COOLING CITIES

HARNESSING NATURAL AREAS TO COMBAT URBAN HEAT

Natural Areas Conservancy

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2021 was the hottest summer on record in the United States. Cities are documented to be hotter than rural areas, in some cases by over 10°F, and extreme heat is the leading cause of weather-related deaths in the United States. Strategies such as planting trees and expanding green spaces are known to combat urban heat, but the magnitude of cooling benefits has not been quantified across different segments of the urban forest, such as between trees in landscaped and forested locations, nor across the patchwork of land cover types that make up our cities.

During summer 2022, the Natural Areas Conservancy (NAC) partnered with 12 cities from the Forests in Cities network to conduct a study focused on quantifying differences in air and surface temperature between types of urban greenspace, with a focus on natural areas. As a result of this study, we found that natural areas are the coolest types of greenspaces in cities. Natural areas were significantly cooler than non-natural and landscaped areas, and forested natural areas have lower air temperature than areas of landscaped trees by several degrees. In some cities on a hot summer day – it was over 10°F cooler in a forested natural area compared to under lanscaped trees just a few hundred feet away in a street scape. We also found that forests that were higher quality tended to be cooler than those that were more degraded during the warmest point of the day and had lower high temperature extremes.

These results highlight the importance of urban natural areas as a place of respite for city residents during the summertime months. Not all city residents have access to nearby greenspace, and getting outside under the shade of a forest canopy can provide a cooler place to spend time outdoors.

These findings also signal that natural areas are an important type of greenspace to consider in plans aimed at addressing urban heat islands and must be maintained to provide the greatest benefits. Protection, management, and expansion of natural areas belongs in urban climate mitigation plans, alongside landscaped greenspace, tree plantings, and other climate engineering techniques.

Photo Credit: Jacob Brinkman

INTRODUCTION

The data is clear: the world is getting hotter

According to NASA, the last nine years have been the hottest since global record keeping began in the year 1880[1].

In the United States, the summer of 2021 was the hottest on record, and the summer of 2022 brought record-breaking heat across the country. In June 2022, a “heat dome” stalled over a large portion of the U.S., putting over 125 million people under excessive heat warnings. This heat wave broke high-temperature records in St. Louis, MO; Nashville, TN; Jackson, KY; Asheville, NC; and several other cities[2]. That July, nighttime temperatures were the warmest in recorded history[3], a record that was broken again the following month in August[4]. August 2022 brought with it another heat wave affecting over 80 million people[5], and more broken records with Philadelphia, PA[6], and Portland, OR[7], both having their hottest August on record.

Heat related illnesses are on the rise

These rising temperatures are leading to increased rates of heat-related illness across the country, with double-digit percent increases in heat exhaustion and heat stroke for all summer months from 2016 to 2021[8] and 67,500 ER visits, and 700 deaths annually[9] — making extreme heat the leading cause of weather-related death across the country. In one year from 2021-2022, New York City saw a staggering 13% increase in summertime heat-related emergency room visits[10]. Due to difficulties in tracking heat-related sickness and death, these reported numbers are likely an underestimation.

City residents are more vulnerable to heat-related risks[11]

Due to the urban heat island effect, cities experience temperatures up to 27°F warmer than nearby rural areas[12]. This trend is alarming in the U.S., where 83% of the population lives in urban areas, a number projected to increase to 89% by 2050[13]. Urban heat also poses environmental equity issues as many of the hottest areas in cities correlate with higher densities of ethnic minorities, and lower income and education levels[14]. Some strategies are being implemented to beat the heat and make cities more livable. For example, opening up cooling centers; changing color and composition of building materials to increase the reflection of the sun’s energy back into space (albedo modification); and expansion of greenspace (e.g., green roofs and tree planting). The latter is most often cited, particularly planting trees in streets and in parks. Urban greenspace is cited as one of the most effective ways to reduce the urban heat island effect and moderate rising temperatures[15].

Plants make our world cooler

Countless studies have showcased the cooling powers of plants, rooted in their ability to circulate water and release it from their leaves (evapotranspiration)[16-19]. Less information is available about the differences in cooling between different types of green space in the urban environment. Multiple studies suggest that adding layers of vegetation decreases temperature[20,21] with one study calling out urban forested natural areas directly[22]. It's also known that it is cooler in tree-shaded than unshaded locations[23]. Layered vegetation is a key characteristic of some natural covertypes, particularly forested natural areas. In context, those findings suggest that natural areas (which usually have more layers of plants), should be cooler, and that forested natural areas (the type with the most layers) should rank among the coolest. A quick look at a map of New York City's greenspace (Figure 1) compared to relative land surface temperature (Figure 2) clearly shows that most "cold spots" on the map correspond with the location of natural areas, especially those that are larger.

What are *natural areas*? In an urban setting, natural areas are green spaces that look and feel like wilderness, but are located within city limits. These areas are not mowed or weeded to prevent trees and understory plants from naturally growing[24], but may be managed to control aggressive species such as vines that strangle trees. This results in multiple layers of plants and, in forested natural areas, different ages of trees growing together in the same place. Natural areas are common in cities, ranging in size from less than one to hundreds of acres.

FIGURE 1

Landcover map of New York City, depicting two classifications of greenspace. The bright green represents landscaped vegetation, comprising mowed lawns, street trees, and park trees. The blue area represents natural areas, comprising forests, grasslands, and wetlands. Data Source: The 2015 Ecological Covertype Map of New York City.

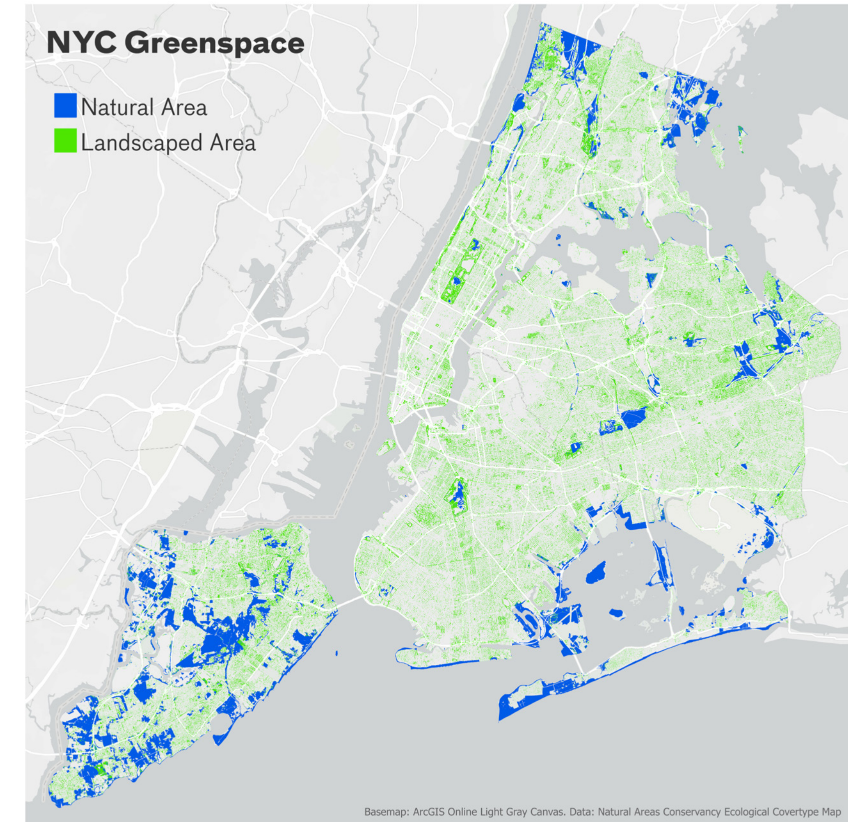
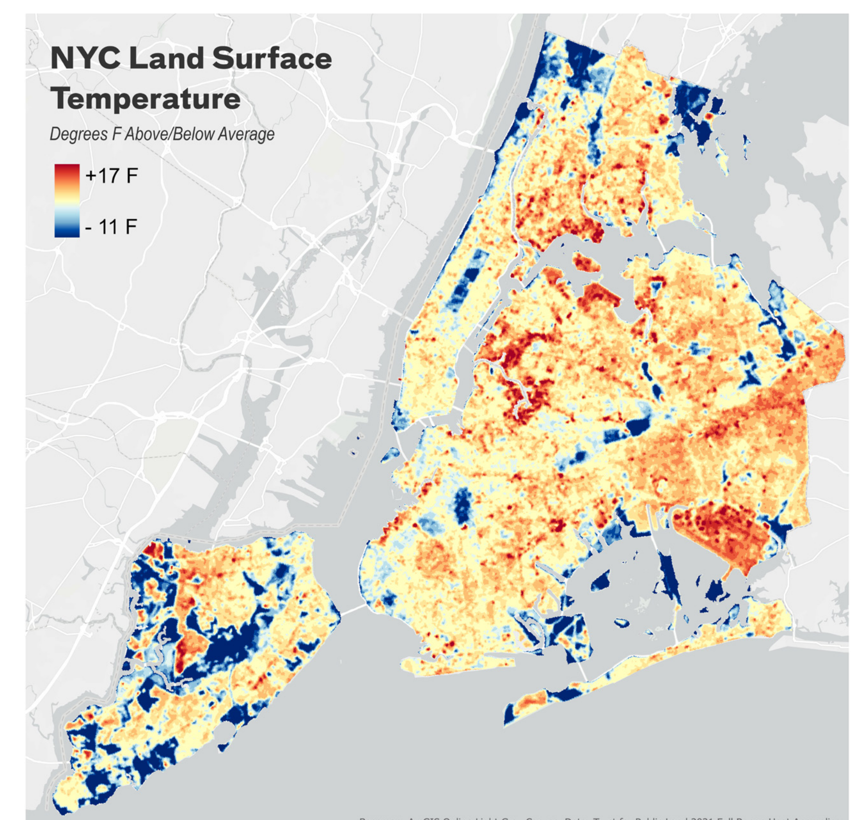


