United States Department of Agriculture

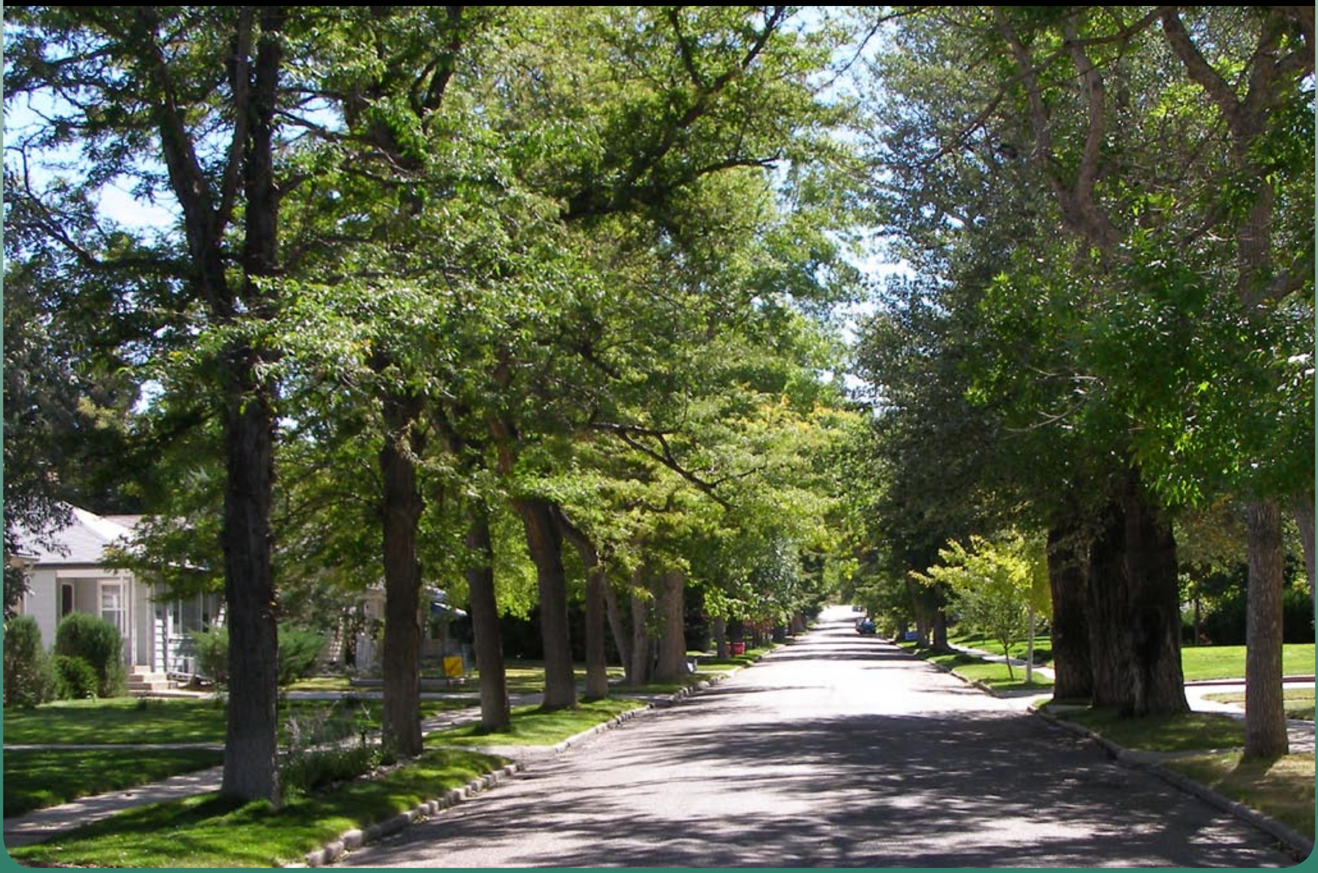
Forest Service

**Northern Research Station**

Resource Bulletin NRS-4

# Assessing Urban Forest Effects and Values

# Casper's Urban Forest



Northern Research Station
USDA Forest Service

UFORE
Urban Forest Effects Model

## Abstract

An analysis of trees in Casper, WY reveals that this city has about 123,000 trees with canopies that cover 8.9 percent of the area. The most common tree species are plains cottonwood, blue spruce, and American elm. The urban forest currently store about 37,000 tons of carbon valued at $689,000. In addition, these trees remove about 1,200 tons of carbon per year ($22,000 per year) and about 50 tons of air pollution per year ($249,000 per year). The structural, or compensatory, value is estimated at $243 million. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Casper area.

## The Authors

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# Executive Summary

Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local and regional society and economy. To better understand the urban forest resource and its numerous values, the USDA Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model. Results from this model are used to advance the understanding of the urban forest resource, improve urban forest policies, planning and management, provide data for the potential inclusion of trees within environmental regulations, and determine how trees affect the environment and consequently enhance human health and environmental quality in urban areas.

Forest structure is a measure of various physical attributes of the vegetation, such as tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Forest functions, which are determined by forest structure, include a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures. Forest values are an estimate of the economic worth of the various forest functions.

To help determine the vegetation structure, functions, and values of the urban forest in Casper, a vegetation assessment was conducted during the summer of 2006. For this assessment, one-tenth acre field plots were sampled and analyzed using the UFORE model. This report summarizes results and values of:

- Forest structure
- Potential risk to forest from insects or diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)
- Changes in building energy use

**Casper's Urban Forest Summary**

| Feature | Measure |
|---|---|
| Number of trees | 123,000 |
| Tree cover | 8.9% |
| Most common species | plains cottonwood, blue spruce, American elm |
| Percentage of trees < 6-inches diameter | 57.5% |
| Pollution removal | 50 tons/year ($249,000/year) |
| Carbon storage | 37,000 tons ($689,000) |
| Carbon sequestration | 1,200 tons/year ($22,000/year) |
| Building energy increase | $26,700/year |
| Carbon emissions increase | $700 / year |
| Structural value | $243 million |

Ton – short ton (U.S.) (2,000 lbs)

