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The Greenest Air Filters: Impact of Urban Green Spaces on Air Quality

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AUTHOR BIO

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ABSTRACT

Urban green spaces have been recognized as a practical strategy to improve urban air quality and reduce health risks associated with air pollution and extreme heat. In cities, exposure to elevated air pollutant concentrations (e.g., ozone and particulate matter) contributes to respiratory and cardiovascular illness, while higher temperatures linked to the urban heat island effect can intensify heat-related medical events. This paper reviews literature on urban green spaces and their ability to improve air quality through three pathways: (1) lowering air temperature through shade and evapotranspiration, (2) filtering and removing air pollutants, and (3) supporting greenhouse gas mitigation through carbon storage and sequestration. The paper uses a targeted evidence scan to establish key outcome categories and then presents a structured comparison of two exemplar case studies. Two exemplary case studies illustrate these pathways by examining how vegetation relates to urban heat patterns and heat-related health outcomes, and by estimating how urban trees remove air pollutants and the associated economic value. Together, these studies demonstrate that urban vegetation can produce measurable environmental and public health benefits through both cooling effects and pollutant removal. However, green spaces alone are unlikely to fully offset major sources of air pollution and greenhouse gas emissions without broader changes in land use, energy systems, and environmental practices.

***Keywords**: Urban green spaces, urban heat island, air pollution, air temperature, ozone, particulate matter, public health, heat-related illness, climate, climate change*

INTRODUCTION

Pollution has become a significant detrimental issue to the Earth's environment and human health. It is important to promote healthy environmental practices, when possible, one of which is urban green spaces (Száraz, 2014). Urban green spaces are specific areas in urbanized land that are intentionally in place to provide vegetation and extra biodiversity to cities that may otherwise lack these features. Urban green spaces encompass a variety of plants such as trees, flowers, bushes, grass, and potential wildlife. There are even urban green spaces with artificial rivers and ponds, which enhance their ecological authenticity and expand the population of different animals. Common examples of these include public parks, botanical gardens, conservatories, green roofs and walls, and street trees. Despite the importance of the environment and human well-being that urban green spaces provide, especially in major metropolitan areas, natural green spaces are disappearing to make room for construction projects like buildings, housing, and roads (Chen et al., 2014).

The scarcity of urban green spaces results in a very uneven proportion between natural and artificial land within urbanized areas. A reduction in the number of green spaces contributes to issues such as rising air temperatures, poor air quality, and increased greenhouse gas emissions, which exacerbate global warming. Urban green spaces and vegetation can effectively trap greenhouse gases like carbon dioxide, absorb air pollutants during photosynthesis, and provide cooling via shade and transpiration. Urban green spaces significantly benefit air quality, and compared to infrastructure-populated locations, pollution levels, air temperature, and greenhouse gas emissions stand to be lowered in urban green spaces.

THE SCIENTIFIC PROBLEM

Many urban lifestyle and infrastructure staples impact air quality through physical processes (temperature effects), chemical processes (pollutant absorption), and biological processes (CO_2 uptake). The Urban Heat Island (UHI) effect is a phenomenon that occurs when urban areas become noticeably hotter than nearby, less industrialized rural regions (Lai & Cheng, 2009). Concrete absorbs heat and slowly releases it as the day goes by, keeping air temperature in cities high. On the other hand, natural surfaces like dirt and grass absorb much less heat, and the heat they do absorb is turned into water vapor through a process known as evapotranspiration, which actively cools the surrounding air (Mohajerani et al., 2017). Landfills located outside the city typically have cooler air with higher pressure. Air flows from higher pressure to lower pressure to create a balance, which blows in pollutants that are produced from landfills into the city. Higher temperatures also provide the ideal setting for the production of ground-level ozone and nitrogen oxides, which are air pollutants, further decreasing the quality of air (Plocoste et al., 2014). These effects are made worse by the greenhouse gas effect. Finally, cars are a common source of air pollution as they burn gasoline and diesel, which release harmful pollutants, and factories and power plants burn lots of fossil fuels for energy, which release a wide range of pollutants as well as greenhouse gases (Rezaei et al., 2023).

