CLIMATE CHANGE RESOURCE CENTER

Urban Forests and Climate Change

Preparers

Hannah Safford, Washington Office; Elizabeth Larry, Washington Office; E. Gregory McPherson, Pacific Southwest Research Station; David J. Nowak, Northern Research Station; Lynne M. Westphal, Northern Research Station.

An archived version of this topic paper is available.

Issues

The urban environment presents important considerations for global climate change. Over half of the world's population lives in urban areas (1). Because cities are more dense and walkable (2), urban per capita emissions of greenhouse gases (GHGs) are almost always substantially lower than average per capita emissions for the countries in which they are located (3, 4). Urban areas are also more likely than non-urban areas to have adequate emergency services (5), and so may be better equipped to provide critical assistance to residents in the case of climate-related stress and events such as heat waves, floods, storms, and disease outbreaks. However, cities are still major sources of GHG emissions (6). Studies suggest that cities account for 40-70% of all GHG emissions worldwide due to resource consumption and energy, infrastructure, and transportation demands (7). Highly concentrated urban areas, especially in coastal regions and in developing countries, are disproportionately vulnerable to extreme weather and infectious disease.

Urban forests play an important role in climate change mitigation and adaptation. Active stewardship of a community's forestry assets can strengthen local resilience to climate change while creating more sustainable and desirable places to live.

Benefits of Urban Forests

The term "urban forest" refers to all trees within a densely populated area, including trees in parks, on streetways, and on private property. Though the composition, health, age, extent, and costs of urban forests vary considerably among different cities, all urban forests offer some common environmental, economic, and social benefits. Trees in a community help to reduce air and water pollution, alter heating and cooling costs, and increase real estate values. Trees can improve physical and mental health, strengthen social connections, and are associated with reduced crime rates. Trees, community gardens, and other green spaces get people outside, helping to foster active living and neighborhood pride.

Carbon capture and energy savings

Urban forests-like any forest-help mitigate climate change by capturing and storing atmospheric carbon dioxide during photosynthesis, and by influencing energy needs for heating and cooling buildings; trees typically reduce cooling costs, but can increase or decrease winter heating use depending on their location around a building and whether they are evergreen or deciduous. In the contiguous United States alone, urban trees store over 708 million tons of carbon (approximately 12.6% of annual carbon dioxide emissions in the United States) and capture an additional 28.2 million tons of carbon (approximately 0.05% of annual emissions) per year (8, 9). The value of urban carbon sequestration is substantial: approximately $2 billion per year, with a total current carbon storage value of over $50 billion (8). Shading and reduction of wind speed by trees can help to reduce carbon emissions by reducing summer air conditioning and winter heating demand and, in turn, the level of emissions from supplying power plants (10). Shading can also extend the useful life of street pavement by as much as ten years, thereby reducing emissions associated with the petroleum-intensive materials and operation of heavy equipment required to repave roads and haul away waste (11). Establishing 100 million mature trees around residences in the United States would save an estimated $2 billion annually in reduced energy costs (12, 1). However, this level of tree planting would only offset less than 1% of United States emissions over a 50-year period (14).

Provision of usable goods

The sustainable use of wood, food, and other goods provided by the local urban forest may also help mitigate climate change by displacing imports associated with higher levels of carbon dioxide emitted during production and transport. Urban wood is a valuable and underutilized resource. At current utilization rates, forest products manufactured from felled urban trees are estimated to save several hundred million tons of CO_2 over a 30-year period. Furthermore, wood chips made from low-quality urban wood may be combusted for heat and/or power to displace an additional 2.1 million tons of fossil fuel emissions per year (15).