FIGURE 2

Land surface temperature anomaly map of New York City for summer 2021. This map depicts the degrees F above and below average for each surface in the city. Yellow areas represent locations that are roughly average temperature, dark blue areas represent the coolest surfaces in the city, and dark red areas represent the warmest. Data Source: Trust for Public Land - Full Range Heat Anomalies Dataset (2021).



SUMMER 2022 COOLING STUDY

To learn more about the cooling potential of different types of greenspace, including different classes of natural areas, the Natural Areas Conservancy conducted a research study in summer 2022 to answer the following questions:

1. **Does land surface temperature vary across categories of natural and landscaped land cover?**
2. **Is the air temperature in forested natural areas cooler than under trees in landscaped areas?**
3. **Are higher quality forested natural areas cooler than lower quality?**

A study rooted in partnership

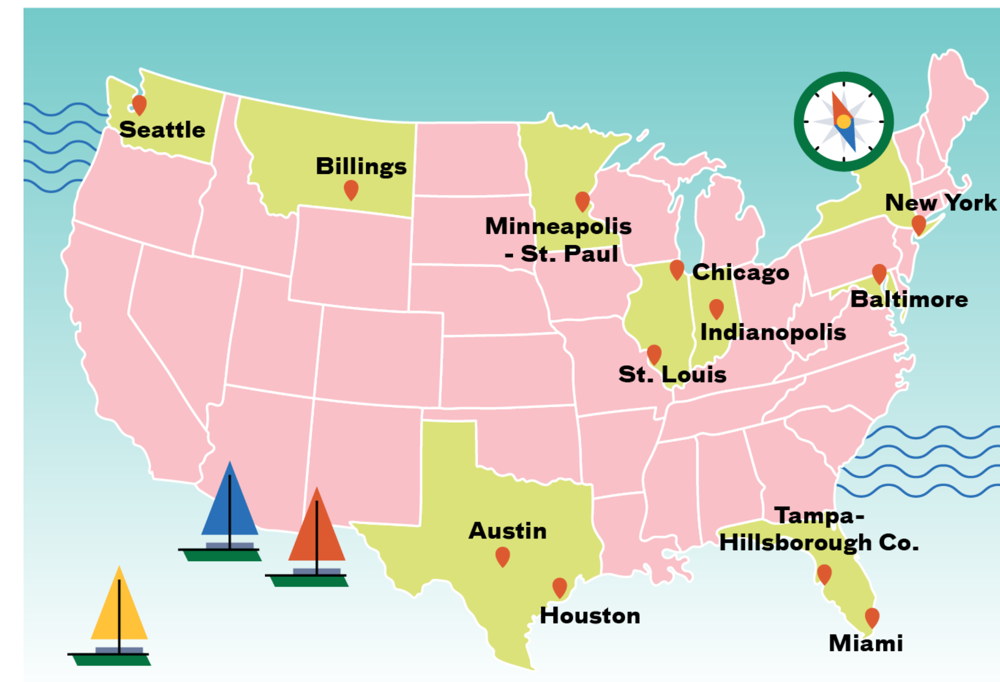
During the summer of 2022, the NAC collaborated with partners from 12 U.S. cities (Figure 3) that are part of the Forests in Cities network, a coalition of urban forested natural areas professionals from across the U.S.[25] In partnership, we conducted a two-part study focused on the cooling benefits of different types of urban greenspace. Across these 12 cities there are over 90,000 acres of forested natural areas.

To answer these questions we used two sources of temperature data: 1) land surface temperature acquired from satellites, and 2) air temperature acquired from sensors placed on trees. We used two separate sources because each has their own strengths.

Land surface temperature data is valuable because it is available for large areas, but is limited because surface temperature can be higher or lower than air temperature depending on the location. Air temperature is valuable because it more closely mirrors what we experience when we are outside, but it is limited because it is much more time consuming and expensive to collect. But interpreting these two sources together can help us answer our questions.

FIGURE 3

All cities that participated in the cooling study. Within each city there were a minimum of three different sites that were entered into the study, each containing three temperature sensors within one mile of each other.



LAND SURFACE TEMPERATURE STUDY

Part one of the study focused on the surface temperature of different land cover types. For this part of the study, we sourced temperature data from the land surface temperature (LST) anomaly dataset developed by the Trust for Public Land[26]. This dataset classifies land area by degrees F above and below average for each city in the study at a 30m resolution. This way of looking at temperature data makes it easier to compare results between cities, some of which will be much warmer or cooler than others due to their geography. Land cover data were acquired by having experts digitize land cover classes using an interactive mapping tool hosted on ArcGIS Online.

Each city digitized land cover for a minimum of three classes, one class from each of the following categories: natural area vegetation, built, and landscaped vegetation. For a detailed description of all land cover classes included, see Appendix A. Our 11 partner cities digitized a total of 953 polygons across 13 unique land cover types, totaling 36,479 acres. For a breakdown by city, see Appendix B. For New York City, we sourced land cover data from New York City's Ecological Covertype Map (ECM)[27], which is a full classification of NYC's land area, allowing for a more in-depth analysis of LST. To analyze this data, we overlaid the LST and land cover data and summarized LST by land cover class. The full methods, including the digitization instructions followed by each city team, can be found in the protocol, which is hosted on the Forests in Cities Resource Library website[28]. Spatial analysis for this part of the study was conducted in ArcGIS Pro 3.0.1.