## Urban Forest Effects Model and Field Measurements

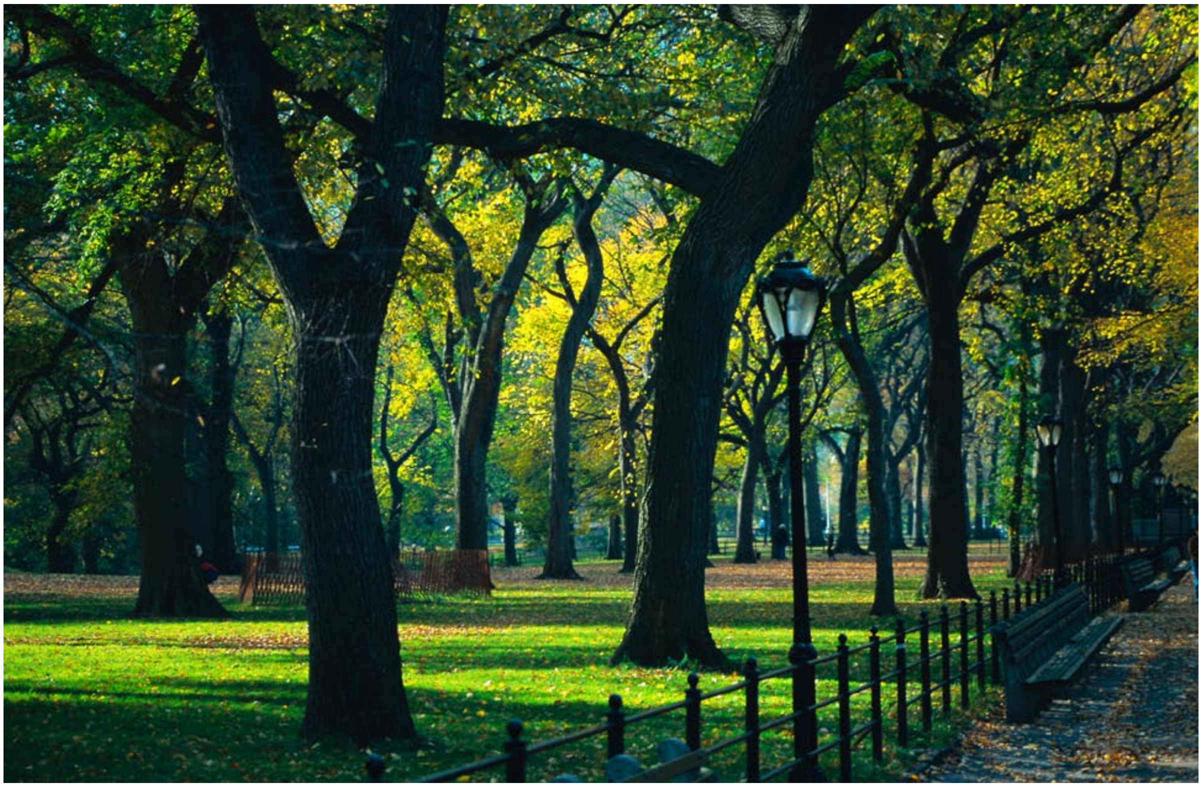
Though urban forests have many functions and values, currently only a few of these attributes can be assessed. To help assess the city's urban forest, data from 234 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model[1].

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects, including:

- Urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, or Dutch elm disease.

In the field, one-tenth acre plots were located in the City of Casper and then post stratified by land use. Land uses were used to divide the analysis into smaller zones. The plots were divided among the following land uses: Business/Commercial/Industrial (51 plots), Institutional (8 plots), Not Zoned (20 plots), Park Historic (40 plots), Planned Development (18 plots), Residential (97 plots). This distribution allows for comparison among land uses.

Field data were collected for the Forest Service by City of Casper personnel; data collection took place during the leaf-on season to properly assess tree canopies. Within each plot, data included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem-diameter at breast height (d.b.h.; measured at 4.5 ft.), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to residential buildings[2].



To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[3]. To adjust for this difference, biomass results for open-grown urban trees are multiplied by 0.8.[3] No adjustment is made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models.[4, 5] As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[6, 7] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[8]

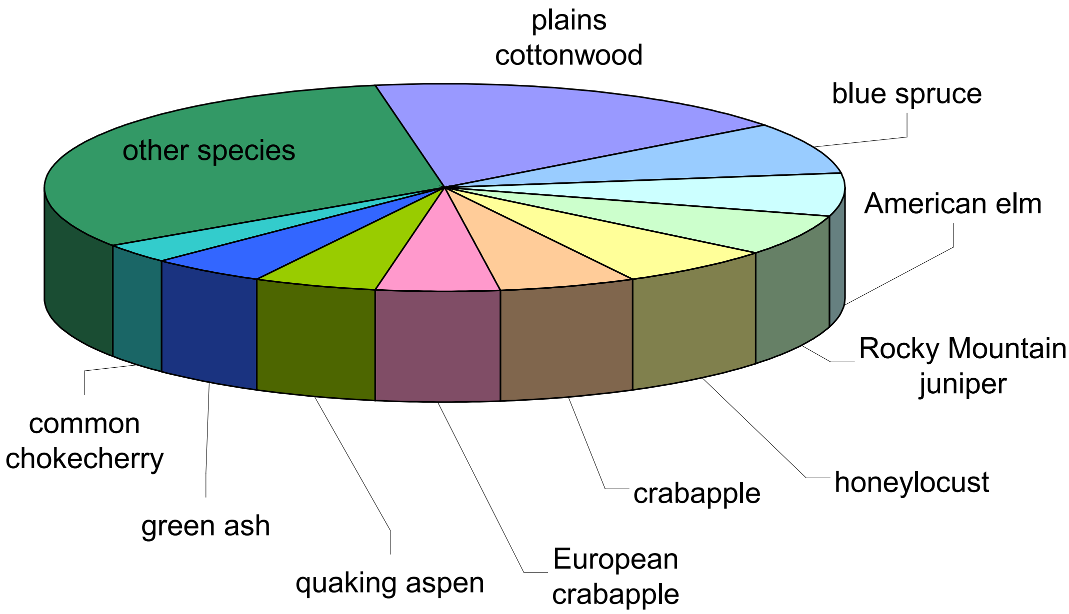
Seasonal effects of trees on residential building energy use was calculated based on procedures described the literature[9] using distance and direction of trees from residential structures, tree height and tree condition data.

Compensatory values were based on valuation procedures of the Council of Tree and Landscape Appraisers[10], which uses tree species, diameter, condition and location information[10].

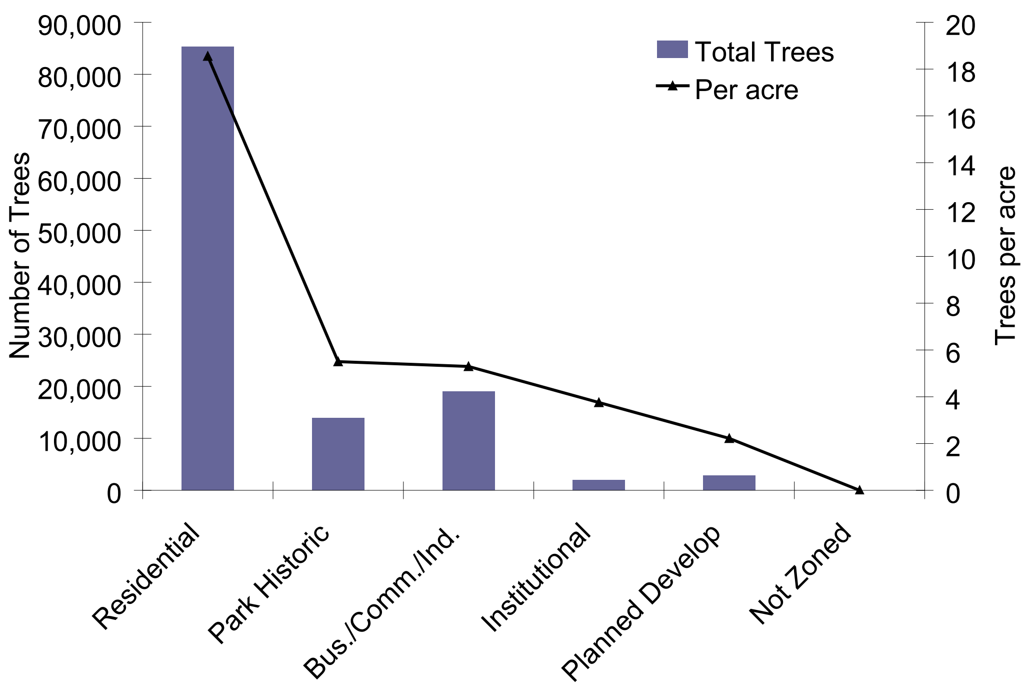
To learn more about UFORE methods[11] visit:
http://www.nrs.fs.fed.us/UFORE/data/ or www.ufore.org