There are many types of air pollutants, but some common air pollutants include nitrogen oxides, sulfur dioxide, carbon monoxide, ozone, particulate matter, and volatile organic compounds. Nitrogen oxides, sulfur dioxide, and carbon monoxide can come from other sources, but are mainly produced through combustion in power plants or the combustion of fuel in car engines. Ozone is produced when nitrogen oxides and volatile organic compounds react and are exposed to high levels of heat and sunlight. Ozone that is produced from this artificial process contains a vast amount of harmful pollution within it. Cities are especially prone to ozone pollution due to the urban heat island effect and a large amount of volatile organic compounds, which are gases that can be emitted from vehicle emissions, gasoline, and industrial activities. Exposure to air pollution over a long period can lead to stroke, lung diseases, itchy eyes, respiratory infections, coughing, and difficulty breathing (Ai et al, 2023). Another issue is particulate matter (PM), which can come from many sources, including dust from construction, metals from industrial processes, and soot from burning fossil fuels. PM can penetrate through the alveolar region in a person's lungs and be carried through the bloodstream to other body parts like the heart and brain (Marshall, 2013).

GREEN SPACES AS A SOLUTION

Research indicates that both the size and quantity of urban green spaces directly correlate with their cooling effectiveness (Hale, 2020). Urban green spaces and plants in general are also a potential solution to mitigate high levels of air pollution in the atmosphere, while also reducing reliance on air conditioning and the fossil fuel use required to power it. Not only does vegetation simply provide shade, but plants undergo a process known as evapotranspiration: a process where plants and soils use surrounding heat to turn water into water vapor and provide evaporative cooling to their surroundings (Knight et al., 2021).

Plants also provide a natural mechanism to help reduce the amount of greenhouse gases in Earth's atmosphere. Plants need to take in carbon dioxide, a greenhouse gas, for photosynthesis and release oxygen as a byproduct, reducing carbon dioxide concentrations in the atmosphere. When plants are done with photosynthesis oxygen is released as a byproduct instead of carbon dioxide which is what other living organisms need to breathe so not only are plants taking away a greenhouse gas which heats the Earth and leads to ground-level ozone production that produce particulate matter, but plants also refresh the air by providing clean, unpolluted oxygen (Stirbet et al., 2020). Plants are also able to capture air pollutants with their leaves. While plants take in carbon dioxide for photosynthesis, air pollutants enter the plants' leaves through the stomata (Han et al., 2022). Air pollutants that end up on soil are also absorbed by plant roots, as plants also take in nutrients and water through the soil.

These are some of the many ways that urban green spaces improve situations of air pollution coupled with high temperatures. Other studies on the environmental effects of urban green spaces have found that tree shade was found to reduce air temperature by about 5-7 Celsius (Armson et al., 2012), urban green spaces reduce local heat beyond their boundaries (Aram et al., 2020), and urban trees have been found to remove and store large amounts of carbon dioxide from the atmosphere (Nowak et al., 2002; Tang et al., 2016). Urban forests have also been found to remove hundreds of thousands of metric tons of air pollution, including ozone, particulate matter, and sulfur dioxide annually (Nowak et al., 2006), and that an increase in urban green space can proportionally reduce atmospheric particulate matter (Sun et al., 2024).

RESEARCH QUESTION AND AIMS

This paper asks how urban green spaces can improve urban air quality and reduce related health risks. It reviews evidence on cooling and UHI reduction, pollutant removal and concentration changes, and greenhouse gas mitigation through carbon storage and sequestration. Two exemplary studies, Hale (2020) and Nowak et al. (2006), are used to illustrate how these mechanisms are studied and what their findings imply for urban planning and public health.

METHODS

This focused narrative review used targeted searches in Google Scholar and PubMed, supplemented by citation chaining. Sources were grouped by outcome type and summarized qualitatively. Hale (2020) and Nowak et al. (2006) were selected as widely cited examples and are discussed side-by-side to highlight differences in study setting, measurements, and outcomes.

