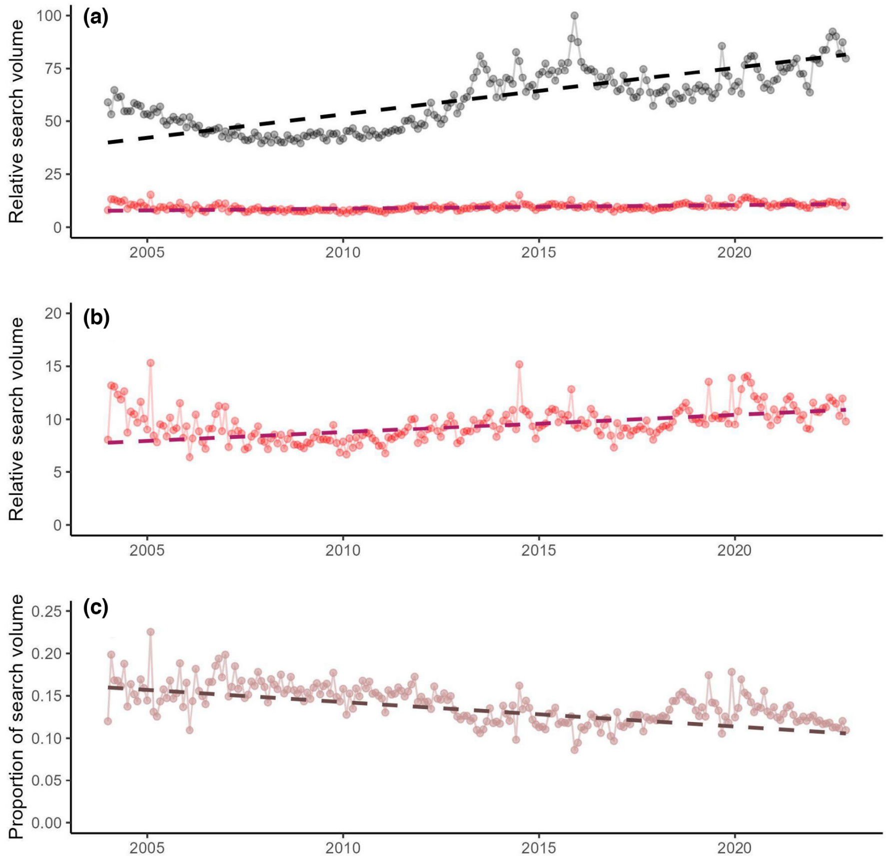

FIGURE 2 Temporal trends of relative search volume associated with specific biophobias (red) and other common psychological phobias (black). Panel (a) represents the relative search volume for both sets using the same scale, whereas panel (b) zooms in on biophobias to reveal the slight positive trend. Panel (c) represents the decreasing ratio of search volume for biophobias relative to that of other common psychological phobias. Points represent monthly search volume data obtained from Google Trends relative to the highest monthly value recorded across all topics (i.e. values are comparable between topics), whereas the dashed line represents the estimated temporal trend using the Thiel–Sen method.

population growth showed a negative relationship with both the probability of recording search interest (estimate ± std. error: -0.761 ± 0.209, p-value < 0.001) and the number of biophobias searched (estimate ± std. error: -0.418 ± 0.108, p-value < 0.001). In fact, searches for a larger number of phobias tended to be concentrated in countries with large and more stable urban populations (Figure 6), where the main population shift from rural to urban areas is likely to have occurred earlier. The model explained 34% of the variation observed in the data.

