Review

The effects of allergenic pollen in green space on mental health, behaviour and perceptions: A systematic review

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ABSTRACT

Recent times have seen an increase in the prevalence of allergic diseases due in part to the alterations and exacerbations of the global pollen cycle resulting from climate change. Climate change related temperature increases are associated with increased pollen production and an earlier and longer pollen season. A broad body of research has emerged demonstrating that green spaces in urban areas have mental health benefits. Yet, whether the relationship between green space and mental health may be altered by the presence of allergenic pollen remains underexamined. Using Scopus and Web of Science as search engines, this paper systematically reviews the emerging body of research exploring how allergenic pollen in green spaces may alter mental health, behavioural and perceptual outcomes. A total of 26 papers were identified. We found relatively consistent evidence that people living near green spaces with higher levels of allergenic pollen (real or perceived) experienced worse mental health than those living near green spaces with lower levels. However, for those currently visiting green space, the mental health effects of allergenic pollen were less clear. There was strong evidence that those who perceived the presence of pollen within a green space had adverse perceptions of that space. Green spaces with higher objective pollen counts also received less visitors. Finally, a small number of studies identified that green spaces that contained mainly hazel, alder, birch, cypress, linden, poplar, plane, maple and juniper trees were all associated with higher perceived pollen levels, avoidance, and adverse mental health effects, although more research is required to confirm this. We conclude with prospects for future research and also highlight the need to closely monitor and carefully select the species that are planted within green spaces.

1. Introduction

Over the past few decades, awareness has grown of the importance of nature and natural environments for human health, including particularly mental health and psychological wellbeing. In urban settings, for instance, green spaces provide ecosystem services, such as increasing resilience to climate change, conserving biodiversity and reducing urban heat through climate regulation, that benefit mental health by reducing potential harms, encouraging connection to nature and providing restorative benefits (Beute et al., 2023; Kabisch, 2019; Lee and Mahes-waran, 2011; Markevych et al., 2017; Marselle, 2019; Wolch et al., 2014).

Yet, green spaces may also provide ecosystem disservices, such as the production of allergens, that adversely affect human health. Certain species of flora present in urban green spaces can produce allergens when pollinating that negatively impact the physical health of those

exposed, such as by exacerbating asthma and rhinitis (Marselle et al., 2021). Higher pollen counts are directly associated with the number and severity of allergic reactions, and consequently more cases of hospitalisation (Dales et al., 2008; Osborne et al., 2017). Globally, rates of allergenic disease are also growing, particularly amongst those residing in urban areas, possibly because of the increasing presence of allergens in these areas (Luschkova et al., 2022).

Less is known about how the presence of allergenic pollen in urban green spaces may affect mental health and alter the ways people interact with and experience these spaces. Recent research suggests that perceiving that a green space contains species that produce allergens may encourage avoidance of the space (Adinolfi et al., 2014), while green spaces with more numerous allergenic species may provide less benefits to users' mental health on average (Stas et al., 2021a). However, to the best of our knowledge, no research has yet consolidated and holistically evaluated this body of evidence with the aim of determining

how mental health is affected by green spaces containing allergenic pollen. There have also been calls for further clarity on what specific qualities of green spaces and which species within them predict health and wellbeing outcomes (Markevych et al., 2017). Understanding how and in what ways allergenic pollen within green space affects mental health could contribute to several emerging gaps in the literature, then.

Further, it is especially necessary to examine the role of allergenic pollen in altering the relationship between green space and mental health given climate change will only exacerbate the amount and severity of allergens produced by plants in urban green spaces. That is, the frequency at which plants are exposed to higher temperatures is increasing, leading to heat stress of the vegetation (Kraemer and Kabisch, 2022) and lengthening the amount and length of time of pollen production (Damialis et al., 2019; Lake et al., 2017). Beyond this, increasing urbanisation and air pollution are altering the type and severity of allergenic pollen produced by species within green spaces (Bernard-Verdier et al., 2022; Gisler, 2021). In this context, the increasing production and severity of allergenic pollen within urban green spaces is likely to shift and transform as the effects of climate change become more pronounced, rendering it essential to determine how mental health is likely to be affected.

Previous conceptualisations of the relationship between urban green space and mental health have tended to focus primarily on the positive components of this relationship (Shackleton et al., 2016). For instance, urban green spaces have recently been proposed to affect mental health through the mitigation of environmental stressors (e.g., air pollution), restoration of capacities (e.g., reducing stress, improving mood), and instoration (e.g., encouraging physical activity or socialisation) (Markevych et al., 2017; Marselle, 2019; Beute et al., 2023). These three pathways are also moderated by an individual's characteristics, the socio-environmental context in which the green space occurs, the space's features (e.g., the plants present, its size, etc.) and the type of green space interaction (e.g., frequency, duration, behaviours undertaken, etc.) (Beute et al., 2023; Marselle et al., 2021).

In these conceptualisations, however, ecosystem disservices are often left out (Marselle et al., 2021) and the role of time or temporality is ignored (Zhou et al., 2022). Those which do include ecosystem disservices primarily focus on how they may directly harm individuals (Marselle et al., 2021), rather than considering how they may alter the other pathways connecting green spaces to mental health. Yet, ecosystem disservices, such as litter and untidiness, have been observed to cause people to have negative perceptions of a green space, resulting in them behaving differently in the space, such as by avoiding it, and experiencing reduced mental health benefits (Baur et al., 2014; Cleary et al., 2019; Lyytimäki et al., 2008). Research in other contexts, such as air pollution, has shown that time could also influence mental health. For instance, people respond and adapt their behaviours in real-time to the presence of air pollution, including by avoiding outdoor activities, reducing the severity of potentially adverse psychological impacts (Lu, 2020). It could be the case that people adapt their behaviour during high pollen seasons in order to avoid potential allergic reactions. Further, people's perceptions of air pollution also change over time, as the levels of pollution vary and people's "attunement" to its presence adjust (Roberts et al., 2023). That is, when people first become exposed to air pollution it is more noticeable and thus bothersome. Yet, over time, they begin to perceive it less and do not dwell to the same extent on its adverse effects. Whether or not the presence of allergenic pollen in green spaces has such perceptive and behavioural effects on the relationship between green spaces and mental health remains to be seen and warrants investigation. Doing so could reveal whether current conceptualisations of the relationship between green space and mental health need to be updated to pay closer attention to temporality, ecosystem disservices and people's perceptions.