Adaptation to climate and weather changes

Urban forests enable cities to better adapt to the effect of climate change on temperature patterns and weather events. Cities are generally warmer than their surroundings (typically by about 1-2°C, though this difference can be as high as 10°C under certain climactic conditions (16, 17)), meaning that average temperature increases caused by global warming are frequently amplified in urban areas. Urban forests help control this "heat island" effect by providing shade and by reducing urban albedo (the fraction of solar radiation reflected back into the environment), and through cooling evapotranspiration (4, 10, 16). Cities are also particularly susceptible to climate-related threats such as storms and flooding. Urban trees can help control runoff from these by catching rain in their canopies and increasing the infiltration rate of deposited precipitation. Reducing stormwater flow reduces stress on urban sewer systems by limiting the risk of hazardous combined sewer overflows (18). Furthermore, well-maintained urban forests help buffer high winds, control erosion, and reduce drought (10, 18, 19).

Increased community resilience

Urban forests provide critical social and cultural benefits that may strengthen community resilience to climate change. Street trees can hold spiritual value, promote social interaction, and contribute to a sense of place and family for local residents (21). Overall, forested urban areas appear to have potentially stronger and more stable communities (21). Community stability is essential to the development of effective long-term sustainable strategies for addressing climate change (22). For example, neighborhoods with stronger social networks are more likely to check on elderly and other vulnerable residents during heat waves and other emergencies (23).

Likely Changes

Urban forests help control the causes and consequences of climate-related threats. However, forests may also be negatively impacted by climate change.

Although increased CO_2 levels and warmer temperatures may initially promote urban tree growth by accelerating photosynthesis, too much warming in the absence of adequate water and nutrients stresses trees and retards future development (24). Warmer winter temperatures increase the likelihood of winter kill, in which trees, responding to their altered environment, prematurely begin to circulate water and nutrients in their vascular tissue. If rapid cooling follows these unnatural warm periods, tissues will freeze and trees will sustain injury or death.

Warmer winter temperatures favor many populations of tree pest and pathogen species normally kept at low levels by cold winter temperatures (24). Although climate change may reduce populations of some species, many others are better able than their arboreal hosts to adapt to changing environments due to their short lifecycles and rapid evolutionary capacity (19, 24). The consequences of these population changes are compounded by the fact that hot, dry environments enrich carbohydrate concentrations in tree foliage, making urban trees more attractive to pests and pathogens (24).

Climate change alters water cycles in ways that impact urban forests. Increased winter precipitation puts urban forests at greater risk from physical damage due to increased snow and ice loading (25). Increased summer evaporation and transpiration creates water shortages often exacerbated by urban soil compaction and impermeable surfaces. More frequent and intense extreme weather events increase the likelihood of severe flooding, which may uproot trees and cause injury or death to tree root systems if waterlogged soils persist for prolonged periods (25).

Especially cold regions may benefit from increased tourism, agricultural productivity, and ease of transport as a result of climate change (3, 4). However, the potential positive implications of climate change are far eclipsed by the negative (3.c). Rising temperatures, increased pest and pathogen activity, and water cycle changes impose physiological stresses on urban forests that compromise forest ability to deliver ecosystem services that protect against climate change. Climate change will also continue to alter species ranges and regeneration rates, further affecting the health and composition of urban forests (20, 26). Proactive management is necessary to protect urban forests against climate-related threats, and to sustain desired urban forest structures for future generations.

Options for Management

City "climate action plans" often incorporate urban forestry into climate change mitigation and adaptation strategies, recognizing that healthy trees and forests can strengthen a community’s ability to withstand and manage climate-related threats. Active urban forest management for climate change strengthens community resilience to climate change impacts (as well as other potential disasters), and creates more livable, desirable places to live, work and play.

Mitigation. Climate change mitigation in urban areas focuses primarily on reducing GHG emissions. Urban forest managers can help aid reductions efforts by preferentially allocating resources to trees that are more effective at mitigating emissions. Large-stature species with dense wood tend to store the most carbon (26), for instance, and trees of certain species may exhibit more desirable lifetime carbon capture-to-emissions ratios (27, 28). Maintaining tree canopy in perpetuity also sustains carbon storage within urban trees and forests and allows carbon to accumulate within urban soils. Urban soils in the United States are estimated to store approximately 1.9 billion metric tons of carbon (29).