AIR TEMPERATURE STUDY

Part two of the study focused on the air temperature under different classes of tree canopy and in forested natural areas of different conditions. This was accomplished by deploying HOBO brand air temperature sensors on trees in groups of three in close proximity (<1 mile) to control for differences in weather across broad distances. In each group, sensors were attached to one landscaped tree, one tree in a high-quality forest, and one tree in a low-quality forest. This arrangement allowed us to look at differences between landscaped areas and forests, and differences within the forest. Experts from each city deployed groups of three sensors at a minimum of three locations ("sites"), for a minimum of 9 sensors in each city. The location of each sensor was marked on an ArcGIS Field map, and information about the location's surrounding area was collected. Forest condition was determined using a scoring system that focused on simple measures of condition such as prevalence of problem/invasive species, native species count, canopy completeness, tree health and several others. The final number of sensors was 120 at 40 locations across all cities (Figure 4). Sensors were programmed to record air temperature every five minutes and remained in place through the end of the summer (September 22, 2022). The full methods, including the forest quality scoring system, can be found in the Forests in Cities Resource Library[29].

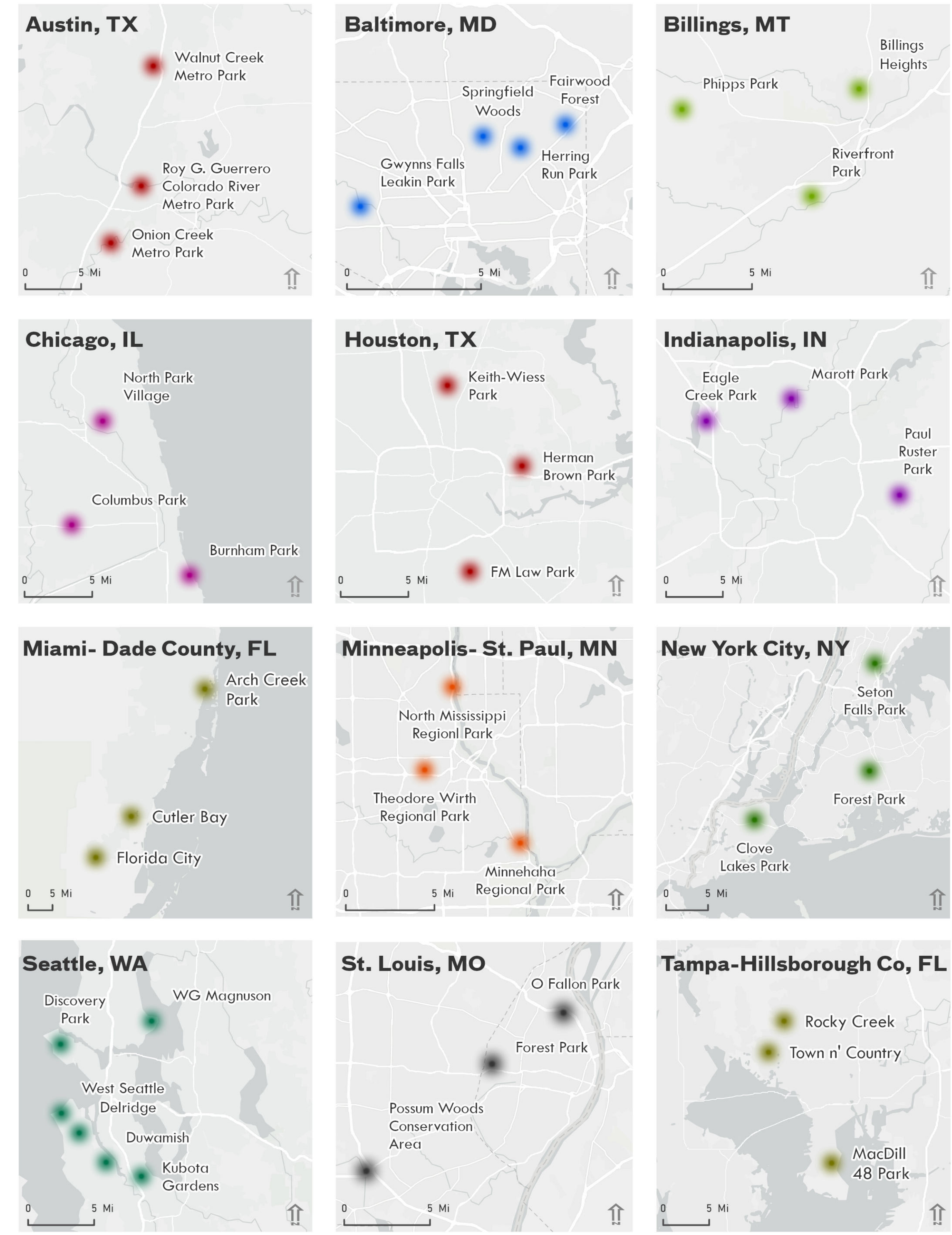


FIGURE 4

A map depicting the locations of each site that was entered into the cooling study. At each of these sites, three temperature sensors were deployed: one on a landscaped tree, one in a forest of high quality, and one in a forest of lower quality. All sensors within a site were placed within one mile of each other and had to be in locations of roughly the same elevation.

PHOTO: Lisa Ciecko from Seattle Parks & Recreation taking down an air temperature sensor from the study site in Kubota Gardens in Seattle, WA. Photo Credit: Crystal Crown, October 2022.

To interpret the information we collected, we focused on differences at the coolest (sunrise) part of the day, the warmest (afternoon), and after sunset when built surfaces radiate heat absorbed during the daylight hours. For analysis, we averaged air temperature by hour, site, location (healthy, degraded, or landscaped), and date per day phase. We also calculated the daily temperature range (DTR - the difference between the lowest and highest temperature in a single day) differences between forested natural areas and landscaped locations. Statistical testing was conducted on this data to examine differences.* To examine within-site comparisons, averages were calculated by site, location, and dayphase and compared.

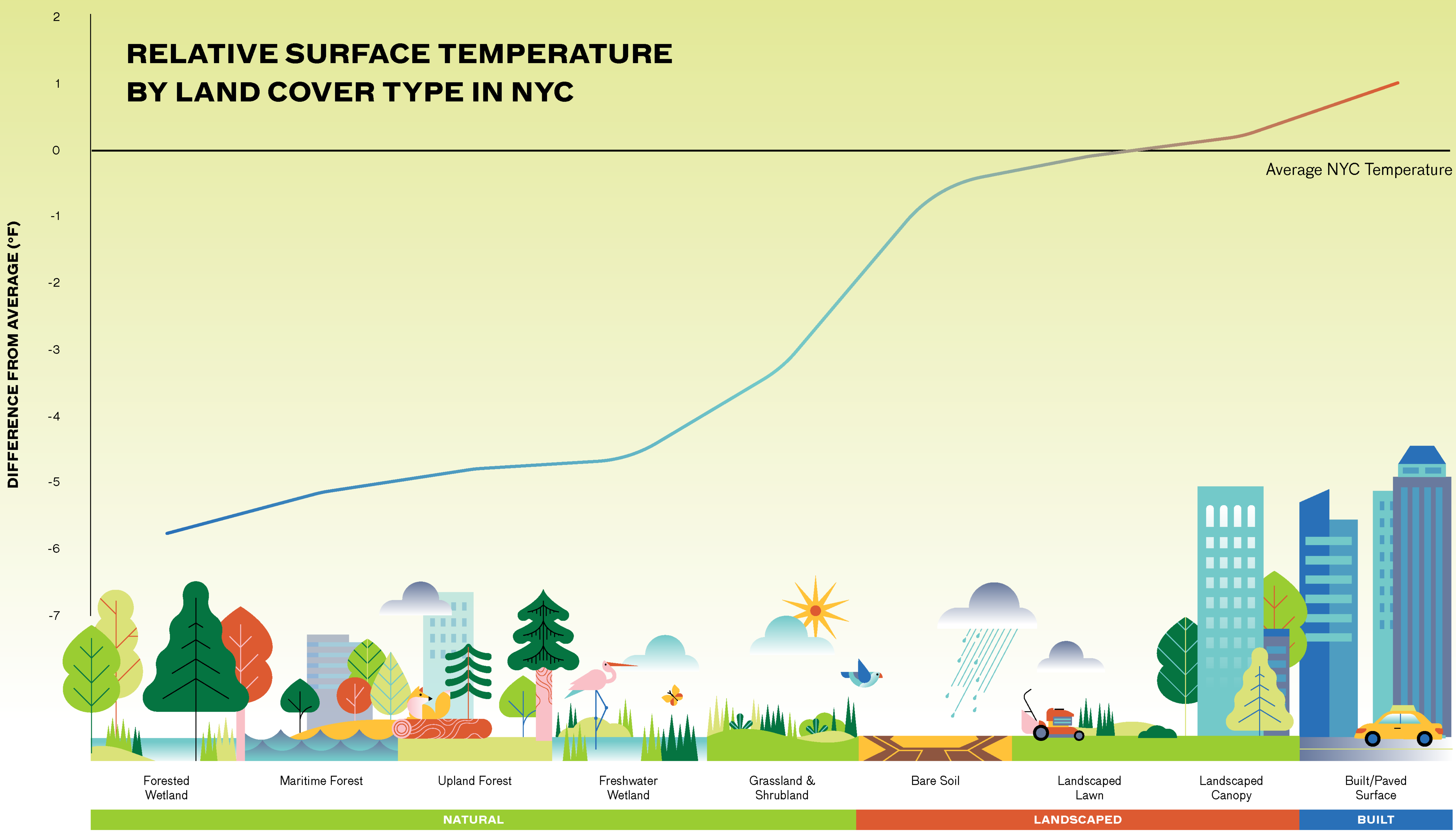
*Hourly average air temperature data and DTR were non-normal. Kruskal-Wallace tests were used to determine the significance of differences between locations for sunrise (n=9,080), afternoon (n=72,632) and after sunset (n=9,079), and DTR (n=9,075). Post-hoc Dunn tests were used to determine which pairwise comparisons were driving any significant results. Statistical testing was done using R version 4.3.2[30,31,32].