Consequently, the aim of this paper is to systematically review literature exploring how and whether the production of pollen alters the way people interact with and experience green spaces, including their mental health. Theoretically, we might expect that the presence of allergenic pollen within a green space might influence its effects on mental health by altering an individual's perceptions of and behaviours within the green space. To test this hypothesis, we ask the following research questions:

1. How does the presence of allergic pollen (real or perceived) in green space affect the relationship between green space and mental health?
2. What are the perceptual and behavioural effects of allergic pollen in green space (real or perceived)?
3. What are the specific species or characteristics of green spaces, if there are any, that are associated with increased allergenic pollen (real or perceived) and adverse mental health, perceptual and behavioural outcomes?

2. Material and methods

Aligning with the World Health Organization (WHO), we view mental health as a continuum with, on the one side, a state of psychological wellbeing where an individual can "cope with the stress of life, realise their abilities, learn well and work well, and contribute to their community", and on the other, the "mental states associated with significant distress, impairment in functioning, or risk of self-harm" (WHO, 2022, p. 8). Perceptions are viewed as an individual's feelings about and perspectives of an environment as shaped by their sensory and subjective experience of the environment (Abraham et al., 2010), while behaviours refer to the actions an individual undertakes within that environment, ranging from avoidance to exercise and socialisation (Lafortezza et al., 2009).

There is no clear or agreed upon definition of exactly what constitutes green space, other than general definitions like "land that consists predominantly of unsealed, permeable, 'soft' surfaces such as soil, grass, shrubs and trees" (Swanwick et al., 2003, p. 97). Perhaps in part this is a result of the wide array of studies that have examined vastly different kind of spaces and defined them as green, such as from small, private gardens to large, urban forests (Klompmaker et al., 2018). Considering that an important element of the relationship between green space and mental health relates to socialising and sense of community (Astell-Burt et al., 2022; Sanesi et al., 2006), and that there is a sense that the space is distinguished from its more urban surroundings, we consequently define green space as any publicly accessible bounded area containing nature of some kind.

The systematic review methodology reported in this paper follows PRISMA guidelines (Moher et al., 2009) and has been registered with PROSPERO [CRD42023442599]. On 25 April 2023, Scopus and Web of Science were searched using the below search terms. Afterwards, we also conducted a hand-search, by inspecting the citations of relevant articles identified in the initial search (snowballing) and also using similar search terms in Google Scholar. The database search, which was limited to title, abstracts and keywords, contained the following categories and search terms:

> "pollen" OR "rhinitis" OR "allergy" OR "allergies" OR "allergen" OR "allergic" OR "medication use" OR "ecosystem disservice* " OR "hay*fever"
>
> AND
>
> "green space* " OR "forest* " OR "park* " OR "woodland* " OR "green infrastructure* " OR "urban greenery"
>
> AND
>
> "mental health" OR "well-being" OR "wellbeing" OR "emotion* " OR "perception* " OR "psychological" OR "quality of life" OR "life quality" OR "behavior* " OR "behaviour* "
>
> AND

"activity* " OR "activities" OR "perceived" OR "exposure" OR "proximity" OR "experience* " OR "valuation" OR "attractiveness"

Papers were eligible for inclusion if they presented empirical data relating predominantly to green spaces containing pollinating or allergen producing species and their impacts on visitors' mental health, perceptions or behaviours. Review articles and those presenting non-empirical results were excluded, as were conference proceedings, editorials and commentaries. We also excluded papers reporting on the mental health effects experienced by those suffering from physical symptoms associated with allergies and rhinitis and that did not contain an element of green space exposure, interaction or usage. Research investigating private greenery, such as household gardens, or those existing in predominantly rural areas were also not included in this review.

Articles were downloaded and imported into EndNote, where duplicates were removed. We screened the titles and abstracts, while removing papers deemed not to have met the inclusion criteria. If it was not immediately clear whether or not allergenic pollen was a consideration in the article, but it potentially satisfied other criteria relating to green space and perceptions, behaviours and mental health, then the paper was included for the final full-text appraisal. Then, the complete text was inspected, with those not meeting the complete eligibility criteria removed (Fig. 1).

After the data screening process was completed, we conducted the data extraction by extrapolating the following from the included articles:

- Authors, year published, article title
- Time period of study (months and year)
- Study location (country)
- Population and participants (gender, age, number)
- Study design (qualitative, quantitative or mixed methods)
- Exposure and outcome variables
- Species being investigated
- Behavioural, perceptive, and mental health outcomes
- Recommendations for future research and limitations.

A quality assessment was conducted using the tool developed by Hawker et al. (2002) for assessing quantitative, qualitative and mixed methods research from different paradigms. This involved assessing the abstract, aims, methods, sampling, data analysis, bias, results, transferability, and usefulness of each paper in relation to criteria outlined by Hawker et al. (2002).

In line with Gough et al. (2012), we sought to conduct a critical interpretive synthesis of the included literature. This involved thematically organising the extracted quantitative and qualitative data to aid in the construction of a theoretical framework for understanding the likely mental health, perceptual and behaviour effects of being in or near a green space containing allergenic pollen. This process involved the collaboration of the entire review team.

3. Results

Twenty-six articles were included in the review. Table 1 shows an overview of the reviewed articles including the study location, information about the studied sample, the study design including pollen measure (with presences of specific species when indicated), study period and outcome measure and, finally, the main result with indication of positive/negative or no impact on mental health.

3.1. Study characteristics

3.1.1. General characteristics

The articles included in the review investigated how allergenic pollen may affect the relationship between green space and mental health, perceptions, and behaviours through different means. The most common approach was quantitative (n = 14), consisting of cross-sectional (n = 9), case-control (n = 2), cohort (n = 2) and longitudinal (n = 1) studies. The remaining were qualitative (n = 6), using interview (n = 3), observational (n = 2) and workshop (n = 1) approaches, and mixed methods (n = 6), adopting combined quantitative and qualitative techniques, such as surveys with closed- and open-ended questions. Only six studies were published before 2020, while the remaining 20 articles were released from 2020 onwards: two in 2020, nine in 2021, eight in 2022, and one in 2023.