Other effective mitigation strategies include strategically planting trees around buildings to promote energy efficiency, enlarging and improving planting sites to improve tree longevity and increase stormwater infiltration, and including trees in street improvement projects (28). Using wood in place of fossil-fuel intensive materials, such as steel and concrete, is also an important mitigation action. Wood, a renewable resource, sequesters atmospheric carbon as it grows; substituting wood products for fossil fuel-intensive alternatives in building construction thereby reduces net GHG emissions (30). Facilitating natural regeneration in cities where possible and working to reduce fossil fuel consumption associated with tree planting and maintenance also helps decrease emissions (27, 31, 32).

Adaptation. Incorporating climate resilience into tree planting and urban forest management plans helps improve the adaptive capacity of a community's tree canopy. Planting a diverse mix of pest-tolerant, well-adapted, low-maintenance, long-lived, and drought-resistant trees ensures greater resilience (27, 28), while planting small groves of especially water-tolerant species in areas receiving peak volumes of stormwater runoff reduces flooding and pollutant transport (28). Establishing and adhering to a regular maintenance cycle can help protect cities from extreme weather events. Young trees must be pruned early and often to encourage development of strong branching structures that are less vulnerable to storm and wind damage, and hazardous or diseased trees must be removed (28). Although urban forests, like all other ecosystems, can never be totally invulnerable to climate change impacts, thoughtful management can improve resilience and help cities and communities better adapt to change.

Urban forest cover is a key mediating variable between climate change impacts and particularly vulnerable population demographics, such as the young, the elderly, and the poor. These populations often suffer disproportionate negative impacts from the multiple health hazards associated with climate change, especially when located near freeways, industry, rivers, landfills, and other areas with little green space. Developing a location-specific list of "climate smart" tree species and planting sites can serve as a useful first step towards increasing urban forest cover in these areas.

Local governance. Due to limited staff and budget resources, many cities rely on partnerships with private landowners, organized citizen groups, and nonprofit agencies in order to effectively manage urban ecosystems. In some areas, citizens participate in advisory commissions that provide input to local officials on policy and regulations governing urban forests. In others, partnerships promote innovative greening strategies that complement or augment existing programs (33, 34). Collaborative governance across traditional boundaries engages constituents, increases environmental and political awareness across generations, and enables communities to better address complex issues such as climate change (35, 36, 37).

Community stewardship. Volunteer-based urban forest initiatives may complement or augment city-run adaptation and mitigation strategies (38, 39). Community volunteers can gather data needed to develop informed urban forest management and climate action plans (35). Neighborhood workdays provide opportunities for residents to join together to restore, maintain, and/or expand the urban forest. Such citizen involvement improves urban forest health while strengthening community social ties, creating an environment conducive to cooperative adaptation to climate change (36, 40).

How to cite

Safford, H.; Larry, E.; McPherson, E.G.; Nowak, D.J.; Westphal, L.M. (August 2013). Urban Forests and Climate Change. U.S. Department of Agriculture, Forest Service, Climate Change Resource

Center. www.fs.usda.gov/ccrc/topics/urban-forests

Recommended Reading

The following documents have been recommended by the authors of the synthesis paper and by the CCRC Production team.

Aguaron, E., and E.G. McPherson. 2012. Comparison of methods for estimating carbon dioxide storage by Sacramento's urban forest. In R. Lal & B. Augustin (Eds.), Carbon Sequestration in Urban Ecosystems. Dordrecht, Netherlands: Springer, 43-71.

Bell, R., and J. Wheeler. 2006. Talking Trees: An Urban Forestry Toolkit for Local Governments. Proc. of ICLEI: Local Governments for Sustainability.

McPherson, E.G., and J.R. Simpson. 1999. *Carbon Dioxide Reductions Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters.* (Gen. Tech. Rep. PSW-GTR-171). Albany, CA: USDA Forest Service, Pacific Southwest Research Station.

McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, and Q. Xiao. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry, 103, 411-416.

