UNIVERSITY OF FLORIDA

EXTENSION

Institute of Food and Agricultural Sciences

Abstract: Restoring the Urban Forest Ecosystem[1]

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Restoring the Urban Forest Ecosystem

The urban forest ecosystem can provide many ecological services and benefits to cities and communities including energy conservation, contributing to global biodiversity, and maintaining hydrologic and nutrient cycles. Yet in many instances these benefits are not realized due to poor health and management of the urban forest. Many opportunities for restoration -- reestablishing the structure and function of the urban forest ecosystem -- exist. The goal of restoration is to return the urban forest to a form which is more ecologically sustainable. A restored urban forest will contribute positively to the community instead of being a drain on its resources. Many of our parks are composed of trees and grass requiring intensive maintenance inputs such as fertilizing, irrigating, mowing and raking. With restoration these parks could take advantage of natural processes such as nutrient and water cycling, thereby saving money, energy and resources for the community. Connecting these restored parks to other ecosystems such as waterways can also contribute to biodiversity and wildlife conservation. Restoration sites can range from backyards to neighborhoods to parks to whole waterways and metropolitan areas. The United States hosts an abundance of successful and innovative urban forest restoration projects which illustrate the potential for creativity, diversity and the ability to tailor projects to local needs and opportunities. This CD-ROM explains basic ecological principles for the urban forest's water, soil, plant and animal communities. It discusses problems common in the urban forest such as aquatic eutrophication, soil aeration, invasive plants and loss of biodiversity. Solutions, strategies, examples, and additional resources are presented to help make urban forest restoration projects successful. Its goal is to inspire the restoration of urban forest ecosystems which will, in turn, restore and conserve our planet for future generations.

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1. This document is the Abstract, Table of Contents, and Acknowledgments for SW-140, Restoring the Urban Forest Ecosystem, a CD-ROM (M.L. Duryea, E. Kämpf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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We dedicate this work to all the hard-working, dedicated and creative people around the U.S. who are finding so many ways to restore the beauty and health to the urban forest ecosystem.

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Chapter 1: Restoring the Urban Forest Ecosystem: An Introduction[1]

Mary L. Duryea[2]

Abstract

Urban and community forests are often managed as individual trees instead of whole forest ecosystems. Cities inventory and manage these tree species to meet many important needs such as energy conservation, beauty, and recreation in the city. Yet, there are many opportunities for urban forest restoration to provide additional ecological benefits such as storm-water management, wildlife management, and biodiversity. Restoring the urban forest ecosystem is reestablishing the ecological health of the urban forest ecosystem. The goal of restoration is to return the urban forest to a form which is more ecologically sustainable for the community; the restored urban forest will contribute positively to the community instead of being a drain on its resources. Many of our parks, for example, are composed of trees and grass requiring intensive maintenance inputs such as fertilizing, irrigating, mowing and raking. With restoration these parks could take advantage of natural processes such as nutrient and water cycling, thereby saving money, energy and resources for the community. Connecting these restored parks to other ecosystems such as waterways can also contribute to biodiversity and wildlife management and conservation. The options for restoration sites include: yards, vacant lots, shopping centers, schoolyards, parks, industrial parks, and waterways. The projects can be varied such as: (1) The simple act of eliminating leaf-raking in a park to reestablish the natural forest floor and the natural cycling of nutrients; (2) The establishment of understory plant species in a schoolyard to promote wildlife; (3) The eradication of an invasive plant species which is eliminating much of the understory biodiversity in a park; (4) The re-design of a parking lot to decrease stormwater runoff and provide a small ecological wetland; or (5) The re-creation of a park with species and ecosystems to be just the way it was in the 1800s. The United States hosts an abundance of successful and innovative urban forest restoration projects. The two key ingredients that make these projects so successful are the involvement of people from the community and the formulation of a restoration plan.

The Urban Forest Ecosystem

To define the urban forest ecosystem we take the original definition of ecosystem and apply it to the urban forest.

1. This is Chapter 1 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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The urban forest ecosystem is a collection of living organic matter (plants, animals, people, insects, microbes, etc.) and dead organic matter (lawn clippings, leaf-fall, branches) on a soil (with all its urban characteristics) through which there is cycling of chemicals and water and flow of energy.

When we think of the urban forest ecosystem we can think of the whole city or community as one ecosystem or we can focus in on a smaller parcel of land as the urban forest ecosystem. The big picture, bird's-eye-view is important to identify sites that might need restoration (**Figure 1**). For example, we might see two parks that could be connected with a greenway to benefit wildlife communities. Or we might see an area of the city which is void of trees, an urban heat island, that could be restored with a tree canopy. Yet, we also need to look at the urban forest ecosystem as smaller parcels of land such as neighborhoods, parks, or schoolyards. At this level we can see specific management alternatives and specific ecological needs for each of these land units.

Figure 1. When we think of the urban forest ecosystem we can think of the whole city or community as one ecosystem or we can focus in on a smaller parcel of land (a park, schoolyard or industrial park, for example) as the urban forest ecosystem. Photo by Hans Riekerk

What is "Restoring the Urban Forest Ecosystem"?

Restoration has traditionally been defined as reconstructing or repairing something, often a work of art or ancient building. Ecologists have defined ecological restoration to be:

- "The return of an ecosystem to a close approximation of its condition prior to disturbance." (National Research Council 1992)
- "The intentional alteration of a site to establish a defined indigenous, historic ecosystem. The goal of this process is to emulate the structure, functioning, diversity and dynamics of the specified ecosystem." (Society of Ecological Restoration 1992)
- "Ecological restoration is the process of renewing and maintaining ecosystem health." (Society of Ecological Restoration 1995)
- "Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices. (Society of Ecological Restoration 1996)

Most of these definitions center around the recovery, repair or re-establishment of native ecosystems. Because of the loss of species, the increase in disturbances and several other factors, exact restoration may be an impossible feat and many people wish to call it rehabilitation.

Restoring the Urban Forest Ecosystem is reestablishing the ecological health of the urban forest ecosystem.

In urban forest ecosystems we have a very different situation, and therefore we need to define restoration differently. The urban forest is a mosaic or patchwork of highly altered landscapes ranging from street trees to neighborhoods with landscaping to shopping centers to waterways to parks to fragments of remaining native ecosystems. For this CD-ROM and its series of publications we have chosen to define restoration as reestablishing the ecological health of the urban forest ecosystem. More specifically, restoration means altering a site (a park, waterway, neighborhood) to a state which is more ecologically sustainable for the community or city. Restoration might reestablish ecological structure, functions, pathways, and/or cycles. A restored site with its renewed or re-introduced ecological attributes will contribute more positively to the community instead of being a drain on its resources.

Examples of potential sites and projects for restoring the urban forest ecosystem include:

- The simple act of eliminating leaf-raking to reestablish the natural forest floor and the natural cycling of nutrients.
- The establishment of understory plant species in a schoolyard to promote wildlife species.
- The eradication of an invasive plant species which is eliminating much of the understory biodiversity in a neighborhood.
- The clean-up of a vacant lot or site in a neighborhood and the establishment of a park.
- The re-design of a parking lot to decrease stormwater runoff and provide a small ecological wetland.
- The re-creation of a park with the native ecosystems that were present 100 years ago.

Potential sites for restoring the urban forest ecosystem include (**Figures 2, 3, and 4**):

Figure 2. A vacant or abandoned lot in an industrial area of town.

The Story of two parks

A description of two hypothetical parks offers insights into the reasons and benefits of restoration.

Figure 3. A small water-retention pond which could be restored with wetland species.

Figure 4. A schoolyard.

Wilson Park

- Wilson Park has five baseball fields and four basketball courts which are under constant use by the community. (**Figure 5**).
- A monoculture of 60-year-old pine trees surrounding the ball fields has swing sets and picnic tables in its understory (**Figure 6**). Last year when bark beetles invested loblolly pines in nearby parks, plantations and natural areas, park managers worried that they might lose this pine forest to the beetle.
- When viewed closely we can see that not only are there no understory plant species but the park managers remove every leaf and twig that falls to the ground (**Figure 7**).
- In another area of the park, managers work to maintain a grass understory under several live oaks (**Figure 8**). With little light for grass growth, addition of fertilizers, water and frequent mowing makes this an intensively

managed area for the park. Every leaf and branch must also be removed in these hardwood and grass forests.

Figure 5. Wilson Park has several baseball fields and four basketball courts which are under constant use by the community.

Figure 6. A monoculture of 60-year-old pine trees surrounding the ball fields has swing sets and picnic tables in its understory. Last year when bark beetles invested loblolly pines in nearby parks, plantations, and natural areas, park managers worried that they might lose this pine forest to the beetle.

- A bird's-eye-view of another hardwood area shows very little remaining on the ground (**Figure 9**). All leaves have been removed and the resulting bare soil shows the exposed and unprotected roots of shrubs and trees (**Figure 10**).

- This kind of management results in intensive use of people and energy resources (**Figure 11**). Often after the natural leaves and branches are removed, landscape mulch is brought in to cover the ground.

Figure 7. When viewed closely we can see that not only are there no understory plant species but the park managers remove every leaf and twig that falls to the ground.

Figure 8. In another area of the park, managers work to maintain a grass understory under several live oaks. With little light, addition of fertilizers, water and frequent mowing makes this an intensively managed area for the park. Every leaf and branch must also be removed in these hardwood forests.

- One of the park managers has planted camelias in one of the bare understories. Because these are an exotic plant, maintenance of these flower gardens has included additional fertilization and installation of an irrigation system (**Figure 12**).

Andrews Park

- Andrews park has a natural creek running through it (**Figure 13**). The creek originates outside the town, and so the park provides a way to connect several ecosystems as it meanders through the park and town.

Figure 9. A bird's-eye-view of another hardwood area in the park shows very little remaining on the ground.

Figure 10. All leaves have been removed and the resulting bare soil shows the exposed and unprotected roots of shrubs and trees.

- Several ponds and other wetland areas support habitat for wildlife in the park (**Figure 14**).
- A walkway across one of the wetland areas offers entry and a look at this wetland ecosystem (**Figure 15**).

Figure 11. This kind of management results in intensive use of people and energy resources.

Figure 12. One of the park managers has planted camelias in one of the bare understories. Because these are an exotic plant, maintenance of these flower gardens has included additional fertilization and installation of an irrigation system. Photo by Larry Korhnak

- Fallen leaves and branches maintain a natural mulch for the park (**Figure 16**).
- Playground areas are well-defined as are the special areas where plant life is being restored (**Figure 17**)
- Fallen logs are left lying next to hiking trails and on the forest floor to enhance natural decay and nutrient cycling (**Figure 18**).
- Signs are utilized to educate people about the park's ecosystems (**Figure 19**).

Developing a Checklist

It's good to look thoughtfully and critically at our parks, neighborhoods, waterways and other urban forests to see how they contribute ecologically

Figure 13. Andrews park has a natural creek running through it. Photo by Larry Korhnak

Figure 14. Several ponds and other wetland areas support habitat for wildlife in the park. Photo by Larry Korhnak

Figure 15. A walkway across one of the wetland areas offers entry and a look at this ecosystem. Photo by Larry Korhnak

to the community. These benefits can be utilized to gain support for restoration projects. By using a checklist we can estimate the benefits for any area within the urban forest ecosystem.

Figure 16. Fallen leaves and branches maintain a natural mulch for the park helping to sustain the nutrient cycle in the ecosystem. Photo by Larry Korhnak

Figure 17. Playground areas are well-defined as are the special areas where plant life is being restored.

A Checklist of Wilson and Andrews Parks shows the contrasting ecological benefits of the two parks (**Figure 20**).

Both parks contribute recreational benefits to the community. The monoculture of loblolly pines and the hardwood forests at Wilson Park provide very little biodiversity compared to the natural ecosystems with many structural layers and plants at Andrews Park. Parking lots and forests with very little understory vegetation and natural mulch result in high levels of stormwater runoff at Wilson Park. The creek and wetland areas along with the forest floor with its high water infiltration rates offer several ways to dispose of stormwater at Andrews Park. Andrews is a low maintenance, low energy-use park compared to the high energy levels to maintain Wilson Park. The removal of all leaves, twigs, and fallen logs at Wilson Park means that nutrients are being removed from the site annually; this will

Figure 18. Fallen logs are left lying next to hiking trails and on the forest floor to enhance natural decay and nutrient cycling. Photo by Eliana Kampf Binelli

Figure 19. Signs are utilized to educate people about the park's ecosystems. Photo by Larry Korhnak

contribute to impoverishment of the site over time. In addition, organic matter will not be present in the soil to aid in water and nutrient retention. This interruption of the natural nutrient cycle can be remedied easily by retaining fallen plant materials as in Andrews Park.

Checklist of Benefits to the Community

Benefits	Wilson Park	Andrews Park
Recreation	++	++
Education	–	++
Biodiversity	– –	++
Energy Conservation	–	++
Hydrology	–	++
Beauty	+	+
Connectivity	– –	++
Nutrient Cycling	– –	++
Socio-Economic	?	?

Figure 20. By using a checklist we can estimate the benefits for any area within the urban forest ecosystem. This checklist compares the ecological benefits of Wilson and Andrews parks.

And finally, the Socio-Economic category of benefits. Parks, greenways and natural areas contribute to the economic health of a community. For example, before the construction of the Pinellas Trail (greenway), the city of Dunedin, FL had a 50% occupancy rate and now with the new greenway, there are no vacancies (Department of Environmental Protection 1996). People come or stay to recreate in communities; wildlife watching alone generates $18.1 billion in the nation (Caudill 1997). Real estate prices are enhanced with the presence of natural areas, parks and trees. The improved psychological well-being of the citizens in a community or neighborhood with parks and trees has also been documented (Schroeder and Lewis 1991). People viewing trees have slower heartbeats, lower blood pressure, and more relaxed brain wave patterns than people viewing urban areas without vegetation (Ulrich 1981).

It can be very advantageous to quantify costs and benefits for maintaining or restoring areas. In addition to stormwater and energy conservation cost reductions, other less tangible benefits such as health and recreation can be demonstrated. Recreational studies have shown that citizens often prefer recreating in parks near their homes, emphasizing the importance of community parks (Schroeder 1990). In Chicago, 50% of all the people visiting forest preserves traveled 10 minutes or less from their homes (Young and Flowers 1982). In 1996, 2.7 million Floridians participated in wildlife recreational activities within a mile of their homes (Florida Game and Fresh Water Fish Commission 1998). It is very important for urban foresters to demonstrate to their city councils and managing agencies the importance of parks and trees as infrastructure in their communities.

Where can We Restore?

The options for restoration sites and projects in cities and communities are endless. Here are a few:

- Yards can be enhanced with native species or even native ecosystems (**Figure 21**).
- Vacant lots, often ignored or treated poorly for many years, are often candidates for restoration.
- The possibilities for better energy conservation and stormwater management in shopping center parking lots are great (**Figure 22**).
- Street trees, aging or lacking diversity, can be restored.
- Schoolyards can become natural areas with unlimited potential as educational areas.
- Industrials parks can be transformed.
- Waterways can be enhanced and connected to support recreational and hydrological benefits (**Figure 23**).

Examples of Sucessful Projects

One objective of this CD-ROM was to find and showcase successful restoration projects in the U.S. We have been overwhelmed with the variety and the high quality of projects being implemented throughout our cities and communities. There is a tremendous amount of creativity, ingenuity, and hard work going into these projects. The high quality and success are due to the amount of effort by so many talented people ranging from young children to funding agency personnel to natural resource managers and community development professionals. Partnerships are a common ingredient

Figure 21. Yards can be enhanced with native species or even native ecosystems. Instead of a typical mono-species hedge or a fence, this area between two neighbors has been restored and planted with native species.

Figure 22. The possibilities for better energy conservation and stormwater management in shopping center parking lots are great.

Figure 23. Waterways such as this creek can be enhanced with native species and connected to support recreational and hydrological benefits.

of these projects. As you can see the variety illustrates the imagination involved and the potential for even more new projects in other communities.

The Forest Park Ivy Removal Project in Portland

Sandy Diedrich saw a problem in her neighborhood park and decided to take the lead in trying to remedy it. Forest Park, is a 5,000 acre urban park in Portland, Oregon -- one of the largest urban forested parks in the country. It has 70 miles of trails and 30 miles of creeks and tributaries. But it also has English ivy, a common landscaping plant, which has invaded the park, covering the native understory plants and trees, and reducing the biodiversity in the forest. Controlling the ivy is a challenge - because it is so mixed with the native plants, herbicides are not feasible. Instead manual control is necessary (**Figure 24**). In 1993, Sandy started a program with volunteers, specifically with high school students (**Figure 25**). She developed workshops and workdays when citizens would come to help. In addition to eradicating the ivy in the park, the workshops taught nearby residents methods for ivy control in their yards - the source of the ivy in the park (**Figure 26**). Through their work with this project, the high school students learned about the basic ecology of the park, working together as a team, and the importance of environmental projects in the community. Alex Johnson, a high school student and crew leader, noted that, "It's a chance to make a difference. I've never known about the forest and here I've learned a lot about nature."

Figure 24. Crew leaders demonstrate ivy removal methods.

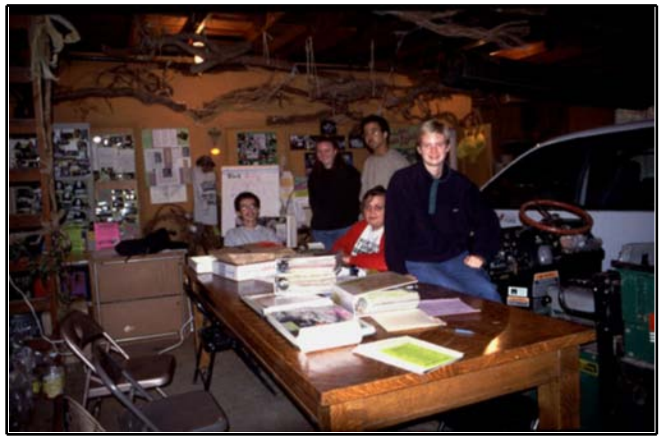

Figure 25. Sandy Driedrich (center) with the crew leaders (Bruno Precciozzi, Kristin Harman, Alex Johnson, and Heidi Dragoo) in the headquarters of the Forest Park Ivy Removal Project.

Figure 26. Standing in front of an area where ivy has been removed and the forest's natural biodiversity is returning.

Drew Gardens in New York

Ray Emanuel and several others in the Bronx, New York identified a site in their community that had potential to be restored. The site was a vacant lot located next to a school; for years this lot was used for dumping and even criminal activities. Their goal was to transform the space into a park for the community and the school children. This community-driven initiative including corporations, the Urban Resources Partnership, and the community began with planning and clean-up of the site. Fall clean-ups and spring festivals involve the community and corporate volunteers. High school students work at the gardens and this work program is part of a job protocol educational program (**Figure 27**). Several high school classes utilize the gardens for their instruction including art, language arts (especially writing), and science classes. Ecology Days at the gardens include stations where participants can learn about subjects such as water testing of the Bronx River, composting, small wildlife, and edible wild plants (**Figure 28**).

Figure 27. A vacant lot located next to a school in New York was transformed into a park for the community and the school children.

Figure 28. Included in this new park, named Drew Gardens, are trails and a deck to view the Bronx River.

Apex Park in Tampa

Apex Park is on Davis Island, a small island in Tampa. It is the first thing you see after you cross the bridge to the island. And the residents wanted the first impression to be the best. So they approached Steve Graham, Tampa's urban forester for assistance in restoring the site, a small piece of land about an acre in size. After researching old photos and documents and some remnant ecosystems in the area, they arrived at a list of plants that would have made up the ecosystem before development of the island (**Figure 29**). They were delighted to find one grass, twisted fiddle leaf, that was endangered and found some specimens still remaining on the island (**Figure 30**). They planted a small area with native tree and shrub species including twisted fiddleleaf. The other small part of the park was landscaped with grass to showcase and allow viewing of the native ecosystem (**Figure 31**). The park has kindled interest among residents in native species and several people have landscaped their yards with many of these species.

Figure 29. With the help of Steve Graham, Tampa's urban forester, the community of Davis Island restored native plants at Apex Park.

Figure 30. One plant, twisted fiddleleaf, was endangered so the community collected specimens and planted it at the park.

Landscaping for Wildlife

An educational program developed by the Florida Cooperative Extension Service has given homeowners the knowledge and tools for landscaping their backyards and small urban lots for wildlife using ecological principles (**Figure 32**). Workshops are aided by the inclusion of a participant's guide, instructor's guide and videos

Figure 31. The other part of the park was landscaped with grass to showcase and allow viewing of the native ecosystem.

developed by extension specialists. The first of three modules entitled "Landscaping for Wildlife: Providing Food in Your Yard" demonstrates how to restore a remnant of native landscape, start a bird-feeding program, control squirrels, plant a wild bird food plot, and feed hummingbirds and butterflies. The second module enables participants to select plants to provide good wildlife cover including bird and bat houses, burrows for toads and other small mammals, treefrog houses, rock piles for lizards and snakes and brush piles for birds and rabbits **(Figure 33)**. The third module highlights the importance of the third wildlife requirement - water.

Figure 32. In the Landscaping for Wildlife program, homeowners learn how to enhance wildlife habitat in their backyards. Photo by Joe Schaefer

Naturescaping For Clean Rivers

Landscaping your backyard can have a positive impact on the environment. That's the theme for Portland's Naturescaping For Clean Rivers project (**Figures 34 and 35**). "Rainwater runoff, or

Figure 33. The second module enables participants to select plants to provide good wildlife cover including bird and bat houses, burrows for toads and other small mammals, treefrog houses, rock piles for lizards and snakes and brush piles for birds and rabbits. Photo by Joe Schaefer

stormwater, becomes a problem in urban areas because of the thousands of acres of impervious surface: roofs, roads, driveways, and parking lots," notes the project workbook. This runoff contains contaminants such as oils, metals, and chemicals. The goal of naturescaping is to improve the quality and reduce the quantity of water reaching storm drains. Workshops teach homeowners how to landscape with native plants which require much less water, fertilizers, mowing, and chemicals to maintain (**Figures 36 and 37**). Other classes include composting, attracting wildlife and reducing pesticide use. Neighbors work together to host workshops in their communities; all workshop participants receive project workbooks which help them develop an action plan for their yard.

Restoring Fire In Haile Plantation

A neighborhood in Gainesville, Florida wanted to restore the native longleaf pine ecosystem as well as reduce the fire hazard for their homes. In the past, fire was a natural disturbance in Florida longleaf pine ecosystems. Yet, development as well as new forest practices have excluded fire from many of Florida's ecosystems. The neighborhood decided to re-instate

Figure 34. In the Naturescaping for Clean Rivers program homeowners learn how to landscape with native plants which require much less water, fertilizers, mowing, and chemicals to maintain. Here a backyard is prepared for planting. Photo by Linda Robinson

Figure 35. The backyard is transformed into an energy and water efficient native landscape. Photo by Linda Robinson

Figure 36. Native wildflowers adorn a "naturescaped" backyard. Photo by Linda Robinson

this natural ecological process to the small patches of forest in their community (**Figure 38**). Fires reduce the competing hardwoods allowing longleaf pine to

Figure 37. Butterfly gardens are a popular part of the Naturescaping program. Photo by Linda Robinson

regenerate and become reestablished in the ecosystem (**Figure 39**). Educational signs are a big part of the program.

Figure 38. A neighborhood in Gainesville, Florida has brought fire in as a management tool to restore the native longleaf pine ecosystem as well as reduce the fire hazard for their homes. Photo by Eliana Kampf Binelli

Greening the Great River Park

The Mississippi River, as with most rivers in the world, became a center of industry and shipping as St. Paul, Minnesota became a prosperous city. But often as with most industrial areas the native forests along the river were destroyed and replaced with industrial buildings, pavement, and warehouses. The Greening the Great River Park Program, established in 1995, seeks to restore many of these areas along the River (**Figures 40 and 41**). This public-private partnership includes The Saint Paul Foundation, City of St. Paul and others including thousands of volunteer and over 240 partner organizations. The project involves the landscaping of over 100 private industrial lands with the four native plant ecosystems

Figure 39. Fires reduce the competing hardwoods allowing longleaf pine to regenerate and become reestablished in the ecosystem.

Figure 40. The Greening the Great River Park Program, established in 1995, seeks to restore many sites in industrial areas along the River. This shows an industrial site before restoration. Photo by Rob Buffler

Figure 41. Over 100 private industrial lands have been landscaped and planted with four native plant ecosystems. This shows the same site after restoration. Photo by Rob Buffler

including 30,000 trees and shrubs that occupied the area in the past. "Our goal is to have a 50% canopy cover throughout the valley. In 20 to 25 years, as the trees reach mature heights, we want the valley to look as though the buildings were placed in a forest rather than some trees were planted around buildings."

A Community Park in New York City

A one-acre lot used as a bus garage for many years and next to three schools was the site for the birth of a community park in New York City. The planning began in 1990 with meetings involving the whole community - city agencies, non-profit organizations (headed by "Open Road"), students, businesses, neighbors and more. The grass-roots park design includes a greenhouse, basketball area, nature pond with plantings, wildlife area, and playground (**Figures 42**). To restore this "brown field" site the area needed to be lined with plastic and new soil needed to be imported. However, the group including professional engineers and school children, decided to develop a composting system and produce compost from nearby businesses to produce the "soil." The newly invented composting system is now sought by many other communities in New York. School classes using the park range from science and gardening to energy and physics to poetry and art. A math class, for example, helped design the greenhouse. Paula Hewitt, the project creator and Open Road Director, emphasizes that "the purpose of the park is to be educational, yet we have a very relaxed, fun atmosphere" (**Figures 43 and 44**). The park is open to the community every day of the year.

Figure 42. The planning for this community park in New York City began in 1990 with meetings involving the whole community - city agencies, non-profit organizations (headed by "Open Road"), students, businesses, neighbors and more. The grass-roots park design includes a greenhouse, basketball area, nature pond with plantings, wildlife area, and playground.

Figure 43. Paula Hewitt, the community organizer, looks for turtles and fish in the park's pond with neighborhood kids.

Figure 44. Gerald Brinson, who started as a volunteer for the park and is now part of the staff, describes the new dock project with flowing water that he is constructing.

Bill Baggs Park

In 1991 Hurricane Andrew struck Miami and its surrounding communities including Key Biscayne. Bill Baggs Park which until that time was mostly occupied with an invasive tree, Australian pine, was completely destroyed (**Figure 45**).

Figure 45. In 1991 when Hurricane Andrew struck south Florida, the non-native Australian pine forest at Bill Baggs Park on Key Biscayne was completely destroyed.

The nearly clean slate provided an opportunity and several visionaries saw that it was a possible chance to restore the park. With partnering between federal, state, county, city and many non-profit groups, a proposal and plan was developed to re-create the park to the way it was 100 years ago. They researched the five native ecosystems including four wetland areas that had occupied the site (**Figures 46 and 47**).

Historical and recreational amenities were also considered - for example, without the shade of the previous forest, nine picnic shelters needed to be constructed (**Figure 48**). Cultural history including archaeological findings were incorporated into the plan (**Figure 49**). The ecosystems were restored and future invasions of non-native plants were monitored by volunteers. Educational displays were important to inform the public about the process of restoration as well as the diversity of the "new" ecosystems (**Figures 50 and 51**).

Figure 46. With partnering between federal, state, county, city and many non-profit groups, a restoration proposal and plan was developed to restore the park with the five native ecosystems that it had 100 years ago. Old documents were studied to carefully re-create and map the ecosystems.

Figure 47. The coastal strand ecosystem three years after planting shows the restoration success.

Figure 48. The shade that had been removed with the Australian pine tree canopy had to be replaced with several picnic shelters.

Figure 49. The historical, cultural, and archaelogical significance of the site such as this 1825 lighthouse with restored lighthouse-keeper's house was an important part of the restoration plan.

Figure 50. Involving the park's neighbors and the community in all the stages was very important to the restoration success. Nearby condominiums can be seen from the restored south Florida slash pine ecosystem.

Streamside Restoration in Virginia

The Difficult Run Watershed in Virginia has over one-half million acres of forests and urban communities. Nonpoint source pollution is affecting the water quality of the Difficult Run River and downstream the Potomac River and Chesapeake Bay. This restoration project is a partnership with the Virginia Department of Forestry, Environmental Protection Agency, Virginia Department of Conservation and Recreation, Chesapeake Bay Foundation and the USDA Forest Service. Together they are striving to:

- Improve water quality by enhancing and restoring streamside forests.

Figure 51. Educational displays were important to inform the public about the process of restoration as well as the diversity of the "new" ecosystems such as the mangroves along the ocean and bay.

- Increase public awareness and education regarding the value of riparian forests.
- Improve fish and wildlife habitat (**Figure 52**).

Over 8,000 trees have been planted to reestablish riparian buffers or streamside forests to restore and maintain this important watershed.

The Two Key Ingredients

These projects have been very successful because they all had two key ingredients. First, the people. All projects became an essential part of the community because they involved the people in the community from the start and then in every step. People included all stakeholders such as citizens (all ages), businesses, non-profit groups, volunteers, and government agencies. Collectively these people put together the second key ingredient to success - a plan. As you will see in Chapter 5, the successful restoration plan contains a vision, goal, objectives, action plans and evaluation tools. Well-developed plans demonstrate the need for the project and are used to seek public and financial support. These plans are usually very effective at obtaining funding and other in-kind support. Successful projects have support of the people and a well laid-out plan (**Figure 53**).

Figure 52. The Difficult Run Watershed Project restores streamside forests which act as buffers to protect water quality and fish and wildlife habitat in riparian ecosystems. Photo by Judy Okay

Figure 53. Successful restoration projects have two key ingredients - support of the people and a well laid-out plan.

Conclusions

There are many options for restoring ecological benefits in your community. It is important to consider the whole city or community as an ecosystem and then to focus in on parcels or projects that could benefit that ecosystem or landscape as a whole. Restoration projects can be as small as backyards to parking lots, city streets, parks, waterways and any place where there are or could be trees. Most often it's important to start with a small manageable project. The United States hosts an abundance of successful and innovative urban forest restoration projects. The Bronx's Drew Park brought life back to a vacant lot next to a school. Portland's Ivy Project removed invasive ivy at the 5,000 acre Forest Park. Greening the Great Green River is restoring industrial parks along the Mississippi River. The possibilities for restoration projects are unlimited and up to the imagination and energy of people (**Figure 54**). Planning and involving the community - the stakeholders - are the two most important ingredients for success.

Figure 54. The possibilities for restoration projects are unlimited and up to the imagination and energy of people.

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Chapter 2: Basic Ecological Principles for Restoration[1]

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Abstract

Traditionally the urban forest has been viewed as trees in the city - often along streets and in small groups in other public places such as parks. However, another way to look at the urban forest is as an ecosystem, including many more living components than trees (people, shrubs, herbs, animals, microorganisms), a physical environment (light, moisture, soil, rocks), energy flow from the sun and water and nutrient cycles. A first step in reorienting our view of urban forests and their management is to review some important ecological principles and to see how they apply to restoration and management. The goal of this chapter is to examine urban forests as ecosystems and to discuss some of the opportunities for managing urban forest ecosystems to provide more natural benefits to communities and cities. By comparing the present state of the urban forest ecosystem (UFE) to natural ecosystems, we can learn how to manage the UFE for some of the natural benefits it can provide. These include energy conservation, stormwater management, wildlife conservation, and recycling or solid waste management. The urban forest ecosystem is an open system with energy and materials constantly entering and leaving the system. Producers (mainly green plants) and consumers (organisms dependent on living and dead plant and animal matter) make up the living portion of all ecosystems which are linked together in complex networks called food webs. Cities are largely consumers relying on production of food, energy and natural resource from outer agricultural, forested and other natural areas. The urban forest ecosystem can provide many opportunities for ameliorating the drain and stress on our natural resources. For example, by cooling the city with a forest canopy, we are less dependent on outside natural resources for air conditioning. By providing natural areas for water infiltration, storage and evaporation of rainwater, the waste water from our streets and other impervious surfaces is reduced. When leaves, branches, and grass-clippings are left on-site instead of being removed, these natural materials sustain the natural nutrient cycle and provide the same benefits that we ascribe to mulches in gardens and landscapes. Urban forests can also help reduce atmospheric CO_2 build-up in two ways by reducing fossil fuel (energy) use and by increasing carbon storage. Finally, the UFE can provide wildlife habitat and help with the movement and conservation of some organisms through connectivity. Seven guidelines to restore and manage the urban forest ecosystem are: (1) Restore and manage the UFE to decrease consumption and contribute to conservation; (2) Restore and manage

1. This is Chapter 2 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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the UFE for its water cycling benefits; (3) Restore and manage the nutrient cycle within the UFE:; (4) Restore and manage the UFE to support greater biodiversity; (5) Restore natural forest ecosystems in the city; (6) Educate policy makers, city managers and the public about the benefits of a healthy UFE; and (7) Incorporate UFE management and restoration into urban and regional planning.

Introduction

Traditionally the urban forest has been viewed as trees in the city - often along streets and in small groups in other public places such as parks **(Figure 1)**. Managing these trees has included inventorying the tree population and assessing their health. We have cultured and managed them mostly as individuals, and this is called arboriculture. However, another way to look at urban forests is as ecosystems, with many more components (people, animals, microorganisms), a physical environment (sidewalks, soil, rocks), energy flow (sun) and processes (water, nutrient cycles) **(Figure 2)**. This ecological perspective is more comprehensive, incorporating biological, physical, chemical and social components. This approach offers a great opportunity to enhance the environmental benefits of forests in urban areas. The environmental benefits gained from a healthy urban forest ecosystem (UFE) include energy savings, reduction of waste and stormwater costs, water quality improvement, increased recreational opportunities and enhanced wildlife and biodiversity conservation. With this outlook we also have the additional opportunity to think in the long-term and to consider the urban forest as part of the larger landscape.

A first step in reorienting our view of urban forests and their management is to review some important ecological principles and to see how they apply to restoration and management. The goal of this chapter is to examine urban forests as ecosystems and to discuss some of the opportunities for managing urban forest ecosystems to provide more natural benefits to communities and cities.

Figure 1. Traditionally the urban forest has been viewed as trees in the city - often along streets and in small groups in other public places such as parks.

Figure 2. Another way to look at the urban forest is as an ecosystem with many more components (people, animals, microorganisms), a physical environment (sidewalks, soil, rocks), energy flow (sun) and processes (water, nutrient cycles).

The Urban Forest As An Ecosystem

An urban forest ecosystem (UFE) is a collection of living matter (plants, animals, people, insects, microbes) and nonliving matter (soil, rocks and dead organic matter) through which there is a cycling of nutrients and water and a flow of energy from the sun. Based on this definition the UFE represents not only the trees but also the other components (including humans, microbes, wildlife and the physical environment) and the interaction of these components.

What are the boundaries of a UFE? We can consider UFEs to be the whole city or smaller parcels within the city. The boundaries of the UFE depend on the nature and scope of our management goals. No matter what the boundaries of the ecosystem are, each ecosystem is linked to other surrounding ecosystems **(Figure 3)**. As we noted above, urban and rural ecosystems also overlap and interact to form landscapes. All the ecosystems on earth together form the biosphere, which contains all of the life on earth.

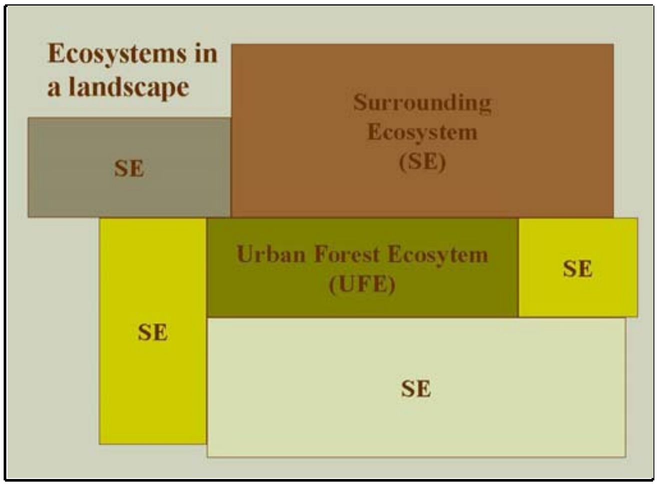

Figure 3. We can consider the UFE to be the whole city or smaller parcels within the city depending on our management goals. The UFE is linked to other surrounding ecosystems which together form the landscape.

Why View the Urban Forest Ecosystem as an Ecosystem?

Cities are part of what used to be rural landscapes, most of them originally forested **(Figure 4)**.

Figure 4. Cities are part of what used to be rural landscapes. Here you can see the natural forest edges of this small city. Photo by Hans Riekerk

By comparing the present state of the urban ecosystem to natural ecosystems, we can learn how to manage the UFE for some of the natural benefits it can provide **(Figure 5)**. These include energy conservation, stormwater management, wildlife conservation, and recycling or solid waste management. Also, by taking an ecosystem view, we can better understand the importance of the structure and function of UFEs which may help solve local problems such as flooding, and air and water pollution. By focusing on urban ecosystem management we can also contribute to solving larger scale problems such as biodiversity conservation and reduction of atmospheric CO_2 concentrations.

Figure 5. By comparing the present state of the urban ecosystem to natural ecosystems, we can learn how to manage the UFE for some of the natural benefits it can provide. Photo by Larry Korhnak

The Structure and Function of the UFE

The UFE is an open system (in thermodynamic terms) with materials and energy constantly entering and leaving **(Figure 6)**.

Energy from the sun is fixed by plant leaves in the UFE. Some of the absorbed energy then flows out of the ecosystem as heat, which warms the air **(Figure 7)**.

The rest of the absorbed solar energy is used to evaporate or transpire water. Materials entering the UFE may be in the form of nutrients (fertilizers), water (in rainfall or irrigation), plants (new plantings or seeds from invasive plants) or other forms of non-solar energy, such as fossil fuels **(Figure 8)**.

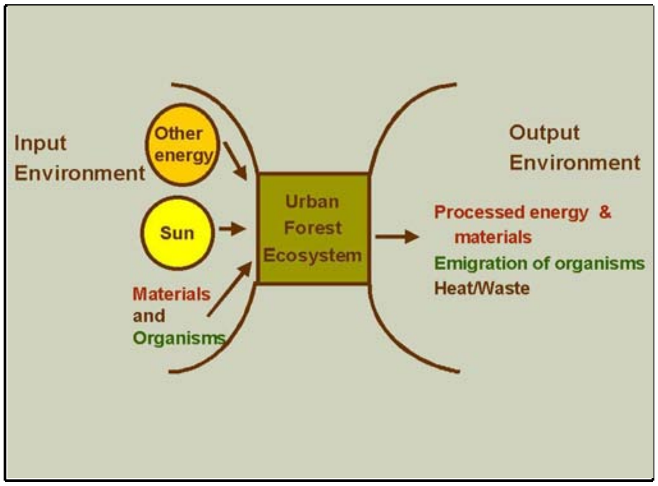

Figure 6. The urban forest ecosystem is an open system with energy and materials constantly entering and leaving the system.

Figure 7. Energy from the sun is fixed by plant leaves in the UFE.

Forms of these same materials may leave the UFE in runoff (storm water), with the wind (seeds) or in trucks going to landfills (yard and solid waste) with much converted to CO_2 and heat **(Figure 9)**.

The UFE may have a very complex structure with a variety of layers including a tree canopy, a shrub understory, an herb layer and a litter layer. The UFE is made up of living things, called biotic components (living plants and animals) and nonliving things, called abiotic components (soil, air, nutrients, water, dead organic matter). Nutrients (such as nitrogen, phosphorus and calcium) and water cycle from the abiotic parts of the ecosystem to the biotic parts and back again. These are called nutrient and water cycling, respectively.

There are two major groups of the living things in the UFE: (1) producers (also called autotrophs)

Figure 8. Fossil fuels are one of the materials entering the UFE for management.

Figure 9. Pruned branches and leaves are materials often leaving the UFE to end up in landfills.

and (2) consumers (also called heterotrophs) **(Figures 10** and **11)**.

Producers, which are mainly green plants, take light energy and store it through the process of photosynthesis. Consumers cannot photosynthesize but instead feed directly on the producers (i.e., herbivores) and other consumers (i.e., carnivores or detritivores or decomposers). Consumers include non-photosynthetic bacteria, fungi, and animals,

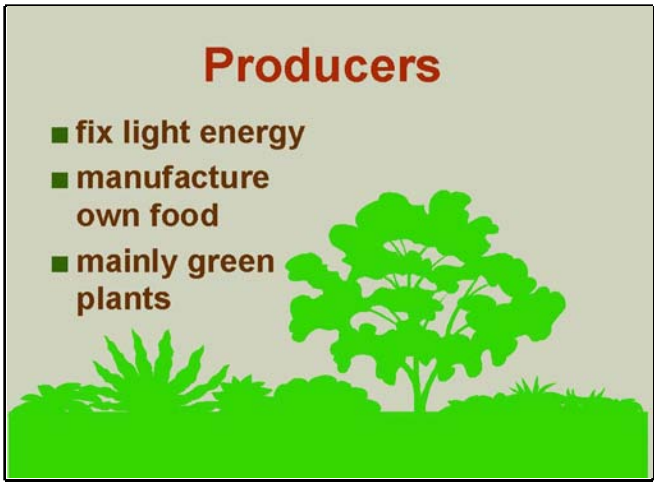

Figure 10. One of the two major groups of living things in the UFE is producers (also called autotrophs).

