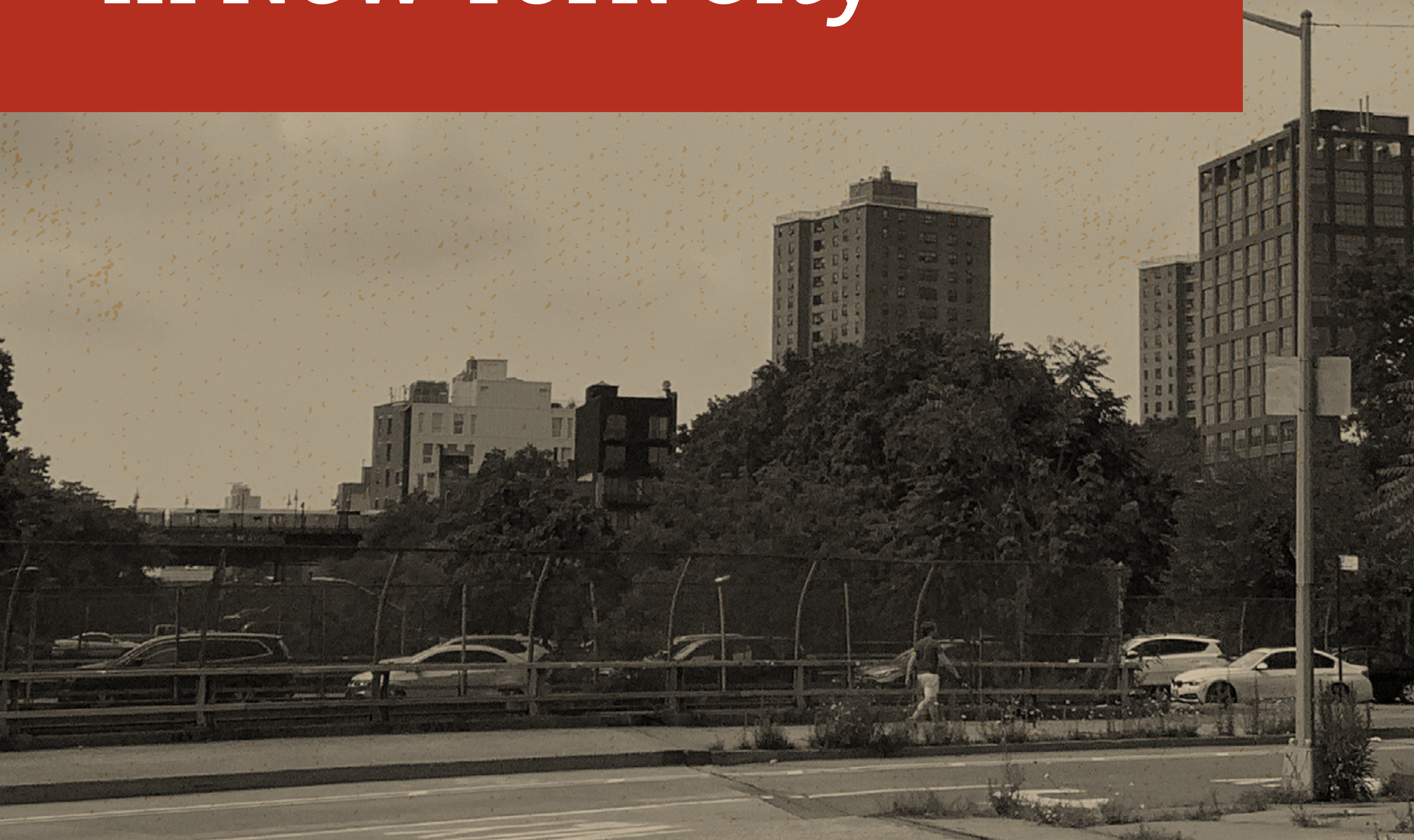
JUNE 2024

Community Heat and Air Mapping Project
for Environmental Justice

Heat-Related Risks, Air Pollution, and Social Vulnerability in New York City



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Editor's Note

This report, two years in the making, shares the findings of our air and heat mapping study, as well as policy recommendations to improve dangerous air quality and heat conditions in our City's most overburdened communities. One of the key findings was the disparate air quality impacts of vehicular traffic on environmental justice communities and how transportation policies, such as congestion pricing, could both reduce emissions and provide beneficial investments to these communities.

Congestion pricing was set to begin on June 30, 2024, but Governor Hochul's recent shocking decision to indefinitely delay its implementation has changed the situation dramatically. In addition to the critical MTA investments and the promise of cleaner air for our most impacted communities, the abandonment of the congestion pricing program by the Governor impedes the rollout of the MTA's regional and place-based mitigation plans. These plans include key commitments from the MTA and other program sponsors to reduce vehicular traffic and tailpipe emissions, expand funding for electric trucks, install charging infrastructure, replace dirty diesel operating trucks at the Hunts Point Produce Market, and establish an asthma center in the Bronx. Years of advocacy to improve New Yorkers' health and environment may have been lost by a single gubernatorial decision, leaving the best interests of environmental justice communities in jeopardy yet again.

We hope that you will read this report with an eye to how the findings - and the dangers they represent - will continue to be felt by the most vulnerable New Yorkers if congestion pricing and other essential initiatives continue to be undermined. We also hope you will consider the many other recommendations the report outlines to help minimize the disproportionate health, climate change, and environmental injustice burdens that environmental justice communities face.

Foreword from the New York State Attorney General

I am proud to have had the opportunity to support the New York City Environmental Justice Alliance (NYC-EJA) and their Community Heat and Air Mapping Project for Environmental Justice (CHAMP-EJ). Knowledge is power, and supporting communities to gather information central to their health and welfare empowers these communities to define problems they face and forge solutions tailored to their needs.

NYC-EJA and its member organizations are on the frontlines of efforts to achieve environmental justice for New York City's low-income communities and communities of color. CHAMP-EJ plays an important role in these efforts by providing communities with information on the sources, types, and levels of local air pollution and excessive heat – knowledge that is a key tool for communities to achieve change and improve lives for their residents.

I applaud the NYC-EJA, and its member organizations El Puente, Good Old Lower East Side (GOLES), THE POINT CDC, UPROSE, and We Stay/Nos Quedamos for undertaking this grassroots air quality and heat monitoring campaign, and for their ongoing commitment and achievement in advancing environmental justice for New York City. I look forward to continuing to work with you and support your important work.

Office of the New York State Attorney General
Letitia James

Executive Summary

According to the World Health Organization, up to 4.2 million people die prematurely every year due to outdoor air pollution. In New York City, $PM_{2.5}$ (fine particulate matter) alone is estimated to cause more than 2,000 deaths each year. Meanwhile, as the climate continues to warm, the health impacts of heat are becoming clearer and more concerning. An average of 350 New York City residents die prematurely of heat-related illnesses annually–a number that is expected to increase with escalating temperatures and heat waves each year. Black New Yorkers are twice as likely to die from heat stress as white New Yorkers. The combination of heat and air pollutants will increase health risks even more during the summer, when ground-level ozone and particulate pollution increase due to higher temperatures, causing poor air quality during heat waves. While deaths are the most tragic outcome, it's important to note that air pollution and heat also cause a variety of other health conditions and hospitalizations, which disproportionately affect low-income communities and communities of color. This is due to a variety of inequitable practices, policies, and systems, such as historic discriminatory housing practices and racist land-use planning, the siting of polluting infrastructure, and a practice of intentionally disinvesting from certain neighborhoods.

The New York City Environmental Justice Alliance (NYC-EJA) member organizations represent environmental justice communities that are disproportionately exposed to $PM_{2.5}$ pollution and the urban heat island effect, among other climate risks and environmental hazards. As a result, these communities suffer from increased rates of respiratory illness, heart disease, stroke, lung cancer, negative birth outcomes, heat-related illnesses, and other life-threatening conditions associated with breathing polluted air on a daily basis or being exposed to the hottest conditions in the city during the warm months. NYC-EJA's Community Heat and Air Mapping Project for Environmental Justice (CHAMP-EJ) is a grassroots air quality and heat monitoring campaign led and informed by five of our member organizations. Our members are community-based organizations (CBOs) located in low-income communities and communities of color, also known as environmental justice communities, in three New York City boroughs: Brooklyn, the Bronx, and Manhattan.

Our previous research found that air pollution in environmental justice communities was poorly characterized, and we wanted to address that gap. In addition, research on heat in NYC has shown concerning trends in vulnerable neighborhoods. With our new round of research, we build and expand upon past findings to respond to the ever-changing landscape of environmental burdens in New York City. We find ourselves in a unique moment, when state and local government agencies and elected officials have indicated a commitment to invest in both air pollution and heat mitigation solutions, in an effort to reduce environmental burdens in disadvantaged communities and improve public health. This research is intended to share our findings from and about our communities and provide recommendations that are community endorsed and data-backed.

El Puente, Good Old Lower East Side (GOLES), THE POINT CDC, UPROSE, and We Stay/Nos Quedamos were the five NYC-EJA member CBOs that led local air quality monitoring efforts in Brooklyn, the South Bronx, and the Lower East Side of Manhattan.

SUMMARY OF

Heat Findings

1 Neighborhoods with large areas of impervious surfaces (such as streets and parking lots) tend to retain excess heat, which spills into nearby residential areas.

Many environmental justice neighborhoods are densely packed with areas of mixed land use that include industrial business, e-commerce, residential, and transit-related polluting infrastructure. Examples include the industrial waterfront of Sunset Park and the industry- and truck-heavy Hunts Point. These areas have disproportionate amounts of asphalt, cement, and other hard, impervious surfaces that are highly effective at retaining excess heat. As a result, these communities have a higher risk of heat impacts, as well as other combined risk factors that increase their baseline heat vulnerability.

2 As vegetation cover decreases, temperature tends to increase

NYC-EJA's data, analyzed in combination with vegetation data for the city, reinforce findings of other studies that document lower temperatures in areas of cities that have higher vegetation cover. This is significant because disadvantaged and environmental justice communities tend to have less vegetation cover (qualities also seen in neighborhoods such as Midtown Manhattan, which has low vegetation and high heat, not because of disinvestment, but due to dense gray infrastructure). In practice, this means that heat-mitigating green infrastructure is most lacking in the areas where it is most needed.

3 Areas with greater vegetation tend to cool more overnight, lowering the risk of adverse health effects. Areas with dense high-rise buildings and gray infrastructure experience smaller temperature changes overnight.

Understanding the differences between morning and evening temperatures can be critical for heat resiliency, as a key indicator for the impacts of heat on human health is the daily low temperature. Areas with greater temperature variation from day to night tend to cool more than other areas at night, which can be very important during a heat wave. Lower night-time temperatures are important to allow the human body to recover from high day-time temperatures, so areas with the largest morning and evening temperature differentials are ideal for better health outcomes. Conversely, in areas where the differential between morning and evening temperatures is lower, night-time temperatures may remain higher, and households without air conditioning could be at higher risk for heat stroke and other heat-related risks.

SUMMARY OF

Air Quality Findings

1

Mobile sampling averages during the sampling period for PM$_{2.5}$ in the Bronx and Brooklyn ranged from 8.9 to 11.4 $\mu g/m^3$. The highest average PM$_{2.5}$ exposure was seen in Hunts Point in the Bronx

The national annual health-based standard for PM$_{2.5}$ is 9.0$\mu g/m^3$. While our measurements cannot be directly compared to this national standard, findings of PM$_{2.5}$ at levels averaging from 8.9 to 11.4$\mu g/m^3$ suggest that NYC-EJA member communities may be breathing air that is unhealthy if these levels persist on a long-term basis. Unsurprisingly, we found the highest average PM$_{2.5}$ readings in Hunts Point in the Bronx, where there is heavily polluting infrastructure such as the Hunts Point Food Market (the largest food distribution center in the country), which brings thousands of trucks' worth of traffic to the neighborhood on a daily basis, impacting the air quality of the surrounding residents. These on-the-ground measurements show the need for greater place-based and hyperlocal mitigation strategies to ensure that everyone is protected by these regulatory thresholds.

2

Hyperlocal, minute-level measurements show PM$_{2.5}$ concentrations up to 18x higher and 49x higher (for mobile and fixed measurements, respectively) than the nearest government-run monitors that report hourly values

The minute-level values from Airbeam3 mobile and fixed samples greatly differed from hourly values recorded by the nearest government monitors. At their maximum, mobile sessions were as high as 18 times greater than the nearest monitor value, and fixed sessions as much as 49 times higher. This further emphasizes the need for hyperlocal, real-time data collection and monitoring, and the need to mitigate polluting infrastructure and emissions. This is consequential to public health, because short-term exposures to high concentrations of PM$_{2.5}$ are associated with negative health outcomes, like heart attacks.

3

Traffic congestion continues to cause pollution spikes twice a day

The main air pollution source is likely vehicular traffic. Recorded air pollution levels were significantly higher during rush hours. As expected, in the South Bronx, Lower East Side Manhattan, and Brooklyn, data indicated that air pollution varies throughout the day, spiking in the morning and evening in correspondence with higher traffic volumes. CHAMP-EJ data highlight how vehicular traffic congestion and densely sited transportation, such as highways and bus depots, are significant contributors to air pollution in environmental justice neighborhoods. This is consistent with our previous findings from 2021, indicating that there has been insufficient action to mitigate this expansive pollution source.

SUMMARY OF

Heat Recommendations

1

Target investments and interventions in areas of the city with an overlap of low vegetation, high heat vulnerability, and high historical disinvestment to increase the amount of vegetation and combat the urban heat island (UHI) effect.

Based on our findings and the vulnerability maps created by local and state governments, a number of areas qualify as disadvantaged communities and should be prioritized for nature-based heat mitigation measures. We recommend that New York City focus its planting and greening efforts in areas of the city with the lowest vegetation cover and highest need. Looking at the heat vulnerability classifications in combination with vegetation density can help identify key areas. From there, funding for planting, maintenance, and additional co-investments for heat and other environmental risk mitigation should be prioritized.

2

Adopt a multi-dimensional approach for heat mitigation that addresses both short- and long-term planning and policy approaches to both social and physical infrastructure.

Due to the complicated nature of heat vulnerability, it is key to create a dynamic approach. Some of the various elements of an effective heat mitigation plan include cooling centers, developing and implementing heat action plans at the city and state levels, developing a maximum indoor temperature policy, reducing the energy burden for low- and moderate-income households so they can access and use cooling technology, and implementing and increasing cooling infrastructure such as cool pavements, cool roofs, green roofs, green space, and green infrastructure. Creating a city that is optimized for heat and other climate-related risks through a variety of multi-hazard solutions is the best way to protect all New Yorkers in a changing climate.

SUMMARY OF

Air Quality Recommendations

1

Apply targeted renewable energy investments and policy interventions to mitigate poor air quality caused by high pollution hot spots.

Air pollution in New York City has a variety of sources and needs multi-sector interventions that address each of them. To meet these needs, NYC-EJA is advocating for improved planning and communication around air quality concerns, targeted renewable energy investments and policy interventions to improve air quality caused by pollution hotspots, expanded green infrastructure and vegetation, and an overall transition to renewable energy, by shutting down peaker power plants, decarbonizing our building sector, and more.

2

Adopt City and State policies to reduce pollution from the transportation sector in environmental justice communities.

As transportation is still one of the leading causes of high pollution in environmental justice communities, it is important to reduce emissions from the transportation sector. Our highest priority transportation policy solutions in NYC include investing in and expanding public transit service, electrifying our vehicles and systems (e.g., convert public transit and school bus fleets to all electric), congestion pricing, and reducing tailpipe emissions and air pollution associated with last-mile facilities and waste transfer stations. Since these measures, such as congestion pricing, are critical to reducing the disproportionate burden of air pollution and increasing the benefits of these policies for EJ communities, it is extremely disturbing that Governor Hochul reneged on her promise to implement congestion pricing weeks away from the program starting on June 30, 2024. The sudden change and setback raises serious questions about the progress and commitment of this administration in meeting the State's emissions targets and creating new funding opportunities.

Conclusion

CHAMP-EJ demonstrates the importance of community-led participatory research and engagement with City and State government initiatives. These entities have the power to make meaningful change and prioritize mitigation measures in areas with poor air quality and high heat burdens. But without community involvement and expertise, we are unlikely to get to the root of the problems that these environmental justice communities are facing. We encourage City and State agencies to consider the findings of this report and the feedback from other CBOs and groups as they move forward with heat and air quality mitigation plans to improve their efficacy and ensure that solutions are scaled appropriately to the challenges at hand.

Introduction

Environmental justice (EJ) communities are low-income communities and communities of color that are forced to live with fewer environmental protections and greater toxic exposure, pollution, and health burdens.

Historically and today, they receive lower levels of municipal investment. Today, we see the legacy of these structural injustices among underserved communities. Our research focuses on the burdens of poor air quality and heat due to their significant, debilitating impacts on public health, and more importantly, the disproportionate burden of these issues on EJ communities.

New York City (NYC) residents face a number of significant environmental health risks. This is particularly true of EJ communities, and while this report focuses on heat and air quality, many other risks exist. Excessive heat is responsible for more deaths and negative health outcomes than any other weather-related event. In NYC, excessive heat is expected to worsen in the coming decades as a result of climate change. The risks related to high temperatures can be exacerbated by social factors such as poverty, lack of access to amenities such as parks and green infrastructure, and poor housing conditions. In addition, air pollution continues to be a leading cause of mortality around the world. Although overall concentrations of pollutants such as fine particulate matter ($PM_{2.5}$) have decreased over recent years in NYC, there are areas where concentrations still represent significant health risks, especially in communities with proximity to traffic, waste management operations, power plants, and other activities and infrastructure that result in $PM_{2.5}$ emissions.

In addition, heat can worsen air pollution and its negative effects through several avenues. For example, hot, sunny weather is more conducive to the creation of some pollutants, such as ozone and particulate pollution. In addition, heat waves and days with temperatures above 90 degrees Fahrenheit result in significantly higher electricity demand as air conditioning use goes up. To the extent that electricity is generated using fossil fuels, that leads to more air pollution. Power plants that are used to fulfill energy demand during peak hours, also known as "peaker plants," are often old, inefficient, dirty, and costly. Within NYC, peaker plants are often sited in EJ communities that have other polluting infrastructure, compounding the effects of pollution on the environment and public health of nearby residents, despite the existence of technologies to transition peaker plants with zero emissions resources. Heat waves also result in more wildfires in fire-prone areas, which leads to severe air pollution risks further afield, as seen in NYC during the Canadian wildfires in 2023. Even more concerning, air pollution and temperature exposures can have an interactive effect on adverse health outcomes.[1]

The New York City Environmental Justice Alliance (NYC-EJA) Community Heat and Air Mapping Project for Environmental Justice (CHAMP-EJ) is a grassroots air quality and extreme heat monitoring campaign led by community-based organizations (CBOs) in low-income communities and communities of color in NYC. Since 2018, NYC-EJA's research has enabled CBOs in the South Bronx, Lower Manhattan, and Brooklyn to measure, map, and understand their communities' exposures to $PM_{2.5}$ air pollution and, since 2022, heat conditions. Findings from previous research on hyperlocal air monitoring can be found in our 2021 CAMP-EJ Report.

In our 2022 research, community members utilized low-cost air quality monitors to collect hyperlocal air quality data in real time to visualize and leverage this data to improve air quality, public health, and community development. Partnering with CAPA Strategies, we used specialized mobile heat monitoring devices to collect heat data to better understand the urban heat island (UHI) effect and how it leads to disproportionate heat burdens during the summer months.

A key factor in this iteration of NYC-EJA's hyperlocal monitoring efforts is the current opportunity we have due to NYC, New York State (NYS), and the federal government publicly committing to and initiating processes to identify and implement mitigation strategies to address air quality and heat issues. Current policy and regulatory work are attempting to substantially remove and reduce climate change risks as the climate crisis bears down upon us. NYC-EJA is using this opportunity to help frame and guide those efforts through an EJ lens to prioritize the most at-risk communities and people.

The NYS Department of Environmental Conservation (DEC) 2022–23 Statewide Community Air Monitoring Initiative (CAM) is a direct result of NYC-EJA and our allies at NY Renews advocating to expand air quality testing in EJ communities. This advocacy involved working to pass and effectively implement the NYS Climate Leadership and Community Protection Act (CLCPA) of 2019, which is the nation's most ambitious climate law among the states. The goal of CAM is to help DEC identify and implement strategies to decrease air pollution and greenhouse gas emissions that contribute to climate change in overburdened NYS communities. In addition, NYS DEC and New York State Research and Development Authority (NYSERDA) have been working on the Extreme Heat Action Plan (EHAP) for New York State. EHAP's goal is to coordinate the state's planning and response efforts in relation to heat burdens to protect residents during heat events, prepare New York for the future impacts of climate change, and more.

There has been growing interest in and attention to these impacts at the city level, with local NYC agencies and elected officials discussing how to better prepare New Yorkers for the harsh conditions to come, as air pollution and temperature records are broken on a regular basis and residents face high exposure burdens. For example, members of the NYC Council have introduced several bills to improve air quality and heat protections. Several City and State agencies and elected officials have also consulted NYC-EJA as they seek to create new plans and improve existing programs related to the climate.