McPherson, E.G., and L. Kotow. 2013. A municipal forest report card: Results for California, USA. Urban Forestry & Urban Greening.

McPherson, E.G.; Qingfu, X.; Aguaron, E. 2013. A new approach to quantify and map carbon stored, sequestered, and emissions avoided by urban forests. Landscape and Urban Planning. 120: 70-84.

Nowak, D.J. 2000. The Interactions between Urban Forests and Global Climate Change. In: Abdollahi, K.K.; Ning, Z.H.; Appeaning, A., eds. Global Climate Change & The Urban Forest. Baton Rouge, LA: Franklin Press, Inc.: 31-44.

Nowak, D.J.; Greenfield, E.J.; Hoehn, R.; LaPoint, E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178: 229-236.

Nowak, D.J., et al. 2010. Sustaining America’s Urban Trees and Forests: A Forests on the Edge Report. Gen. Tech. Rep. NRS-62. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Nowak, D.J., J.C. Stevens, S.M. Sisinni, and C.J. Luley. 2002. Effects of Urban Tree Management and Species Selection on Atmospheric Carbon Dioxide. Journal of Arboriculture. 28(3): 113-22.

Nowak, D.J., and D.E. Crane. 2002. Carbon Storage and Sequestration by Urban Trees in the USA. Environmental Pollution. 116: 381-89.

Ritter, M.A., K. Skog, and R. Bergman. 2011. Science Supporting the Economic and Environmental Benefits of Using Wood and Wood Products in Green Building Construction. Gen. Tech. Rep. FPL-GTR-206. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Romero-Lankao, P., and D.M. Gratz. 2008. Urban Areas and Climate Change: Review of Current Issues and Trends. Issues paper for the 2011 Global Report on Human Settlements.

Scharenbroch, B.C. 2012. Urban trees for carbon sequestration. In R. Lal and B. Augustin (Eds.), *Carbon Sequestration in Urban Ecosystems*. Dordrecht, Netherlands: Springer, 121-138.

Related Links

Climate Action Reserve: contains the Urban Forest Project Protocol and appendices.

U.S. Energy-Related CO2 Emissions: provides current estimates of U.S. carbon dioxide emissions from energy-related activities by sector.

U.S. Greenhouse Gas Inventory Report: provides total U.S. emissions of greenhouse gases by source, economic sector, and greenhouse gas.

Heat Island Effect: presents basic information on urban heat islands and the influence of trees on the heat island effect, including related research and demonstration projects.

Seattle reLeaf: portal for urban forestry in the city of Seattle, Washington. Site includes resources for community involvement, information on urban tree planting, care, and restoration, and the City's urban forest management plan.

Research

These summaries represent Forest Service research related to urban areas and climate change. More examples will be added as our Research Roundup is updated.

Assessment of disturbance impacts on U.S. forest carbon sequestration

Researchers are estimating forest carbon lost due to hurricane and insect disturbances in order to produce more accurate estimates of carbon sequestration by U.S. forests. Equations created to estimate total forest carbon loss based on damage could be adapted in the future to project carbon loss due to any disturbance impact.
Contact: Steve McNulty

Assessing Local Urban Forest Carbon Storage, Sequestration and Effects on Emissions from Building Energy Use

The i-Tree suite of models is designed to link research with local data on tree populations to assess the services and values provide by trees. The model is constantly being updated with new features and is being used globally. The model estimates numerous ecosystem services, disservices, and values, and includes estimates of tree carbon storage and annual sequestration, and their effects on building energy and consequent emissions from power plants.
Contact: David J. Nowak

Baltimore Ecosystem Study

Studies on carbon dioxide concentration, CO_2 and H_2O flux, and the effects of multiple air pollutants on urban forests are being conducted in Baltimore. Urban conditions may represent possible future scenarios: elevated carbon dioxide, ozone, nitrogen deposition and elevated temperatures. A 40 m Forest Service lookout tower near Baltimore is used to conduct air quality and meteorological flux research. This is the first permanent tower to estimate carbon flux and carbon sequestration in an urban/suburban forest ecosystem. Metropolitan areas have an average tree cover of 33.4% (urban counties) and support 25% of the USA's total tree canopy cover, and their inclusion in climate models is essential for accuracy.
Contact: John Hom