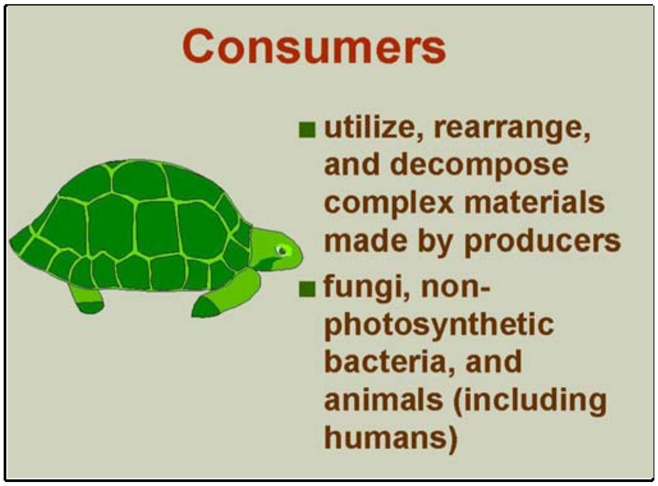

Figure 11. The other major group of living things in the UFE is consumers (also called heterotrophs) which cannot photosynthesize but instead feed directly on the producers (i.e., herbivores) and other consumers (i.e., carnivores and decomposers).

including humans. Producers and consumers are linked together in complex networks called food webs **(Figure 12)**. Food webs are important to recognize in UFE management, because the disruption or elimination of one part of the web may impact other organisms and ecosystem functioning in unexpected ways.

Comparing Natural and Urban Ecosystems

Natural ecosystems have a balance of production and consumption constantly operating. If by chance the ecosystem produces more than it consumes, the excess energy is stored as carbon (in the wood of tree stems, peat in bogs, etc.). If a fire or another disturbance lowers plant production, the

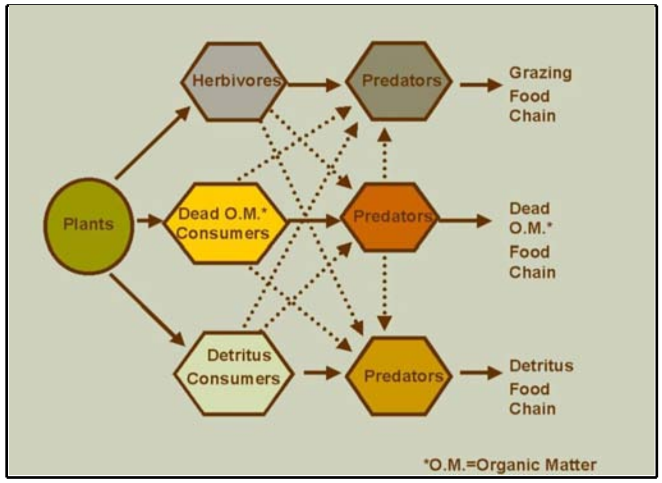

Figure 12. Producers (mainly green plants) and consumers (organisms dependent on living and dead plant and animal matter) are linked together in complex networks called food webs.

consumer populations will adapt accordingly. Cities, on the other hand, are largely consumers relying on production of food, energy and natural resources in outer agricultural, forested and other natural areas (Odum 1983) **(Figure 13)**. Seldom do cities produce these necessities within their perimeter in quantities sufficient to support large numbers of people. At the same time, cities must contend with the wastes that are produced, often sending solid wastes and waste water out of the city.

Figure 13. Cities rely on natural and domesticated environments for resources. At the same time these cities must contend with the wastes that are produced, often sending solid wastes and waste water out of the city (adapted from Odum 1983).

How Can the UFE Help?

The urban forest ecosystem can provide many opportunities for ameliorating the drain and stress on our natural resources. For example, by cooling the city with a forest canopy, we are less dependent on outside natural resources for air conditioning **(Figure 14)**.

Figure 14. By cooling the city with a forest canopy, we are less dependent on outside natural resources for air conditioning. Photo by Hans Riekerk

By providing natural areas for water infiltration, storage and evaporation of rainwater, the waste water from our streets and other impervious surfaces is reduced **(Figure 15)**.

Figure 15. By providing natural areas for water infiltration, storage and evaporation of rainwater, the waste water from our streets and other impervious surfaces is reduced. Photo by Larry Korhnak

By providing places for recreation, fewer people will need to use fossil fuels to leave the city for their nature experiences **(Figure 16)**.

Figure 16. By providing places for recreation, fewer people will need to use fossil fuels to leave the city for their nature experiences. Photo by Larry Korhnak

By supporting, for example, water quality, forest management, and growth management policies for lands outside our cities, we will sustain our natural and domesticated ecosystems. Infusing our cities and communities with more urban forest ecosystems will restore natural structure and processes to our urban forests making us less dependent on our limited natural resources outside the city.

Characteristics of the UFE

The Urban Heat Island

Cities can reach temperatures 7^{o} to 15^{o} F higher than in the surrounding rural ecosystems. This is called the urban heat island effect **(Figure 17)**.

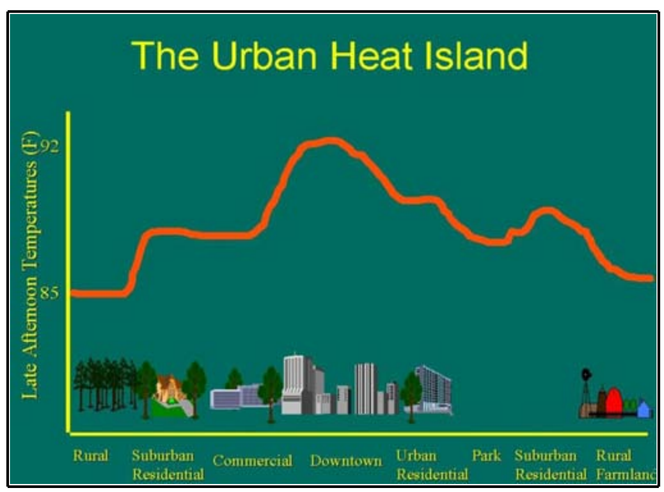

Figure 17. A city is 7^{o} to 15^{o} F warmer than the surrounding countryside. Adapted from Oke 1982.

Some of the reasons for this heat buildup are:

(1) cities generate heat from burning fossil fuels (factories, cars, heating and air conditioning),

(2) city structures absorb and store solar heat (especially dark surfaces such as asphalt roads and dark roofs),

(3) through decreased vegetation and rapid routing of rainwater to storm sewers, cities have much less natural cooling due to the evaporation and transpiration of water,

(4) air pollutants may slow the outflow of heat away from urban surfaces, and

(5) cities usually have less air movement to take heat out of the city (Lowry 1967; Oke 1982).

Large numbers of trees can reduce local air temperatures by 1^{o} to 9^{o} F (McPherson 1994). Evapotranspiration by trees lowers air temperatures in two ways. First, when precipitation is intercepted by trees and other plants, the evaporation of this water cools the air. Secondly, trees constantly take up water from the soil and lose water to the air. This process, called transpiration, also lowers air temperature. Therefore, the UFE can reduce heat buildup in the city by storing less heat, using more of the sun's energy for evaporative cooling, and shading buildings and other surfaces so that they require less fossil fuel energy for cooling **(Figures 18** and **19)**.

Figure 18. The urban forest ecosystem through evaporative cooling and shade can contribute to reducing the temperatures in the urban heat island. This parking lot is a contributor to high temperatures in the urban heat island.

Figure 19. The urban forest ecosystem through evaporative cooling and shade can contribute to reducing the temperatures in the urban heat island. This parking lot demonstrates trees properly placed to reduce temperature.

Nutrient Cycling in the UFE

Chemicals circulate from the plants and animals to the soil and back again, as part of the nutrient cycle **(Figure 20)**. The health of plants in the ecosystem is mainly dependent on the soil for its source of nutrients. Dead organic matter in the soil, also called detritus, is the long-term storage site for essential nutrients. Decomposers (primarily microrganisms) break down the detritus and release the nutrients held in the organic matter into organic forms that can be reused by plants, thus completing the nutrient cycle. In the UFE, this cycle is often disrupted or arrested because most of the dead organic material such as lawn clippings, leaves, branches, and logs are removed and hauled to landfill sites or chipped for application to other sites. By doing so, we are denying the UFE of a readily recyclable source of fertilizers, which then must be imported in the form of man-made fertilizers.

What happens when we remove these natural materials from a backyard, a park, or a schoolyard in the UFE?

- the soil may be exposed, resulting in erosion,
- plant roots may be exposed and desiccated or damaged **(Figure 21)**,
- fossil fuels are used to blow leaves, clean the site and transport the yard waste to landfills or compost piles **(Figure 22)**,

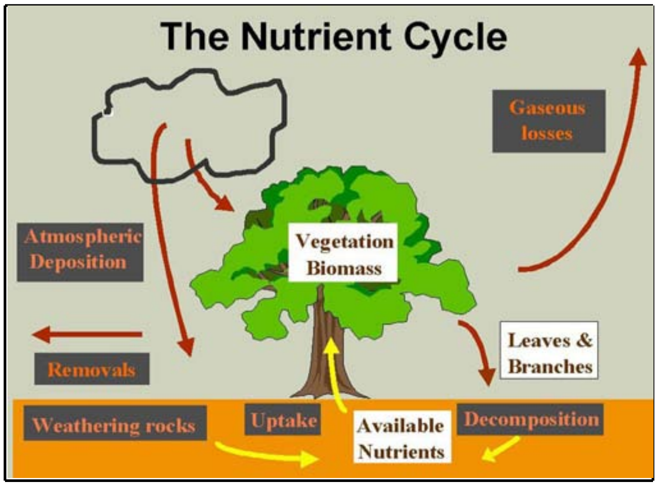

Figure 20. Chemical elements in ecosystems circulate from the plants and animals to the soil and back again, as part of the nutrient cycle.

- the organic matter removed no longer helps the moisture and nutrient holding capacity of the soil,
- wildlife and other organisms that depend on decaying wood or litter for habitat and/or food cannot live in this neatly maintained environment,
- precious plant nutrients are removed often requiring fertilizer applications for replacement **(Figure 23)**,
- fertilizers, water, mulches, and pesticides brought in to support and maintain this altered system are manufactured at a great fossil fuel cost.

Instead of using tremendous amounts of energy to remove branches, leaves, and snags, we can utilize these materials to sustain the health of the UFE. These natural mulches can be recycled on-site for free where they will serve as natural fertilizers. When they remain on-site, these natural materials provide all the benefits that we ascribe to mulches in gardens and landscapes **(Figure 24)**.

It is quite feasible to take advantage of natural nutrient cycling processes in UFE, contributing in the process to conservation (water, energy, and soil) and improving the environment both locally and globally. Landscapers need to change many ingrained practices, such as leaving more dead plant materials on the ground. Creating "natural" or "semi-natural"

Figure 21. When natural plant materials are removed from a landscape, many plant roots may be exposed and desiccated or damaged.

Figure 22. Many leaves and branches that could be piled or spread (recycled) in a homeowner's landscape are instead transported to landfills or urban compost piles.

Figure 23. Precious plant nutrients are removed from the landscape either resulting in plant deficiencies or requiring fertilizer applications.

Figure 24. When leaves, branches, and grass-clippings are left on-site, these natural materials provide all the benefits that we ascribe to mulches in gardens and landscapes.

areas in parks, backyards and other appropriate sites will have favorable results for nutrient cycling and other UFE processes such as cycling.

Water Cycling in the Urban Forest

Water forms a critical link between the earth's surface and the atmosphere. After water falls to earth as rain (and in other forms), it flows downhill into creeks or soaks into ground, entering the ground water (**Figure 25**).

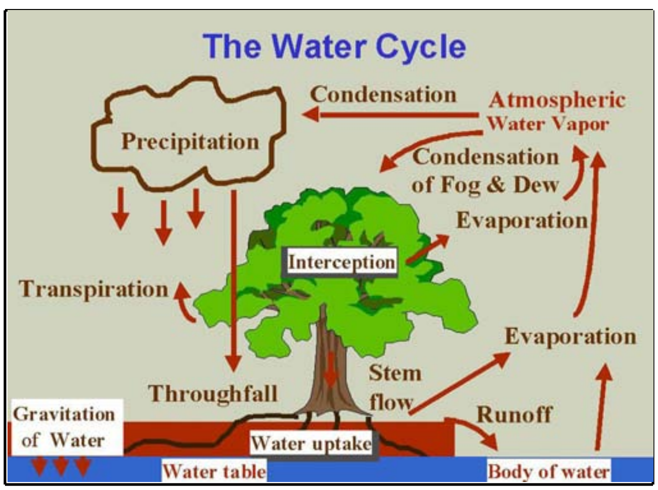

Figure 25. In the water cycle, water falls to the earth as precipitation, enters the ground or flows as runoff to rivers, lakes and the ocean, and is taken up (used) by plants and other organisms. By evaporation from vegetation, land and bodies of water, water re-enters the atmosphere to begin the cycle once again.

Water in creeks flows into rivers, lakes and finally the ocean. Water reenters the atmosphere by evaporation from the land and sea and and by evaporation and transpiration from vegetation (see **Chapter 6 - The Hydrological Cycle**). In the UFE, impervious surfaces such as buildings, paved streets and parking lots interrupt this water cycle by collecting the water and channeling it into sewers, canals and other structures.

The consequences of interrupting the natural water cycle include:

1. decreased infiltration of water into soil,
2. more runoff, which must then be managed and accomodated,
3. decreased water quality as pesticides, fertilizers and other pollutants are concentrated in the collected runoff,
4. erosion of unprotected soils and
5. less evaporation of water with its associated cooling effect.

How does the UFE help restore the water cycle? First, vegetation in the UFE intercepts rainfall and evaporation of this water helps cool the city. Second, soils absorb water; then it is either taken up by plants or percolates to the water table or creeks instead of running into storm sewers. The result is lower stormwater treatment costs and less flooding potential in the city (**Figures 26 and 27**).

Figure 26. In the city, impervious surfaces such as buildings, paved streets and parking lots interrupt the water cycle by collecting the water and channeling it into sewers, canals and other structures. Photo by Larry Korhnak

Also, if soils are protected with mulches and plants, less erosion will result in less sediment entering the water. Wetlands also serve as storage areas for water. Restoring and managing wetlands in cities will lower the rate and volume of stormwater runoff, control floods and erosion and help purify water that will reach the water table. For example, after storm in Dayton, Ohio the existing urban forest reduced runoff by 7%. A slight increase in the urban forest canopy could reduce runoff by 12% (Sanders 1984).

Figure 27. Soils in the UFE absorb water; then it is either taken up by plants or percolates to the water table or creeks instead of running into storm sewers. Photo by Larry Korhnak

Educating policy makers, city managers and the public about the benefits of vegetation in the UFE and cost-saving potential is essential to more efective management of the water cycle. For further discussion on the water cycle, see **Chapter 6- The Hydrological Cycle**.

Carbon Storage and Sequestering by UFEs

Carbon dioxide (CO_2) in the atmosphere is increasing globally and is the principal contributor to the expected increase in the greenhouse effect (global warming). The two main sources of CO_2 are the burning of fossil fuels and deforestation (Houghton et al. 1996). Trees, litter, soil and organic matter all store carbon (C). Since organic matter contains 50% C, the more biomass (plant and animal matter) on the earth, the less CO_2 in the atmosphere.

In an ecosystem, carbon is taken in as CO_2 in the process of photosynthesis **(Figure 28)**. Carbon is either stored as living or dead plant material or consumed by other organisms in the food web. CO_2 is also given off during respiration. Forests can store much greater amounts of C in the vegetation and soils than any other type of ecosystem on earth due mainly to the relatively massive storage in tree stems.

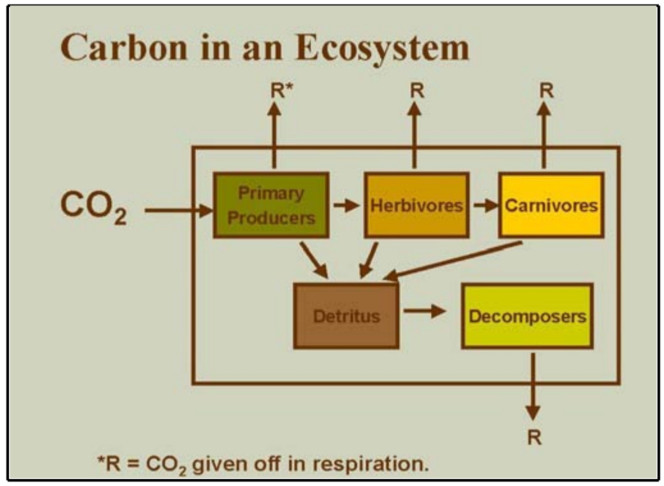

Figure 28. In an ecosystem carbon is taken in as CO_2 in the process of photosynthesis. Carbon is either stored as living or dead plant material or consumed by other organisms in the food web. CO_2 is also given off during respiration.

Can the UFE help to store more carbon? Forests store carbon in their plants, roots, forest litter and animals. One urban study estimated that the 69 million acres of urban forest in the U.S., with an average of 28% canopy cover, store annually a net 6.5 million tons of C (Rowntree and Nowak 1991). However, the whole world puts out 5.4 billion tons C per year (deforestation alone accounts for 1.6 billion tons) (Sundquist 1993). Urban forests in the USA therefore currently only remove 0.1% of the output. Even though urban forests are not likely to be better managed just for C sequestration, it is important to recognize that C sequestration by the UFE is an additional benefit, albeit small.

To summarize, the UFE can contribute to reduce atmospheric CO_2 in two ways: First, by reducing fossil fuel (energy) use in the cities **(Figure 29)**; Second, by increasing C storage from planting and managing trees especially in cities where tree cover is currently low.

The UFE can reduce energy (fossil fuel) use in several ways:

- By lowering temperatures in the city, UFEs reduce energy use for air conditioning.
- By letting leaves and branches remain in the UFE, we use less energy to clean up and transport materials.
- By planting trees and landscapes that use only natural rainfall, we decrease dependence on irrigation.
- By being attractive places for recreation, UFEs can encourage people to stay in the city for their nature experiences instead of using fossil fuels to drive elsewhere.
- By reducing stormwater runoff, we use less energy to transport and treat stormwater.

Figure 29. The UFE can contribute to reduce atmospheric CO_2 by reducing fossil fuel (energy) use in the cities.

Wildlife in the UFE

Urbanization and urban sprawl have resulted in habitat loss, highly fragmented forests, drained wetlands and disrupted migration routes for wildlife. Also, in many situations wildlife is dependent upon two or more ecosystems, and these may not be available. A forest fragment is a small parcel separated from the larger forest (see also **Chapter 3 - Biodiversity**). In the UFE, forest fragments often become small parks or undeveloped and often degraded land. These fragments may be too small or too distant to support many wildlife species characteristic of natural areas. However, by connecting some smaller fragments, larger ecosystems can be simulated and some migration routes and habitats restored **(Figures 30** and **31)**. For further discussion on wildlife, see **Chapter 8 - Wildlife**.

Figure 30. This creek outside of a small city is connected to a wetland inside the city allowing migration of some wildlife species. Photo by Hans Riekerk

Figure 31. By connecting some smaller fragments, larger ecosystems can be simulated and some migration routes and habitats for wildlife may be restored. Photo by Larry Korhnak

Biodiversity

Until recently, efforts in biological conservation have largely focused on preservation and protection of individual species, subspecies and populations, through the implementation of the Endangered Species Act. However, scientists and practitioners are realizing today that this has not always been successful or even possible, and that many other species have been ignored as a result. More recently there is a greater focus on ecosystem management with the idea that by managing and restoring whole ecosystems, biodiversity and whole food webs, as well as individual species, may be better protected. Urban forests, which range from highly degraded woodlots to monocultures of exotic trees to semi-natural ecosystems, may play an important role in managing for biodiversity. Although urban forests cannot be expected to support all species groups (for example large mammals or other wide-ranging animals), if effectively managed, they can provide habitat at a smaller scale, increase the effectiveness of larger nearby reserves, and help with the movement and conservation of some organisms through enhanced connectivity **(Figure 32)**.

Thus urban forests can be "stepping stones between ecosystems" (Franklin 1993) **(Figure 33)**. At a smaller scale, biodiversity can also be restored by enhancing the ecosystem's natural structure, creating multi-age ecosystems in several stages of succession, controlling invasive plant and animal species, leaving stumps, leaves, snags and logs to

Figure 32. Although urban forests cannot be expected to support all species groups (for example large mammals or other wide-ranging animals), if effectively managed, they can provide habitat at a smaller scale, increase the effectiveness of larger nearby reserves, and help with the movement and conservation of some organisms through enhanced connectivity. A corridor of forest provides this connectivity. Photo by Henry Gholz.

improve nutrient cycling and for wildlife and by planting native species that mimic composition of nearby ecosystems. (For further discussion, see **Chapters 3 - Biodiversity**, **4 - Plant Succession and Disturbances**, and **9 - Invasive Plants**.)

Opportunities for Restoring and Managing the UFE More Ecologically

How can we restore and manage the urban forest ecosystem? We propose the following seven guidelines:

Restore and manage the UFE to decrease consumption and contribute to conservation:

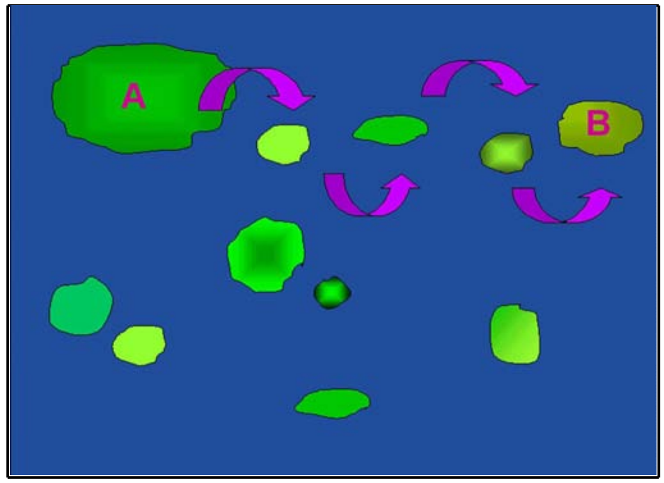

Figure 33. Urban forests can be "stepping stones between ecosystems" (Franklin 1993).

- Take advantage of natural nutrient cycling by leaving grass clippings, leaves, branches and logs on the ground and thereby reduce the tremendous amount of energy expended to remove plant materials from the landscape.
- Plant and maintain trees around buildings to reduce energy consumption for cooling and heating.
- Save energy used for stormwater management by increasing areas within the UFE for water infiltration and evaporation.
- Manage the UFE to encourage recreation in the city, thereby decreasing energy consumption for travel to distant recreation sites.
- Plant tree species that are adapted to local conditions and require only natural rainfall (after establishment) to save water and energy costs from irrigation.

Restore and manage the UFE for its water cycling benefits:

- Decrease storm water runoff and flooding by increasing pervious surfaces (soils) in the city to absorb water.
- Encourage increased canopy and vegetation for increased evaporation and transpiration of water to decrease stormwater runoff and treatment costs.

- Increase the retention of water in the UFE for evaporative cooling to lower urban heat island temperatures.
- Increase soil water infiltration in UFE soils along with the retention of sediments and pollutants to improve water quality.
- Restore and manage wetlands in cities to lower the rate and volume of stormwater runoff, control floods and erosion and help purify water that will reach the water table.

Restore and manage the nutrient cycle within the UFE:

- Leave grass clippings, leaves, branches and logs on the ground to decompose and provide nutrients.
- Use less fertilizers by taking advantage of nutrients that naturally exist and cycle through the system.
- Rake and distribute on-site mulch in the UFE to protect the soil, retain moisture and increase the nutrient holding capacity of the soil.
- Plant less nutrient-demanding species.

Restore and manage the UFE to support greater biodiversity:

- Include many different species and life forms (herbs, shrubs, trees) in the UFE to provide wildlife habitat and resist disturbances.
- Restore small ecosystems (with their structure and function) as important connections in the landscape.
- Restore and manage waterways to connect with other ecosystems.

Restore forest ecosystems in the city:

- Take a role in restoring natural ecosystems by establishing one on a vacant lot, in a schoolyard, at a park or another potential site.
- Restore smaller model ecosystems to serve as demonstration sites for restoration and ecology education.
- Educate people about the UFE by restoring or improving the health of degraded ecosystems.
- Reduce deforestation by encouraging developers to retain more green space or larger forest areas in their developments.

Educate policy makers, city managers and the public about the benefits of a healthy UFE:

- Cost-savings benefits,
- Recreation opportunities,
- Tourism benefits of healthy UFE's,
- Energy-saving,
- Wildlife conservation,
- Benefits to natural cycles and recycling,
- Water quality improvement,
- Stormwater management, and
- Carbon sequestration.

Incorporate UFE management into urban and regional planning:

- Demonstrate how the UFE will benefit regional environmental, economic and social health.
- Be involved in the planning process to incorporate UFE management into plans.
- Educate people to think about the UFE when developing new areas and in downtown redevelopment projects.
- Consider and educate people about the ecological, economic and social benefits of the UFE at the local to global scale.

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Chapter 3: Biodiversity and the Restoration of the Urban Forest Ecosystem[1]

Eliana Kämpf Binelli[2]

Abstract

Biodiversity is the variety of life and all the processes that keep life functioning. Global biodiversity provides many ecosystem services, such as protection of water resources, nutrient storage and cycling, and pollution mitigation. These ecosystem services have recently been estimated to provide $33 trillion per year. Biodiversity occurs at many levels from genetic diversity to species diversity to ecosystem diversity. Biodiversity has been reduced in urban areas through ecosystem destruction, degradation and fragmentation of remaining ecosystems. Biodiversity can be increased in urban areas by managing the landscape as a whole and improving connectivity between ecosystem fragments. Biodiversity can also be restored by (i) leaving stumps, leaves, snags and logs to improve nutrient cycling and for wildlife, (ii) planting native species that mimic composition of nearby ecosystems, (iii) controlling invasive plants and animals, (iv) enhancing the ecosystem's natural structure, and (v) creating multi-age ecosystems in several stages of succession. Ecological processes to restore include natural disturbances (e.g., fire), ecological succession, nutrient cycling and hydrological cycling.

Introduction

While watching TV, reading newspapers, listening to the radio or even talking to friends, we all have heard something about biodiversity. Issues such as old-growth forests and the spotted owl, tropical deforestation, hunting of whales and many other topics related to biodiversity have made the news.

Biodiversity has emerged as one of the key environmental concerns in the debate over the worldwide depletion of natural resources. Biodiversity is now a matter not only of scientific interest but also public concern throughout the world.

But, what exactly is biodiversity? Why is it important? Are urban forests important to the conservation and maintenance of biodiversity? Why should urban foresters, citizens, policy makers and professionals be concerned about biodiversity in urban areas? Can we restore biodiversity in our cities? How? This publication will discuss these questions and how managers can incorporate biodiversity into urban forest restoration projects.

1. This is Chapter 3 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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What Is Biodiversity?

Biodiversity, the short term used for biological diversity, is "the variety of life and all the processes that keep life functioning" (Keystone Center 1991). Biodiversity includes 1) the variety of different species (plants, animals - including humans, microbes and other organisms), 2) the genes they contain, and 3) the structural diversity in ecosystems.

The wealth of biodiversity supports ecological processes which are essential to maintain ecosystems on earth **(Figure 1)**. Examples of such ecological processes are the nutrient cycle, the hydrological cycle, and natural succession.

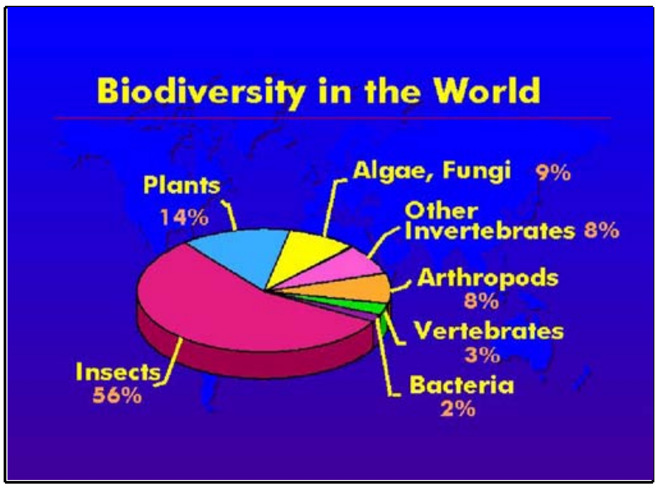

Figure 1. The exact number of existing species in the world is unknown, with estimates varying from as low as 5 million to as high as 100 million species. Most are insects that play critical roles in ecosystems such as decomposition and nutrient cycling.

One of the most fundamental attributes of biological diversity is that it is always changing. The wealth of biodiversity is the product of hundreds of millions of years of evolutionary history. The process of evolution means that the pool of living diversity is dynamic and constantly changing. Climatic, geologic, hydrologic, ecological and evolutionary processes generate biodiversity and keep it forever changing (Noss and Cooperrider 1994). We explore this issue with more details in **Chapter 4 - Succession and Disturbances.**

Levels of Biodiversity

Let's explore in more detail how biodiversity occurs in ecosystems. The key to an effective analysis of biodiversity is the definition of each level of organization that is being addressed.

Biodiversity is usually considered at three different nested levels: 1) gene, 2) species and 3) ecosystem. Changes in one level of biodiversity may have impact on the next level and vice-versa. For example, imagine that an exotic disease (Dutch elm disease or Chestnut blight) is introduced to an urban forest with low species diversity (mostly elms or chestnut trees). Since the genetic pool of these urban forests is limited to species susceptible to these diseases, not only individual species will be affected but also the whole ecosystem to which these species belong.

Gene level

Biodiversity at the genetic level refers to the information contained in the genes of all individual plants, animals and microorganisms. This level of biodiversity is critical in order for species to adapt to changing conditions and to evolve.

Restoration ecologists usually recognize the genetic level of biodiversity in restoration projects. For example, after Hurricane Andrew struck in South Florida in 1992, all the Australian pines (*Casuarina equisitifolia*) were destroyed in Bill Baggs, a heavily used urban park in Miami. Prior to the hurricane, Australian pine, which is a highly invasive species, covered a large portion of the park. The natural removal of Australian pines by the Hurricane provided a great opportunity to restore the park to conditions closer to its previous natural conditions. In this project, it was recommended that seeds be collected from local ecosystems within 50 miles radius of Bill Baggs in order to ensure a well-adapted genetic pool to the climate and soils of this specific location **(Figure 2)**.

Species level

This level is what most people have in mind when they think about biodiversity. Most simply, species diversity is the number of species present in an area. However, the specific combination of

Figure 2.1 Photo by Mary Duryea

Figure 2.2 Photo by Mary Duryea

Figure 2. The Bill Baggs Cape Florida Restoration Project, considered the genetic level of biodiversity by collecting genetic material from areas representative of the region's ecosystems. Several small ecosystems were restored including wetlands (2.1), and uplands (2.2).

species and their relative abundance are also important considerations.

It is common in many cities across the US to find neighborhoods where streets are all planted with the same tree species. In fact, if we consider even the whole city, we would find only a few species planted over and over again. The diversity of street tree species is critically low in many U.S. cities and towns (Sun 1992). In Oakland CA, for example, only four species make up 49 percent of the tree population (Nowak 1993), and in Chicago IL, six species or genera constitute more than half of the population (Nowak 1994).

A classic example of problems associated with lower species diversity is the extensive use of American elm (*Ulmus americana*) as a street and urban tree in U.S. cities after World War II. American elm constituted 95 percent of all street trees (200,000 elms) in Minneapolis MN, for instance (Price 1993). When Dutch elm disease, a fungus spread by bark beetles that causes wilting and dieback of elms, was introduced in the late 1960's, nearly all American elms were killed in Minneapolis and in the rest of the country **(Figure 3)**. Besides the obvious aesthetic problems, this lack of biodiversity necessitated major and expensive efforts to eradicate and dispose of the killed elm trees.

Figure 3.1 Photo by Mary Duryea

The Dutch elm disease outbreak and the loss of virtually all American elms illustrate the

Figure 3.2 Photo by Edward Gilman

Figure 3. American elms (*Ulmus americana*), were once extensively planted in streets and parks in many cities and towns across the U.S. (3.1). The introduction of Dutch elm disease killed nearly all the elms (3.2) and reminds us that the species level of biodiversity is critical when managing urban forests.

consequences of lack of species diversity. Besides, by planting only a few tree species or genera, the age diversity of the species planted may be extremely reduced. The end result of this practice is many old, decaying trees to be removed, pruned and managed at the same time, increasing the city's or municipality's tree maintenance costs.

Biodiversity can be enhanced at the species level by simply increasing the number of different tree species planted (preferably native species present in natural ecosystems in the region). Additionally, by planting species each year instead of all in one year, the age diversity in urban forests can also be increased.

Ecosystem level

The structure of the urban forest is an important biodiversity consideration at the ecosystem level. Structure in forests is characterized by the nature and abundance of the various vegetation layers (canopy, subcanopy, shrub layer and ground cover) and the presence of dead logs and snags. It is important that ecosystems retain their natural structure.

In most ecosystems, a greater structural diversity will support a greater diversity of wildlife and will ensure better ecosystem functioning. A forested ecosystem should have snags (dead standing trees) **(Figure 4)** and logs **(Figure 5)**, which provide habitat for small mammals, amphibians and reptiles and food for many insects and fungi (which in turn are food for birds).

Figure 4.1

Structural diversity should be reintroduced in restoration projects. There are several ways in which this can be accomplished. For example, a snag can be created by cutting a hazard tree but leaving a taller stub to decay. Many urban forest restoration projects also import logs and snags by salvaging trees in areas slated for development. These trees are then used as either downed logs or "planted" back in the ground like giant posts to decay, increasing the structural diversity and enhancing nutrient cycling.

Why Is Biodiversity Important?

Recently, all natural ecosystems on earth have been estimated to provide **$33 trillion annually** in ecosystem services (Costanza *et al.* 1997). This is twice the combined gross domestic product of all nations in the world. Ecosystem biodiversity

Figure 4.2

Figure 4. Snags provide important ecosystem structure. They are habitat for birds (4.1), mammals, termites, insects, frogs and several microorganisms and are also important for the nutrient cycle (4.2).

provides us with these services, which include the protection of water resources, nutrient storage and cycling, pollution bioremediation (biologically based environmental cleanup), maintenance of ecosystems, soil formation, climate regulation and other natural processes, recreation and food production.

Biodiversity occurs at several spatial scales (locally, regionally, globally). This means that biodiversity has significance at a global scale as well as in our own city backyards. Some of the values associated with biodiversity include:

- ecosystem functioning,
- future value, and

Figure 5. In a natural forest, there will be snags and logs in different stages of decay. Different living organisms use these different stages.

- educational and recreational benefits.

Ecosystem functioning

When ecosystems are diverse, there is a range of pathways for many ecological processes and for primary production. If one of these pathways is damaged or destroyed, an alternative pathway may be used and the ecosystem can continue functioning (Kimmins 1996). For example, when a particular bacteria species is missing from the nutrient cycle, in a diverse ecosystem, another organism may be present to carry out the same function **(Figure 6)**. However, some organisms, such as top predators, also play an important role in ecosystem functioning but cannot be easily replaced. In any case, if the biological diversity is greatly diminished, the functioning of the ecosystem may be at a risk.

The associated costs of losing the ability of ecosystems to function are extremely high. The

Figure 6. An example of ecosystem services is the decomposition of organic matter by microorganisms and other species, such as these fungi. Photo by Larry Korhnak

degradation of wetlands is a dramatic example of the problems associated with loss of ecosystem biodiversity. Floods, problems in water quality and quantity for natural and human systems, and declines in fish and wildlife populations, have all been linked to wetlands destruction, degradation and fragmentation. The Everglades is an extensive ecosystem in Florida which currently faces such problems. Costs for restoring natural ecosystem services and biodiversity to the Everglades have been estimated to be hundreds of million of dollars. Congress recently approved the expenditure of $1.5 billion to restore only some areas of the Everglades (South Florida Ecosystem Task Force 1998).

Future value

Natural ecosystems are a reservoir of continually evolving genetic material, irrespective of whether their values have been recognized. The same genetic material may have important but yet to be discovered medicinal, economic, aesthetic, recreational or intrinsic values for future generations.

An example of one of the most promising discoveries in recent years has been taxol, which was initially isolated from the Pacific yew (*Taxus brevifolia* Nutt.), a tree species in the Douglas-fir forests of the Pacific Northwest that was until recently considered unimportant **(Figure 7)**. Taxol has been used in the treatment of ovarian and breast cancers. In the U.S., approximately 25% of all prescriptions contain active ingredients derived from plants (Principe 1989).

Figure 7. The bark of Pacific yew (*Taxus brevifolia* Nutt.) trees contains taxol, a new drug for treating several forms of cancer. Photo by Dr. AC Mitchell

Biodiversity is also essential in biological control and for the breeding of disease resistant species. Use of genetically resistant plant species for food production, clothing, commercial and urban forestry is derived from a wide array of diverse native species.

Educational and recreational benefits

One of the most important reasons to manage and protect biodiversity in urban centers is their educational and recreational values. Recreational benefits are perhaps the most important value of biodiversity in urban areas. People value natural areas for a variety of reasons: psychological renovation through contact with nature, jogging and hiking, birdwatching, photographing, and many other activities. The aesthetic value of ecosystems also contributes to the emotional and spiritual well-being of a highly urbanized population **(Figure 8)**.

Figure 8.1 Photo by Mario Binelli

Figure 8.2 Photo by Mario Binelli

Figure 8. Recreational benefits of biodiversity are closely related to aesthetic, psychological (8.1 and 8.2) and educational values.

In 1991, 30 million Americans participated in wildlife watching and another 14 million adults went fishing (U.S. Fish and Wildlife Service 1992). Nationwide, wildlife viewers spent $18 billion (Norris 1992). Watchable wildlife recreational activities provide local economies with important income generated by sales, employment and tax revenues. For example, Florida's watchable wildlife generated $3.5 billion in 1996 (Florida Game and Fresh Water Fish Commission 1998).

Some ecosystems, especially those close to metropolitan centers are becoming extremely rare. For example, Florida's scrub ecosystems are now surrounded by the greater Orlando urban area and are threatened by human encroachment and development. Ultimately, it will be up to these urban citizens to protect such ecosystems and their benefits. In this case, there is some evidence that the Florida scrub jay, an endangered bird in the scrub ecosystem, may persist in residential areas, provided adequate patches of the scrub ecosystem remain preserved nearby. (Florida Game and Fresh Water Fish Commission 1997). These urban remnant ecosystems could be powerful tools for educating urban citizens about the importance and value of such diverse ecosystems **(Figure 9)**.

Increasing urbanization accelerates human pressures on remaining natural ecosystems. At the same time, however, recreational spaces have to be managed for this increasing population. In 1996, 2.7 million Floridians participated in wildlife

Figure 9.1

Figure 9.2 Photo by Larry Korhnak

Figure 9. Managing for biodiversity in urban areas is an excellent opportunity for integrating ecological, educational (9.1) and recreational values (9.2).

recreational activities within a mile of their homes and 543,000 visited natural areas around their homes (Florida Game and Fresh Water Fish Commission 1998). Urban forests may play an important role in integrating recreational demands and conservation of natural resources.

Now that we have discussed some values of biodiversity, **why should urban managers consider biodiversity in the restoration of urban forests as ecosystems?** Urban and community forests have been estimated to provide nationwide $3 billion a year in social, ecological and economic benefits (McPherson and Rowntree 1991). These benefits include conservation of energy, pollution control, and improvement of aesthetic quality of cities. By managing and restoring urban forests for biodiversity, such benefits could be greatly enhanced. For example, by restoring ecosystems and their associated natural processes, such as nutrient and hydrological cycling, local communities could save money, energy and resources. Restoring an urban wetland to provide habitat for wildlife would also contribute to recreational and economic opportunities. Removal of invasive species from a city's park, for instance, may bring back the natural diversity and functioning of the ecosystem, which in turn might improve its recreational and aesthetic value for the local community.