The locations of samples across the articles are displayed in Fig. 2. These included countries located in Southern Europe (n = 8), Western Europe (n = 4), Eastern Asia (n = 4), Eastern Europe (n = 3), Northern Europe (n = 3), North America (n = 3), Oceania (n = 1), South America (n = 1) and South-eastern Asia (n = 1). While 25 of the articles had samples located in only one country, one article reported on a sample which was located across eight countries (Belgium, England, France,
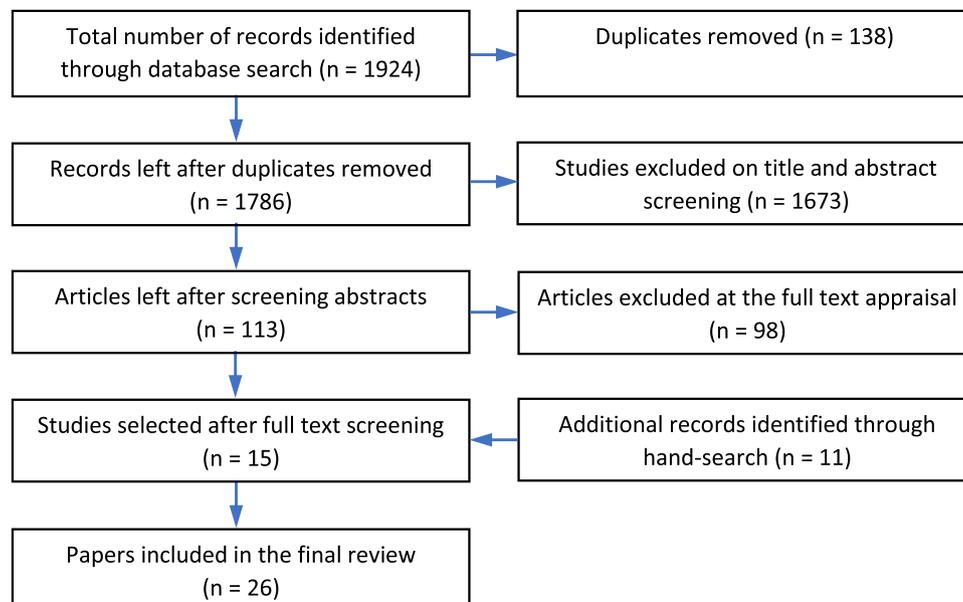


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Total number of records identified        →    Duplicates removed (n = 138)
through database search (n = 1924)
            ↓
Records left after duplicates removed      →    Studies excluded on title and abstract
         (n = 1786)                             screening (n = 1673)
            ↓
Articles left after screening abstracts    →    Articles excluded at the full text appraisal
         (n = 113)                              (n = 98)
            ↓
Studies selected after full text screening ←    Additional records identified through
         (n = 15)                               hand-search (n = 11)
            ↓
Papers included in the final review
         (n = 26)
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Fig. 1. Flow diagram of preferred reporting items for systematic reviews and meta-analyses (PRISMA).

Table 1
Articles included in the review. Note: The arrows indicate the magnitude and direction of the relationship. For instance, an arrow pointing up represents higher or greater magnitude, while an arrow pointing down indicates low or less.

Author/s (Year)	Location	Sample	Study Design	Pollen measure	Month/s	Outcome Measure	Result
Adinolfi et al. (2014)	Granada, Spain	People of all ages travelling through park (n not provided)	Qualitative (behavioural observation)	Objective: current density and amount of allergenic plant species within park	Apr-May	Behaviour: total current no. of visitors in park and the activities being undertaken	Parks with ↑ density of allergenic species recorded ↓ visitors (i. e., ↑ rate of avoidance)
Aerts et al. (2020)	Flanders, Belgium	Adults with pollen allergies residing in Flanders (n = 88)	Quantitative (cohort survey)	Subjective: self-reported perceived presence of (hazel, alder, birch) allergenic trees near residence	Month/s not specified but noted to occur during high pollen period	Mental health: short-term emotional distress (GHQ-12)	↑ perceived presence of allergenic trees near residence predicted ↑ emotional distress
Alvarez et al. (2021)	Florida, USA	Adults residing in Florida (n = 724)	Quantitative (cross-sectional survey)	Subjective: self-reported concern for presence of pollen from trees around the home	Aug	Perceptions: self-reported preferences for urban forest attributes	19% of participants indicated concern with living close to pollen-producing plants Participants had ↑ preference for native species, biodiversity, and fully grown trees
Baltazar et al. (2022)	Calamba City, the Philippines	Adults residing in Calamba City and who had visited Jose Rizal Plaza Park (n = 675)	Mixed methods (survey with quantitative and qualitative components)	Subjective: self-reported environmental disservices within park they had previously visited	Apr-Jul	Mental health: self-reported worry about environmental disservices	Participants valued the parks environmental services more than they worried about its disservices, such as allergies
Baumeister et al. (2022)	Baden-Württemberg, Germany	Adults residing in Baden-Württemberg (n = 755)	Quantitative (cross-sectional survey)	Subjective: participant identified environmental disservices within urban forest they had previously visited	May-Sep	Perceptions: self-reported preferences for urban forest attributes Mental health: self-reported perceived psychological health and perceived life satisfaction (unspecified continuous scales used)	4% of participants identified plants causing allergy as a disservice More total disservices identified predicted ↓ perceived life satisfaction (but not perceived psychological health)
Bentley et al. (2023)	Central England, UK	Adults residing in central England (n = 194)	Qualitative (workshops)	Subjective: self-reported smells, including potentially pollen, experienced when visiting a park and urban forest	Feb, Apr, Jun & Oct	Mental health: self-reported wellbeing	Green spaces with ↑ pollen smell were reported to ↓ wellbeing
Boudier et al. (2022)	8 European countries (Belgium, England, France, Italy, Norway, Spain, Sweden, Switzerland)	Adults who were participants in a population study: European Community Respiratory Health Survey (n = 3686)	Quantitative (longitudinal survey)	Objective: extent of greenness surrounding residential address measured using NDVI Subjective: self-reported allergy status	Month/s not specified	Mental health: health-related quality of life (Short Form-36; SF-36)	Association between green space and ↑ quality of life was not modified by allergy status
Christoforidi et al. (2022)	Crete, Greece	Adults residing in Crete (n = 703)	Quantitative (cross-sectional survey)	Subjective: self-reported perceptions of green spaces services and disservices	May-Jun	Behaviour: self-reported perceptions of barriers to visiting green space	Allergies to green space was listed as a barrier to visitation by less than 10% of participants (time, distance, mobility, and maint-enance were larger barriers)
Ćwik et al. (2018)	Rzeszów, Poland	People of all ages travelling through park (n not provided)	Qualitative (behavioural observation)	Objective: allergenicity of park (as calculated by the Index of Allergenicity of Urban Green Spaces)	Sep-Oct and May-June)	Behaviour: total current number of visitors in park and the activities being undertaken	Parks with ↑ number of allergenic species (silver birch trees) had ↓ visitor numbers

Table 1 (*continued*)

