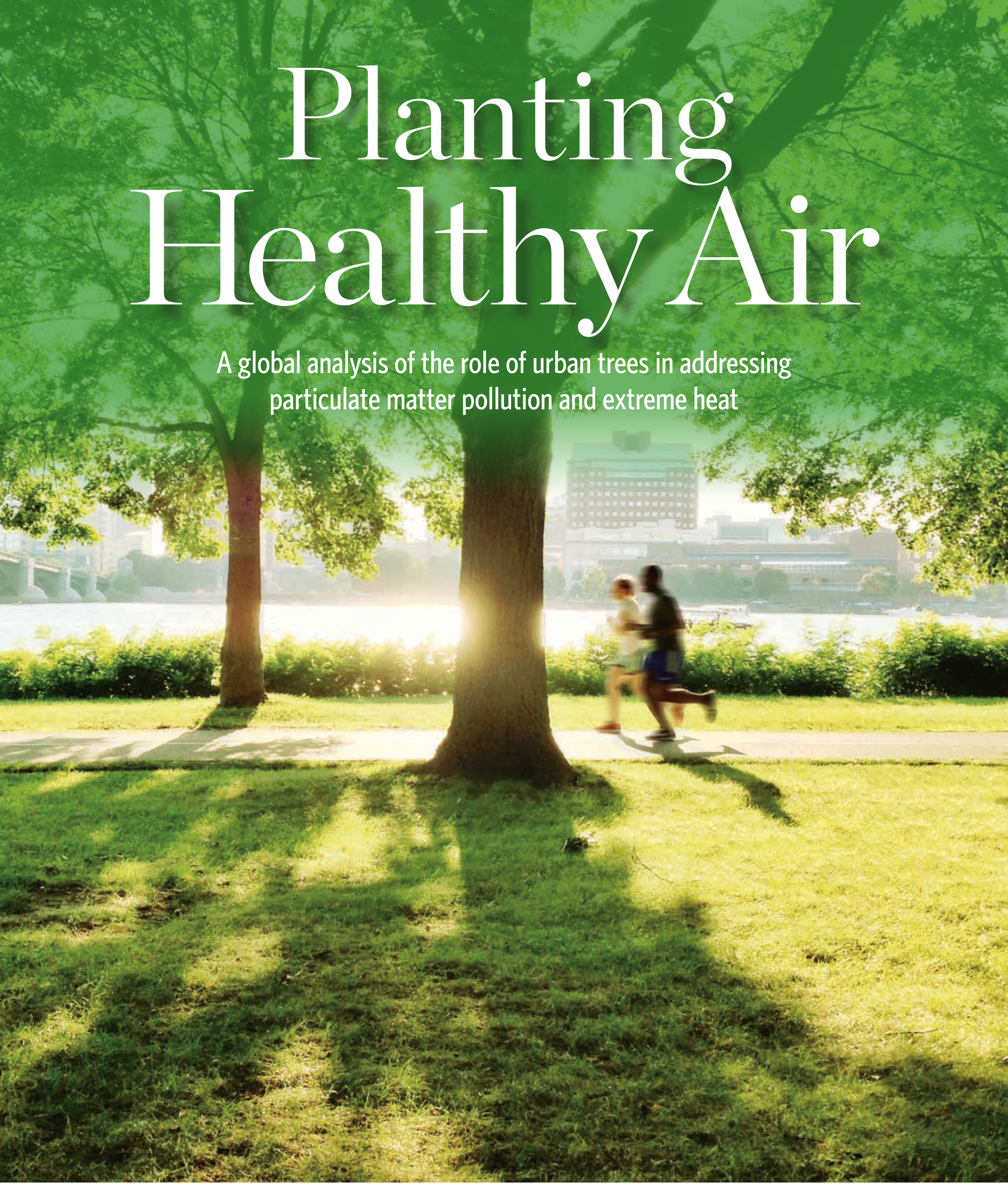
Planting Healthy Air

A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat



Executive Summary

The Nature Conservancy

In collaboration with

C40 CITIES

By 2050,

the vast majority of humanity will live in cities, towns, and other urban areas.