FINDINGS

Forested natural areas are the coolest land cover type

Forested classes were the coolest land cover type overall. Depending on city and forest type, they ranged from 3 - 9°F cooler than average, and one of the four forest classes (Appendix A) ranked the coolest type overall for 10 cities.** The coolest type was conifer forest, included only for Seattle, WA, which was 9°F cooler than average. For other cities, forest types that have wetter conditions—forested wetlands and mangrove forests—were particularly cool. In all cities that submitted areas of these types (n=8) they ranked in the top two coolest, with forested wetland being 6°F cooler than citywide average. Mangroves (specific to our Florida cities) ranked 3 - 3.5°F cooler than average. In cities where multiple canopied natural land cover types (forest, woodland, and savannah) are present, those with higher canopy (forest) tended to be cooler than classes characterized by lower canopy (woodlands or savannahs), though all natural canopy classes were cooler than average. See full results in Appendix B.

** For the two other cities, one did not have any forest classes included in the final dataset.

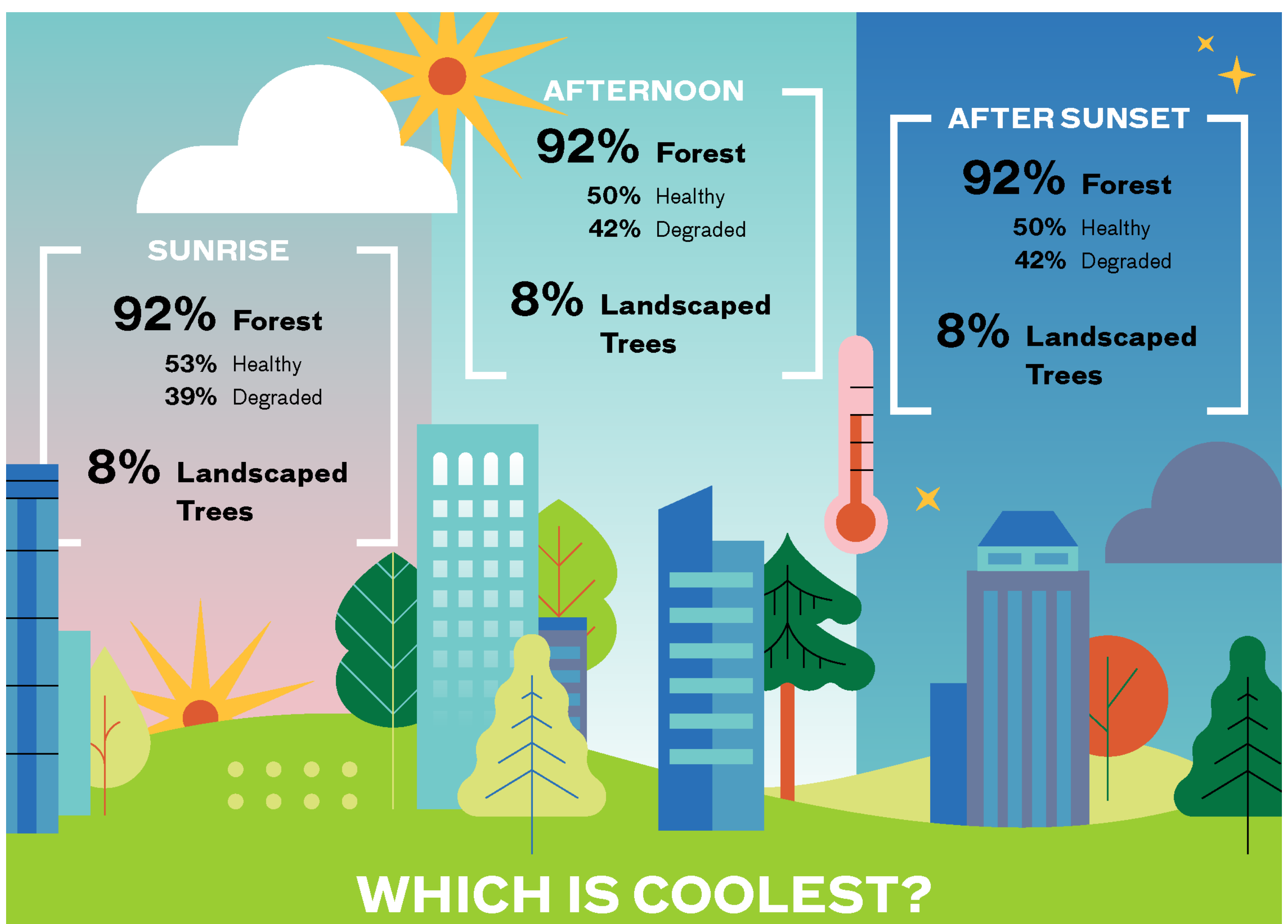

RELATIVE SURFACE TEMPERATURE BY LAND COVER TYPE IN NYC
DIFFERENCE FROM AVERAGE (°F)
2
1
0
-1
-2
-3
-4
-5
-6
-7
Average NYC Temperature
Forested Wetland
Maritime Forest
Upland Forest
Freshwater Wetland
Grassland & Shrubland
Bare Soil
Landscaped Lawn
Landscaped Canopy
Built/Paved Surface
NATURAL
LANDSCAPED
BUILT

Air temperature in forested natural areas was cooler than under landscaped tree areas, and healthy forests were the coolest

Using data from all cities, we found that air temperature in forested natural areas was the coolest. Forested natural areas (healthy and degraded) were significantly cooler than landscaped locations during all day phases, and healthy natural areas were significantly cooler than degraded only during the hottest part of the day (afternoon). The average temperature differences between healthy and degraded, and degraded and landscaped locations were, respectively: sunrise: 0.1°F and 0.9°F; afternoon: 0.5°F and 1.4°F; and after sunset: 0.1°F and 1.2°F.