This report examines available data related to heat and fine particulate matter, including data that was collected by NYC-EJA member organizations. This report also includes policy recommendations to address and mitigate the risks posed by these environmental factors. We hope to see NYS DEC, NYSERDA, and local agencies incorporate our findings and recommendations as they develop mitigation strategies through processes such as CAM and EHAP.

Participating NYC-EJA Members

NYC-EJA has 13 member organizations across the five boroughs, five of which were key contributors to this research project.

Good Old Lower East Side ↗

(GOLES) is a CBO that advocates for improved community housing and preservation, environmental resilience and disaster recovery, and improved environmental quality in the Lower East Side neighborhood of Manhattan.

We Stay/Nos Quedamos ↗

(NQ) is a South Bronx–based housing and social service organization that works with and involves the community in plans and policies addressing long-term affordable housing, open space, environmental justice, and community renewal.

El Puente ↗

A youth-centered human rights organization focusing on education, the arts, environmental justice and wellness to inspire leadership for social justice. El Puente serves the neighborhoods of Williamsburg and Bushwick in Brooklyn (as well as Puerto Rico) and advocates for improved air quality, community and youth development, environmental justice advocacy, and climate change policies.

THE POINT Community Development Corporation ↗

(THE POINT CDC) is a CBO that focuses on community and youth development, environmental justice, and the cultural and economic revitalization of the Hunts Point section of the South Bronx.

UPROSE ↗

A CBO that promotes sustainability and resiliency through community organizing, education, leadership development, and cultural and artistic expression and serves the community of Sunset Park in Brooklyn.

These five CBOs each worked with community members to collect weeks worth of air data for this report, in addition to assisting with the necessary recommendations to address the issues. While all five of these members collected extensive air quality data, due to some challenges with equipment and data continuity in the Lower East Side, some of those data were not included in the majority of the air quality analyses. The heat data were collected and analyzed separately and include findings from all of the communities these CBOs represent.

Heat in NYC

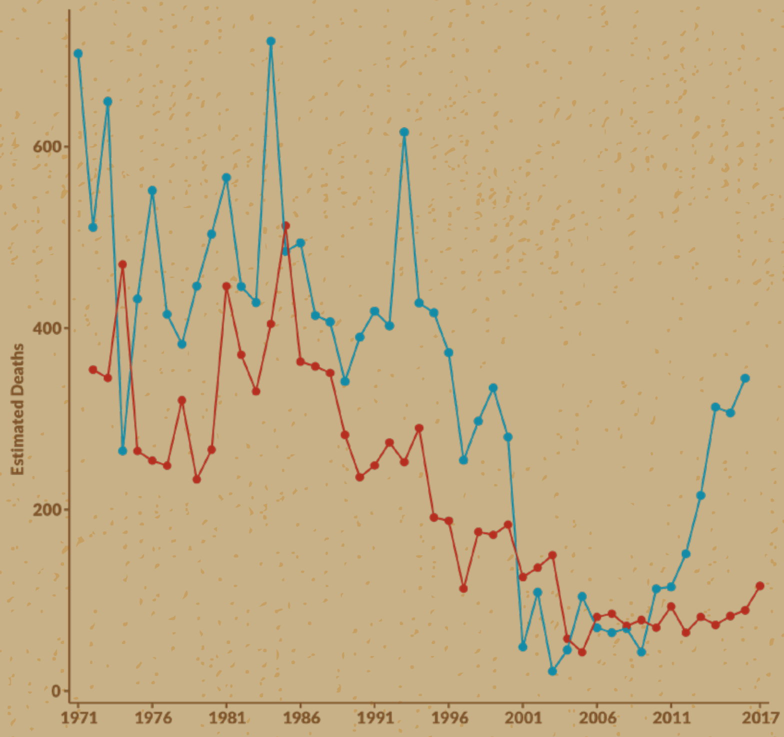
Heat, often overlooked among weather-related impacts, actually causes the highest rates of mortality compared to other types of weather, with an estimated 350 heat-related deaths per year in NYC.[2]

In addition to the severity of heat-related illness and prevalence of heat-related deaths, life-saving hot weather solutions such as air conditioning, cooling centers, and effective hot weather advisory and emergency service networks are either inaccessible, unaffordable, or underdeveloped. It is also important to note that while heat mortality and risk are often associated with extreme heat events such as heat waves, recent evidence has shown that heat-related health impacts see a marked increase during "non-extreme hot days" of temperatures starting at 82°F (Figure 1).[2]

FIGURE 1
Estimated Heat-Related Deaths in NYC during Extreme Heat Events versus Non-Extreme Hot Days

Deaths During Extreme Heat Events

Deaths on Days at or above 82° F



Source: *Produced using data from DOHMH. NYC Health. 2023. 2023 New York City Heat-Related Mortality Report. a816-dohbesp.nyc.gov/IndicatorPublic/data-features/heat-report*

Figure 1 shows the number of estimated heat-related deaths from 1971 to 2017, with the red line showing all deaths attributed on extreme heat event days and the blue line showing deaths on days at or above 82°F. We see a significant decrease in heat-related deaths in the late 1990s and early 2000s that can likely be attributed to improvements in, and increased use of, cooling strategies such as air conditioning. However, in 2011 there is a marked uptick in the number of heat-related deaths, particularly on these non-extreme hot days. This may be attributable to adjustments to the way the NYC Department of Health and Mental Hygiene (DOHMH) is defining and reporting heat-related deaths, but even so, this is a huge uptick warranting our attention, government action, and public education–particularly given that climate change is expected to cause worsening heat conditions.

In the United States, data from the National Oceanic and Atmospheric Administration (NOAA) indicate that between the 1960s and 2020s, heat waves have become more frequent and their average duration has increased (summarized in Figures 2 and 3). These trends pose a significant risk for people, especially for urban populations that experience the UHI effect where the built environment results in higher temperatures than in surrounding rural areas.

What is a Heat Wave?

A heat wave, defined by the National Weather Service as "a period of abnormally hot weather generally lasting more than two days," is among the most dangerous and deadliest natural disasters. Abnormally hot weather is defined relative to the regional climatic conditions, so in NYC, a heat wave is a period of "at least 3 consecutive days with high temperatures of at least 90 degrees".[3] According to the Intergovernmental Panel on Climate Change (IPCC), human activities have warmed the atmosphere and all regions of the world have recorded increases in extreme heat events. Because heat waves are expected to become more frequent, we will have to adapt to heat-related risks and potential increases in human morbidity and mortality associated with these events.[4]

FIGURE 2
Average Number of Heat Waves in the United States per Year

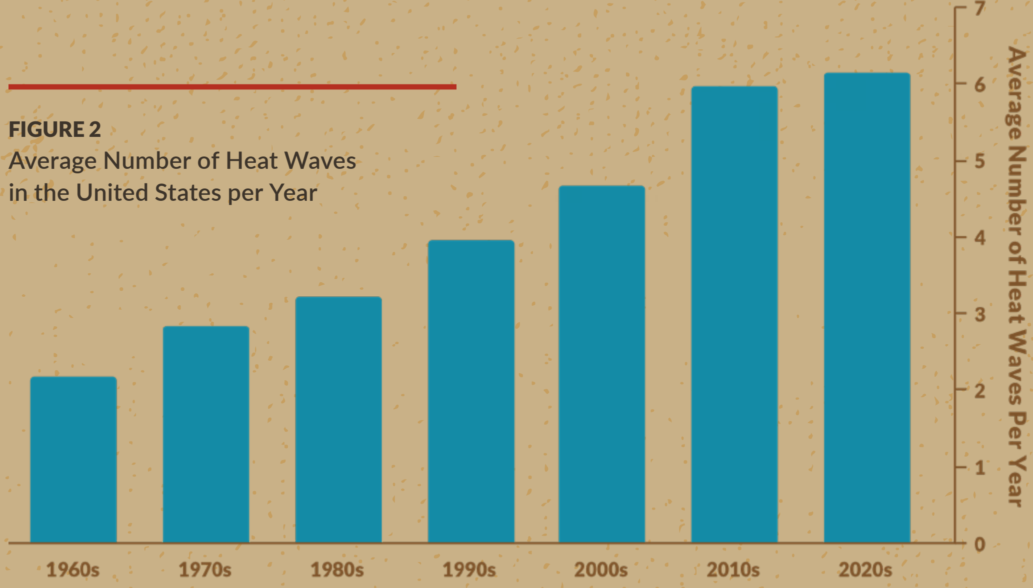
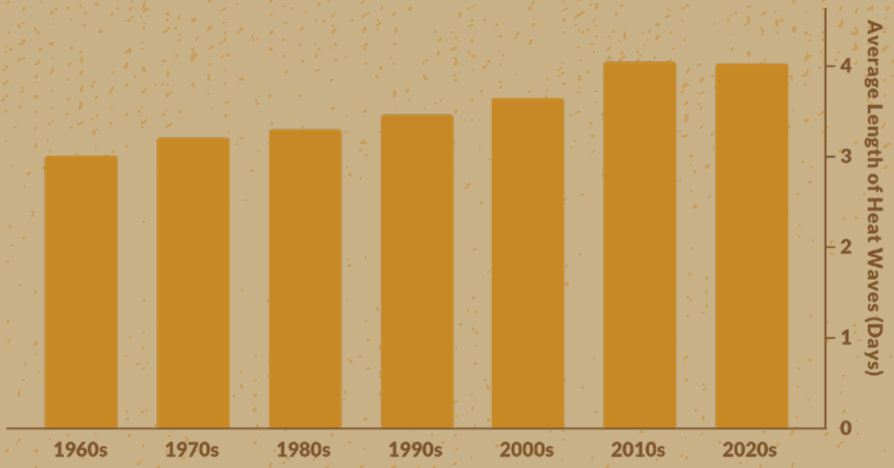


FIGURE 3
Average Duration of Heat Waves in the United States (Days)



Source: *United States Environmental Protection Agency (EPA). EPA's Climate Change Indicators in the United States: www.epa.gov/climate-indicators*

What Is the Urban Heat Island Effect?

The urbanized built environment, including buildings, houses, roads, and infrastructure systems, is made of materials that absorb and retain the sun's energy and then re-emit it in a way that results in higher localized temperatures than in natural environments with high levels of vegetation.[5] This is known as the urban heat island (UHI) effect.

Research indicates that the UHI effect typically results in higher daytime and nighttime temperatures, increasing human health risks during heat waves.[5] Nighttime temperatures and the daily low temperatures recorded in an area are of particular relevance, since high temperatures at night can prevent the human body from cooling off. This produces heat-related stress and can exacerbate heat-related morbidity and mortality.[6]

The UHI Index is a measure of the difference in temperature between an urban area and a reference rural area.[7] A recent study by Climate Central estimated the UHI Index for cities across the United States and reported that NYC has the highest UHI Index in the country, with about 78% of the city's population experiencing an UHI Index of 8°F or higher.[8] This temperature differential puts NYC's vulnerable populations at risk of heat-related public health impacts. Understanding current and projected risks from heat is critical for resilience planning. The Centers for Disease Control and Prevention (CDC) has a tool that tracks heat exposure and heat-related illness in the United States that can support heat-related risk mitigation programs.[9]

Heat is already a significant public health concern in NYC. In 2020, the City Council passed, in part due to NYC-EJA's advocacy, Local Law 84, which requires "annual reporting of heat vulnerability and heat-related deaths."[10] According to City estimates, between 2011 and 2019, there were on average 350 premature deaths where heat played a role, either directly or by exacerbating an underlying health condition. Heat-related deaths disproportionately impact non-Hispanic Black New Yorkers. Geographically, the Bronx and Brooklyn are also disproportionately impacted compared with the other boroughs.[11] This kind of information is critical for resilience planning and to ensure that vulnerable populations are better served and protected.

The NYC Panel on Climate Change (NPCC) has projected an increasing frequency of heat waves and a higher number of days with temperatures above 90°F and above 95°F for the rest of the century.[12] Table 1 shows the NPCC's projections for the 2050s compared with a baseline reference based on average values for the period 1981–2010. Based on these estimates, the number of days with temperatures reaching 90°F or higher in 2050 could increase by up to four times compared with the baseline value. Similarly, the number of heat waves experienced in NYC could double or triple in the 2050s compared with the baseline value.

TABLE 1
Predicted Heat-Related Events in NYC for the 2050s

Heat Related Event	Baseline (1981–2010)	Low Estimate (10th percentile)	Middle Range (25th–75th percentile)	High Estimate (90th percentile)
Number of Days/Year with Max Temp at or Above 90°F	17	32	38 to 62	69
Number of Days/Year with Max Temp at or Above 95°F	4	10	14 to 32	35
Number of Heat Waves/Year	2	4	5 to 8	9
Mean Heat Wave Duration (Days)	4	5	5 to 6	6

Source: *Braneon, C., Ortiz, L., Bader, D., Devineni, N., Orton, P., Rosenzweig, B., McPhearson, T., Smalls-Mantey, L., Gornitz, V., Mayo, T., Kadam, S., Sheerazi, H., Glenn, E., Yoon, L., Derras-Chouk, A., Towers, J., Leichenko, R., Balk, D., Marcotullio, P., & Horton, R. (2024). NYC climate risk information 2022: Observations and projections. Interim Report for Public Release climateassessment.nyc. Page 24*

The recently published New York State Climate Impacts Assessment projects similar trends. According to their estimates, temperatures in NYC in the 2080s could be 6–10 degrees higher than they were during the period 1981–2010. Their estimates also suggest that the number of days with temperatures above 95°F in NYC will increase significantly. Central Park, for example, is expected to experience 14 to 32 days with temperatures over 95°F by the 2050s and up to 54 days by the 2080s.[13]

These projections highlight the need for climate change adaptation to address expected increases in heat waves and heat-related events. Key components of climate change adaptation in NYC in this area should include early warning systems, identifying what parts of the city may experience worse temperature increases and heat island effects, and determining where the most vulnerable populations are located.

In addition to Local Law 84 mentioned earlier, NYC-EJA advocated to pass Local Law 85 of 2020 which requires City agencies to post the City's heat emergency plan to their respective public website.[10]

Heat-Related Risks and Vulnerable Populations

In order to determine where mitigation and intervention efforts are needed, we must accurately identify vulnerable populations. We can use a number of socio-economic and related indicators to do this. NYS, with the guidance of the Climate Justice Working Group (CJWG), has developed the Disadvantaged Community (DAC) Criteria.[14] The DACs were determined using 45 indicators including environmental burdens, climate change risks, population characteristics, and health vulnerabilities that can all contribute to more severe adverse effects of climate change. Figure 4 shows areas that have been identified as DACs throughout NYC based on these criteria, including much of the Bronx, northern Manhattan and the Lower East Side, northern parts of Staten Island, and large tracts of Brooklyn and Queens.

Separately, the NYC DOHMH has developed the Heat Vulnerability Index (HVI), which includes data about surface temperature, green space, air conditioning access, poverty, and percent minority population for each neighborhood.[15] Figure 5 highlights the areas across NYC that have a high Heat Vulnerability Index (HVI), in addition to the location of NYC-EJA member organizations. Not surprisingly, environmental justice communities, many of which are the communities where NYC-EJA members operate, show some of the highest vulnerability to heat-related risks. Tools such as the DAC Criteria and HVI can be critical for identifying priority areas for policy implementation and funding.

FIGURE 4
Disadvantaged Communities (DAC) in New York City By Census Tract

DAC
Non-DAC

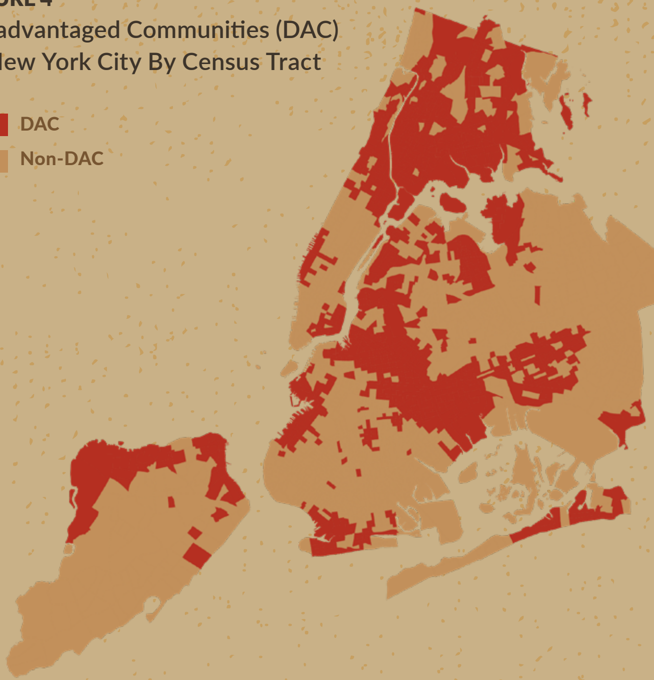
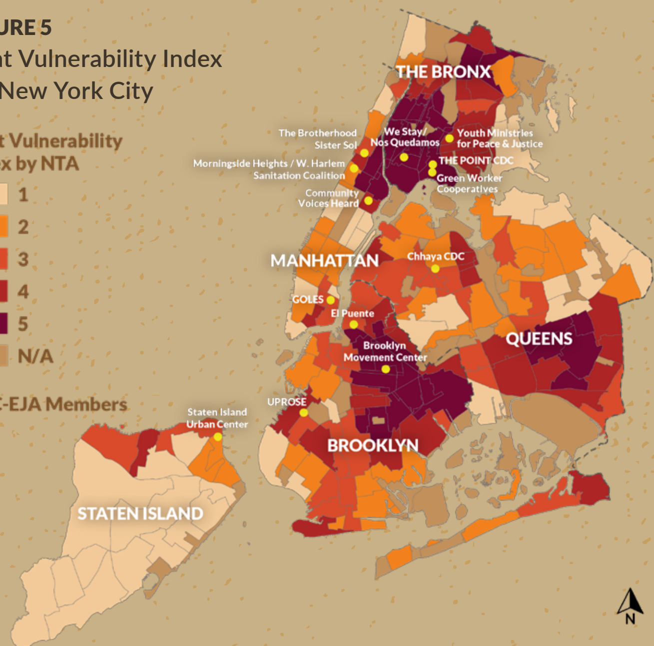


FIGURE 5
Heat Vulnerability Index for New York City

Heat Vulnerability Index by NTA
1
2
3
4
5
N/A

NYC-EJA Members



Source: *Data from New York State Department of Environmental Conservation (NYS DEC). 2023. New York State's Draft Disadvantaged Community Criteria.* *https://climate.ny.gov/-/media/project/climate/files/LMI-dac-criteria-fact-sheet.pdf*

Source: *Data from NYC DOHMH. Environment and Health Data Portal. Understand how environments shape health in NYC.* *https://a816-dohbesp.nyc.gov/IndicatorPublic/data-explorer/climate/?id=2411#display=map*

Air Quality and Public Health

Air quality is determined by the amount of pollution in the air at a given time.

Air pollutants include a range of "hazardous substances from both human-made and natural sources."[17]

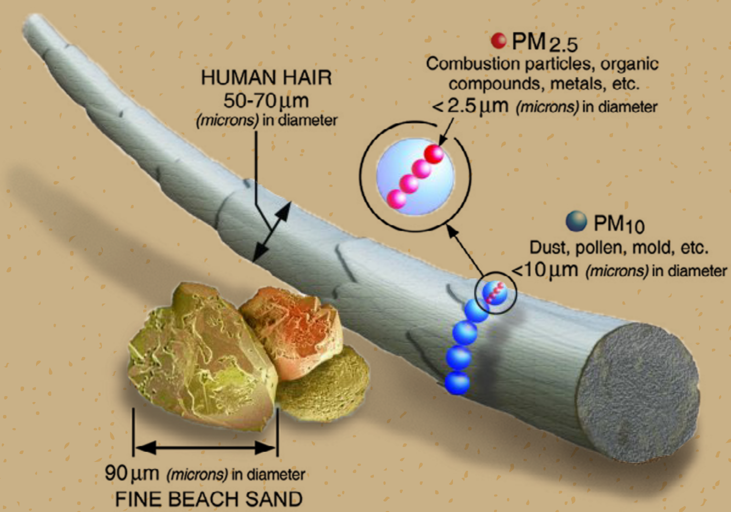
Vehicle emissions, emissions from burning gas to heat homes, byproducts of manufacturing and power generation, power plant emissions, smoke from wildfires, volcanic eruptions, and natural methane releases are all sources of air pollution. Some of the pollutants that are of greatest concern to EJ communities include ozone, NOx, SOx, VOCs, and fine particulate matter ($PM_{2.5}$).[16]

The World Health Organization (WHO) estimated that 4.2 million premature deaths were caused by ambient (outdoor) air pollution in 2019.[17] Worldwide, the combined effects of ambient air pollution and household air pollution are associated with 6.5 million premature deaths annually.[16] In NYC, $PM_{2.5}$ is linked to 2,000 premature deaths each year.[18] These are alarming statistics when the compounding risks of climate change are added to the equation, indicating a risk of even greater premature deaths as climate impacts increase. According to the United States Environmental Protection Agency (EPA), climate-driven changes in weather conditions, such as temperature, will likely increase ground-level air pollutants like ozone and particulate matter ($PM_{2.5}$) in many regions of the United States.[19]

In June 2023, NYC was affected by the devastating Canadian wildfires that ripped through the country, sending unprecedented amounts of smoke south into the United States. During this emergency, NYC had some of the worst air quality on the planet, with AQI reaching as high as 484 out of 500.[20] The choking smoke turned the skies a deep orange and endangered residents, many of whom were already at high risk for respiratory distress due to respiratory conditions and pre-existing air pollution burdens. These baseline conditions of disparity were dramatically worsened during the June 2023 emergency and led to an 81% increase in emergency room visits, most of which were in primarily BIPOC communities.[20]

The WHO has stated that air pollution has a direct impact on public health, posing a risk for mortality and specific diseases such as lung cancer and heart disease. Breathing in air pollutants has an impact on the lungs, heart, and brain along with almost every other organ and can lead to disease. Fine particulate matter ($PM_{2.5}$) is a significant environmental health risk, as these very small particles (Figure 6) can penetrate deep into the lungs, enter the bloodstream, and travel to organs, causing systemic damages to tissues and cells. Some of the health problems caused or exacerbated by $PM_{2.5}$ include premature death for both infants and adults from heart and lung disease, irritation of the airways, aggravated asthma, adverse birth outcomes, and neurodevelopmental disorders.[23,24] Infants and children, the elderly, low-income populations, and those with pre-existing diseases are among the most vulnerable to the health impacts of $PM_{2.5}$ exposures.[25]

FIGURE 6
Particulate Matter *Credit: EPA*



What is the Air Quality Index (AQI)?