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Planting Healthy Air

The 21st century will be the urban century, as more than 2 billion additional people arrive in cities globally. This rapid urbanization is unprecedented in human history, and by 2050, the vast majority of humanity will live in cities, towns, and other urban areas.[1] Yet at this moment of the "triumph of the city,"[2] the world's urban areas are also facing many significant challenges, from providing jobs and utilities to a burgeoning citizenry, to protecting their residents from crime and violence, to safeguarding urban environmental assets. Among the most pressing of global urban environmental challenges is air quality. In most cities, the most damaging air pollutant is particulate matter, which is emitted from a variety of sources, especially the burning of agricultural residues, fuelwood, and fossil fuels.[3] Fine particulate matter (less than 2.5 micrograms, µg, in diameter, also known as $PM_{2.5}$) can be deeply inhaled into the lungs and is estimated to cause 3.2 million deaths per year (around 4 percent of the global burden of disease) (Figure E1), primarily from cerebrovascular disease (e.g., stroke) and ischemic heart disease (e.g., heart attack).[3, 4] $PM_{2.5}$ exposure also contributes to chronic and acute respiratory diseases, including asthma. And the problem has the potential to get worse: One study forecast that by 2050, fine particulate matter could kill 6.2 million people per year.[4] Cities and national governments are well aware of the threat $PM_{2.5}$ poses, and they are urgently looking for ways to reduce it.

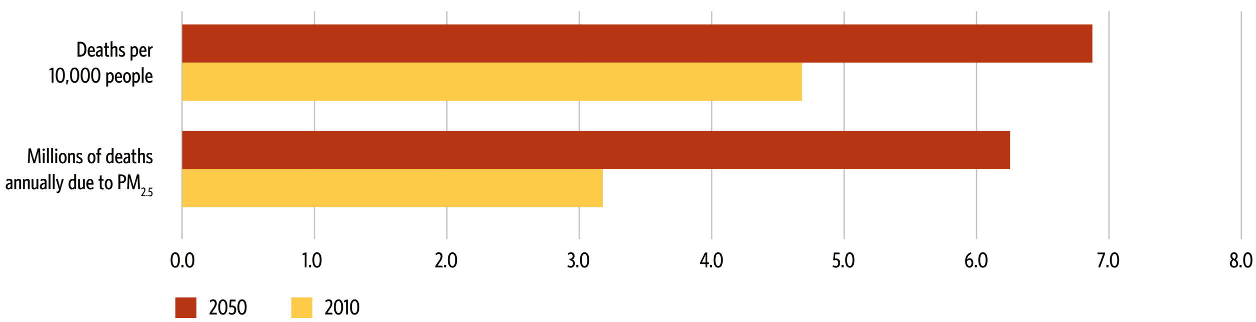

Figure E1. Forecasted global mortality from $PM_{2.5}$ in 2050 compared to 2010, expressed either as the total number of deaths, or as the number of deaths per 10,000 people. The number of people forecasted to be killed will almost double (i.e., increase by 100 percent). Some of that increase is due simply to population growth. The number of deaths per 10,000 people, however, is still expected to go up by roughly 50 percent, primarily due to an increase in $PM_{2.5}$ concentrations in cities in the developing world. Data taken from Lelieveld et al.[4]

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Another pressing problem cities face is that the air is simply so hot in summer that human health is impacted. Already, heat waves are the weather-related disaster that causes the most mortality globally (Figure E2), killing an estimated 12,000 people on average annually[5] and making life unpleasant for millions. Climate change is only going to make the threat of urban heat waves more severe, as the increase in greenhouse gases traps more of the sun's energy, increasing the frequency and severity of heat waves.[6] One World Health Organization report forecasts that by 2050, deaths from heat waves could reach 260,000 annually,[7] unless cities adapt to the threat. Just as smart cities are trying to reduce their concentration of $PM_{2.5}$, thousands of cities are looking for ways to better manage—and adapt to—excess heat.