CASE STUDY FINDINGS

Hale's Case Study: Green Space as a Heat Adaptation Strategy

Hale's case study aimed to determine whether increasing tree canopy and urban green spaces in San Diego could help reduce the number of health issues related to heat. Researchers examined the relationships between green space density, air temperature, and heat-related medical emergencies. The research methodology consisted of three sequential phases. Phase 1 involved a green space distribution assessment, where the first step in this process was to understand the current distribution of green space in San Diego using data from green space maps, which provided the spatial framework for subsequent analyses. Phase 2 was a health impact analysis, where researchers gathered heat-related injury and hospitalization data in San Diego and examined how these outcomes connected to green space using maps in QGIS (Geographic Information System). Phase 3 involved predictive modeling, where slope coefficients derived from meta-regression analyses were used to calculate changes in health burden and air temperature reduction associated with increasing green space (Hale, 2020).

To do this, different types of data were looked at to determine the effectiveness of urban green spaces as a way to combat heat waves. First, researchers gathered data on the amount of green space and pavement in areas within San Diego using satellite imagery. Next, researchers gathered data on how many hospital visits were related to heat exposure in areas with sizable and minimal urban green space, allowing them to look for patterns on whether more green space is related to fewer health issues related to heat. Researchers also examined the temperature for each zip code, as the amount of green space varied from one area to another. To get the data relationship between heat and heat-related hospitalizations, zip codes for areas in San Diego were used to categorize different sections of temperature, because a more coastal area will naturally be cooler than a more inland area. Hospitalization records were then gathered from the California Office of Statewide Health Planning and Development from 2004 to 2013 and reviewed for hospital visits related to exposure to extreme heat, such as strokes and dehydration. Researchers were then able to look into the number of hospital visits in a day with and without heat waves or high air temperatures.

Nowak et al.'s Case Study: Air Pollution Removal by Urban Trees and Shrubs in the U.S.

In contrast to Hale's heat-focused case study, Nowak et al. examined urban green spaces through the lens of air pollution removal. The goal of the study was to measure the amount of pollution that urban trees were able to remove, to investigate how this amount varied between cities in the U.S., and to determine the economic value of this pollution removal. The methodology and data collection focused on both tree cover and measured air pollution concentrations across multiple cities. First, tree coverage assessment was conducted using satellite imagery and aerial photographs along with field surveys from the U.S. Forest Service, where the percentage of land shaded by trees and the types of trees in 55 U.S. cities were recorded (Nowak et al., 2006).

Next, air pollution monitoring was conducted using air pollution data from the same cities, specifically the concentrations of ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter in the U.S. atmosphere. The data was gathered from hourly readings from the U.S. EPA Air Quality System, which allowed the researchers to monitor hour-by-hour changes in pollution levels and how much trees were able to impact this number. To generate quantitative removal estimates, the study employed a pollutant flux calculation model that integrated tree canopy coverage data, leaf area measurements and seasonal variations, meteorological conditions (temperature, humidity, wind speed), and pollutant-specific deposition velocities.

Comparison Across the Two Case Studies

Overall, Hale's case study and Nowak et al. 's case study both evaluate urban green space as an environmental and public health intervention, but they differ in their outcome focus, scale, and outcome metrics. Hale (2020) focuses on green space density in a single region (San Diego) and examines air temperature and heat-related medical outcomes, using spatial analysis and predictive modeling across phases that link green space distribution to health impacts. Nowak et al. (2006), in contrast, focuses on tree cover across many U.S. cities and uses air monitoring datasets and pollutant flux modeling to estimate air pollution removal and variation between cities, linking canopy and leaf area to changes in pollutant concentrations. Together, the two studies provide complementary evidence that urban vegetation can reduce temperature-related health risks and remove major air pollutants, showing how urban green spaces influence air quality through multiple pathways.

DISCUSSION

Key Findings and Implications of Hale (2020)

Hale (2020) found that green space was able to reduce air temperature, which reduced hospital visits for heat-related issues in neighborhoods. Conversely, areas with less urban green space had higher levels of heat-related hospitalization. The way green space is implemented into society is less critical than simply adding more; green space was consistently associated with a positive impact on air temperature. However, the way they are added, especially in less wealthy communities, has to be carefully planned because they can increase housing prices and rent. The study also noticed urban green space could provide other benefits for human wellbeing, like improved air quality, better mental health, and a reduction in carbon dioxide. And the paper advocates for proper care in and the expansion of urban green spaces to promote better well-being and health. Overall, this case study contributes essential evidence that urban green space can reduce air temperature in cities and directly improve health outcomes during heat exposure.