AQI is a scale created to contextualize how much pollution is in the air at a given time, separated into colors that represent AQI measurements. In order, the colors are Green (AQI of 0–50), Yellow (AQI of 51–100), Orange (AQI of 101–150), Red (AQI of 151–200), Purple (AQI of 201–300), and Maroon (AQI of 301–500), with green being the healthiest and maroon being extremely hazardous to health. For people in sensitive groups, anything at or above orange (101+) causes increased vulnerability to air pollution–related negative health impacts. For the average person, anything at or above a red or 151+ AQI reading is likely to cause adverse health outcomes.[21,22]

What Is Fine Particulate Matter ($PM_{2.5}$)?

This is the term for a mixture of solid particles and liquid droplets found in the air. These particles can be emitted directly from a source such as a fire or construction site, or they can form in the atmosphere via complex chemical reactions from pollutants emitted from power plants and vehicles. Some particles, such as dust, soot, and smoke, can be seen with the naked eye. Others are so small they can only be detected using an electron microscope. These inhalable particles, with diameters that are 2.5 micrometers and smaller, can be inhaled deep into the lungs where they can cause a variety of health problems.[26]

A key finding from our previous CAMP-EJ report showed that hyperlocal air quality measurements in our member organizations' neighborhoods reached $PM_{2.5}$ concentrations up to 20 times higher than those air quality measurements officially reported by state and local government monitors. These government monitors are designed to measure air pollution to determine how well states and municipalities are meeting the air quality standards set by the EPA and legislated in the Clean Air Act. However, these standards are regularly updated as science is refined and do not provide comprehensive insights into the air all residents are breathing at a given time, as air pollution levels can vary significantly over very short distances and time periods. This is of critical importance because the hyperlocal conditions we monitored better represent what communities are experiencing and breathing in at ground level, helping to explain the persistent poor health outcomes related to and exacerbated by air pollution.

Government air quality standards are designed to protect the general population, but concentrations below the standards can still result in adverse health impacts. As scientists continue to study the link between public health and $PM_{2.5}$, they continue to find impacts at lower concentrations.[28] This is why the $PM_{2.5}$ standards are periodically revised and tend to become stricter over time. In addition, these standards account only for $PM_{2.5}$ alone, without consideration for possible impacts caused by a combination of multiple air pollutants.

The WHO has developed their own target value for $PM_{2.5}$ concentrations, suggesting cities should aim for concentrations below 5 µg/m^3.[29] Assessing whether an area meets the conditions established by an environmental standard or a recommended value set forth by organizations such as the WHO requires monitoring stations that continuously measure air pollution levels. The next section describes current monitoring efforts in NYC by regulatory and government agencies, as well as community efforts.

What are U.S. Air Quality Standards?

Air quality standards set a reference concentration level for pollutants that should not be exceeded. For example, the EPA has two standards for $PM_{2.5}$. The 24-hour standard is set at 35 µg/m^3 and is meant to protect the population from health impacts associated with short-term exposures to $PM_{2.5}$. The annual standard is set at 9.0 µg/m^3 and is meant to protect the population from longer-term exposures to air pollution.[27]

Air Pollution Monitoring in New York City

The NYS DEC maintains a network of air quality monitoring stations to assess compliance with the National Ambient Air Quality Standards (NAAQS) established by the Clean Air Act. The annual averages from NYS DEC's air monitors (Appendix A) are generally below the annual $PM_{2.5}$ standard established by EPA, which indicates that in the last few years the city was in compliance with the Clean Air Act. However, this does not mean there are no air quality risks associated with $PM_{2.5}$ in the city. The network is composed of a small number of stations located high above street level and cannot detect hotspots of air pollution that may be present in the area, nor can it detect what people experience on the ground. In addition, recent claims indicate that there is no safe level of $PM_{2.5}$ exposure, suggesting there may be greater risk to health than recognized by the U.S. government and room for improvement.[30]

In response to a grassroots-led demand for a just transition and shift to renewable energy in 2019, New York lawmakers passed the most ambitious state climate law in the nation, the NYS Climate Leadership and Community Protection Act (CLCPA). A key initiative of CLCPA was conducting air quality monitoring in disadvantaged communities that are considered to have the highest air pollution.[31] As a result, NYS DEC began a Community Air Monitoring Initiative in 2022. The mobile monitoring activities were completed in 2023 with an initial report expected in 2024.

Separately, as part of the New York City Community Air Survey (NYCCAS) program, the NYC DOHMH established a network of fixed monitoring stations that is significantly larger than the one operated by NYS DEC. It consists of about 100 sites in a variety of different environments, including different kinds of streets with various traffic levels, sidewalks, and parks.[15] Both DEC and DOHMH stations have retired many monitors over the last several years, making it difficult to assess air quality changes over time.

Figures 7 and 8 summarize the annual mean concentrations of $PM_{2.5}$ obtained by the NYCCAS for 2009 and 2019. According to the data, between 2009 and 2019 the average concentration of $PM_{2.5}$ decreased by 38% in NYC, improvements that can be credited to the EJ movement's work to enact policies as far back as the Bloomberg administration and their introduction of PlaNYC in 2007, and ongoing since then. Despite the overall notable improvements, many of the areas that continued to show the highest levels of air pollution in 2019 were EJ communities, including neighborhoods where NYC-EJA members operate, such as Sunset Park, Williamsburg, Lower Manhattan, and the South Bronx. In addition, these maps obscure data below the 8 μg/m^3 level, meaning it would be difficult for NYC to measure pollution in relation to the stricter WHO air quality standards.

FIGURE 7
2009 Annual Average $PM_{2.5}$ Concentrations

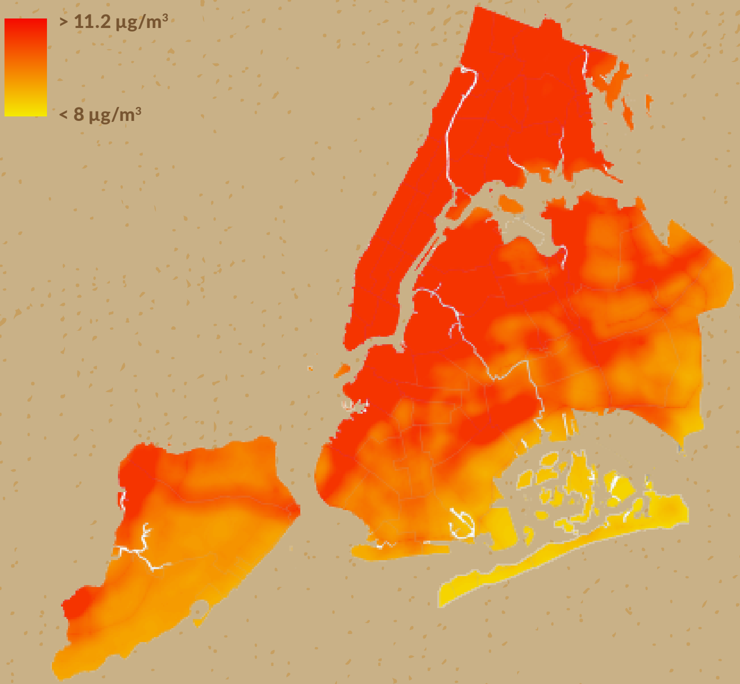
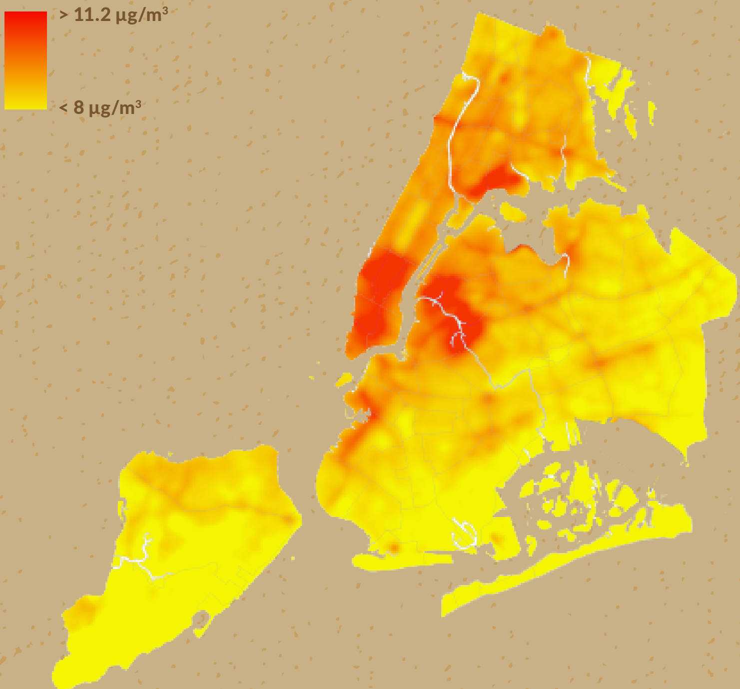


FIGURE 8
2019 Annual Average $PM_{2.5}$ Concentrations



Source: *New York City Community Air Survey (NYCCAS), New York City Department of Health and Mental Hygiene.* *https://nyccas.cityofnewyork.us/nyccas2021v9/report/2*

Methods

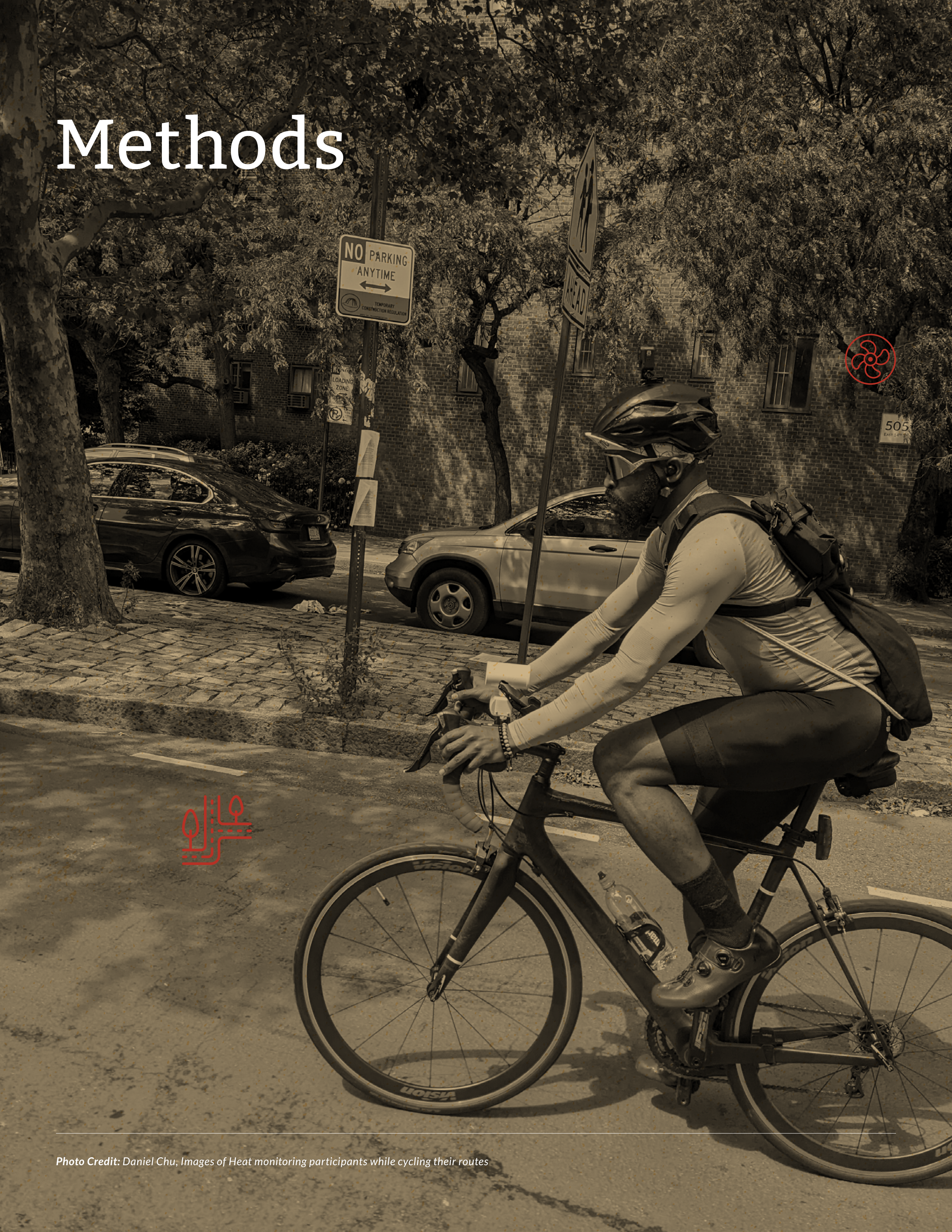


Photo Credit: *Daniel Chu, Images of Heat monitoring participants while cycling their routes*

Heat

A key focus of this research was examining the vulnerability of disadvantaged communities to extreme heat, caused or exacerbated by the UHI effect.

We collected data on air temperature based on factors tied to these concerns, informed by the NYC Heat Vulnerability Index.

Criteria for Selecting Priority Areas

Based on the literature on heat-related health risks and NYC-EJA's ongoing work in EJ communities in NYC, we used the following criteria and data sources to identify priority areas for our research and to help direct policies aimed at mitigating heat-related risks:

- High predicted temperatures in the Heat Watch Reports – Bronx, Manhattan[32] and Brooklyn[33]
- Low temperature differences between morning and evening hours
- High heat vulnerability index values[34]
- Low vegetation cover (based on data published by The Nature Conservancy and NYC-EJA)
- Proximity to major highways and sources of air pollution (using results of CHAMP-EJ or the Community Air Survey from DOHMH)[15]

Environmental justice communities, and communities where NYC-EJA member organizations are active, are key priority areas where New York City and state policies aimed at mitigating heat-related risks could have significant benefits. They include, but are not limited to, the South Bronx; Upper Manhattan and the Lower East Side in Manhattan; and Sunset Park, South Williamsburg, and Bedford-Stuyvesant in Brooklyn.

CAPA Strategies Heat Measurements and Predictions

In 2021 and 2022, CAPA Strategies, LLC, with the support of NOAA and the National Integrated Heat Health Information System (NIHHIS), conducted heat measurements in NYC. In July 2021, CAPA Strategies conducted a monitoring campaign in the Bronx and Upper Manhattan using heat sensors fixed onto automobiles. In 2022, NYC-EJA partnered with CAPA Strategies, local science teacher Sarah Slack, and The Brown Bike Girl (Courtney Williams) to organize a grassroots heat monitoring campaign in Brooklyn and Lower Manhattan. Williams helped NYC-EJA get volunteers from her experienced cyclist network to assist with the day-long monitoring project throughout these areas of the city. We used the publicly available data from the 2021 monitoring day to supplement our project and findings. We will focus on explaining the nuances of our own data in this report. For more information about the 2021 data collection, see CAPA's Bronx-Manhattan Heat Watch report,[32] and for our 2022 data collection, see CAPA's Brooklyn-Lower Manhattan Heat Watch Report.[33]

On July 30, 2022, we collected single-day measurements using mobile heat sensors mounted to handlebars of bicycles. Volunteers rode the bicycles around different neighborhoods of the city via predetermined routes that were created with the expertise of CAPA, community leaders, and The Brown Bike Girl. Volunteers biked their assigned route three times over the course of a single day, from 6–7 am, from 3–4 pm, and from 7–8 pm. Routes spanned the majority of lower Manhattan and Brooklyn (Figure 9). The results were used as inputs to an analytic model to estimate air temperature more broadly across those parts of the city during those focal time periods. The model incorporates key determinants of local microclimates (aspects of the built environment and vegetation cover), which support understanding local differences in temperature from place to place. These differences can also be used to identify areas of the city that would be most affected during heat waves.

FIGURE 9
CAPA Heat Watch Brooklyn and Lower Manhattan Bicycle Routes on July 30, 2022

Source: *Produced using data from CAPA Strategies, Inc.*

NYC-EJA and NYC-EJA member organization staff members.

Clockwise from top left:

- NYC-EJA staff doing an air monitoring session
- NYC-EJA staff train UPROSE youth air monitoring participants
- An AirBeam3 attached to a volunteer's bag
- A group of El Puente youth participants doing an air monitoring session

Air Quality

Community Monitoring of $PM_{2.5}$: AirBeam Measurements

As with our first community air monitoring project, CAMP-EJ, we partnered with HabitatMap, an environmental technology nonprofit, to use their air monitors and the AirCasting website. Participants from five NYC-EJA member organizations used Airbeam3 monitors (Figure 10) which are low-cost, palm-sized air monitors that measure PM_1, $PM_{2.5}$, PM_{10}, temperature, and relative humidity, of which $PM_{2.5}$ was our primary focus. We then worked with the member organizations to set up training sessions with their respective monitoring teams (primarily made up of NYC Summer Youth Employment participants and other young community members).

We created walking routes for the volunteers in partnership with the member organizations and Dr. Chris Lim, Assistant Professor at the Department of Community, Environment & Policy, at The University of Arizona's Zuckerman College of Public Health. Each route was approximately a 1-hour walk that started and ended at the organization's office. The walks traversed as many land use types and points of interest or concern as possible, while still being safe for the young volunteers to travel several times a week. Monitoring teams consisted of at least 3–5 participants, with at least one adult supervisor to assist and keep the younger participants safe. Over the course of 4–6 weeks, each organization was tasked with walking their route 2–3 days a week, including once in the morning and once in the afternoon on each of those days.

In addition to the mobile air monitoring, there was one fixed monitor at or near each of the organizations' office locations. These AirBeam3s were set to run for the entire duration of the monitoring period. This additional data assisted with the analysis of the mobile monitoring data.

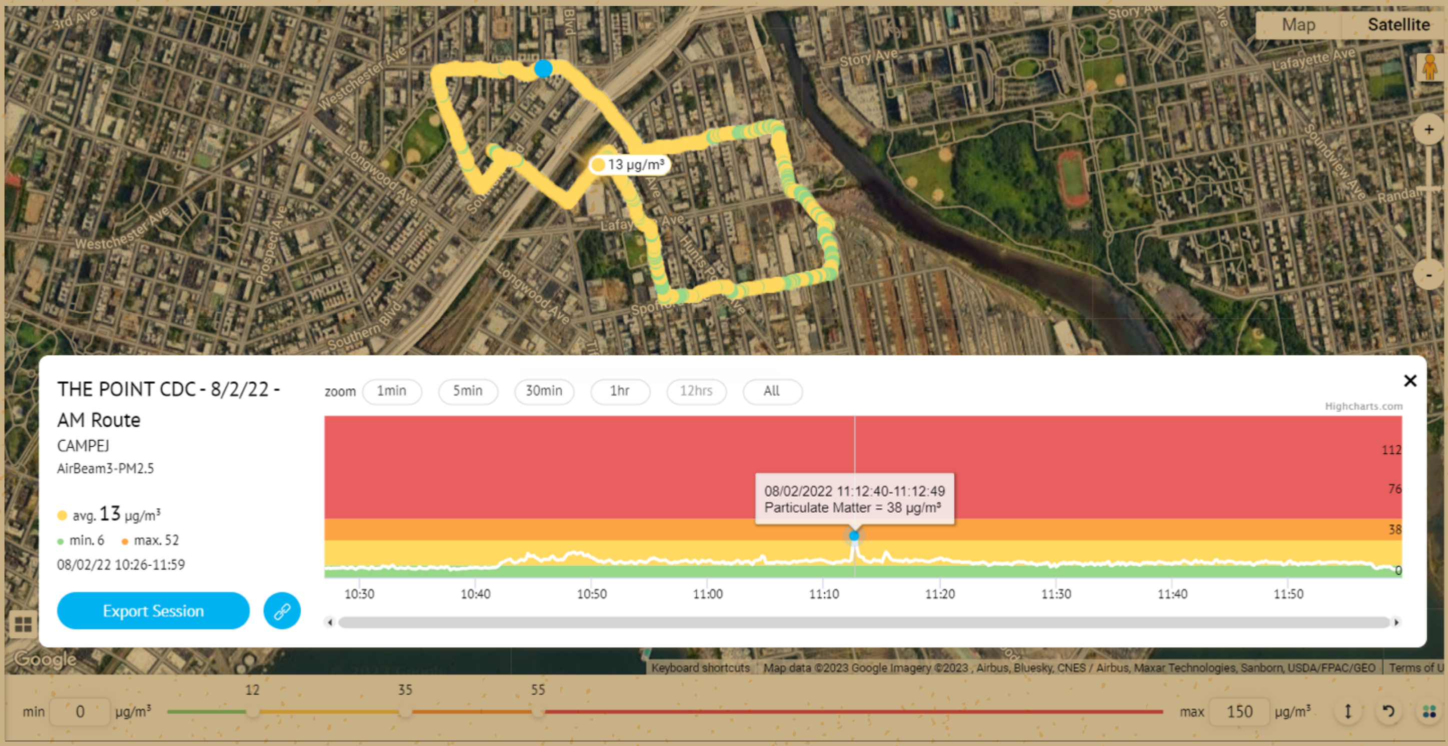
FIGURE 10
AirBeam3, a Low-Cost Air Quality Monitor Developed by HabitatMap

Photo Credit: *Carlos Restrepo*

The AirBeam3 records $PM_{2.5}$ concentrations and can be used with the Aircasting application to visualize and map the data (e.g., Figure 11). The data, as displayed in AirCasting, relate $PM_{2.5}$ concentrations to health risks for people, with colors from green (no risk) to yellow and orange (risks for vulnerable populations, such as children) and red (significant risks for the general population). The data presented in Figure 11 reflect the $PM_{2.5}$ concentrations a local resident may experience during a weekday walk around the neighborhood in the afternoon, ranging from 6–52 µg/m³ (avg. 13 µg/m³), with the highest values posing significant risks to vulnerable populations. This color range is distinct from the abovementioned AQI color system.