Comparison of Methods for Estimating Urban Forest Carbon Storage

Elena Aguaron-Fuente and Greg McPherson authored a chapter in the book Carbon Sequestration in Urban Ecosystems. They found substantial variability in sequestration estimates produced by four methods-i Tree Streets, i-Tree Eco, the CUFR Tree Carbon Calculator, and Urban General Equations-and concluded that the latter could be used to produce conservative estimates from remotely sensed data compared to urban-based species-specific equations.
Contact: E. Gregory McPherson

Economic impacts of insect outbreaks triggered by climate change

When climate change triggers forest insect outbreaks, these episodes may affect a variety of

non-market forest resources, such as recreational values, real estate values and scenic values. A multi-disciplinary team is currently investigating how climate change-induced changes in damage caused by mountain pine beetle, hemlock wooly adelgid and southern pine beetle affect non-market forest resources.
Contact: Thomas Holmes

Effects of urban climate on land surface phenology

Researchers are studying urban climate drivers and their effects on land surface phenology variation to determine if a higher urban index (level of "urbanness") affects specific aspects of forest vegetation timing and development. Results of this study may yield urban index thresholds which could be used by urban planners to avoid altering the development of urban forest vegetation.
Contact: William Hargrove

Effects of urban tree management and species selection on atmospheric carbon dioxide

Trees sequester and store carbon in their tissue at differing rates and amounts based on such factors as tree size at maturity, life span, and growth rate. Concurrently, tree care practices release carbon back to the atmosphere based on fossil-fuel emissions from maintenance equipment (e.g., chain saws, trucks, chippers). Management choices such as tree locations for energy conservation and tree disposal methods after removal also affect the net carbon effect of the urban forest. Different species, decomposition, energy conservation, and maintenance scenarios were evaluated to determine how these factors influence the net carbon impact of urban forests and their management. If carbon (via fossil-fuel combustion) is used to maintain vegetation structure and health, urban forest ecosystems eventually will become net emitters of carbon unless secondary carbon reductions (e.g., energy conservation) or limiting decomposition via long-term carbon storage (e.g., wood products, landfills) can be accomplished to offset the maintenance carbon emissions. Management practices to maximize the net benefits of urban forests on atmospheric carbon dioxide are discussed.
Contact: David J. Nowak

Forest tree genetic risk assessment system: a tool for conservation decision-making in changing times

The Forest Tree Genetic Risk Assessment System (ForGRAS) is a framework that allows managers to assess the relative risk of genetic degradation to forest trees affected by multiple threats.
Contact: Kevin Potter

Impacts of Disturbances and Climate on Carbon Sequestration and Biofuels

Currently, U.S. forests and forest products offset about 20% of the nation's fossil fuel emissions.

However, recent findings cast doubt on the sustainability of this offset. First, the strength of the U.S. forest carbon offset may be weakening due to forest ageing, climate variability, and increasing natural disturbances. Second, climate change is expected to further increase frequencies of insect outbreaks and wildfire, and alter species composition in forest ecosystems, consequently influencing forest carbon pools in a significant way. These current and projected forest carbon cycle dynamics need to be considered in strategic forest planning and management decisions in coming decades if the nation's forests are to provide stable or even increasing ecosystem services.
Contact: Yude Pan, Richard Birdsey

Technology development to support a national early warning system for environmental threats
Scientists and collaborators have launched the ForWarn tool, the strategic research component of the national early warning system, to help natural resource managers rapidly detect, identify, and respond to unexpected changes in the nation's forests. ForWarn produces maps showing potential forest disturbance across the conterminous United States at 231-meter resolution every 8 days, based on images obtained over the preceding 24-day analysis window.
Contact: William Hargrove