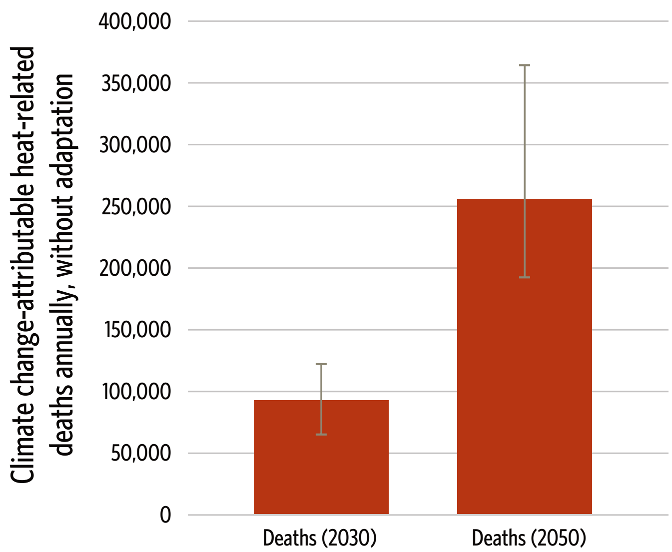


Figure E2. Forecast of climate change's impact on deaths due to excess heat, expressed as annual mortality numbers in 2030 and 2050. The WHO study looked at a range of climate scenarios, which cause a range of mortality (shown with the error bars). Data taken from WHO (2014).

Can nature help address these twin problems of air that is too dirty or too hot? Trees and other vegetation, whether planted along a city street or growing in a park or residential yard, provide many benefits to people, such as aesthetic beauty, enhancement of property values, erosion prevention, stormwater management, and noise reduction. Trees also sequester carbon, helping mitigate climate change. Parks also provide space for urbanites to recreate, which brings real physical and mental health benefits. It looks like trees may play an important role in making our air healthier, too. Dozens of studies now show that tree leaves filter out particulate matter from the atmosphere, along with many other air pollutants. Similarly, many scientific studies show that the shade trees cast, along with their transpiration of water during photosynthesis, can help reduce air temperatures while also reducing electricity use for residential cooling. But questions remain for urban leaders and public health officials:

- What fraction of the air-quality problem (particulate matter and excess heat) can trees solve?
- Which cities and which neighborhoods can be helped most?
- How much investment is needed, in terms of trees planted or dollars spent?
- Where are trees a cost-effective investment, relative to other strategies that can reduce PM or ambient air temperature?

Trees are already providing large benefits

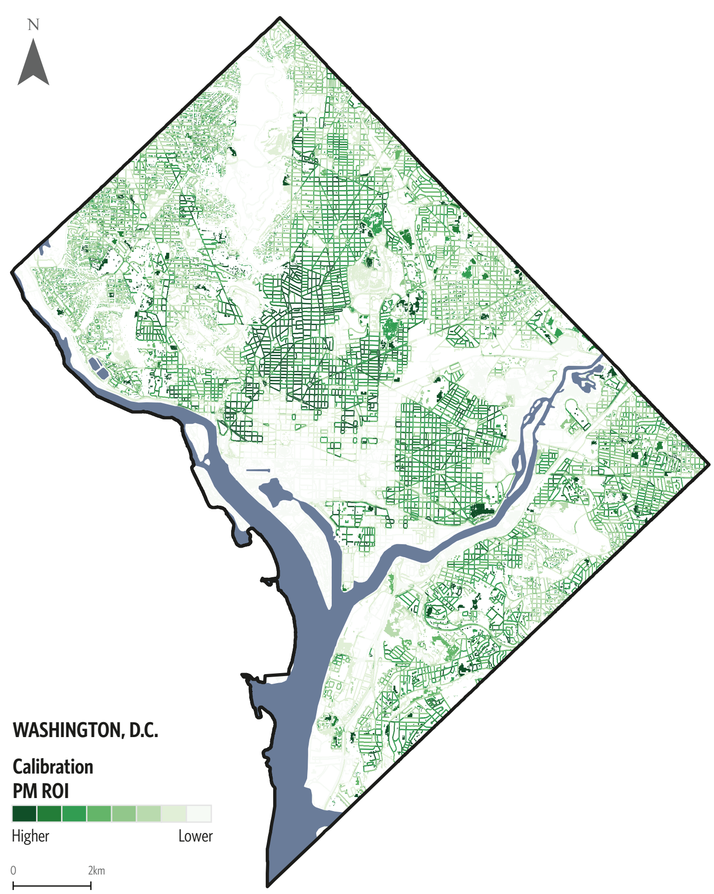
The Nature Conservancy conducted—in coordination with C40—the first global study of cities to answer these questions. We collected geospatial information on forest and land cover, $PM_{2.5}$ pollutant concentration, and population density for 245 cities, and then used established relationships in the literature to estimate the scope of current and future street trees to make urban air healthier. We established three scenarios (High, Medium, and Low) that describe the range of reduction in PM concentration and temperature that trees have been shown to provide. We focused our analysis on street trees, since our review of the scientific literature indicated that proximity between trees and people was needed to deliver meaningful reductions in PM or temperature. The 245 cities we studied currently house around 910 million people, or about a quarter of the world's urban population.