4 | DISCUSSION

Our results confirm that online information-seeking behaviour is common for a wide range of phobias, including biophobias. We observed a strong correlation in worldwide search volume between general and health-related searches for phobias, suggesting that the more popular phobias dominate online interest across a range of search contexts. The relative interest in the different phobias also aligns broadly with estimates of their occurrence in the global human population, suggesting that the frequency of information-seeking behaviour for each phobia may be representative of their prevalence across the globe. For example, social phobia is considered the most widespread anxiety disorder (Stein & Stein, 2008), and it was also the most commonly searched phobia online. Social phobia affects mostly younger individuals, having been reported in one of three individuals aged between 16 and 29 (Jefferies & Ungar, 2020), which may also help to justify its online search frequency given the larger participation of younger generations on the Internet (International Communication Union, 2022). Other common specific phobias such as acrophobia and claustrophobia (Eaton et al., 2018) were among the top-searched phobias as well. Likewise, arachnophobia was the most searched biophobia online, confirming evidence in the psychological literature which regards fear of spiders among the most prevalent biophobias, and indeed the most common in many contexts (e.g. Polák et al., 2020; Zsido, 2017). Interestingly, this hints that the search volume for (bio)phobias on the Internet could be used as an easy-to-collect, inexpensive proxy for monitoring the relative prevalence, and spatial and temporal patterns for some of these pathologies—in line with previous work evaluating the potential of online data for monitoring and forecasting disease outbreaks (Amusa et al., 2022; Mavragani & Gkillas, 2020; Pelat et al., 2009).

Beyond the differences in relative search volume between phobias, we also observed a general increase in the online search volume for biophobias and other phobias between 2004 and 2022. Search interest for biophobias increased less prominently than that directed at other phobias, but this pattern seems to be largely driven by the rapidly growing interest in social phobia compared to the other specific phobias assessed in our study. On the one hand, social anxiety tends to be more prevalent in rural and semiurban settings (Jefferies & Ungar, 2020), and internet use in these areas is catching up with cities (International Communication Union, 2022), so this trend may