FIGURE 5

At all points in the day, the forest was cooler than landscaped locations at a large majority of locations. Within forests, the high-quality location tended to be cooler than the forested.



While these temperature differences may not seem prominent, a deeper dive shows more extreme differences at specific dates and times. For example, at 6pm on September 3 at the Billings Heights site (Billings, MT), the forest was over 14°F cooler than the landscaped location. At 8pm on July 21 at Seton Falls Park (New York City, NY), the difference was over 13°F; and at Possum Woods Conservation Area (St. Louis, MO), the difference was nearly 12°F on September 20th at 5pm. Overall, all cities had times where the forested location was at least 5.5°F cooler than nearby areas of landscaped trees.

Comparison of site-level averages showed sunrise, afternoon, and after-sunset air temperature in forested natural areas were cooler than under a nearby landscaped tree at 92% of sites. Within that 92%, during afternoon and after sunset, healthier locations were coolest at 50% of sites, and degraded at 42% of sites, and at sunrise, healthier locations were coolest at 53% of sites, and degraded at 39%. Full site-level comparisons are in Appendix C.

A look at the afternoon temperatures on the hottest day we had data for in each city showed similar trends. For these hot days, it was coolest in the higher quality forest at 51% of sites, in the lower quality forest in 46% of sites, and under landscaped canopy at 3% of sites. Averages across all afternoon readings in the dataset showed that in the afternoon, the landscaped canopy was around 2°F warmer than in a degraded forest location, which was 0.5°F warmer than the higher quality forest. But within sites, that difference varied throughout the day. See Figure 7 for the air temperature over 24 hours on a city's hottest day at four study sites.

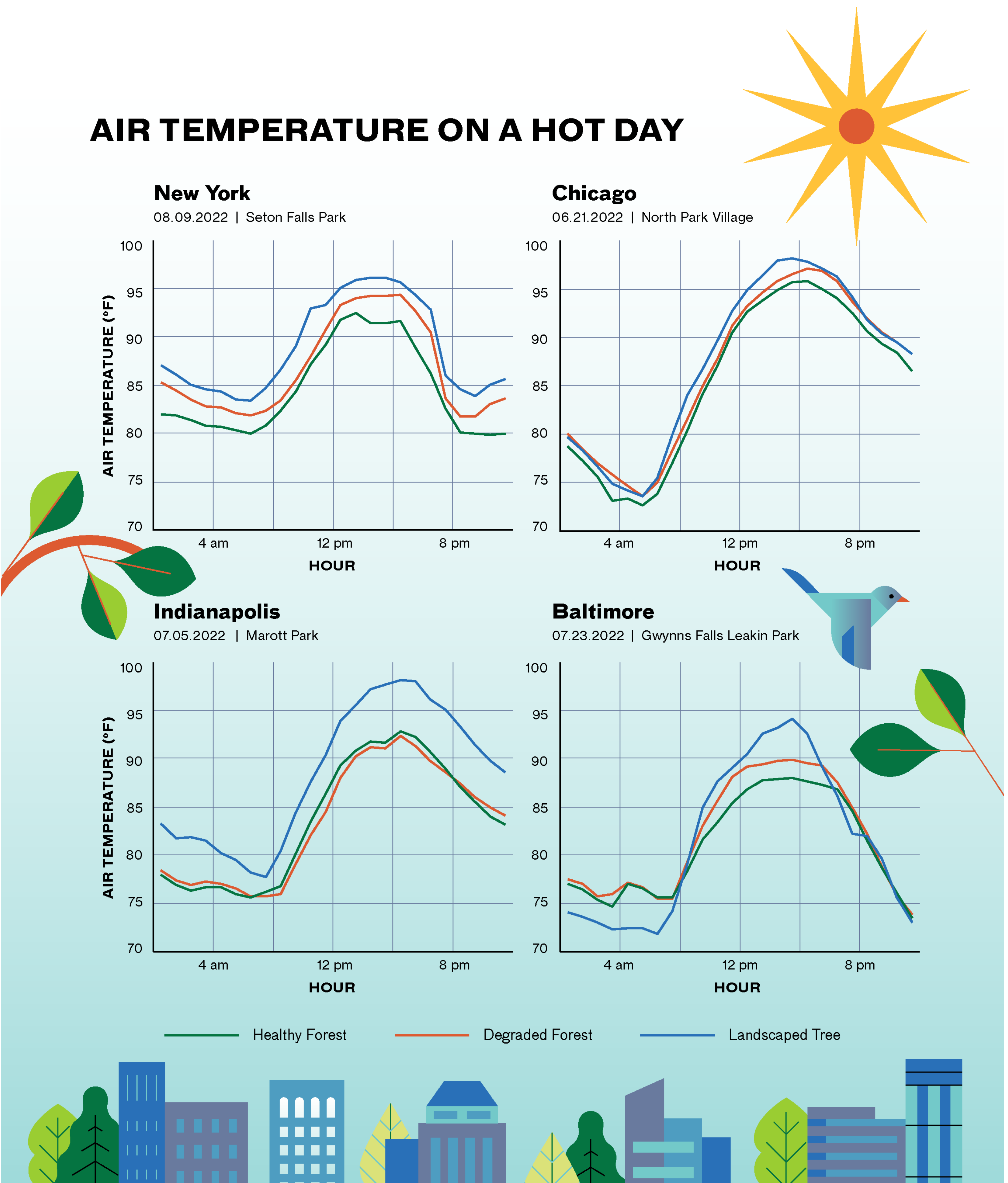


FIGURE 6

Air temperature on the hottest day of the summer at four study sites.

Forests have a smaller daily air temperature range and fewer high temperature extremes

The daily temperature range across locations within sites was significantly different. Forested natural areas of both condition classes experienced a smaller range of daily temperatures than non-forested locations, and healthy forests had a smaller range than those in a more degraded state. Healthy forested locations had temperatures that spanned an average of 18.0°F, degraded spanned 19.1°F, while landscaped areas had a larger range of 19.6 °F. What's more, we found that forested locations had the lowest daily maximum temperature 85% of the time. Within that 85%, healthy had the lowest in 54% of cases, and more degraded location in 31%. This suggests that forested natural areas can offer a buffer by a few degrees against the extremes. This finding has been supported by other research which has shown that forests may buffer temperature fluctuation better than non-forested locations[33,34], because vegetation provides insulation that limits temperature extremes.

TAKEAWAYS

Natural areas are the coolest greenspaces in cities

Forested natural areas provide city residents with an escape from increasing temperatures. In this study we found that natural areas are significantly cooler than non-natural and landscaped areas. Forested natural areas were in particular the coolest, providing temperatures that can be several degrees or more lower than areas of landscaped trees. Results from the land surface temperature study support this, showing forested land cover types as cooler than other types of greenspace. This finding highlights the potential to include natural areas in plans aimed at addressing urban heat islands. As extreme temperatures become more common, natural areas should be incorporated into solutions alongside more common practices such as street tree planting, green roof installation, and innovations in building materials.

Natural areas are significantly cooler than non-natural and landscaped areas.

All natural areas do not cool equally

Healthier forested areas tended to be cooler than those in a more degraded state during the hottest point in the day. These higher quality forests also experienced a smaller range of daily temperatures and fewer high heat extremes than both landscaped locations and forests in a more degraded state. Understanding the relationship between forest condition and cooling impacts is important. Urban forests face many threats including fragmentation and increased pressures from problem species[35].

These high levels of disturbance put forested natural areas at risk of deteriorating to their most degraded state where all tree canopy is lost. Because of these pressures, forest management is key to maintaining forests and their benefits, including heat mitigation, into the future.

To sustain natural area cooling benefits - funding and protection is needed

Unfortunately, funding for management in municipal budgets is scarce. A recent report by the NAC found that just 0.7% of NYC Parks' expense budget is allocated to the care of forested natural areas[36], though they comprise 24% of parkland. A survey of the collaborating cities from this study showed that, on average, 4% of city park budgets were allocated to the care of forested natural areas, despite making up the majority of city parkland.