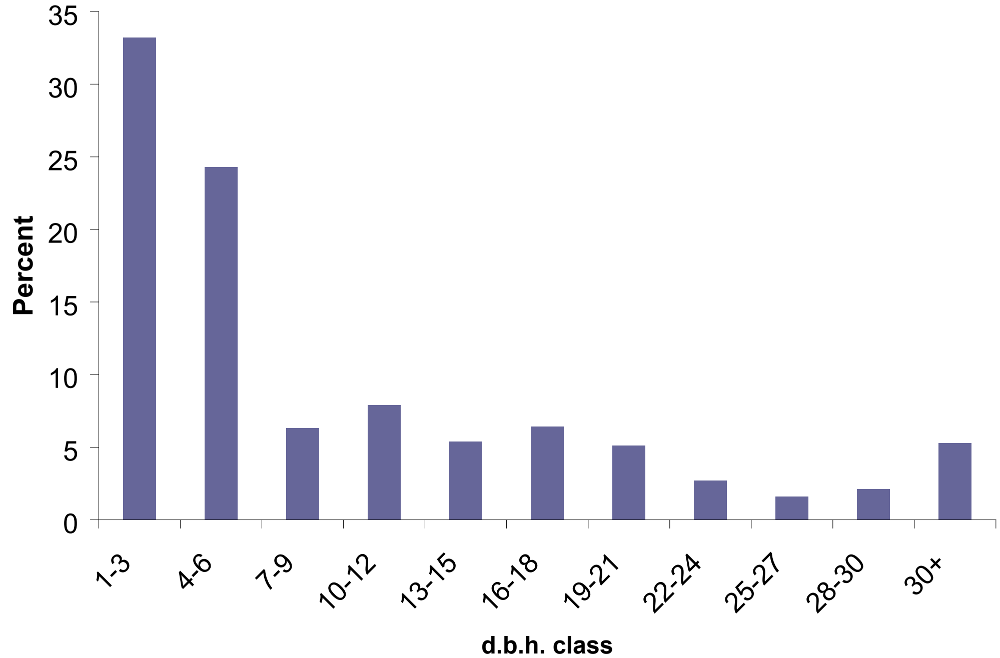
## Tree Characteristics of the Urban Forest

The urban forest of Casper has an estimated 123,000 trees with a tree cover of 8.9 percent. Trees that have diameters less than 6 inches account for 57.5 percent of the population. The three most common species in the urban forest are plains cottonwood (17.5 percent), blue spruce (8.1 percent), and American elm (6.7 percent). The 10 most common species account for 68.3 percent of all trees; their relative abundance is illustrated below.

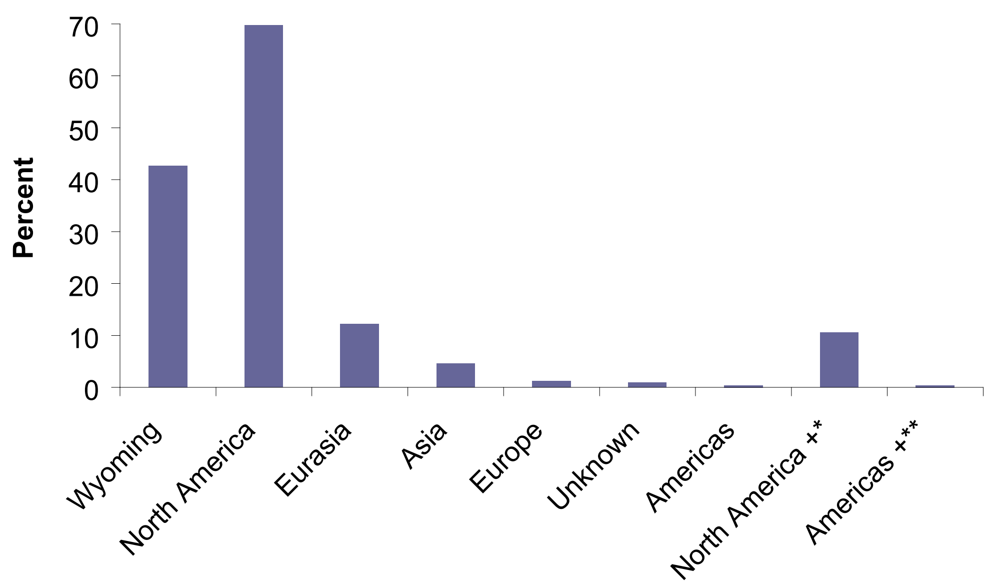



The highest density of trees occurs in the Residential (18.6 trees/acre), followed by the Park Historic (5.5 trees/acre) and the Business/Commercial/Industrial (5.3 trees/acre). The overall tree density in Casper is 9.1 trees/acre, which is lower than other city tree densities (Appendix I), which range from 14.4 to 119.2 trees/acre. However, most of these cities are in forested ecotypes, unlike Casper, which is located in a grassland ecotype. Cities in grassland areas tend to have lower tree cover than cities found in forested regions.





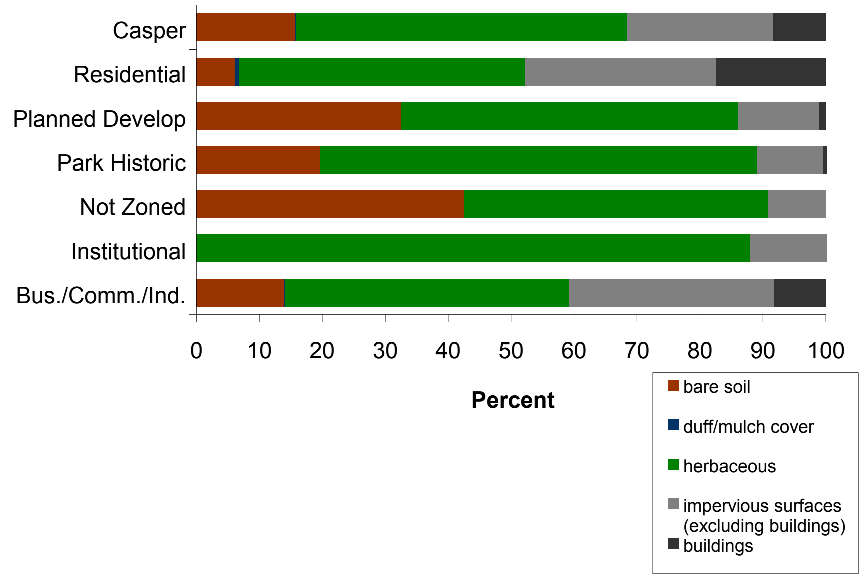

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotics species are invasive plants that can potentially out-compete and displace native species. In Casper, about 43 percent of the trees are from species native to Wyoming. Trees with a native origin outside of North America are mostly from Eurasia (12.2 percent of the species).