Managing for biodiversity in urban areas will require a more holistic approach than usually seen. Urban forests are more than a collection of street trees. Remnants of natural areas, waterways, parks, backyards, right-of-ways and industrial parks both in public and private properties are all part of the urban forest ecosystem.

Can Biodiversity Be Protected In Urban Forests?

Most human-made habitats, such as a landscaped park, have lower biodiversity than natural forests. However, urban environments usually include a great diversity of habitats (such as water retention ponds, industrial parks, railway rights-of-way, greenways, and others) which may support some wildlife and plant species. In some cases, urban habitats may even play a significant role in the conservation of 'rare' or 'threatened' species. For example:

1. Rare prairie plant species in the Midwestern US are found alongside railroads and highways. In such areas these species are protected from the agricultural activities that destroyed much of the original prairie habitat (Ahern and Boughton 1994).

2. Of the 144 threatened and endangered wildlife species of Illinois, 14% (20 species) have been recorded in recent times in Cook county, the most urbanized county of the Chicago Metropolitan area (Friederici 1997).

How Is Biodiversity Reduced In Urban Areas?

The ultimate threat to global biodiversity is an increasing human population and the consequent increased use and development of the world's remaining natural ecosystems. The largest threat to biodiversity in urban areas is the reduction and alteration of the total area of natural ecosystems available to native animal and plant species **(Figure 10)**. Ecosystem destruction, degradation and fragmentation may significantly reduce biodiversity.

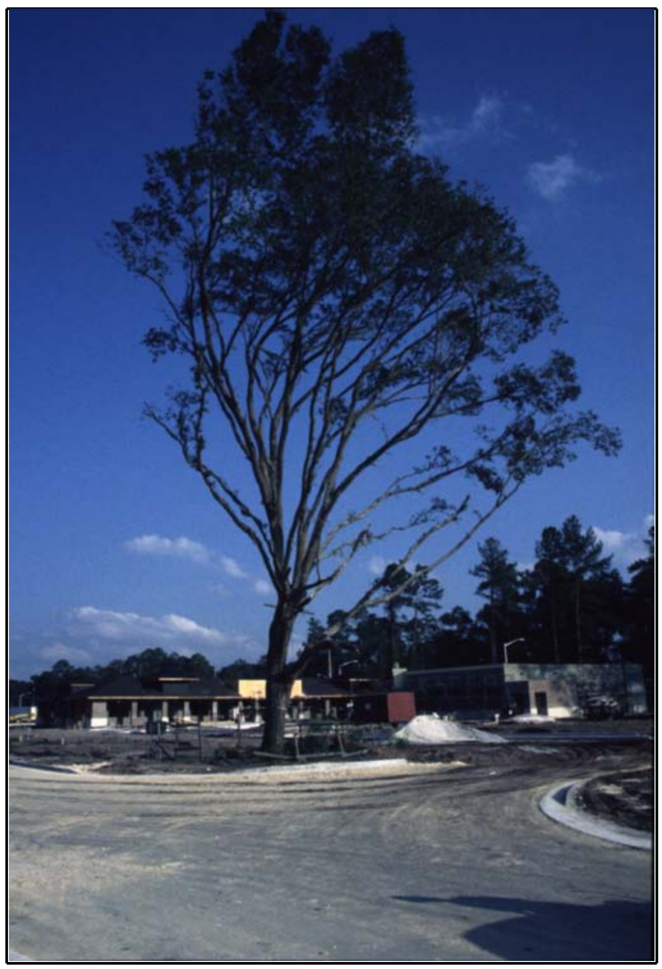

Figure 10.1

Ecosystem destruction

Frequently, urban natural areas are completely eliminated during residential and/or commercial development. Usually, after construction exotic trees, shrubs and lawns are established. Additional

Figure 10.2

Figure 10.3

amounts of fertilizers and irrigation, frequent mowing and mulch are required for such intensively managed areas.

If instead natural areas are preserved and incorporated during development, biodiversity could be maintained. Natural areas have much lower maintenance requirements when compared to traditional landscaping. Additionally, aesthetically pleasing environments, such as natural urban remnants, increase the economic value of residential and commercial areas.

Figure 10.4

Figure 10. Biodiversity is lost by ecosystem destruction (10.1), fragmentation (10.2) and degradation. Figure 10.3 illustrates a degraded longleaf pine ecosystem that has been invaded by exotic species whereas figure 10.4 illustrates a healthy longleaf pine ecosystem. The diversity of the longleaf pine ecosystem is associated with its herbaceous layer and a relatively open canopy.

Ecosystem degradation

Ecosystem degradation may not be easily noticed in the short-term and is difficult to detect and harder to quantify. Degradation is of greater long-term concern, since its effects are cumulative and may build up only very slowly. Degradation deteriorates and disrupts ecosystem processes. Some examples of causal degrading agents are pesticides, chronic air pollution and invasive species. Erosion, or removal of the litter from a forested site would also cause ecosystem degradation by interrupting nutrient cycling.

Microorganisms in the soil (such as invertebrates, fungi and bacteria) carry out critical ecosystem functions (such as decomposition and nitrogen fixation). Yet these organisms are so small that they usually go unnoticed until the consequences of their disruptions are too obvious to neglect.

In metropolitan centers, for instance, air pollutants slowly accumulate in urban forest soils over time. The gradual accumulation of hydrocarbons in a New York urban forest, for example, formed a hydrophobic soil layer, which in turn, has decreased the population and activity of soil microbes and invertebrates. This hydrophobic layer, coupled with trampling and high concentrations of heavy metals in urban soils, have also reduced the rates of microbial processes, affecting the nitrogen cycle in these forests (White and Mc Donnell 1988).

Ecosystem fragmentation

Landscapes become fragmented when natural ecosystems are broken up into remnants of vegetation that are isolated from each other **(Figure 11)**. Therefore, fragmentation results in a landscape that consists of remnant areas of native vegetation surrounded by other land uses. At a larger scale the landscape is composed of cities, farms, rivers, rural areas and natural areas **(Figure 12)**. In the urban area the landscape might include strips of street trees, backyards, schoolyards, shopping centers, creeks, rivers, parks, landfills, industrial parks and fragments of natural areas **(Figure 13)**.

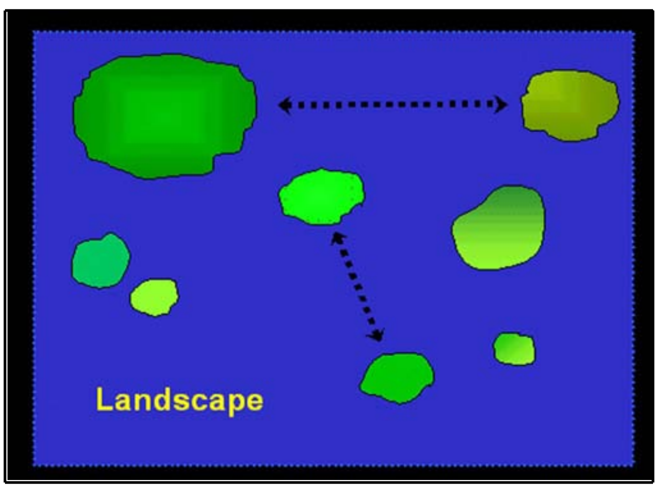

Figure 11. In urban areas, ecosystems that used to be continuous are now fragmented in the landscape.

Figure 12.1 Photo by University of Florida, Map and Imagery Library.

Figure 12.2

Figure 12. At a larger scale, the landscape is composed of cities (12.1), farms, rivers, rural areas, natural areas and fragments of natural areas (12.2).

Ecosystems are Connected and Inter-related

The landscape is a mosaic of several different ecosystems. It is important to recognize that natural ecosystems are connected and inter-related. Fragmentation of natural ecosystems will affect ecosystem processes, plants, and wildlife. Turtles, for example, live in water but need upland ecosystems to lay their eggs. If we fragment upland ecosystems, by either constructing a road between the ecosystems or putting a fence around the upland, turtles will be prevented from reproducing **(Figure 14)**.

This example shows that we need integrated management and restoration efforts, where ecosystems are allowed to interact with each other. Roads, fences or other human-made boundaries may limit the flow of nutrients and water and the movement of plants and animals between ecosystems.

Figure 13.1

Figure 13.2

Figure 13.3 Photo by Paul West, Seattle Department of Parks and Recreation

Figure 13. In urban areas, the landscape is composed of street trees (13.1), backyards, shopping centers (13.2), parks, industrial parks and fragments of natural areas (13.3).

Figure 14. This yellow bellied turtle (*Trachemys scripta*) was stranded by a road while trying to move to an upland ecosystem to lay eggs. This usually happens when the interconnectedness of ecosystems is not taken into account. Photo by Joseph Schafer

What happens to ecosystem fragments?

Let's take a closer look at an ecosystem that has been fragmented and isolated. Usually, conditions in the surrounding landscape are different from conditions in the ecosystem fragment. As a result, an edge is formed between the landscape and the ecosystem fragment. Every ecosystem has an edge, but the amount of edge in urban ecosystem fragments increases tremendously as a result of external factors in the landscape. As the edge increases, the size of the interior core is reduced.

The core area of an ecosystem fragment is the undisturbed interior area of that ecosystem. In this core area we usually have:

- functional ecological processes,
- a greater diversity of native species,
- a diversified structure with multilayered vegetation (trees, shrubs, herbaceous and ground cover plants), logs and snags,
- a greater diversity of wildlife with area-sensitive birds, mammals, and other animals, and

• an undisturbed microclimate.

Several external factors from the landscape can affect ecosystem fragments **(Figure 15)**. Along the edge of the ecosystem fragment there is increased solar radiation. Since there is more light available, species that grow better in full sun will become established closer to the forest edge while shade tolerant species will be restricted to the interior core (Saunders et al. 1991). Invasive species will also be favored in edges and more disturbed areas.

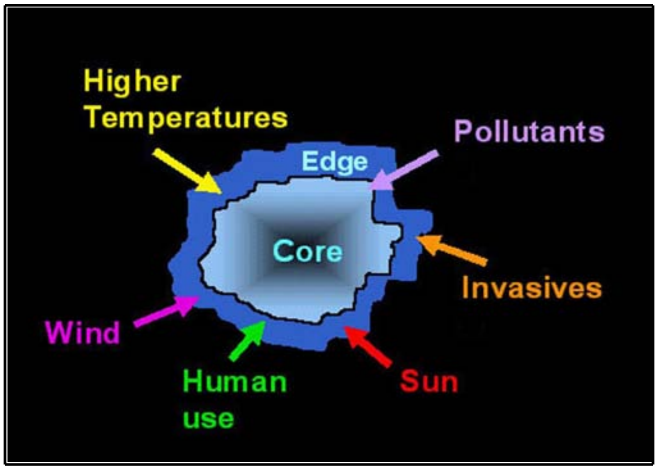

Figure 15. External factors from the landscape affect ecosystem fragments. The greater these external influences, the greater the edge and smaller the core area.

Trees at the edge will also be more susceptible to wind, air pollution and increased temperatures, resulting in a drier microclimate (Saunders et al. 1991). In turn, nutrient cycling may be affected because the heating of the soil may affect microorganisms, litter decomposition, and soil moisture retention.

Therefore, fragmentation alters the structure, composition and function of ecosystems. A principle to remember is that the more you alter the structure, composition and function of ecosystems, the greater the energy needed to restore the ecosystem back to its original condition.

One example is Forest Park, a 5,000-acre urban park in Portland, Oregon. This park is an ecosystem fragment that has been greatly impacted by the surrounding land uses. The neighboring communities landscape their yards with English ivy (*Hedera helix*), an invasive and aggressive species. By bird dispersal and vegetative growth, English ivy has spread and invaded this forest **(Figure 16)**. English ivy alters the structure of the forest (by impeding the growth and development of native plants), its composition (now there is only English ivy underneath the canopy) and, consequently, this ecosystem's functioning (alteration of nutrient cycling, since decomposition of organic matter may be affected). The amount of energy required to restore this ecosystem is tremendous. It is an ongoing effort, but as a result, native species are regenerating and biodiversity is slowly coming back to Forest Park.

Figure 16. These high school students are removing English ivy, an invasive species that completely took over Forest Park, an urban park in Portland, Oregon. Photo by Mary Duryea

How Can Buffer Zones Help?

Buffer zones are semi-natural areas located around areas of higher natural values, such as core areas. A buffer zone around an ecosystem fragment will minimize external influences and help maintain the ecological integrity of the ecosystem's core area. Establishment of buffer zones around natural and semi-natural areas permits integration of human land uses while still managing for biodiversity **(Figure 17)**.

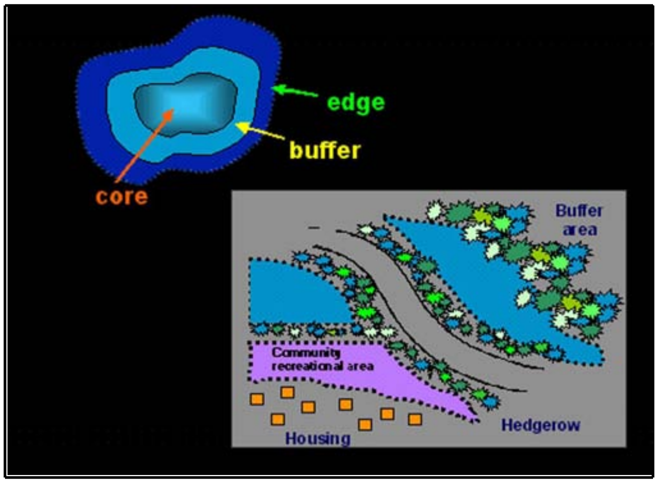

Figure 17. Buffer zones in urban settings can minimize external influences of the surrounding landscape and maintain the ecological integrity of urban ecosystem fragments.

How does fragmentation affect biodiversity?

Fragmented ecosystems are isolated and in urban areas the distance between fragments may be large. This, coupled with the increase in edge area and reduction of the core area, will decrease flow of genes and seed dispersal. Animals and plants that used to be in the whole area are now restricted to smaller patches.

Connected ecosystems or unfragmented landscapes will have a greater diversity of native species **(Figure 18)**, due to their larger core area, a lower edge:core area ratio and less isolation (compared to smaller fragments).

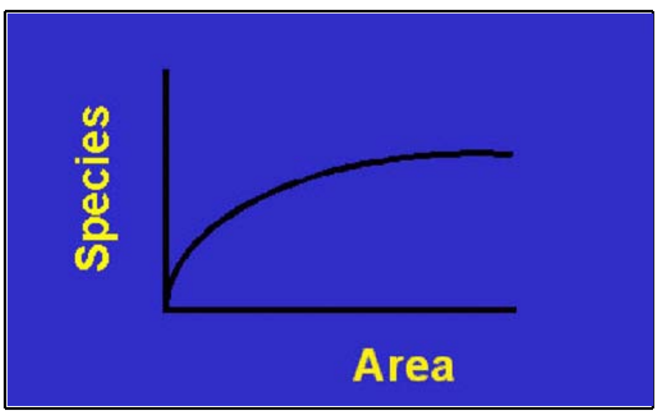

Figure 18. The greater the area, the greater the number of species in the ecosystem (adapted from MacArthur and Wilson 1967).

Let's examine the consequences of fragmentation on bird populations. Area sensitive birds, such as flycatchers, vireos and warblers, will be reduced with fragmentation and reduction in core area. Area sensitive birds are those that need a large undisturbed area and hence would only live in the interior core area of a large fragment (Adams and Dove 1989) **(Figure 19.1)**. Habitat generalist birds can be quite common in more urbanized areas and may thrive in many different conditions. Cardinals, jays, house wrens, and catbirds are examples of habitat generalist birds **(Figure 19.2)**.

If we want to enhance the diversity and the presence of area sensitive birds in urban areas, we need to restore and connect core areas of ecosystems (for more information on wildlife, see **Chapter 8-Wildlife**).

Figure 19.1 Photo by Thomas G. Barnes

How Can We Connect Fragmented Ecosystems In The Urban Landscape?

The search for solutions to the problems of ecosystem loss, degradation and fragmentation has led to a growing number of new projects and solutions. Most projects are based on ecologically

Figure 19.2 Photo by Thomas G. Barnes

Figure 19. Area sensitive birds, such as certain types of owls (19.1) may have their diversity reduced with fragmentation and a reduction in core area. However, habitat generalist birds, such as common sparrows (19.2) may be favored in a patchy environment.

sound principles. Basically, we attempt to connect fragmented ecosystems in the urban landscape and manage the landscape as a whole. By doing so, the distance between ecosystems fragments will be shortened, improving connectivity of isolated fragments.

Connectivity is essentially the opposite of fragmentation. Instead of breaking landscapes into pieces we are seeking ways to restore broken connections between fragmented ecosystems **(Figure 20)**.

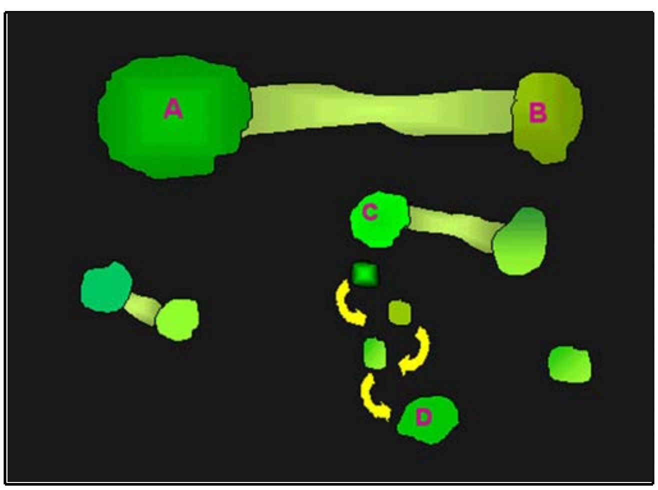

Figure 20.1

Effective connectivity is measured by the potential for movement and flow of genes, that is, movement and migration of animals (especially

Figure 20.2

Figure 20. In Figure 20.1, patches A and B used to be part of the same contiguous ecosystem. A corridor may provide linkage between these ecosystem fragments. Riparian coridors (20.2) are landscape linkages that may connect several ecosystem fragments in the urban-rural interface.

birds) and dispersal of plants. Many factors determine the effectiveness of connectivity, and it varies depending on the ecosystem of interest. Usually, effective connectivity will depend on:

- presence of barriers (e.g., fences which would limit migration),
- distance between ecosystem fragments,
- amount of edge in the landscape linkage,
- nature of the surrounding landscape, and
- species which will benefit from promoted connectivity (e.g., whether a bird,a mole, a plant).

Connectivity can be promoted by using corridors, greenways, and stepping stones.

Corridors

Corridors are strips of natural vegetation linking ecosystem fragments. They can be defined as "any area of habitat through which an animal or plant propagule has a high probability of moving" (Noss 1991). Preserves or fragmented ecosystems with high biodiversity level or rare species may be linked by corridors **(Figure 21)**.

Figure 21. This corridor may be serving as linkage for birds between fragmented ecosystems. Photo by Henry Gholz

Table 1. Benefits and disadvantages of ecological corridors.

BENEFITS	DISADVANTAGES
enhance biotic movement (because they permit flow of genes)	spread of diseases
provide extra foraging areas for species that require more resources than those available in a single patch	increased predation
provide wildlife plant habitat	

Figure 22. The proposed network of natural areas, buffer zones and corridors forms a bigger regional network of ecosystems for the state of Florida. This corridor network connects two important waterways, Ockefenokee (North Florida) and Everglades (South Florida), which have been disconnected for decades.

Whether corridors will provide all or none of the benefits listed in **Table 1**, will depend on several factors. For instance, a corridor that has a high proportion of edges compared to the interior forest may facilitate spread of pests, diseases and catastrophic fires or increase exposure of wildlife to predators and domestic animals.

Groups of corridors can be combined to form corridor networks. By adding several corridors and integrating them with buffer zones and natural preserves, connectivity may be increased **(Figure 22)**.

Many restoration projects in cities begin with river connections. Why are rivers and creeks considered good linkage corridors? First, because riparian ecosystems are considered to be one of the richest habitat types, with alluvial soils, abundant insects and plant species. They constitute one of the most biologically productive and diversified habitat types with complex and multilayered vegetation (see **Chapter 6 - The Hydrologic Cycle**). Second, rivers and creeks are natural corridors which pass through many ecosystems, so the linkages between these ecosystems already exist.

Greenways

Greenways are a type of corridor designed to connect open spaces for ecological, cultural and recreational purposes. There are a wide variety of greenway projects around the country. We can find greenways projects that are managed as corridors between natural areas (with an ecological objective) and others that are for purely recreational purposes. Greenways range from narrow urban trails to winding river corridors to very wide, landscape level linkages.

It is important to define the goals of greenways. In some instances, an urban greenway restricted to a very narrow width, creating a beautiful space for recreation, may be the primary goal **(Figure 23)**. However, relatively few greenways have been designed with detailed consideration of ecological functions (Smith and Hellmund 1993). Nonetheless, a greenway's ecological function should be considered and promoted whenever possible. An example is the Rio Grande Valley State Park in New Mexico. This park is a heavily used urban recreation area located only 2 to 3 miles from downtown Albuquerque, NM. The park contains extensive riparian forests of native cottonwood (*Populus deltoides*) and black willow (*Salix nigra*). These forests contrast with the typical arid Southwest areas surrounding them and for this reason host a high diversity of wildlife and migratory birds.

Figure 23.1 Photo courtesy of Rio Grande Valley State Park

Although activities like hiking, horseback riding, picnicking, and nature walks are encouraged, the Rio Grande Valley State Park gives high priority to recreational trail design in order to protect sensitive and unique habitats. Degraded areas have been restored with native trees and shrubs, following removal of saltcedar (*Tamarix spp.*), an invasive species. Connectivity between high quality areas for wildlife movement also have high priority. This greenway effort seeks to restore natural species and ecosystems processes, but also recognizes the need to make resources available and enjoyable for people.

Figure 23.2

Figure 23. Some greenways, such as the Rio Grande Valley State Park in New Mexico (23.1), provide better ecological function than this bicycle trail (23.2) in Florida. Rio Grande Valley is a heavily used urban park that also provides connectivity for wildlife and ecosystems.

Stepping Stones

As mentioned before, viewing the landscape holistically, instead of focusing on each separate area in isolation, should be the objective of urban managers. Even where it is not possible to connect ecosystems through corridors, stepping stones can be provided. Stepping stones (Franklin 1993) are smaller habitats that permit some plants and animals to move across the landscape from one ecosystem fragment to the other **(Figure 24)**. Some interior species, such as many native birds, may not find them useful, but for some other species, such as small mammals and reptiles, the connectivity enhances habitat.

The minimum ideal size for ecosystems to remain fully functional is often unknown. However, some scientists theorize that an optimum landscape has large patches of natural vegetation supplemented with small patches scattered as stepping stones throughout the landscape (Franklin 1993, Noss 1991,

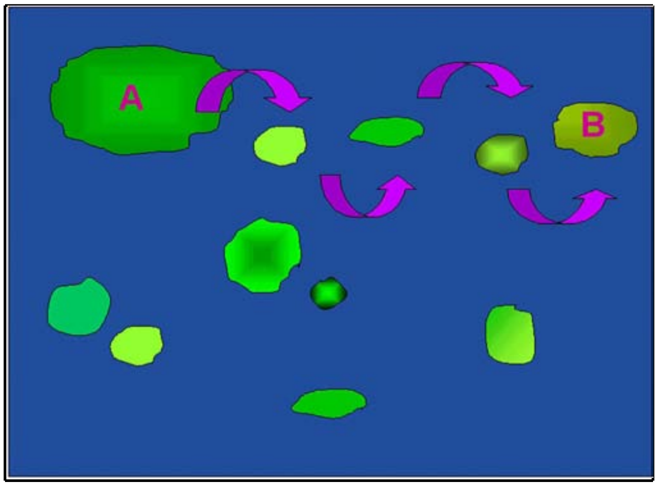

Figure 24. Stepping stones or small patches of ecosystems may help some species move from one larger ecosystem fragment (A) to another (B).

Adams 1994). In summary, stepping stones provide habitat for species that will live in small areas and help the flow of genes so birds and some plants will be able to move across the landscape.

How Can We Restore Biodiversity In Urban Areas?

There are numerous ways to enhance biodiversity in parks, neighborhoods, abandoned areas, backyards, industrial zones and other urban forest restoration projects, including:

- leaving stumps, leaves, snags and logs on-site to enhance the ecosystem's natural structure, maintain the nutrient cycle, and provide habitat for wildlife and other organisms,
- planting native species in combinations that mimic nearby ecosystems,
- controlling invasive plants and animals which may eliminate native species,
- enhancing the ecosystem's structural diversity, and
- creating multi-age ecosystems (forests) in several stages of ecological succession typical of that ecosystem (see **Chapter 4 - Plant Succession and Disturbances**).

In these urban forest restoration projects, it is essential to maintain and/or restore the ecosystem's ecological processes, such as:

- **natural disturbances**: such as fires and natural hydroperiods (for instance, re-instating flooding in drained wetlands),
- **ecological succession**: understand ecological succession in nearby similar ecosystems and consider establishing these successional stages (for more information see **Chapter 4 - Plant Succession and Disturbances**),
- **nutrient cycle**: promote and educate about the need for retaining leaves, twigs, branches and logs on site to store and cycle nutrients (see **Chapter 2 - Basic Ecological Principles**), and
- **hydrological cycle**: find ways to aid the hydrological cycle. Examples include leaving natural mulched areas for better water infiltration and maintaining vegetative cover to prevent water erosion (see **Chapter 6 - Hydrologic Cycle**).

Examples of Restoration Projects

There are many projects in cities and urban areas that restore urban forests as whole ecosystem(s). Biodiversity is often an important part of these restoration projects, either at a small or large scale.

Reintroducing Fire in Gainesville, FL

Natural fire regimes are important ecological processes that should be reintroduced in fire-adapted ecosystems, including urban forest ecosystems.

For example, the longleaf pine ecosystem, a natural forest type of the Southern US, is adapted to periodic and light fires. Fires keep adjacent hardwood species from invading longleaf pine forests **(Figure 25.1)**. In the process, these fires maintain an extremely diverse flora in the ground layer **(Figure 25.2)**. There are more than 100 herbaceous species in sites no larger than an acre and at least 190 rare and endemic species associated with this ecosystem (Hardin and White 1998). Fires are essential to maintain this ecosystem's natural structure, that is, an open canopy of longleaf pines and the diverse ground layer. If fires are suppressed, this unique flora is largely lost.

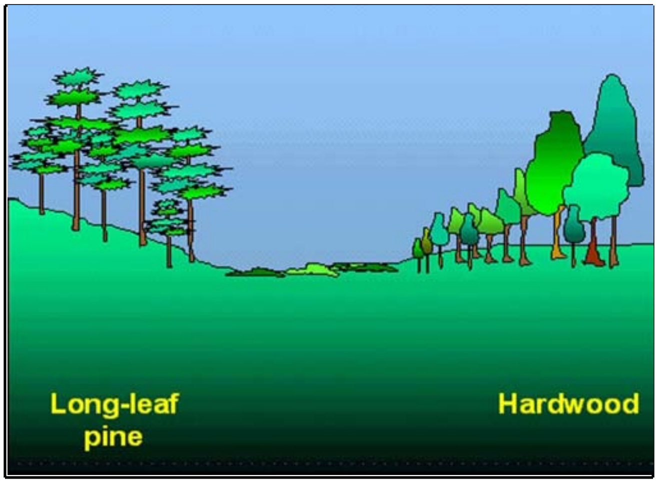

Figure 25.1

Figure 25.2

Figure 25. Frequent but low intensity fires keep adjacent hardwood species from invading longleaf pine ecosystems (25.1), and are essential to maintain these forests' natural structure and ground layer biodiversity (25.2).

Fires have been reintroduced in remnants of longleaf pine ecosystems in urban areas. An example is a subdividion in Gainesville, FL, that contains patches of a longleaf pine ecosystem interwoven with houses, golf courses and streets. Periodic prescribed fire is applied to these patches of longleaf pine, maintaining its open canopy and rich herbaceous species. Education plays a key role in such innovative pratices in urban centers **(Figure 26)**.

Figure 26.1

Figure 26.2

Northeast Anne Greenbelt Forest Restoration in Seattle, WA

Downtown Seattle has a 35-acre restoration project developed by the Seattle Department of Parks and Recreation (SDPR), University of Washington and the local community. This project is part of a greater effort to apply integrated landscape management practices in parks and other areas in the Seattle region **(Figure 27)**.

Figure 26.3

Figure 26. This subdivision in Gainesville, FL has patches of a longleaf pine ecosystem (26.1) interwoven with houses, golf courses and streets (26.2). Periodic prescribed fire is applied to these patches. Education plays a key role in such innovative practices in urban areas (26.3).

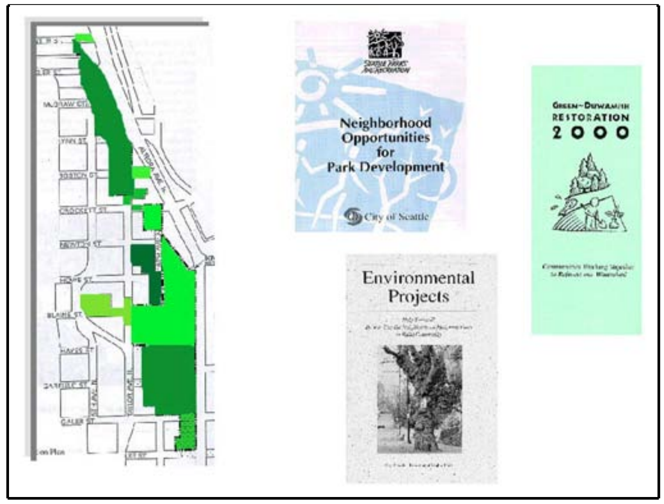

Figure 27. The Northeast Anne Greenbelt Forest Restoration is a neighborhood restoration project in Seattle, WA (map at left). Other similar small scale projects are funded and coordinated by the Seattle Department of Parks and Recreation.

The site was heavily invaded by exotic invasive species (English Ivy , bindweed, Himalayan blackberry, and Scotch broom), ornamental plants and weeds, and was also a dumping ground for trash. Additional problems were soil erosion and lack of wildlife.

The partners worked together and developed a plan to:

- remove the exotic vegetation,
- plant varying native species to provide food and cover for wildlife and to enhance structural diversity,
- create logs and snags to provide habitat for invertebrates, woodpeckers, and decomposers, and
- plant trees with deep roots and understory vegetation to help stabilize the soil and reduce erosion.

Today, the area has been cleared of exotics, erosion has been stabilized and an environmental center has been established, where the local community promotes educational and recreational activities.

Chicago Wilderness in Chicago, IL

The Chicago Wilderness is a combined effort of 60 partnering organizations, including landowners, local, regional and federal agencies, universities and conservation agencies. The Chicago Wilderness' primary goal is to restore ecological processes that maintain biodiversity. Their work is to improve the region's biodiversity at all levels: genetic, species and ecosystem diversity throughout the landscape. To meet this goal they have several objectives:

- to document the region's ecosystems,
- to help restore natural communities on public and private lands,

- to prevent further loss of critical ecosystems and, at the same time, promote carefully planned development,
- to promote education, outreach and volunteer opportunities, and
- to define restoration strategies (including removal of aggressive invasive species, thinning of native trees to promote growth of savannas and woodlands species, use of prescribed fire and planting of native species).

To date, there are over 109 Chicago Wilderness collaborative projects ranging from biodiversity initatives to prairie and savanna restoration projects with prescribed burning to backyard biodiversity initiatives to restoration of threatened and endangered species **(Figure 28)**.

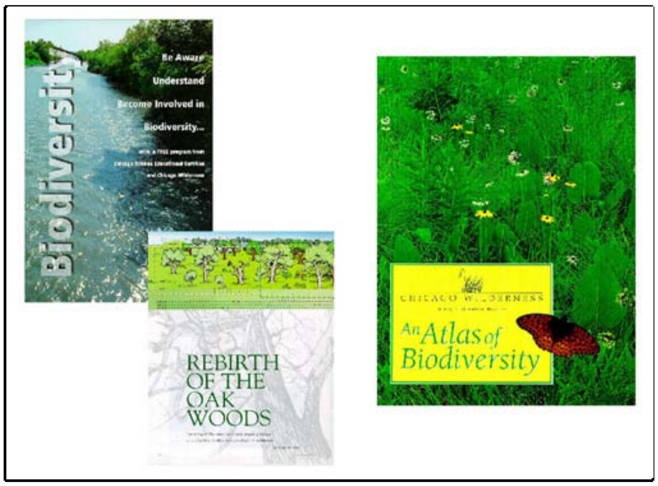

Figure 28. Outreach materials utilized by Chicago Wilderness educate citizens about the region's biodiversity and strategies for restoration.

Monitoring Success

Monitoring is a crucial part of every ecosystem restoration project. Monitoring provides the opportunity to gather information about how ecosystems in urban areas work and how ecosystems and people interact over time. It is also a critical activity for reevaluating the success or failure of projects so that we can apply this accumulated knowledge and experience to future projects.

Ecosystems are complex and inter-related and even the best studied and planned projects might have unexpected results. One example of a learning experience is a salt marsh, 8 km south of downtown San Diego, CA. The restored ecosystem was supposed to provide habitat for an endangered bird, the light-footed clapper rail (*Rallus longirostris* Levipes) **(Figure 29)**. Cordgrass species (*Spartina* spp.) were transplanted from nearby wetlands to provide nesting sites for the bird. However, the plant did not grow to 90 cm, the bird's preferred height. Researchers working on the project thought the problem was due to the marsh's sandy, nutrient-poor soil, so they added nitrogen fertilizers. But the fertilizer favored another plant, pickleweed, which outgrew the desired grass (Malakoff 1998). Researchers are still trying to determine the best methods for restoring this ecosystem.

Figure 29. Since ecosystems are complex and inter-related, careful planning and monitoring are essential elements of restoration projects. The example of this salt marsh and the light-footed clapper rails reminds us that there are no easy recipes. Photo by David Sarkozi

Conclusions

Urban forest ecosystems present many opportunities for restoring biodiversity, whether in a backyard, neighborhood, park or natural area. It is essential to know and understand the natural ecosystems in these areas in terms of vegetation, structural diversity, wildlife, natural disturbance regimes and the nature of their ecological processes. When managing ecosystems for biodiversity, we should pay attention to ecosystem structure and its functioning. Ecological processes, such as nutrient cycling, hydrological cycling, and ecological succession should be reinstated in the urban forest ecosystem as a comprehensive strategy for biodiversity conservation.

Corridors, buffer zones, greenways, and stepping stones are all ways in which urban forests can be managed as ecosystems. While large scale projects may help reestablish connectivity and maintain important ecological processes, small scale projects, such as removing invasive species or restoring native species in a small city park, also contribute.

However, management of the landscape as a whole can only be accomplished if we take an interdisciplinary and integrated approach toward urban forests. This requires a combined and joint effort of local, state and federal governments, as well as private, public and grass-root initiatives. Education plays a critical role in generating informed citizens who are essential partners in the establishment of restoration projects in cities.

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Chapter 4: Plant Succession and Disturbances in the Urban Forest Ecosystem[1]

Eliana Kämpf Binelli, Henry L. Gholz, and Mary L. Duryea[2]

Abstract

Ecosystems are dynamic. Disturbances lead to changes in ecosystems, collectively called succession. Disturbances can be natural and/or anthropogenic (human-caused). Natural disturbances, such as wildfire, play an important role in forest succession. Knowledge of natural disturbance regimes is important to maintaining biodiversity. In forest succession, species composition, ecosystem structure and ecosystem functioning all change gradually over time. In urban areas, the alterations of natural disturbance regimes, along with the introduction of invasive species have altered natural succession. Natural disturbances vary in spatial scale (from small to large areas) and temporal scale (from hours to eons). Variation in the temporal and spatial scales of disturbances leads to ecosystems spread over the landscape that are in different successional stages. This landscape diversity meets the needs of a variety of wildlife species. In order to restore more natural successional regimes, we have to learn about ecosystems: their natural disturbance regimes, their expected stages of succession, and how they fit into the overall landscape. Small scale urban forestry projects should incorporate the concepts of succession, while eliminating invasive species and re-introducing natural disturbances regimes. Large scale projects can also adopt these strategies, but have the additional opportunity to manage for several stages of succession across the landscape and to restore missing stages of succession.

Change

A common misperception is that nature is in an unchanging balance. However, natural scientists have found strong evidence against this idea and we now know that change is one of the most fundamental characteristics of natural ecosystems.

Since trees generally live much longer than humans, the forests they are in were also perceived as unchanging. But, in fact, forests are highly dynamic. In many forests, wildfires, floods, windstorms or insect infestations produce major, but infrequent changes. In other forests, change is more subtle: single trees die and are replaced while most trees remain alive. However, since individual trees can live a long time, it is difficult to see or measure changes in forests over short periods of time.

1. This is Chapter 4 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu
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There are two related aspects of change over time in forests: ***disturbances*** and ***succession***. Disturbances lead to subsequent changes in ecosystems, which are collectively called succession.

This chapter discusses the dynamic nature of forest ecosystems and why it is important to understand disturbances and succession in order to manage and restore urban forest ecosystems successfully.

Disturbances

What are disturbances?

Disturbances are any event, either natural or human-induced (anthropogenic), that changes the existing condition of an ecosystem. Disturbances in forest ecosystems affect resource levels, such as soil organic matter, water and nutrient availability, and interception of solar radiation. Changes in resource levels, in turn, affect plants and animals over time, leading to succession.

Disturbances occur in all ecosystems. We often think disturbances result only from human activity. However, the definition of disturbance should not carry a connotation of negative human impact; naturally occurring disturbances are part of every ecosystem on earth.

What types of disturbances affect forests?

All forests are subjected to both natural and anthropogenic disturbances. Examples of naturally occurring disturbances include wildfires, winds (hurricanes, tornadoes and windstorms), insect and disease epidemics, landslides, ice storms, floods and droughts (**Figure 1**).

Examples of anthropogenic disturbances include pollution, conversion of forests to nonforest areas, timber harvesting, prevention of wildfires, global warming, alteration of natural hydroperiods (flooding), application of herbicides, introduction of exotic species, litter raking, trampling and compaction, fertilization and irrigation (**Figure 2**).

The urban forest ecosystem is also subjected to anthropogenic and natural disturbances. However, natural disturbances, such as wildfires and normal

Figure 1.1 Photo by Larry Korhnak

Figure 1.2 Photo by Larry Korhnak

Figure 1. Historical fires (1.1) and natural hydroperiods (1.2) are examples of naturally occurring disturbances which have been virtually eliminated from urban forest ecosystems.

Figure 2.1 Photo by John Rieger, CA Department of Transportation

Figure 2.2 Photo by Larry Korhnak

Figure 2. Conversion of forests to development (2.1) and raking of litter (2.2) are examples of anthropogenic disturbances in urban forest ecosystems.

flooding periods, have been virtually eliminated from urban forest ecosystems **(Table 1)**.

Table 1. Types of disturbances that occur or have been eliminated from urban forest ecosystems (UFE's)

TYPES OF DISTURBANCES THAT OCCUR MOST OFTEN IN UFEs
• removal of topsoil and soil grading • air and soil pollution • litter raking • introduction of invasive species
NATURAL DISTURBANCES THAT HAVE BEEN ELIMINATED FROM UFEs
• natural fires • normal periodic flooding • nutrient cycle

The focus of this chapter will be on naturally occurring disturbances and their importance to ecosystems. Ideally, restoration should return a site to a condition that includes a natural disturbance regime, but it may also be aimed at minimizing those anthropogenic disturbances that are considered undesirable.

The Importance of Natural Disturbances: Yellowstone and the Suppression of Wildfires

Fire may be the most widespread natural disturbance in the world's forest ecosystems. In fact, many forest and wildlife species persist because of periodic fire disturbance. However, the perspective that all disturbances are abnormal led to the Smokey the Bear syndrome where all forest fires were perceived as bad.

A classical example of the consequences of fire suppression is the 1988 catastrophic fire that swept through Yellowstone National Park, killing much of its vegetation. The natural cycle of fire disturbance in the park had been interrupted for more than one hundred years by intentional fire suppression. This led to a dense invasion by shade-tolerant trees and understory vegetation, and excessive accumulation of litter and woody debris in the forest, which eventually caused rampant, intense and impossible to control wildfires **(Figure 3)**.

Why are disturbances important?

Disturbances are the norm for forest ecosystems. Completely undisturbed forests are extremely rare or even nonexistent.

The role that natural disturbances play in forests is one of renewal. Whether the disturbance is big or small, mild or intense, it plays an important role in determining a forest's succession **(Figure 4)**. Disturbances initiate succession in ecosystems by killing some or all individuals (depending on its intensity), as well as disrupting litter/detrital (dead organic matter) pools.