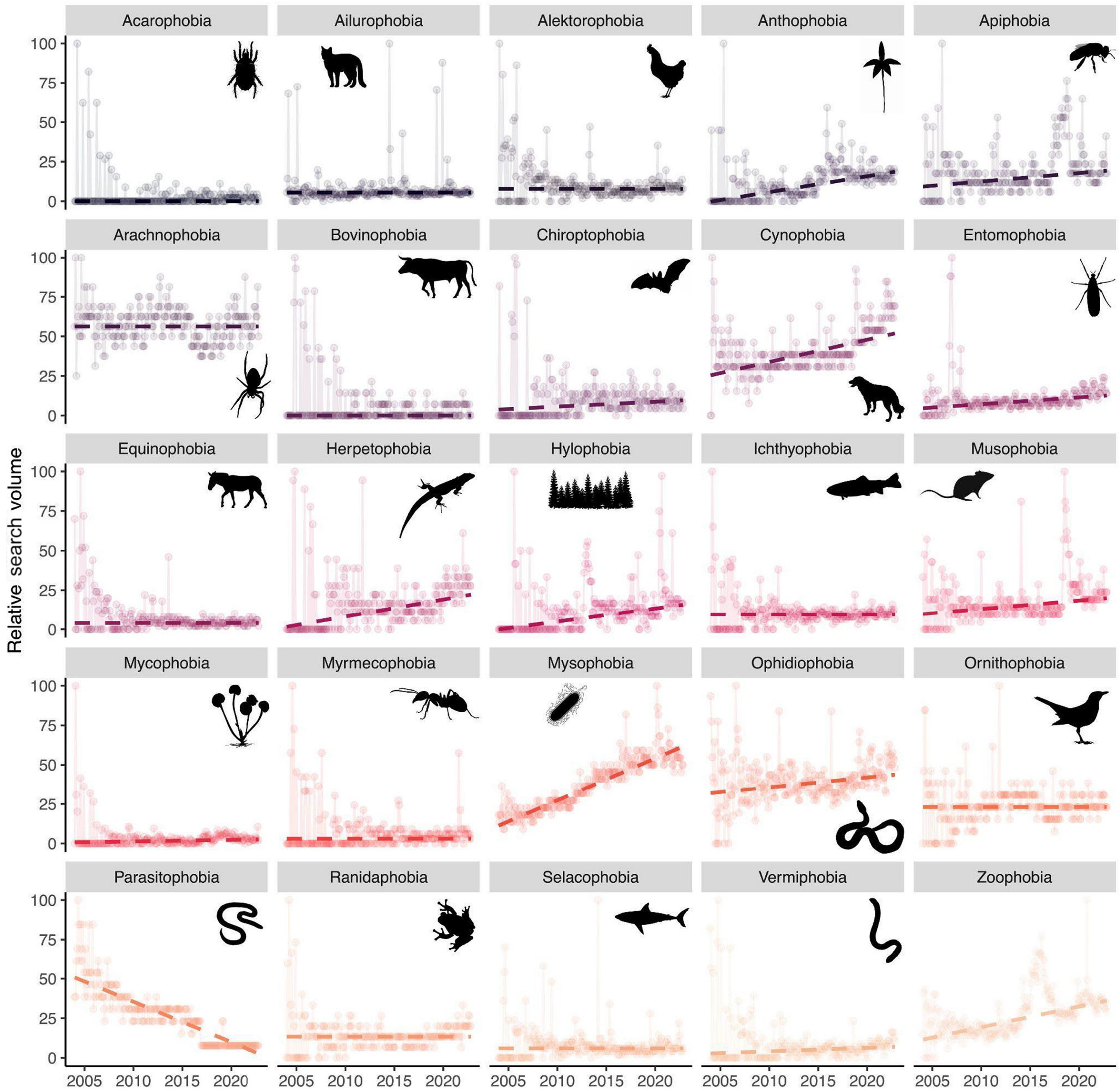

FIGURE 3 Temporal trends of relative search volume associated with each of the 25 specific biophobias assessed here. Points represent monthly search volume data obtained from Google Trends relative to the highest monthly value recorded for each topic (i.e. values are specific to each topic), whereas the dashed line represents the estimated temporal trend using the Thiel-Sen method. A summary table of temporal trend statistics for each biophobia is available in Supporting Information (Table S2). Silhouettes taken from PhyloPics 2.0 (http://phylopic.org/), except for Hylophobia taken from Clipart library (http://clipart-library.com/).

be partly explained by increasing internet access and representation of searches for social phobia in our sample. On the other hand, biophobia tends to be more frequent in urban areas with lower access to nature (Zhang et al., 2014), and the observed increase in search volume may be more indicative of a growing prevalence in society. We recognise that care should be taken when interpreting temporal trends observed in information-seeking behaviour (Correia et al., 2019; Ficetola, 2013) and other sources of information should be sought for additional evidence. Still, this result provides quantitative support to the belief that biophobias may be broadly prevalent in modern societies and possibly becoming more widely represented on the internet, for example through biophobic individuals that only recently gained internet access such as inhabitants of emerging urban areas or younger members of the public (Fukano & Soga, 2021; Soga et al., 2023; Zhang et al., 2014). A similar assertion can be made towards nonbiophobias, and particularly social phobia, which is known to be increasingly prevalent worldwide (Jefferies & Ungar, 2020).