Tree Growth and Longevity Working Group and Database
An international research symposium held September 12-13, 2011 at the Morton Arboretum heralded a rousing start for this new group. The meeting brought 150 internationally renowned researchers and practitioners to learn the current state of knowledge concerning urban tree growth, mortality, and longevity, identify important gaps in our knowledge, discuss promising new methodologies, prioritize research and education needs, and outline a course of action for future research and outreach.
Contact: E. Gregory McPherson

Updated US National Carbon Storage and Sequestration Estimates
The latest research on urban forests in the United States reveals that urban whole tree carbon storage densities average 7.69 kg C per m2 of tree cover and sequestration densities average 0.28 kg C per m2 of tree cover per year. Total tree carbon storage in U.S. urban areas (c. 2005) is estimated at 643 million metric tons ($50.5 billion value; 95% CI = 597 million and 690 million metric tons) and annual sequestration is estimated at 25.6 million metric tons ($2.0 billion value; 95% CI = 23.7 million to 27.4 million metric tons). Estimates are presented by state and include the latest urban tree cover data and field data from urban areas across the United States.
Contact: David J. Nowak

Urban Ecosystems and Social Dynamics
Healthy urban forests have the ability to cut heating and air conditioning use, resulting in reduced costs and atmospheric emissions from power plants. Tree shade reduces air temperature and the amount of radiant energy absorbed and stored by built surfaces. Additionally, trees reduce the velocity of wind, slowing the infiltration of outside air. Research shows that properly selected, located, and managed trees can drastically reduce city and residential energy costs and lessen our reliance on new power plants.
Contact: Greg McPherson

Urban Forests and CO_2 Reduction
Urban forests improve air quality by reducing atmospheric carbon dioxide levels and absorbing air pollutants. Trees can directly sequester carbon dioxide as woody and foliar biomass while they grow. Properly planted and managed trees can also reduce the need for heating and air conditioning, resulting in fewer emissions released into the atmosphere. A study of one Southwest region's six million trees reveals that the trees remove and store approximately 304,000 tons of atmospheric CO_2, 12,000 tons of ozone, and 9,000 tons of particulates.
Contact: Greg McPherson

Urban Forests and Climate Change: Greenhouse Gas Reporting Protocols
PSW's Center for Urban Forest Research is leading a team in the development of greenhouse gas reporting protocols for urban forests. The Urban Forest Reporting Protocols will use state-of-the-art science from the Center for Urban Forest Research to provide cities, utilities, and other organizations with an opportunity to predict, measure, and verify the role of urban trees in fighting global climate change.
Contact: Greg McPherson

Tools

i-Tree Tools: software suite for urban forestry analysis and benefits assessment.

ecoSmart Landscapes Portal: suite of tools for environmental evaluations of outdoor landscaped spaces.

STEW-MAP: publicly available data and interactive maps that enable users to visualize and track civic environmental stewardship initiatives.

Urban Tree Canopy (UTC) Assessment: collection of metrics on the urban tree canopy used to inform urban resource management decisions.