Fires initiate succession by reducing the number of plants on a site and creating openings in the canopy and near the ground, allowing understory plant species and tree seedlings to grow. For example, in the longleaf pine ecosystem in the southern U.S., frequent low intensity fires keep the ground clear of underbrush. These fires kill many saplings of trees and a few larger trees, while allowing sufficient seedlings to become established and maintaining an open tree stand of low density. In the absence of fire, the forest eventually loses the

Figure 3. Suppression of natural cycles of fire disturbance in the Yellowstone National Park caused fires of destructive dimensions in 1988. Photo by Jeff Henry

Figure 4.1 Photo by Jeff Henry

longleaf pine and is completely dominated by older shade-tolerant trees.

Fires revitalize the soil by allowing some nutrients that are bound in the leaf and branch litter to be returned to the soil. Trees and branches that fall in forest fires create habitat for ground-nesting birds,

Figure 4.2 Photo by Jeff Henry

Figure 4.3 Photo by Jeff Henry

Figure 4. Fires play an important role in forest renewal and succession. Figures 4.1, 4.2, and 4.3 sequentially show the regrowth of vegetation following the 1988 Yellowstone National Park catastrophic fires.

reptiles and amphibians **(Figure 5)**. Thus, fires can provide conditions for a wide variety of plant and animal species, and maintain biodiversity in forests. Disturbances, such as fire, are therefore a major diversifying force in forest ecosystems.

Figure 5.1 Photo by Larry Korhnak

Figure 5.2 Photo by Larry Korhnak

Figure 5. Fires (5.1) release nutrients that were bound in the leaves, branches and organic matter and make them available for plant uptake (5.2). Burned logs and snags are also habitats for a variety of mammals, reptiles and amphibians.

However, it is important to note that not all disturbances renew and invigorate ecosystems. Some disturbances are damaging and result in destabilization of the ecosystem. One example of such a disturbance is chronic pollution, which may cause long-term cumulative impacts that may not be easy or possible to reverse.

Disturbances and Biodiversity

Prairies, oak savannas, and long-leaf pine ecosystems of the Southern U.S. are examples of ecosystems that are dependent on frequent, low-intensity ground fires. These fires have occurred historically at intervals of 1 to 25 years. The life histories of the dominant species in these communities have been shaped evolutionarily by fire (Platt et al. 1988). Without fire, these ecosystems gradually change to other vegetation types **(Figure 6)**. A knowledge of natural disturbance regimes is essential for maintaining regional biodiversity.

Ecologists have evidence that species diversity will be highest at some intermediate frequency or intensity of disturbance (Connell 1978, Pickett and White 1985). Frequent disturbance allows only species that colonize rapidly to persist, whereas long periods without disturbance may exclude desirable dominant plant species from the ecosystem **(Figure 7)**.

Land managers should realize that species in any region have adapted, through evolution, to a particular disturbance regime. If we radically alter that regime, many species will be unable to cope with the change and will be eliminated.

Figure 6.1

Figure 6.2

How often do disturbances occur?

The disturbance regime is a combination of how often the forest is disturbed (***frequency***), how severe the disturbance is (***intensity***), and how large the affected area is (***extent***). In general, the frequency and intensity of natural disturbances are inversely

Figure 6.3

Figure 6. Longleaf pine ecosystems are dependent on frequent, low intensity ground fires. Fires maintain an open canopy (6.1) and an extremely diverse flora in the ground layer (6.2). In the absence of fires, other species, such as vines and shrubs, are favored resulting in the loss of this ecosystem's natural diversity (6.3).

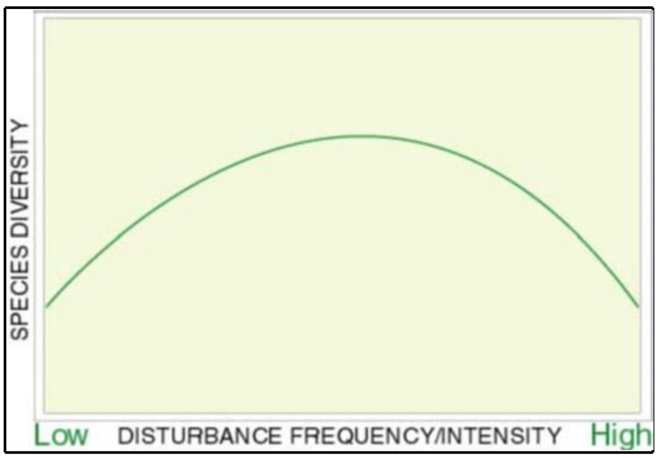

Figure 7. The intermediate disturbance hypothesis indicates that species diversity is highest at intermediate frequencies or intensities of disturbance.

related. For example, volcanic eruptions or large meteor impacts (high intensity) fortunately only occur rarely (at a low frequency).

Some anthropogenic disturbances, such as global climate change, occur only at a very low intensity. However, these disturbances may be directional and may cause large cumulative effects over a long period of time. Because short-term effects are small, they are very difficult to detect.

If a disturbance is very intense, ecosystems can be totally destroyed, as when a forest is converted to a parking lot. The more intense the disturbance, the more difficult and costly it is to restore what was there before. Severe erosion, for instance, may lead to a degraded ecosystem that will never fully recover to the prior condition without extremely costly intervention, such as importing soil.

In urban areas the challenge is to determine the appropriate natural disturbance regime to mimic and/or reinstate.

Succession

What is succession?

The changes in an ecosystem that follow a disturbance are collectively called ***succession***. Succession is a dynamic and continuous process, often occurring gradually over time. Forest succession is the change in species composition, age and size, and ecosystem structure and function over time.

Let's consider the development of an abandoned farm field in the Piedmont of the Southeastern U.S. over time to demonstrate succession **(Figure 8)**. This farm field is surrounded by pine-hardwood forests, typical of this part of the country **(8.1)**. During the first year or two, annual forbs cover the field **(8.2)**. Plants such as goldenrod and asters follow the second and third year (Perry 1994). In this early stage of succession, if we walk in this field, we can hear birds such as grasshopper sparrows and meadowlarks (Meyers and Ewel, 1990).

Figure 8.1

The grass-forb stage would be gradually replaced by a shrub-pine-seedling community that will last perhaps 15 to 20 years (without further

Figure 8.2 Photo by Natural Area Teaching Laboratory at University of Florida

Figure 8.3 Photo by Natural Area Teaching Laboratory at University of Florida

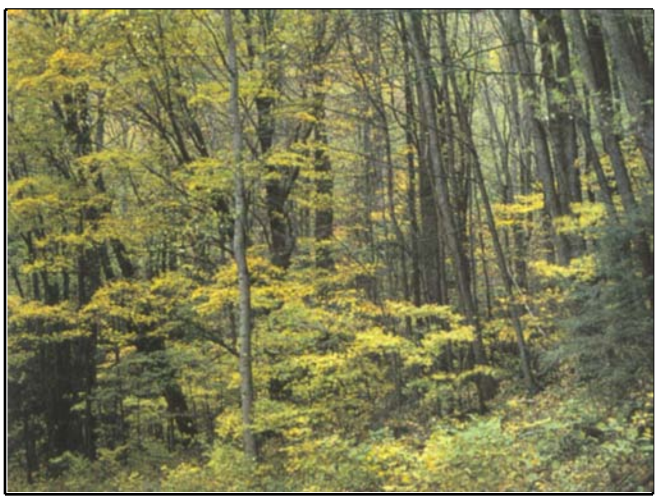

Figure 8.4 Photo by USDA Forest Service

Figure 8. Sequence of successional stages in an abandoned farm field in the southeastern U.S. over time. During the first years (8.1) the area is colonized by a mixture of pioneer species (8.2). This stage is gradually replaced by a shrub-pine community (8.3). In about 150-200 years, without further disturbances, an oak-hickory forest may replace the pine forest (8.4).

disturbances) **(8.3)**. Birds such as the yellowthroat and field sparrow will be common. Pine seedlings continue to grow in the abundant sunlight and, from about year 25 to year 100, a pine forest may dominate the site, providing habitat for birds such as the pine warbler (Meyers and Ewel 1990).

Pine seedlings do not grow in the shade of taller pines, but shade-tolerant oaks and hickories do. In about 150 to 200 years, in the absence of fire, an oak-hickory forest may replace the pine stand **(8.4)**. Birds such as the red-eyed vireo will thrive in the deciduous forest (Meyers and Ewel 1990). The seedlings of oak and hickory, capable of growing in the shade of the older trees, will thrive and thus replace the older oaks and hickories that die of disease, old age or other causes.

However, if fire does occur again, or the trees are harvested, pine forests can be maintained in the landscape for hundred of years. Natural disturbances can keep an ecosystem in a certain successional stage for long periods of time. This issue will be discussed further in the section **The Role of Disturbances in Succession**.

Why is succession important?

Urban trees are often managed as individuals instead of as parts of ecosystems. Individual urban trees and other vegetation may well provide many benefits such as energy conservation, beauty, recreation and climate amelioration. Yet, by managing them as part of an ecosystem, additional benefits can be achieved, such as increased animal biodiversity, reduced storm-water runoff and erosion, and significantly reduced maintenance costs.

Ecosystems that proceed through natural succession may be managed with much less costly intervention (**Figure 9**). Urbanization and its associated activities have a profound impact on natural succession, with the end result that little natural succession occurs in most metropolitan areas. For example, a widespread practice in urban forests is to clean out the understory by raking leaves, branches, seeds and seedlings on the forest floor. Logs and snags are also often removed. Such a loss of the understory, along with logs and snags may have negative consequences for many wildlife species dependent on these forest structures. In the long term, such practices will lead to loss and degradation of the forest itself, since nutrients are not efficiently stored and recycled. As trees die, there are no replacements, since the seed bank and seedlings were removed, and natural succession is severed. As a consequence, erosion increases and fertilizers and soil amendments must be used to bring nutrients back to the system.

Figure 9.1

Figure 9.2 Photo by Larry Korhnak

Figure 9.3 Photo by Larry Korhnak

Figure 9. Ecosystems that are able to follow natural succession, such as naturally landscaped backyards (9.1), may be managed without costly intervention. Such backyards will require less mowing, irrigation, fertilizers, herbicides and pesticides (9.2) when compared to backyards that use lawns extensively with only a few scattered trees (9.3).

Likewise, the extensive use of ornamental invasive species and "weed-free" lawn areas have similar impacts. Herbicides, fertilizers, pesticides, irrigation, and frequent mowing and raking are often required to maintain such areas, representing extra maintenance costs for urban managers. On the other hand, natural ecosystems that are able to follow succession can be managed without these additional costs (**Figure 10**).

To successfully manage urban forest ecosystems, managers need to understand how living and dead vegetation, wildlife and various disturbances interact. The ecological and economic advantages of maintaining and/or restoring natural succession need to be identified and incorporated into the management of the urban forest ecosystem.

Types of succession

There are two types of succession, primary and secondary.

Primary succession

Primary succession occurs in environments that lack organic matter and which have not yet been altered in any way by living organisms. Primary succession includes the development over time of the original substrate into a soil, and occurs over centuries or even eons.

The 1981 eruption of Mount Saint Helens in Washington provided an example of primary succession **(Figure 11)**. This eruption wiped out most or all traces of life in a substantial area to the northeastern part of the mountain, leaving barren areas of deep ash deposits **(11.1)**. A set of organisms adapted to survive and reproduce in these conditions has since become established **(11.2)**. Some plants were able to extract nitrogen directly from the atmosphere (nitrogen-fixing species) and most were also dependent on the formation of fungal association

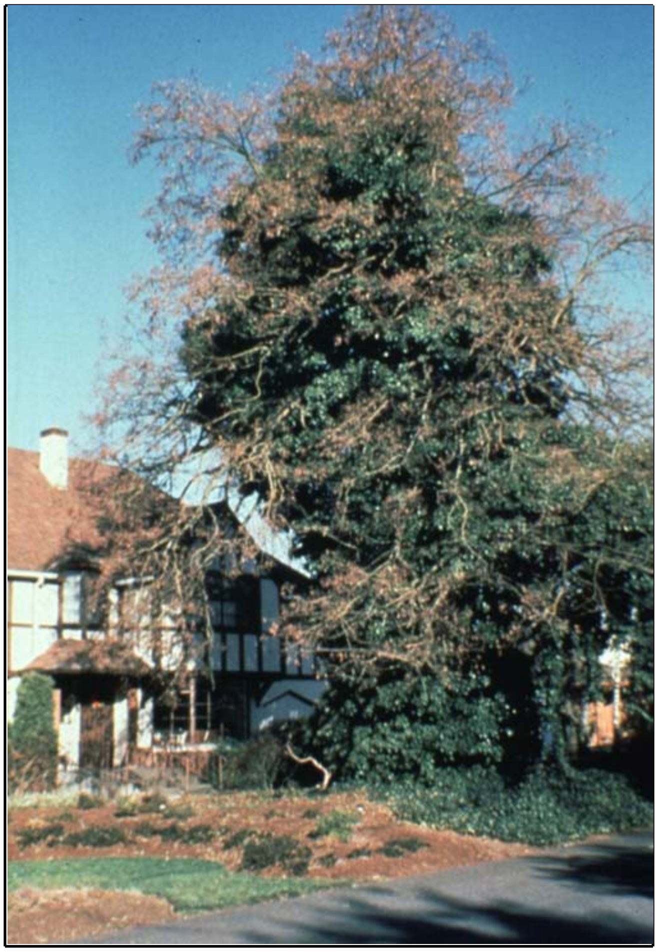

Figure 10.1 Photo by Linda Robinson

Figure 10.2

Figure 10. Extensive use of ornamental invasive species will affect succession. This English ivy (10.1), for example, displaced and killed a native pine species. Control of invasive species, whether mechanical or chemical, is a costly and time consuming operation (10.2).

with the roots (mycorrhizae) for extracting nutrients from the ash (Perry 1994).

Because of these characteristics, such organisms began to modify the site by accumulating nutrients and building up soil organic matter. As these organisms modify the site further, they will eventually be replaced by other organisms better adapted to the new conditions. For example, plants that required abundant light to grow will be replaced by more shade tolerant species.

As trees become established, there may be relatively long periods of this successional stage (e.g., Douglas-fir forests), which may persist only until the next eruption **(11.3)**. In areas protected from future eruptions, a relatively persistent ecosystem may eventually occupy the site (e.g., Western hemlock forest) (Perry 1994) **(11.4)**.

Another example of primary succession occurs on rock or subsoil surfaces exposed by landslides.

Figure 11.1 Photo by Michael P. Doukas

Primary succession can occur in urban forests where, for example, surface soil and organic matter have been completely removed from a site. In this case,

Figure 11.2 Photo by Lyn Topinka

Figure 11.3 Photo courtesy of R. Emetaz, U.S. Department of Agriculture

primary succession can be hastened through the addition of top soil.

Secondary succession

Secondary succession occurs in an environment that has supported mature vegetation in the past, and where, after the disturbance, the substrate (i.e., soil) remains relatively intact.

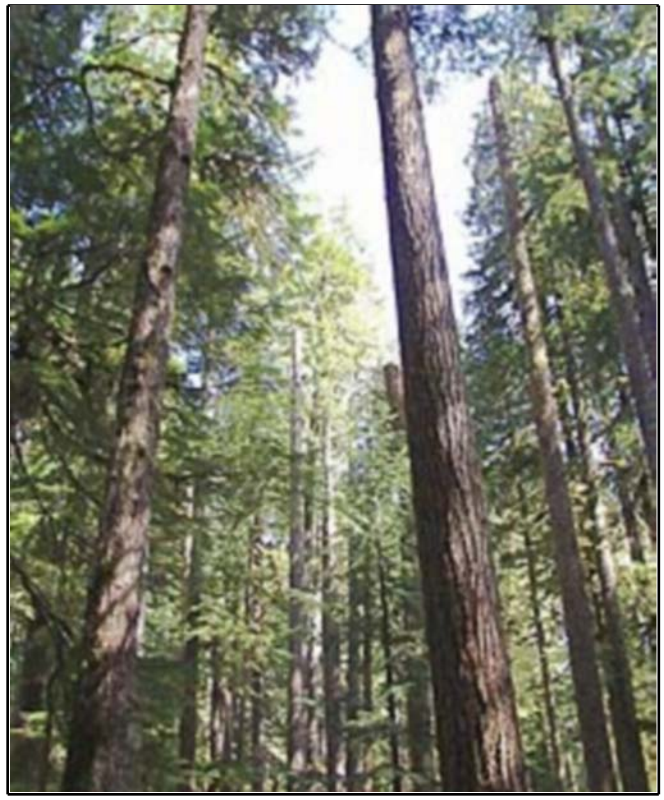

Figure 11.4 Photo courtesy National Park Service

Figure 11. The eruption of Mt. Saint Helens is an example of primary succession. It eliminated most traces of life in a substantial area of the northeastern part of the mountain (11.1). Less than a decade later, pioneer and early successional plants have colonized the area (11.2). Eventually, Douglas-fir forests will become established (11.3) and, without further disturbance, over several hundred years a Western hemlock forest may eventually occupy the area (11.4).

Secondary succession also occurs in urban areas. Suppose you decide to give up the fight with weeds in your backyard and no longer mow your lawn. The changes that take place will be typical of "old-field" secondary succession. First, your backyard would be colonized by a variety of plants, mostly annuals. Within a few years, these plants would be joined by perennials and smaller shrubs and the grass would start to disappear. Later, a mix of taller shrubs and tree species would seed in. Then, maybe 50 years from now, you would have a successional forest in your backyard.

Additional examples of secondary succession include the changes in vegetation and ecosystem characteristics in abandoned agricultural fields and in forests after clear-cuts, windstorms or fires.

The Role of Disturbances in Succession

Let's consider again the previous succession example of an abandoned farm field in the Southeastern U.S. **(Figure 8).** Natural disturbances may occur ***at any time*** during the development of the abandoned farm field into the pine or oak-hickory forest. Natural disturbances can keep an ecosystem in a certain successional stage for long periods of time. Fire of any type, for example, may prevent hardwood regeneration and maintain pine forests in the landscape for hundred of years.

Natural disturbances vary in spatial scale (they may occur in small, medium or large areas) and temporal scale (they occur at different time periods). For instance, individual trees or a group of trees may die and fall, forming small gaps in the forest, while wildfires may kill trees over thousands of acres **(Figure 12)**. Consequently, in many forested ecosystems, disturbance leads to a condition where local successional patches are continuously formed, leading to a "shifting mosaic" across the landscape (Bormann and Likens 1979).

Figure 12. In many forested ecosystems, disturbances such as fires, promote areas with burned and unburned vegetation. Small successional patches are formed. Eventually, across broad stretches of forest, there will be patches of vegetation in several successional stages. Paul Schmalzer

Different wildlife species are adapted to different successional stages **(Figure 13)**. In "old-field" succession, for instance, pine warblers would be common to the pine forest successional stage, while red-eyed vireos and wood thrushes would be found in oak-hickory forests.

Some mature forests (such as old-growth forests in the northwestern US) take many hundreds of years to reach a late successional stage. Some species associated with these forests, such as the northern spotted owl (*Strix occidentalis*), may not survive if only earlier stages of succession are present (Eckert 1974). It is a major challenge is to determine and maintain an appropriate mix of successional stages within a landscape.

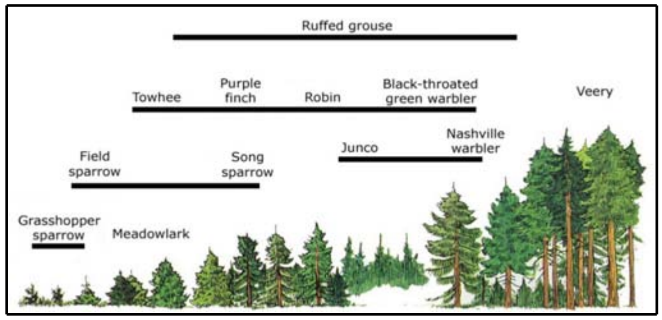

Figure 13. These bird species require different successional stages as habitats. Adapted from Smith 1990

Different Stages of Succession Provide Habitat for Different Wildlife Species

The American kestrel (*Falco sparverius*) needs several stages of succession to meet its requirements for food and cover **(Figure 14**). This bird feeds primarily on insects and small mammals, which are present in early successional stages that contain annual and perennial forbs and grasses. However, it also requires intermediate and late stages of succession, such as mixed woodlands (shrubs and trees) and more mature forests, for nesting (Neilson and Benson 1991).

American kestrels are widely distributed in North America. However, the number of southeastern American kestrels (*Falco sparverius paulus*) has decreased over 80% in the last 50 years (Wood et al. 1990). The main cause for the decline has been the destruction of longleaf pine ecosystems, the preferred nesting habitat for this species.

Other animals are also highly dependent on a certain stage of successional development. For instance, the structure and stage of development of

Figure 14. American kestrels are widely distributed in North America. They feed on insects and small mammals, which are present in early stages of succession (grasses and forbs). However, the American kestrel also requires intermediate and late stages of succession, such as mixed woodlands (shrubs and trees) for nesting. Photo by David Sarkosi

scrub vegetation has a profound effect on wildlife habitat availability in Florida **(Figure 15)**.

Figure 15.1 Photo by Wayne Peterson

Figure 15.2 Photo by Anne Birch

Figure 15.3 Photo by Paul Schmalzer

Figure 15. The Florida scrub jay (15.1) is endemic to the scrub ecosystem in the southeastern U.S. It requires a low shrub layer, bare ground and a few scattered trees (15.2) avoiding canopied areas. The scrub ecosystem is maintained by periodic fires (15.3).

The Florida scrub jay (*Aphelocoma coerulescens coerulescens*) **(15.1)**, an endemic species in Central Florida, is restricted to the pine/oak scrub ecosystems **(15.2)**. This bird requires a low shrub layer, bare ground and a few scattered trees, avoiding heavily canopied areas. The scrub ecosystem is maintained by periodic fires **(15.3)**. In this case, if fire is excluded for long periods of time, a sand pine canopy develops and scrub jays abandon the site (Woolfenden and Fitzpatrick 1984) **(15.4)**.

Succession in More Detail

Following a severe disturbance, sites are initially dominated by early successional plants, called **pioneer species**. Pioneers are usually prolific seeders (or sprouters), fast-growing and short-lived species, and generally intolerant of shade.

Pioneer species are then followed by shrubs and early successional trees which, in turn, are eventually replaced by late-successional species. Later successional species are generally shade tolerant and may grow much more slowly. Their seedlings will survive and grow beneath an established canopy, and eventually they will overtop the shrubs and replace early successional trees (**Figure 16**). Therefore, during succession, pioneers create conditions conducive to species that will form an intermediate or transitional community. This, in turn, creates conditions favorable to species that form late-successional communities.

Figure 16. Following a disturbance, sites are initially dominated by early successional plants, called pioneer species (grasses and herbs). Pioneers are then followed by other shrubs and early successional trees which, in turn, are eventually replaced by late-successional species.

The composition and relative dominance of various plant species changes over time because, in part, they have different life strategies (some plants grow best in full sun while others require shade, for example). Succession can be viewed as a biological race to make optimum use of available site resources, such as light, soil, nutrients and water.

The pattern of vegetation found in a landscape results from the interactions among soil types, water availability, life history strategies of plants and natural disturbances, all of which vary at different spatial and temporal scales (Turner 1987). These interactions will result, over time, in patches of vegetation in different stages of succession across the landscape. Therefore, the dynamics of forests cannot be grasped by looking at only a single site, and individual forests' stands should not be managed in isolation from others in the landscape in which they are embedded (Perry 1994).

Phases of secondary succession

Although succession is a continuous process, it is useful to identify four main phases in secondary succession (after Bormann and Likens 1979):

1. Reorganization phase

This is the period immediately following a disturbance, when pioneer species are establishing. There is usually a high availability of resources

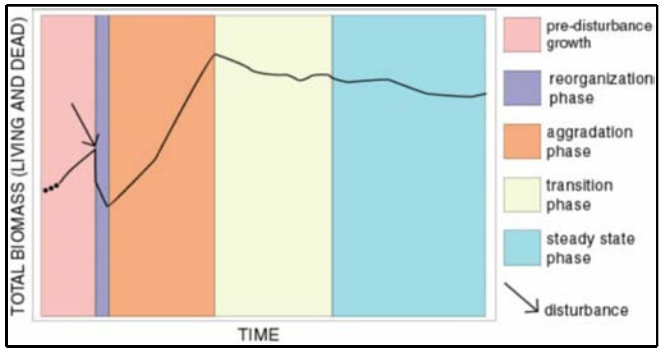

Figure 17. Bormann and Likens (1979) proposed four phases of secondary succession: reorganization, aggradation, transition and steady state (or climax).

(light, nutrients and water) and plant competition is low. Because the quantity of leaves per unit of ground area is not yet high, loss of water from leaves is low and runoff of water is high. Consequently, there is also a high potential for nutrient losses from the soil and erosion, since nutrient uptake by plants is low and water runoff high.

2. Aggradation phase

During this phase, plants rapidly accumulate biomass, especially in woody stems, while detritus also builds up on the ground. Restoration ecologists usually try to shorten the reorganization phase, and consequently hasten the aggradation phase, by planting trees and shrubs that will grow quickly, covering the site with leaf surface area.

3. Transition phase

This phase is characterized by a first wave of tree mortality, caused by increased competition among the pioneer trees, accumulation of snags and logs, and the establishment of shade tolerant species in the understory.

4. Steady State (or Climax) phase

The transition phase ends at a stage characterized by large accumulations of both living biomass and coarse woody debris (snags and logs). Forests that reach this phase usually have high structural diversity. Tree growth slows down in this phase, accompanied by increased tree mortality; any growth that does occur is offset by mortality.

The period of time that different ecosystems stay in each of these successional phases depends on environmental conditions and the nature of disturbance regimes. For example, the reorganization phase usually passes quickly but after severe disturbances or in harsh climates it can be greatly prolonged. Likewise, the aggradation phase varies widely from one forest type to another, and is much more rapid in favorable environments and where denser, more even-aged stands develop.

Changes in ecosystem function, structure and composition through succession

In addition to species composition, the structure and functioning of ecosystems also change during succession (**Table 2**). For example, most forest ecosystems only have abundant logs and snags (structure) later during succession or after a disturbance, such as a severe windstorm. In other ecosystems, a low intensity, frequent disturbance such as ground fire, burns low vegetation and some trees, releasing nutrients and competition, which changes both the pattern of nutrient cycling (function) and the vertical layering of vegetation (structure).

Table 2. Changes in ecosystem function, structure and composition that occur during succession.

ECOSYSTEM ATTRIBUTE	ASSOCIATED CHANGES
Function	high rainfall interception, efficient nutrient cycling, cooler environment (evapotranspiration cooling), high filtration of air pollutants, lower runoff.
Composition	number of plant, wildlife and microorganism species.
Structure	presence of logs and snags, layering of live vegetation, litter accumulation.

Species composition, ecosystem structure and ecosystem function all change during succession and are linked. By changing one component, such as composition, there will be changes in the ecosystem's function and structure. Invasive plants, for example, can modify the functioning of ecosystems (such as nutrient cycling and productivity) as well as their species composition (**Figure 18**).

For example, *Myrica faya* has invaded young volcanic areas in Hawaii. These areas are extremely nitrogen-deficient, and no native nitrogen-fixing plants exist. Because *Myrica faya* actively fixes nitrogen, it can form dense stands which out-compete and may replace native vegetation. Its invasion completely alters nutrient cycling and the rate and direction of primary succession (Vitousek 1986).

Figure 18.1 Photo by Edward Gilman

Figure 18.2 Photo by Edward Gilman

Figure 18. Several invasive plants, when introduced to natural areas can modify the ecosystem's function and alter natural succession. For instance, Chinese tallowtree (*Sapium sebiferum*) (18.1 tree, 18.2 inflorescence), can alter nutrient cycling and productivity by displacing native vegetation in natural areas.

Changing Natural Succession: The Casuarina Example

Casuarina species are nitrogen-fixing, fast-growing species which are tolerant of infertile soils. As a result, they would seem to be an excellent choice for restoration projects, growing very fast, shortening the reorganization and aggradation phases and, consequently, reducing water runoff and nutrient losses.

However, *Casuarinas* are also highly aggressive invasive species **(Figure 19)**. By planting them, nitrogen is added to soils, altering the nutrient cycle. A thick litter layer is also produced, reducing germination of native plant species (Ewel 1986), and altering the composition of plant species in the next successional stage. Wildlife species are also affected, since food sources and cover have been modified **(see also Chapter 9 - Invasive Plants)**.

Figure 19.1

Figure 19.2

Figure 19. Australian pine (*Casuarina* spp.), an aggressive invasive species, alters composition, structure and function of ecosystems. These fast-growing species form monospecific stands (19.1) that displace native vegetation. They are seen here growing above the original ecosystem's canopy (19.2).

Managing Disturbances and Succession

Natural disturbance regimes and succession have often been altered by humans, such as through the introduction of exotic species and the suppression of natural fires. To restore ecosystems it is necessary to actively manage succession.

Goals for restoring ecological succession could be economic (e.g., reducing maintenance costs of an urban park), ecological (e.g., restoring the normal hydrological period of an urban wetland) or aesthetic or recreational (e.g., bringing birds and watchable wildlife back to a neighborhood greenspace). These goals are not mutually exclusive. For example, the Patuxent Wildlife Research Center, near Laurel, Maryland integrates both ecological and economic goals in the management of succession. In 1960, the U.S. Fish and Wildlife Service and Potomac Electric Power Company agreed to implement a management program that would develop a shrubland community on a newly constructed right-of-way. Mowing was halted and selective herbicides were periodically applied to undesirable tree species. After 30 years, the right-of-way was dominated by a shrub community with high diversity and heavy use by wildlife (Obrecht et al. 1991). Additionally, the economic goal of reducing the number of trees growing too close to powerlines has also been achieved.

A restored site (an urban park, for instance) may contain one or more types of ecosystems or remnants of ecosystem. It is important then, to understand historical patterns of succession in these ecosystems.

Information should be regularly collected to document patterns and effects of management, including current and historical site conditions, such as soils, vegetation and disturbances. A site inventory should be conducted to determine the potential of the site (see also **Chapter 7 - Soil and Site Factors**). If a location is too degraded (due to pollution, nutrient loading, or heavy pesticide use), it may not be possible to restore it to a desired historical successional stage. Realistic and feasible restoration goals will ultimately determine a project's success.

A particular stage, or a mosaic of different successional stages, may be chosen as the objective of restoration, based on the information collected from the site inventory. The plant species to be established should be those characteristic of the corresponding natural successional stages. For instance, planting trees and shrubs to attract as many bird species as possible, many of which are not typical of the desired successional stage, may not lead to a sustainable objective.

Incorporating disturbances and succession into small scale projects

Restoration projects in small areas may include ecosystem(s) in which succession can be effectively managed. These situations may include the restoration of a bare site, elimination of invasive species or re-introduction of more natural disturbances.

Restoring bare sites

On a bare site, one stage of succession could be chosen and a first effort to restore it could be by planting a mix of all species typical of that successional stage. However, it may take decades for the trees to become mature, and litterfall and logs may need to be imported if a late successional stage is to be approximated. Introduction of natural disturbance regimes, such as frequent ground fire, may be desirable or necessary in some cases.

The Greening the Great River Park Program, established in 1995, seeks to restore native ecosystems along the Mississippi River in St. Paul, MN. The project involves the landscaping of industrial lands with four native plant ecosystems, including forests and prairies. For example, a 35-acre project will restore a natural prairie ecosystem close to downtown St. Paul **(Figure 20)**. Prairies will be maintained in a grassy successional stage by using frequent low intensity fires. "Prescribed fire" and/or shrub/tree cutting will be used to maintain this grass-like stage and keep weeds under control. Such strategy will provide, in the long run, an important successional stage that was missing from this urbanized landscape.

Figure 20.1 Photo courtesy of Chicago Wilderness

Eliminating invasive species

In some sites, removal of invasive plants may be sufficient to release native species from competition and restore natural succession. In the Ivy Removal Project in Forest Park, Portland, removal of English ivy (*Hedera helix*) has renewed the health of the existing vegetation **(Figure 21)**. English ivy is an aggressive exotic vine, extensively planted in the surrounding neighborhoods, that has invaded the park and suppressed its native vegetation. Regular

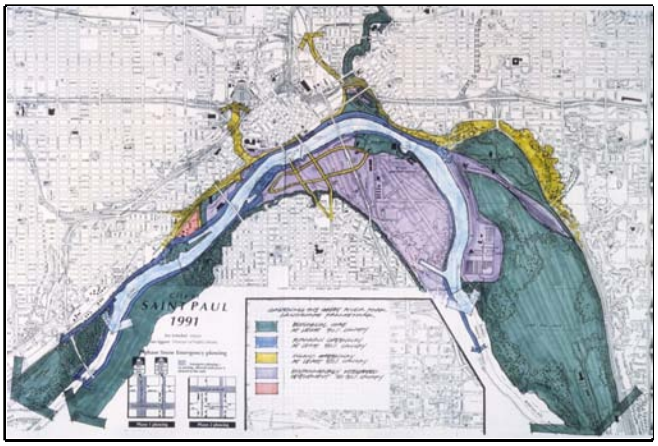

Figure 20.2 Photo courtesy of Greening the Great River Park

Figure 20. Prairies are maintained in a grassy successional stage by frequent low intensity fires (20.1). The Greening the Great River Park initiative (20.2), uses prescribed fire and/or cutting to maintain the grass successional stage of prairies in a 35-acre project in downtown St. Paul, MN.

removal of ivy has allowed native plant species to follow natural succession by eliminating plant competition.

Figure 21. The Ivy Removal Project, removes English ivy (*Hedera helix*) that has invaded Forest Park in Portland, OR, suppressing its native vegetation. In this case, removal is sufficient to release native species from competition and bring back natural succession.

However, in cases where the site has been invaded by aggressive invasives and native vegetation has been seriously damaged, removal of invasives may have to be followed by planting. A mix of native plant species typical of the desired successional stage can be planted (as in the bare site situation). An example occurred at Bill Baggs, a heavily used urban park in Miami FL, where a hurricane destroyed the monoculture of Australian pines (*Casuarina equisitifolia*) that previously dominated the park's vegetation **(Figure 22)**.

Figure 22.1

Figure 22.2

Figure 22. Australian pine (*Casuarina equisitifolia*), a highly invasive species, covered major areas of this urban park, Bill Baggs (22.1, beyond buildings) and suppressed native vegetation. After hurricane Andrew struck (22.2) natural removal of Australian pines allowed managers to restore the park's natural ecosystems.

Australian pines covered major areas of the park and suppressed the native vegetation prior to the hurricane. The "clean slate" that resulted from this natural removal of Australian pines allowed managers to reestablish the ecosystems that existed before by planting native species typical of that area. For more information on invasive species see **Chapter 9 - Invasive Plants**.

Re-introducing natural disturbances

When re-introducing disturbances, ecosystem characteristics and site conditions should be carefully considered. In the Southern U.S., for example, upland ecosystems are adapted to frequent (every 1 to 15 years) low intensity fires. In the case where fire has been absent for long periods of time, thinning of trees and/or manual removal of excessive fuel loads may be necessary prior to application of prescribed fire. Such management practice would prevent damage (and other associated risks) by a high intensity fire to which this ecosystem is not adapted.

On the other hand, where high intensity disturbances have been excluded for excessively long periods, other strategies may need to be pursued. For instance, the sand pine scrub ecosystems, also in the Southern U.S., are adapted to infrequent (every 15 to 100 years) high intensity fires. Historically, after a lengthy fire-free period, an intense fire occurs. If fires become too frequent, sand pines disappear, and the association becomes oak shrub or changes to other pines. If fires become too infrequent, a xeric hardwood forest develops. Most scrubs naturally depend on fires, but these fires need to be applied in such a way that various stages of development are maintained within isolated fragments. Without these fragments, species with special habitat requirements (such as the endemic Florida mouse, *Podomys floridanus*, the Florida scrub lizard, *Scelopors woodi*, the gopher tortoise (*Gopherus polyphemus*) and the sand skunk, *Neoseps reynoldsi*) might be eliminated (**Figure 23**). Although preliminary steps have been taken to develop techniques to burn the scrub, reintroduction of fires in scrub ecosystems within urban areas may not be feasible (due to liability, fire control considerations and public reaction). In such areas, patches of the scrub ecosystem could be maintained by cutting, scraping and chopping to simulate fires (Meyers and Ewel, 1990). Implementation of either burning or mechanical techniques will require careful attention to public education.

Figure 23.1 Photo by Anne Birch

Figure 23.2 Photo by Dave Rich

Figure 23. In the scrub ecosystem of the southern U.S., the correct frequency and intensity of fire is critical. If fires become infrequent and too intense, a sand pine ecosystem develops, excluding the endangered scrub lizard (*Sceloporus woodi*) (23.1) and gopher tortoise (*Gopherus polyphemus*) (23.2).

In other ecosystems, small or large gaps may need to be cut to stimulate further succession. Such a practice is becoming common for restoration of longleaf pine ecosystems in the Southeastern U.S., where dense hardwood thickets now dominate many sites. Gaps are cut and regenerated (**Figure 24**), and prescribed fire is used to keep hardwoods from re-invading.

Re-instating several different stages of succession in one area can only be achieved on very large land areas. Small sites may prove not to be functional, although a small mosaic of semi-natural successional stages may, nevertheless, be effective in

Figure 24.1

Figure 24.2

Figure 24. In the longleaf pine ecosystems in the southeastern U.S., gaps are cut to stimulate succession (24.1). Such practice allows regeneration (24.2) and the return of a missing stage of succession to the landscape.

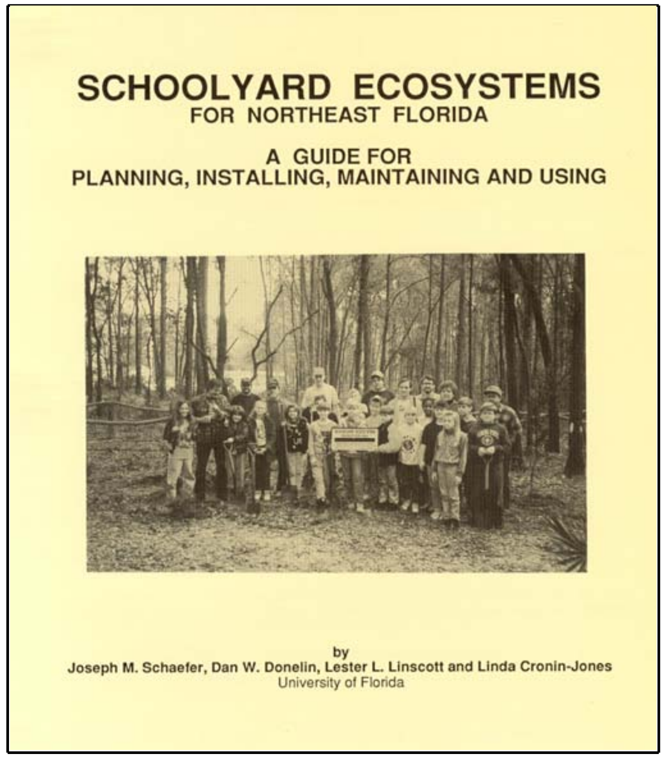

Figure 25.1

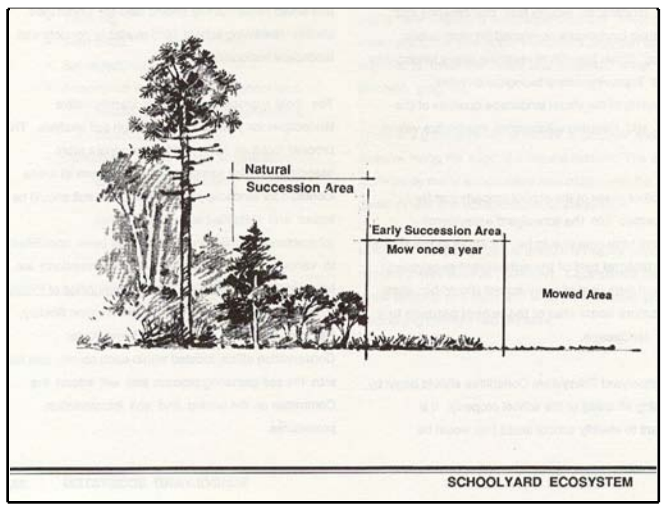

Figure 25.2

Figure 25. The Schoolyard Ecosystems for the Northeast Florida initiative (25.1) encourages the establishment of successional stages in school areas. The objective is to teach students about different animals that utilize a mowed area, an early successional patch and a more mature area (25.2).

schoolyards for educational purposes. The Schoolyard Ecosystems for Northeast Florida initiative, for example, teaches students about different animals that utilize a combination of small patches of mowed areas, early succession and more mature areas (**Figure 25**). Some important structural elements, such as logs, snags, brush piles and plants with different heights, are constructed to simulate a more mature area and to promote wildlife.