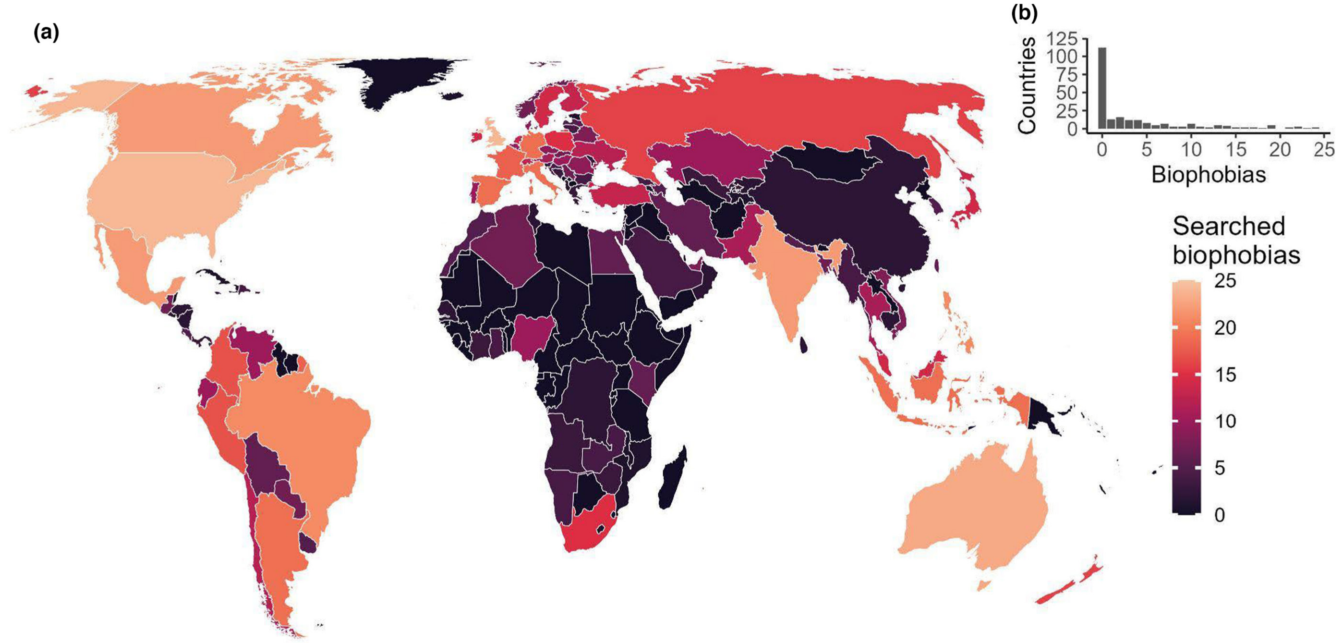

FIGURE 4 Map (a) and distribution (b) of the number of biophobias with recorded search interest for each country.