References

1. Population Reference Bureau. 2012. 2012 World Population Data Sheet. Accessed from http://www.prb.org/pdf12/2012-population-data-sheet_eng.pdf (August 19, 2013).
2. The Cities Alliance. 2007. Liveable Cities: The Benefits of Urban Environmental Planning. Accessed from http://www.citiesalliance.org/sites/citiesalliance.org/files/CA_Docs/resources/cds/liveable/li (August 19, 2013).
3. For more information, see:
   a. United Nations Human Settlements Programme (UN-Habitat). 2011. Cities and Climate Change: Global Report on Human Settlements. Earthscan.
   b. Hoornweg, D. 2010. Cities and Climate Change: An Urgent Agenda. Urban Development Series Knowledge Papers No.10, International Bank for Reconstruction and Redevelopment/The World Bank.
   c. Parry, M.L., et al. [eds.] 2007.Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, MA: Cambridge University Press.
4. Romero-Lankao, P., and D.M. Gratz. 2008. Urban Areas and Climate Change: Review of Current Issues and Trends. Issues paper for the 2011 Global Report on Human Settlements.
5. Myers, S.R., C.C. Branas, B.C. French, M.L. Nance, M.J. Kallan, D.J. Wiebe, and B.G. Carr. 2013. Safety in Numbers: Are Major Cities the Safest Places in the United States? Annals of Emergency Management (Epub ahead of print). Accessed from http://www.annemergmed.com/webfiles/images/journals/ymem/FA-5548.pdf (August 19, 2013).
6. Dodman, D. 2009. Blaming Cities for Climate Change? An Analysis of Urban Greenhouse Gas Emissions Inventories. Environment and Urbanization. 21(1): 185-201.
7. U.S. EPA. 2009. Buildings and their Impact on the Environment: A Statistical Summary. Accessed from http://www.epa.gov/greenbuilding/pubs/gbstats.pdf (March 11, 2013).
8. Nowak, D.J.; Greenfield, E.J.; Hoehn, R.; LaPoint, E. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution. 178: 229-236.
9. U.S. EPA. 2013. DRAFT Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. Accessed from http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2011.pdf (April 5, 2013).

10. Nowak, D.J., et al. 2010. Sustaining America's Urban Trees and Forests: A Forests on the Edge Report. Gen. Tech. Rep. NRS-62. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.
11. McPherson, G., and J. Muchnick. 2005. Effects of Street Tree Shade on Asphalt Concrete Pavement Performance. Journal of Arboriculture. 31(6): 303-310.
12. Akbari, H., S. Davis, S. Dorsano, J. Huang, and S. Winnett. 1992. Cooling our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing. Washington, D.C.: U.S. Environmental Protection Agency.
13. Akbari, H., J. Huang, P. Martien, L. Rainier, A. Rosenfeld, and H. Taha. 1988. The Impact of Summer Heat Islands on Cooling Energy Consumption and Global CO_2 Concentrations. Proc. of ACEEE 1988 Summer Study in Energy Efficiency in Buildings, vol. 5. Washington, D.C.: American Council for an Energy-Efficient Economy: 11-23.
14. Nowak, D.J., and D.E. Crane. 2002. Carbon Storage and Sequestration by Urban Trees in the USA. Environmental Pollution. 116: 381-89.
15. Sherril, S., and S. Bratkovitch. July 2011. Carbon and Carbon Dioxide Equivalent Sequestration in Urban Forest Products. Dovetail Partners, Inc.
16. Bristow, R.S., R. Blackie, and N. Brown. 2012. Parks and the Urban Heat Island: A Longitudinal Study in Westfield, Massachusetts. In: Fisher, C.L. and C.E. Watts, Jr. [eds.] Proc. of the 2010 Northeastern Recreation Research Symposium. Gen. Tech. Rep. NRS-P-94. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 224-230.
17. Kovats, S., and R. Akhtar. 2008.Climate, Climate Change and Human Health in Asian Cities. Environment and Urbanization. 20: 165-75.
18. Fazio, J.R. (ed). 2010. How Trees Can Retain Stormwater Runoff. Tree City USA Bulletin No. 55. Arbor Day Foundation: Nebraska City, NE.
19. Cullington, J., and J. Gye. 2010. Urban Forests: A Climate Adaptation Guide. Part of the BC Regional Adaptation Collaborative (RAC). Ministry of Community, Sport and Cultural Development: British Columbia, Canada.
20. Nowak, D.J. 2010. Urban Biodiversity and Climate Change. In: Muller, N., P. Werner, and J.G. Kelcey (eds). Urban Biodiversity and Design. Wiley-Blackwell Publishing: Hoboken NJ. 101-117.
21. Dandy, N. 2010. The Social and Cultural Values, and Governance, of Street Trees. Climate Change & Street Trees Project: Social Research Report. The Research Agency of the Forestry Commission.
22. Williamson, T., S. Dubb, and G. Alperovitz. 2010. Climate Change, Community Stability, and the Next 150 Million Americans. College Park, MD: The Democracy Collaborative.
23. Klinenberg, E. 2002. Heat Wave: A Social Autopsy of Disaster in Chicago. Chicago: University of Chicago Press.