Author/s (Year)	Location	Sample	Study Design	Pollen measure	Month/s	Outcome Measure	Result
Dickinson and Ramalho (2022)	Perth, Australia	Practitioners involved in delivery and maintenance of green spaces (n = 27)	Qualitative (interview)	Subjective: self-reported perceptions of species planted within urban forest	Jun-Aug	Perceptions: self-reported perceptions of the importance of urban forest	40% of practitioners identified urban forests as having disservices such as causing allergies
Fernandes et al. (2019)	Porto, Portugal	Adults walking on streets containing trees in Porto (n = 281)	Quantitative (cross-sectional survey)	Objective: total number of allergenic species located within urban street trees	Month/s not specified	Perceptions: self-reported perceptions of the health benefits of urban street trees	People living closer to Black Poplar (highly pollinating) trees had ↓ perceptions of the health benefits of trees
Hui and Jim (2022)	Hong Kong, China	Adults walking on streets proximate to parks in Hong Kong (n = 467)	Quantitative (cross-sectional survey)	Subjective: self-reported perceptions of the services and disservices of green space	May-Jun	Perceptions: self-reported willingness to pay to improve local green spaces	Less than 50% of participants perceived allergenic potential of green spaces as a disservice Those who perceived allergens as a disservice had ↓ willingness to pay for green spaces
Misiune et al. (2021)	Vilnius, Lithuania	Green space experts (n = 6) Adults residing in Vilnius (n = 444)	Mixed methods (interview of experts and cross-sectional survey of adults in Vilnius)	Subjective: self-reported perceptions of green space services and disservices	Apr	Behaviour: self-reported frequency of visit to green space	Those who reported allergies as a disservice visited green space less frequently
Morita et al. (2009)	Tokyo, Japan	Adults visiting urban forest (n = 498)	Quantitative (cross-sectional survey)	Subjective: self-reported pollen allergy status	Nov-Dec	Behaviour: self-reported frequency of visit to and avoidance of green space	29% of participants reported that they avoid urban forests during pollen season (65% did not) No statistical difference between frequency of visit to urban forest and pollen allergy status
Pineda-Guerrero et al. (2020)	Bogotá, Colombia	People of all ages visiting green spaces (n = 500)	Mixed methods (survey with closed and open-ended questions)	Subjective: self-reported perceptions of the services and disservices of green space	Month/s not specified	Perceptions: self-reported willingness to pay to conserve local green spaces	Participants had ↓ willingness to pay for green spaces containing disservices such as causing allergies
Pinto et al. (2021)	Coimbra, Portugal	People of all ages visiting or using green spaces (n = 1000)	Mixed methods (survey with closed and open-ended questions)	Subjective: self-reported perceptions of services and disservices of green space	Jul-Aug	Behaviour: self-reported motivations to visit green space Mental health: self-reported emotional well-being	94% of visitors considered allergic reactions of low concern and thus played little role in influencing behaviour or mental health
Sefcik et al. (2019)	Philadelphia, US	Residents of Philadelphia who were guardians or caretakers of children living in low-resource neighbourhoods (n = 42)	Qualitative (interview)	Subjective: self-reported perceptions of services and disservices of green spaces	Month/s not specified	Behaviour: self-reported barriers to visiting green space Mental health: self-reported mental health benefits of being in green spaces	Allergies listed as a barrier to visiting green spaces Participants reported mental health benefits of being in green space that was lost when deterred from visiting
Speak and Salbitano (2021)	Florence, Italy	Adults living in Florence (n = 592)	Mixed methods (survey with closed and open-ended questions)	Subjective: self-reported perceptions of services and disservices of urban trees	Jun-Sep	Perceptions: self-reported attitudes towards urban tree species and characteristics	15% of participants identified pollen allergies as the reason they disliked a particular species Species disliked because of pollen included cypress, lindens and poplar
Speak et al. (2022)	Bolzano, Italy	Survey included residents of Bolzano (n = 57) Workshop included architects, planners, designers, residents,	Mixed methods (public consultation, workshop, smart phone application and	Subjective: self-reported perceptions of services and disservices of urban trees	Month/s not specified, but noted to be summer	Perceptions: Self-reported preference for urban tree species and green space characteristics	Less than 10% of participants listed pollen allergies as a disservice of urban trees instead tending to consider them an

Table 1 (*continued*)

| Author/s (Year)	Location	Sample	Study Design	Pollen measure	Month/s	Outcome Measure	Result
Stas et al. (2021a)	Belgium (whole country)	business owners (n = 30) Adults residing in Belgium who are also tree pollen allergy patients (n = 157)	survey to enter opinions) Quantitative (cohort survey)	Objective: residential green space quantified by using geodatasets and calculating basal area of allergenic trees	Jan-May	Mental health: short-term psychological distress measured through General Health Questionnaire-12 (GHQ-12) Mental health: stress over past month measured through Perceived Stress Scale (PSS)	essential part of streets ↑ presence of allergenic trees near residence was associated with ↑ psychological distress and perceived stress over past month ↑ green space cover associated with ↓ psychological distress and perceived stress
Stoia et al. (2022)	Bucharest, Romania	Residents of Bucharest and visitors to Tineretului Park in Bucharest (n = 202)	Quantitative (cross-sectional survey)	Objective: certain plant species and trees in park	May-July	Perceptions: self-reported perceptions of services and disservices of green spaces	8.5% of participants perceived allergies as a disservice of parks
Talal et al. (2021)	Portland, US	Adult visitors to a park (n = 42)	Qualitative (interview)	Subjective: self-reported perceptions of green space	Jul-Sep	Mental health: self-reported experiences of green spaces, including cognitive and emotional response Perceptions: self-reported preferences for urban green space types	Some participants reported that visiting green spaces with ↓ pollen levels caused them to feel happy Preferences were for species that were non-invasive or non-harmful
Tian et al. (2020)	Wuhan, Changsha and Nanchang, China	Residents over 16 years of age in three cities in China (n = 3000)	Quantitative (cross-sectional survey)	Subjective: self-reported perceptions of the services and disservices of green space	Nov	Perceptions: self-reported willingness to pay to conserve green spaces	Participants with ↑ disservice perceptions, such as green space pollen causing allergies, had ↓ willingness to pay
Vujcic et al. (2019)	Belgrade, Serbia	Adults residing in Belgrade (n = 201)	Quantitative (case-control survey)	Subjective: self-reported pollen allergy status and use of medication	Oct-Nov	Mental health: self-reported perceived chronic mental health Mental health: self-reported effects of green space on mood Behaviour: self-reported usage and activities undertaken in parks	No significant association between the mental health of green space visitors and pollen allergy status Participants using medications perceived ↑ effect of green spaces on mood and used green spaces less frequently for running or common activities
Wojnowska-Heciak et al. (2022)	Poland (whole country)	Adults residing in Poland that have motor disabilities (n = 212)	Quantitative (cross-sectional survey)	Subjective: self-reported beliefs that street trees cause allergies	Jan-Feb	Mental health: self-reported impact of street trees on health and wellbeing	While participants perceived that street trees may aggravate allergies, they also viewed them as beneficial for health and wellbeing
Zhang et al. (2021)	Nanjing, China	Residents of all ages living in Nanjing (n = 2023)	Quantitative (case-control survey)	Subjective: self-reported allergic disease Objective: rate and composition of species within green space and allergenic potential	Oct	Perceptions: self-reported satisfaction with residential greening	↓ extent of allergic disease predicted ↑ satisfaction level with green space Residents near green spaces with more pollen present reported ↑ allergic disease prevalence and lower satisfaction levels with residential greening
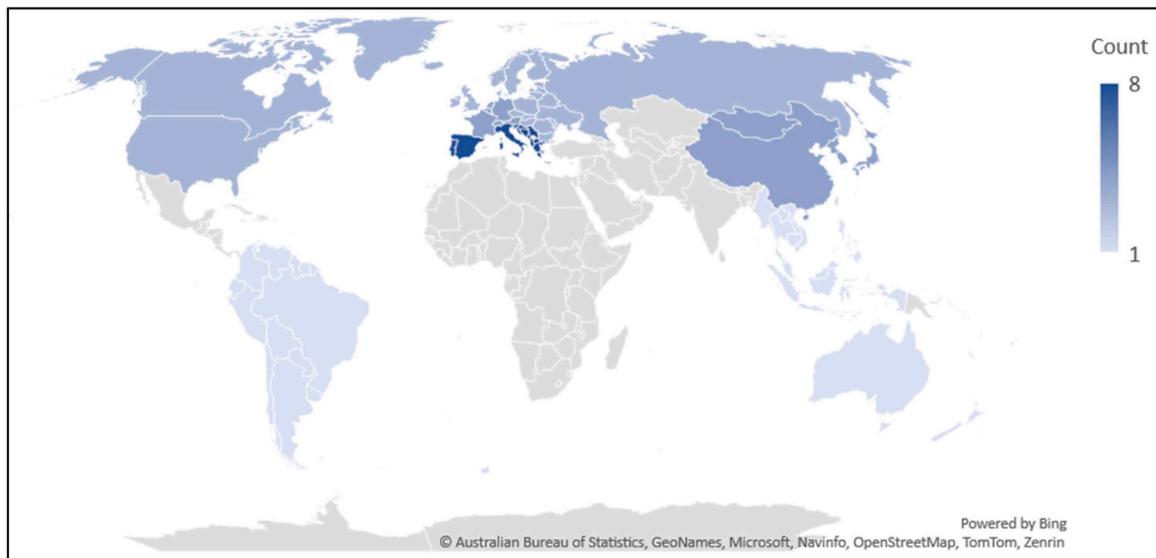
Fig. 2. Geographical distribution of the studies included in this review by percentage of total studies.