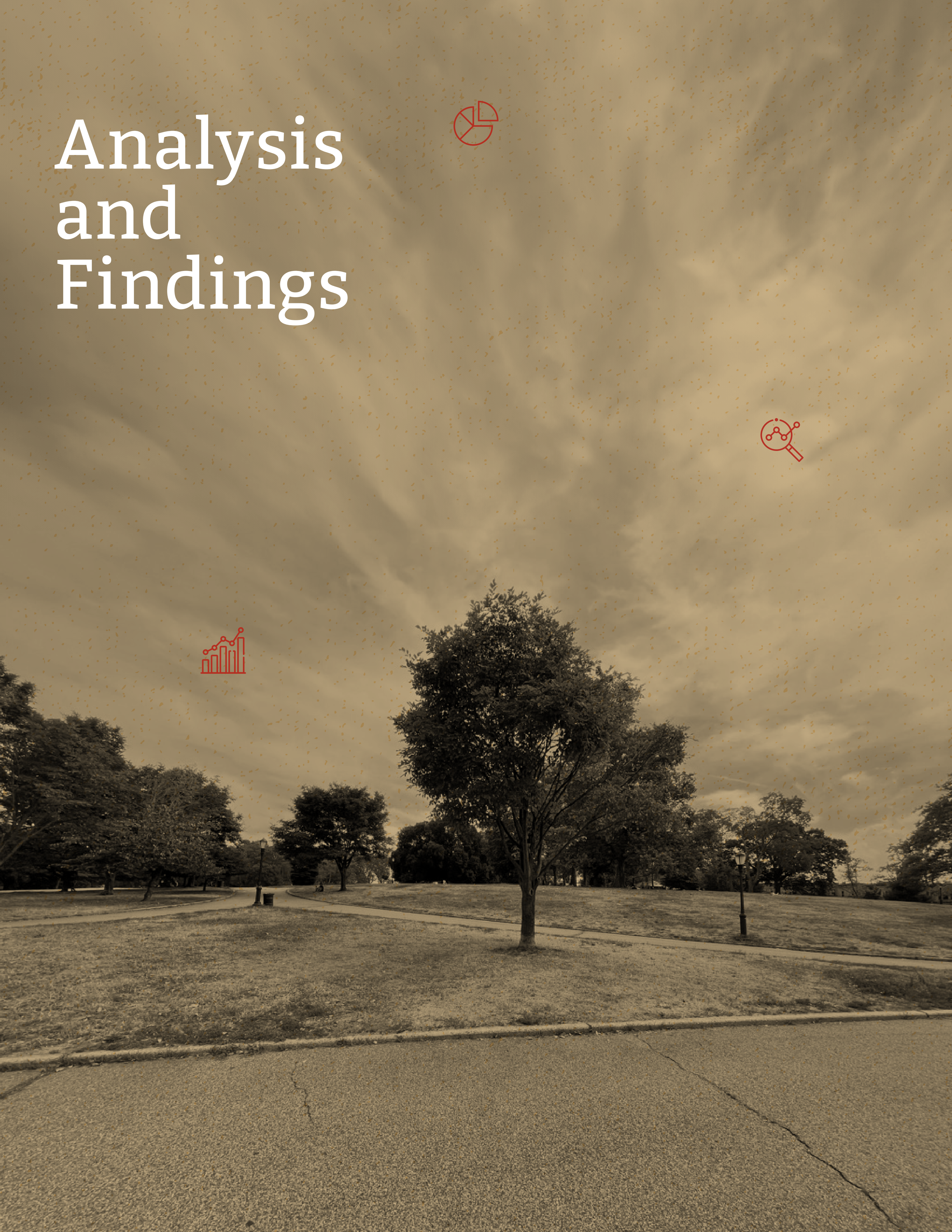
These data can be very useful for community residents and organizations that want to better understand local air quality conditions to advocate for policies and programs to improve air quality. In addition, understanding where spikes in air pollution concentrations occur can help communities pinpoint sources of air pollution, or hotspots, that should be mitigated or avoided at certain times of day, when possible. They may also show where traffic management could be improved to address traffic-related air pollution. Although data from a single session cannot be generalized to potential exposures throughout the year for community residents, this kind of information can also help communities identify locations where more data and monitoring are needed.

FIGURE 11
AirCasting Session and route from THE POINT CDC with Data Collected in the Bronx on June 2, 2022



Source: *HabitatMap, AirCasting Platform. www.habitatmap.org/aircasting*

Analysis and Findings



Heat

The goal of data collection was to assess spatial and temporal variations in urban heat in several neighborhoods of NYC.

The analyses presented in this section were conducted by CAPA Strategies and Dr. Peter Marcotullio, Professor of Earth and Environmental Sciences at Hunter College, City University of New York.

These comparisons also show that the temperature and experience of heat can vary significantly from one location to another, even over relatively small distances.

Key Points

Based on the literature on heat-related health risks and NYC-EJA's ongoing work in EJ communities in NYC, we used the following criteria and data sources to identify priority areas for our research and to help direct policies aimed at mitigating heat-related risks:

- Neighborhoods with large areas of impervious surfaces (such as streets and parking lots) tend to retain excess heat, which spills into nearby residential areas.
- As vegetation cover decreases, temperature tends to increase.
- Areas with greater vegetation tend to cool more overnight, lowering the risk of adverse health effects. Areas with dense high-rise buildings and gray infrastructure experience smaller temperature changes overnight.

Community Monitoring of Heat

The temperature estimates produced by CAPA show significant variation in temperatures over the area covered. Given current predictions about climate change, understanding these temperature differences and how heat will impact different neighborhoods will become increasingly important. Figure 12 shows the results of the temperature estimates in parts of the Bronx and Upper Manhattan based on measurements taken on July 24, 2021. Figure 13 shows the results of the temperature estimates in lower Manhattan and parts of Brooklyn based on measurements taken on July 30, 2022. It is important to note that the temperature range for each of these maps, which represent the heat measured at different times of day, are all scaled to the range measured at that time, and are therefore different. The time periods in Figures 12 and 13 refer to 6–7 am (AM), 3–4 pm (PM), and 7–8 pm (Evening).

FIGURE 12

Temperature Predictions Based on Local Monitoring in Parts of the Bronx and Upper Manhattan for July 24, 2021

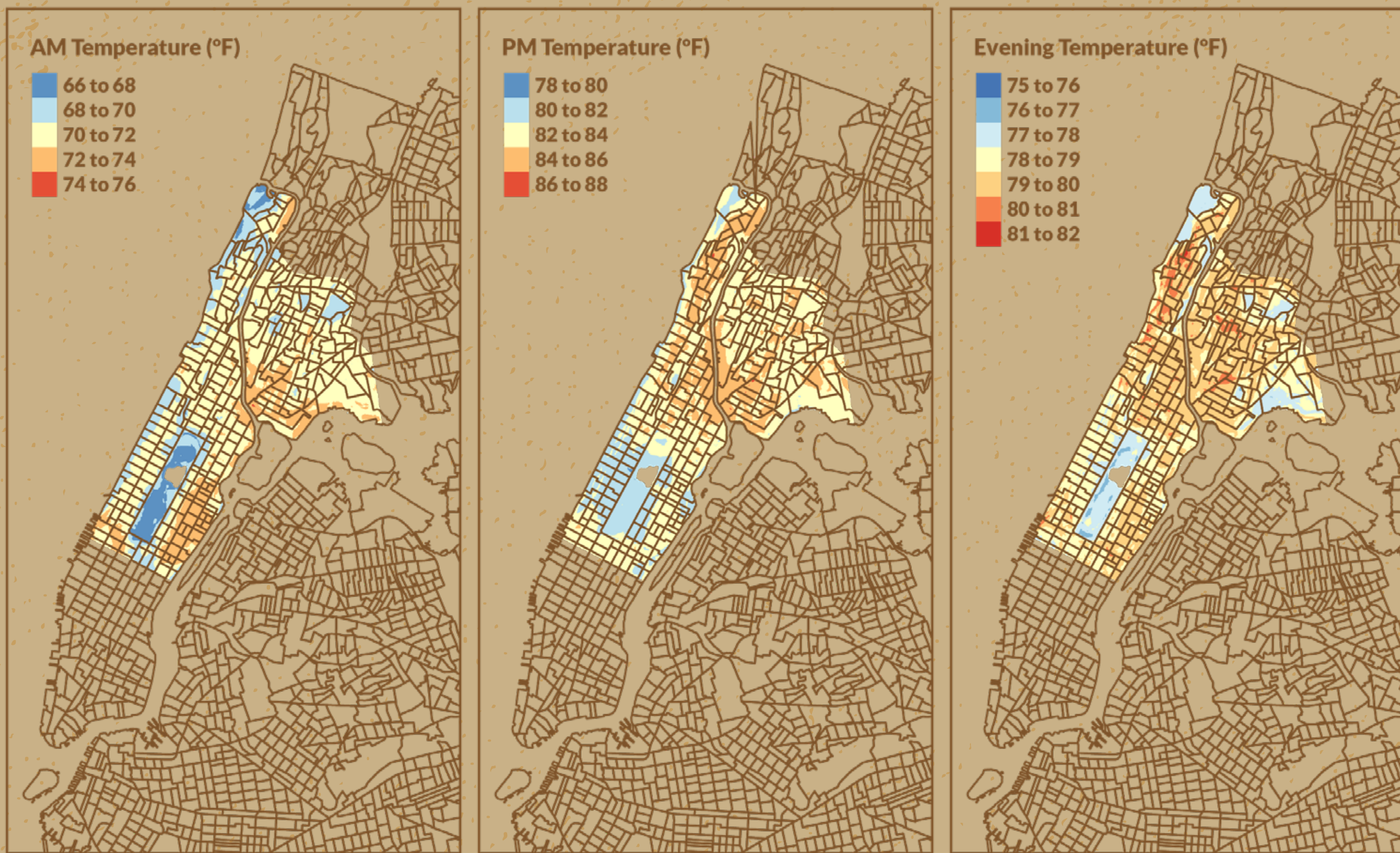
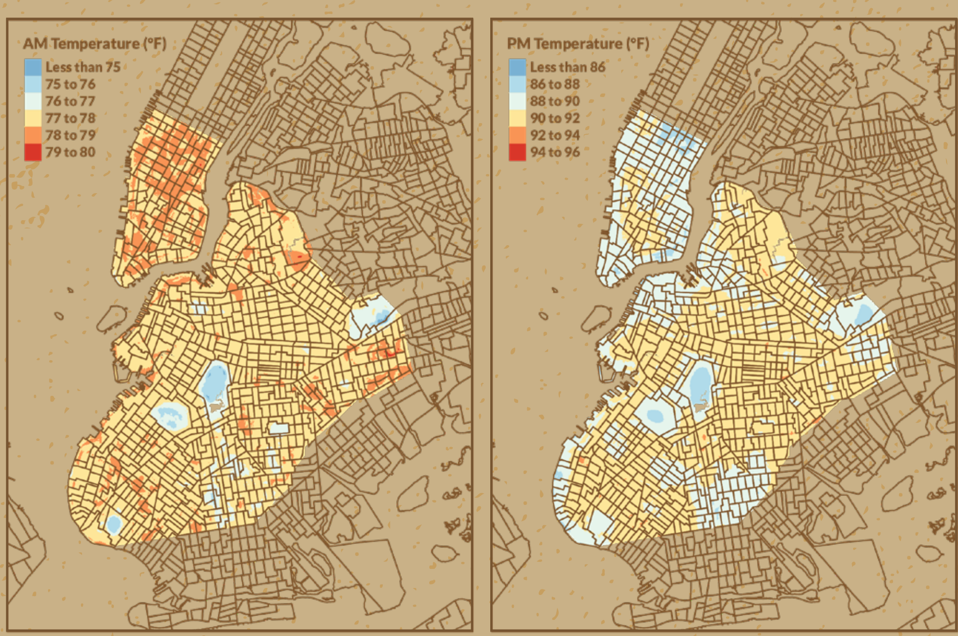


FIGURE 13

Temperature Predictions Based on Local Monitoring in Lower Manhattan and Parts of Brooklyn for July 30, 2022



Source: *Data from the CAPA Strategies, LLC. Heat Watch Report. Brooklyn and Lower Manhattan, New York. 2021, 2022*

CAPA's analysis of the data represented in Figures 12 and 13 revealed that high-density development around commercial areas, areas with plentiful impervious surfaces, and asphalt roads with little vegetation tend to trap, retain, accumulate, and concentrate heat. In addition, areas with more vegetation and canopy cover, or that are close to parks, tend to stay relatively cooler on warm days. These findings suggested a relationship between the data we collected with CAPA and the distribution of vegetation.

Identifying Vulnerable Populations and Priority Areas for Risk Management

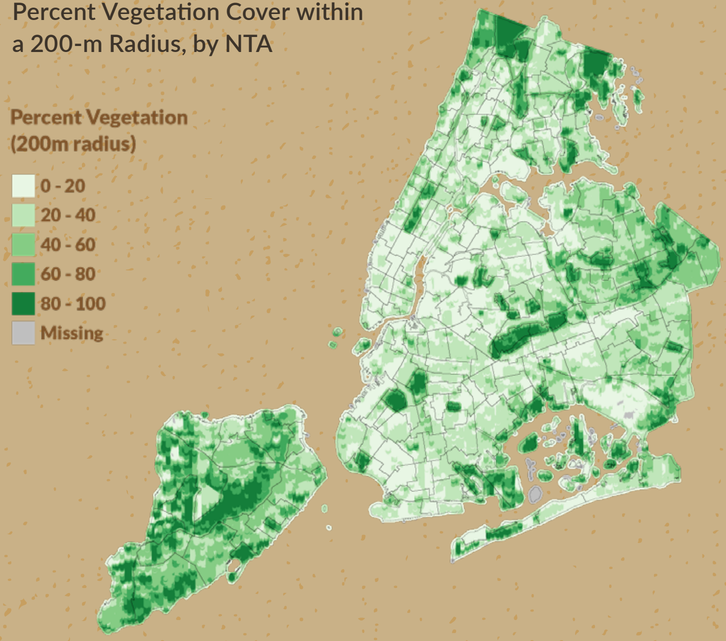
The heat measurements produced by CAPA Strategies and risk assessment tools such as the NYS DACs (Figure 4) and the Heat Vulnerability Index (Figure 5) are important tools to address heat-related risks and to understand how heat may impact different neighborhoods in the city. One component of HVI is vegetation cover. This variable is key to identifying areas where green infrastructure projects, cool roofs and pavements, and other policies could mitigate heat-related risks. Vegetation is also an important variable for addressing air pollution risks, as increased vegetation cover is known to improve air quality.

The Nature Conservancy's NY Cities Program and NYC-EJA have collaborated through a partnership called Just Nature NYC to analyze vegetation density across NYC. The goal was to understand where there is insufficient vegetation density to reduce the UHI effect, which can be captured at different scales (Figure 14). These data can be combined with measures of vulnerability and information on where vegetation cover can be easily increased (e.g., by planting trees and growing their canopy) to identify priority areas for policy interventions.[36]

What is Vegetation Cover?

Vegetation refers to all plants. In this work, vegetation cover is determined by the amount of a given land area that is covered by any plants, from a top-down view, including grasses, shrubs, and trees. This is a useful metric for our work because research has shown that the UHI effect can be decreased when an area is covered by at least 32% vegetation, with temperatures showing a measurable decrease after this threshold is met.[35] To learn more about how vegetation cover provides cooling benefits, see our Just Nature NYC Blog Post.

FIGURE 14
Percent Vegetation Cover within a 200-m Radius, by NTA



Source: *Treglia, M. L., Piland, N. C., Kanekal, S., & Sanders, V. (2023). Vegetation Density Across NYC: Analysis of Land Cover Data (2017) within 200 meter Buffers of Points (1.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8370381*

Analysis of Vegetation Cover by Neighborhood Tabulation Areas (NTAs) in NYC

Dr. Marcotullio, Professor of Geography at Hunter College and Director of the CUNY Institute for Sustainable Cities, examined the relationship between vegetation cover, using data provided by The Nature Conservancy, and the spatially explicit air temperature models provided by CAPA Strategies for 2021 and 2022. The vegetation data, which represents the proportion of land area covered by vegetation within 200 meters of points across the city, were used in the analysis to understand how vegetation varied across different geographies in NYC.

As Figure 14 shows, there are substantial differences across the city in terms of vegetation cover. It is important to assess how vegetation cover differs among neighborhoods to identify where policies can be implemented to better manage risks related to heat and air pollution. Dr. Marcotullio's analysis used 2020 Neighborhood Tabulation Areas (NTAs) to assess these differences. First, neighborhoods of NYC-EJA member organizations, all of which are DACs, involved with this study were compared with all of the DAC neighborhoods (NYC-EJA member neighborhoods included), the non-DAC neighborhoods, and the major parks and green spaces in the city in terms of vegetation cover. The relevant NYC-EJA member neighborhoods include Bushwick, Bedford-Stuyvesant, Sunset Park, Williamsburg, Hunts Point, Mott Haven - Port Morris, Lower East Side, and Melrose (Figure 15).

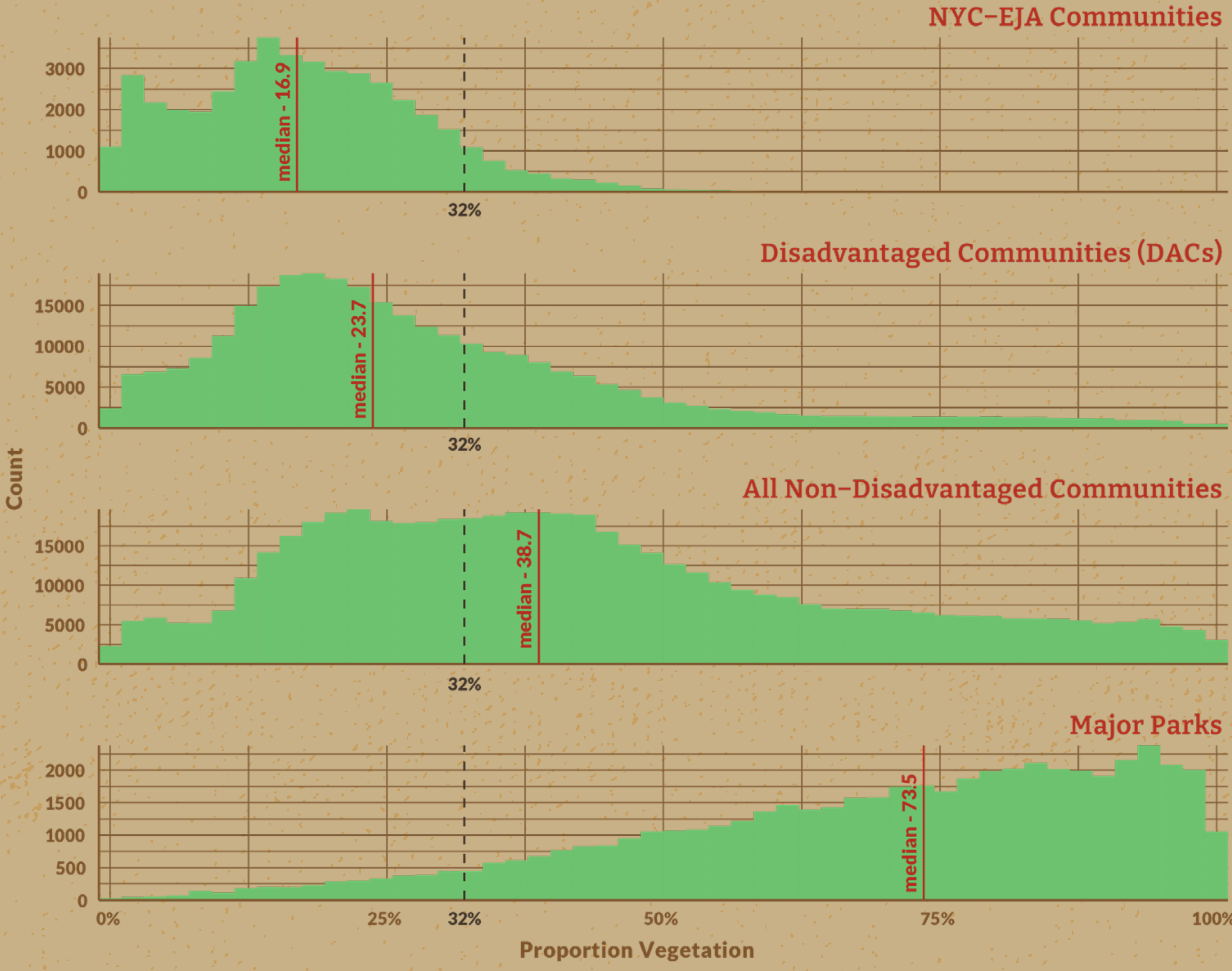
We compared the average vegetation density across NTAs where NYC-EJA members operate with that of the rest of the NTAs in NYC. First, the vegetation data were aggregated at the NTA level and a mean was obtained for NYC-EJA NTAs and all other NYC NTAs. Next, we used t-tests to determine whether the means were significantly different. There was a large difference between each community category (Figure 16). It is clear that NTAs where NYC-EJA members operate have a much lower median percentage vegetation cover, falling far below the

FIGURE 15
Participating NYC-EJA Member Organization Neighborhood Tabulation Areas (NTAs)

NTAs are Lower East Side, Port Morris, Melrose, Longwood and Hunts Point, Williamsburg, East Williamsburg, South Williamsburg, Bushwick (West), Bushwick (East), Bedford-Stuyvesant and Sunset Park.