Incorporating disturbances and succession into large scale projects

Parts of larger project areas (greater than about 20 acres) may present situations similar to small scale projects (with some bare sites, sites invaded by exotic invasive species and sites where disturbances could be re-introduced). But in larger areas, there is also the opportunity to manage for several stages of succession at the same time, if a mixed successional landscape is typical of the ecosystem in question or could be used for educational purposes. Learning about the ecosystem, its stages of succession and how they fit into the overall landscape becomes critically important. The Chicago region, for example, contains prairies, savannas, woodlands and forests. The absence of fire has impacted these ecosystems and their stages of succession in the landscape. Oak savannas have been almost totally excluded in the Chicago area and prairies have been invaded by woody species. Historically, the frequency and intensity of fire determined the successional stage of these ecosystems, that is, whether a given piece of land would be an open grove or a dense forest (**Figure 26**). Restoration efforts in this case are based on re-introducing fires. To date, fire has been reintroduced in several areas and native species typical of the region's ecosystems are being planted. In some areas, native trees have been cut to allow more light to reach the ground (**Figure 27**). Such practices allow the landscape to support several stages of succession, ranging from open prairies to forests.

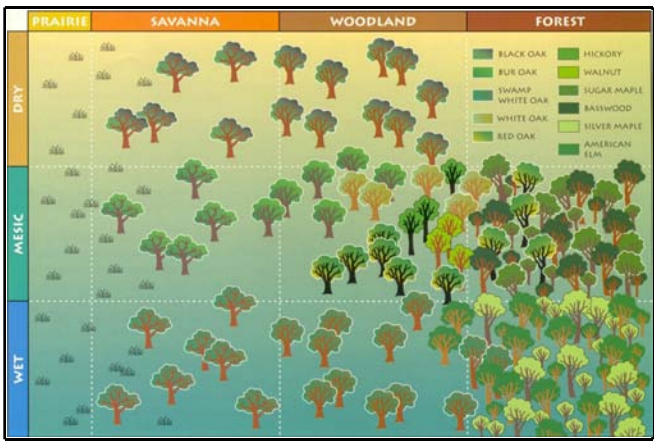

Figure 26. Historically, the frequency and intensity of fire determined the successional stage of ecosystems (whether a given piece of land would be an open grove or a dense forest) in the Chicago area. Photo courtesy of Chicago Wilderness

Some continuous or intermittent form of management may be needed to create disturbances in situations where human activity has severely modified natural disturbances cycles. Efforts to restore historical flooding cycles in the South Platte River watershed illustrate the need for an integrated restoration plan for a whole region. The floodplains along the South Platte river in Nebraska consist of a mosaic of different vegetation types. The presence of wooded or open vegetation was historically determined by natural periodic floods. Forests were confined to drier sites, since native woody species, such as willows (*Salix* spp.) and cottonwoods (*Populus* spp.), would not survive flooding. Grasses,

Figure 27.1 Photo courtesy of Chicago Wilderness

Figure 27.2 Photo courtesy of Chicago Wilderness

Figure 27. Due to suppression of fires, the once open savannas in the Chicago area (27.1) developed into thickets of vegetation deprived of sunlight (27.2). Oak savannas began losing their vast diversity of plants and animals and were almost excluded from the landscape.

on the other hand, could tolerate flooding, allowing for open areas along the river.

Channelization and upstream development reduced the water flow and, consequently altered flooding periods. As a result, previously open areas of the floodplain are nowdrier and invaded with adjacent native forest species. Before channelization and development, migratory birds, such as the endangered whooping crane (*Grus americana*) and the sandhill crane (*Grus canadensis*) **(Figure 28)**, used the open grassy floodplains for feeding and avoided roosting in areas with abundant woody species. Because of these changes in natural succession, the whooping crane population decreased 80% over 30 years.

Figure 28. Sandhill crane (*Grus canadensis*) populations have decreased as a consequence of successional changes in ecosystems along the South Platte River. Photo by Larry Korhnak

Current restoration efforts include selective clearing of trees along some parts of the river. However, restoration of historical patterns of succession in the region will ultimately depend on the reinstatement of normal flood periods. An integrated upstream restoration effort along all the South Platte River extension will be required to achieve such a goal (U.S. Fish and Wildlife Service 1981).

In another example from Central Florida, scrub vegetation without fire grows very tall and thick with very little open space for the endangered gopher tortoise (*Gopherus polyphemus*) to nest and feed (**Figure 29**). Little sunlight can reach the ground and herbs, which are a food source for this tortoise, can no longer grow (Smith 1997). Conservationists are using prescribed fires to restore the open nature of the historic scrub ecosystem. A number of other animals with wide ranges, such as black bear, white-tailed deer, bobcat, gray fox and spotted skunk, also utilize the scrub and should benefit from the efforts as well (Meyers and Ewel 1990).

Conclusions

Disturbances and succession occur virtually in every place on earth. To successfully manage the urban forest ecosystem, managers need to understand natural disturbance regimes and how species

Figure 29. Without fire the scrub ecosystem grows very tall and thick with very little open space for the endangered gopher tortoise (*Gopherus polyphemus*) to nest and feed. Photo by Ben Coffin (with the Friends of the Enchanted Forest in Titusville, FL)

composition, ecosystem structure and wildlife interact over time within these regimes.

There are many opportunities to incorporate the concepts of disturbance and succession in either small or large scale urban restoration projects:

- Learn about the historical disturbance regimes that occur in the ecosystems in your region. Remember that disturbances have a variable spatial and temporal scale. If appropriate, propose re-introducing some disturbances back to these ecosystems.

- Understand the successional stages of the ecosystem(s) you are managing.

- Take advantage of any research conducted that relates to historical site conditions, including soils, climate, vegetation and disturbances. Conduct a site analysis and decide whether your restoration plans should include disturbances and succession management.

- Manage site-specifically but remember that the site you are managing belongs to a larger landscape that may contain other successional stages.

- Remember that species composition, ecosystem structure and ecosystem function are linked and change during succession. Invasive plants, for example, can modify the functioning and structure of ecosystems as well as their species composition.

- Start with small demonstration projects.

Remember that succession and natural disturbances do not always follow our human-made geographical boundaries. Integrated efforts may be needed to better achieve restoration goals at the landscape level.

It is also important to involve the local community in every step of the restoration process. Successful urban forest restoration projects often include an educational and outreach component. Educate people about the benefits of succession and the benefits of re-introducing natural disturbances.

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Chapter 5: Developing a Restoration Plan That Works[1]

William G. Hubbard[2]

Abstract

A plan can be defined as a predetermined course of action. Regardless of the type of plan, they all have a number of similar components. First a vision - a future desired condition or state - must be defined. Goals and objectives are then used to achieve the vision. Measurable goals and objectives form a basis for project evaluation. Guiding principles are incorporated into the goals and objectives to ensure that achievement of the vision is attained in a high quality and defendable manner. It is important to identify and involve stakeholders in the planning process from the beginning and to have a framework and a process to identify and resolve issues. Gathering and analyzing information about the restoration site is critical. An action plan with a timeline outlines activities and responsibilities. A plan for monitoring should be developed before the project is started. Monitoring evaluates how well the project objectives have been met. Determining project costs, benefits and funding sources is essential to the restoration project's success. As the plan progresses, care should be taken to outline its relationship to other plans. A well-thought-out, well-developed plan will help the community achieve its vision.

Introduction

According to many planners, a plan can be defined as a predetermined course of action. Plans have three characteristics: *they must involve the future*, *they must involve action* and *they must involve an element of personal or organizational identification or causation*. In other words, plans are designed to get someone or something (a business for example) from point A to point B in a certain time frame. This will most likely be accomplished by someone or a group of people taking actions toward the stated goal(s) and objective(s) **(Figure 1)**.

Figure 1. Plans provide a common vision and a path toward its accomplishments. Photo by Larry Korhnak

1. This is Chapter 5 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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But why develop a plan? We have heard all the lines before and if we are not careful we will fall into the same cynical trap of thinking about why we don't like to plan and why plans don't work. For example, plans:

- sit on the shelves and collect dust!;
- rarely succinctly develop the goals, objectives and pathways to success;
- are shaped by politics or personnel changes which often render them useless;
- often become outdated as soon as they are done; and
- don't fit today's style of managing by the seat of our pants!

However, what can a plan provide?

- a common vision for the community;
- well-defined and measurable goals and objectives;
- a logical plan of action;
- organized and focused efforts toward accomplishing a goal;
- a document to assess and justify budgetary requirements; and
- a plan to obtain funding.

Principles of Planning

Larsen et al. 1990, reviewed many plans and provided a number of suggestions for principles of good planning. His tips are to:

1. Integrate and balance resource allocations. Good planning integrates all urban resources. It does not pit one resource against another.
2. Communicate a clear vision. Good planning generates a clear vision of the outcomes and contributions to meeting local, regional, and national needs.
3. Recognize limits. Good planning recognizes limits on the outcome's ability to produce a mix of goods and services in perpetuity.
4. Seek informed consent. Good planning welcomes citizen involvement. Decisions should be made and explained openly. Dialogue among disparate interests should be facilitated.
5. Finish in a reasonable time. Good planning is completed in a reasonably short period of time. Short periods facilitate incremental planning and stability among key players. People can actually harvest the fruits of their labor.
6. Be people-oriented. Good planning recognizes that individuals, both inside and outside the agency or effort, make the difference between good and bad plans **(Figure 2)**.
7. Promote active administrative leadership. Good planning requires active involvement and leadership on the part of responsible administrators.
8. Match analysis to questions at hand. Good planning involves use of analytical tools for purposes of evaluating options. Such tools should not drive or dominate the process.
9. Be both locally oriented and nationally balanced. Good planning should be locally oriented and should also give ample consideration to national constituencies.

Types of Plans

Before we begin the nuts and bolts of urban forest ecosystem restoration planning let's review some of the more common types of plans:

Strategic Plan

Strategic planning can be defined as a disciplined effort to produce fundamental decisions and actions that guide an organization. This kind of planning typically involves broad-scale information gathering, an exploration of far-reaching alternatives, an emphasis on future implications of present decisions and an ability to accommodate divergent interests and values (Bryson, 1988).

Figure 2. Good planning recognizes that individuals, both inside and outside the agency or effort, make the difference between good and bad plans. Photo by Larry Korhnak

Comprehensive Plan

Comprehensive planning involves taking into account as many planning needs as possible under one umbrella plan. The comprehensive plan often involves stakeholder input early on. Many counties and cities now undergo comprehensive planning which includes plans for economic development, land-use plans and environmental plans.

Master Plan

Similar to the comprehensive plan, the master plan is not as comprehensive and involves more specific goals and objectives. Master Street Tree Plans of the past for example involved planting plans, maintenance plans, budgetary plans and educational plans.

Operational Plan

The operational plan can be defined as that which puts the strategic, comprehensive or master plan into action. It outlines who is responsible for what by when. Activities are often outlined on a timeline with expected outcomes.

Management Plan

Similar to the operational plan but more detailed, the management plan might even outline day-to-day management activities that need to be accomplished in order to achieve the stated goals and objectives.

Restoration Plan

As we willl see later, a restoration plan is merely a type of management, master or action plan that focuses on restoring specific areas.

Budget or Fiscal Plan

The budgetary or fiscal process of any organization or entity is usually complex. Monetary management is complex because it equates very closely to people's value systems. Budgetary instructions, accounting procedures, etc., are all enclosed in this important type of plan.

Communication and Education Plan

A final plan worth mentioning is the communication and education plan. In a sense, this is a strategic plan where appropriate communication of goals, objectives, issues and progress is vitally important to the success of any plan. Special care must be given to produce a good communication plan.

Etc. Etc. Etc. Plan

Plans are made for everything these days. Land-use plans, zoning plans, etc. The importance is not necessarily the specific name of the plan but what it purports to achieve. It is also interesting to point out that plans are often nested and involve a systems approach **(Figure 3)**.

Components of the Restoration Plan

Regardless of the type of plan, they all have a number of similar components. In the following sections we will discuss several of these components. We will also discuss some of the issues involved in creating a successful plan. Specifically, the following outline will be followed for developing a restoration plan:

• Scope, Vision, Goals and Objectives

• Guiding Principles

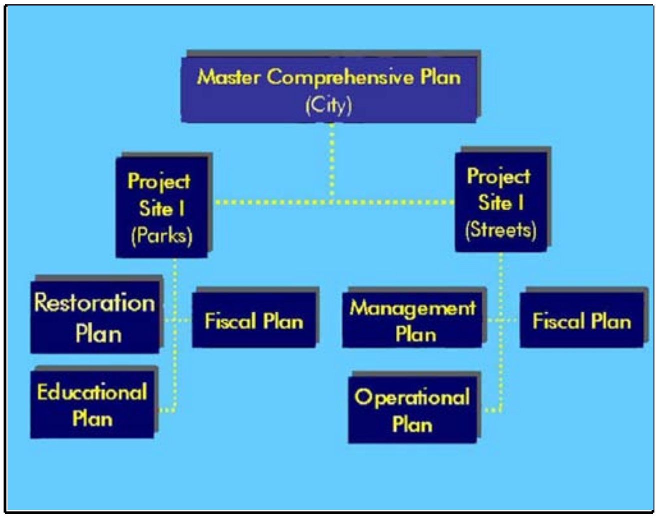

Figure 3. An example of a systematic approach to planning involving many different plans.

- Stakeholder Involvement
- Identifying Problems and Issues
- Information Gathering and Analysis
- Developing a Timeline and Detailing Actions - the Action Plan
- Monitoring and Evaluating
- Budget and Finance
- Relationship to Other Plans

Scope, Vision, Goals and Objectives

Scope

Before we look at vision, goals and objectives it is important to understand the scope of the proposed restoration project. This will have an important influence on the development of the plan. Many times, this is the difference between a restoration project versus a restoration program or one project versus many projects. For example, community or ecosystem-wide plans are different from a plan specifically designed for a section or plot of land in an urban area. Regardless of the size or scope, planning techniques are very similar. The complexity and interrelationships distinguish the two. Scope is important to keep in mind when initiating the planning process.

Vision

Plans are based on vision. Vision involves creativity, imagination, and sometimes thinking outside of the box. Basically, the vision is the desired future condition or state (**Figure 4**). It is the result of closing your eyes and literally visioning what the outcome of your plan might look like. A shared vision is critical if you want everyone's buy-in (see below for stakeholder input).

Figure 4. A vision is the desired future condition or state. Greening the Great River Park in St. Paul, MN has a plan for restoring industrial lands along the Mississippi River. Their vision is to have these restored industrial areas look like they were set in an established forest. Photos by Rob Buffler

An excellent example is from Metro, the regional government in Portland, Oregon. They are working on what is called the Metropolitan Greenspaces Vision:

- *It is our vision to protect, on a long-term basis, natural areas, open spaces, trails and greenways that lend character and diversity to our region even as more and more people move here to share our special place.*

- *It is our vision to balance our urban focus and drive for economic health and prosperity with an array of wildlife habitats in the midst of a flourishing cosmopolitan region.*

- *It is our vision to conserve and enhance a diversity of habitats woven into a lush web of protected greenspaces. (Metropolitan Greenspaces Master Plan, July 1992).*

Goals and Objectives

Goals and objectives are used to achieve your vision. Measurable goals and objectives form a basis for project evaluation **(Figure 5)**.

Figure 5. The Metropolitan Greenspaces Master Plan in Portland, Oregon has a goal to restore green and open spaces in neighborhoods where natural areas are all but eliminated. Whitaker Ponds is one of the selected neighborhood restoration sites. Photo by courtesy of Metro Regional Parks and Greenspaces

Goals and objetives are actual steps, which if taken in an orderly, strategic fashion will result in attainment of the vision. For example, the goals for the Metropolitan Greenspaces System include:

- *Create a cooperative regional system of natural areas, open space, trails and greenways for wildlife and people in the four-county metropolitan area.*

- *Protect and manage significant natural areas through a partnership with governments, nonprofit organizations, land trusts, interested businesses and citizens, and Metro.*

- *Preserve the diversity of plant and animal life in the urban environment, using watersheds as the basis for ecological planning.*

- *Establish a system of trails, greenways and wildlife corridors that are interconnected.*

- *Restore green and open spaces in neighborhoods where natural areas are all but eliminated.*

- *Coordinate management and operations at natural area sites in the regional Greenspaces system.*

- *Encourage environmental awareness so that citizens will become active and involved stewards of natural areas.*

- *Educate citizens about the regional system of greenspaces through coordinated programs of information, technical advice, interpretation and assistance.*

Another example of possible goals and objectives comes from the Society for Ecological Restoration (SER) and is based on a common definition of ecological restoration. According to SER, ecological restoration is the process of assisting the recovery and management of ecological integrity.

Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices.

The definition above was developed by the SER Policy Working Group after almost a year of consultation and deliberation; it was passed by a mail vote of the SER Board in October 1996. The SER Policy Working Group is now working on a detailed description of attributes, goals and objectives, which will accompany the definition:

- *To restore highly degraded but localized sites;*

- *To improve productive capability of degraded production lands;*

- *To enhance conservation values in protected landscapes;*

- *To enhance conservation values in productive landscapes* (Journal of Restoration Ecology 1995)

The Bill Baggs Cape Florida Restoration Project Example

The Bill Baggs Cape Florida Restoration Project (1992) can also be used to exemplify the development of a vision, goals and objectives in a restoration project. Bill Baggs is a heavily used urban park near Miami. Prior to Hurricane Andrew's strike in 1992, the park had extensive areas dominated by Australian pine (*Casuarina equisitifolia*), an invasive tree. The natural removal of Australian pines by the Hurricane provided a great opportunity to restore the park to conditions closer to its previous natural conditions. The Bill Baggs Cape Florida Park vision, goals, and objectives were:

***Vision*:**

- To reforest the park with native vegetation (**Figure 6**); and
- To improve the historical, recreational and educational opportunities and the facilities in the park (**Figure 7**).

- ***Goals*:**

  - The primary goal was to restore the park's original natural processes while providing compatible public recreational opportunities;
  - Reforest the park to predominantly native vegetation for beneficial environment purposes and for public outdoor recreation benefits; and
  - Eradicate exotic plants at Cape Florida and re-establish the historic native natural communities.

Objectives:

- Stabilize and protect the natural and cultural resources of the park;
- Re-open public recreation areas as soon as possible;
- Preserve and restore the original natural communities and natural processes of the park, to the extent possible; and
- Restore pre-hurricane levels of public recreation.

Figure 6. The Bill Baggs Cape Florida Restoration Plan was to reforest the park with native vegetation. Photo by Mary Duryea

Figure 7. The second vision of the Bill Baggs Cape Florida Restoration Project was to "improve the historical, recreational and educational opportunities and the facilities in the park." Photo by Mary Duryea

Guiding Principles

Guiding principles are incorporated into goals and objectives to ensure that the plans vision is attained in a high quality and defendable manner **(Figure 8)**.

Some guiding principles that have been used in the past for example are:

Figure 8. Guiding principles such as sound scientific facts are incorporated into goals and objectives to ensure that the plan's vision is attained in a high quality and defendable manner. Photo by Larry Korhnak

- *Science* - Projects need to be planned and supported by sound scientific facts and reasoning.

- *Stewardship* - Ultimately, the goal of many restoration projects is stewardship. Agreement on what this means will be important.

- *Integration and partnership* - Today's world necessitates multi-discipline, agency/entity involvement.

- *Economics* - Sound economics insures the plan matches the economic resources.

Stakeholder Involvement

It is important to identify and involve stakeholders in the restoration planning process from the beginning. Stakeholders are the people who will be impacted by the restoration project. Buy-in from community, government, independent organizations (NGOs, Universities), private sector, investors, employees/employer, among others is absolutely necessary at an early phase. Failure to do so will undermine the process and the plan and may be a waste of time and money **(Figure 9)**.

Figure 9. It is important to identify and involve stakeholders in the restoration planning process from the beginning. Photo by Mary Duryea

What kind of input will be necessary? Some of the important questions you may ask at the outset are: Who are your stakeholders and what information do you want from them? Are they members of the community that may be affected by the decisions made? Make an extensive list of who may have an interest in your restoration project.

Retreat-style settings, Delphi surveys and other ways to gather input and understand issues have been used to include stakeholders. The Delphi process was originally developed in the 1950s by Olaf Helder and Norman Dalkey, both scientists at the Rand Corporation, as an iterative, consensus building process for forecasting futures. It has since been deployed as a generic strategy for developing consensus and making group decisions in a variety of fields. An interest group is typically assembled, either through correspondence or face-to-face discussion, to assess issues of mutual concern.

While the individuals in the group share a common interest (the subject of the Delphi), they usually represent different points of view. Each member of the group is asked to give his/her comments regarding a particular set of issues. A facilitator analyzes the individual comments and produces a report documenting the response of the group. The individuals then compare what each person said to the group's normative response as a basis for discussion. The discussion, again via remote or face-to-face conversation, is used to share, promote, and challenge the different points of view. Once this is done, the participants, having the benefit of the previous discussion, anonymously comment on the issues again. A new group report is generated and the process repeats itself. This process continues until the group reaches consensus or stable disagreement.

If you would like further information about stakeholder involvement and identification, and the Delphi process, check the **Suggested Readings** section at the end of this chapter.

Identifying Problems and Issues

When involving stakeholders it is important to have a framework and a process to identify and resolve issues **(Figure 10)**.

Figure 10.1 Photo by Larry Korhnak

Figure 10.2 Photo by Larry Korhnak

Figure 10. When involving stakeholders it is important to have a framework and a process to identify and resolve issues, such as issues concerning compatible recreational uses.

Examples of identification include expert review of your project from a university faculty member or private consultant or public review through town hall meetings or forums, the media, etc. The issues confronting the project may be social, economic and environmental. Addressing these issues will help to revise and shape the restoration plan. Some example issues may include:

- Compatible recreational uses;
- Biological and physical limitations for the site;
- Consensus on vision, goals and objectives;
- Private property rights issues;
- Land conflicts;
- Conflicts with current infrastructure;
- Conflicts with other plans; and
- Compatibility with laws and regulations.

Information Gathering and Analysis

Once your vision, goals/objectives, guiding principles and stakeholder input have been determined, a next logical step will be to determine where to obtain the information you will need for the restoration project **(Figure 11)**.

Figure 11. Information gathering and analysis such as this site assessment of a wetland will guide the development of goals and objectives. Photo by Larry Korhnak

The information gathering and analysis phase might incorporate the use of the following tools:

Natural Resources

1. aerial photographs/remote sensing data
2. geographical information systems (GIS)

3. field data collection

4. soil maps

5. climatic data

Historical

1. library

2. historical societies

3. municipal records

Infrastructure

1. GIS

2. city and utility agencies

Community/Social

1. stakeholder input and others

2. town meetings and focus groups

Where can you go for this information? More and more can be obtained from the Internet. GIS maps and data, soils information, climatic data, etc. are sometimes located on various websites. Other information can be found at the public works or other municipal departments. Social and stakeholder data usually needs to be collected first hand as discussed previously.

Following this very important step of data collection and analysis it may be necessary to refine or redirect the current vision, goals and objective. For example, stakeholder input may be needed again as you collectively review the results from GIS maps. A real problem in some parts of the country for example is the control and management of invasive exotic species. The vision may have been the complete eradication of all invasive species in a given geographical location. Review of maps and other data, however, may render achievement of this vision extremely costly or impossible. A renewed vision may be a healthy ecosystem with a manageable level of this invasive species and complete eradication of it on public lands. Stakeholders will need to understand why the vision has been revised. Maps are an excellent way to communicate.

Developing a Timeline and Detailing Actions - The Action Plan

Once agreement has been coalesced, the next step is to outline the beginning of an action plan. In general, there is more than one way to reach the plans objectives. Successful restoration projects often spend time early on identifying, evaluating and selecting alternative paths and solutions. Various criteria are used to reach consensus on the proper alternatives to use. Economic analysis (cost-benefit, capital budgeting, social accounting methods, etc.) is one way. Public input and voting is another. It is important to remember to use the guiding principles to choose the best alternative.

An example of restoring a longleaf ecosystem in an urban setting using three alternatives should illustrate this. The restoration team and stakeholders determined three potential courses of action after extensive discussion involving restoring a 15-acre tract of land in a metropolitan area.

- *Roller drum and chop site. Plant two-year-old containerized longleaf pine seedlings, burn regularly, keep nuisance wildlife out with fencing. Monitor health and regeneration success.*

- *Leave existing vegetation on the site. Plant six-year-old longleaf pine saplings. Apply herbicides.*

- *Seed the area after a light winter burn. Manually remove the weeds, brush and competition.*

Following the decision to follow one alternative, the next step is detailing the actions. Basically, action planning states what will be done, by whom, and when. It includes a timeline and estimated costs and resource needs **(Figure 12)**.

One thing that is often overlooked is developing a system for foreseeing and overcoming barriers in action planning. The best systems involve enhanced communication plans with the general public, stakeholders, consultants and others involved in developing and implementing the plan.

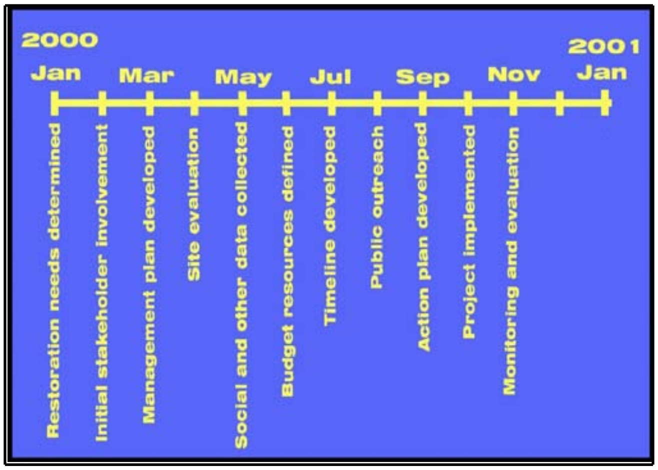

Figure 12. An example action plan timeline.

Monitoring and Evaluating

The next step is monitoring and evaluating the plan's effectiveness. How do you do this? Some examples relating to the regeneration restoration project cited before include:

Site visits

1. *regeneration surveys*
2. *hydrologic and soils testing*
3. *testing and evaluating the ecosystem structure and functioning*

Physical mapping

1. *aerial photography*
2. *GIS mapping*

Social

1. *public reaction*
2. *benefits and effects on neighbors*

It is important to have a plan for monitoring before the project is begun **(Figure 13)**. Monitoring may begin with base-line data collection and continues on during project implementation. Monitoring evaluates how well the project's objectives have been met. It demonstrates and elucidates both successes and failures.

Figure 13. A plan for monitoring should be developed before the project is started. Monitoring evaluates how well the project objectives have been met. Photo by Larry Korhnak

Budget and Finance

Determining project costs, benefits and funding sources is essential to the restoration project's success **(Figure 14)**. Following are a few questions that the planning/implementation team, along with stakeholders, policy makers and others need to address.

Figure 14. Determining project costs, benefits and funding sources is essential to the restoration projects success. Photo by Larry Korhnak

What will this project cost? What are the benefits?

• *Benefit-Cost Ratio*: In this type of analysis, the project is undertaken when the benefit to cost ratio is greater than one. If more than one project is desired, then the project with the highest ratio is undertaken.

• *Net Present Benefits (NPB)*: Due to the nature of many public projects, it may take many years to reap the full benefits. To take into account the long-term nature of these projects, all costs and benefits are equated to a common time (usually the present). If there is anything left after subtracting net present costs from net present benefits, the project will be of value to the community and can be judged as economically sound, all else being accounted for.

• *Capital Budgeting*: In many instances, a capital budgeting process will need to be invoked. Ranking of competitive projects by benefit-cost ratio or net present benefits may help in the final analysis. Great care should be taken to outline the assumptions used and to equate all projects as to scale and time.

• *Use of other economic tools*: Be sure to review the literature for more information that may be useful, specifically opportunity cost and the traditional economic tools that have been modified for the new fields of ecological and environmental economics.

What are the Funding Mechanisms?

Some funding options to investigate include:

• special options tax

• bond issuance

• general tax revenues

• private foundations

• public and private grants

Robert Miller's Urban Forestry textbook (Miller 1997) lists a number of funding mechanisms that can be investigated. Finally, many successful plans have been implemented because they were already developed and the right funding came through. The importance of having a plan ready when budget opportunities become available cannot be stressed enough. Timing and preparedness go hand-in-hand. For references and additional information on budget and finance issues check the **Suggested Readings** session at the end of this chapter.

Relationship to Other Plans: Plans are Interrelated

As the planning process proceeds, it will become obvious that no longer can we plan in a vacuum. The interrelationship and interdependence of planning is more relevant today than ever before. In addition, many citizens are beginning to realize that a healthy economy is tied directly to a healthy ecosystem, making environmental planning very important. More communities are incorporating a systems approach to planning that is similar to comprehensive planning **(Figure 15)**.

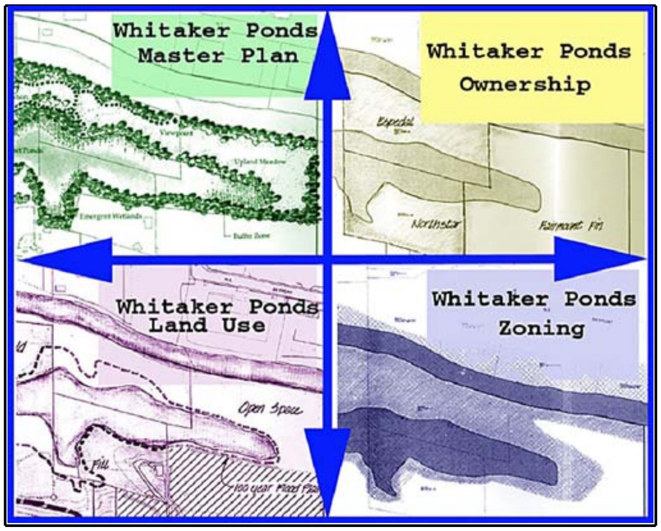

Figure 15. As the plan progresses, care should be taken to outline its relationship to other plans. Photo by courtesy of Metro Regional Parks and Greenspaces

As your plan progresses, care should be taken to outline its relationship to other plans. These plans include:

• Comprehensive

• Transportation

• Land

- Capital improvement
- Risk management and hazard assessment
- Community facilities and utilities plan
- Public outreach
    1. media
    2. schools
    3. professional groups
- Volunteer action plan

Conclusion

Urban ecosystem restoration planning is a highly complex and dynamic process. As with any process, there are innumerable factors to consider and no cookbook solutions. A careful review of the literature and of other plans from around the country should be beneficial to anyone considering restoration plan development. A well-thought-out, well-developed restoration plan will help the community achieve its vision **(Figure 16)**.

Figure 16. A well-thought-out, well-developed restoration plan will help the community achieve its vision. Photo by Larry Korhnak

Suggested Readings

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Chapter 6: Restoring the Hydrological Cycle in the Urban Forest Ecosystem[1]

Lawrence V. Korhnak[2]

Abstract

Forests provide a protective cover for the landscape and cycle much of the precipitation back to the atmosphere. They are essential components of many aquatic ecosystems. When native forests are removed and replaced with impervious surfaces and high maintenance vegetation, much of the water that would have been returned to the atmosphere or percolated into the ground water, washes off the landscape. The quantity and energy of this runoff erodes landscapes, deteriorates aquatic habitat, and floods human habitat. In addition, the runoff washes away chemicals that have been concentrated on the land to support high maintenance vegetation. Polluted runoff, referred to as non-point source pollution, is our nation's most serious water quality problem. Reestablishing the urban forest can help to protect the landscape and associated aquatic ecosystems. Runoff can be reduced, use of polluting chemicals can be lowered, and aquatic habitat and ecosystem links can be reestablished.

Forest Water Cycle

Forest Water Cycle Overview

On average, two-thirds of precipitation entering U.S. forests is returned to the atmosphere through evaporative processes. Most of the remainder percolates through the porous forest soils to streams or fills underground geological storage space. Forests function as a protective layer and are a key link between the atmosphere and the land in the water cycle (**Figure 1**).

The forest canopy intercepts both the falling rain and its kinetic energy. Some of the intercepted rainfall is evaporated to the atmosphere while the rest drips to the ground as through-fall or runs down the trunk as stem-flow. Forest soils are generally very porous so little through-fall washes over the soil surface as runoff to water bodies. Instead, most of the through-fall seeps or infiltrates into the soil. The sun's energy evaporates water from inside the leaves in the canopy in a process called transpiration. Transpiration from the foliage creates a moisture deficit that is transmitted as a suction force all the way down to the tree roots. Much of the soil water is sucked up by plant roots to replace the water

1. This is Chapter 6 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kämpf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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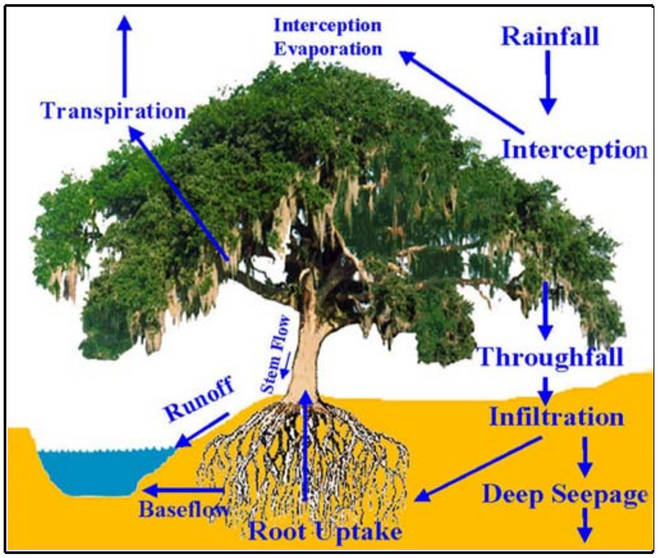

Figure 1. Forests are a key link in the cycle of water between the atmosphere and the land.

transpired from the foliage. Depending on the soils, geology, and other factors, some of the remaining soil water will percolate deeper, and some will move laterally into nearby streams.

Interception and Through-fall

Much of the rain falling on a forest landscape will first impact the canopy vegetation (**Figure 2**). Some will eventually drip to the ground and some will be evaporated from the vegetation back to the atmosphere. This evaporative loss is referred to as interception loss. The percentage of rainfall intercepted and evaporated by the forest canopy in the U.S. ranges from about 12%-48% of rainfall depending on the climate, tree type, and canopy structure. For example, interception losses of 12% were reported for mature hardwoods in the southern Appalachian mountains (Kimmins, 1997), 18% for pine flatwoods in Florida (Riekerk et al. 1995), 40% for ponderosa pine in Arizona, and 43% for a beachforest in New York (Kimmins 1997).

The kinetic energy of rainfall can cause significant soil erosion (**Figure 3**). A one inch storm will deliver about 2 million foot pounds per acre of kinetic energy. Most of this energy can be adsorbed by the forest canopy and forest litter. Without this shield the rainfall energy will break up soil particles into smaller more easily transportable materials. Most of the splashed soil will move downhill. The fine particles resulting from the rainfall breakup of

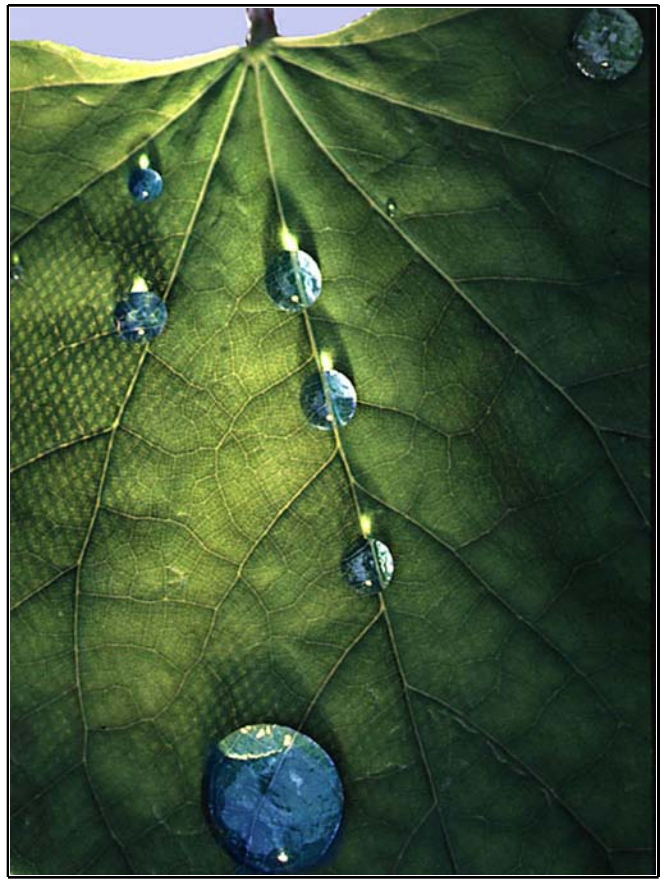

Figure 2. Much of the rain falling onto a forest landscape will first impact the canopy vegetation. Some will eventually drip to the ground, but on an annual average 12% to 48% will be evaporated from the vegetation back to the atmosphere.

larger soil aggregates will clog soil drainage and result in more runoff. This can result in sheet flow and sheet erosion. This water energy will concentrate in small depressions called rills, which over time may develop into gullies. Left unchecked, erosion can carve canyons (**Figure 4**).

One way researchers measure interception losses is to measure rainfall inputs into the forest (either above the canopy or in a nearby open area), and at the same time measure through-fall with collection devices (for example troughs and funnels) under the canopy (**Figure 5**). Interception losses are the difference between these two measurements. Interception is related to canopy leaf area which can be measured with leaf fall traps.

Figure 3. The kinetic energy of rainfall can cause significant soil erosion. A one inch storm will deliver about 2 million foot pounds per acre of kinetic energy. Much of this energy can be adsorbed by the forest canopy. Photo by Andrew Davidhazy, Rochester Institute of Technology, School of Photographic Art and Sciences.

Figure 4. In Georgia at Providence Canyon State Park you can observe the severe erosion that can result from permanently removing the forest canopy from the landscape.

Transpiration

Transpiration is the evaporation of water from within living plant tissue. Solar energy creates a water potential gradient by evaporating water through leaf openings called stomata (**Figure 6**). This gradient is transmitted to the roots where soil water is absorbed and transported to the foliage via the conductive network of xylem. Transpiration in the continental US ranges from about 30%-60% of precipitation and is a function of climate, vegetation type, and stand structure (leaf area). A Florida pine forest transpires almost a million gallons per acre in a year (Riekerk et al.1995).

Figure 5. Through-fall is measured with troughs and funnels placed under the canopy. The measurements are often correlated with canopy leaf area, which is estimated in this figure with leaf fall traps.

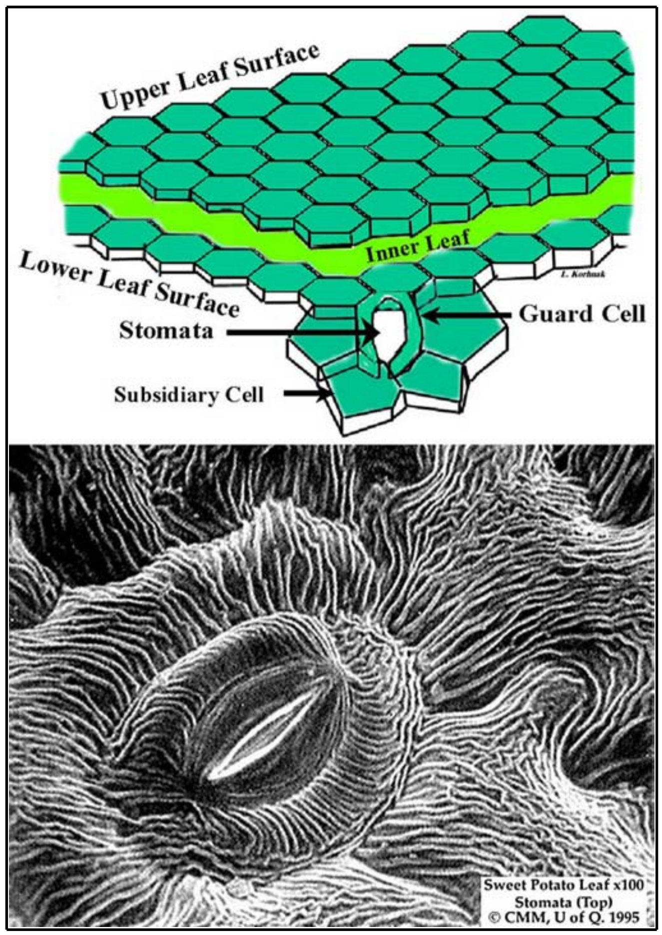

Figure 6. Energy from the sun evaporates water from inside living plant tissue through openings called stomata. The guard cells can open and close the opening and provide some regulation of the process. Photo micrograph courtesy of the Center for Microscopy and Micro Analysis.