*North America+ refers to tree species that are native to North America and one other continent
**Americas+ refers to tree species that are native to North and South America and one other continent

# Urban Forest Cover and Leaf Area

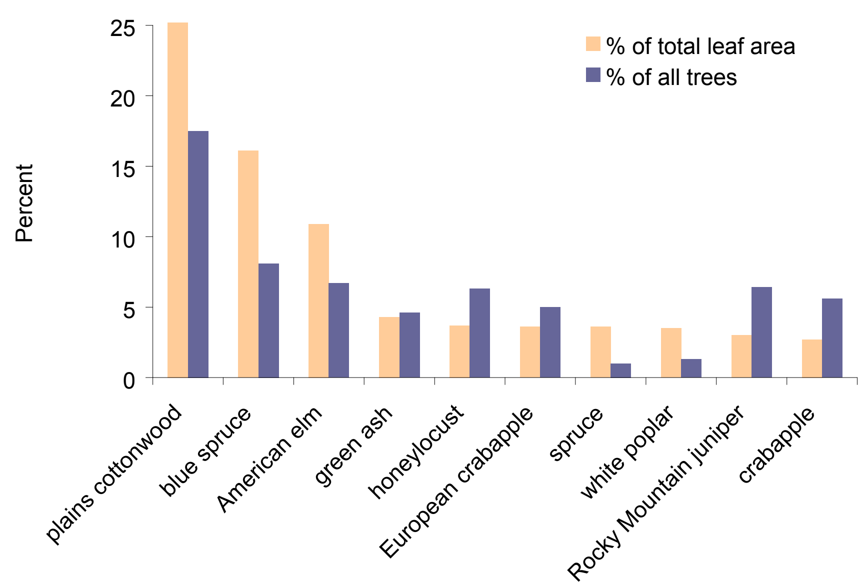
Trees cover about 8.9 percent of Casper, shrubs cover 2.0 percent of the city. Dominant ground cover types include herbaceous (e.g., grass, gardens) (52.5 percent), impervious surfaces (excluding buildings) (e.g., driveways, sidewalks, parking lots) (23.3 percent), and bare soil (15.7 percent).




Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In Casper trees that dominate in terms of leaf area are plains cottonwood, blue spruce, and American elm.

Tree species contributing a relatively large amount of leaf area per tree (typically larger trees) are spruce, white poplar, blue spruce. Species contributing a relatively small amount of leaf area per tree (typically smaller trees) are pine, common juniper, and quaking aspen.

The importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative abundance. The most important species in the urban forest, according to calculated IVs, are plains cottonwood, blue spruce, and American elm.




| Common Name | % Pop[a] | % LA[b] | IV[c] |
|---|---|---|---|
| plains cottonwood | 17.5 | 32.2 | 49.7 |
| blue spruce | 8.1 | 16.1 | 24.2 |
| American elm | 6.7 | 10.9 | 17.6 |
| honeylocust | 6.3 | 3.7 | 10.0 |
| Rocky Mountain juniper | 6.4 | 3.0 | 9.4 |
| green ash | 4.6 | 4.3 | 8.9 |
| European crabapple | 5.0 | 3.6 | 8.6 |
| crabapple | 5.6 | 2.7 | 8.3 |
| quaking aspen | 5.0 | 0.5 | 5.5 |
| white ash | 3.1 | 1.7 | 4.8 |

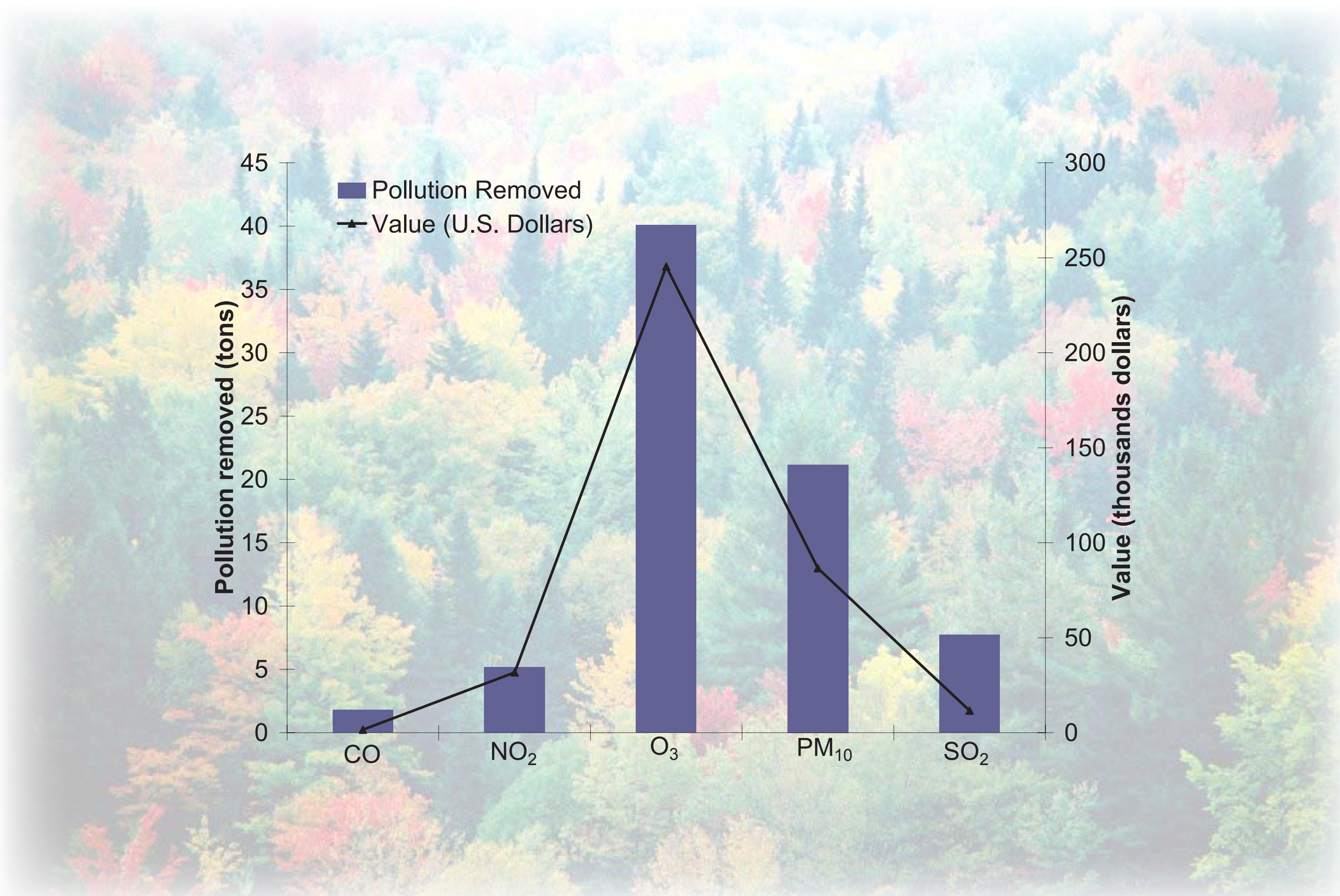
[a] percent of population
[b] percent of leaf area
[c] %Pop + %LA

## Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[12]

Pollution removal by trees and shrubs in Casper was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for the year 2000. Pollution removal was greatest for ozone ($O_3$), followed by particulate matter less than ten microns ($PM_{10}$), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), and carbon monoxide (CO). It is estimated that trees and shrubs remove 50 tons of air pollution (CO, $NO_2$, $O_3$, $PM_{10}$, $SO_2$) per year with an associated value of $249,000 (based on estimated national median externality costs associated with pollutants[13]). Trees remove about 3.1 times more air pollution than shrubs in Casper.