32% threshold represented by the black dashed line. We also see that these select NYC-EJA neighborhoods have a lower percent vegetation than all other DACs. Unlike NYC-EJA neighborhoods and DACs, non-DAC communities have a median higher than the 32% threshold, which means that they are more likely to be protected from the negative heat-related impacts associated with the UHI effect. For a table of these distributions, please see Appendix B.

FIGURE 16
Different Levels of Vegetation within a 200-m Radius Across Different Subsets of Geographies



Data span NYC-EJA NTAs, DAC and non-DAC census tracts, and major parks. Bars to the right of the black, dashed line represent points with at least 32% vegetation cover in the 200-m radius: a threshold for key cooling benefits. Note that the points in NYC-EJA NTAs and DAC census tracts typically do not have that critical level of vegetation.

Source: *Produced using data from Treglia, M. L., Piland, N. C., Leu, K., Van Slooten, A., & Maxwell, E. N. (2022). Practical Canopy for New York City—Data Layer and Summarized Results [Data set]. Zenodo. doi: 10.5281/zenodo.6547492 and NYS DEC. 2023. New York State's Draft Disadvantaged Community Criteria.* *https://climate.ny.gov/-/media/project/climate/files/LMI-dac-criteria-fact-sheet.pdf*

Similarly, Figure 17 shows the percentage of each community category that falls below or above the 32% vegetation threshold needed to decrease the UHI effect. Again we see that the NYC-EJA NTAs central to this report have the least vegetation cover of all the categories. Additional figures to explain this relationship can be found in Appendix B.

Dr. Marcotullio then examined the relationship between vegetation cover, using the data discussed above, and the temperature measurements provided by CAPA Strategies for 2021 and 2022.

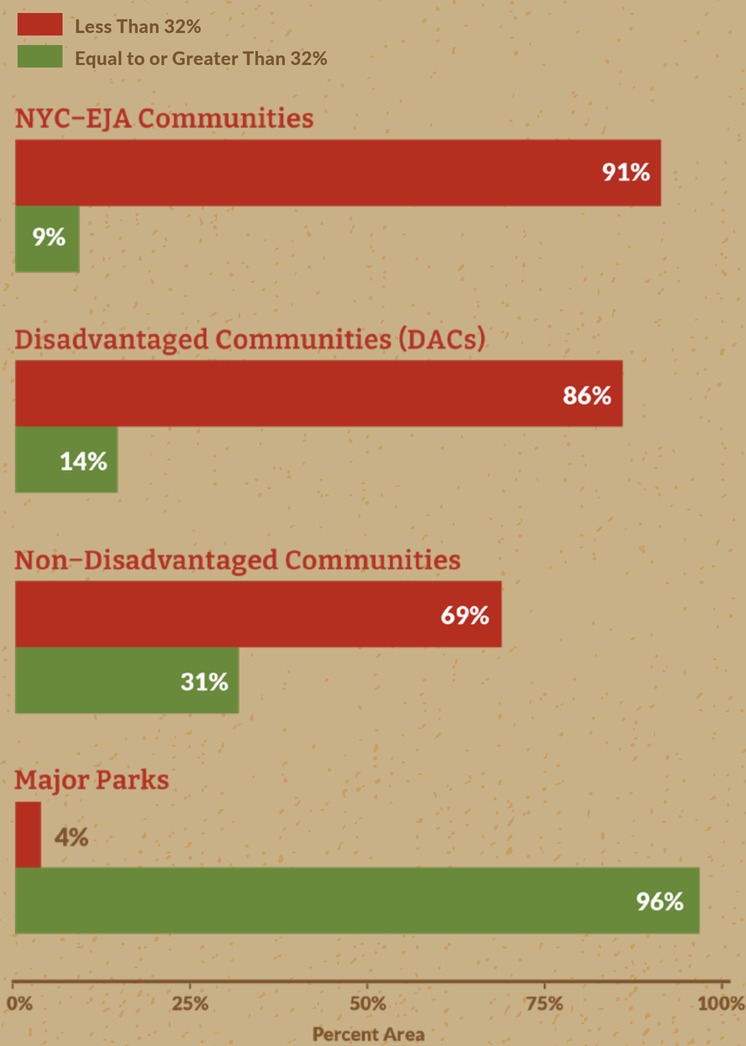
The overall goal of the analysis was to explore the following:

1. Is there any association between percent vegetation cover and temperature levels during different times of day and different locations within NYC?

2. Is there any association between change in temperature during the day and percent vegetation cover?

To address the first question, we did a bi-variate comparison between temperature and vegetation cover for every point with a 200-m radius. This temperature and vegetation comparison was also observed at different locations and times of day. These results are shown in Figures 18 and 19. The analysis suggests that, in general, there is an inverse relationship between these two variables. Areas with higher vegetation cover tend to have lower temperatures.

FIGURE 17
Percent of Area for NYC-EJA NTAs, DAC and Non-DAC Census Tracts, and Major Parks with 32% Vegetation Cover in a 200-m Radius



Source: *Data from Treglia, M. L., Piland, N. C., Leu, K., Van Slooten, A., & Maxwell, E. N. (2022). Practical Canopy for New York City—Data Layer and Summarized Results [Data set]. Zenodo. doi: 10.5281/zenodo.6547492 and NYS DEC. 2023. New York State's Draft Disadvantaged Community Criteria https://climate.ny.gov/-/media/project/climate/files/LMI-dac-criteria-fact-sheet.pdf*

FIGURE 18
Relationship between Vegetation Cover and Temperature in Study Areas of the Bronx and Upper Manhattan

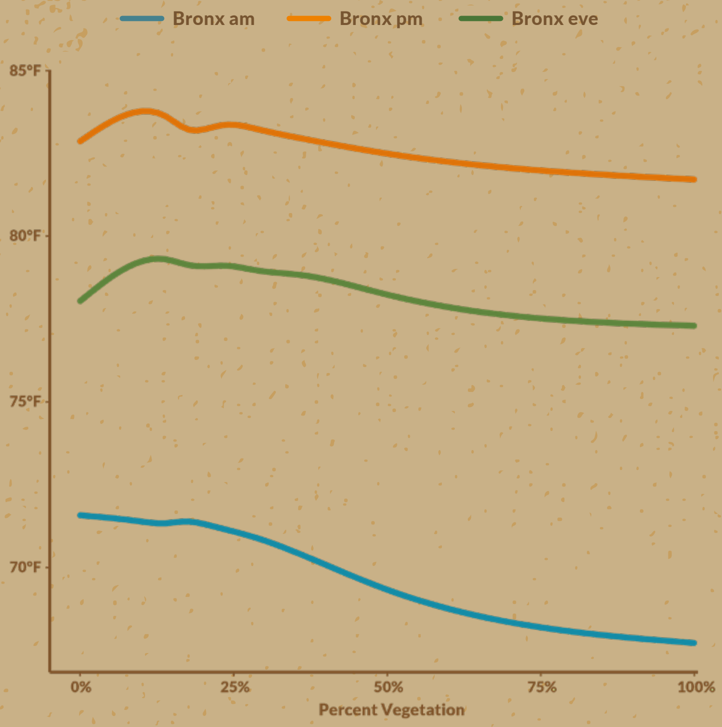
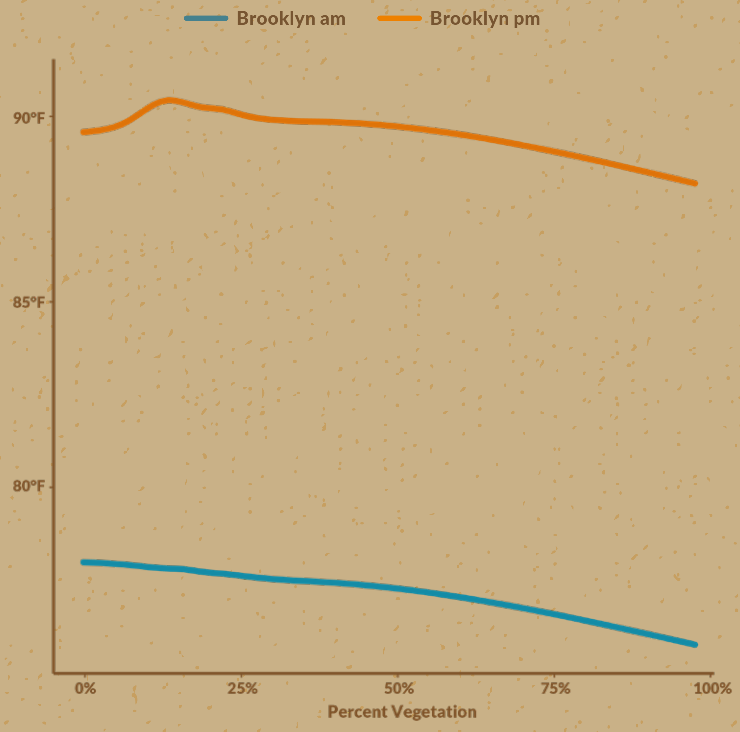


FIGURE 19
Relationship Between Vegetation Cover and Temperature in Study Areas of Brooklyn and Lower Manhattan

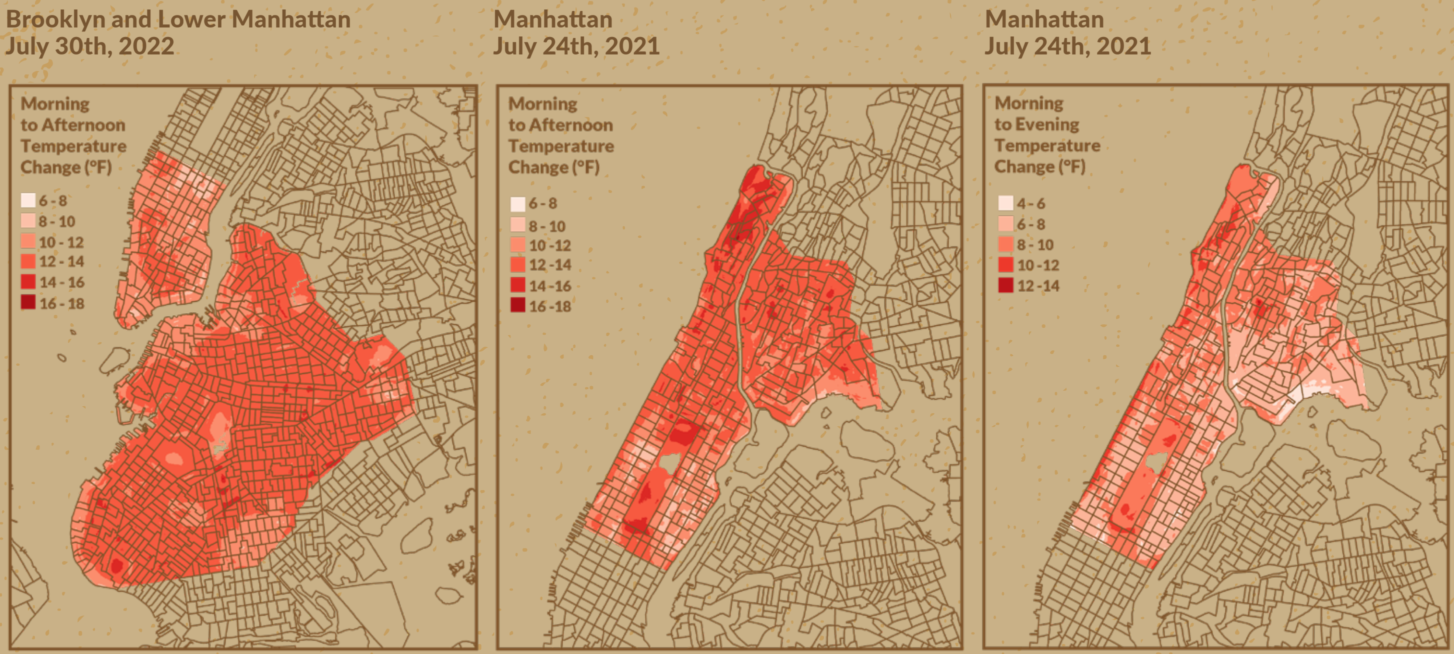


Source: *Data from CAPA Strategies, Inc and The Nature Conservancy's New York Cities Team/NYC-EJA*

Looking at Figures 18 and 19, we can see clearly that at each time of day shown, temperature is higher when vegetation cover is lower. While the temperature difference may seem small, it is noteworthy due to how consistent it is and the fact that the data are limited to a single day of temperature measurements. For more information about these findings, please see Appendix B.

To determine whether change in temperature during the day is associated with percent vegetation cover, we used the continuous heat data from our CAPA data collection. Morning temperatures were subtracted from afternoon and evening temperatures to measure the difference in temperature throughout the day. This provided a measure of the total change in temperature, overlaid with census tracts. Figure 20 shows the differences between AM and PM temperatures in parts of the Bronx, Manhattan, and Brooklyn based on CAPA's measurements. The results of Dr. Marcotullio's analyses indicate that there is a relationship between change in temperature during the day and vegetation cover. For the Bronx, upper and lower Manhattan, and Brooklyn, the larger the temperature difference, the greater the vegetation cover.

FIGURE 20
Differences in AM and PM Temperatures in Selected Areas of New York City



Source: *Peter J. Marcotullio. 2023. Analysis of data from CAPA Strategies' Heat Watch reports*

However, the maps tell a slightly different story between boroughs. For the Bronx and upper Manhattan, the areas of greatest temperature change are forested areas such as Central Park and Fort Tryon Park, while in Brooklyn and lower Manhattan, some of the smallest temperature changes were in the forested areas of Prospect Park, Sunset Park, and Highland Park. The reason for this is uncertain, but may be due to incomplete data in the Brooklyn and Lower Manhattan heat monitoring campaign, in which the evening data collection could not be included in the modeling and analysis. In both cases, the areas with a lot of high-rise buildings had some of the smallest temperature changes.

Understanding these differences between morning and evening temperatures can be critical for heat resiliency, as a key indicator for the impacts of heat on human health is the daily low temperature. High differential areas are most likely to have the lower temperatures late at night, which can be very important during a heat wave. Lower night-time temperatures allow the human body to recover from high daytime temperatures, so areas with the largest morning and evening temperature differentials offer better health outcomes. Conversely, in areas where the differential between morning and evening temperatures is lower, nighttime temperatures may be higher, and in those areas, households without access to air conditioning could be at higher risk for heat stroke and other heat-related risks.

This kind of temperature monitoring and predictive analysis should be continued and extended in the future in order to better understand where the greatest risks from heat-related events are likely to be and where the most vulnerable populations are located. Understanding this is critical for both risk communication and for implementing policies to mitigate these risks.

Air Quality

The analyses presented in this section were conducted by Dr. Lim. The goal of data collection was to assess spatial and temporal variations in air pollution in several neighborhoods of NYC.

Data were compared with information from nearby fixed monitors maintained by the NYS DEC.

These comparisons show that air pollution can vary significantly from one location to another, even over relatively small distances.

Key Points

- Mobile and fixed sampling using AirBeam3 monitors was conducted to measure fine particulate matter ($PM_{2.5}$) levels in several locations in the Bronx and Brooklyn. Over the entire sampling periods, mobile sampling averages ranged from 8.9 to 11.4 $\mu g/m^3$, and fixed sampling averages ranged from 6.2 to 8.5 $\mu g/m^3$. The highest average exposure was seen at THE POINT CDC, in the Bronx.

- The values from mobile and fixed samples greatly differed from values recorded by the nearest government monitors. At the maximum, hyperlocal, minute-level measurements mobile sessions recorded values as high as 18x greater than that of the nearest monitor value, and fixed sessions recorded values as high as 49x greater.

- The main air pollution source is likely to be from traffic. Traffic congestion continues to cause pollution spikes twice a day, with higher pollution during morning and nighttime rush hours.

Two sets of data were used in the analyses presented in this section. Mobile monitoring refers to data collected by users who took the monitors with them during a walk around a pre-established route in a neighborhood during specified hours of the day. They show how air pollution varies as a person goes from one location to another. Fixed monitoring, on the other hand, refers to the use of the AirBeam monitors in a stationary or fixed location running continuously during the sampling period. Such data show how air pollution varies throughout the day at a fixed location.

Mobile Monitoring

For mobile monitoring, 7,302 minutes of data (approximately 120 hours) were collected between July 19 and August 25, 2022. For the analyses, datasets outside the planned sampling time (10 a.m. to 12 p.m.; 2 to 4 p.m.) were removed, which resulted in 5,234 minutes of data. For fixed monitoring, data were collected from July 18 to September 24, 2022. The summary statistics for mobile and fixed sessions are shown in Tables 3 and 4, which include the mean, median, minimum, maximum, and standard deviation of the measured $PM_{2.5}$ values, along with the number of minutes of data collected and the number of sessions. The tables demonstrate that the number of sessions and data were highly uneven across locations, especially for mobile sessions. The mean values were the highest at The Point CDC for both mobile and fixed sampling. For both mobile and fixed sessions, the mean $PM_{2.5}$ values were similar, while the maximum measurements observed varied significantly. These peaks are of particular concern, as even short exposure to high air pollution, as seen with these hotspots, can be very harmful to health.

TABLE 2
Summary Statistics for Mobile Sessions

	Mean	Median	Min	Max	SD	Minutes	Sessions
El Puente	9.87	8.39	0.68	121.45	6.89	1,454	31
Nos Quedamos	10.14	8.58	1.25	55.30	6.16	718	15
Park	11.00	12.68	2.80	24.75	5.56	215	5
THE POINT CDC	11.40	11.47	1.55	76.24	5.03	1,875	29
UPROSE	8.90	6.58	0.80	39.55	6.54	972	16

TABLE 3
Summary Statistics for Fixed Sessions

	Mean	Median	Min	Max	SD	Minutes	Sessions
El Puente	7.44	6.00	0.00	130.00	5.48	63,588	3
Nos Quedamos	7.94	7.00	0.00	270.00	6.42	48,923	1
Park	6.24	5.00	0.00	89.00	5.46	44,624	1
THE POINT CDC	8.49	8.00	0.00	117.00	5.78	94,022	3
UPROSE	7.97	7.00	0.00	195.00	5.99	84,299	3

Mobile Sessions

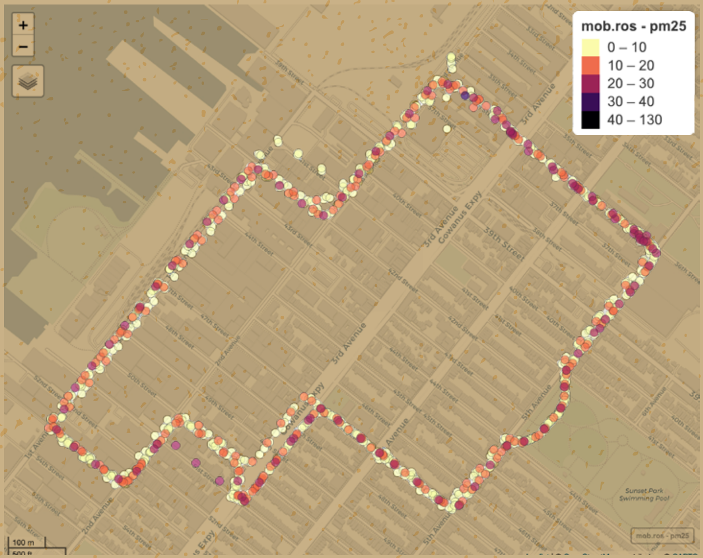
Data collected from all the raw mobile sessions are mapped in Figures 21–24. There were a few points outside the pre-established routes, but generally the data in the following maps reflect a specific route followed during all sessions recorded in each neighborhood over the course of the entire study period.