Italy, Norway, Spain, Sweden, Switzerland; Boudier et al., 2022).

Studies' approaches to examining how exposure to green space containing allergenic pollen affects individuals' perceptions, behaviours, or mental health varied. Most subjectively measured the amount of pollen by asking participants their opinion on whether, or to what extent, a particular green space contained allergens (n = 17). Some determined the amount of pollen in a green space objectively, by measuring the number or extent of allergenic species (n = 6). Finally, a minor selection limited their samples to pollen allergy sufferers and investigated how this affected their relationships to green spaces, generally (n = 3).

The quality assessment found nine articles were rated as good quality and 17 as fair (see Supplementary Material). The most common issue emerging from studies rated as fair quality was an insufficient reflection or discussion of ethical and bias-related concerns. Considering the focus on mental health in several of the studies included in this review, such research should carefully consider ethics processes and how the conduction of the research may cause harm, as well as outlining what was done to minimise this risk.

3.1.2. Sample population characteristics and green space characteristics

Nearly half of the papers had samples consisting of adults (men and women over the age of 18) who were residing in close proximity to some form of green space (n = 11). Others investigated specific categories of individual and how they were affected by green space containing species producing allergenic pollen, including people currently visiting green spaces (n = 8), adults with pollen allergies (n = 3; Aerts et al., 2020; Stas et al., 2021a; Vujcic et al., 2019), green space experts and practitioners (n = 1; Dickinson and Ramalho, 2022), and people with limited mobility (n = 1; Wojnowska-Heciak et al., 2022). An additional two papers also contained mixed samples consisting of both green space practitioners and residents (Misiune et al., 2021; Speak et al., 2022).

The types and characteristics of green space examined across the papers included in this review varied somewhat. The most common types of green space investigated was urban parks within city limits (n = 17) and urban forests (n = 15), while street trees (n = 4) were less so. The majority of studies also did not specify which species were present within the green space being examined (n = 17). Of the papers that did identify individual species, the following were investigated: plane (n = 4), birch (n = 3), hazel (n = 3), poplar (n = 3), alder (n = 2), maple (n = 2), pine (n = 2), cypress (n = 2), linden (n = 2), cedar (n = 1), juniper (n = 1), nettle (n = 1), oak (n = 1), olive (n = 1) and willow (n = 1).

3.2. Effects of green spaces containing allergenic pollen

Most studies focused on the effects of pollen in green space on one outcome measure: perceptions (n = 10), behaviours (n = 5) or mental health (n = 6). A smaller selection sought to measure more than one of these outcomes collectively (n = 5), such as perceptions and mental health (Baumeister et al., 2022; Talal et al., 2021) and behaviours and mental health (Pinto et al., 2021; Sefcik et al., 2019; Vujcic et al., 2019). Fig. 3 represents this collection of studies, with a further breakdown of whether they found strong, weak or no evidence of a relationship between pollen in green space and perceptions, behaviours or mental health. Evidence was defined as strong if the authors found, quantitatively, a statistically significant relationship between pollen in green space and the selected outcome or, qualitatively, clear and consistent descriptive indication by participants that pollen influenced the outcome. Weak evidence included inconsistent descriptive reports or findings of a small or near significant statistical relationship. No evidence related to research which found no effect of pollen in green space on the measured outcome.