The current stock of street trees in our studied cities is already delivering real benefits. We estimate that trees are currently providing on average 1.3 million (Low scenario to High scenario range: 0.0 to 6.1) people at least a 10 $\mu g/m^3$ reduction in $PM_{2.5}$, 10.2 million (1.0 to 15.4) people at least a 5 $\mu g/m^3$ reduction, and 52.1 million (23.8 to 63.1) people at least a 1 $\mu g/m^3$ reduction. Similarly, trees are already providing 68.3 million people with a roughly 0.5 to 2.0° C (0.9 to 3.6° F) reduction in summer maximum air temperatures. As discussed in detail in the report, this magnitude of impact on PM and temperature has real health benefits for those affected.

These numbers are just for the current stock of street trees. As we show in the report, many cities are struggling to maintain their current stock of street trees, and our results emphasize the importance of investments to maintain this stock. However, in many cities there also exist substantial additional opportunities for adding tree cover to further mitigate air pollution and summer heat. In this study, we assessed the impact of such large-scale but feasible tree cover increases, measuring their return on investment (ROI) in terms of $PM_{2.5}$ reduction or temperature mitigation delivered to people per dollar spent.

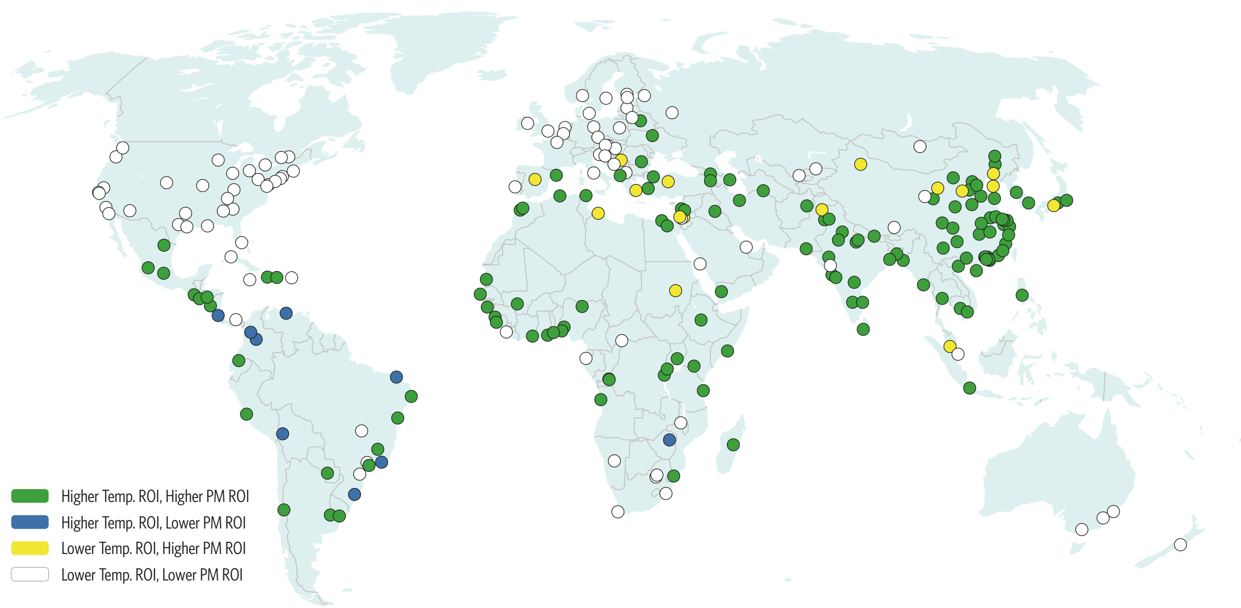
The importance of targeting

Our literature review showed that trees provide meaningful but locally concentrated reductions in PM and temperature, with the majority of mitigation generally within within 300 meters of plantings. Targeting the neighborhoods with the highest mitigation impacts becomes crucial (Map E1). Our results show substantial variation within cities, with the best neighborhoods for street tree planting often having 100-fold greater return on investment (ROI) in tree planting compared to the least suitable neighborhoods. Generally, those neighborhoods are characterized by higher population density and thus more people who will benefit from cleaner air, and by higher concentrations of $PM_{2.5}$ that can be removed by trees. We discuss guidelines for plantings in the report that can be used to select species with high PM removal capacity, as well as appropriate spacing among plantings, since it is important to avoid the trapping of airflow from particulate sources (e.g., highways) in areas where people are present. Population density and PM concentrations also drive variation among cities in ROI (Map E2). An additional factor that varies among cities is the cost of tree planting; all else being equal, cities with lower planting and maintenance costs have higher ROI. Globally, tree planting and maintenance costs tend to be lower in less developed countries. However, within countries, there is substantial variation among cities, driven by differences in availability of planting stock, labor costs, and the scale of a city's urban forestry program.