FIGURE 21
Route for Mobile Air Pollution Monitoring around THE POINT CDC, in the Hunts Point neighborhood in the Bronx

FIGURE 22
Route for Mobile Air Pollution Monitoring around Nos Quedamos, in the Melrose neighborhood in the Bronx

FIGURE 23
Route for Mobile Air Pollution Monitoring around El Puente, in the Williamsburg neighborhood in Brooklyn

FIGURE 24
Route for Mobile Air Pollution Monitoring around UPROSE, in the neighborhood of Sunset Park, Brooklyn



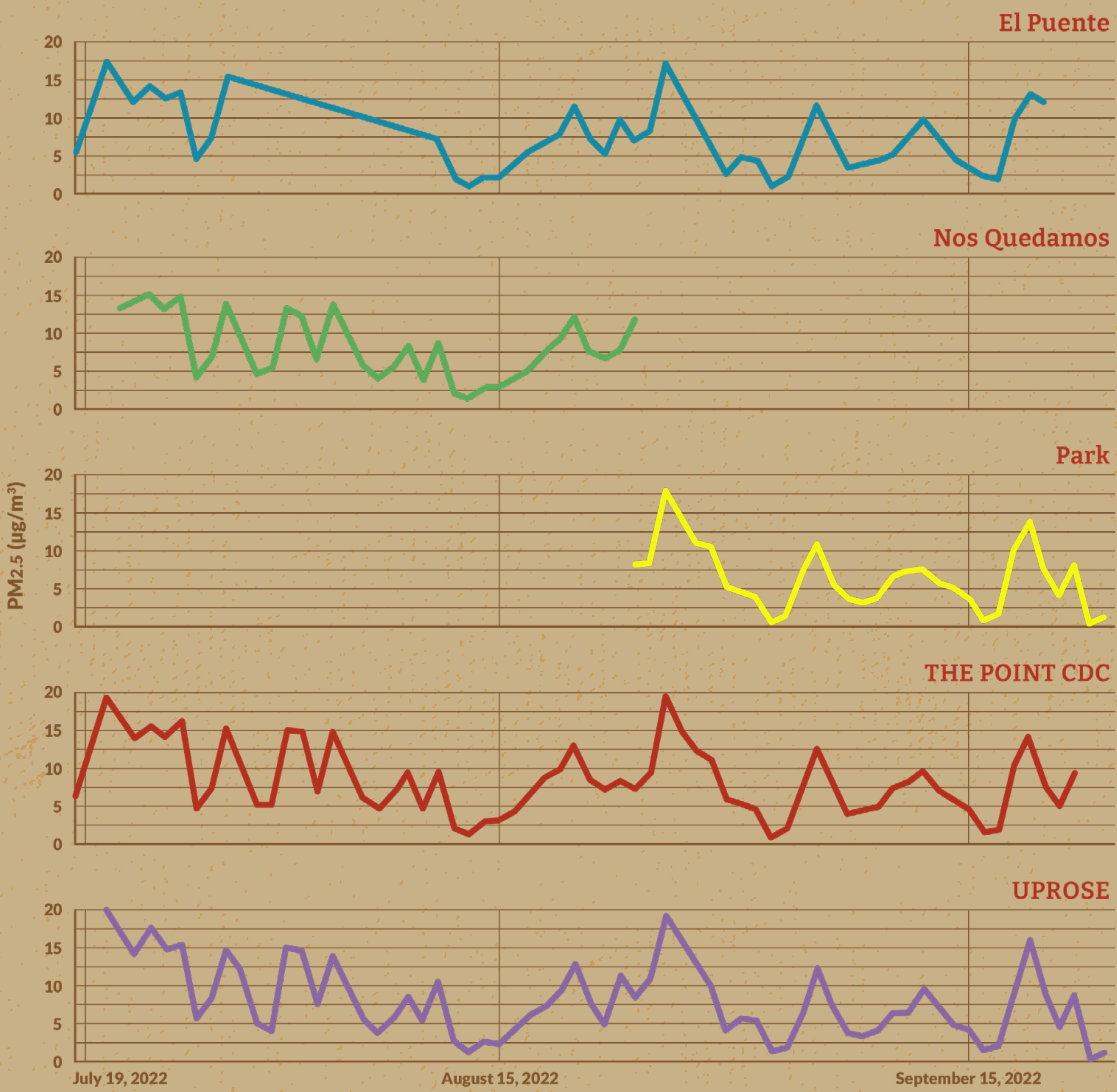
The number of mobile sampling sessions and the amount of data varied significantly by both location and hour. Table 4 provides a summary of the data. Most of the Nos Quedamos sessions were done in the morning, whereas other sessions were more evenly spread out. While this makes it difficult to compare neighborhoods, the sessions provide important information about each neighborhood and about differences in air quality by time of day. Mobile sessions observed very high values in some of the sessions, with values regularly above 20 $\mu g/m^3$ and going up to 121.45 $\mu g/m^3$. This kind of data collection can provide critical information about hotspots of air pollution and can also help communities identify sources of pollution in their area.

TABLE 4
Summary Statistics by Hour and Location for Mobile Sessions ($\mu g/m^3$)

	Hour	Mean	Median	Min	Max	SD	N
El Puente	10	10.48	10.60	2.38	19.41	5.04	87
	11	10.24	9.85	1.95	121.45	7.91	612
	12	10.44	11.84	2.98	19.48	6.73	36
	14	13.44	13.00	4.44	29.15	5.52	127
	15	9.07	7.02	0.68	27.78	6.15	498
	16	6.04	6.48	1.18	13.50	3.14	94
Nos Quedamos	10	8.70	7.72	1.25	55.30	5.64	310
	11	12.31	11.87	1.61	31.47	5.63	184
	14	9.20	6.28	2.12	25.36	6.52	182
	15	15.37	15.50	2.33	36.98	5.08	42
Park	10	24.75	24.75	24.75	24.75	–	1
	11	11.11	13.12	2.80	19.94	5.14	147
	12	10.55	6.44	3.68	19.86	6.22	67
THE POINT CDC	10	13.94	14.34	7.68	23.30	3.70	180
	11	11.96	12.47	1.55	32.40	4.28	671
	12	9.76	10.97	1.87	21.79	3.86	236
	14	8.83	8.53	1.71	20.00	3.77	259
	15	11.51	10.73	1.63	59.35	5.66	447
	16	13.41	9.26	7.67	76.24	9.42	82
UPROSE	10	7.33	3.98	1.43	21.10	5.92	111
	11	6.11	3.83	1.50	22.92	4.85	186
	14	11.26	9.05	0.95	26.89	7.68	143
	15	9.98	7.78	0.80	39.55	6.75	459
	16	7.03	7.12	2.85	21.02	3.22	73

The average $PM_{2.5}$ values per sampling session are shown in Figure 25. The overall daily average values ranged from 3 to 20 µg/m³. Again, it is difficult to compare and interpret these findings due to the uneven nature of the data collection.

FIGURE 25
Summary Statistics by Hour and Location for Mobile Sessions (µg/m³)



Fixed Sessions

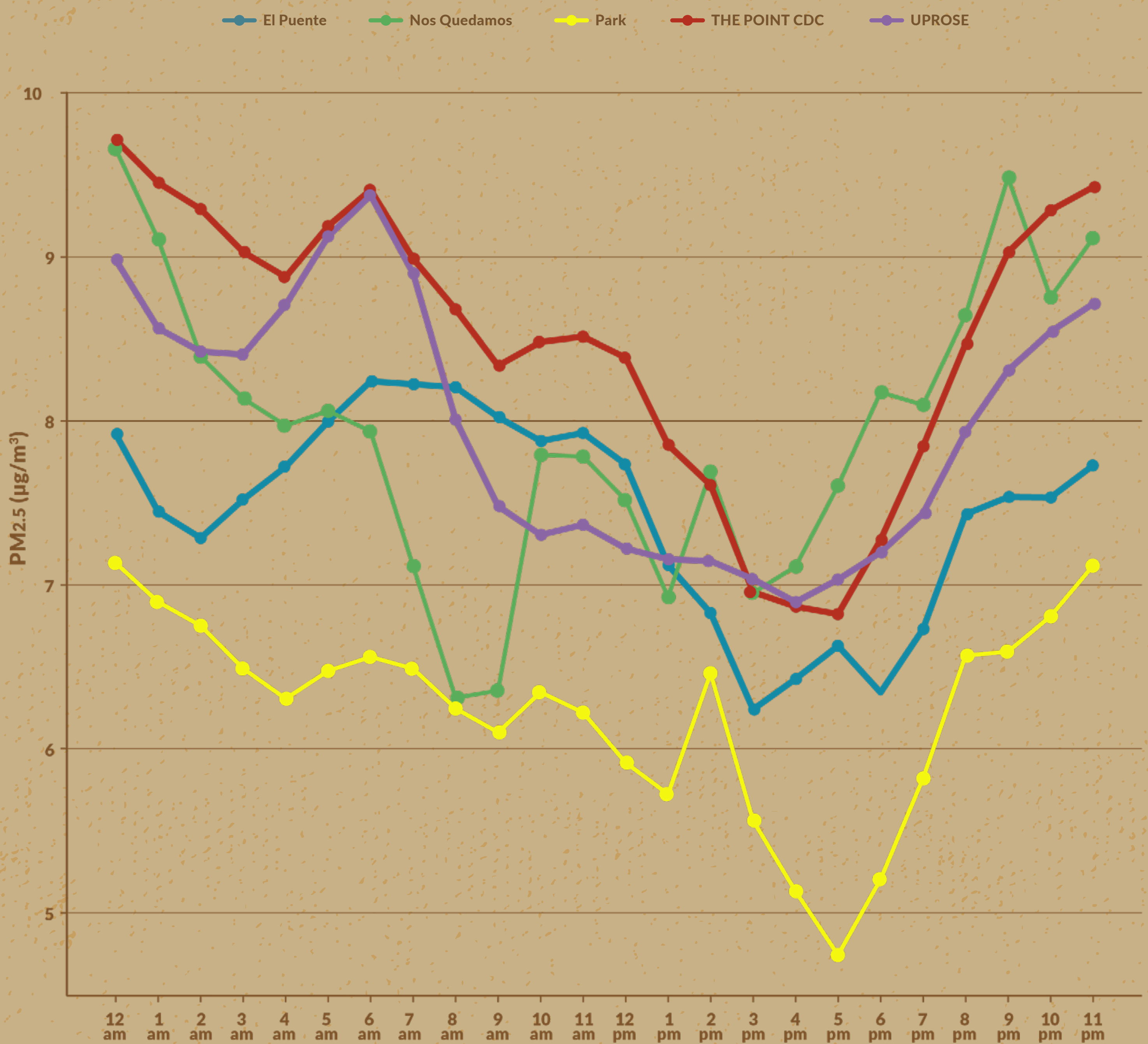
The fixed sessions showed clearer temporal and spatial trends than the mobile sessions due to near continuous monitoring. The results are summarized in Table 5 and Figure 26. Across most locations, the lowest values were observed in the afternoon. In general, the highest values were observed in the morning and late night. This suggests that traffic likely plays a prominent role in air pollution concentrations, as morning and evening rush hours and truck traffic from areas like the Hunts Point Food Market (which is busy with trucks late at night and early in the morning) intersect with these timeframes.

TABLE 5

Summary Statistics by Location and Time of Day for Fixed Sessions (µg/m^3)

	Hour Group	Mean	Median	Min	Max	SD
El Puente	12–6am	7.73	6	0	109	5.70
	6am–12pm	7.80	7	0	85	5.72
	12–6pm	6.60	6	0	103	4.84
	6pm–12am	7.39	6	0	130	5.52
Nos Quedamos	12–6am	8.47	8	0	70	5.65
	6am–12pm	7.14	6	0	270	6.68
	12–6pm	7.41	7	0	208	6.28
	6pm–12am	8.82	8	0	231	7.09
Park	12–6am	6.66	6	0	25	5.43
	6am–12pm	6.22	5	0	24	5.42
	12–6pm	5.47	4	0	89	5.36
	6pm–12am	6.58	5	0	53	5.56
THE POINT CDC	12–6am	9.28	8	0	62	6.14
	6am–12pm	8.56	8	0	31	5.58
	12–6pm	7.23	7	0	65	5.00
	6pm–12am	8.81	8	0	117	6.09
UPROSE	12–6am	8.80	8	0	62	6.42
	6am–12pm	7.71	6	0	195	5.82
	12–6pm	7.08	6	0	110	5.22
	6pm–12am	8.19	7	0	45	6.23

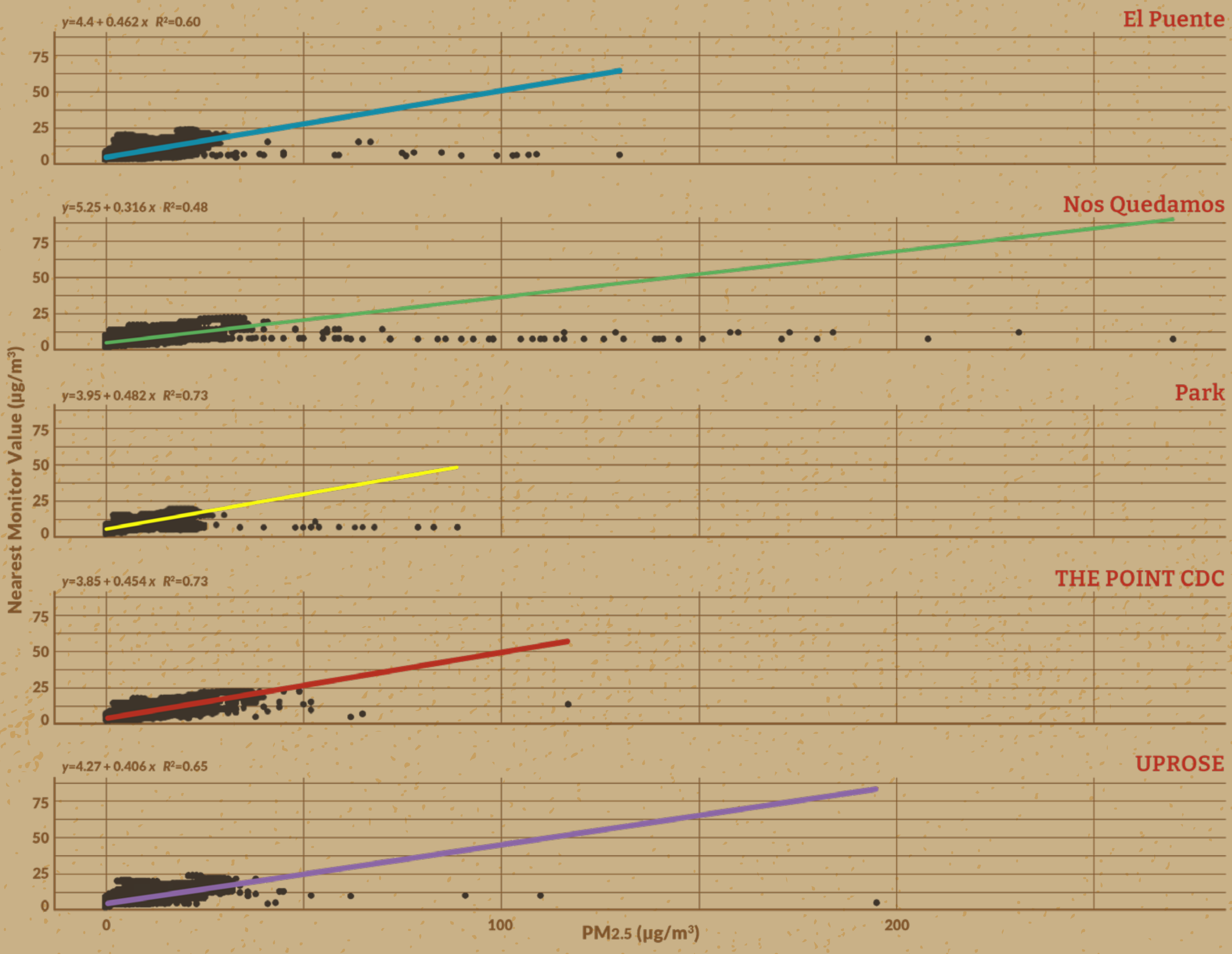
FIGURE 26
Mean $PM_{2.5}$ Hourly Values for Fixed Stations by Time of Day and Location



As shown in Figure 27, the agreement between fixed session values and closest DEC monitors was fairly high, with $R^2>0.6$ for most locations except for Nos Quedamos ($R^2=0.48$). The lowest measurement values were observed in the park, while the highest values were seen at THE POINT CDC. The plot also depicts that there can be very high discrepancies between sensor and reference monitor values, accounting for the finding that fixed sessions recorded values as high as 49x greater than the reference monitors. For example, when reference monitor values were low (<25 μg/m³), the AirBeam3 readings could reach up to >100 μg/m³, showing the importance of hyperlocal monitoring that can identify significant emission sources that impact communities. This discrepancy, however, could also be due to sensor outliers or distance between sensors and monitors, requiring caution with interpretation.

FIGURE 27

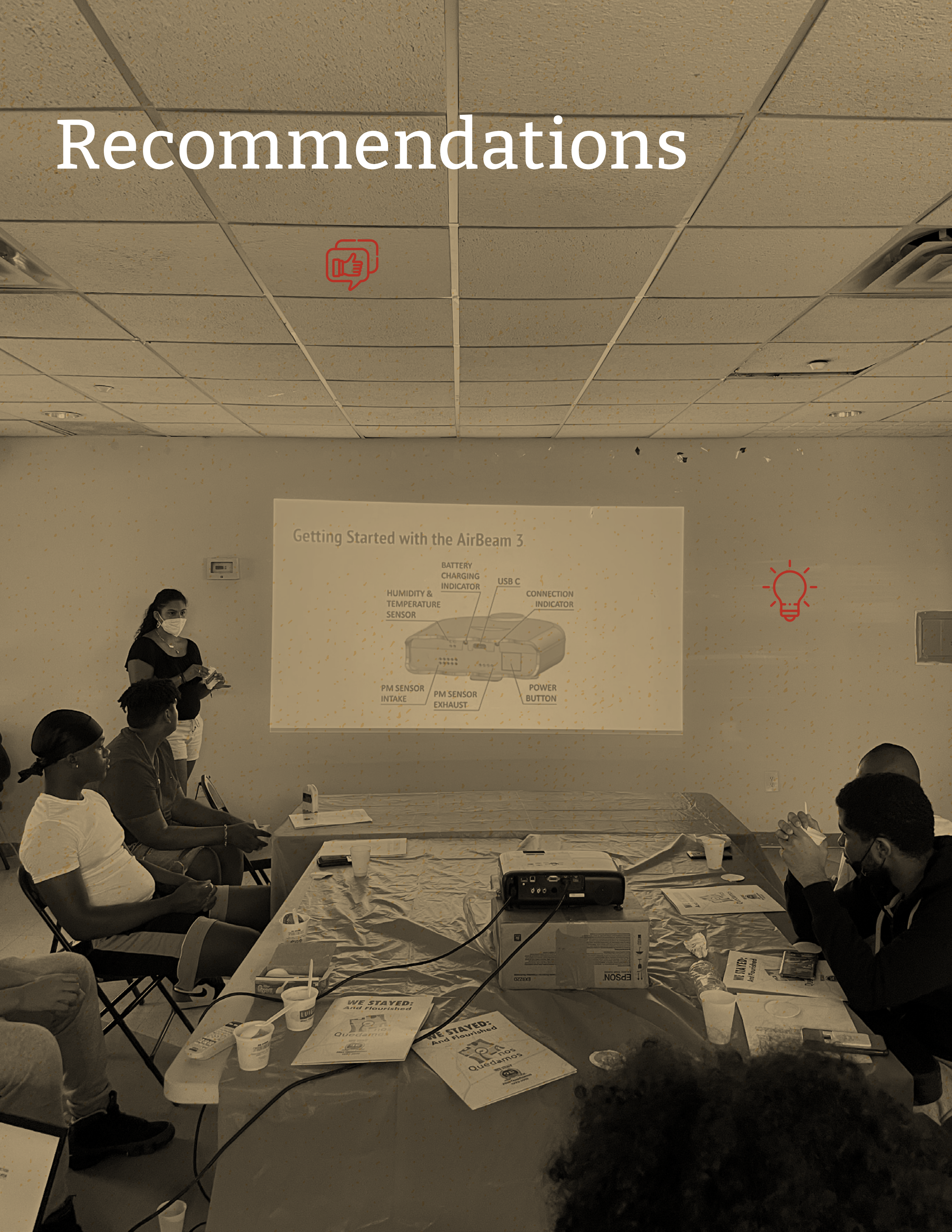
Stationary Values from This Study (x-axis) vs. Readings from the Nearest DEC Air Pollution Monitor (y-axis)



Source: Data for NYS DEC Monitors, NYS DEC (New York State Department of Environmental Conservation). 2024. DEC Air Monitoring Website. www.nyaqinow.net
El Puente was located 3.2 km away from the nearest DEC stationary monitor, while Nos Quedamos was 14.3 km from the nearest DEC monitor.