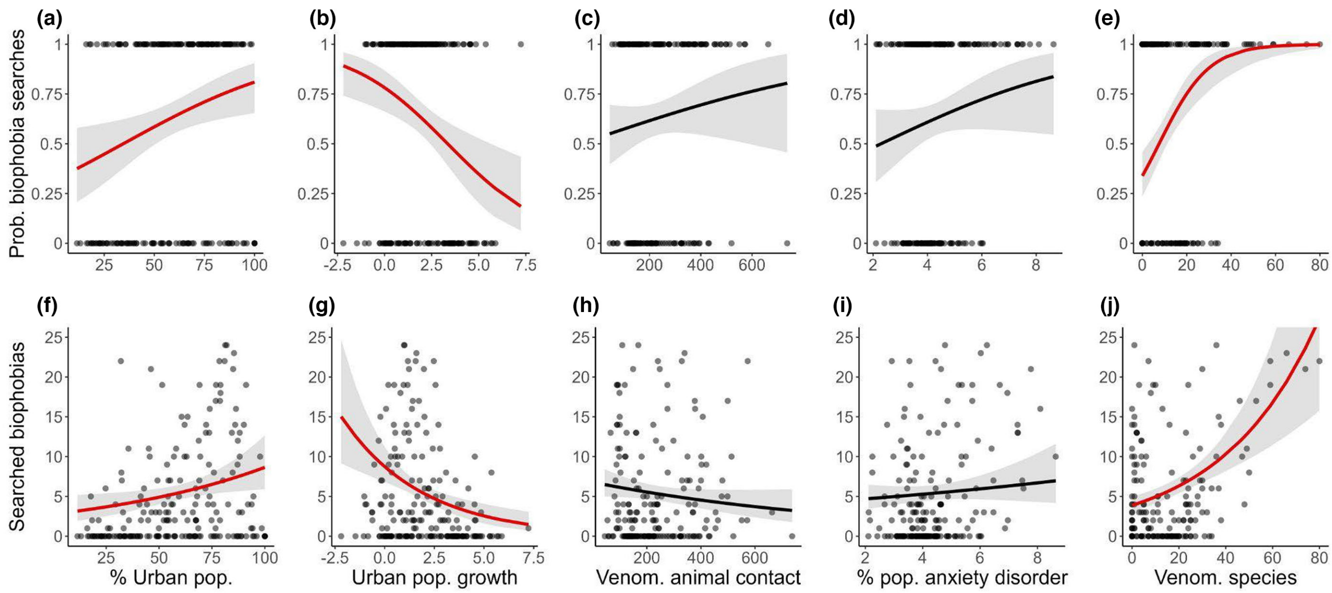

FIGURE 5 Relationship between country-level search interest for biophobias and (i) percentage of urban population (a, f), (ii) urban population growth (b, g), (iii) incidence of contact with venomous animals per 100,000 individuals (c, h), (iv) percentage of population with an anxiety disorder (d, i) and (v) extant venomous species (e, j). Individual plots represent the relationship predicted by a zero-hurdle count model between each predictor variable and the probability of a country recording search interest for any biophobia (top row, a–e) or the number of biophobias with recorded search interest (bottom row, f–j). Variables with a significant effect (p-value ≤ 0.05) predicted by the model are highlighted in red (model results available in Table S3).

Arthropods featured prominently among the most prevalent biophobias (5 of 25 searched biophobias), all showing stationary or increasing temporal trends. Arachnophobia gathered the most search interest overall, but internet searches remained relatively stable throughout the sampled period. Other phobias related to arthropods, such as apiphobia and entomophobia, were less frequently searched for but showed a growing interest in recent years. Between 2004 and 2022, mysophobia (fear of germs) showed the steepest temporal increase in the relative volume of online searches. We observed a spike in the relative volume of searches for mysophobia concomitant with the onset of COVID-19 pandemic in 2020, and search interest during this period greatly surpassed that of arachnophobia. This result aligns with reports of newly formed obsessions with dirt, germs and viruses during the COVID-19 pandemic

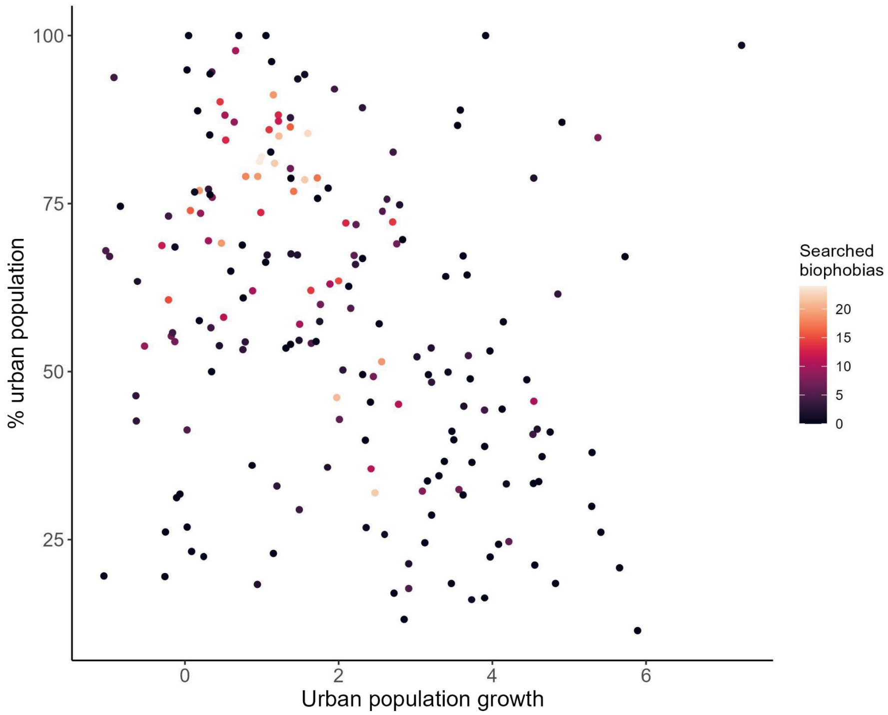

FIGURE 6 Relationship between urban population growth and the percentage of urban population. Colour gradient marks the number of searched phobias in a given country.