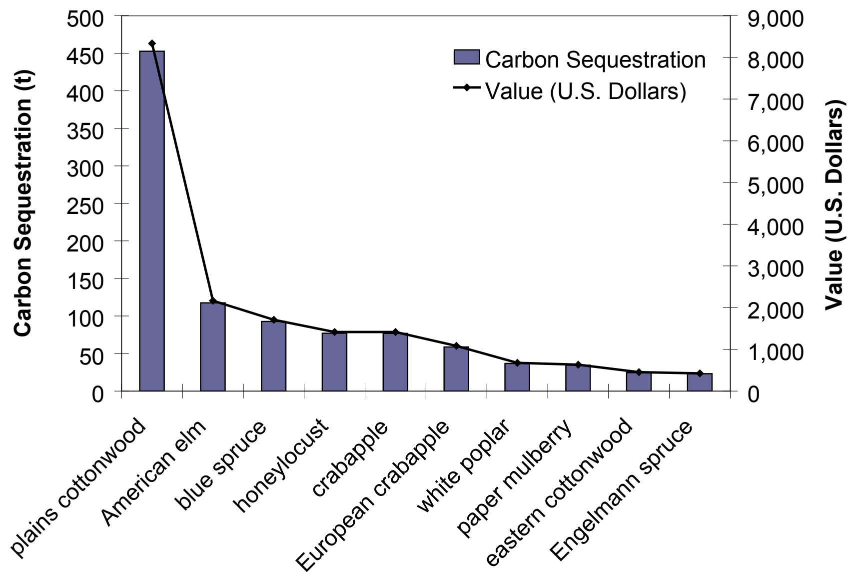
Due to limited pollutant monitors in Casper, pollution concentration data for CO, $NO_2$, and $SO_2$ were derived from the nearest city in the Casper region with monitors.



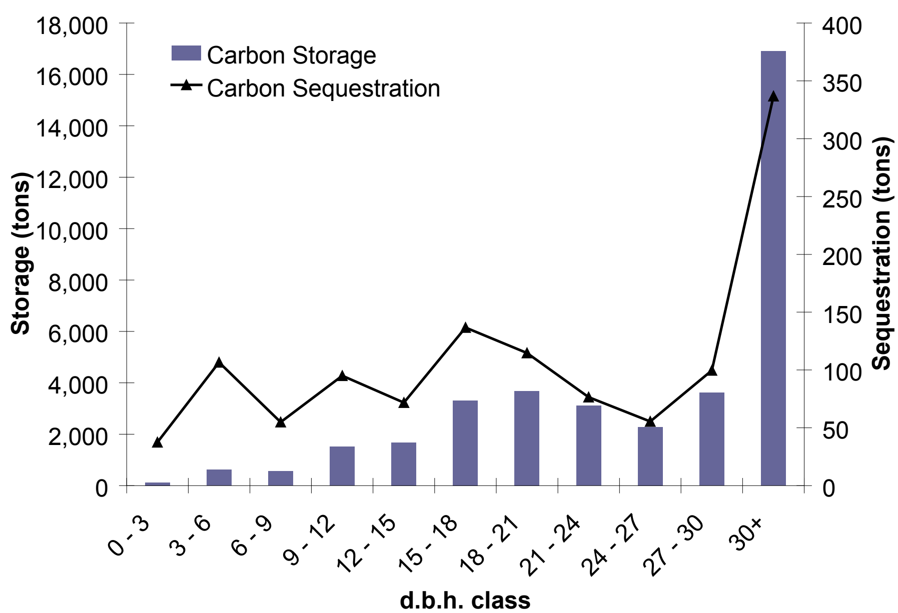
## Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[14]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Gross sequestration by trees in Casper is about 1,200 tons of carbon per year with an associated value of $22,000. Net carbon sequestration in the Casper urban forest is about 640 tons.




Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Casper are estimated to store 37,000 tons of carbon ($689,000). Of all the species sampled, plains cottonwood stores and sequesters the most carbon (approximately 50.9 percent of the total carbon stored and 38.2 percent of all sequestered carbon).



## Trees Affect Energy Use in Buildings

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space-conditioned residential buildings[9].

Based on average energy costs in 2002 dollars, trees in Casper are estimated to increase energy costs from residential buildings by $26,700 annually. Trees also cost an additional $700 in value per year by increasing the amount of carbon released by fossil-fuel based power plants (an increase of 100 tons of carbon emissions).

Better placement of trees around residential buildings to avoid shading structures during the winter or to increase windbreaks could increase energy savings from trees in Casper.

**Annual energy use change due to trees near residential buildings**

| | Heating | Cooling | Total |
|---|---|---|---|
| MBTU[a] | -8,600 | n/a | -8,600 |
| MWH[b] | -100 | 500 | 400 |
| Carbon avoided (t) | -220 | 110 | -110 |

[a]Million British Thermal Units
[b]Megawatt-hour

**Change in annual residential energy expenditures[c] (U.S. $) during heating and cooling seasons**

| | Heating | Cooling | Total |
|---|---|---|---|
| MBTU[a] | -55,000 | n/a | -55,000 |
| MWH[b] | -6,000 | 34,000 | 29,000 |
| Carbon avoided (t) | -3,200 | 2,500 | -700 |

[a]Million British Thermal Units
[b]Megawatt-hour
[c]Based on state-wide energy costs

## Structural and Functional Values

Urban forests have a structural value based on the tree itself (e.g., the cost of having to replace the tree with a similar tree). The structural value[10] of the urban forest in Casper is about $243 million. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees.

Urban forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. There are many other functional values of the urban forest, though they are not quantified here (e.g., reduction in air temperatures and ultra-violet radiation, improvements in water quality). Through proper and management, urban forest values can be increased. However, the values and benefits also can decrease as the amount of healthy tree cover declines.

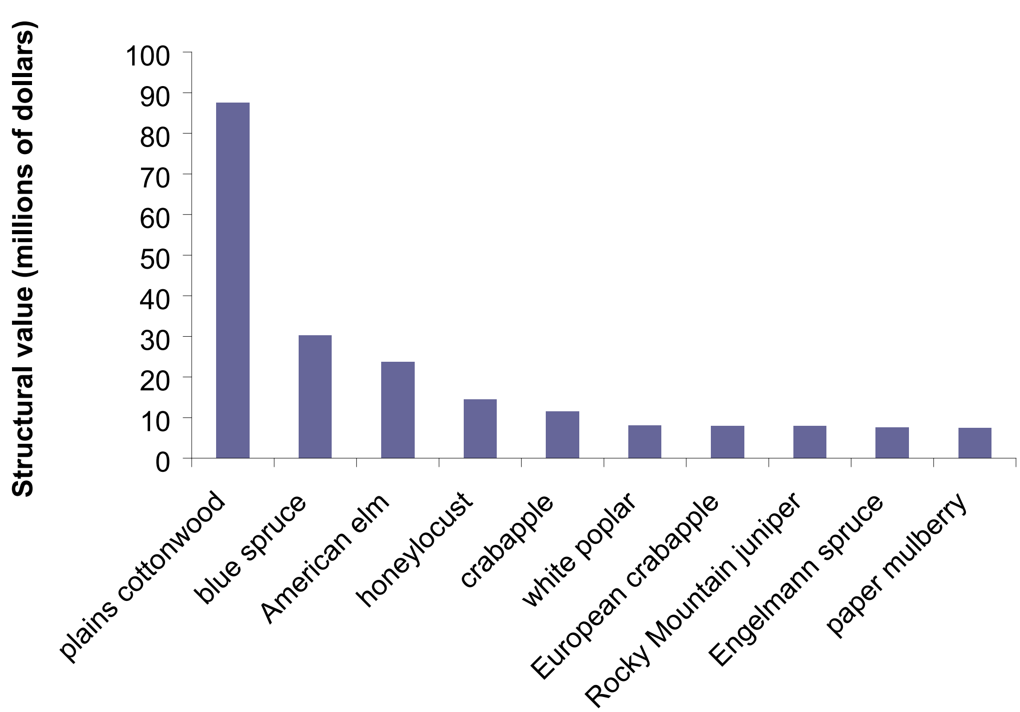
**Structural values:**

- Structural value: $243 million
- Carbon storage: $689,000

**Annual functional values:**

- Carbon sequestration: $22,000
- Pollution removal: $249,000
- Increased energy costs and carbon emissions: $-26,700