For additional information about the Air Pollution analysis methods, please see Appendix C

Recommendations



Based on the findings of this research and our ongoing work with NYC-EJA member communities, we offer the following recommendations to City and State policymakers, elected officials, and agency representatives. There are a myriad of concerns that need to be addressed, and we present a variety of adaptation and mitigation solutions that can be implemented as policies, capital projects, or community partnerships to address heat-related and air pollution risks, as well as other environmental justice and social objectives.

Heat-Related Policies

- Expand Cooling Center access: make more spaces (such as libraries, schools, community centers, senior centers, and faith-based institutions) with cooling facilities available to those in disadvantaged communities so they have a safe place to go when the weather is dangerous for health, decreasing the risk of poor health outcomes.
- Develop and implement a citywide long-term comprehensive extreme heat plan to monitor and evaluate heat mitigation measures to both assess and adjust to the increasing needs of at-risk populations and the associated climate risk. In addition, adjust existing and create new programs, policies, and projects in response to evaluation findings.
- Finalize, codify, and implement the NYS Extreme Heat Action Plan, including a dedicated, long-term funding stream to enable effective adoption, as well as comprehensive heat mortality reporting.
- Develop and implement a maximum indoor temperature policy that ensures residents have access to cooling solutions in their homes during the warm months.
- Reduce the energy burden for low- and moderate-income households so that they are able to access and use cooling technology (e.g., expand the NYS Home Energy Assistance Program, HEAP, to assist low-income households by subsidizing energy bills).
- Expand NYC CoolRoofs and pavements: use materials that reflect more solar radiation and evaporate water faster to reduce surface and ambient temperatures and help with water management, especially if pavement materials are permeable and allow water to be absorbed by the ground instead of running off to storm sewers.[37]
- Implement social safety net infrastructure (such as the Be A Buddy Program) in partnership with existing CBOs to improve community cohesion and investment.[38]
- Develop and enact worker health and safety protections for both indoor and outdoor workers in relation to hot weather conditions.
- Expand, and make more accessible, heat mitigation solutions like “cool corridors”.
- Increase public awareness about heat-related risks and how to avoid related negative health outcomes.

Air Quality–Related Policies

- Advocate for the NYS DEC CAM initiative to incorporate the findings of this report and commit to working with NYC-EJA member organizations on local hotspot mitigation initiatives.
- Institute “Spare the Air Days” and improve planning and communication around air quality emergencies and concerns.[39]

- Improve and enact transportation sector policies, including investing and expanding public mass transit, electrifying vehicles and expanding charging infrastructure (e.g., convert bus fleet to all electric), increasing non-motorized forms of transit, and reducing e-commerce–related air pollution.
- Develop and enact outdoor worker health and safety protections in relation to air quality emergencies.

Policies with Combined Benefits

- Increase investments to expand, protect, and manage vegetation cover, as planting trees and other vegetation helps reduce the urban heat island effect, improves air quality, and helps with stormwater/combined sewer overflow management.
  - Equitably reach 30% canopy cover across NYC by 2035.
- Incentivize green roofs, which can reduce indoor building temperatures, reduce energy use, help with stormwater management, and help mitigate carbon emissions and other air pollutants from energy generation.
- Implement and deploy targeted clean energy policies and investments: make an overall shift to renewable energy, shut down fossil fuel–based peaker power plants, decarbonize our most polluting sectors, expand renewable energy and battery storage, develop universal energy demand management, etc.
- Invest in urban farms: agricultural activities in cities can help reduce local temperatures by adding vegetation and changing microclimates, as well as helping communities produce additional/more nutritional food and providing additional incomes and jobs.

While all of the abovementioned strategies are important and useful pieces of the puzzle to achieve meaningful mitigation of heat and air quality concerns, we explain a few of NYC-EJA's highest priorities in-depth below.

Green Infrastructure Policy

As previously noted in the findings section, vegetation and green infrastructure are important indicators of community heat resilience. In addition, they can actively decrease the effects of UHI and improve air quality. We also found that vegetation cover differs significantly between EJ neighborhoods, including those where NYC-EJA member organizations operate, and the rest of the city. Adopting more green infrastructure (GI) projects, like the projects included in NYC's Green Infrastructure Program, in these neighborhoods could reduce these differences and ensure a more equitable distribution of benefits.

GI policies have been adopted in NYC to varying degrees. The current status of projects is viewable on the Green Infrastructure Map, which allows users to "find green infrastructure (GI) practices in NYC neighborhoods." [40] The GI projects in this portal are designed to address water management issues related to runoff and combined sewer overflows. For example, some of these projects collect stormwater from various hard surfaces before it can cause flooding and overwhelm the sewer system.[40]

Given the potential benefits of GI projects, it is worth examining their geographical distribution to assess whether certain areas with heat-vulnerable populations lack such projects. Sunset Park in Brooklyn, for example, has a high HVI score and lacks GI projects that could help address resilience to heat. From a policy perspective, it would be good to use GI projects to address multiple objectives, including heat risks. That said, there can be challenges with introducing new vegetation; for example, allergen-associated asthma, attributed to certain trees, can have negative impacts on residents. Like many strategies, vegetation is not a perfect solution on its own. But selecting species with care can help optimize outcomes, and multiple benefits that can be realized with vegetation: heat mitigation, biodiversity, cleaner air, improved mental health, and more. It is also important to ensure that local perspectives and concerns are represented in policy; the communities with whom NYC-EJA members work have called for increased vegetation, green infrastructure, and natural spaces.

In our advocacy, as part of the Forest For All NYC (FFANYC) coalition, we are pushing a goal of reaching 30% tree canopy cover equitably across NYC by 2035. The goal for increasing canopy equitably to 30% is now codified in legislation we supported, Local Law 148 of 2023, which also requires development of a NYC Urban Forest Plan and regular monitoring, although no time horizon was defined. The emphasis on equity is critical to ensure that EJ communities receive investments that can help expand canopy, without causing unintended consequences like green gentrification. Evidence shows that reaching the 30% canopy threshold has a tangible beneficial impact on heat mitigation efforts.

Water features, including drinking water fountains, sprinklers, and other outdoor water features for recreation and outdoor pools, along with parks and green areas, can also help communities mitigate the impacts of heat. The NYC Department of Parks and Recreation has created a map that combines the location of such features with vegetation cover and social vulnerability. This is an additional resource that can be used to ensure that neighborhoods with high heat vulnerability are prioritized for additional water features. Detailed temperature measurements, such as the ones conducted by CAPA Strategies and described in previous sections of this report, are also instrumental to help policymakers identify where these kinds of water features are most needed. We recommend an expansion of hyperlocal heat and humidity monitoring to better characterize these vulnerabilities and to help with resilience planning moving forward.

Heat Policy

One of NYC-EJA's goals is to greatly improve the City and State's response to heat during the warm months. These hot conditions are increasing in severity, and we want to ensure that NYC is adequately prepared for the risks. We view this from the lens of several key pieces of policy that we hope to formalize as legislation, at the local and state levels.

One clear and immediate need is the improvement and expansion of cooling centers. Several of the most disadvantaged areas of NYC have the fewest number of cooling centers available to their residents,[41] who are also at highest risk of negative health impacts and most likely to lack air conditioning (or the means to use it) in their homes. Having a cooling center nearby would be especially beneficial to the elderly and those with mobility issues who may find it difficult to reach existing centers. In addition, cooling centers lack dedicated funding and have limited oversight from the City (particularly with recent proposed City budget cuts that have forced many buildings that often function as cooling centers, such as libraries, to decrease their already limited hours). These challenges leave a lot of room to improve the way cooling centers currently function and are distributed. Meanwhile, the State does not require cooling centers to be made available, but leaves it up to the discretion of the local municipalities, meaning that many parts of the state have no formal cooling centers at all.

In addition, we are advocating for the adoption of a maximum indoor temperature policy at the city (and eventually at the state) level. Similar to the winter's minimum indoor temperature law, which ensures that residents have the means to stay warm during the cold months, EJ advocates would like to see a counterpart in the warm months to mitigate negative heat-related health impacts.

A natural step to enable such a policy to be effective and equitable is to increase funding for the NYS Home Energy Assistance Program (HEAP) and expand its usage to offer low- and moderate-income households utility assistance during the summer months. In addition, HEAP should include energy-efficient technology like heat pumps as allowable equipment under the program. Historically, this program has primarily been used for winter energy burden relief.

Finally, we would like to see comprehensive heat action plans at both the City and State levels created and codified into law, with dedicated funding sources to implement them. One of the issues with heat preparedness and protection for residents is a lack of organized, pre-planned, response structures that address the needs and concerns of the community, particularly those who are most at risk in disadvantaged parts of the city and state.

Energy Policy

The need for increased electrification of the transportation and building sectors in NYS will increase demand on the electricity grid over the next two decades. Meanwhile, the energy sector itself is already seeing challenges toward achieving the state's mandate of zero-emissions by 2040. The constraints on New York's energy grid also mean that most of upstate has already shifted away from fossil fuel power generation, while population centers like NYC remain heavily dependent on fossil fuels.[42, 43, 44] NYC is home to some of the state's oldest, most polluting, and least efficient power plants. At the same time, the state has repeatedly demonstrated the technical capability of replacing our existing fossil fuel–based grid with renewable energy and battery storage.

In the near term, utility-scale battery storage development is the most effective way of transitioning fossil fuel power plants with low capacity factors or reducing power plant emissions through hybridization, although complete replacement must be pursued over hybridization for peakers whenever technically feasible. While renewable energy generation like solar and wind has already received multiple rounds of certificates to lower cost and incentivize production, the same has not been done for energy storage. NYSERDA should commence solicitations for battery storage as soon as possible, prioritizing mature projects located near EJ communities. New solicitations for renewable energy should also come with mandates for energy storage development in order to minimize curtailment or intermittency, especially for the offshore wind sector.

Even with the benefits of battery storage, the state still needs a lot more renewable energy generation. Multiple contract cancellations of solar, onshore wind, and offshore wind projects in 2023 signal previous failures to adequately assess and award renewable energy development. Although adjustments have been implemented since 2019, the emphasis on project cost over project maturity and EJ benefits continues to incentivize developers to focus on profit instead of on energy development mandates, putting CLCPA obligations in danger. To socialize project costs without increasing energy burden, we need policies in the state budget process, proceeds from the cap-trade-and-invest program, federal funding opportunities, and public authority securities. With the New York Power Authority's (NYPA's) new ability to develop and operate renewables, and the anticipated public takeover of the Long Island Power Authority (LIPA), NYSERDA, NYPA, and LIPA can unlock tremendous funding and development potential to ensure adequate buildout of a renewable energy grid.

As the electrification of other sectors continues, an energy policy that focuses on realizing a zero-emissions supply side can only be achieved with responsible management of demand. Currently, high energy–consumption areas of New York do not have any form of large-scale demand response programs. Although pilot projects have been implemented in the past, such as the Brooklyn-Queens Demand Management program, new demand response and efficiency measures must be rapidly deployed. Ordering utilities to implement municipal opt-out demand response programs can have a tremendous impact on ensuring that electrifying buildings, transportation, and industries will not have a negative effect on parallel efforts to clean up the grid. These new programs, in combination with investments in new demand technologies such as virtual power plants, can enable emissions reductions from the energy sector, especially in disadvantaged communities, in the short term and enable a successful full transition to zero-emissions in the long term.

Transportation Policy

Transportation policy can have a significant impact on air quality in dense urban areas such as NYC, since vehicular traffic is a major source of $PM_{2.5}$. In addition, the dense network of streets and highways in NYC contributes to the UHI effect, since materials such as asphalt readily absorb energy from the sun and convert it to heat, which warms the air around these infrastructure systems. Transportation systems and infrastructure can also be severely affected by extreme weather events like heat waves that can damage streets and other transportation infrastructure.

There are a number of approaches to reduce traffic-related pollution. For example, congestion pricing was an initiative that was ready to be implemented by the Metropolitan Transportation Authority (MTA) in NYC, starting June 30, 2024, until the Governor recently announced its indefinite delay. The main goal was to reduce vehicular traffic congestion in mid- and lower-Manhattan, by charging vehicles that enter Manhattan below 60th Street a fee. The fee would constitute an economic disincentive to driving into the central business district and potentially reduce traffic-related air pollution. In addition, the revenue raised from congestion pricing would be a dedicated funding stream for MTA capital projects, such as bus electrification, and community improvements, including green infrastructure, that address both air quality and heat-related health risks. Funds generated by congestion pricing would also be prioritized for transit projects that will improve air quality in EJ communities. Embedded in the final federal government approved environmental assessment is a regional and place-based mitigation plan by the MTA and other program sponsors which included commitments such as replacing up to 1,000 diesel-operated transport refrigeration units, establishing an asthma case management program and Bronx center, and funding for electric trucks and electric vehicle chargers to ensure there are no hotspots of air pollution in EJ communities, like the South Bronx. Given Governor Hochul's recent, egregious announcement to delay congestion pricing indefinitely, dedicated funding for scheduled and future MTA capital projects, along with traffic congestion and emissions reduction measures, hang in the balance.

Another approach to significantly improve air quality through the transportation sector is promoting the use of electric vehicles. Electric vehicles do not emit $PM_{2.5}$ from tailpipe emissions. To that end, NYS has adopted targets to increase the share of electricity generated from renewable sources of energy, which would reduce the air pollution emissions associated with generating electricity for electric vehicles. Advances in battery technology now allow large vehicles such as buses to run on electricity. Although even buses that depend on fossil fuels tend to emit less air pollution per rider than single occupancy vehicles, they can still be significant sources of $PM_{2.5}$. Therefore, switching to electric buses can significantly improve air quality, especially in neighborhoods where bus depots are located and where communities rely heavily on buses.

The MTA aims to convert its entire bus fleet to all-electric by 2040. Between now and 2040, local policies should prioritize the use of electric buses on routes with high levels of air pollution, including in EJ communities. Localized air quality monitoring with input from communities, such as monitoring using AirBeams as described in this report, could help identify areas where adopting electric buses would be most beneficial. Another strategic approach could be to convert buses that use bus depots located in EJ communities to electric buses and provide adequate charging infrastructure.

Promoting non-motorized and more environmentally friendly forms of transportation, such as walking, bicycling, using electric vehicles, and taking mass transit, can lead to improved air quality in addition to other public health benefits. As NYC continues to make progress in this area, ensuring that streets are safe for pedestrians and cyclists, including green infrastructure and promoting these alternatives to driving in EJ neighborhoods should be a priority. Expanding rail and other modes of public transit can reduce total vehicle miles traveled and car dependency, thus reducing tailpipe emissions.

Furthermore, promoting zero-emission and non-truck modes of delivery transportation can also help improve air quality. Due to a recent rise in e-commerce in the last decade, NYC has experienced an increase in unregulated siting and operation of last-mile warehouses. To meet the demands of next- and same-day shipping, these facilities require hundreds or thousands of truck trips per day. The recent NYC Community Air Survey report from the NYC DOHMH and Queens College of the City University of New York highlights that citywide, annual average levels of four key pollutants ($PM_{2.5}$, NO, NO2, and SO2) have gone down between 2009 and 2021. However, the report also indicates that in the most recent years of data collection, neighborhoods that have a higher density of warehouses with loading docks in industrial areas are still experiencing higher levels of pollution. Updating our zoning regulations to address the siting, operation, and clustering of these last-mile facilities can advance cleaner modes of delivery and protect our communities.

Conclusion

Excessive heat and air pollution are two risk factors that can have severe negative public health consequences in NYC. Heat waves are deadly extreme weather events that are projected to increase over time as climate change intensifies, while mortality rates related to excessive heat disproportionately impact communities of color and low-income New Yorkers. Similarly, air pollutants such as fine particulate matter ($PM_{2.5}$) emitted from vehicles, energy generation infrastructure, and the burning of fossil fuels increase the risk of respiratory and heart disease, as well as other public health issues. These two risk factors are linked. According to the literature, fine particulate matter ($PM_{2.5}$) is often correlated with temperature because they have similar drivers.[1,45] For example, when temperatures increase, demand for electricity goes up, leading to higher levels of air pollution from fossil fuel power plants. Similarly, when temperatures rise, the risk of wildfires, a significant cause of air pollution, also increases. Elevated exposures to both air pollution and temperature can have an interactive impact on health outcomes.[1] The main findings of this report indicate that some of the most vulnerable communities in NYC–DACs and areas with high Heat Vulnerability Index values–are also the most impacted by heat and air pollution.

NYC-EJA has been actively advocating for the implementation of policies in NYC that reduce these risks, with a particular emphasis on neighborhoods that have been historically disadvantaged by burdens of high pollutant emissions and a lack of services and amenities to reduce environmental health risks. As part of these efforts, NYC-EJA has worked with experts to provide new environmental data and new ways to analyze this data to examine important geographical differences in the risks faced by residents in disadvantaged neighborhoods. The new spatial and temporal data and analyses related to heat and air pollution presented in this report can be used in conjunction with risk identification tools such as the NYS DAC Criteria and the Heat Vulnerability Index discussed in the Introduction of the report, to identify priority areas and communities where the policies and recommendations discussed can be implemented.

CHAMP-EJ illustrates the value of community-led data gathering and analysis in addressing environmental justice concerns in NYC. The analysis in this report underscores the need for continued hyperlocal air and heat data collection, which is imperative to inform policy and intentionally improve health outcomes in frontline communities. This type of grassroots hyperlocal data gathering can both address gaps in official data collection by the City or State, and give communities the data and information to advocate for needed investments in their neighborhoods.

References

[1] Rahman, M.M., R. McConnell, H. Schlaerth, J. Ko, S. Silva, F.W. Lurmann, L. Palinkas, J. Johnston, M. Hurlburt, H. Yin, G. Ban-Weiss, and E. Garcia. 2022. The effects of co-exposure to extremes of heat and particulate air pollution on mortality in California: implications for climate change. *American Journal of Respiratory Critical Care Medicine*.

[2] NYC. 2023. 2023 NYC Heat-Related Mortality Report. (Access date: May 17, 2024)
Link ↗

[3] NWS (National Weather Service). 2024. National Weather Service New York, NY Excessive Heat Page. (Access date: April 9, 2024)
Link ↗

[4] IPCC (Intergovernmental Panel on Climate Change). 2023. Synthesis Report of the IPCC Sixth Assessment Report (AR6). Summary for Policymakers. (Access date: May 10, 2023)
Link ↗

[5] EPA (U.S. Environmental Protection Agency). 2016. Heat Island Effect. (Access date: May 10, 2023)
Link ↗

[6] EPA (U.S. Environmental Protection Agency). 2023. Health and Environmental Effects of Particulate Matter (PM)
Link ↗

[7] CalEPA (California Environmental Protection Agency). 2023. Understanding the Urban Heat Island Index.
Link ↗

[8] Climate Central. 2023. Urban Heat Hot Spots.
Link ↗

[9] CDC (Centers for Disease Control and Prevention). 2023a. Heat & Health Tracker.
Link ↗

[10] New York City Council. 2020. A local law to amend the administrative code of the city of New York, in relation to annual reporting of heat vulnerability and heat-related deaths. Law number: 2020/084.
Link ↗

[11] NYC Health. 2023. 2023 New York City Heat-Related Mortality Report.
Link ↗

[12] Braneon, C., L. Ortiz, D. Bader, N. Devineni, P. Orton, B. Rosenzweig, T. McPhearson, L. Smalls-Mantey, V. Gornitz, T. Mayo, S. Kadam, H. Sheerazi, E. Glenn, L. Yoon, A. Derras-Chouk, J. Towers, R. Leichenko, D. Balk, P. Marcotullio, and R. Horton. 2024. NYC climate risk information 2022: Observations and projections. Interim Report for Public Release.
Link ↗

[13] Lamie, C., D. Bader, K. Graziano, R. Horton, K. John, N. O'Hern, and S. Spungin. 2024. Chapter 2: New York State's changing climate. In New York State Climate Impacts Assessment [Interim version for public release].