3.2.1. Perceptions

Most studies recording individual's perceptions of a green space measured the presence of allergenic pollen within the space by asking to what extent they perceived the space contained allergens (n = 10). Of these, studies that had samples not limited by allergy status tended to observe that less than 50% of participants actually perceived allergenic pollen within a green space as a potential harm or even identified it as an ecosystem disservice (Alvarez et al., 2021; Baumeister et al., 2022; Dickinson and Ramalho, 2022; Hui and Jim, 2022; Speak and Salbitano, 2021; Stoia et al., 2022; Tian et al., 2020; Wojnowska-Heciak et al., 2022). Those who did perceive that a green space contained allergens, however, valued the green space less or were less willing to pay to conserve it (Alvarez et al., 2021; Hui and Jim, 2022; Pineda-Guerrero et al., 2020; Speak et al., 2022). Green spaces with a greater diversity of species (without increases to airborne pollen) were perceived more positively (Speak and Salbitano, 2021; Zhang et al., 2021), non-native species were perceived more negatively and to be more likely to produce allergenic pollen than native ones (Dickinson and Ramalho, 2022; Talal et al., 2021), and there were mixed preferences for tree size (Alvarez et al., 2021; Speak et al., 2022). Green spaces containing pine and oak trees were perceived in a positive light because they were not considered to produce pollen, and also for their provision of shade and pleasant scents (Speak and Salbitano, 2021; Speak et al., 2022). Cypress,
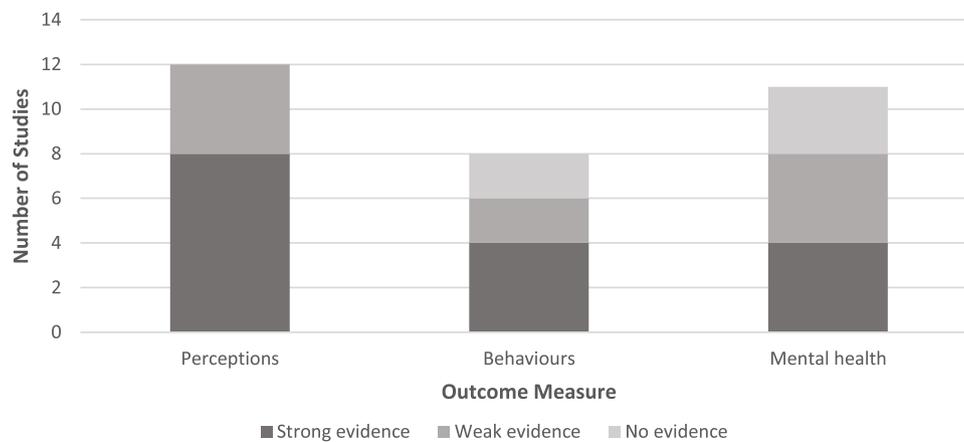
Fig. 3. Share of articles by outcome measure and an indication of whether or not the study found evidence supporting a negative relationship between allergenic pollen within a green space and the outcome measure.

linden, poplar, maple and juniper trees were perceived more negatively because of their potential to exacerbate pollen allergies (Speak and Salbitano, 2021; Stoia et al., 2022).

Two studies objectively measured the presence of pollen within green spaces by recording the type of species present, their allergenic status, and then asking green space users for their perception of these spaces. Green spaces containing black poplar trees were perceived by participants as being less beneficial for human health (Fernandes et al., 2019), while people who self-identified as having allergic disease were less satisfied with green spaces containing species with a greater allergenic status (Zhang et al., 2021).

3.2.2. Behaviours

The majority of articles asked participants whether allergenic pollen or allergies were a factor that altered their behaviour within green spaces (n = 6), instead of actually measuring the levels of pollen within. Three of these investigated whether general populations identified allergies as a factor that discouraged them from accessing green space. Across these, allergies were identified as a barrier to visiting green space by a minority of the sample, while other factors, such as time limitations, distance, mobility or maintenance, were often listed as greater hindrances (Christoforidi et al., 2022; Misiune et al., 2021; Sefcik et al., 2019;). Misiune et al. (2021) observed that those who visited green space less frequently were more likely to list allergies as a barrier than more frequent visitors. A further three articles asked visitors to green spaces if allergies altered their behaviour within the space. Vujcic et al. (2019) observed that allergy sufferers undertook running and other common activities less frequently within green spaces than those without allergies, even when medication use was taken into account (Vujcic et al., 2019). Conversely, two articles reported allergies played little role in determining what activities, such as jogging and socialising, people undertook when within a green space (Pinto et al., 2021; Morita et al., 2009).

Finally, only two studies evaluated whether the objective presence of pollen in a green space led to adapted or altered behaviours relating to green space visitation patterns amongst a general population. In both of these, green spaces containing high levels of allergenic species (such as birch, hazel, poplar, and plane) were avoided by people, often experiencing less total visitors than parks without these species (Adinolfi et al., 2014; Ćwik et al., 2018).

3.2.3. Mental health

Most studies investigating mental health used self-developed survey questions (n = 5) or analysis of interview results (n = 3) to determine a participant's mental state. Only three articles used previously developed scales for measuring mental health, including health-related quality of

life through the Short Form-36 (SF-36) (Boudier et al., 2022), psychological distress through the General Health Questionnaire-12 (GHQ-12) (Aerts et al., 2020; Stas et al., 2021a), and stress via the Perceived Stress Scale (PSS) (Stas et al., 2021a).

Eight articles evaluated how individual's perceptions of the levels of pollen within a particular green space related to their mental health. Amongst general populations, those who perceived high levels of pollen in green space surrounding their residence reported experiencing worse subjective wellbeing or life satisfaction (Baumeister et al., 2022; Bentley et al., 2023). Similarly, when residents perceived a possibility of experiencing an allergic reaction because of the green space surrounding their home, they self-reported less general mental health benefits from that green space (Sefcik et al., 2019). For pollen allergy sufferers, greater emotional distress was reported amongst those who perceived green space around their home contained higher levels of pollen when compared to those who perceived lower levels (Aerts et al., 2020; Stas et al., 2021a). In relation to emotions, adults were reported to feel happier in green spaces when they perceive allergenic pollen was not present (Talal et al., 2021) and to feel concern or worry when they detected it was (Baltazar et al., 2022). Conversely, for those currently visiting urban green spaces, wellbeing was not significantly different between those who perceived they might or might not experience allergic reactions in that green space (Pinto et al., 2021; Wojnowska-Heciak et al., 2022).

A smaller selection objectively measured green space and its relation to some mental health outcome. Residents with allergies living near green spaces with objectively more allergenic tree species (common hazel, alder and birch) exhibited greater short-term distress and perceived stress than those living near spaces with less allergenic trees, but this occurred in the context of green space cover still predicting reduced distress and stress (Stas et al., 2021a). Conversely, allergy status was found not to predict psychological wellbeing amongst participants living in areas with objectively more green space around their home – although, the allergenic potential of this green space was not taken into account (Boudier et al., 2022; Vujcic et al., 2019).

4. Discussion

This review provides the first collation of evidence evaluating whether the presence of allergenic pollen within urban green space influences individuals' perceptions, behaviours, and mental health. The evidence reviewed indicates that the effects on mental health are not entirely conclusive, with results differing depending on whether participants lived near green space, were actively visiting it, and their allergy status. There was relatively consistent evidence that residents living near green space they perceived to contain high levels of

allergenic pollen experienced worse mental health outcomes, such as lower wellbeing and greater emotional distress. For visitors to green space, negative emotional responses to the presence of pollen, such as concern, were also observed, but wellbeing was not significantly different. Finally, allergy status did not seem to predict wellbeing amongst those living near a greater quantity of urban green space, but in the one case where the allergenic index of such green space was taken into account, allergy sufferers exhibited greater distress and perceived stress. So, it could be the case that green spaces with low allergenic potential have beneficial mental health effects independently of allergy status, while those with a higher allergenic potential only benefit those without allergies and have either reduced or negative effects on those with allergies. It should be noted that, broadly speaking, the mental health effects of exposure to urban green spaces observed in these studies are still positive overall but that these effects are reduced in cases of high allergenic pollen counts.