Map E. Neighborhood-level patterns in the return on investment (ROI) of tree planting to reduce particulate matter for one city, Washington, DC. Streets that are darker green have higher return on investment.

There are similar patterns in ROI of tree planting for air temperature mitigation, with ROI varying among neighborhoods 100-fold. The ideal high-ROI neighborhood would have high population density (or a concentration of sensitive populations) leading to a larger number of people benefiting from heat reduction by trees. We discuss planting guidelines for air temperature mitigation as well, noting where guidelines that maximize temperature mitigation diverge from guidelines that would maximize PM removal. Population density and planting costs drive large variance in ROI of temperature mitigation among cities (Map E2). Note, however that arid cities may face a trade-off when planting trees: While more trees will reduce maximum temperatures (and PM concentrations), they also require water, which may be scarce, for irrigation at least during part of the year.



Map E2. Return on investment of tree planting to reduce ambient temperatures for global cities.

Photo © Devan King

Nature is a cost-effective solution

Our research also shows that urban street tree planting and canopy enhancement can be a cost-effective way to make the air healthier. For particulate matter the cost of reduction, in $/ton, varies significantly across neighborhoods, and in some neighborhoods is lower than published emission-control costs for other available strategies (Figure E3). However, the median cost of tree planting for PM mitigation is higher than that of five out of six broad categories of strategies we considered, suggesting that in many cases other conventional PM reduction strategies may be less costly. The cost of reducing temperatures (in $/° C from implementing the practice over a 100-square-meter area area) also varies significantly across neighborhoods, and in some places is lower than for any available conventional strategy. The median cost of tree planting is less than every other strategy considered except for cool-roof technologies. Of course, in cases where both PM concentrations and high temperatures are a concern, the comparative attractiveness of tree cover additions would be much higher still, as none of the conventional "grey" alternatives address both heat and PM problems. Moreover, the other co-benefits that trees provide (carbon sequestration, aesthetic beauty, stormwater mitigation, etc.) further increase the comparative attractiveness of tree cover as a solution.

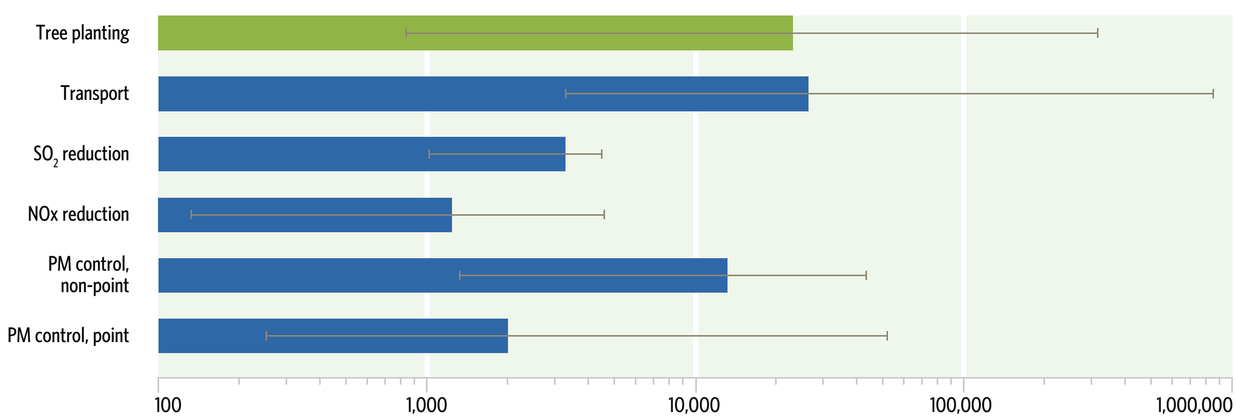
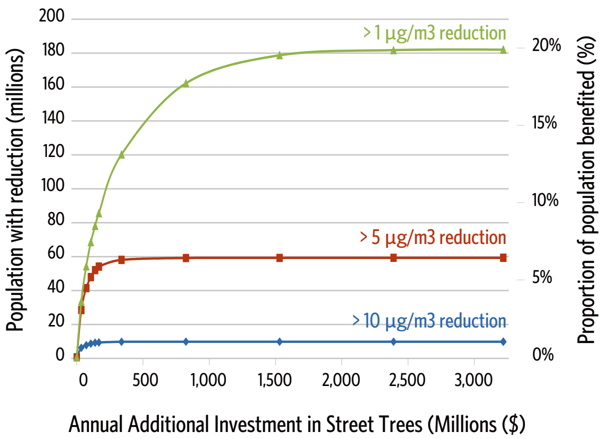