[14] DEC (New York State Department of Environmental Conservation). 2023. Division of Air Resources, Community Air Monitoring Initiative 2022-2023, Mobile Air Monitoring.
Link ↗

DEC (New York State Department of Environmental Conservation). 2023. New York State's Draft Disadvantaged Community Criteria.
Link ↗

[15] New York City Department of Health and Mental Hygiene, 2023. New York City Community Air Survey (NYCCAS): Neighborhood Air Quality 2008–2019.
Link ↗

[16] NIH (National Institutes of Health). Air Pollution and Youth Health. (Access date: May 17, 2024)
Link ↗

[17] WHO (World Health Organization). 2022. Ambient (outdoor) air pollution.
Link ↗

[18] DOHMH (New York City Department of Health and Mental Hygiene). 2022. Real-Time Air Quality: $PM_{2.5}$ in NYC. (Access date: May 17, 2024)
Link ↗

[19] EPA (U.S. Environmental Protection Agency). 2024. Climate Change Impacts on Air Quality. (Access date: May 17, 2024)
Link ↗

[20] Public Advocate. 2023. Orange Sky, Red Alert: A Review of Air Quality Emergencies in New York City. (Access date: May 17, 2024)
Link ↗

[21] AirNow. What Is the AQI? (Access date: May 17, 2024)
Link ↗

[22] NWS (National Weather Service). Air Quality Index. (Access date: May 17, 2024)
Link ↗

[23] EPA (U.S. Environmental Protection Agency). 2023. Using Cool Pavements to Reduce Heat Islands.
Link ↗

U.S. EPA (U.S. Environmental Protection Agency). 2023. Climate Change Indicators: Heat Waves. (Access date: May 10, 2023)
Link ↗

[24] Coomes, K.E., J.J. Buonocore, J.I. Levy, C. Arter, S. Arunachalam, L. Buckley, A. Berberian, J. Gunasti, and F. Perera. 2022. Assessment of the health benefits to children of a transportation climate policy in New York City. *Environmental Research* 215 (2022) 114165.
Link ↗

[25] Perera, F., and K. Nadeau. 2022. Climate Change, Fossil-Fuel Pollution, and Children's Health. *The New England Journal of Medicine*. 386: 2303–2314. DOI: 10.1056/NEJMra2117706

[26] EPA (U.S. Environmental Protection Agency). 2023. Fine Particulate Matter. (Access date: May 17, 2024)
Link ↗

[27] EPA. 2024. NAAQS Table.
Link ↗

[28] Hayes, R.B., C. Lim, Y. Zhang, K. Cromar, Y. Shao, H.R. Reynolds, D.T. Silverman, R.R. Jones, Y. Park, M. Jerrett, and J. Ahn. 2020. $PM_{2.5}$ air pollution and cause-specific cardiovascular disease mortality. *International Journal of Epidemiology*. Feb 1; 49(1): 25–35.

[29] WHO (World Health Organization). 2021. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.
Link ↗

[30] American Lung Association. 2023. Particle Pollution.
Link ↗

[31] NYS DEC (New York State Department of Environmental Conservation). 2023.

[32] CAPA Strategies, LLC. 2021. Heat Watch Report. Bronx and Manhattan, New York.

[33] CAPA Strategies, LLC. 2022. Heat Watch Report. Brooklyn and Lower Manhattan, New York.

[34] NYC DOHMH (New York CIty Department of Health and Mental Hygiene). Interactive Heat Vulnerability Index.
Link ↗

References

[35] Johnson, S., Z. Ross, I. Kheirbek, and K. Ito. 2020. Characterization of intra-urban spatial variation in observed summer ambient temperature from the New York City Community Air Survey. *ScienceDirect.* Urban Climate. 31.
Link ↗

[36] Treglia, M.L., N.C. Piland, K. Leu, A. Van Slooten, and E.N. Maxwell. 2022. Understanding opportunities for urban forest expansion to inform goals: working toward a virtuous cycle in New York City. *Frontiers in Sustainable Cities* 4:944823. doi: 10.3389/frsc.2022.944823

[37] MOCEJ (Mayor's Office of Climate and Environmental Justice). 2024. NYC CoolRoofs
Link ↗

[38] MOCEJ (Mayor's Office of Climate and Environmental Justice). 2024. Be a Buddy: A Community-Based Climate Resiliency Model.
Link ↗

[39] The New York City Council. Intro 1199-2023.
Link ↗

[40] NYC DEP (Department of Environmental Protection). 2023. Green Infrastructure Program Map.
Link ↗

[41] NYC Comptroller. 2022. Overheated, underserved: Expanding cooling center access. New York City Comptroller Brad Lander. August 4, 2022.
Link ↗

[42] Jones, Brad. 2017. A Tale of Two Grids: Bridging New York's Renewable Energy Divide. Crain's New York Business. May 19, 2017.
Link ↗

[43] Casey, Christopher. 2020. NRDC Sues FERC Over Orders That Threaten NY Clean Energy. NRDC Expert Blog. June 30, 2020.
Link ↗

[44] 2020 Load & Capacity Data Report. 2020. New York Independent System Operator.

[45] Amos, P.K. Tai, L.J. Mickley, and D.J. Jacob. 2010. "Correlations between fine particulate matter ($PM_{2.5}$) and meteorological variables in the United States: Implications for the sensitivity of $PM_{2.5}$ to climate change," *Atmospheric Environment* 44: 3976-3984.

Additional Sources

CDC (Centers for Disease Control and Prevention). 2023b. CDC/ATSDR SVI Data and Documentation Download. Agency for Toxic Substances and Disease Registry.
Link ↗

EPA (U.S. Environmental Protection Agency). 2008. Reducing Urban Heat Islands: Compendium of Strategies. Draft.
Link ↗

EPA (U.S. Environmental Protection Agency). 2024. Heat Island Effect.
Link ↗

González, J.E., L. Ortiz, B.K. Smith, N. Devineni, B. Colle, J.F. Booth, A. Ravindranath, L. Rivera, R. Horton, K. Towey, Y. Kushnir, D. Manley, D. Bader, and C. Rosenzweig. 2019. New York City Panel on Climate Change 2019 Report Chapter 2: New Methods for Assessing Extreme Temperatures, Heavy Downpours, and Drought. *Annals of the New York Academy of Sciences.* Special Issue: Advancing Tools and Methods for Flexible Adaptation Pathways and Science Policy Integration. 1439 (1):30–70.
Link ↗

HabitatMap. 2022. AirCasting is an open-source environmental data visualization platform that consists of a smartphone app and online mapping system.
Link ↗

HabitatMap. 2023. Taking Matter into Your Own Hands: About AirBeam.
Link ↗

Kheirbek, I., K. Wheeler, S. Walters, G. Pezeshki, and D. Kass. 2010. NYC Department of Health and Mental Hygiene. Air Pollution and the Health of New Yorkers: The Impact of Fine Particles and Ozone
Link ↗

NWS (National Weather Service). 2023. During a Heat Wave. Safety National Program. (Access date: May 10, 2023)
Link ↗

NYC DOHMH (New York City Department of Health and Mental Hygiene). Environment and Health Data Portal. Understand How Environments Shape Health in New York City.
Link ↗

NYS DEC (New York State Department of Environmental Conservation). 2002. Bureau of Air Quality Surveillance Division of Air Resources. Ambient Air Quality Report 2022.
Link ↗

NYS DEC (New York State Department of Environmental Conservation). 2024. DEC Air Monitoring.
Link ↗

Treglia, M.L., N.C. Piland, K. Leu, A. Van Slooten, and E.N. Maxwell. 2022. Practical Canopy for New York City—Data Layer and Summarized Results [Data set]. Zenodo. doi: 10.5281/zenodo.6547492

WHO (World Health Organization). 2023. Heatwaves. Overview. (Access date: May 10, 2023)
Link ↗

Appendix A

NYS $PM_{2.5}$ Concentrations (2020–2023)

	Site	Monitor Type	2020 Mean (µg/m³)	2021 Mean (µg/m³)	2022 Mean (µg/m³)	3-yr Average Annual Mean (µg/m³)
Manhattan	IS 45	Filter	7	7.5	6.9	7.1
	IS 143	Continuous	7.3	7.9	7.5	7.6
	CCNY	Continuous	6.3	7	6.1	6.5
Bronx	IS 52	Filter	6.7	7.5	6.6	6.9
	IS 52	Continuous	8.3	9	8	8.5
	Morrisania	Continuous	5.8	6.6	6.1	6.2
	NYBG	Filter	7	7.1	6.9	7
Queens	Maspeth	Continuous	5.6	6.4	5.9	5.9
	Queens	Continuous	5.6	8.9	8.9	7.8
	Queens	Filter	6.9	7.1	6.3	6.8
	Queens NR	Continuous	6.6	7.5	6.8	6.9
	Queens NR	Filter	7.4	7.7	7	7.4
Brooklyn	JHS 126	Filter	7.3	7.6	7.3	7.4
	PS 274	Continuous	5.5	7.6	8	7
	PS 314	Continuous	5.5	8.2	8	7.2
Staten Island	Freshkills	Continuous	5.9	6.6	5.8	6.1
	Port Richmond	Continuous	5.9	6.8	6.1	6.3
	Port Richmond	Filter	7.7	8.4	6.8	7.6

Source: *New York State Department of Environmental Conservation (NYS DEC). Bureau of Air Quality Surveillance Division of Air Resources. Ambient Air Quality Report 2022. www.dec.ny.gov/docs/air_pdf/2022airqualreport.pdf*

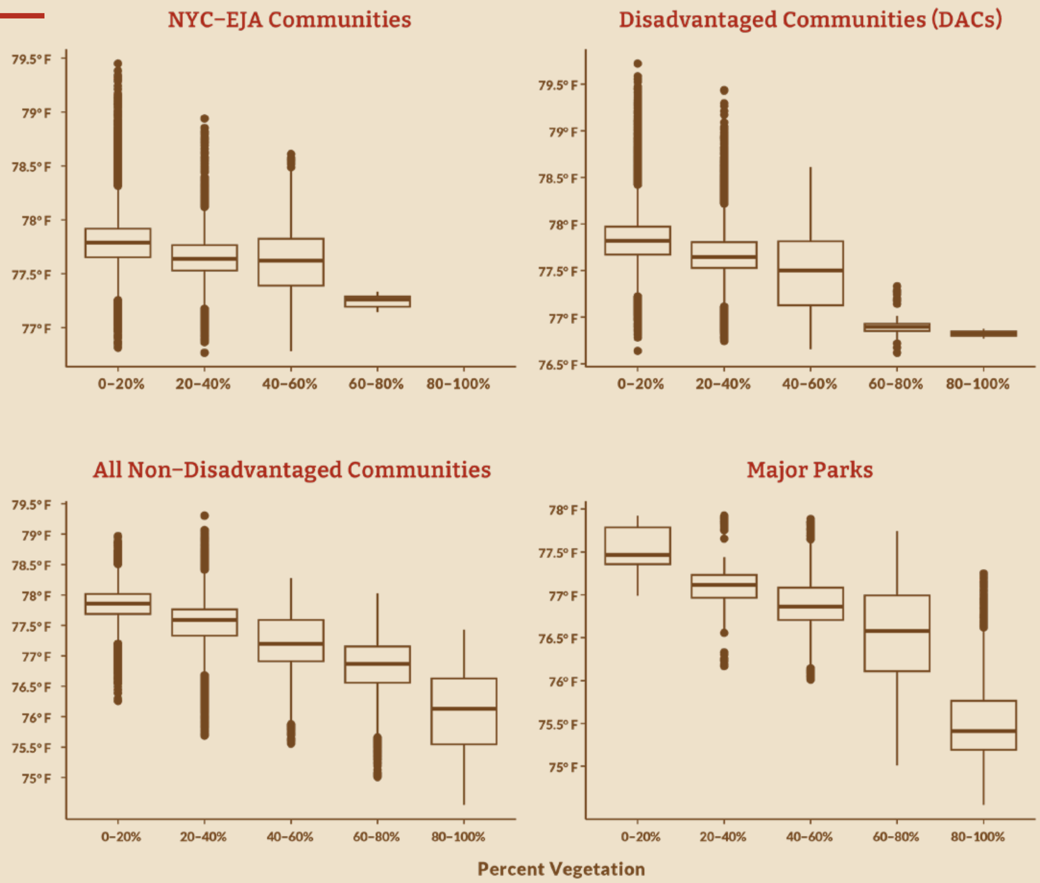
Appendix B

Additional Heat Analysis and Figures

Vegetation Distribution Statistics (%)

Designation	Median	Mean	Min	Max	SD
NYC-EJA Communities	16.9	17.7	0	75.7	10.7
Disadvantaged Communities (DACs)	23.7	28.5	0	100	19.5
All Non-Disadvantaged Communities	38.7	42.5	0	100	23.8
Major Parks	73.5	69.6	0	100	21.6

FIGURE A
Distribution of Temperature by Percent Vegetation Cover for Brooklyn and Lower Manhattan, AM



Appendix B

Additional Heat Analysis and Figures

FIGURE B
Distribution of Temperature by Percent Vegetation Cover for Brooklyn and Lower Manhattan, AM

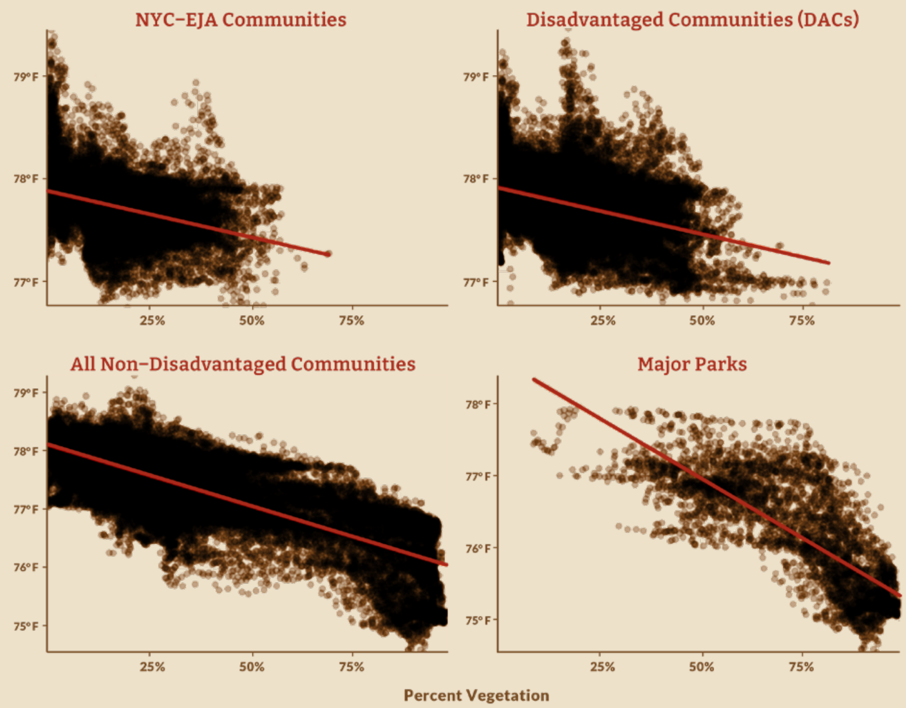
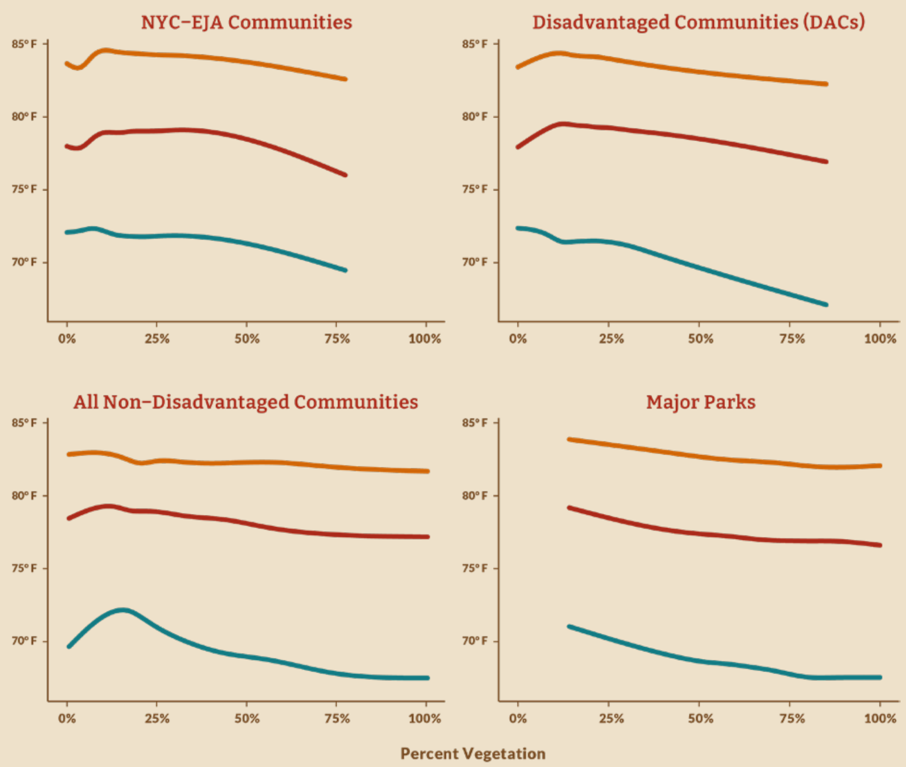


FIGURE C
Bronx and Upper Manhattan Temperatures by Percent Vegetation Cover, in NYC-EJA Communities, All DACs, All Non-DACs, and All Major Parks

Bronx am Bronx pm Bronx eve

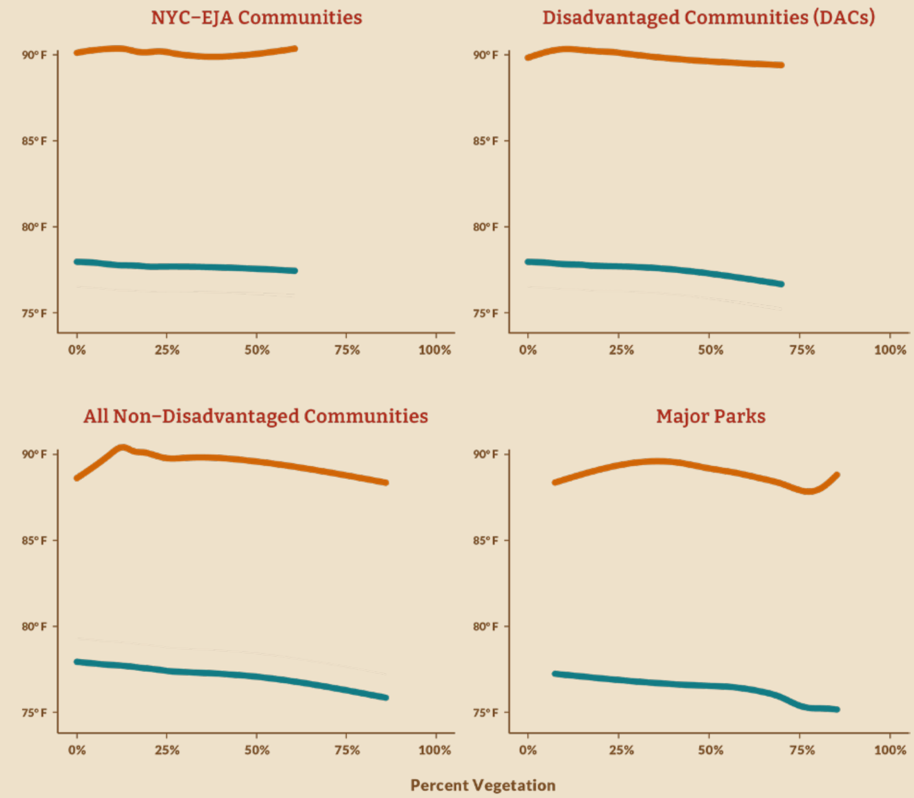


Appendix B

Additional Heat Analysis and Figures

FIGURE D
Brooklyn and Lower Manhattan Temperatures by Percent Vegetation Cover, in NYC-EJA Communities, All DACs, All Non-DACs, and All Major Parks

Brooklyn am Brooklyn pm



Appendix C

Air Pollution Predictive Model

A random forest (RF) model was used to predict $PM_{2.5}$ concentrations in parts of New York City using the data collected by NYC-EJA member organizations. First, highly correlated variables (absolute correlation>0.8) were removed. Random forests, in brief, are an ensemble of decision trees, each of which is constructed using the best split for each node among a subset of randomly chosen predictors. Random search, which randomly chooses the combination of hyperparameters at every iteration, was used to tune and optimize the model.

Finally, we employed the stacked ensemble model, a machine learning ensemble approach that involves training a learning algorithm to combine the predictions of several other learning algorithms. First, all of the other algorithms are trained using the available data, then a 'meta-classifier' algorithm (chosen from the list of algorithms) is trained to make a final prediction combining all the predictions of the other algorithms as additional inputs. We evaluated and selected a diverse group of machine-learning algorithms, including random forest ('rf'), Bayesian generalized linear model ('bayesglm'), k-nearest neighbors ('knn'), recursive partitioning and regression trees ('rpart'), and partitioning using deletion, substitution, and addition moves ('partDSA'). This resulted in R^2 of around 0.3 for rf, whereas a stacked ensemble model using rf as the classifier resulted in R^2 of around 0.6, which is predictive of the $PM_{2.5}$ models. Some of the most important variables to predict particulate matter concentrations according to the model are: apartment buildings and roads and residential areas. Using the rf and stacked ensemble approach, we then made a prediction map based on the grid. Looking at the map, air pollution levels were especially elevated near large roadways.

The strength of the machine learning approach is that it is able to take into consideration highly complex relationships between each variable used to predict air pollution. Many of the land-use variables used in our model are highly correlated, and standard linear regression is unable to consider this in detail. Furthermore, the modeling predictive capabilities of machine learning are often higher than those of standard regression approaches. Machine learning approaches, however, are "black box" in nature, and the resulting outputs are harder to interpret. Furthermore, they do not return the direction of the relationship between a variable and air pollution (e.g., positive or negative), so it is not possible to say whether a land-use predictor increases or decreases air pollution levels.