outbreak (Abba-Aji et al., 2020; Alateeq et al., 2021). Vertebrates were also undisputed protagonists across biophobias, with mammals, reptiles, birds and fish cumulatively representing 12 of the 25 searched biophobias. Among the vertebrate-related biophobias, the most searched and fastest growing was cynophobia, the fear of dogs. This is perhaps unsurprising when considering the frequency of human–dog interactions in modern societies and the fact that dogs are highly ranked in online lists of deadliest animals to humans, alongside disease-transmitting mosquitoes and snakes (Forrester et al., 2018; Kamerow, 2014). Finally, plants and fungi were poorly represented among the explored biophobias (3 of 25), yet the relative search volume for plant-related phobias increased over time. One possible justification for this trend is that increasing fear of plants may be associated with other phobias. For instance, fear of flowers (Anthophobia) is usually associated with the fact that they attract bees and other arthropods that feed on their pollen and nectar (Saimbi et al., 2017). Likewise, an irrational fear of forests (Hylophobia) may be linked to the sense of claustrophobia and nyctophobia provoked by walking into a densely wooded area (Herzog & Kropscott, 2004; Herzog & Kutzli, 2002).

Our analysis of factors that correlate with interest in biophobias at the country level also yielded relevant insights into the drivers of biophobia in modern societies. In our analysis, we observed that countries with a higher number of venomous species and larger and more stable urban populations tended to show interest in more biophobias. The positive relationship we found with the level of urbanisation provides indirect support to the 'urbanisation-disgust hypothesis' (Fukano & Soga, 2021). This hypothesis was recently proposed in an attempt to explain the high prevalence of disgust towards insects, spiders and other arthropods in modern societies. Based on a large-scale online questionnaire survey, Fukano and Soga (2021) demonstrated that urbanisation increases the chance of seeing arthropods indoors, and this induces stronger disgust responses than outdoor arthropods. According to this study, urbanisation is also associated with lesser knowledge about arthropods, ultimately broadening the range of species towards which people feel disgusted. This lack of knowledge about biological groups that may pose danger to humans may be particularly conducive to the development of biophobias in environments where a higher number of venomous species occur, as individuals may develop unfounded fears due to an inability to distinguish potentially dangerous from innocuous organisms. Beyond the lack of information, the outright spread of misinformation may also play an important role in the development of biophobias (Mammola et al., 2022a). The underpinnings of the 'urbanisation-disgust hypothesis' therefore align with both the 'direct conditioning' and 'informational' pathways proposed by Rachman (1977) for the acquisition of specific phobias. Both pathways have also been associated with the emergence of fear towards dogs (e.g. Doogan & Thomas, 1992), providing a reasonable explanation for the relatively high prevalence of searches for biophobias pertaining to common household pet animals which do not necessarily fit with the 'urbanisation-disgust hypothesis'. Furthermore, biophobias can also be transmitted socially as a learned or conditioned behaviour (Lemelin & Yen, 2015), and may be reinforced in the absence of direct knowledge and experiences with nature in urban environments. This process is referred to as 'modelling' by Rachman (1977) and has also been proposed as a common mechanism driving the emergence of phobias towards household pets (King et al., 1997). Likewise, modelling may also be a relevant pathway in the emergence of fear towards venomous taxa, as we found no relationship between interest in biophobias and the rate of direct encounters with venomous animals. We also found no evidence of a relationship between interest in biophobias and the prevalence of anxiety disorders in the population, indicating that biophobias may be driven by different factors from those linked to other mental disorders. Overall, further research is needed to disentangle the relative importance of the three pathways in the origin of biophobias, as it is likely that all three pathways are simultaneously present and potentially interact in driving the emergence of different biophobias at the population level (King et al., 2000; Rachman, 1977).