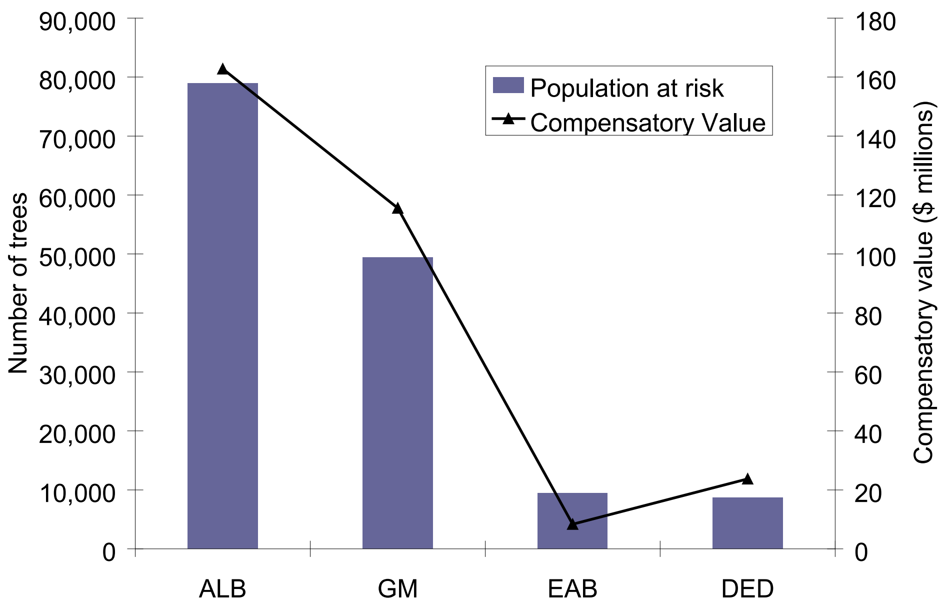
More detailed information on the urban forest in Casper can be found at http://www.nrs.fs.fed.us/UFORE/data. Additionally, information on other urban forest values can be found in Appendix I and information comparing tree benefits to estimates of average carbons emissions in the city, average automobile emissions, and average household emissions can be found in Appendix III.



## Potential Insect and Disease Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential impact: Asian longhorned beetle, gypsy moth, emerald ash borer, and Dutch elm disease.

The Asian longhorned beetle (ALB)[15] is an insect that bores into and kills a wide range of hardwood species. ALB represents a potential loss to the Casper urban forest of $163 million in structural value (64.1 percent of the population).




Kenneth R. Law
USDA APHIS PPQ
(www.invasive.org)

USDA Forest Service Archives
(www.invasive.org)

David Cappaert
Michigan State University
(www.invasive.org)

The gypsy moth (GM)[16] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $116 million in structural value (40.2 percent of the population).

Emerald ash borer (EAB)[17] has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 7.7 percent of the population ($8 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by the Dutch elm disease (DED). Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States.[18] Although some elm species have shown varying degrees of resistance, Casper possibly could lose 7.0 percent of its trees to this disease ($24 million in structural value).

# Appendix I. Comparison of Urban Forests

A commonly asked question is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

**I. City totals, trees only**

| City | % Tree cover | Number of trees | Carbon storage (tons) | Carbon sequestration (tons/yr) | Pollution removal (tons/yr) | Pollution value U.S. $ |
|---|---|---|---|---|---|---|
| Calgary, Canada[a] | 7.2 | 11,889,000 | 445,000 | 21,400 | 326 | 1,611,000 |
| Atlanta, GA[b] | 36.7 | 9,415,000 | 1,344,000 | 46,400 | 1,663 | 8,321,000 |
| Toronto, Canada[c] | 20.5 | 7,542,000 | 992,000 | 40,300 | 1,212 | 6,105,000 |
| New York, NY[b] | 20.9 | 5,212,000 | 1,350,000 | 42,300 | 1,677 | 8,071,000 |
| Baltimore, MD[d] | 21.0 | 2,627,000 | 597,000 | 16,200 | 430 | 2,129,000 |
| Philadelphia, PA[b] | 15.7 | 2,113,000 | 530,000 | 16,100 | 576 | 2,826,000 |
| Washington, DC[e] | 28.6 | 1,928,000 | 526,000 | 16,200 | 418 | 1,956,000 |
| Boston, MA[b] | 22.3 | 1,183,000 | 319,000 | 10,500 | 284 | 1,426,000 |
| Woodbridge, NJ[f] | 29.5 | 986,000 | 160,000 | 5,560 | 210 | 1,037,000 |
| Minneapolis, MN[g] | 26.4 | 979,000 | 250,000 | 8,900 | 306 | 1,527,000 |
| Syracuse, NY[d] | 23.1 | 876,000 | 173,000 | 5,420 | 109 | 568,000 |
| San Francisco, CA[a] | 11.9 | 668,000 | 194,000 | 5,100 | 141 | 693,000 |
| Morgantown, WV[h] | 35.5 | 658,000 | 93,000 | 2,890 | 72 | 333,000 |
| Moorestown, NJ[f] | 28.0 | 583,000 | 117,000 | 3,760 | 118 | 576,000 |
| Jersey City, NJ[f] | 11.5 | 136,000 | 21,000 | 890 | 41 | 196,000 |
| Casper, WY[a] | 8.9 | 123,000 | 37,000 | 1,200 | 50 | 249,000 |
| Freehold, NJ[f] | 34.4 | 48,000 | 20,000 | 545 | 22 | 110,000 |

**II. Per acre values of tree effects**

| City | No. of trees | Carbon Storage (tons) | Carbon sequestration (tons/yr) | Pollution removal (lbs/yr) | Pollution value U.S. $ |
|---|---|---|---|---|---|
| Calgary, Canada[a] | 66.7 | 2.5 | 0.12 | 3.7 | 9.0 |
| Atlanta, GA[b] | 111.6 | 15.9 | 0.55 | 39.4 | 98.6 |
| Toronto, Canada[c] | 48.3 | 6.4 | 0.26 | 15.5 | 39.1 |
| New York, NY[b] | 26.4 | 6.8 | 0.21 | 17.0 | 40.9 |
| Baltimore, MD[d] | 50.8 | 11.6 | 0.31 | 16.6 | 41.2 |
| Philadelphia, PA[b] | 25.1 | 6.3 | 0.19 | 13.6 | 33.5 |
| Washington, DC[e] | 49.0 | 13.4 | 0.41 | 21.3 | 49.7 |
| Boston, MA[b] | 33.5 | 9.1 | 0.30 | 16.1 | 40.4 |
| Woodbridge, NJ[f] | 66.5 | 10.8 | 0.38 | 28.4 | 70.0 |
| Minneapolis, MN[g] | 26.2 | 6.7 | 0.24 | 16.4 | 40.9 |
| Syracuse, NY[d] | 54.5 | 10.8 | 0.34 | 13.5 | 35.4 |
| San Francisco, CA[a] | 22.5 | 6.6 | 0.17 | 9.5 | 23.4 |
| Morgantown, WV[h] | 119.2 | 16.8 | 0.52 | 26.0 | 60.3 |
| Moorestown, NJ[f] | 62.1 | 12.4 | 0.40 | 25.1 | 61.3 |
| Jersey City, NJ[f] | 14.4 | 2.2 | 0.09 | 8.6 | 20.7 |
| Casper, WY[a] | 9.1 | 2.8 | 0.09 | 5.6 | 13.9 |
| Freehold, NJ[f] | 38.3 | 16.0 | 0.44 | 34.9 | 88.2 |