Figure E3. Cost-effectiveness of street tree planting to reduce particulate matter, compared with common categories of conventional mitigation strategies. The green bar shows the median cost-effectiveness of street tree planting across sites, while its error bars show the minimum and maximum cost-effectiveness. All values for cost-effectiveness are standardized to US2015$/ton. Note that while the median cost per ton PM removed is higher for street trees than the median cost of many conventional strategies, there is significant variance, and on many sites tree planting is cost-competitive relative to the other grey infrastructure strategies. Moreover, this comparison is biased in favor of conventional strategies because their cost-effectiveness is expressed in terms of $/ton emissions avoided at the emissions source (not all of which translates into local concentration reductions for people), while that of trees represents the actual cost-effectiveness in producing local reductions for people.

Not only can street tree planting in some neighborhoods be a cost-effective way to make air healthier, it can also deliver these benefits to a significant fraction of urban residents. The global investment curve for trees to reduce $PM_{2.5}$ pollution is shown in Figure E4. For instance, we estimate, under our Medium impact scenario, that an annual $100 million additional global investment in trees (including planting and maintenance costs) would give 8 million additional people a large reduction of $PM_{2.5}$ (> 10 μg/m³), 47 million people a moderate reduction (> 5 μg/m³), and 68 million people a modest reduction (> 1 μg/m³). The shape of the investment curve for temperature looks similar (Figure E5). An annual investment of $100 million would give an additional 77 million people a 1° C (1.8° F) reduction in maximum temperatures on hot days (Medium impact scenario).



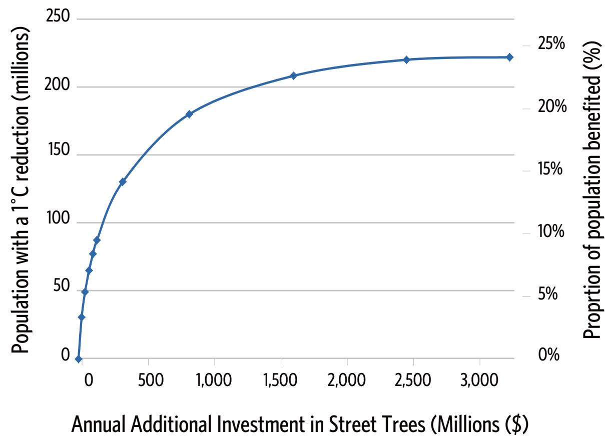


Figure E4 (left). The global potential for street trees to benefit urban dwellers with reduced PM concentrations, given different annual investments in tree planting and maintenance. Results shown are for our Medium scenario of the effectiveness of trees in removing PM. Note that the curves for 5 and 10 μg/m³ flatten out at high investment levels because there are relatively few cities (principally the most polluted) where street tree planting can remove more than this amount of pollution. Once investment in street tree planting has fully occurred in these cities, additional investment in tree planting won't increase the number of people receiving a reduction of more than 5 μg/m³, but will continue to increase the number of people receiving more modest reductions of 1 μg/m³.