In addition to underfunding, destruction of natural areas for development is a continuous threat faced in urban environments, as city populations grow and the demand for land is heightened. Despite their outsized ecosystem services and greater public acceptance of the importance of nature, losses continue. Some of the cities that participated in this study have been heavily affected. Notable losses include 5,000 acres over the last 10 years in Hillsborough County, FL, and unknown hundreds of acres in Austin, TX, and Chicago, IL, in that same timeframe. Some losses have made headlines in New York City[37] and Atlanta, GA[38], where residents took to protesting against developers.

PHOTO: A healthy upland forest in Paul Ruster park in Indianapolis, IN, containing multiple sizes/ages of trees, dead wood to provide habitat for wildlife, and a healthy understory layer. Photo Credit: Brenda Howard, May 2019.

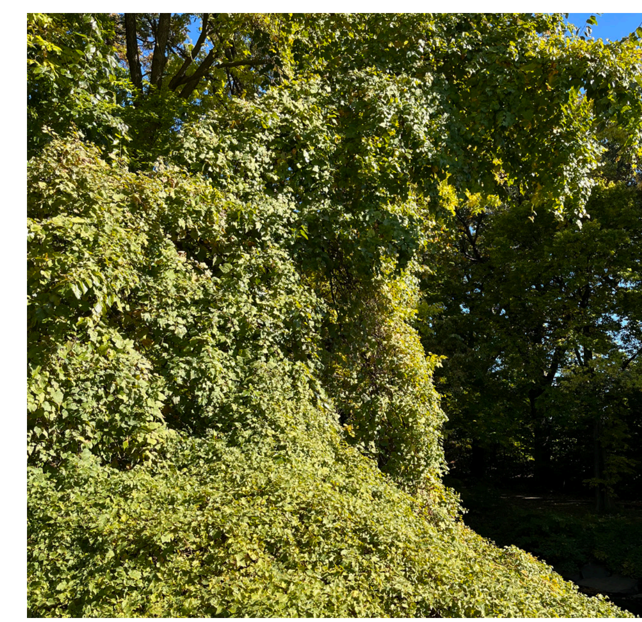


PHOTO: A degraded forest overtaken by aggressive vines along the Bronx River in New York City. When aggressive vine species are left to grow unmanaged, they can strangle and kill trees, resulting in a loss of tree canopy, and smother young trees, preventing the next generation of trees from growing. Photo Credit: Giselle Herrera, 2022.

Healthy natural areas do more than cool our cities

Natural areas are often underappreciated, and may be viewed as unmanaged "weedy"[39] areas when compared to mowed grass and trees in neatly landscaped parks and lining streets, but countless studies have shown: these areas are vital to us and the wildlife that call our cities home. While all greenspace is important for fostering the health and wellbeing of life in cities, natural areas punch above their weight. These areas provide more ecosystem benefits per unit area than landscaped areas. This includes habitat for wildlife, capturing stormwater, cleaning the air, storing carbon, and providing unique places of respite that have known mental and physical health benefits[40,41,42].

Our summer 2022 cooling study with participation from 12 cities across the U.S. is a crucial step in broadening our understanding about the cooling potential of urban natural areas. To learn more from this set of data, we plan to conduct more analyses to examine which characteristics have the most influence on cooling, including the extent of canopy cover, size of natural area, elevation, types of plants present, and specific factors that relate to forest health. Work is also planned to explore how far outside the natural areas the cooling extends, a crucial point to clarify to enable us to include them in climate adaptation plans.

CALL to ACTION

It's clear—urban natural areas should be part of climate action plans, but are underfunded and unprotected, leaving them imperiled in cities across the country. These spaces cannot persist without your help. For preservation to be a reality, policymakers need to allocate sufficient funding for natural area maintenance to reduce the risks of degradation, and pass land protections laws to prevent development. Without proper funding and protection, the vast benefits of natural areas will diminish in many cities, leading to hotter and less livable cities. Cities must also invest in infrastructure including safe, accessible trail networks; nearby restrooms; and sources of drinking water to maximize residents' access to and benefits from natural areas. Without these changes, cities face challenges in preserving their natural areas and sharing the advantages that come with them. But you can help:

- **Contact your elected officials and request additional funding for natural areas care in your city.**
- **Does your city have a volunteer stewardship program? Sign up and pitch in to help maintain your local trails and natural spaces.**
- **Visit your local natural areas and post about it on social media. The best way for natural areas to get more attention (and protection) is to increase their profile.**

The time is NOW for urban natural areas to be integrated into climate action plans.

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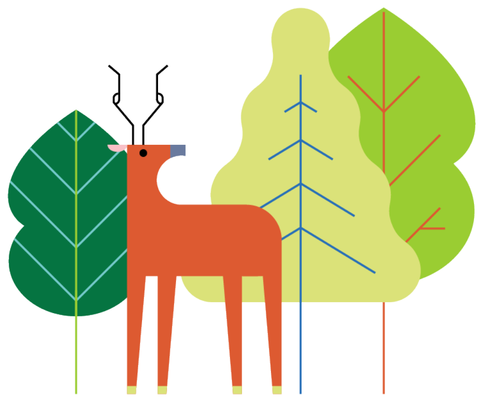


NATURAL AREA CLASSES

Upland Forest: Tree dominated, closed canopy communities on soils that are well-drained and never regularly flooded; or on soils that are usually well-drained and not hydric, and lack predominantly wetland vegetation. Site is usually not within or adjacent to a wetland. Canopy cover >75%. Contains structural understory layers that can include herbaceous and shrub species. Subtypes:

- Conifer Dominated
- Deciduous Dominated

Upland Woodland: Tree dominated communities on soils that are well-drained and never regularly flooded; or on soils that are usually well-drained and not hydric, and lack predominantly wetland vegetation. Site is usually not within or adjacent to a wetland. Canopy covers 51-75%. Contains structural understory layers that can include herbaceous and shrub species. Canopy. Subtypes:

- Conifer Dominated
- Deciduous Dominated

Savannahs: Plant communities co-dominated by woody and herbaceous species, where the woody canopy is open enough to support herbaceous species requiring high light levels. The woody stems that form the canopy may be isolated or clustered. The herbaceous component may occur as a matrix, as patches in a woody matrix, or an intermediate state. Canopy covers 10-50%. Subtypes:

- Tree Dominated
- Shrub Dominated

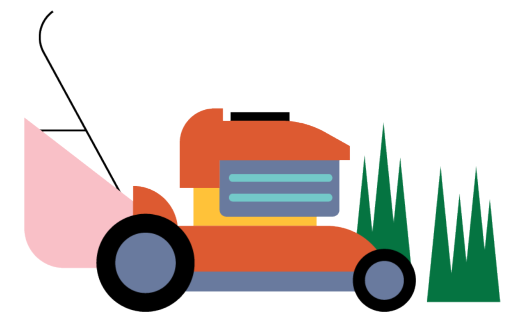
Shrubland: Shrubs are dominant in the overstory and/or midstory and/or understory. Site dominated by shrubs (>50% cover). Trees are absent from the site OR cover <25%.

Forested Wetland: A forested wetland (PFO) or swamp is a closed-canopy tree-dominated vegetation type adapted to tolerate flooded conditions, where the soil is saturated or flooded for some or all of the growing season.

Freshwater Wetland: Palustrine sites dominated by shrubs or herbaceous plants (PSS & PEM). Wetland communities that are permanently saturated by seepage, permanently flooded wetlands, and wetlands that are seasonally or intermittently flooded (these may be seasonally dry). Sites can be within or adjacent to a mapped or unmapped wetland.

Grassland: Open uplands dominated by grasses, graminoids, forbs, or vines, with occasional scattered shrubs. Trees are absent from the site OR trees cover <10% of the site.