The "Transpiration Pump" also helps to draw nutrients from the soil into the tree. Trees have been described as "solar powered chemical machines that mine the soil for minerals" (**Figure 7**). In addition to sucking up water, trees also draw in their required nutrients. For vigorously growing forests, trees will uptake about 100 kg/ha/yr of Nitrogen and 15 kg/ha/yr of Phosphorus (Kimmins 1997).

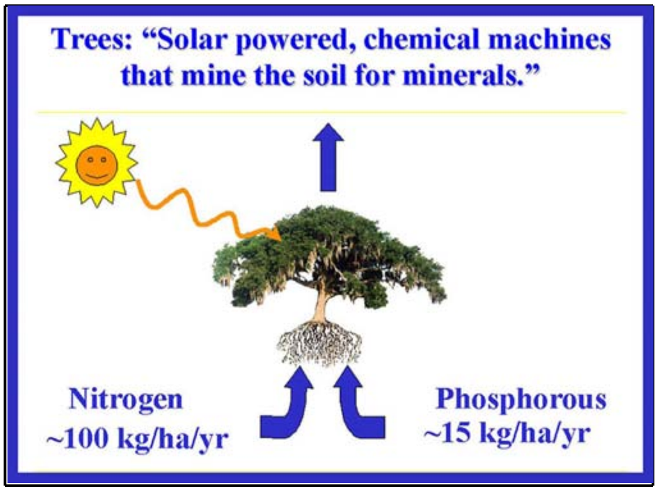

Figure 7. With the aid of the "transpiration pump" trees can remove significant amounts of nutrients from the soil.

Transpiration is difficult to measure, but two methods are the sap flow gage and the leaf chamber. Sap flow is measured by applying a known heat source around the trunk of the tree and measuring the heat energy that is removed by the sap flowing up the trunk to replace transpired water (**Figure 8**).

Figure 8. A sap flow gage measures sap flowing up the tree trunk on its way to be transpired from the leaves.

The leaf chamber is a small transparent chamber that encloses the leaf and measures the moisture that enters and exits the chamber **(Figure 9**). The positive difference is transpired moisture. One major difficulty of both these methods is scaling up the measurements from individual trees and leaves to the forest.

Figure 9. The leaf chamber measures water transpired from foliage enclosed in the chamber. Scaling these measurements up to the forest level is a challenge.

Evapotranspiration

The sun's energy will evaporate water from many of the components of the forest ecosystem. Often researchers will combine all the evaporative losses into one measurement, called Evapotranspiration (ET). Evapotranspiration includes transpiration, interception evaporation, soil evaporation, and water body surface evaporation (**Figure 10**). In temperate forest regions about 70% of the precipitation is returned to the atmosphere through evapotranspiration (Hewlett 1982).

Infiltration

Infiltration is the movement of water from the soil surface into the soil (percolation is the movement of infiltrated water through the soil). Generally, there is a lot of space between the soil particles in forest soils and this allows water to easily seep into the soil (**Figure 11**).

For coarse to medium textured forest soils, the infiltration capacity is high and ranges from about 15 to 75 mm/hr (Brooks et al. 1991). Vegetation, both in the canopy and on the forest floor, protect the soil from compaction by rain energy. Forest floor

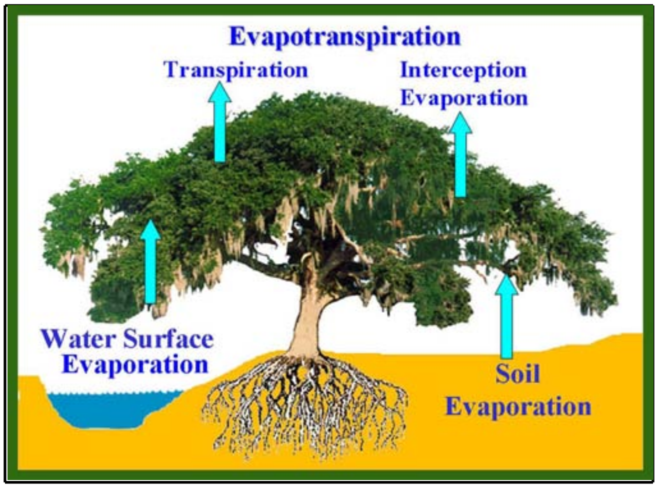

Figure 10. Evaporation is a term used for the sum of all the evaporative water losses in a forest.

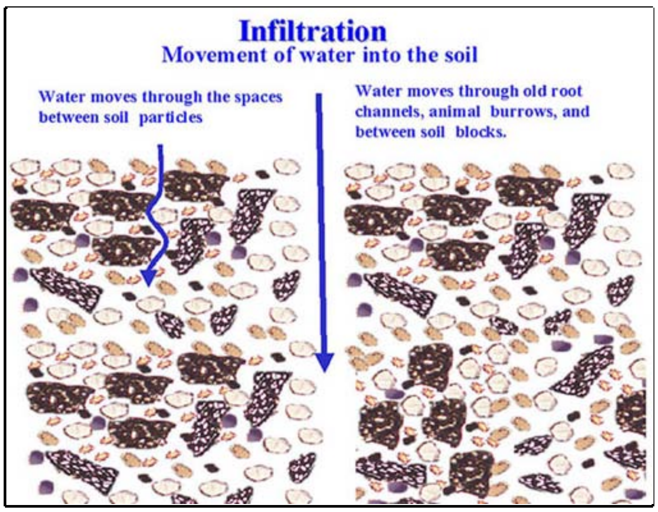

Figure 11. Water moves into the soil through both the small spaces between soil particles and the larger spaces between blocks of soil.

vegetation, both alive and dead, prevents rain splash erosion from clogging soil pores with colloidal material (**Figure 12**). In addition, forest floor vegetation increases infiltration capacity by retarding surface flow, thus giving water more time to sink in. Raking the forest floor clean of vegetation, as is done in many urban parks, will reduce the ability of the forest to soak in rainfall and thus increase storm water runoff. Roots and old root channels also make the soil more pervious.

Runoff

Surface runoff in the forest landscape occurs when the rainfall (or through-fall) intensity exceeds the infiltration capacity of the soil and surface storage is full. Forest soils generally have infiltration

Figure 12. The live and dead vegetation on the forest floor serve important functions in the infiltration process. Photo by Ken Clark.

capacities that exceed most rainfall events. So how does storm flow occur in the forest? Precipitation falling on the stream channel and saturated areas near the stream are the source of most early storm flow. As rain continues to fall, the saturated source area expands due to direct precipitation and infiltration, and from water infiltrating elsewhere and moving down slope. This expanding saturated variable source area contributes most of the storm flow to forest streams (**Figure 13**).

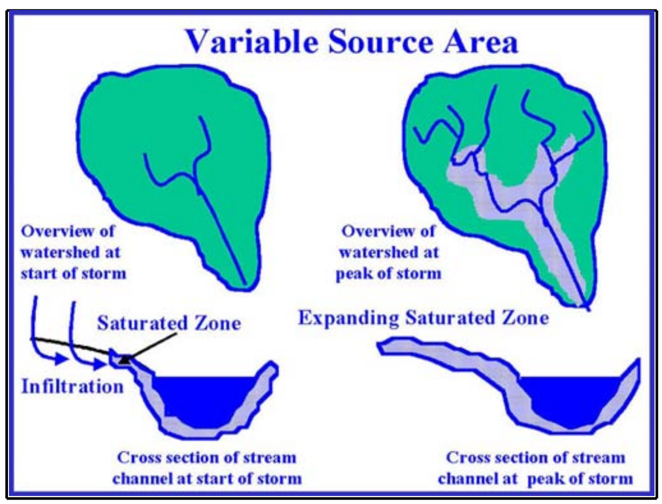

Figure 13. An expanding saturated source area contributes most of the storm flow to forest streams.

One method scientists use to answer questions regarding the hydrological impacts of forest management is with paired watershed experiments. In this method the water outputs of similar drainage basins are measured with hydrological structures like flumes and weirs (**Figure 14**). Data are collected from the watersheds for several years before treatment in order to establish statistical relationships. Then the treatment is applied to one of the watersheds and the post treatment data is analyzed to determine if the statistical relationship changed in a significant way.

Figure 14. A weir is one type of structure used for measuring forest stream flow. It is an important tool for answering questions about the effects of land management on the hydrological cycle. Photo by Hans Riekerk.

Seepage and Groundwater

Much of the water infiltrating into the soil supplies evapotranspiration demands. The remainder will seep down (percolate) until it hits a permeability barrier, for example clay or rock, and then will move down laterally. Lateral seepage provides flow to streams in dry weather (base flow). In more permeable soils, seepage may move deeper down into porous geological formations, called aquifers. Depending on the geology, the groundwater may remain stored in the aquifer for less than a week or for over 10,000 years. In regions with dissolved limestone geology (karst) groundwater will often move down gradient in undergrounds rivers. When these underground rivers intersect surface openings they form springs. When they intersect openings in the ocean floor they form blue holes. Occasionally the pressure of the spring flow will force the water above the ground surface to form fountain-like artesian springs. Most of the earth's water is in the oceans, but over 99% of the liquid water associated with the land is groundwater. Groundwater is an essential resource for drinking water (**Figure 15**). In many areas of the country forest land is being bought to protect ground water supplies from pollution associated with other land uses. High quality groundwater is also important for growing the food we eat (**Figure 16**).

Figure 15. In much of the U.S. groundwater supplies critically needed drinking water. This photo shows groundwater returning to the surface as a spring and some of its surrounding forested catchment area. Springs keep many rivers flowing during periods of dry weather.

Figure 16. Good quality groundwater is also important for irrigating and growing the food we need to eat.

Impacts of Urbanization on the Water Cycle

Overview

Forests provide a protective cover for the landscape and cycle much of the precipitation back to the atmosphere. They are also essential components of many aquatic ecosystems. When native forests are removed and replaced with impervious surfaces and high maintenance vegetation, water that would have been returned to the atmosphere or percolated into the groundwater, washes off the landscape (**Figure 17**).

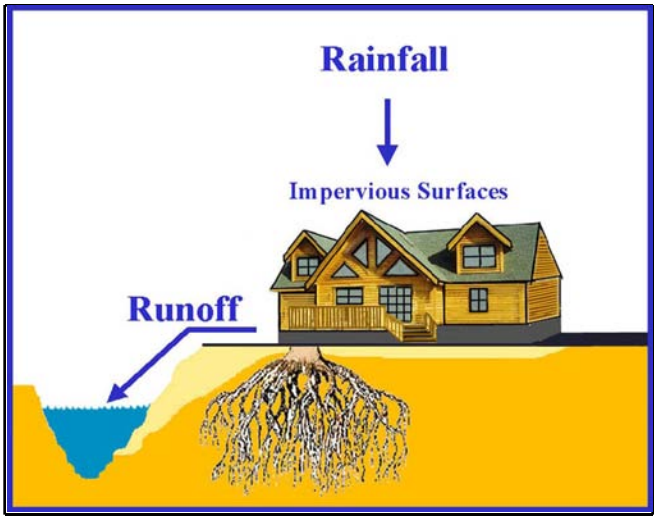

Figure 17. The urban landscape distorts and shortens the hydrological cycle.

The percent of runoff increases almost in direct proportion to the impervious area. In addition, impervious surfaces prevent storage of water in the soil and urban activities often fill in natural water storage areas like flood plains and wetlands. The result is that increased amounts of water are delivered to water bodies in a shorter period of time. More water moving faster causes floods and erosion that damage both life and habitat (**Figure 18**).

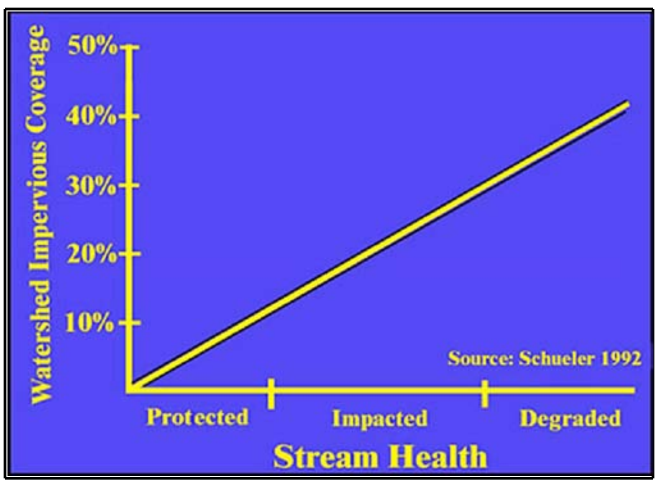

Figure 18. The replacement of forest with urban impervious surface will degrade stream health. Source: Schueler 1992.

Water washing over the urban landscape transports nutrients and other chemicals into aquatic ecosystems. This type of pollution is termed "non-point source", and it is our nations most serious water quality problem. Nutrients can stimulate algae production to the point where the ecosystem is no longer inhabitable by native organisms. Other pollutants have toxic effects on aquatic organisms and contaminate drinking water.

Forests are an integral component of many aquatic ecosystems. They provide water temperature moderation, support food webs, provide in-stream habitat and stabilize stream banks. Breaking the forest ecosystem-aquatic ecosystem link will diminish the biological value of aquatic ecosystems.

Water Quantity Problems

Altering the Landscape Will Alter the Hydrology

Disturbing a forested landscape with agricultural and urban activities will alter the response of the landscape to precipitation events. Forests retain and evaporate most of the incoming precipitation (**Figure 19**). The hydrograph (graph of discharge over time) for the forest watershed reflects this lower and more gradual release of water (**Figure 20)**.

Figure 19. In the forest water cycle, most of the precipitation is returned to the atmosphere and infiltrates into the soil. Flow to streams is slowed and moderated by the forest's complex structure.

In agricultural landscapes, heavy machines and livestock compact the soil. Compacting squeezes the soil particles closer together and reduces the soil pore space. With less pore space, rainfall will not soak into (infiltrate) the soil as well. A landscape with a reduced infiltration capacity will produce more runoff (**Figure 21**). The hydrograph will have a higher peak and because more water travels the faster surface route, the peak flow rate will occur earlier.

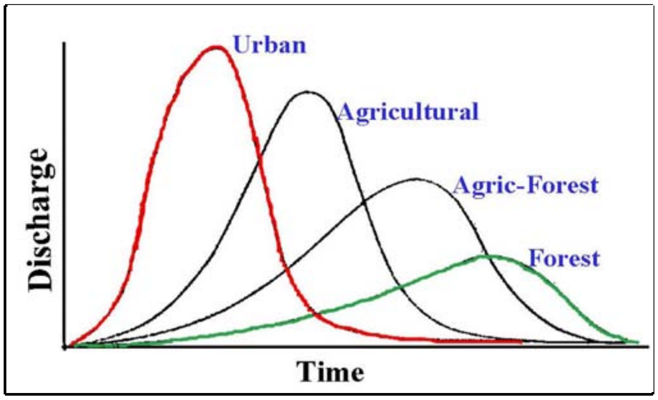

Figure 20. Water from the forest is released in lower amounts and more slowly compared to other land uses. Source: Beaulac and Reckhow 1982.

Figure 21. In the agricultural landscape, soil compaction results in less infiltration and increased runoff. Photo by USDA.

In the urban landscape even more runoff will be produced faster because the soil is often highly compacted or covered with impervious surfaces (**Figure 22**). Impervious area distorts the hydrological cycle. Infiltration, storage, and transpiration are reduced and runoff increases in proportion to the percent impervious area (**Figure 23**). Urban impervious surfaces are designed to move water quickly off site. More runoff and less delay of runoff results in higher peak-flows and flooding. **Figures 24, 25, and 26** show generalized changes in the water cycle resulting from different levels of impervious area in urban landscapes (EPA 1993a).

The Importance of Storage

In the forest water cycle, precipitation is captured and stored by the forest vegetation, forest litter, and soils. If preconditions are dry and the amount of rainfall is moderate, much of this water will be temporally stored and returned to the

Figure 22. In the urban landscape, impervious surfaces produce more runoff in a shorter period of time.

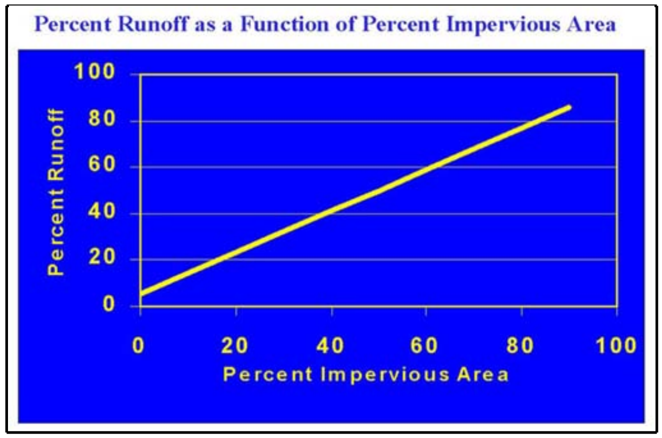

Figure 23. When forests are replaced with impervious surfaces, transpiration and infiltration are reduced and runoff increases in proportion to the percent impervious area. Source: Novotny and Olem 1994.

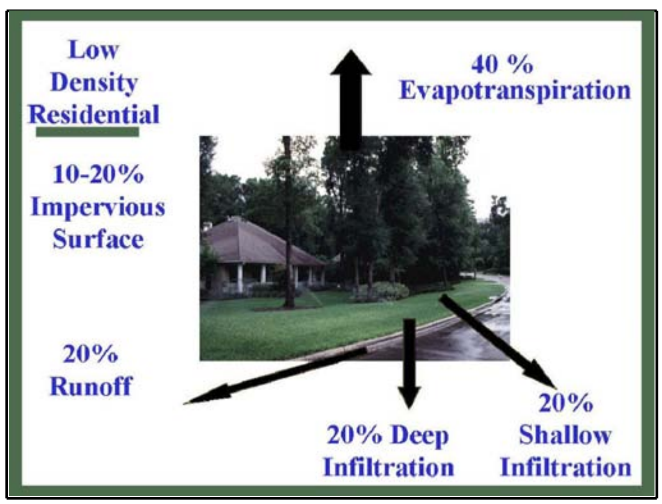

Figure 24. In low density residential areas with 10 to 20 % impervious area, evapotranspiration and groundwater account for most of the water loss.

atmosphere through evaporative processes. Under wetter conditions there is less storage, and more rainfall may become stream flow. However, the

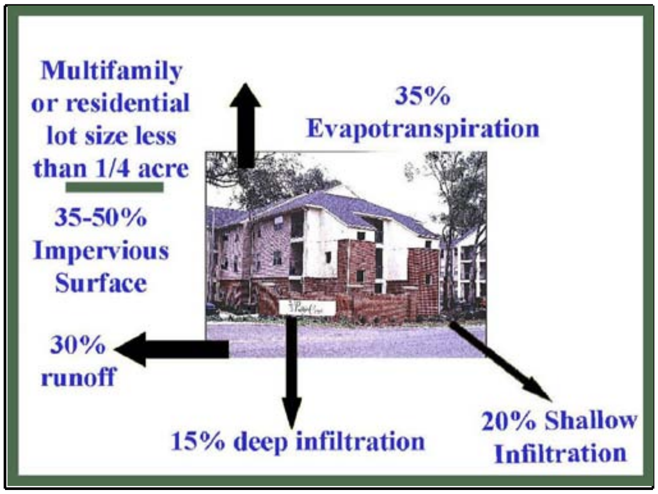

Figure 25. As the percent impervious area increases in higher density residential area outputs to evapotranspiration and groundwater are reduced and surface water runoff increases.

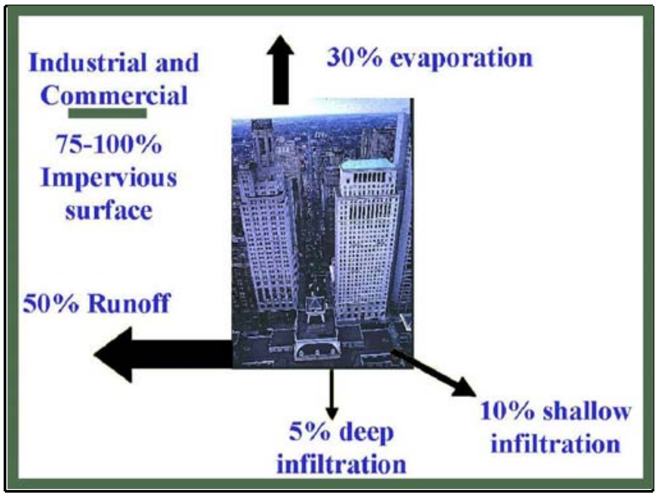

Figure 26. Surface water predominates the water cycle in commercial and industrial areas.

complex structure of the forest landscape creates a tenuous path that delays the water's release from the land. This delay will result in more gradual stream inputs and a gentler rise in stream flow (**Figure 27**).

In urban systems, the storage capacity of vegetation is reduced, soil compaction reduces soil storage space and impervious surfaces prevent rainfall from entering much of the soil altogether. Often flood plains, wetlands and other depressional storage sites are filled in, further reducing storage (**Figure 28**). As a result, more water reaches the stream in a shorter period of time.

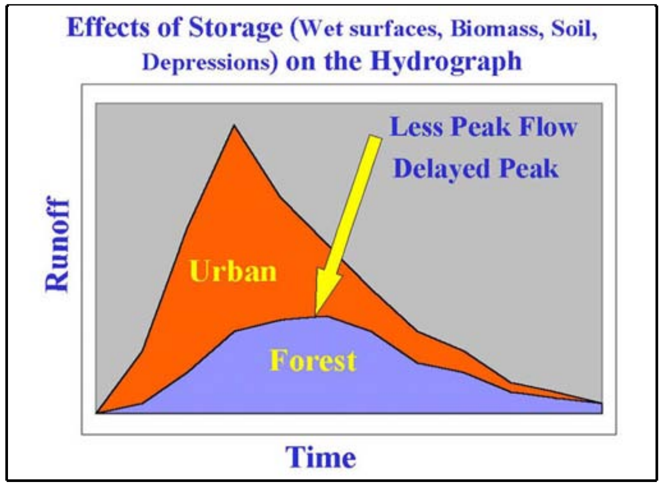

Figure 27. Storage of precipitation, in the forest canopy, litter, soil, and wetlands, is important for reducing flood hazards.

Figure 28. In urban areas flood plains and wetlands are often filled in reducing hydrological storage. In addition, these areas near the water are often prime real-estate. These factors combine to set up conditions for destructive flooding events.

Flooding and Aquatic Habitat Degradation

Flooding and erosion resulting from altered landscapes are serious concerns for human life and property. They also impact aquatic organisms and degrade their habitat. Impervious surfaces often form an effective conveyance system for rapid transport of runoff into urban water bodies such as streams. The quantity of stream flow is equal to the cross sectional area of the stream channel multiplied by the average stream velocity. To convey the additional runoff produced from disturbed landscapes, the cross sectional area of the stream and/or the stream velocity must increase. Streams increase their cross sectional area by rising up their banks, and many have natural flood plains for conveying runoff from extreme precipitation events. In the urban landscape, the flood plain may be filled in and built in, and flooding will occur (**Figure 29**).

Figure 29. Reduced storage, high runoff rates, and concentrated peak flows will often result in flooding in urban landscapes.

The energy of water increases exponentially as its velocity increases. High energy urban stormwater runoff scours stream bottoms, and erodes and undercuts their banks (**Figure 30**). Stream side vegetation and aquatic habitat are washed away and conditions are set for destructive landslides.

Figure 30. High energy urban stormwater runoff scours stream bottoms, erodes and undercuts their banks. This degrades aquatic habitat and creates dangerous landslide conditions.

Water Quality Problems

Non-Point Source Pollution

Increased runoff is not the only concern when the forested landscape is altered. Generally, forest ecosystems require little if any extraneous inputs of chemicals and disturbance is infrequent. On the other hand, to sustain agricultural and urban activities, nutrients, pesticides, herbicides, and energy producing chemicals are concentrated on the landscape. Urban impervious surfaces are associated with intensive land uses that generate pollution. They function as an efficient conveyance system for transporting pollutants directly to aquatic ecosystems, bypassing the pollutant removal functions of the soil (**Figure 31**).

Figure 31. Roads often function as an efficient system for transporting pollutants to aquatic ecosystems.

Soil disturbance is frequent in agricultural and urban watersheds. Construction in urban watersheds removes the protective vegetative cover and erosion can produce 10 to 100 times more sediment than natural areas (up to 50,000 ton/km^2/yr) (Novotny and Olem 1994) (**Figure 32**).

Figure 32. Pollution washed from altered landscapes is referred to as non-point source pollution. This aerial photo shows a sediment plume in a lake washed from upstream construction in an urban watershed. Photo by Hans Riekerk.

Stormwater generated from urbanized landscapes will wash pollutants into aquatic ecosystems, often causing severe dysfunction (**Figure 33**). This type of diffuse pollution is called non-point source pollution. In contrast, point source pollution originates from focused sources such as the effluent from waste water treatment plants (**Figure 34**).

Figure 33. Stormwater runoff will wash many pollutants off urban impervious surfaces into aquatic ecosystems.

Figure 34. Point source pollution often originates from waste water treatment plants and factories whose discharges are emitted at discrete, identifiable locations such as pipes and ditches.

Much progress has been made in cleaning up point source pollution, but treating non-point source pollution problems are generally more difficult and costly. Non-point source pollution is responsible for the majority of the impaired use of our nations waters. Of the total pollution load to our nations waters, non-point sources contribute 90% of nitrogen, 90% of the fecal coliform bacteria, 70% of the oxygen demand, 70% of the oil, 70% of the zinc, 66% of the phosphorus, 57 % of the lead, and 50% of the chromium (Thompson et al. 1989).

Measurement of Non-Point Source Pollution

Different land uses have been measured to export different amounts of substances (**Figure 35**). Activities that increase runoff (such as soil compaction and paving), and activities that expose pollutants to washing off the land (such as over fertilization), will contribute to higher export rates. The exports are usually measured in kilograms leaving the land area (per hectare) for a year. These values are determined by measuring the quantity and quality of water leaving a known area of drainage basin.

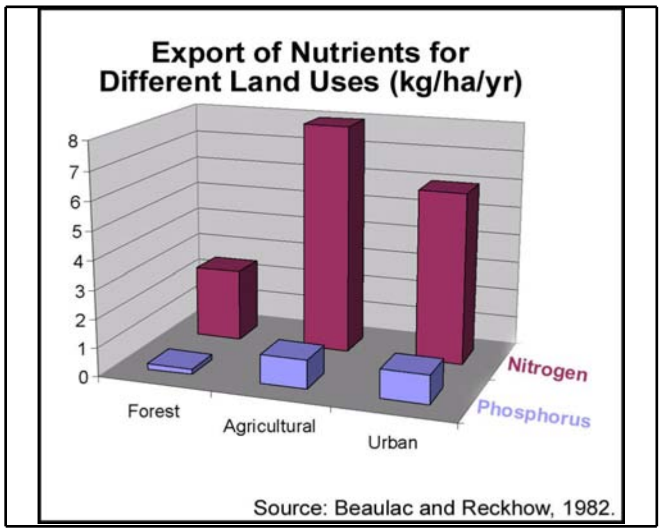

Figure 35. The forest landscape exports much less pollutants than more intensive land uses.

Typically, the first step in measuring the amount of water leaving a land area is to develop a stream height-discharge relationship (rating equation) for a stable section of the stream channel. On smaller streams the stream cross section is often modified into a more hydraulically uniform shape by a flume (**Figure 36**) or weir (**Figure 37**).

Discharge is the product of cross sectional area of the stream channel multiplied by the average stream velocity. Depth measurements are taken along the cross section to calculate the area and velocity measurements are taken at different depths at different locations to determine the average velocity.

Figure 36. Flumes are flow modification structures designed to accurately measure the amount of water passing through them. They are self cleaning and can work with relatively low head loss, but they are very expensive.

Figure 37. Weirs also measure flow, and they are less expensive than flumes. However, they dam up the water behind them which can cause many problems.

This process is repeated for a wide range of flow conditions and the data are used to construct an equation that will estimate stream flow from stream height. These equations have been determined under lab conditions for weirs and flumes, but real world conditions will modify their flow characteristics, so on-site calibration is good practice.

Flow proportional sampling is required for an accurate determination of the amount of substance (for example nitrogen or phosphorus) passing through the measurement station. This is accomplished by a microcomputer that reads the stream stage, calculates a flow from the rating equation, and activates an automated sampler to take a water sample when the specified volume of water has passed through the measurement section.

Here is a simple hypothetical export calculation. From a topographic map and an inspection of the watershed, the contributing area to a stream gaging station was determined to be 10 ha. The total water passing through the measurement channel for a year was 10,000 m^3. The average total nitrogen concentration of the volume weighted samples was 5,000 mg/m^3. The mass of nitrogen is calculated by multiplying the flow volume by the concentration. For this example:

10,000 m^3 x 5,000 mg/m^3 = 50,000,000 mg or 50 kg of nitrogen. Thus the land export was 50 kg/10 ha/yr or 5 kg/ha/yr.

From the perspective of the receiving water body, for example an urban lake, the land export is referred to as a load. The loading rates of the nutrients nitrogen and phosphorus into water bodies are one of the crucial factors that determine their biological and physical conditions. Proposed changes in land use in a lake's watershed can be used to predict the change in nutrient loads and the probable biological and physical impacts to the lake. Export and load information are used to guide watershed restoration efforts.

Eutrophication

Nutrient loading of aquatic ecosystems causes eutrophication or nutrient enrichment. Symptoms of eutrophication may include decreased water clarity, algal blooms, nuisance growth of macrophytes, unpleasant taste and order, dissolved oxygen depletion, fish kills, and altered species diversity and richness (**Figure 38**) (National Academy of Sciences 1969).

Nutrients in urban storm water runoff are the leading source of impairment of our nation's estuaries (EPA 1996). Developmental stresses pose a serious threat to the health of these productive and complex ecosystems (**Figure 39**). By the year 2010 almost half of the U.S. population will live near coastal waters, and the population of many coastal

Figure 38. Nutrients washed from high maintenance urban landscaping may stimulate algae growth and distort system ecology. In severe cases the resulting environmental changes will make the ecosystem uninhabitable to native species.

Figure 39. Increasing development in our coastal areas will result in more storm water runoff making an already serious problem worse.

Figure 40. Fertilizers in storm water runoff can destroy critical habitat for many of the species that provide us delicious seafood. Photo Philip by Greenspun, M.I.T.

cities is predicted to triple in the next 15 years (EPA 1996). Nutrients imported into estuarine watersheds to sustain high maintenance landscapes are washing into the estuaries and disrupting ecological relationships. For example nitrogen from fertilizers can stimulate dense growth of algae that will shade out sea grass. Sea grass is critical spawning and nursery habitat for much of our seafood (**Figure 40**).

Nutrients are essential for the existence of both terrestrial and aquatic ecosystems but the level of nutrients will play a major role in determining the character of the ecosystem. When urban storm water washes excess nutrients into an aquatic ecosystem, the nature of the ecosystem will change. This human influenced process of nutrient enrichment of aquatic ecosystems is called cultural eutrophication. In severe cases the resulting environmental changes may make the ecosystem uninhabitable to native species.

Most often the root of the problem is excessive inputs of the critical plant nutrients, nitrogen and phosphorus. When one or both of these nutrients limit plant growth, additional inputs will stimulate aquatic weed and algae growth. The aquatic plant community often provides the primary source of organic carbon energy and forms the foundation of the ecosystem. Changes in this critical component of the ecosystem will have system wide impacts.

Often the impacts are undesirable. Algal blooms will decrease water clarity. This lowers the recreational and aesthetic value of the water body. If the water body is an important drinking water supply, algal blooms may impart a bad taste and odor to the water and clog treatment systems. In addition, dense algal blooms will shade out submerged aquatic plants. These aquatic plants are important breeding and nursery grounds for many sport and food fish. Conditions in highly nutrient rich water bodies favor filter and bottom feeding fish. These will multiply to the detriment of many other species and reduce the species diversity of the ecosystem. Aquatic ecosystems, especially shallow ones and those with low flushing rates, tend to keep and recycle the nutrients they obtain. Therefore, it is difficult and expensive to restore many impacted water bodies.

Oxygen

Urban storm water can reduce dissolved oxygen levels in aquatic ecosystems by reducing the dissolved oxygen holding capacity, by stimulating algae respiration with nutrients, and by stimulating microbial respiration with organic carbon sources (**Figure 41**).

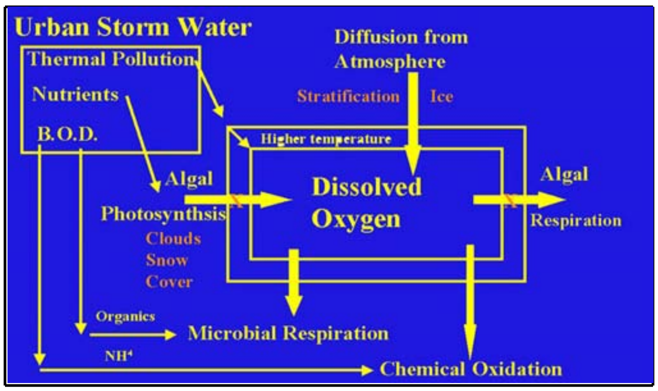

Figure 41. Urban storm water can reduce dissolved oxygen levels in aquatic ecosystems by reducing the dissolved oxygen holding capacity, by stimulating algae respiration with nutrients, and by stimulating microbial respiration with organic carbon sources.

The oxygen holding capacity of water is a function of the water temperature. Specifically, colder water can contain more oxygen than warmer water. For example, water at 3 degrees C can contain 13 mg/l of dissolved oxygen while water at 35 degrees C will only hold 7 mg/l of dissolved oxygen. In an urban system, water from heated buildings, hot streets and roofs can raise the temperature of water bodies. Removal of trees that shade urban streams will also raise water temperatures. To compound the problem, elevated water temperatures will often increase the metabolic rate of cold blooded aquatic organisms, thus increasing their need for oxygen.

Nutrients, especially phosphorus and nitrogen, can stimulate increases in algae populations. When there is adequate sunlight and inorganic carbon, algae will produce large amounts of oxygen during photosynthesis. In fact, oxygen levels may actually climb above saturated levels in a system with high densities of algae during bright sunlight. However, at night or during extended cloudy periods, the algae will remove large amounts of oxygen from the water for their metabolic needs. Under extreme conditions, the algae can deplete the dissolved oxygen supply and fish kills will occur (**Figure 42**). This is most common under conditions where diffusion of oxygen from the atmosphere into the water is impaired, such as when the water is covered with ice or when the water column is prevented from mixing due to thermal stratification.

Figure 42. Under certain conditions, high levels of algae can deplete oxygen in water resulting in fish kills.

Algae and fish are not the only competitors for dissolved oxygen in aquatic ecosystems. Aquatic bacteria will feed on organic materials washed into water bodies. They convert oxygen into carbon dioxide in a biochemical process similar to our metabolism of food. When large amounts of organic materials are washed into a water body, bacterial growth and metabolism can be stimulated to the point that their consumption of oxygen will exceed system inputs. For many bacteria, when the oxygen is used up they can make use of alternate oxidants such as nitrate, and oxidized forms of manganese, iron, and sulfur. Unfortunately, many higher level aquatic organisms are dependent on dissolved oxygen, and when it is depleted they will die. Also certain chemicals, for example ammonium, will combine with dissolved oxygen and make it unavailable. The oxygen depleting properties of pollution are often measured as Biochemical Oxygen Demand or BOD. BOD is determined by measuring the oxygen loss of a water sample in a sealed bottle kept in the dark for five days.

Aquatic Habitat Alteration

Even if urbanization had no impact on water quality and quantity, there are often other severe impacts on aquatic life. In many urban areas the physical structure of aquatic habitats are modified for municipal functions to the detriment of biological functions. Trees removed from stream banks expose the stream to less moderated temperature conditions (higher in the summer, colder in the winter) (**Figure 43**).

Figure 43. In a forested stream, trees moderate water temperatures, support food webs, provide stream habitat and stabilize the banks.

Removing trees also removes an important source of fuel for detrital food webs. During urbanization, stream channels are straightened, large woody debris removed, and even the bottom substrate may be covered with pavement (**Figure 44**). These types of modifications remove critical stream habitat and sterilize the aquatic ecosystem's ability to support aquatic life. In extreme cases, urban streams are "blacked out" by enclosing them in pipes and covering them up.

Restoration

Overview

Restoring the urban forest can help to restore the hydrological cycle and improve the functioning of aquatic ecosystems. Significantly increasing tree canopy coverage will reduce stormwater runoff and

Figure 44. In many urban streams the forest has been removed and the aquatic ecosystems that they supported can not exist. Photo by Judy Okay

peak flow, and increase the water storage capacity. Urban forests are particularly critical near creeks, streams, and rivers, where they act as riparian forest buffers (**Figure 45**).

Forested riparian areas stabilize banks, uptake nutrients, and provide shade, habitat, and food for aquatic ecosystems. The magnitude of chemicals used to support high maintenance urban landscapes is overwhelming our efforts to treat polluted runoff. Programs that encourage landscaping with native forest trees can help because these trees will often require less inputs of chemicals and water. Urbanization alters and fragments aquatic ecosystems, sometimes so severely that they cease to function. More environmentally orientated planning can prevent the problem, and reforestation is often the key element in restoring the system.

Increasing Tree Coverage

Increasing or preserving tree coverage in an urban watershed can have water quantity and quality benefits. However, the scale of the restoration effort needs to match the scale of the problem. A small urban park, even one with a big tree will do little to restore the water cycle to a big city (**Figure 46**). Larger scale efforts are usually needed. Storm water modeling with CITYgreen© software (American Forests 1996) demonstrates the scale of coverage needed with its expected water quantity benefits (**Figure 47**).

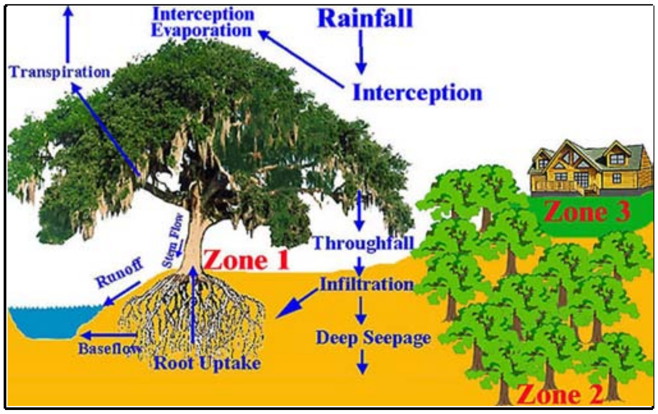

Figure 45. Urban forests are particularity critical near creeks, streams, and rivers, where they act as riparian forest buffers. Forested riparian areas stabilize banks, uptake nutrients, and provide shade, habitat, and food for aquatic ecosystems.

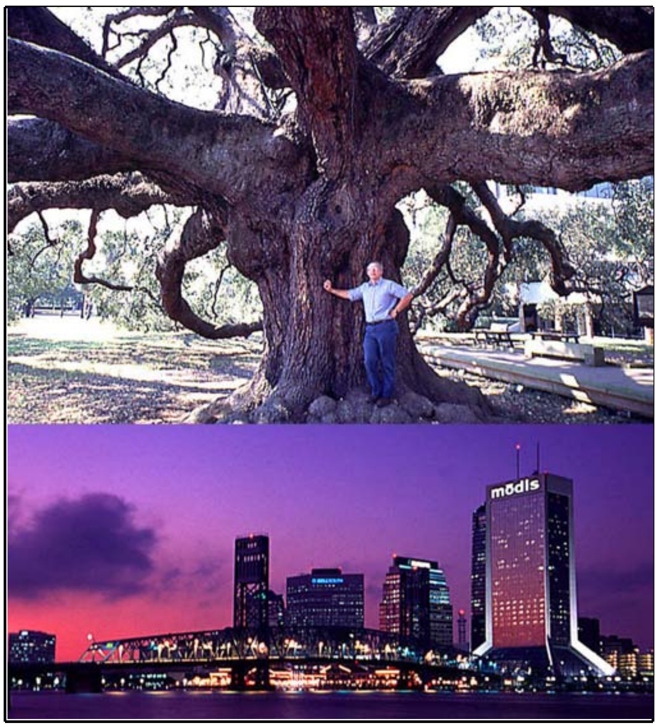

Figure 46. Increasing or preserving tree coverage in an urban watershed can have water quantity and quality benefits. However, the scale of the restoration effort needs to match the scale of the problem.