24. Tubby, K. V., and J. F. Webber. 2010. Pests and Diseases Threatening Urban Trees under a Changing Climate. Forestry. 83(4): 451-59.
25. Johnston, M. 2004.Impacts and Adaptation for Climate Change in Urban Forests. Proc. of 6th Canadian Urban Forest Conference, Kelowna, B.C.
26. Ordonez, C., P.N. Dunker, and J. Steenberg. 2010. Climate Change Mitigation and Adaptation in Urban Forests: A Framework for Sustainable Urban Forest Management. Paper prepared for presentation at the 18th Commonwealth Forestry Conference, Edinburgh.
27. Nowak, D.J., J.C. Stevens, S.M. Sisinni, and C.J. Luley. 2002. Effects of Urban Tree Management and Species Selection on Atmospheric Carbon Dioxide. Journal of Arboriculture. 28(3): 113-22.
28. Bell, R., and J. Wheeler. 2006. Talking Trees: An Urban Forestry Toolkit for Local Governments. Proc. of ICLEI: Local Governments for Sustainability.
29. Pouyat, R.V., I.D. Yesilonis, and D. Nowak. 2006. Carbon Storage by Urban Soils in the United States. Journal of Environmental Quality. 35: 1566-1575.
30. Ritter, M.A., K. Skog, and R. Bergman. 2011. Science Supporting the Economic and Environmental Benefits of Using Wood and Wood Products in Green Building Construction. Gen. Tech. Rep. FPL-GTR-206. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.
31. Nowak, D.J. 2012. Contrasting Natural Regeneration and Tree Planting in 14 North American Cities. Urban Forestry and Urban Greening. 11: 374-382.
32. Abdollahi, K.K., Z.H. Ning, and A. Appeaning (eds). 2000. Global Climate Change and the Urban Forest. GCRCC and Franklin Press, Baton Rouge: 31-44.
33. Connolly, J.J., E.S. Svendsen, D.R. Fisher, and L.K. Campbell. 2013. Organizing Urban Ecosystem Services Through Environmental Stewardship Governance in New York City. Landscape and Urban Planning 109, 76-84.
34. Mincey, S.K., and B.C. Fischer. 2013. Solutions for Sustainable Urban Forest Governance and Management. SPEA Insights.
35. Bloniarz, D.V., and H. D. P. Ryan. 1998. Urban Forest Resource Inventories: A Community Based Approach. Proceedings of the Society of American Foresters National Convention.
36. Svendsen, E. S., and L. K. Campbell. 2008. Urban Ecological Stewardship: Understanding the Structure, Function and Network of Community-Based Urban Land Management. Cities and the Environment. 1(1): 1-32.
37. Campbell, L., and A. Wiesen. 2009. Restorative Commons: Creating Health and Well-Being Through Urban Landscapes. Gen. Tech. Rep. NRS-P-39. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.
38. Westphal, L. 1994. Overcoming Obstacles: Creating Volunteer Partnerships. Journal of Forestry. 92(10): 28-32.

39. Westphal, L. 2003. Social Aspects of Urban Forestry: Urban Greening and Social Benefits: A Study of Empowerment Outcomes. Journal of Arboriculture. 29(3): 137-147.
40. Kuo, F.E. 2003.The Role of Arboriculture in a Healthy Social Ecology. Journal of Arboriculture. 29(3): 148-155.

Search CCRC

Related Topics

Silvicultura para el Cambio Climático

Maple Syrup

Agroforestry

Assisted Migration

Forests, Water, and Climate Change

Effects of Drought on Forests and Rangelands

Forest Management for Carbon Benefits

Importance of Forest Cover

Private Forestland Stewardship

Silviculture for Climate Change

About the Climate Change Resource Center

The Climate Change Resource Center welcomes your comments and suggestions:
ccrc@fs.fed.us, USDA FS Climate Change Resource Center