The behavioural effects were also not entirely conclusive. The small amount of research that objectively considered the amount of pollen within a green space did find that people were more likely to avoid these spaces than those with lower levels of pollen. However, research that asked participants if allergies caused them to alter their behaviours, such as exercising or socialising, in green spaces had mixed results, with some finding altered behaviours and others noting no difference.

The perceptual effects were more consistently agreed upon. Amongst general populations, less than 50% of participants tended to perceive allergenic pollen as a harm or ecosystem disservice offered by green space. However, this is not entirely surprising given that only around 20% of people worldwide suffer from allergic rhinitis (Settipane and Schwindt, 2013). Those who did perceive allergenic pollen was present within a green space, were consistently observed to value the green space less than those who did not perceive the presence of pollen, such as by having lower willingness to pay to preserve the space.

Finally, from the few studies that did clearly outline or specify the particular characteristics or species present in the green space, we identified characteristics of green spaces that were associated with (real or perceived) higher pollen counts. However, it should be noted that too few studies have been conducted to draw definitive conclusions, so the characteristics mentioned here are done so speculatively and to highlight where future research should investigate. Green spaces that contained mainly hazel, alder, birch, cypress, linden, poplar, plane, maple, and juniper trees were associated with higher perceived pollen levels, avoidance, and less beneficial mental health effects. Conversely, green spaces containing pine and oak trees, native species, and greater biodiversity were often perceived to contain lower levels of pollen and correlated with improved mental health outcomes, valuations of the green space, and visitation rates.

4.1. Conceptualising the relationship between green space and mental health

This review also informs conceptualisations of the relationship between urban green space and the mental health of visitors and those living in close proximity. That is, the findings emerging across the literature included in this review have relevance for how we may understand urban green space has restorative, instorative and mitigative impacts on mental health (Beute et al., 2023; Kabisch et al., 2017; Markevych et al., 2017; Marselle, 2019; Marselle et al., 2021).

Beginning with the ability of green space to provide restoration, such as through stress reduction and mood improvement, this review highlights the potential for the inverse to be true. Finding that those who perceived a green space contained elevated levels of allergenic pollen were more likely to exhibit distress and negative emotions appears to reveal that green spaces also have the potential to exacerbate stress rather than restore it. Little research has explicitly explored such adverse effects of green spaces on mental health (Shackleton et al., 2016), but some evidence suggests that individual's perceptions of a green space,

particularly its aesthetic attractiveness, may influence their self-rated restoration after interacting with that green space (Liu et al., 2022; Wang et al., 2019). Adding to this literature, then, this review indicates that an individual's perceptions of the allergenic potential of a green space can adversely affect their evaluations of that space (Hui and Jim, 2022; Tian et al., 2020; Wojnowska-Heciak et al., 2022; Fernandes et al., 2019; Speak et al., 2022; Zhang et al., 2021) and, consequently, contribute to stress rather than restoring it (Baltazar et al., 2022; Talal et al., 2021).

The present review also offers some insights into the mitigative benefits of green spaces on mental health, such as by reducing exposure to urban heat. Green spaces have been proposed to mitigate the adverse effects of air pollution by cleaning the air, while also providing immunological benefits by exposing people to more diverse ecosystems, reducing the likelihood of people developing allergies during childhood (Stas et al., 2021b; Yin et al., 2023). Yet, in cases where high amounts of allergenic pollen are present, it is likely that the opposite is true and allergies are exacerbated by green spaces (Stas et al., 2021b). Allergy sufferers are well-documented to also suffer from poor mental health as a result of the physical symptoms they experience (Stas et al., 2021a). So, while it is difficult to determine the extent to which such physical symptoms might be contributing to the adverse mental health effects observed by the research in this review, it is possible some of the effect might be emerging from these symptoms. Certainly, some research included in the review observed that those who described experiencing allergy symptoms suffered worse mental health outcomes (Aerts et al., 2020; Stas et al., 2021a). It is possible, then, that the mitigative benefits of green spaces on mental health, as with the restorative potential, can act in the reverse to impede mental health in green spaces where allergenic pollen is present.

As for the theorised instoration benefits provided by green spaces, such as through physical exercise and socialisation, some limited insights are offered. The findings generally confirm previous proposals that the characteristics or features of a green space affect the likelihood of people visiting and accessing that space (Fongar et al., 2019), with green spaces that contained more allergenic pollen (real or perceived) being more likely to be avoided by potential visitors (Adinolfi et al., 2014; Bentley et al., 2023; Ćwik et al., 2018; Misiune et al., 2021; Sefcik et al., 2019). While broader research has observed that certain behaviours within green space, such as exercise and socialising, are determined by the features of that space, such as path networks and lighting (Lee et al., 2015), the studies included in this review observed little difference between exercise and social behaviours and the presence of pollen in green space (Pinto et al., 2021; Christoforidi et al., 2022; Morita et al., 2009). These studies did draw their samples from those already within green spaces. It could be the case that if broader urban populations outside green spaces were asked if the presence of pollen in a park affected their likelihood of socialising or exercising in that space, results would differ, as those already within green spaces might be likely to be unaffected by pollen.

Another explanation for the limited evidence supporting behavioural changes relating to use of the green space could relate to medication, given the possibility that those with allergies taking medication might be able to still use green spaces, even though they identify as suffering from allergenic disease. Only one study (Vujcic et al., 2019) considered the effects of medication use on behaviour, observing that those taking medication for allergies indicated they were less likely to exercise in green space. Aerts et al. (2020), while examining mental health rather than behaviour, did observe that medication use protected against the development of psychological distress amongst allergy sufferers. Although, it is difficult to determine whether this mental health effect emerges from instoration-related behavioural changes or reduced physical symptoms associated with allergies. More research on how high pollen counts relate to behaviour, medication and consequently mental health is required.

Finally, the findings also suggest interrelationships between

perceptions, behaviours and ecosystem disservices. For instance, those who perceived a green space positively were more likely to visit it or be willing to pay for its upkeep, while conversely, those who perceived the space as containing a high number of ecosystem disservices (including the presence of allergens but also pollution, safety, and others) were more likely to view it negatively and avoid it (Bentley et al., 2023; Ćwik et al., 2018; Hui and Jim, 2022).