Figure 47. Computer models such as CITYgreen© software (American Forests 1996) can demonstrate the value of the ecological services that trees provide. Illustrations from CITYgreen

Their model predicts increasing tree coverage on an example residential development will reduce storm water runoff and save money. With a 30% tree cover the model predicts a 5 % decrease in runoff volume, a 9 % decrease in peak flow and a 15 acre feet/square mile increase in water storage. Potential storm water storage treatment savings were estimated to be about $120,000/square mile. When the tree canopy coverage is increased to 70%, the model predicts a 17 % decrease in runoff volume, a 27 % decrease in peak flow and a 48 acre feet/square mile increase in storage. Potential storm water storage treatment savings were estimated to be about $390,000/square mile.

There are some issues that must be considered when evaluating the water quantity and quality benefits of tree cover. The first is the timing of benefits. Storm water engineers must design new developments so that they meet hydrological specifications for the first storm, not how the development will respond many years later when the canopy has grown to significant coverage. The development must also continue to meet hydrological specifications in winter when deciduous trees have lost their cover. Storm water engineers also know that canopy storage will be quickly filled by the large storms that cause flooding events. However, canopy storage can reduce the runoff of the frequent smaller storms, and thus has the potential to reduce pollutant loading to aquatic ecosystems.

Riparian Forest Buffers

Riparian forest buffers have the potential to reduce the amount of runoff and pollutants washing into riparian ecosystems. They also stabilize stream banks and moderate water temperatures. Preserving or restoring forested riparian buffers also preserves some of their ecological functions such as providing terrestrial and aquatic habitats, and supplying the source for detrital food webs. Many forested riparian areas also contain flood plains and wetlands that provide additional water quantity and quality benefits. Forested riparian buffers are aesthetically beautiful areas and can provide some forms of low impact recreation.

There are three functional zones comprising a well designed forested riparian buffer (**Figure 48**). Zone 3 is a flat grassy area about 10m wide at the urban-buffer interface (**Figure 49**). Its major function is to convert channelized urban flow into sheet flow and slow water velocity to less than 0.3 m/sec. Zone 3 performs some settling, filtering, and infiltration.

Zone 2 is a vigorously growing forest with a width of 15 to 150m (**Figure 50**). The required width depends on the load amount and the buffer slope, soils, vegetation and level of allowed disturbance. The major function of Zone 2 is to provide the environment and contact time (at least 9 minutes) for pollutant removal through sedimentation, filtration,

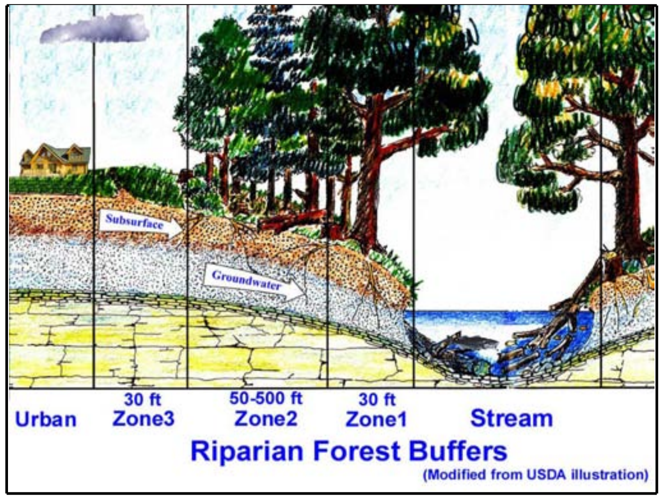

Figure 48. There are three functional zones comprising a well designed forested riparian buffer. The zones are designed to spread out and infiltrate storm water, assimilate nutrients, and preserve the aquatic habitat.

Figure 49. Zone 3 is a flat grassy area about 10m wide at the urban/buffer interface. Its major function is to convert channelized urban flow into sheet flow and slow water velocity to less than 0.3 m/sec. Zone 3 performs some settling, filtering, and infiltration. Photos are of the "Difficult Run" urban riparian project, courtesy of Judy Okay, Virginia Department of Forestry.

cation exchange, and plant uptake. In forest and agricultural situations, selective removal of trees from Zone 2 is recommended. Tree removal removes nutrients and keeps the forest in a vigorous growth stage.

Zone 1 is the mature forest at the land-water interface and it controls the physical, chemical, and trophic status of the stream (**Figure 51**). Zone 1 should be at least 10m wide. The major water quality functions of Zone 1 are to stabilize the stream bank and to shade and stabilize water temperatures. Anoxic (without oxygen) organic soils in this zone

Figure 50. This photo was taken down slope from Figure 49 and shows the establishment of a zone 2 managed forest. The left side is at planting and the right side is three years after planting. Photo by Judy Okay, Virginia Department of Forestry.

can remove nitrogen by the process of denitrification, but uptake of other nutrients may be balanced by litter fall. Zone 1 also provides detritus for the aquatic food web and large woody debris for critical aquatic habitat.

Figure 51. Zone 1 is the mature forest at the land/water interface. It most directly controls the physical, chemical, and trophic status of the stream. Photo by Judy Okay, Virginia Department of Forestry.

Forested riparian buffers have their limits (Herson-Jones et al. 1995). Pollutant removal effectiveness is poor when the slopes are greater than 10% and with soils that have infiltration rates less than 0.64 cm/hour. Disturbance (many recreational activities) will greatly reduce their effectiveness. The scale of the buffer needs to match the scale of the source area. Poor performance can be expected with high rates of channelized flow from large impervious areas. Upstream Best Management Practices (BMPs) may be required to scale the load to match the buffer's capacity. Even under good conditions total suspended solid removal is estimated to be 50%.

Source Control

The United States has 30 million acres of lawn. On these lawns over 100 million tons of fertilizer and 80 million pounds of pesticides are applied annually (Borman et al. 1993) (**Figure 52**). This rate of application is ten times the rate chemicals are used per acre on US farms. The importation and concentration of chemicals in urban watersheds saturates and overwhelms our efforts to treat polluted non-point source runoff. In an effort to reduce harmful impacts to our aquatic ecosystems, many new programs are focused on reducing the sources of non-point pollution. These programs encourage landscaping that uses and exports less water and chemicals. Some examples of these types of programs are BayScaping in the Chesapeake Bay area (http://www.acb-online.org/bayscapes.htm), Nature Scaping in the Portland, Oregon area (http://www.enviro.ci.portland.or.us/), Florida Yards and Neighbors (http://207.0.223.151/extension_service/toc.htm), and EPA's Green Communities (http://www.epa.gov/greenacres/).

Figure 52. Over 100 million tons of fertilizer and 80 million pounds of pesticides are applied annually to U.S. lawns.

The general strategy of these programs is to encourage landscaping that uses less pollutants and produces less runoff. Native vegetation and ground covers are recommended because they generally require less inputs of water and chemicals (**Figure 53**). In addition, exotic landscaping vegetation can escape and cause hydrological and other ecosystem problems (**Figures 54 and 55**) (See **Chapter 9-Invasive Plants**).

Figure 53. This is an example of a yard that uses native trees and low maintenance ground cover. Native trees are often adapted to local conditions and require less supplemental inputs of water, fertilizer, and pesticides. In this example the trees also provide pine needles for an attractive and low maintenance ground cover.

Figure 54. Exotic landscape plants can require more water and chemicals and contribute to urban water pollution. In addition, they can invade and damage natural ecosystems. The Salt Cedar (Tamarix sp.) shown on the right in the above photo (Zion National Park) has invaded much of the Southwest altering hydrology and displacing native plants.

The reduction of impervious surfaces by using gravel driveways (**Figure 56**) and on-site retention landscaping (**Figure 57**) are examples of practices that will reduce the export of water and pollutants.

Aquatic Habitat Improvement

The impact of urbanization on aquatic ecosystems goes beyond the damage caused by increased runoff and poor water quality. Frequently, urbanization degrades the physical aquatic habitat by altering its morphology, changing or even paving the bottom substrate, and altering light inputs. Intakes for domestic water supplies and dams will drastically disrupt stream continuity. Aquatic systems are parts of larger ecosystems. Poor urban planning can break links to other systems that provide essential functions to aquatic systems. For example, filling in wetlands and flood plains can eliminate breeding and nursery habitat, and removing upland forests eliminates an important source of energy for detrital food webs. Conversely, forested aquatic ecosystems provide essential elements for upland ecosystems and

Figure 55. Salt Cedar has roots that can reach depths of 30 meters and individual trees can use 800 liters of water per day. Large stands of Salt Cedar can lower the ground water below the level that native vegetation can reach. They also adsorb salts from deeper soil layers and ground water and transport it to their leaves (see above photo). This salt increases the soil salinity above levels that many native plants can tolerate.

Figure 56. Reducing the impervious surfaces at a home by having an attractive gravel driveway instead of an impervious paved one, will significantly reduce the amount of water and pollutants that runoff property. The cumulative impact of many citizens reducing their pollutant load can make the restoration of aquatic ecosystems possible.

Figure 57. Large stormwater treatment facilities often have poor pollutant reduction performance. A better solution is to keep stormwater on site and allow it to be filtered by the soil. This picture shows a "rain garden" where runoff from the roof and driveway will be retained and pollutants filtered out by the soil. Photo by Judy Okay, Virginia Department of Forestry.

they often function as crucial corridors necessary for the survival of many species.

Figure 58 shows an urbanized stream that would not function with even the best water quality. Stream morphology has been drastically altered, the bottom substrate paved over, and stream-side communities have been eliminated.

Figure 58. Even with the best of water quality this urbanized stream will be a non-functioning ecosystem. The stream morphology has been altered, the bottom substrate paved over, and stream communities have been eliminated.

In **Figure 59** important stream habitat has been restored by importing large woody debris directly into the stream. Large woody debris provides important nesting, cover and substrate for aquatic life. Stream vegetation has been replanted to provide shade for cooler and more stabilized water temperatures and to provide detritus for food webs.

Figure 59. In this stream, important habitat has been restored by importing large woody debris directly into the stream. Large woody debris provides important nesting, cover, and substrate for aquatic life. Streamside vegetation has been replanted to provide shade for cooler and more stabilized water temperatures, and to provide detritus for food webs.

Engineering is necessary for a city to function properly. Many cities are discovering that with a little extra care, engineering functions can be combined with ecological principles to provide functioning aquatic habitats. For example, retention ponds are used in urban areas to provide storage for increased runoff and to settle out particulate pollutants. Although the pond in **Figure 60** may perform some of those functions, it provides little if any aquatic habitat. On the other hand, the detention pond in **Figure 61** incorporated wetlands and forests to provide ecological functions as well as engineered treatment of urban storm water.

Figure 60. Retention ponds are used in urban areas to provide storage for increased runoff and to settle out particulate pollutants. Although this pond may perform some of those functions, it provides little if any aquatic ecosystem habitat.

Urban parks also provide an opportunity for aquatic habitat restoration or preservation. Often

Figure 61. On the other hand this pond was designed to be a functioning ecosystem.

urban parks contain a significant amount of impervious area and high maintenance vegetation that can cause degradation of associated aquatic habitat (**Figure 62**). With careful design forested urban parks can provide recreational opportunities as well as a functional aquatic habitat (**Figure 63**) .

Figure 62. Figures 62 and 63 are parks in Mt. Dora, Florida. Although this traditional urban park provides needed recreation activities, the natural habitat has been paved or grassed, and the water features only provide limited aesthetic value.

Figure 63. Nearby Palm Island Park, also at Mt. Dora, Florida, has been left as an intact ecosystem. A board walk allows people to explore the upland/wetland/aquatic wonders with little negative impact to the hydrological cycle and the ecosystems dependent on it.

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Chapter 7: Site Assessment and Soil Improvement[1]

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Abstract

The first step in any restoration project is to gain an appreciation of the site. The site needs to be defined, delineated, inventoried, and assessed for the restoration goals and objectives to be successfully accomplished. A key component in assessing sites for ecological restoration is developing, both for your own reference and others, a story of site development or a site picture. This is called determining the site context. Each site should be assessed for its ecological and societal context. An ecological management unit (EMU), the smallest treatable unit -- smallest restorable unit -- must be the focus for restoration management activities. Through the assessment process, the primary concern is the ecological restoration of the EMU. An initial site assessment should include inventory of resources, space, size, diversity, temporal changes, disturbances, stress, natural cycles, organic matter, management, form, and development of a final action-list. However, it is just as important to the success of any restoration project to include the stake holders, decision-makers and social systems in all phases of the project. Assessment is a part of the planning and management process, not a disjunct and separate piece. Remember that every site and situation will be different.

Another decisive step to be considered in a restoration project is soil health evaluation and improvement. Soil health management is essential for (and a part of) healthy and sustainable ecological systems. A number of soil features become degraded or destroyed over time in highly stressed environments. An average urban soil usually has few essential elements, poor drainage, erosion, soil compaction, a heavy texture, little organic matter, and a low diversity and small number of beneficial organisms. Restoration activities need to be prescribed carefully in trophic level order to assure success -- in other words, truly start at the bottom and restore upward. The soil is the foundation upon which we restore ecosystem functions and structures. The soil attributes to be restored successfully include texture, structure, bulk density, water, aeration, element holding capacity, essential elements, organic matter, contamination, and trophic enrichment.

Introduction

The urban forest is the tie which binds humans to life sustaining ecological systems. Beyond the urban forest are the rocky and barren hardscapes of paved and roofed deserts. We have interspersed these buildings and roads with a few parks and road-side trees which are often maintained with too many resources and much energy. It is time to take back a

1. This is Chapter 7 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kampf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu
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heritage of forest and field, and live more gently among the trees. Restoration of these altered and often exhausted ecological systems will not be quick or easy. Yet the results and rewards are important to the future health of our cities and communities.

A restoration process includes an understanding of basic rules and perceptions regarding a community's ecological resources and how to plan and make decisions which impact these resources. Other chapters in this CD-ROM review the ecological principles and processes as well as the development of a management plan. However, one of the first steps in the restoration process is assessing the site's resources. The soil is probably one of the most damaged parts of the ecosystem in the urban forest, therefore, restoring soil health of a site is a critical step to successful restoration. The first part of this chapter, **Site Assessment**, is concerned with the steps involved in this assessment. The second part of this chapter, **Soil Improvement**, presents the principles of soil health and methods for its restoration.

Site Assessment

Every surface and space in the urban forest is a resource containing site. Most sites are severely lacking in many resources, either through a lack of quantity or quality. Many sites have experienced disturbances such as hydrological alterations, invasion of exotic species, compaction from recreational activities and fragmentation. In restoring these sites, urban foresters seek to restore resources and processes. The first step in any restoration project is to gain an appreciation of the site. The site needs to be defined, delineated, inventoried, and assessed even before the goals and objectives for restoration are developed. Having a clear picture of the site is essential to describe and defend restoration options and plans to peers, stake-holders, decision-makers, site workers, and resource owners/controllers **(Figure 1)**.

Site components include:

- life resources
- life connections,

Figure 1.1 Photo by Mary Duryea

Figure 1.2 Photo by Larry Korhnak

Figure 1. Having a clear picture of the site is essential to describe and defend restoration options and plans to peers, stake-holders, decision-makers, site workers, and resource owners/controllers.

- biological units,
- climate,
- topography,
- geology, and
- past history (disturbances, stresses, and mechanical damage).

What were the past historic ecosystems like on the site? Using maps, interviews, GIS and other resources, the historic ecosystems on the site need to be described with their flora and fauna and natural disturbances. Then the current ecosystems need to be described; what is there now and why? And finally how does this site fit into the landscape and the master plan for the region? Does it have regional significance, ecological significance, and/or social significance **(Figure 2)**?

Figure 2.1 Photo by Mary Duryea

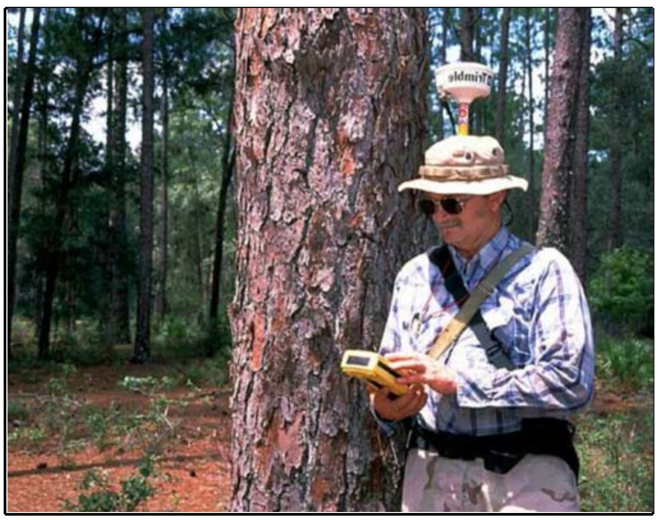

Figure 2.2 Photo by Larry Korhnak

Figure 2. Maps, GIS and other resources can be useful tools for assessing past and current site conditions in a restoration project.

Site Context

A key component in assessing sites for ecological restoration is developing, both for your own reference and others, a story of site development or a site picture. This is called determining the site context. How did the site arrive at its current condition? Included in this assessment is determining what it was like in the past. And finally an evaluation of the possibilities for restoration. Developing a full description of the site, its attributes and processes, is critical for identifying the possibilities and constraints to restoration. Practically speaking, a restoration site might be a perfect biological or ecological candidate, but socially unacceptable for restoration. Each site should be assessed for its ecological and societal context.

The ecological story of a site must be determined in any assessment process. The ecological context of a site includes, but is not limited to:

- **Anthropogenic changes** to the ecosystems on the site.
- **Site history** (biological, physical, chemical), including presence of toxins, hydrological alterations, substrate changes such as impervious layers, soil interfaces, and past abuse.
- **Soils**, including fill, compaction, interface problems, depth, drainage, aeration, contamination, and flooding regimes.
- **Topography/slope**, including cold pockets, soil depth, water relations, and wind impacts.
- **Energy balance**, including incoming radiation and its distribution/dissipation, urban heat island effects, wind and direction, light quality and quantity, and night lighting.
- **Water balance**, including relative humidity, precipitation, evaporation, irrigation, and site water demand.
- **Biological components** (animals, plants, microbes, etc.) and their interactions, including pests, competition, allelopathy, disturbance, succession, and mechanical damage.
- **Genetics**, including cultivars, natives, exotics, and genetic interactions with the environment (response to stress, strain, abuse, and pests).
- **Space**, including space for growth, expansion, crowding, stagnation, and space to structurally support life-forms.
- **Climate**, including precipitation, temperature, wind, pollution deposition, wind/pest interactions, variability (winter to summer or

day to night), drought concerns in summer and winter, lag effect (e.g., time delay) of symptom expression, and problems of scale.

Climate is a critical feature of the site to understand. In general, urban climates (local to meso-climate scales) are significantly different than average climate data collected at regional weather stations. Urban climates, when compared to national/regional averages, have: 25% lower wind speeds from obstructions; 12% greater calm days (air mass stagnation); 1.5 degrees F greater annual temperature; 2.7 degrees F greater minimum winter temperature; 7% greater precipitation events (more precipitation events but less per event); 5% lower relative humidity (geometrically increased site water demands); 7% greater cloudiness; 17% less incoming radiation (clouds and pollution); and, 10 times more common pollutants (Craul 1992). For further information check Craul's urban soils books listed in the **Suggested Readings** section.

In general, the urban climate is drier and hotter, with less usable water, more pests, and more pollution than normal. All these climate factors combined lead to greatly increased stress on ecosystems.

The societal context or story of a site must be determined in any assessment process. The societal context of a site includes, but is not limited to:

- **Anthropogenic changes of management**, such as changes in ownership from private to public with different management goals, objectives and implementation.

- **Historical significance**, including archaeological importance as well as more recent cultural significance.

- **Social significance**, including public / private ownership, emotional attachment, and pride or remorse of ownership.

- **Aesthetics**, considering the interaction between ecology and aesthetics. In the past we have accepted great architectural and aesthetic trade-offs disregarding local site ecology and biological functions.

- **Political significance**, including delineating who takes credit, pays bills, and is included.

- **Economics**, including analysis of values produced versus costs.

- **Site circulation and access**, including movement around and across the site, how access is allowed, and security issues.

- **Liability and environmental vandalism**, including safety, noise pollution, traffic control, and asset loss.

- **Regulatory environment**, including zoning, endangered species, wetlands, and erosion.

- **Cultural practices and public awareness** including herbicides, tree removals, topping, and perceptions of existing programs.

Once a site can be viewed in its ecological and societal context, an ecological restoration process can be fitted within the identified constraints to maximize ecological and biological values in a sustainable manner. An urban forester should list site constraints in a carefully prepared management plan by prioritized order from the most limiting to least limiting. For each constraint identified in the management plan, plans for dealing with the constraint need to be included.

Management Units

In our assessment system for identifying and prioritizing process and site constraints, a management unit must be identified and delineated. Without mapable management units, discrete boundaries for treatments, and accurate planning edges, management confusion can exist as well as administrative accountability problems. What is the space and its dimensions for your restoration plan? What is the ecological management unit?

An ecological management unit (EMU), the smallest treatable unit -- smallest restorable unit -- must be the focus for restoration management activities. An EMU is a human-defined, limited area which can include one or more ecosystems. Site assessment requires identification, delineation, and declaration of an ecological management unit

(EMU). In natural resource management, a written management plan can not be fulfilled without understanding what is being managed, for what purpose, and its size, shape, or form. From an ecological restoration standpoint, the criteria we must use to apply, maintain and evaluate our actions depend upon our abilities to delineate an ecological management unit.

The necessity for setting boundaries and management limits is self-evident for any restoration manager. Unfortunately, many academic concepts of ecosystems fail to provide walls, limits or boundaries. The landscape includes many interconnected smaller ecosystems of various spacial scales, overlapping with each other and the restoration site. The conceptual problems with these ideas of ecosystems is which one you are trying to restore? What sub-division? What portion? How do you declare victory, evaluate actions, or prepare budgets if the spacial extent of the ecological restoration area is nebulous? Discrete boundaries for the restoration project are critical to planning, implementing and the success of the project.

Politics and Science

Through the assessment process, the primary concern has been the ecological restoration of the EMU. However, it is just as important to the success of any restoration project to include the stake-holders, decision-makers and surrounding social systems in all phases of the project **(Figure 3)**. It is also critical to the project that science and politics remain separated. An ecological restoration project needs to compartmentalize and keep separate ecological science from social, cultural and economic-based decision making. Physical, chemical, and structural facts need to be clearly separated from human feelings, needs and value judgements. Ecology is apolitical in the natural world. Politicizing ecology can destroy objectivity in decision-making and allow mis-use or selective use of scientific information. Professional respect and accountability can be eroded quickly if you lose sight of the science and political separation.

Figure 3.1 Photo by Rob Buffler

Figure 3.2 Photo by Mary Duryea

Figure 3. It is important to the success of any restoration project to include stake-holders, decision-makers and surrounding social systems in all phases of a project.

The Assessment Process

There are many tools and methodologies for assessing damaged and exhausted EMUs to determine whether they are viable candidates for restoration, and to identify the magnitude of efforts required for a restoration project. Presented here is a basic checklist for an assessment process. It is assumed you have already set goals and objectives, and identified a number of constraints (see **Chapter 5 - Developing a Management Plan**). Assessment is a part of the planning and management process, not a disjunct and separate piece. Remember, every site and situation will be different. You are encouraged to develop assessment systems which best serve your ecological and political situations.

The following assessment process has been used successfully for urban and community forest sites, land development interface sites, and for damaged or abused environmental management sites in Europe and North America. This assessment process is presented as a guide to collecting information for planning restoration activities in an ecological management unit. The following information must be determined:

1. Quantify

The first step is to define and delineate (on maps and on the ground) the EMU and its context in the landscape. This step is an inventory of resources, processes and rates of change, and a classification or analysis of what exists (quantify and graphically classify).

2. Size

Assess the EMU and determine if it is large enough to sustain the values and outputs expected. This step is an assessment of scale problems including biodiversity, genetic variability, reproductive spheres, and colonization potential.

3. Space

Assess the spacial relationships between the EMU and other ecosystems in the landscape for current and future connectivity, fragmentation, and ecological integrity. Record quality and quantity of information on ecological gaps, fragments, corridors, and ecotones.

4. Diversity

Assess the variability, density, and diversity of species and their habitat. Included should be information on natives, exotics, and habitat composition for key species.

5. Time

Temporal changes across a site will be many. Assess the pattern and timing of when individuals and species are expected to age and die, and successional patterns for the site (See **Chapter 4 - Plant Succession and Disturbances**). Considerations are life-spans of key and dominant species, current age classes and structures, and how life-forms are removed or enter a site.

6. Disturbance

Assess historical and present disturbance regimes including the type, intensity, and frequency (see **Chapter 4 - Plant Succession and Disturbances**).

7. Stress

Assess historic and present stress components of the site. Stress includes anthropogenic problems, competition, allelopathy, pests including invasive species, and environmental constraints to survival and growth (see **Chapter 9 - Invasive Species**).

8. Natural Cycles

Assess the effort and consequences of activities to recover historic material and energy cycling processes. Assess how to restore the natural cycles such as nutrient cycling to encourage a more natural support (lower maintenance) of site functions and move away from human-centered support. Take special care in observing energy flow, the hydrology on the site, and nutrient status and processing (see **Chapters 2 and 6 - Ecological Processes** and **Restoring the Hydrologic Cycle**)

9. Organic Matter

The presence of organic matter on the site is critical to the nutrient cycle and the health of the site. Special concern should be targeted at large woody debris and soil organic matter.

10. Management Resolve

Assess on-site and within the management system the appreciation of ecological realities (sometimes natural ecosystems may appear messy, unkept, or chaotic compared to sites with single species or grassy parks) and acceptance of change.

11. Action Check-List

The principle means of restoring the EMU can include:

- Re-instituting successional processes.
- Re-instating disturbance regimes.
- Enriching the genetic resources (living things), including:
  - Adding and/or replacing "key" organisms (trees, vertebrates, fungi, arthropods, worms, etc.)
  - Modifying native systems to include more trophic levels.
- Improving site resources, including:
  - Increasing organic matter (woody biomass, soil and litter).
  - Improving soil exchange capacity (element cycling and holding).
  - Improving soil health (pore space and structure).
  - Increasing water availability (cycling, use, flow,
  - Modifying or enriching nitrogen cycling.
  - Altering site light resources (light and shade management).
- Minimizing stress on key species.
  - Contain or eliminate heavy metals.
  - Control pollution.
  - Control heat.
  - Control exotics.
  - Physically protect site from mechanical and chemical damage.
  - Control oxygen availability and water drainage trade-offs in soil.

Soil Improvement

Introduction

Soil health management is a very critical portion of a renovation process to sustain ecological functions. Soils are the primary contact point between living organisms and are a biologically, chemically, and physically active portion of the environment. Soils are the ecological interface for materials and energy exchange, and a matrix that supports, houses, and stores essential elements and living things. Mineral, dead, near-dead, and living things are all held in a thin layer of ecological volume called soil. Conceptually, a soil for restoration can be considered a matrix of living things rather than an engineering material. Soil is the basis for urban ecosystem productivity.

The resources soil provide to support ecosystem productivity include:

- growth materials (15 of 18 essential elements plus water from the soil,)
- transport and storage of growth materials,
- buffer change and variability,
- physical and chemical protection,
- structural growth matrix, and
- primary energy exchange surface.

Good soil management is essential for (and a part of) healthy and sustainable ecological systems. A number of soil features become degraded, destroyed or exhausted over time in highly stressed environments. Soil assessments concentrate on those chemical, physical, and biological features of soil resources which can limit colonization, survival, and growth of living things. Restoration activities need to be prescribed carefully in trophic level order to assure success--in other words, truly start at the bottom and restore upward. The soil is the foundation upon which we restore ecosystem functions and structures **(Figure 4)**.

Figure 4. Soils form the basis for urban forest ecosystem productivity. Photo by Larry Korhnak

Ideal Soils

Ideally a soil is composed of materials and space in roughly equal proportions. A "perfect soil" for ecological development is considered to have 45% mineral materials and 5% organic materials (living and dead), and 50% pore space divided equally between large air-filled pores and small water-filled pores. A perfect soil has horizontal layering developed through an assortment of genesis processes. These layers are called "horizons" **(Figure 5).** Horizonation requires time to develop from the last major disturbance on the site. As such, most urban soils have little horizonation, but do develop these characteristics if allowed to remain relatively undisturbed.

An ideal soil profile (from the surface downward) would have four horisons as seen in **(Table 1).** Most urban soils deviate wildly from ideal soil features, but by knowing theoretical limits, restoration changes can be judged for value.

Urban Soil Features

Urban soils have many unique features. Urban soil features which are most limiting to a restoration process are listed below:

Figure 5. Ideal soils have horizons or zones where different process occur such as organic matter breakdown, weathering, leaching, and material accumulation. Photo by Larry Korhnak

Table 1. An ideal soil profile.

Horizons	Description
A horizon	surface soil with maximum organic matter accumulation, good porosity, many living organisms, most active tree roots, and represents a zone leached by precipitation and soil weathering factors
B horizon	"subsoil" where clays accumulate
C horizon	oxidized parent material
D horizon	unoxidized parent material

- great vertical and horizontal variation,
- compacted structure,

- modified infiltration, percolation and water holding capacity,
- crusting or water repellent surface,
- pH changes (usually increasing pH),
- restricted aeration and drainage,
- impotent or disjunct element cycling,
- modified ecology of soil organism activities (no organic material),
- toxins and contaminants,
- soil temperature changes, and
- reduced mineralization rates (from organic matter) and accelerated nitrification.

An average urban soil is disturbed and highly variable caused by digging, cutting, filling, trenching and scraping **(Figure 6)**. The average urban soil has few essential elements, poor drainage, and a compacted, heavy texture. Within the soil are many blatant, sharp interfaces between layers and parts. The average urban soil has little organic matter and surface litter with a low diversity and small number of beneficial organisms. Erosion remains a terrible problem.

Figure 6. Urban soils are often altered by digging, cutting, trenching, scraping and, as shown here, by filling. Photo by Larry Korhnak

The Manageable *10*

The soil attributes that affect and control soil resources, and present the most potential for ecological restoration success are:

1. texture
2. structure
3. bulk density
4. water
5. aeration
6. element holding capacity
7. essential elements
8. organic matter
9. contamination
10. trophic enrichment

Each of these restoration attributes represent opportunities for a manager to be successful.

1. Soil Texture

Texture is the relative percentage of sand, silt, and clay-sized particles in the mineral portion of the soil. Most soils are a mixture of various particle sizes and distributions. Texture directly affects water and oxygen, and indirectly affects essential elements. The clay component of a soil dominates soil activity. As clay contents approach and exceed 20-25% in the soil particle mixture, the chemistry and limitations of the clays control soil attributes **(Figure 7)**.

Soil texture can be modified by amendments but it is not practical for large scale projects. For example, on an average house lot the top foot of soil weights 400 tons. To convert soil texture in this zone from a clay soil to a sandy clay loam requires the removal of 120 tons of the clay soil and its replacement with 120 tons of sand. At the one-foot depth mark, the interface between the first foot and second foot of soil would be limiting to tree growth. The texture change provided by this amendment process successfully increased aeration pore space. It is clear from this example that soil texture changes are of little practical importance other than in beds, containers, or planting holes.

One area where texture is critical to understanding restoration processes is at textural interfaces. An interface is where soil texture changes

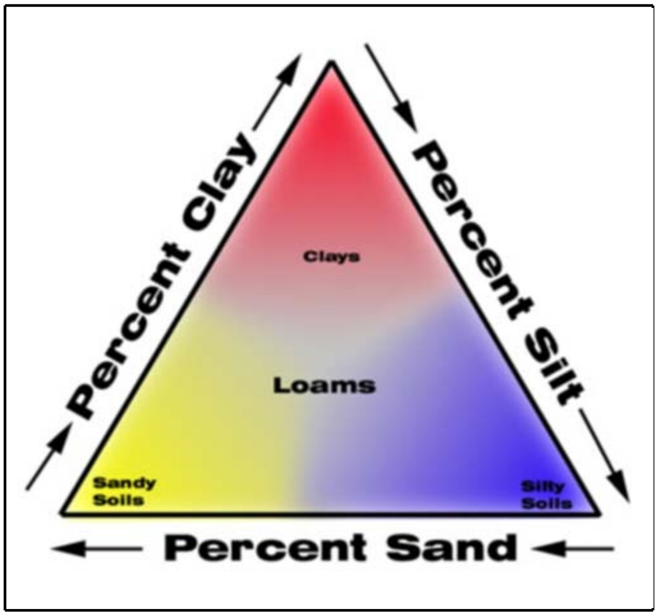

Figure 7. Texture is the relative percentage of sand, silt, and clay-sized particles in the mineral portion of the soil.

over short distances (less than 1- 4 inches). These interfaces are most often horizontal layers, but can be lens or vertical layers which texturally vary from adjacent layers. Textural interfaces below the soil surface can provide many gas and water exchange limitations.

There are four primary texture interface types:

Type 1 Interface = finer texture soil to coarser textured soil (small pores to large pores) -- water can not move from one layer to the next until the upper fine-textured layer is saturated (water will remain in the fine soil if it is at less-than-saturation.) Bathtub effect!

Type 2 Interface = coarser textured soil to finer texture soil (large pores to small pores) -- water movement is away from coarser textured soil and limited by water movement into finer soil (water can build-up at the interface if in excess, but continues to move into finer soil.) Drought effect!

Type 3 Interface = coarse horizontal or vertical layers of gravel, large sand, organic materials, etc. -- water must saturate soil above the coarse layer before moving into the coarse layer (water will perch above the coarse layer.) Because of hydraulic conductivity processes, the tree depends upon local water and local essential elements. This interface limits rooting area from the bottom. Perched water, limited oxygen flow!

Type 4 Interface = gradual texture changes where mixing or incorporation has spread out the interface distance -- good interface width for minimizing water problems is 1 foot. (1- 4 feet depending on texture changes.)

Working examples utilizing trees showing the importance of interface problems to restoration work follow. Tree #1 is planted in a native coarse soil with a root ball composed of fine textured soil. Water is added immediately above / over the root ball. Because of the interface (rapidly changing average pore sizes), water can not move across the interface until the soil in the root ball saturates. The result is the tree sits in a near-saturated soil much of the time. (Type #1 Interface). An additional result is water applied to the site will not necessarily enter the root ball leaving the tree drought stricken.

Tree #2 is planted in a native fine soil with a root ball which is composed of coarse textured soil. Water added directly above the root ball will move across the interface, although slowly. Water will be drawn into the surrounding fine textured soil from the large pore spaces of the root ball soil. The result is a tree under low soil water conditions much of the time. (Type #2 Interface).

Tree #3 is planted in native fine soil with a root ball composed of fine textured soil and a layer of gravel in the bottom of the planting hole. Water will be perched above the coarse layer and move through only as the soil above saturates. The result is water and oxygen movement through the soil is disrupted. (Type #3 Interface). A tree will have a limited rooting area until it breaks through the coarse layer. Depending upon the scale and duration of water and oxygen movement disruption in the soil, roots may never escape soil constraints.

2. Soil Structure

Structure in soil is represented by aggregates of the basic texture particles in specific shaped structures. The primary types of soil structure are platelike, prismlike, blocklike and spheroidal. Soil particles are held in these structural aggregates by adhesive forces from organic, colloidal, or metal oxide coatings. Soil structure can be modified by amendments.

Organic matter amendments (composted organic material not merely organic mulch) promote granulation in both sandy and clay soils. Organic materials added to sandy soils generate more small pore development, which sandy soils lack. Organic materials added to clay soils generate more large pore development, which clay soils lack. In both coarse and fine soils the improvement in structure from organic matter additions improves the availability of water and oxygen **(Figure 8)**. Care must be exercised when working with clay soils because they are very susceptible to compaction of pore spaces and destruction of structural units when wet.

An example of soil improvement through structural change could be compared to the attempted textural change example given above. The example cited modifying water and oxygen availability in the top foot of an average house lot. Adding 1.2 tons of composted organic material to the soil will have a similar effect as replacing 120 tons of soil with sand. A simple conclusion is restoration can be successful and cost-effective by concentrating on soil structure changes rather than soil texture changes. A critical feature of organic matter additions is do not allow sub-surface layers to develop.

Figure 8. Organic matter can add beneficial structure to clay and sands. As shown here organic matter gives sand a granular structure that improves water availability. Photo by Larry Korhnak

3. Bulk Density and Pore Space

Bulk density is the relative density of a soil including its pore space volume. It is measured by dividing the dry weight of a soil by its volume. If soil was just mineral material, an average density of common minerals would be 2.65 g/cc. As we discussed earlier, half of an ideal soil should be pore space (voids or spaces between solid soil materials)-- which makes ideal bulk density 1.3 g/cc (50% pore space.)

The characteristics of pore space varies by soil texture. Sands have many large pores filled with air. Clays have many small pores filled with water. Clays have greater total pore space than sand but it is filled with tightly held water. For example the typical air filled pore space of a drained soil would be 35% for sand, 25% for silt, and only 15% for clay.

Unfortunately urban soils are moderate to heavily compacted by footsteps, light vehicles, and heavy construction vehicles. This compaction shrinks large pore spaces which usually hold air, as well as decreasing total pore space (increasing bulk density.) Depending upon soil texture and structure, tree root growth problems can be initiated with only small increases in bulk density **(Figure 9)**.

Figure 9. Bulk density in urban soils is often increased by compaction. The decrease in pore space can cause tree growth problems. Photo by Larry Korhnak

For example, roots have difficulty physically penetrating beyond a bulk density of 1.75 g/cc. Oxygen availability constrains tree root growth as air pore space drops below 15% volume of the soil. **Table 2** presents soil attributes where tree root growth begins to be significantly limited for each soil texture class.

Compaction prevents root and soil functions essential to life. Compaction is found across all types of sites. Construction sites have been found to average 60% greater bulk density than neighboring native soils. A rule of thumb is an increase in bulk density by 1/3, causes a loss of 1/2 root and shoot growth. Compaction is not easily reversed. Harvest sites (logging decks, major skid trails, and forest road trails) can be effectively mapped after 40 years based only upon soil compaction and tree growth data. Time does not heal all.

Table 2. Soil attributes where root growth begins to be significantly limited for each soil texture class.

soil texture	root-limiting bulk density g/cc	root-limiting % pores filled with air	% total pore space in soil
sand	1.8	24	32
fine sand	1.75	21	34
sandy loam	1.7	19	36
fine sandy loam	1.65	15	38
loam	1.55	14	41
silt loam	1.45	17	45
clay loam	1.5	11	43
clay	1.4	13	47

There have been many compaction treatments proposed over the years. Surface tillage as deep as possible (at least 8 inches) and sub-soiling (winged bars below 16 inches), can be used when no tree roots are present to decrease bulk density. A soil can be amended with non-compressible, porous materials like washed flyash to provide pore space. Soil can also be amended with large gravel or small blocky stones to provide large airspaces and a bearing surface.

When trees are present, mulching can be used to minimize continued compaction pressure, and dissipate raindrop energy and surface erosion. Core aerators made for deep penetrations (12-16 inch long) can be effective but in heavily compacted soil may not be effective beyond 3-5 inches deep and may be difficult to use. Punch aerators create open soil space but compact the side of the surrounding hole. Surface aerators (2-4 inches deep) generate a low bulk density zone over a compacted zone just below, thus presenting a very limited root colonization area. Aerators are undergoing a major conceptual re-engineering period for assisting with restoration of severely compacted soils.

The primary means of reducing compaction problems both concentrate on generating more surface areas/ecological volume for root initiation and colonization. The two methods are vertical mulching and radial trenching. Vertical mulching uses a series of vertical holes augured into the soil to a depth of 14-24 inches on 2-3 feet centers under the drip line of the tree. The treatment can be expanded into soil areas useful for root colonization. The 1-2 inch diameter soil cores should be backfilled with washed, graded, and non-compressible materials open to the atmosphere. A composted organic matter and mineral light mix would be ideal with an organic mulch placed over the surface. Over time, material subsidence will require refilling holes.

Radial trenching uses a trencher or thin back-hole to dig trench lines from 2 - 14 inches wide. Each trench line begins on the ground surface 4-6 feet away from the tree trunk. As the trencher moves outward from the trunk area, the cutting head is allowed to dig downward to its operating depth. The trenches are backfilled with washed, graded, and non-compressible materials open to the atmosphere.

A composted organic matter and mineral light-mix would be ideal with an organic mulch on the surface. Various growth stimulators and soil enrichment materials may be added. Five to six trenches are initiated near the trunk and extend out to one and one-half the drip-line distance. As the distance between trenches increases, intermediate new trenches can be added, depending upon site and soil limitations.

4. Water

Water is held around the soil particles and within soil pores. Water sticks together and is pulled through a soil to the top of a tree by the process of transpiration. Depending upon soil texture, some water is held too tightly by soil particles to be extracted by trees. The traditional soil-water terms are defined in **Table 3**:

Table 3. Definition of soil-water terms.