Mangrove Forest: Brackish to saline coastal wetlands dominated by mangrove trees and other halophytic vegetation. Found in tropical and subtropical regions.



LANDSCAPED VEGETATION CLASSES

Maintained Lawn w/ Trees: Highly-manipulated, landscaped areas dominated by cultivated (usually cool season) turf grasses. Cemeteries could be included in this cover type. No canopy cover constraints.

Mowed Lawn: Highly-manipulated, landscaped areas dominated by cultivated (usually cool season) turf grasses. Trees are absent from the site.

BUILT/PAVED

Paved/Built: Areas dominated (>=75%) by built/impermeable surfaces such as pavement and buildings.

CITY	LAND COVER CLASS (LISTED COOLEST TO WARMEST)	CATEGORY	°F ABOVE/ BELOW CITYWIDE AVERAGE	ACRES	POLYGONS
Austin, TX	Upland Deciduous Forest	Natural	-3.21	4,415.11	15
	Trees Over Mowed Lawn	Landscaped	0.00	253.92	9
	Built	Built	+2.68	210.29	10
Baltimore, MD	Upland Deciduous Forest	Natural	-7.46	120.11	11
	Mowed Lawn	Landscaped	-1.15	80.69	11
	Built	Built	+3.85	719.13	10
Billings, MT	Trees Over Mowed Lawn	Landscaped	-5.36	177.47	8
	Mowed Lawn	Landscaped	-3.50	86.66	8
	Built	Built	+1.57	260.77	10
	Grassland	Natural	+5.23	395.49	9
Chicago, IL	Forested Wetland	Natural	-7.11	173.49	12
	Upland Deciduous Forest	Natural	-5.66	170.57	15
	Tree Savanna	Natural	-5.12	133.53	13
	Freshwater Wetland	Natural	-4.94	306.20	13
	Grassland	Natural	-4.51	150.40	14
	Trees Over Mowed Lawn	Landscaped	-2.57	114.07	20
	Mowed Lawn	Landscaped	-2.47	173.73	27
	Built	Built	+1.42	289.70	31
Houston, TX	Forested Wetland	Natural	-5.80	1,431.70	10
	Grassland	Natural	-1.77	91.74	8
	Mowed Lawn	Landscaped	-0.76	95.98	11
	Trees Over Mowed Lawn	Landscaped	-0.45	252.93	13
	Built	Built	+3.28	148.51	16
Indianapolis, IN	Forested Wetland	Natural	-5.71	382.84	9
	Upland Deciduous Forest	Natural	-5.69	402.58	10
	Mowed Lawn	Landscaped	-1.86	74.14	8
	Built	Built	+6.28	162.06	11
Miami-Dade County, FL	Upland Deciduous Forest	Natural	-3.18	256.63	17
	Mangrove Forest	Natural	-3.00	762.25	11
	Trees Over Mowed Lawn	Landscaped	-0.98	202.10	8
	Conifer Woodland	Natural	-0.95	398.02	14
	Built	Built	+2.07	151.41	22
Minneapolis-St. Paul, MN	Upland Deciduous Forest	Natural	-8.22	222.92	14
	Forested Wetland	Natural	-7.44	63.36	12
	Deciduous Woodland	Natural	-5.41	51.02	11
	Trees Over Mowed Lawn	Landscaped	-2.59	333.78	11
	Grassland	Natural	-2.36	48.52	13
	Built	Built	+4.59	131.84	10

CITY	LAND COVER CLASS (LISTED COOLEST TO WARMEST)	CATEGORY	°F ABOVE/ BELOW CITYWIDE AVERAGE	ACRES	POLYGONS
New York City, NY*	Forested Wetland	Natural	-5.79	279.95	-
	Maritime Forest	Natural	-5.16	1,388.81	-
	Upland Forest	Natural	-4.81	11,804.22	-
	Freshwater Wetland	Natural	-4.65	1,336.88	-
	Grassland & Shrubland	Natural	-3.3	4,864.26	-
	Bare Soil	Natural	-0.56	1,227.06	-
	Mowed lawn	Landscaped	-0.12	26,426.76	-
	Landscaped Canopy	Landscaped	+0.20	25,990.50	-
	Built	Built	+0.99	114,196.95	-
Seattle, WA	Upland Coniferous Forest	Natural	-9.01	259.25	11
	Forested Wetland	Natural	-7.65	83.77	11
	Upland Deciduous Forest	Natural	-7.08	730.57	19
	Trees Over Mowed Lawn	Natural	+0.77	206.82	13
	Mowed Lawn	Landscaped	+1.93	82.58	17
	Built	Built	+3.85	523.65	19
St. Louis, MO	Trees Over Mowed Lawn	Landscaped	-3.96	1,135.15	15
	Upland Deciduous Forest	Natural	-2.86	1,405.81	16
	Mowed Lawn	Landscaped	-1.21	175.87	15
	Built	Built	+4.42	540.59	14
Tampa-Hillsborough County, FL	Mangrove Forest	Natural	-3.51	847.90	10
	Forested Wetland	Natural	-3.20	5,959.12	129
	Upland Deciduous Forest	Natural	-2.82	2,164.86	64
	Deciduous Woodland	Natural	-2.05	3,026.61	39
	Freshwater Wetland	Natural	-1.98	507.75	28
	Shrubland	Natural	-1.45	647.73	9
	Grassland	Natural	+0.82	3,915.79	28
	Mowed Lawn	Landscaped	+1.02	177.95	10
	Built	Built	+3.37	191.26	11

* The polygon count column is empty because NYC's land cover data is based on a full citywide coverage that is not broken down into discrete polygons.