Data collection group

[a] City personnel
[b] ACRT, Inc.
[c] University of Toronto
d U.S. Forest Service
[e] Casey Trees Endowment Fund
[f] New Jersey Department of Environmental Protection
[g] Davey Resource Group
[h] West Virginia University

## Appendix II. General Recommendations for Air Quality Improvement

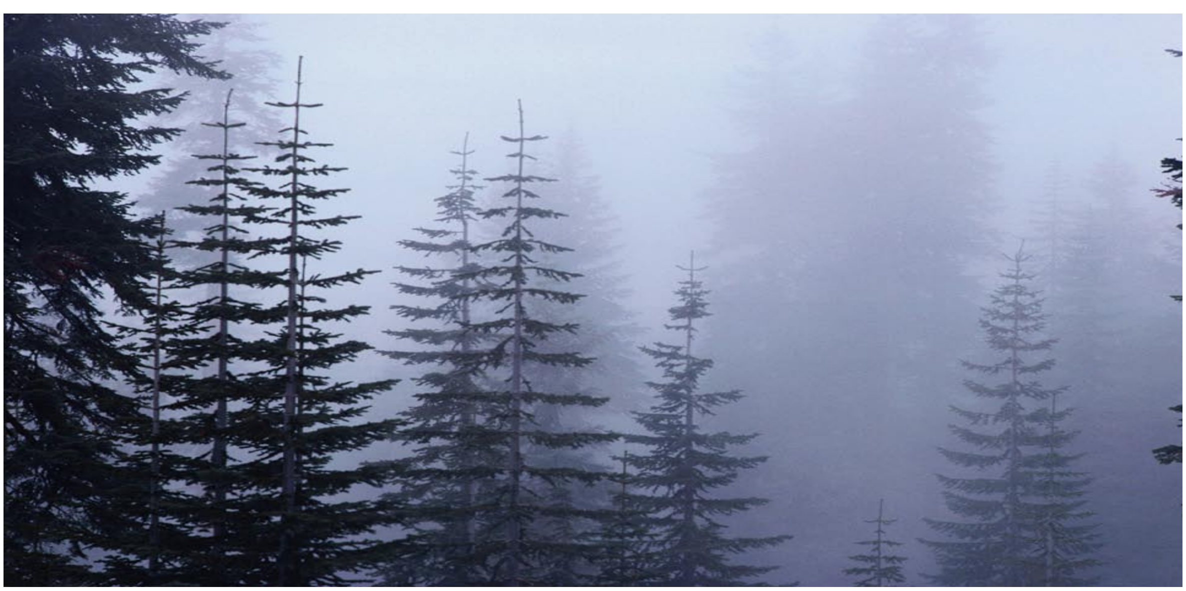
Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. Four main ways that urban trees affect air quality are:

**T**emperature reduction and other microclimatic effects
**R**emoval of air pollutants
**E**mission of volatile organic compounds (VOC) and tree maintenance emissions
**E**nergy conservation on buildings and consequent power plant emissions

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities. Local urban forest management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include:

| Strategy | Reason |
|---|---|
| Increase the number of healthy trees | Increase pollution removal |
| Sustain existing tree cover | Maintain pollution removal levels |
| Maximize use of low VOC-emitting trees | Reduces ozone and carbon monoxide formation |
| Sustain large, healthy trees | Large trees have greatest per-tree effects |
| Use long-lived trees | Reduce long-term pollutant emissions from planting and removal |
| Use low maintenance trees | Reduce pollutants emissions from maintenance activities |
| Reduce fossil fuel use in maintaining vegetation | Reduce pollutant emissions |
| Plant trees in energy conserving locations | Reduce pollutant emissions from power plants |
| Plant trees to shade parked cars | Reduce vehicular VOC emissions |
| Supply ample water to vegetation | Enhance pollution removal and temperature reduction |
| Plant trees in polluted or heavily populated areas | Maximizes tree air quality benefits |
| Avoid pollutant-sensitive species | Improve tree health |
| Utilize evergreen trees for particulate matter | Year-round removal of particles |



## Appendix III. Relative Tree Effects

The urban forest in Casper provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the city[19], average passenger automobile emissions[20], and average household emissions[21].

**General tree information:**
Average tree diameter (d.b.h.) = 9.3 in.
Median tree diameter (d.b.h.) = 4.9 in.
Average number of trees per person = 2.4
Number of trees sampled = 235
Number of species sampled = 47

**Average tree effects by tree diameter:**

| D.b.h. | Carbon storage | | | Carbon sequestration | | | Pollution removal | |
|---|---|---|---|---|---|---|---|---|
| Class (inch) | (lbs) | ($) | (miles) [a] | (lbs/yr) | ($/yr) | (miles) [a] | (lbs) | ($) |
| 1-3 | 6 | 0.06 | 20 | 1.8 | 0.02 | 7 | 0.1 | 0.21 |
| 3-6 | 41 | 0.38 | 150 | 7.1 | 0.07 | 26 | 0.3 | 0.67 |
| 6-9 | 143 | 1.31 | 520 | 14.1 | 0.13 | 51 | 0.6 | 1.48 |
| 9-12 | 310 | 2.85 | 1,130 | 19.5 | 0.18 | 71 | 0.9 | 2.12 |
| 12-15 | 506 | 4.66 | 1,850 | 21.6 | 0.20 | 79 | 0.7 | 1.72 |
| 15-18 | 854 | 7.87 | 3,130 | 35.2 | 0.32 | 129 | 0.9 | 2.17 |
| 18-21 | 1,185 | 10.92 | 4,340 | 36.9 | 0.34 | 135 | 1.7 | 4.13 |
| 21-24 | 1,815 | 16.72 | 6,650 | 44.8 | 0.41 | 164 | 1.7 | 4.21 |
| 24-27 | 2,408 | 22.18 | 8,820 | 58.4 | 0.54 | 214 | 1.6 | 4.03 |
| 27-30 | 2,780 | 25.61 | 10,180 | 76.6 | 0.71 | 281 | 1.2 | 2.99 |
| 30+ | 5,347 | 49.25 | 19,580 | 106.5 | 0.98 | 390 | 2.8 | 7.06 |

[a] miles = number of automobile miles driven that produces emissions equivalent to tree effect

**The Casper urban forest provides:**

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 44 days or
Annual carbon emissions from 22,000 automobiles or
Annual C emissions from 11,300 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 4 automobiles or
Annual carbon monoxide emissions from 15 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 160 automobiles or
Annual nitrogen dioxide emissions from 110 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 5,700 automobiles or
Annual sulfur dioxide emissions from 90 single family houses