Collectively, then, we propose that the studies included in this review indicate that the presence of allergenic pollen within green space has the potential to adversely affect mental health, or at least reduce the potential beneficial effects. By altering people's perceptions of and behaviours within green spaces, the restorative, instorative and mitigative capacities provided by green spaces may be altered, leading to worse mental health outcomes (Fig. 4).

4.2. Potential limitations and future research

As with other reviews that have been conducted on the effects of green space interaction and visitation, a number of limitations occur across the studies included in this review that may go some way to explaining the inconsistencies noted in the results (see, for instance, Holland et al., 2021). First, it was difficult to determine to what extent temporality plays a role in shaping mental health outcomes depending on different pollinating periods throughout the year, as was theorised at the onset, because none of the included studies examined pollen counts at different points in the same year and compared perceptual, behavioural or mental health outcomes across those times. Ćwik et al. (2018) did study green space visitor behaviour at two points throughout the year, in spring and autumn, but aggregated rather than compared the data. Similarly, Bentley et al. (2023) conducted four focus groups consisting of forest visits for each season of the year but did not consider what role different pollen levels would play in influencing mental health. Future research should compare mental health outcomes during different seasons with altering levels of allergenic pollen within a single green space.

Second, the wide range of types of green space and species investigated across the studies render it difficult to generalise results and make comparisons between findings. For instance, only a limited selection of the research included actually noted which particular species were contained within the green spaces being examined, allowing identification of problematic species to occur. Going forwards, researchers should attempt to identify the species or characteristics of green spaces and their quantities that are causing those visiting or living nearby to perceive or experience allergens as a problem.

Third, as few studies opted to use existing mental health measures or scales, with most implementing self-developed questionnaires, it is difficult to compare outcomes for individual conditions or symptoms across the studies, given their different means of measuring mental health. This present review is not the first to notice that research on green space and mental health tends to predominantly use self-developed questionnaires to measure mental health. Wendelboe-Nelson et al. (2019) reported a tendency towards self-developed questionnaires in broad green space and mental health research and suggested that a diversity of research approaches may be responsible, with papers defining green space and mental health differently and thus seeking to measure both in altering ways. The variety of mental health measures observed in this present review is likely a result of this diversity, too, then. As Patalay and Fried (2021) suggest, particular settings call for specific scales, depending on the time needed to conduct the survey, the location, etc. Given a small body of research spanning various mental health outcomes has been developed now, future research should further consolidate this research by using similar methods to measure mental health and observe whether results are replicable in different contexts or case studies.

Fourth, the methods adopted to determine whether the presence of pollen influences mental health, behaviours or perceptions varied greatly. Approaches that involved recruiting participants who were already within green space were inherently affected by bias as the sample is representative solely of those who visit green space. Whilst these studies do have their own merits, such as revealing why people might visit green space, they do little to reveal the views and activities of those who do not frequent urban nature. Future research investigating whether the real or perceived presence of allergenic pollen in a green space discourages exercise and socialisation would be particularly beneficial.

Finally, it was intriguing that none of the studies included in this review considered the effects of allergenic green spaces from an environmental justice perspective. That is, while a number of studies did compare those suffering from an allergic disease with non-sufferers, the overall conceptual approach was not framed in relation to access or the
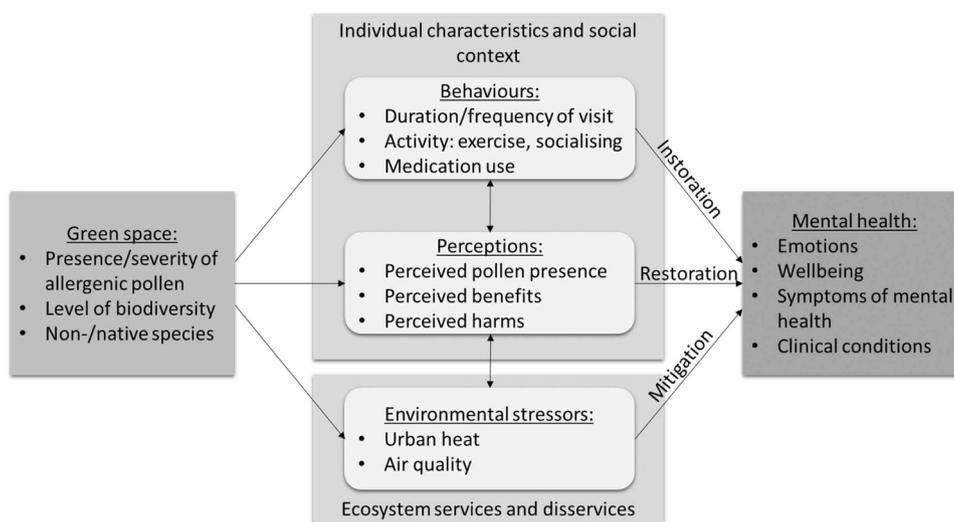

Fig. 4. Conceptual model depicting the relationship between green space, the presence of pollen, and users' perceptions, behaviours and mental health or wellbeing. Note: Every arrow indicates both a potentially positive or negative relationship, although it is expected that should the severity of allergenic pollen in the green space be high then behaviours, perceptions and mental health will be negatively affected. E.g., if the pollen levels are perceived to be high then some visitors will perceive the green space less positively, whereas the vice versa is also true.
The model is adapted from Beute et al. (2023), Markevych et al. (2017), Marselle (2019) and Marselle et al. (2021).

unequal distribution of harms. Despite this, justice could be perceived to be hindered as those with allergic disease have less capacity to access to green spaces with high allergenic potential and communities of socio-economic disadvantage and minorities live in neighbourhoods with a greater proportion of green spaces with allergenic potential (Burbank et al., 2023). It was also the case that the majority of the research had concentrated on case sites in the Global North. While some research on the Global South is starting to emerge, such as in Colombia (Pineda-Guerrero et al., 2020) and the Philippines (Baltazar et al., 2022), more is warranted, particularly given the uneven rise of temperatures and production of pollen likely to be experienced as a result of climate change.

5. Conclusion

This review has highlighted that allergenic pollen within urban green spaces can alter the mental health, behaviour and perceptions of those interacting with the green space, although evidence is not entirely conclusive. As the first review, to the best of our knowledge, to consolidate and holistically evaluate this literature, our findings affirm the need to closely monitor the species that are planted within green spaces, particularly given climate change is set to increase pollen and allergen production and that allergic disease is on the rise globally (Damialis et al., 2019; Dean et al., 2011; Lake et al., 2017). Ensuring that green spaces produce as few allergens as possible and contain high levels of biodiversity will enable their physical and mental health benefits to be felt by as many people as possible, contributing to a fairer and more just society.

CRediT authorship contribution statement

Legg Rupert: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Visualization. **Kabisch Nadja:** Conceptualization, Formal analysis, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2024.128204.

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