While our analyses provide interesting insights about the prevalence of biophobias in contemporary societies that are largely concordant with recently proposed hypotheses about their possible origins, the search engine data used here is not without its caveats and interpretation of results should be weighted accordingly. Beyond the challenges associated with assessing temporal trends from search engine data outlined above, there are also issues related to the content validity of internet searches (Correia et al., 2019; Mellon, 2013). Our use of topic searches instead of keyword searches accounts for some of the issues associated with multiple meanings and synonyms that are present in vernacular language (Correia et al., 2017). For example, Google Trends recognises topics for both 'Arachnophobia' the movie and the biophobia, which can help differentiate the use of the same word in different contexts. However, the way the algorithm separates the two contexts remains a 'black-box' and thus we cannot exclude the existence of some noise in the data. Finally, there are well-known differences in Internet access across the world (Graham et al., 2015; Graham & Dittus, 2022) which correlate with urbanisation patterns and may confound some of the patterns observed.

Despite these caveats, it is undeniable that interest in biophobias is global and that this topic is deserving of more research. Our analyses support the idea that living in urban environments may lead to a disconnection from nature due to a reduced chance of directly encountering wildlife and that this, in the long run, may increase the prevalence of a wide range of biophobias. This reinforces the message of a growing body of literature stressing the importance of developing and maintaining urban green space for people and biodiversity (e.g. Amano et al., 2018; Hand et al., 2017; Lee & Maheswaran, 2011; Sadler et al., 2010; Soga et al., 2020; Sugiyama et al., 2021). Providing opportunities for urban populations to interact and develop a healthy relationship with nature may help shield them from misguided fears and anxieties towards other life forms, with obvious benefits for mental health and general well-being. This, in turn, may translate into benefits for biodiversity that goes beyond those emerging from providing nature with spaces to thrive in cities. The growing absence of societal knowledge about species driven by the extinction of experiences with nature has negative implications for biodiversity conservation (Jarić et al., 2022), but these are likely to be emphasised if ignorance gives way to fear, anxiety and other negative emotions. Less popular groups such as arthropods, plants and fungi receive lesser conservation support and resources (Adamo et al., 2022; Gonçalves et al., 2021; Mammola et al., 2022b) and may be particularly impacted if negative emotions towards them become more widespread. In the absence of more direct experiences, digital, visual and other media may play a key role in reconnecting urban publics with nature (Silk et al., 2021), potentially contributing to enhance support for conservation and reduce biophobia prevalence. While the specific links between biodiversity conservation and biophobias remain poorly explored, they provide a fertile area for further scientific inquiry.

AUTHOR CONTRIBUTIONS

Ricardo A. Correia collected data, carried out analyses and prepared figures, with contributions by Stefano Mammola. Ricardo A. Correia and Stefano Mammola cowrote the manuscript.

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CONFLICT OF INTEREST STATEMENT

RAC is an associate editor of People and Nature but took no part in the peer review and decision-making processes for this paper.

DATA AVAILABILITY STATEMENT

Data on relative search volume for each phobia are available from Google Trends (https://trends.google.com). Data and code used to model country-level interest in biophobias are available on GitHub (https://doi.org/10.5281/zenodo.7923575).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1: Summary plot of the country-level relationship between the number of biophobias with recorded search volume and four explanatory variables considered for modelling: (i) share of urban population, (ii) urban population growth, (iii) incidence of venomous animal contacts per 100.000 inhabitants, (iv) share of population with incidence of mental disorders, and (v) number of extant venomous species.

Table S1: List of phobias used in this study, detailed description of each phobia and associated Google Knowledge Graph topic identifier.

Table S2: Summary statistics of Mann–Kendall tau and Thiel Sen slope estimator used to assess temporal trends for each biophobia.

Table S3: Summary table of the zero-hurdle count model relating the number of biophobias with recorded search interest and five explanatory variables.

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