Key Findings and Implications of Nowak et al. (2006)

Nowak et al. (2006) were able to conclude that trees removed about 711,000 metric tons of pollution in these U.S. cities annually, which equated to about 3.8 billion dollars in money saved for health and environmental costs. Factors like the number of trees, the amount of leaves a tree has, and the weather all impacted how much pollution trees in different cities were actually able to absorb. Even though air quality improved in the cities, trees removed less than 1% of pollution per hour. However, because trees are constantly absorbing pollutants, these small hourly reductions add up over time, especially across all the cities and trees in the U.S. Additionally, in areas with 100% tree cover, short-term improvements are a lot more noticeable, such as a 16% decrease in ozone and sulfur dioxide. The study also notes that trees help reduce air temperatures and reduce energy use, which are also beneficial for helping the air quality. Overall, this case study provides strong quantitative evidence that urban trees and shrubs can remove major air pollutants, even though percent improvements at the city level may appear small when averaged across large urban areas.

Comparison of the Two Case Studies with Support from Literature

When compared side-by-side, Hale (2020) and Nowak et al. (2006) illustrate two complementary ways urban green spaces improve air quality. Hale focuses on temperature and health outcomes in one urban region, showing that increased green space density is linked to lower air temperature and fewer heat-related medical emergencies, which aligns with evidence that vegetation cools urban areas through shade and evapotranspiration and helps reduce UHI-related heat exposure (Knight et al., 2021; Mohajerani et al., 2017). In contrast, Nowak et al. focuses on pollutant removal across many U.S. cities, estimating how urban trees reduce ozone, particulate matter, sulfur dioxide, and other pollutants, consistent with findings that urban forests can remove substantial quantities of pollution and that expanding green space can contribute to proportional reductions in particulate matter (Nowak et al., 2006; Sun et al., 2024). Together, the studies support the conclusion that urban green spaces can improve air quality through both cooling effects and direct pollution filtration, while also reinforcing that green spaces alone are unlikely to fully offset major sources of pollution and greenhouse gas emissions without broader shifts in energy use and environmental practices (Rezaei & Millard-Ball, 2023; Száraz, 2014).

Study Limitations and Quality Notes

Several limitations apply when interpreting findings across the evidence scan and the two featured case studies. First, studies vary in how they define and measure “green space” (e.g., canopy cover, park proximity, or vegetation density) and rely on different methodological approaches, including field measurements, remote sensing, and modeling, which limits direct comparability across results. This is particularly relevant when comparing Hale (2020), which links green space patterns to temperature and heat-related medical outcomes in a single region, with Nowak et al. (2006), which estimates pollutant removal across multiple U.S. cities using canopy and air monitoring data. Second, air quality and temperature outcomes are strongly influenced by meteorological conditions, seasonal variation, and local emissions sources, which can produce mixed results across locations and contribute to differences observed between study settings. Finally, while the broader literature and both case studies support measurable benefits of urban vegetation, green spaces alone are unlikely to fully offset pollution and greenhouse gas emissions without broader changes in energy use and environmental practices. Two case studies were selected to provide clear, measurable, and complementary examples across the paper's key outcome areas, such as heat/health and pollutant removal, while still allowing for structured comparison within the scope of a focused review.

CONCLUSION

Overall, the review of relevant literature and the two case studies suggest that urban green spaces can improve air quality and support health in cities in more than one way. Hale (2020) shows that areas with more vegetation can be cooler and may have fewer heat-related medical problems. Nowak et al. (2006) shows that trees and shrubs can remove pollutants relevant from the air, and that this adds up to meaningful benefits when measured across many cities. Together, these studies support the idea that urban vegetation can lower heat and help reduce pollution exposure, which are both important for public health. At the same time, the size of these benefits depends on the local context, such as how much green space exists, weather patterns, and how much pollution is being produced. Green spaces can help, but they cannot solve air pollution or climate change on their own. The strongest approach is to combine urban greening with strategies that reduce pollution at its source, such as cleaner transportation, cleaner energy, and better city planning.

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