Figure E5 (right). The global potential for street trees to benefit urban dwellers with reduced temperatures, given different annual investments in tree planting and maintenance. Results shown are for the Medium scenario. Under the High scenario an equivalent number of people would see a 2°C reduction, whereas under the Low scenario the same number of people would see a 0.5°C reduction.

These magnitudes of reductions in $PM_{2.5}$ concentrations and temperature achievable with tree cover can provide modest but significant reductions in disease. Based on the well-established relationship between outdoor $PM_{2.5}$ concentration and mortality, we estimate that the maximum possible tree planting in our cities (cost = $3.2 billion annually) would reduce PM-related mortality by 2.7 percent to 8.7 percent, saving between 11,000 and 36,000 lives annually in our study cities. In this executive summary, we focus only on mortality numbers, but there are, of course, a range of health impacts, from missed days at school or work to hospitalizations to premature death. Research indicates that for every death from $PM_{2.5}$ there are many people hospitalized or otherwise affected by PM, so we expect that, similarly, the number of people who would benefit in some way from the maximum possible tree planting would be many times larger than the avoided mortality figure.

The effect of high temperature on mortality is also well documented in the literature. Based on studies that functionally relate mortality to high temperature, we estimate that the maximum possible tree planting in our cities would reduce high temperature-related mortality by 2.4 percent to 5.6 percent, saving between 200 and 700 lives annually in our study cities. Note that this figure is for the current climate, and with climate change potential increasing mortality from heat more than 20-fold, it seems likely this figure of lives saved by street trees will be substantially larger in the future.

Additionally, tree planting could reduce electricity use and increase carbon sequestration. We estimate that our maximum possible street tree-planting scenario would reduce residential electrical use in our 245 cities by 0.9 percent to 4.8 percent annually (9.8 billion to 48 billion KWhr). Under the maximum street tree-planting scenario, net carbon sequestration would increase by 2.7 million to 13 million tons CO_2. Combined with estimates of the avoided CO_2 emissions due to electricity use reduction, we estimate the total impact of our maximum street tree-planting scenario as an annual reduction of 7.0 million to 35 million tons CO_2. Note that these climate mitigation benefits are provided in addition to the benefits to human health from PM reduction and temperature mitigation.

Nature will matter even more in the future

Finally, our analysis of trends over time suggests that the ecosystem services supplied by trees will be even more crucial in the future. There may be a 50 percent increase in the rate of mortality caused by $PM_{2.5}$ by 2050, most of it in urban areas,[4] and summer maximum temperatures in our sample of cities are forecast to increase by 2-5˚C (4-9° F) over the same time period. While these twin threats post a challenge to the health of those in cities, all else being equal, they will also increase the importance of the trees that are already there. There will also be a dramatic increase in urban population, which increases the number of people who might benefit from nature's services. Finally, all this urban development, or simply societal underinvestment in replacing trees lost, may reduce the amount of urban greening. For instance, we found that 26 percent of cities had a decline in forest cover over the period between 2000 and 2010, whereas only 16 percent of cities had an increase in forest cover over the time period.

Conclusions

We are at the beginning of the urban century. One of the preeminent tasks of cities will be making themselves vibrant, healthy, attractive places to live. This report has focused on just one small part of this task: the quest to make urban air healthier. Cities continue to strive to reduce concentrations of particulate matter and other atmospheric pollutants. And they are beginning to plan for the increased frequency and intensity of heat waves that climate change will likely bring. Succeeding against these twin challenges—air pollution and excess heat—will require an array of approaches. In this report, The Nature Conservancy – in coordination with C40 Cities Climate Leadership Group – has tried to understand whether nature can play a role in helping to solve these twin challenges.

The answer appears to be a qualified "yes." Street trees can be a part of a cost-effective portfolio of interventions aimed at controlling particulate matter pollution and mitigating high temperatures in cities. While trees cannot and should not replace other strategies to make air healthier, trees can be used in conjunction with these other strategies to help clean and cool the air. Moreover, trees provide a multitude of other benefits beyond healthier air. In the right spot, trees can both help make our air healthier and our cities more verdant and livable.

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Acknowledgements

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Global investment of $3.2 billion annually –

less than $4 per resident

– in these cities can save tens of thousands of lives, and improve the health of tens of millions of people.

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Protecting nature. Preserving life.

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