Particulate matter less than 10 micron ($PM_{10}$) removal equivalent to:
Annual $PM_{10}$ emissions from 28,200 automobiles or
Annual $PM_{10}$ emissions from 2,700 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 1.4 days or
Annual C emissions from 700 automobiles or
Annual C emissions from 400 single family homes

## Appendix IV. Tree Species Sampled in Casper

| Genus | Species | Common Name | Percent Population | Percent Leaf Area | IV[a] | Potential Pest[b] ALB | GM | EAB | DED |
|---|---|---|---|---|---|---|---|---|---|
| Acer | ginnala | Amur maple | 0.4 | 0.2 | 0.6 | 🌲 | | | |
| Broussonetia | papyrifera | paper mulberry | 0.6 | 0.7 | 1.3 | | | | |
| Cornus | florida | flowering dogwood | 0.4 | 0 | 0.4 | | | | |
| Elaeagnus | angustifolia | Russian olive | 2.2 | 0.6 | 2.8 | 🌲 | | | |
| Fraxinus | americana | white ash | 3.1 | 1.7 | 4.8 | 🌲 | | 🌲 | |
| Fraxinus | pennsylvanica | green ash | 4.6 | 4.3 | 8.9 | 🌲 | | 🌲 | |
| Gleditsia | triacanthos | honeylocust | 6.3 | 3.7 | 10 | | | | |
| Gymnocladus | dioicus | Kentucky coffeetree | 0.4 | 0.1 | 0.5 | | | | |
| Juniperus | communis | common juniper | 2.1 | 0.1 | 2.2 | | | | |
| Juniperus | scopulorum | Rocky Mountain juniper | 6.4 | 3 | 9.4 | | | | |
| Malus | prunifolia | plumleaf crabapple | 0.4 | 0.7 | 1.1 | | | | |
| Malus | pumila | apple | 0.4 | 0 | 0.4 | 🌲 | 🌲 | | |
| Malus | species | crabapple | 5.6 | 2.7 | 8.3 | 🌲 | 🌲 | | |
| Malus | sylvestris | European crabapple | 5 | 3.6 | 8.6 | | | | |
| Picea | engelmannii | Engelmann spruce | 0.4 | 1.5 | 1.9 | | | | |
| Picea | mariana | black spruce | 0.8 | 2.2 | 3 | | | | |
| Picea | pungens | blue spruce | 8.1 | 16.1 | 24.2 | | | | |
| Picea | species | spruce | 1 | 3.6 | 4.6 | | | | |
| Pinus | edulis | pinyon pine | 0.4 | 0.1 | 0.5 | | | | |
| Pinus | maritima | pinus maritima | 0.5 | 0.5 | 1 | | | | |
| Pinus | nigra | Austrian pine | 1.5 | 0.2 | 1.7 | | | | |
| Pinus | species | pine | 1.5 | 0 | 1.5 | | | | |
| Pinus | sylvestris | scotch pine | 0.4 | 0.1 | 0.5 | | | | |
| Poitea | punicea | caracol illo | 0.5 | 0 | 0.5 | | | | |
| Populus | alba | white poplar | 1.3 | 3.5 | 4.8 | 🌲 | | | |
| Populus | angustifolia | narrowleaf cottonwood | 1.5 | 0.5 | 2 | 🌲 | 🌲 | | |
| Populus | deltoides | eastern cottonwood | 0.4 | 2.6 | 3 | 🌲 | | | |
| Populus | nigra | black poplar | 0.4 | 0.2 | 0.6 | 🌲 | | | |
| Populus | sargentii | plains cottonwood | 17.5 | 32.2 | 49.7 | 🌲 | 🌲 | | |

Continued

## Appendix IV continued

| | | | Percent | Percent | | Potential Pest[b] | | | |
|---|---|---|---|---|---|---|---|---|---|
| Genus | Species | Common Name | Population | Leaf Area | IV[a] | ALB | GM | EAB | DED |
| Populus | tremuloides | quaking aspen | 5 | 0.5 | 5.5 | 🌲 | 🌲 | | |
| Prestoea | montana | Sierra palm | 0.4 | 0.1 | 0.5 | | | | |
| Prunus | species | cherry | 0.4 | 0.1 | 0.5 | 🌲 | | | |
| Prunus | virginiana | common chokecherry | 3.1 | 0.6 | 3.7 | 🌲 | | | |
| Purshia | pinkavea | Pinkava's cliffrose | 2.3 | 0.2 | 2.5 | | | | |
| Quercus | alba | white oak | 0.6 | 0 | 0.6 | | 🌲 | | |
| Quercus | macrocarpa | bur oak | 0.4 | 0 | 0.4 | | 🌲 | | |
| Salix | alba | white willow | 0.4 | 0 | 0.4 | 🌲 | 🌲 | | |
| Salix | babylonica | weeping willow | 0.4 | 0.2 | 0.6 | 🌲 | 🌲 | | |
| Salix | matsudana | corkscrew willow | 0.8 | 0.9 | 1.7 | 🌲 | | | |
| Salix | species | willow | 0.4 | 0 | 0.4 | 🌲 | 🌲 | | |
| Sassafras | albidum | sassafras | 0.4 | 0.4 | 0.8 | | | | |
| Syringa | persica | Persian lilac | 0.6 | 0 | 0.6 | | | | |
| Tilia | americana | American basswood | 0.4 | 0 | 0.4 | 🌲 | 🌲 | | |
| Tilia | cordata | littleleaf linden | 0.8 | 0.1 | 0.9 | 🌲 | 🌲 | | |
| Tilia | europaea | European linden | 0.4 | 0.5 | 0.9 | 🌲 | 🌲 | | |
| Ulmus | americana | American elm | 6.7 | 10.9 | 17.6 | 🌲 | | | 🌲 |
| Ulmus | pumila | Siberian elm | 2.5 | 0.6 | 3.1 | 🌲 | | | |
| Ulmus | serotina | September elm | 0.4 | 0.1 | 0.5 | 🌲 | | | 🌲 |

[a] IV = importance value (% population + % leaf area)

[b] ALB = Asian longhorned bettel; GM = gypsy moth; EAB = emerald ash borer; DED = Dutch elm disease

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### Explanation of Calculations of Appendix III and IV

19 Total city carbon emissions were based on 2003 U.S. per capita carbon emissions, calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/1605aold.html ) divided by 2003 total U.S. population (www.census.gov). Per capita emissions were multiplied by Minneapolis population to estimate total city carbon emissions.

20 Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobiles assumed 6 pounds of carbon per gallon of gasoline with energy costs of refi nement and transportation included (Graham, R.L.; Wright, L.L.; Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 emissions. Climatic Change. 22:223-238.)

21 Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from:

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Nowak, David J.; Hoehn, Robert E. III; Crane, Daniel E.; Stevens, Jack, C.; Walton, Jeffrey T. 2006 **Assessing urban forest effects and values, Casper's urban forest.** Resour. Bull. NRS-4. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 20 p.

An analysis of trees in Casper, WY reveals that this city has about 123,000 trees with canopies that cover 8.9 percent of the area. The most common tree species are plains cottonwood, blue spruce, and American elm. The urban forest currently store about 37,000 tons of carbon valued at $689,000. In addition, these trees remove about 1,200 tons of carbon per year ($22,000 per year) and about 50 tons of air pollution per year ($249,000 per year). The structural, or compensatory, value is estimated at $243 million. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Casper area.

KEY WORDS: urban forestry; ecosystem services, air pollution removal; carbon sequestration; tree value

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