SITE INFORMATION		SUNRISE AIR TEMPERATURE (°F)^				AFTERNOON AIR TEMPERATURE (°F)^^			
CITY	SITE NAME	HEALTHY	DEGRADED	LANDSCAPED	COOLEST	HEALTHY	DEGRADED	LANDSCAPED	COOLEST
Austin, TX	RG Guerrero	75.05	74.83	75.82	Degraded	94.41	94.42	94.16	Landscaped
	Onion Creek	73.07	73.41	74.57	Healthy	93.87	94.28	93.80	Landscaped
	Walnut Creek	75.28	75.75	76.02	Healthy	93.64	93.70	93.78	Healthy
Baltimore, MD	Gwynns Falls Leakin Park	68.28	68.54	67.23	Landscaped	79.58	80.85	82.28	Healthy
	Herring Run Park	68.34	67.43	69.44	Degraded	79.43	79.32	82.31	Degraded
	Springfield Woods*	72.05	71.38	--	--	84.11	85.96	--	--
	Fairwood Forest*	72.76	72.56	--	--	83.20	82.91	--	--
Billings, MT	Billings Heights	53.38	53.59	56.43	Healthy	78.49	80.46	82.82	Healthy
	Phipps Park	61.30	59.92	56.30	Landscaped	80.50	82.45	82.17	Healthy
	Riverfront Park	52.27	53.77	54.75	Healthy	80.48	79.98	80.93	Degraded
Chicago, IL	Burnham Park	68.51	68.10	69.22	Degraded	75.98	76.65	77.52	Healthy
	Columbus Park	67.53	67.03	67.95	Degraded	78.02	77.19	79.68	Degraded
	North Park Village	66.21	66.39	66.79	Healthy	76.71	76.67	78.37	Degraded
Houston, TX	FM Law Park	75.28	74.49	74.99	Degraded	89.08	89.37	89.94	Healthy
	Herman Brown Park	75.54	75.68	76.94	Healthy	88.59	88.34	89.35	Degraded
	Keith Weiss Park	75.34	75.15	76.58	Degraded	88.59	89.59	90.69	Healthy
Indianapolis, IL	Eagle Creek Park	65.02	66.99	66.12	Healthy	78.78	78.45	80.08	Degraded
	Paul Ruster Park	65.83	64.88	64.94	Degraded	78.74	79.34	81.19	Healthy
	Marott Park	65.14	64.90	65.98	Degraded	77.14	76.23	80.79	Degraded
Miami-Dade County, FL	Florida City	75.81	75.92	78.13	Healthy	87.68	87.14	87.38	Degraded
	Cutler Bay	77.00	75.55	79.14	Degraded	87.77	88.67	86.91	Landscaped
	Arch Creek Park	78.37	79.35	80.91	Healthy	85.37	86.71	87.65	Healthy
Minneapolis-St. Paul, MN	Theodore Wirth Regional Park	63.81	63.46	63.33	Landscaped	76.98	76.17	78.78	Degraded
	North Mississippi Regional Park*	64.44	--	64.71	--	76.95	--	78.64	--
	Minnehaha Regional Park	61.64	61.90	61.84	Healthy	76.76	78.42	77.95	Healthy
New York City, NY	Clove Lakes Park	69.42	69.45	70.31	Healthy	79.12	79.79	82.12	Healthy
	Seton Falls Park	68.40	69.21	70.71	Healthy	78.08	80.14	82.00	Healthy
	Forest Park	69.94	69.83	71.95	Degraded	78.31	78.18	82.74	Degraded
Seattle, WA	MG Magnusson	58.58	57.26	60.28	Degraded	73.13	76.22	75.75	Healthy
	Delridge	57.42	55.84	59.01	Degraded	71.40	72.50	73.51	Healthy
	Discovery Park	57.31	57.48	57.72	Healthy	68.32	69.64	71.39	Healthy
	Duwamish	59.24	60.29	59.57	Healthy	70.91	74.69	75.21	Healthy
	Kubota Gardens	59.02	59.21	59.21	Healthy	73.64	73.98	76.83	Healthy
	West Seattle	57.32	58.33	58.70	Healthy	69.23	68.82	71.87	Degraded
St. Louis, MO	Forest Park	69.20	68.75	69.25	Degraded	82.29	80.23	84.82	Degraded
	O Fallon Park	70.71	70.36	70.98	Degraded	82.13	81.74	85.05	Degraded
	Possum Woods CA	67.69	67.93	68.38	Healthy	81.28	81.23	85.19	Degraded
Tampa-Hillsborough County, FL	MacDill 48 Park*	76.38	--	77.08	--	84.92	--	87.79	--
	Rocky Creek	74.30	74.60	74.43	Healthy	85.09	84.74	86.11	Degraded
	Town n' Country	74.03	74.87	76.07	Healthy	85.40	85.65	86.65	Healthy

*Air temperature data for these sites is not available for some locations.

^Average air temperature for all air temperature readings within 30 minutes of sunrise for the whole summer.

^^Average air temperature for all air temperature readings from 12:00-7:00 PM for the whole summer.

SITE INFORMATION		AIR TEMPERATURE AFTER SUNSET(°F)^				DAILY AIR TEMPERATURE RANGE (°F)^^			
CITY	SITE NAME	HEALTHY	DEGRADED	LANDSCAPED	COOLEST	HEALTHY	DEGRADED	LANDSCAPED	COOLEST
Austin, TX	RG Guerrero	82.06	81.70	82.57	Degraded	24.70	25.45	24.14	Landscaped
	Onion Creek	80.54	80.87	81.69	Healthy	26.23	26.91	24.39	Landscaped
	Walnut Creek	82.21	82.65	82.93	Healthy	23.65	22.89	22.63	Landscaped
Baltimore, MD	Gwynns Falls Leakin Park	71.53	71.99	70.42	Landscaped	15.10	16.57	20.81	Healthy
	Herring Run Park	72.61	71.47	74.13	Degraded	14.51	15.80	17.06	Healthy
	Springfield Woods*	77.08	76.17	--	--	16.77	23.09	--	--
	Fairwood Forest*	76.77	76.24	--	--	14.49	14.28	--	--
Billings, MT	Billings Heights	62.43	63.54	66.35	Healthy	32.08	36.19	33.26	Healthy
	Phipps Park	70.39	69.01	65.91	Landscaped	26.41	31.14	34.49	Healthy
	Riverfront Park	63.27	63.12	65.60	Degraded	35.79	35.63	35.01	Landscaped
Chicago, IL	Burnham Park	71.78	71.49	73.09	Degraded	13.05	14.79	14.04	Healthy
	Columbus Park	72.14	71.24	72.85	Degraded	15.09	14.74	17.09	Degraded
	North Park Village	69.97	70.11	70.92	Healthy	15.70	16.06	17.50	Healthy
Houston, TX	FM Law Park	79.23	78.24	79.61	Degraded	20.03	21.36	21.25	Healthy
	Herman Brown Park	79.80	80.20	81.29	Healthy	18.83	18.04	18.18	Degraded
	Keith Weiss Park	78.87	79.62	81.06	Healthy	19.23	20.70	20.50	Healthy
Indianapolis, IL	Eagle Creek Park	68.78	70.99	70.95	Healthy	18.23	14.97	18.18	Degraded
	Paul Ruster Park	70.68	69.70	69.91	Degraded	16.77	18.80	21.29	Healthy
	Marott Park	69.53	69.36	71.20	Degraded	15.58	14.80	19.13	Degraded
Miami-Dade County, FL	Florida City	78.95	78.68	81.22	Degraded	18.02	19.57	14.48	Landscaped
	Cutler Bay	79.96	78.38	81.69	Degraded	17.40	20.86	12.65	Landscaped
	Arch Creek Park	80.42	81.41	82.89	Healthy	11.53	12.24	11.91	Healthy
Minneapolis-St. Paul, MN	Theodore Wirth Regional Park	69.16	68.34	68.25	Landscaped	17.98	18.50	21.09	Healthy
	North Mississippi Regional Park *	70.08	--	70.54	--	16.57	--	18.77	--
	Minnehaha Regional Park	65.59	65.93	66.11	Healthy	20.87	24.04	22.54	Healthy
New York City, NY	Clove Lakes Park	73.64	74.26	75.60	Healthy	14.11	14.73	16.94	Healthy
	Seton Falls Park	71.71	73.37	75.55	Healthy	14.43	15.98	16.18	Healthy
	Forest Park	73.74	72.90	76.52	Degraded	12.80	12.46	16.13	Degraded
Seattle, WA	MG Magnusson	62.80	61.24	65.70	Degraded	20.14	25.77	20.32	Healthy
	Delridge	61.88	59.71	64.45	Degraded	17.60	22.49	19.38	Healthy
	Discovery Park	61.18	61.82	62.37	Healthy	14.68	15.75	17.79	Healthy
	Duwamish	63.72	65.94	65.26	Healthy	14.72	18.68	19.46	Healthy
	Kubota Gardens	64.09	64.42	64.39	Healthy	18.05	18.22	22.04	Healthy
	West Seattle	61.41	62.67	63.45	Healthy	15.67	15.05	18.35	Degraded
St. Louis, MO	Forest Park	74.04	73.27	74.40	Degraded	17.73	15.86	21.50	Degraded
	O Fallon Park	75.56	75.36	76.48	Degraded	15.90	15.75	19.35	Degraded
	Possum Woods CA	72.07	72.26	73.05	Healthy	19.07	18.29	23.04	Degraded
Tampa-Hillsborough County, FL	MacDill 48 Park*	78.04	--	79.00	--	14.66	--	14.01	--
	Rocky Creek	76.61	76.80	76.68	Healthy	17.13	16.28	19.15	Degraded
	Town n' Country	76.38	76.90	78.59	Healthy	18.35	17.90	18.05	Degraded

*Air temperature data for these sites is not available for some locations.

^Average air temperature for all air temperature readings 3 hours after sunset - calculated by averaging all readings within 30 minutes of that time - for the whole summer.

^^Average range of air temperature for all days where all readings were present. Calculated by subtracting the minimum from the maximum air temperature for the day and averaging that for all days at a site.