Term	Definition
Field capacity	the amount of water held against the force of gravity
Permanent wilting point	water content level where the soil holds water so tightly that trees can not extract it (water contents at or below this level are unavailable to the tree)
Tree-available water	water present in soil between field capacity and permanent wilting point that trees can extract from the soil

Tree-available water varies by soil texture. Sandy loams probably have the greatest amount of water available to a tree of any soil texture. Clays contain more total water than other texture types, but most of this water (up to 75%) remains tied tightly to the clay surfaces and micro pores, and so, unavailable to a tree. Sands contain little water but what is present is almost all available for tree up-take and growth.

Water movement can be disrupted in urban soils. The many textural/structural interfaces within urban soil profiles, allow many water and oxygen availability problems to exist. In highly disturbed urban soils with many interfaces, water around the roots is critical to tree survival. Even the process of installing irrigation (depending upon backfill) can change water flow through the soil. Irrigating to correct turf water shortages will usually over-water trees. Trees should be separately zoned for irrigation in a landscape.

As site water inputs exceed outputs, soil health and tree roots are damaged. In addition, a number of pathogens thrive under poor drainage conditions. Drainage can be estimated by perculation tests. Irrigation should be adjusted to the drainage class of the soil, seasonal precipitation, and evaporation demands. A $20,000.00 / 100 year old tree is irreplaceable in three generations while the turf and small shrubs are immediately replaceable at a modest price. Priority must be given to high-value landscape items like trees **(Figure 10)**.

Figure 10. Irrigation should be adjusted to the drainage class of the soil, seasonal precipitation, and evaporation demands. Priority must be given to high-value landscape items like trees. Photo by Larry Korhnak

In the urban landscape the generation and transportation of heat can have an impact on water use in a tree and on a site. For every 18 degrees F increase in temperature above 40 degrees F, site and tree water evaporation and respiration almost double. The more heat a site must dissipate, the more water must be evaporated. Lack of evaporative surfaces and few heat blocking or dissipating shade structures allow heat accumulation on a site. Heat accumulation "cooks" trees and soils present, while heat moving onto the site from surrounding hardscapes demands site water use for evaporation. Irrigation must be tuned for handling additional heat loads.

5. Aeration

Aeration is oxygen moving in large soil pores from atmosphere to tree root surfaces. Soils have combinations of aerobic and anaerobic sites and the balance between them is constantly changing through the seasons, days, or years. Oxygen movement can only be assured by the presence of large pores, fracture lines, decayed root lines, or aeration columns. Compaction and flooding can produce many water-filled pores. Oxygen moves 1,000 times slower across a water barrier (water-filled pore) than across a gas filled pore. Therefore wet or compacted soils do not allow oxygen to effectively move to roots. Any place where soil atmospheric oxygen drops below 5% concentration, root growth stops.

As oxygen moves in the soil, many organisms use its oxidation power before it reaches tree roots. Under poor drainage and low oxygen conditions, oxygen can be used up quickly. Once the oxygen is consumed, soil organisms (not tree roots) begin to use other elements for respiration. The respiration sequence is oxygen, nitrogen, manganese, iron, sulphur, and carbon. An entire year's fertilization load of nitrogen can be respired away into inert nitrogen gas within weeks under near anaerobic conditions. Once the soil organisms start to respire sulphur and carbon, many materials are formed that will require purging or rinsing out of the soil for best recovery. The warmer the temperature, the quicker oxygen is consumed and the faster alternative respiration will occur (i.e. doubling rate sequence for respiration with increasing temperature).

Solutions for aeration problems are good drainage and open soil surface for gas exchange. To meet these goals, drain and sump systems can be installed. These systems are made of perforated pipes sunk to various depths. A drain system may include a number of interconnected horizontal and vertical pipes which were either pre-positioned before planting or trenched-in afterwards. The goal of a drainage system is to allow gravitational water to move away from the soil and away from root colonization areas. Sump systems use large diameter perforated pipes vertically sunk into the ground well beyond rooting depth to allow for accumulation of gravitational water in the pipes. These water containing pipes can then be pumped out periodically. These pipes can also be used to quickly saturate a soil area by filling with water during droughts.

The other major form of aeration modification is accomplished by terra-forming or sculpturing the landscape. Designing berms, terraces, raised mounds, and topography changes from grading practices can all be used to gain root colonizable space. These structures must be built to minimize erosion and should be able to withstand a 100-year rainstorm event.

6. Element Holding Capacity

Trees take-up essential elements in ionic forms from soils. A small portion of the essential elements are readily available, dissolved in tree-available water. Most essential element ions are held near the surfaces of clay and organic particles. Clays and portions of organic materials (humus) have negatively charged areas that attract and keep the positively charged ions (cations) in close proximity. These binding sites help keep essential elements from being washed from the site. Cations include calcium, manganese, zinc, magnesium, potassium, and ammonium.

Cation exchange capacity (CEC) is a measurement of the positive charged ion holding or storage capacity of a soil. A calculation for rough estimation of CEC is:

CEC = ((% organic matter in the soil) X 2.0) +
((% clay in soil) X 0.5)

The formula suggests how effective additions of clay and composted organic matter might be to a soil. Organic matter is four times more effective for improving CEC as clay. For soil type and texture, relative CEC varies: sand =1; loam=5; silt loam=8; clay=15. Cation exchange capacity generally increases with soil pH.

Organic materials also have surface areas with positive charges that attract negatively charged ions (anions) like nitrate, phosphate, sulfate, chloride, borate and molybdate. Anion exchange capacity (AEC) is a small part of soil chemical activity. Anions either move freely with water, like nitrates, or are bound in insoluble forms like phosphates **(Figure 11)**.

Figure 11. Organic matter has many charged areas that attract and conserve elements important for plant growth. Photo by Larry Korhnak

7. Essential Elements

There are a number of elements essential to the life and health of living things. Air (CO_2) and soil water (H_2O) provide three essential elements (O, H, and C). Soil provides the remaining 15 essential elements. An ecological system will progresses until any one essential element or process becomes limiting. It matters little how much nitrogen is added to a site if zinc is the most limiting element to tree growth. Below is **Table 4** which provides a general and relative ratio of essential elements in trees.

On most terrestrial sites, nitrogen is usually limiting for a number of reasons. Phosphorus can be limited on wet and poorly drained soils. Fertilization prescriptions should be nitrogen-centered but assure easy phosphorus availability. Elements most often limiting in order of importance are N, P, Mg, and K. Excessive nitrogen fertilization has caused a number of overdose events and over-medication programs to damage ecosystems and trees, especially the very old and the very young. Ecologically, both large doses and no doses can be less productive and less healthy than mid-ranges.

8. Organic Matter

Organic matter is once-living materials decomposing and eroding back into the soil **(Figure 12)**. As noted in the above discussions, organic

Table 4. Ratio of essential elements in trees. (* = from CO_2 and H_2O)

MACROS:		**MICROS:**	
hydrogen	60,000,000*	chlorine	3,000
carbon	35,000,000*	iron	2,000
oxygen	30,000,000*	boron	2,000
		manganese	1,000
nitrogen	1,000,000	zinc	300
potassium	250,000	copper	100
calcium	125,000	molybdenum	1
magnesium	80,000		
phosphorus	60,000	Transformers**:**	
sulfur	30,000	cobalt	
		nickel	

matter can improve soil structure, bulk density, water and element holding capacities, and aeration. Organic materials provide fuel, food and habitat for the detritus engine of the soil. Urban forest soils often have no or limited organic matter as well as the associated flora and fauna which break-up and decompose organic materials. Therefore the natural processes of element cycling usually occur only in small amounts on urban sites. Leaving fallen plant materials on site and/or incorporating organic admendments can greatly improve soil health and in-turn the health of the urban forest.

9. Contamination

Soil is both easily polluted and difficult to clean or restore. Contamination effects can out-right kill and damage ecological and biological systems. In addition, contamination acts to disrupt and poison restoration processes **(Figure 13).** General classes of contamination in soils are: lead and other heavy metals (a legacy that does not decay); pesticides; salt; petroleum products; biological excretions (urine, feces, etc.); litter/construction materials; soil

Figure 12. Organic matter is once-living materials decomposing and eroding back into the soil. Photo by Larry Korhnak

crusting (hydrophobic surfaces from petroleum, allelopathic materials, and organic coatings); and buried trash from past construction and land-uses (cement wash-outs, general land fills, garbage dump (current or historic), poor coverage with top soil, methane, and soil subsidence associated problems).

Figure 13. Soil is easily polluted but difficult to clean or restore. Soil contamination disrupts biological and restoration processes. Photo by Larry Korhnak

Three examples of contamination which might disrupt ecological restoration activities include:

1. Lead in soils from the days of leaded gasoline (in Minneapolis, MN it was estimated that 2,000 tons per year of lead dust from autos fell on to soil surfaces),

2. Animal and human wastes concentrate toxins and salt content in fresh feces and urine. There is also a risk of viral and bacterial disease with contact of in-place soil or air-bourne soil, and

3. Floods wash down the contents of storage bins, sheds and tanks from up-watershed to those below, generating deposition and clean-up problems.

Solutions to soil contamination problems begins with identifying concerns and soil testing. Associated with testing for contamination should be development of a water and soil contamination map of the site. Once this map is complete, a prioritization system can be developed for other treatments or activities. Contamination treatments could include the complete removal or tie-up of materials in the soil using pH, plasma jets, organisms, chemicals, and /or barriers. Removal of contaminated soil might fall under toxic waste regulatory agencies to supervise. Mulching and careful nitrogen fertilization across well-drained sites can accelerate bacteria and soil processes which can minimize or destroy some contaminants. Cultivation or addition of a wetting agent might assist with health restoration by breaking-up soil and organic material crusts. Keep human contact away from contaminated areas including collecting or consumption of plant tissues, fruits, nuts, and mushrooms.

10. Trophic Enrichment

Enrichment is the addition, infection, contamination, or repatriation of the site with various living things. A simple teaching model uses the term "WAFBOM" which represents worms, arthropods, fungi, bacteria, and organic material added to a site. This multi-level trophic enrichment attempts to restart the detritus ecological engine needed for soil and tree health **(Figure 14).** There remains a concern about infecting sites with exotic organisms, especially worms and fungi. Gene set trade-off must sometimes be made in site restoration. Fully conceived and operating processes, once established, may eventually eliminate poor species or organisms.

Many urban sites for restoration are far removed (islands) from sources of reintroductions and infections of living things. If you build the perfect restored system, species may find the site or not (if you build it, they may not come). Active intervention and infection at multiple trophic levels can accelerate the site colonization process. Urban sites are tough on beneficial organisms like arthropods, worms, fungi and bacteria especially where increased heat loads quickly "burn-out" organic matter in the soil. Many sites could benefit from organism infection in the nursery, or organism inoculum applied at planting time.

Organic matter remains a universal resource for restoration of urban forest sites. The organic matter is the feed stock and habitat for beneficial soil organisms and for tree roots. Composted organic matter can be top-dressed over the site with a thin protective layer of non-compressible, organic mulch covering. Restoration managers are then placed in a position of animal husbandry (microbe-jockeys). Managers should beware of the wolves (pathogens and exotic higher plants) among the sheep. Native gene sets should always be conserved, but exotics might help recover a site faster, serving as a nurse crop or successional predecessor. Ecological and genetic trade-off must always be made.

Figure 14. Worms, arthropods, fungi, bacteria, and organic material often need to be added to restoration sites to restart the detritus ecological engine needed for soil and tree health. Photo by Larry Korhnak

Conclusions

A key component in assessing sites for ecological restoration is developing, both for your own reference and others, a site picture, also called determining the site context. Each site should be assessed for its ecological context and societal context. An ecological management unit (EMU), the smallest treatable unit -- smallest restorable unit -- must be the focus for restoration management activities. In addition to the ecological considerations for a project, it is also important to the success of any restoration project to include the stake-holders, decision-makers and surrounding social systems in all phases of the project. Site assessment is a part of the planning and management process, not a disjunct and separate piece. Remember every site and situation will be different. An initial site assessment should include inventory of resources, space, size, diversity, temporal changes, disturbances, stress, natural cycles, organic matter, management, and a final action-list.

A restoration process includes an assessment of present conditions, how they are changing, and concentration of efforts on site factors which can be repaired or improved -- soil health components. Good soil management is essential for (and a part of) healthy and sustainable ecological systems. Since a number of soil features becomes degraded or destroyed over time in highly stressed environments, soil evaluation and improvement becomes imperative. An average urban soil has few essential elements, poor drainage, a compacted, heavy texture, with little organic matter, low diversity and small number of beneficial organisms. Restoration activities need to be prescribed carefully in trophic level order to assure success -- start at the bottom and restore upward. The soil is the foundation upon which we restore ecosystem functions and structures. The soil attributes affecting and controlling soil resources to be restored successfully include texture, structure, bulk density, water, aeration, element holding capacity, essential elements, organic matter, contamination, and trophic enrichment.

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UNIVERSITY OF FLORIDA

EXTENSION

Institute of Food and Agricultural Sciences

Chapter 8: Enriching and Managing Urban Forests for Wildlife[1]

Joseph M. Schaefer[2]

Abstract

Many positive outcomes result from enriching and managing urban forests for wildlife. However, effective management requires careful planning. Baseline data on wildlife species that are currently using the site should be collected prior to the implementation of any plans. A site evaluation is needed to determine what ecosystem components need to be installed to improve the ecological value of the property. Clear goals and objectives must be established to effectively guide the process. Three approaches to implementing a plan are managing habitat, stocking species, and controlling negative impacts of people and pets. Periodic monitoring of species occurrence on the site will help to measure success and will also indicate ways the plan should be revised to obtain better results if necessary.

Introduction

The concept of accommodating both humans and wildlife in the same area is nothing new. Humans have always lived with other animals. However, over geologic time, human populations have increased and drastically extended their dominance on the landscape. Many plant and animal species that were once wild are now domestic. Ecosystems that evolved through millennia of natural processes and stochastic events have been severely humanized within decades.

Many benefits can result from efforts to enrich and manage wildlife in urban forests. Native animals attracted to properly managed sites can provide recreational and educational opportunities for local residents (**Figure 1**). People involved in planning, installing and using areas managed for wildlife realize how decisions can directly influence environmental quality and are likely to develop a better land ethic. These areas also include the use of native plants that require less water and nutrients than exotic grasses and ornamental plants.

Developing a Plan for Wildlife

Effective wildlife management cannot be done on just a whim. It requires careful planning. The current condition of the site(s) needs to be determined, and then a team of experts and stakeholders should discuss and agree on what they want to accomplish. An effective wildlife management plan should contain base-line data, a site evaluation, goals and objectives. For more

1. This is Chapter 8 in SW-140, "Restoring the Urban Forest Ecosystem", a CD-ROM (M.L. Duryea, E. Kämpf Binelli, and L.V. Korhnak, Eds.) produced by the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: June 2000. Please visit the EDIS Web site at http://edis.ifas.ufl.edu

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Figure 1. Native animals attracted to properly managed sites can provide recreational and educational opportunities for local residents. Photo by Larry Korhnak

information on developing plans for restoring the urban forest ecosystem, see **Chapter 5 - Developing a Management Plan**.

Base-line Data

Data on the current status of wildlife should be collected before any other decisions are made. These data will show which species are already present on the project site(s). By comparing this list to a list of species that have been documented to occur in the same habitat types or ecosystems within the same geographic range, you can identify those species that could be accommodated. A team of experts can determine the species or groups of species on which the project should focus.

Small Snakes, Turtles, Lizards, Frogs, Toads, Salamanders, Mice and Shrews

Acceptable scientific survey methods should be used to collect these data. A drift-fence, pitfall trap array is the best method to collect animals that crawl or walk on the ground (for example: small snakes, turtles, lizards, frogs, toads, salamanders, mice and shrews) **(Figure 2).** The materials needed for this include a shovel, two 5-gallon plastic buckets with lids, tin snips, and one 10-foot x 2-foot x 1-inch board. In your project area, at least 5 yards from an edge, dig a hole about 2-feet deep and 1-foot wide. Make several holes in the bottom of the buckets by drilling or hammering a nail or screwdriver. The holes in the bottom will help rain water to drain out of the bucket so caught animals will not drown. Place one of the 5-gallon buckets in the hole so the top edge is level with the ground surface. Cut a 1-inch slit about 3 inches deep in the rim of the bucket with tin snips. Dig a 10-foot long trench about 3 inches deep out from the slit in the bucket. Lay the board down next to the trench to determine where to dig a hole for the second bucket (about 9.5 feet from the first bucket). Dig a hole for the second bucket; cut a slit in the rim; stand the board on its side in the trench and in the slits in the two buckets; and backfill dirt against both sides. You may need to support the board in the middle with a stake or two. If your site is large enough, you can use several bucket arrays placed in different microhabitats (for example, shaded and unshaded areas) so you can see if some species have a preference for different areas. Shade each bucket with the lid elevated at least 6 inches above the ground to allow larger animals such as box turtles to enter. Place a damp sponge in the bottom on the buckets so captured animals will not dry out. Collect these data for four consecutive days of each season.

Figure 2. A drift-fence, pitfall trap array is the best method to collect animals that crawl or walk on the ground, such as small snakes, turtles, lizards, frogs, toads, salamanders, mice and shrews.

Larger Mammals

Larger mammals do not have to be caught to record their presence. Raccoon, opossum, fox, and others can be surveyed with tracking stations **(Figure 3)**. A tracking station consists of a bare soil area (about 3-feet in diameter) covered with a layer of dry Quickcrete (to better detect prints). In the center, place a cotton ball immersed in oil or water from a tuna fish can and placed on a stick pushed into the ground. Check for tracks early each morning for four consecutive days.

Figure 3. Larger mammals such as raccoons can be surveyed with tracking stations. Photo by Larry Korhnak

Birds

A stationary count method is recommended to most effectively detect birds in various layers of vegetation **(Figure 4)**. Count stations should be permanently marked outside and on a map to assure reuse consistency. Select locations that will give you the best chance of detecting birds on the site. Usually, at least one station located about 50 feet from the site will give you an opportunity to see birds without scaring them away. Survey at this station first. Then go into the site to survey at one or more stations. Space your stations about 100 yards apart. If your site is smaller, then use only one station. Approach each station quietly. Wait one minute at the station for the birds to get used to you before counting. Record all birds seen or heard for the next 5 minutes. Count only those birds that appear to be using the site, not those merely flying over it. Bird counts should begin as close to sunrise as possible on calm, clear mornings. Bird surveys should be conducted four consecutive days of each season.

Site Evaluation Checklist

A quick-and-easy instrument can be used to assess the ecological value of a site. Wildlife biologists have been using tools such as this **Site Evaluation Checklist** (see Appendix 1 at the end of the chapter) for decades to estimate site suitability for certain species. This particular Checklist is designed to evaluate a site based on the occurrence and diversity of important ecosystem components. It helps to focus attention on the items that are missing

Figure 4. A stationary count method is recommended to most effectively detect birds in various layers of vegetation. Photo by Larry Korhnak

and how a manager can increase the ecological value by installing them properly.

Goals and Objectives

The next step is setting clear goals and objectives that will guide the process from beginning to end (see also **Chapter 5 - Developing a Management Plan**). Goals are broad statements that give a project general direction; objectives provide specific destinations and time lines for different aspects of the project. An example goal for wildlife enrichment and management could be to enrich wildlife within the Cincinnati park system. An example of a specific objective would be to increase the current number of native wildlife living in the Cincinnati Zoological Park by 5 within the next 3 years. Progress toward achieving objectives can be measured; progress toward goals cannot **(Figure 5)**.

Implementing the Plan

There are three different approaches to executing a plan to enrich and manage wildlife: managing habitats; stocking species; and managing people and pets. These approaches are not exclusive of and can often complement each other.

Managing Habitats

A habitat is simply where an animal lives. It is their address (**Figure 6**). When using the term wildlife habitat, you must always refer to an animal that lives or may potentially live there. And of

Figure 5. An example goal for wildlife enrichment and management could be to enrich wildlife in a park. Photo by Larry Korhnak

course, the animal(s) would not be able to live there if the area did not accommodate their survival needs. To say that a particular piece of land is good wildlife habitat is meaningless. You must say whether it is good for black bear, pigeons, snakes or some other animal or group(s) of animals. In other words, it is a good place for them to live because it provides all of the life-sustaining requirements for the species. To manage a habitat is to make the place more or less suitable for a particular species depending on whether the goal is to increase or decrease numbers of the species. The latter goal may be appropriate for species that are involved in damage or nuisance situations.

Figure 6. A habitat is simply where an animal lives. It is their address. Photo by Larry Korhnak

A natural ecosystem is a place where living and non-living components interact in a condition that has been relatively untouched by recent human society. Living components include plants that fix energy from the sun and manufacture food for the other living components, animals. Non-living components include soil, water, and minerals that are important for the survival of plants and animals. Ecosystems can be good or bad places (habitats) for different species to live depending on whether or not the ecosystem contains all of the components that the species needs to survive. A tropical rainforest is a very productive ecosystem, and provides good habitats, or living conditions, for many species. However, it is not good habitat for polar bears.

Many ecosystems in their existing condition do not provide good habitats for species that once thrived in them. As a result of human development and land uses, many natural ecosystem components are often destroyed and the interactions that made them productive ecological systems no longer take place. We can be good conservationists by putting back or restoring as much of the original ecosystem as possible. The theory behind improving habitat is to build it and they will come.

Some sort of general knowledge of ecosystems may be needed to help make this seemingly endless task more feasible. Keep in mind that any living or non-living component of a natural ecosystem supports more natural ecosystem interactions than asphalt and concrete. Even plant-free, sandy areas may provide habitat to support a food chain consisting of ants, ant-lions, and lizards. The following are some ecological concepts that will help you to be most effective in restoring an ecosystem.

The most fundamental concept that applies to any ecosystem restoration effort is the more diversity, the better. Restoration undertakings are most cost efficient and ecologically effective when the greatest diversity of ecosystem components is provided. For example, $100 could purchase 5 holly trees that will provide food for a variety of bird species. Or, this same amount of money could purchase one holly tree, an oak tree, a birdhouse, some butterfly and hummingbird nectar plants, and material to build a pond. These diverse ecosystem components can provide not only berries for birds, but also acorns for squirrels, nesting cover for chickadees, nectar sources for dozens of butterfly species and hummingbirds, and a place for eggs and tadpoles of many frog species. This diversity concept can also be applied to each type of ecosystem component (e.g., trees, shrubs, perennials, birdhouses, and water). For more information on biodiversity, see **Chapter 3 - Biodiversity**.

Living and non-living ecosystem components installed in urban areas help to restore the natural value of sites making them better places for native wildlife to live. In other words, management practices that would include adding native components would improve the habitats for many native wildlife. These components provide some of the essential requirements for animals: food, cover, water, and space.

Food

Plants are the primary source of nutrients and energy for animals. Some animals only eat plants (herbivores or vegetarians); some eat plants and other animals (omnivores), and some eat only meat (carnivores). All of this eating, transfers energy and nutrients to animals in the ecosystem's food web. When animals eliminate some of the undigested food or die, this nutrition is available for plants. This cycle of life continues within the ecosystem as long as there are sufficient food components (for more information on nutrient cycle, see **Chapter 2 - Basic Principles**).

Animals eat many plant parts. Squirrels eat seeds, nuts, bark and buds. Insects eat leaves and fruits. Birds eat nuts, seeds and fruits. Some of these plant parts are only available at certain times of the year. Buds are mostly available in the spring and fruits and nuts in the fall. Adult cardinals eat mostly seeds during winter, but eat insects when they are feeding nestlings in the summer. Bluebirds eat insects during summer, but include fruit in their winter diet. If a site, does not have all of the foods required at different times of the year, animals must find food somewhere else and may leave the site temporarily or permanently. Diets of each individual (including humans) also change with age. Baby humans consume different foods than adults. Baby butterflies (caterpillars) eat leaves of specific plant species while most adults eat flower nectar **(Figure 7)**.

Diversity in structure and species of plants is much better than a large number of one species **(Figure 8)**. Food from some plants is most available during summer, others during the fall or some other season. Variety provides food year-round. Some animals nest close to the ground but feed on fruits or insects of taller plants. Others nest in the highest parts of the tallest trees and feed on or close to the ground. A diversity of vertical vegetation layers will provide suitable vertical habitat for the greatest variety of animal species **(Figure 9).**

Figure 7. Baby butterflies (caterpillars), such as this Gulf Fritillary caterpillar, eat leaves of specific plant species while adults eat flower nectar. Photo (right) by Larry Korhnak

Figure 8. A diversity of vertical vegetation layers will provide suitable vertical habitat for the greatest variety of animal species.

Cover

Like humans, wildlife species need protection from both predators and weather. Cover also helps restrict the amount of food available at any time to each level in a given food web so that the energy flow will be sustained generation after generation. For example, if bird nests were highly visible to predators, every egg and nestling would be eaten and

Figure 9. In developed areas vertical vegetation layers are often eliminated.

no offspring would be available to continue the important balance between predators and prey.

Cover requirements are almost as diverse as food requirements and can be provided by both plant and non-plant ecosystem components. Some plants are excellent fruit or nut producers, but their foliage is not thick enough to offer good cover (for example, dogwood trees). Dozens of birds, mammals, reptiles and amphibians use tree cavities for nesting and sleeping (birdhouses can help to artificially replace this natural component). Many birdhouses of the same size will accommodate only those birds of a certain size, but a diverse selection of birdhouses can provide nesting cover for birds as large as barred owls and as small as chickadees **(Figure 10)**. Dozens of species use underground burrows for nesting, sleeping and hiding.

Figure 10. A Great-Crested Flycatcher finds cover in a birdhouse.

Water

Fresh water is essential for most plants and wildlife. Many animals need to drink water and other species such as frogs and toads require standing water during all or some of the year to complete their life cycles. A water source on one piece of property may be critical to all wildlife living in the entire neighborhood **(Figure 11)**.

While traditional, elevated birdbaths are accessible only to birds, a pond with gently sloping sides allows many kinds of wildlife to choose different depths to satisfy their requirements. Even small depressions in rocks or soil that retain water only temporarily help satisfy wildlife water requirements. Some amphibians mostly use temporary ponds that hold water only for a few months out of the year.

Figure 11. A fresh water source, such as this constructed pond, is essential for wildlife. Photo by Larry Korhnak

Space

An animal's need for space is simply the size of an area containing sufficient food, cover, and water for the creature to survive. This size varies depending on the density and availability of these resources. For example, a cougar (*Felis concolor*) needs about 100 $miles^2$ (Nowak and Paradiso 1983) and an Eastern robin (*Turdus migratorius*) needs about 1/3 acre (Young 1951; **Figure 12)**.

Most wildlife species are not able to satisfy their space requirements on a typical urban site. Because animals readily move across property lines, larger suitable habitats can be accomplished if adjacent properties containing suitable habitats are connected to the project site.

As previously mentioned, most species have vertical space requirements too. Some, such as the American crow (*Corvus brachyrhynchos*), nest high in tall trees but feed on the ground. Others, like the hooded warbler (*Wilsonia citrina*) and brown thrasher (*Toxostoma rufum*), nest close to the ground but feed in small trees.

Figure 12. An animal's need for space is simply the size of an area containing sufficient food, cover, and water for the creature to survive. A robin needs about 1/3 acre. Photo by Thomas G. Barnes

Other Habitat Concepts

Type of Ecosystem

Ecologists have developed a system of assigning names to ecosystems according to their unique natural characteristics. This also makes mapping, management, and in some cases land use regulation easier. Processes, interactions and components that define ecological systems occur in patterns across the landscape. Fire frequency is greater in prairie, chaparral, and savannah sites than in riparian areas. Areas with sandy/loamy soils are more suitable than clay for burrowing animals such as gopher tortoises, pocket gophers and ground squirrels.

Each ecosystem shares some characteristics with adjacent ones, but is also very different from them. For example, surface water flows downhill carrying nutrients from upland to wetland sites. If a prairie ecosystem is drastically altered during the process of building a school facility, a highway, a house, or a shopping center, all of the processes, interactions and components unique to the prairie are also altered as well as those in adjacent areas that were shared. Replacing a prairie with temperate forest components would not be the best way to restore the ecosystem that was destroyed. Restoring the proper piece of the landscape puzzle is the best way to improve the ecology of the site so it interacts best with surrounding areas **(Figure 13)**.

Figure 13. In a landscape, each ecosystem shares some characteristics with adjacent ones, but it is also very different from them. Restoring the proper piece of the landscape puzzle is the best way to improve the ecology of the site so it interacts best with surrounding areas. Photo by Hans Riekerk

Corridors

Many intact, relatively unaltered ecosystems have been reduced in size or fragmented due to various human development activities. These smaller fragments often are not large enough to support larger wildlife species. However, these fragments can be connected with corridors that are ribbons of suitable habitat for specific species connecting larger habitat blocks. This connection effectively increases the total size of the remnant ecosystem and its ability to maintain sizable wildlife populations **(Figure 14)**. Genetic variation is maintained because genetic material is carried freely through the corridor and among large habitat blocks by dispersing wildlife. Scattered animals also can use corridors to recolonize areas that have suffered from local extinctions. Corridor width is the most important variable affecting its function. Wider strips are more valuable than narrow ones. For more information on corridors and ecological connectivity, see **Chapter 3 - Biodiversity.**

Figure 14. Corridors may connect ecosystem fragments and provide suitable habitat for some species. Photo by Henry Gholz

Edge Effects

One obvious characteristic of urban forests is the sharp contrast between various land uses/vegetation on these sites. Many human-made, sharp edges or borders between vegetation types are found in this type of landscape. These sharp edges cause many problems for wildlife and their habitats. Human-modified areas surrounding a forest fragment are usually altered into earlier successional stages **(Figure 15)**.

Figure 15. Human-made sharp edges or borders between vegetation cause many problems for wildlife and their habitat.

These areas are attractive to pioneering species that invade several hundred meters into the adjacent forest fragment and alter the plant species composition and relative abundance which in turn affects the suitability of the habitat for various wildlife species. Along forest edges, avian brood parasites (cowbirds), nest predators (small mammals, grackles, jays, and crows), and non-native nest hole competitors (e.g., starlings) are usually abundant. Cowbirds feed in open areas and lays their eggs in other species' nests found along forest edges. Many birds cannot distinguish this foreign egg from their own and devote all of their energy to raising the young cowbirds. The eggs of the host species are either removed by the adult cowbird or are pushed out of the nest by the more aggressive cowbird nestling. The result is cowbird numbers increase at the expense of the host species **(Figure 16)**.

A field-forest edge also attracts a variety of open-nesting birds, but such an edge functions as an "ecological trap." Birds nesting near the edge usually have smaller clutches and are more subject to higher rates of predation and cowbird parasitism than those nesting in either adjoining habitats (Brittingham and Temple 1983). A general principle

Figure 16. Along forest edges, avian brood parasites are usually abundant; here a cowbird has laid its eggs in a thrushs nest.

is that the greater the contrast between adjacent vegetation types, the greater the edge effect.

Noise associated with construction, operation, and maintenance of developments can cause harmful impacts on wildlife. Animals that rely on their hearing for courtship and mating behavior, prey location, predator detection, homing, etc., will be more threatened by increased noise than will species that use other sensory modalities. However, due to the complex interrelationships that exist among all the organisms in an ecosystem, direct interference with one species will indirectly affect many others.

Any forest tract has a "core area" that is relatively immune to deleterious edge effects and is always far smaller than the total area of the forest **(Figure 17)**. Relatively round forest tracts with small edge-to-interior ratios would thus be more secure, whereas thin, elongated forests (such as those along unbuffered riparian strips) may have very little or no core area and would be highly vulnerable to negative edge effects.

Edge effects have been shown to negatively impact wildlife species within at least 300 feet of forest boundaries (Janzen 1986, Wilcove et al. 1986). Studies of nature reserve boundaries have provided data that support the need for buffer zones of decreasing use outside reserve boundary (Adams and Dove 1989) **(Figure 18)**. The core of these areas must be protected from cats, dogs, human activities,

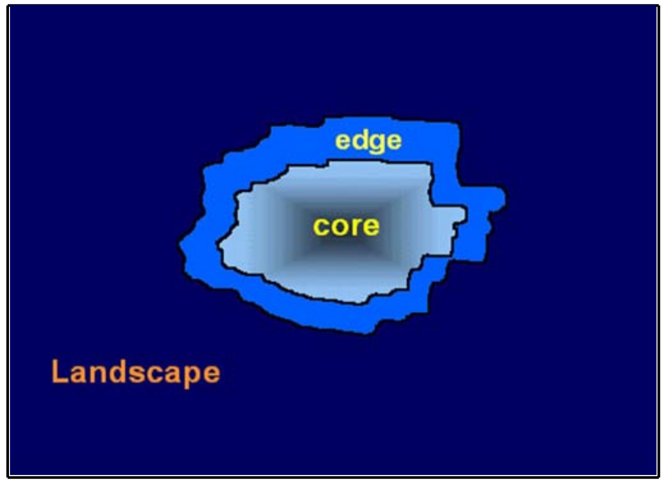

Figure 17. Any forest fragment has a core area relatively unaltered by deleterious edge effects.

noise, predators, exotic competitors, parasitism and other detrimental effects of development.

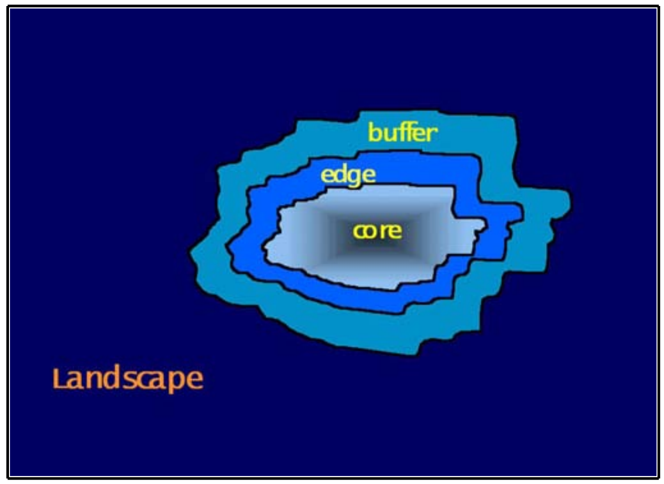

Figure 18. The core area of a fragmented forest may be protected by the use of buffer zones.

Connection of Wetlands and Uplands

Wetlands are ecosystems that are periodically inundated with water. They perform many functions including flood control, water quality enhancement, water supply, nutrient cycling, and good habitat for many species (**Figures 19 and 20**). Most species of birds, mammals, reptiles and amphibians feed or breed in wetlands but also need access to surrounding uplands to fulfill all of their life-sustaining requirements. For example, aquatic turtles spend most of their time feeding on plants and animals in the water. However, one day each year, the female must travel out of the water and find relatively sandy upland soil to dig holes and lay eggs. Some of these animals that move back and forth between wetland

and upland areas become food for upland animals, adding both energy and organic matter to the upland community. Surface runoff then carries some of the organic material back into the wetlands. The preservation or restoration of linkages between uplands and wetlands is essential for preserving and enhancing the structure and function of both systems.

Figure 19. Most species of birds, mammals, reptiles and amphibians feed or breed in wetlands but also need access to surrounding uplands to fulfill all of their life-sustaining requirements. This wetland, for instance, has no upland connection.

Figure 20. This wetland has good upland connections, essential to most species of birds, mammals, reptiles and amphibians to fulfill all of their life-sustaining requirements.

Stocking Species

Wildlife are stocked or transplanted in a number of situations. Recovery plans for some species in danger of becoming extinct include captive breeding programs that include releasing the offspring into suitable habitat areas. Game farms raise quail, pheasant and other animals and release or stock them in areas for hunters. Sometimes, animals living on a proposed construction site may be removed and transplanted to an area not slated for development. Other stocking situations involve live-trapping animals that are causing damage or nuisances and releasing them in areas far away from the site of infraction. The condition of the receiving habitat is an important consideration in all cases. If the habitat is evaluated as suitable, then you must answer the question, why is the species not already present in sufficient quantities?

The consequences of stocking species are extremely complex. Many wildlife species can carry dozens of diseases. Unless they are tested and found to be disease free, introducing individuals into a new area might enhance the spread of diseases **(Figure 21)**. Also, new animals in an area can raise numbers above carrying capacity (the number of animals that can be supported by the areas resources).

Figure 21. The consequences of stocking are extremely complex. Many wildlife species, such as this gopher tortoise, might spread diseases if introduced to a new area. Photo by Larry Korhnak

Managing People and Pets

Some wildlife adapt to increased human activities in urban environments, but others do not. Human-caused sounds, such as lawnmowers, leaf-blowers, cars and trucks, and radios, may interfere with important wildlife communications. Many species are not tolerant of and will not live in areas with high noise levels.

Education is the preferred method to manage people. The goal of these educational programs should be to change the behavior of people within different target audiences so their activities are more compatible with the wildlife management plans. People who use the site or affect the site by their activities need to understand the consequences of their existing behavior and what they need to do to become less damaging members of their ecosystem.

Predation and harassment of wildlife by free-ranging domestic cats and dogs are other challenges in urban ecosystems **(Figure 22)**.

Figure 22. Predation and harassment of wildlife by free-ranging domestic cats and dogs are a challenge in urban ecosystems. Photo by Larry Korhnak

Cats can be especially devastating to ground feeding and ground breeding species. Hunting is a feline instinct, and predation rates are not related to hunger. One study reported that a single cat, which regularly consumed domestic food, killed over 1,600 mammals and 60 birds in Michigan during an 18-month period (Bradt 1949). Domestic cat predation has extirpated and endangered several bird and mammal species and populations (Humphrey and Barbour 1981; Gore and Schaefer 1993). Another study concluded that domestic cats were killing about 39 million birds in Wisconsin each year (Coleman and Temple 1996).

Management of people and pets may include restricting use of some areas where sensitive species may live and educational programs informing people of the detrimental impacts of free-ranging pets.

Monitoring and Evaluating

Changes in wildlife use of the site should be monitored at least annually during the growing and breeding seasons. Use the same methods that you did for the baseline surveys. Winter surveys of migratory species using the site are also recommended. Continue to compare these data to lists of species that have been documented to occur in the same ecosystems within the same geographic range. A chart comparing the number of wildlife species found on the site (y-axis) with time (x-axis) will illustrate the success of your project **(Figure 23)**.

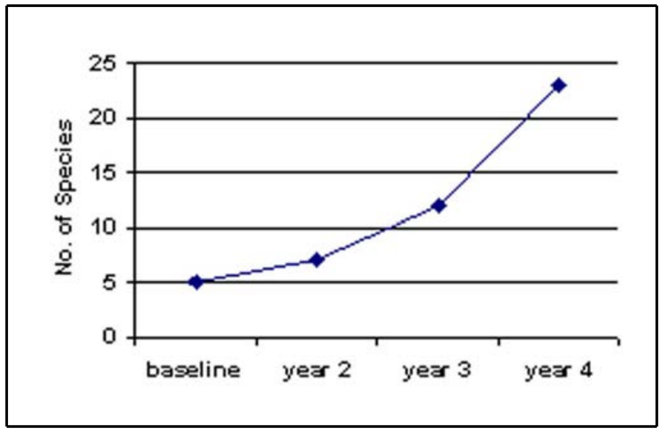

Figure 23. Comparing the number of wildlife species found in an area during several years will help illustrate progress toward restoring wildlife.

Revising the Plan

Annual meetings should be held to discuss the results of the surveys and other pertinent information. If progress toward achieving stated goals is satisfactory, continue as planned. If results are not acceptable, decisions should be made for revising the methods. Project managers also need to be able to adapt to unexpected events, such as damaging storms that may alter original management plans **(Figure 24)**.

Figure 24. Annual meetings should be held to discuss the results of the surveys and other pertinent information. Photo by Larry Korhnak

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The Golden Nature Guide Series. Publisher: Golden Press, c/o Western Publishing Company, Racine, WI 53404. Includes: Golden Guide to Pond Life, Golden Guide to Butterflies and Moths, Golden Guide to Birds, Golden Guide to Trees, Golden Guide to Reptiles, and Golden Guide to Mammals.

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Appendix 1. Site Evaluation Checklist -- This checklist can be used to determine the ecological value and site suitability for certain species at any urban site.

COMPONENTS	POINTS
FOOD COMPONENTS	**Point Values**
1. Butterfly plants (Choose one from both nectar and larvae categories)	
1 species of nectar plants	2 pts
2-5 species of recommended nectar plants	4 pts
> 5 species of recommended nectar plants	5 pts
Recommended larvae plants for 1 species of butterfly	3 pts
Recommended larvae plants for 2-5 species of butterfly	4 pts
Recommended larvae plants for > 5 species of butterfly	5 pts
Total (of maximum possible 10 pts)	__ pts
2. Hummingbird plants (Choose one)	
1 species of recommended nectar plants	2 pts
2-5 species of recommended nectar plants	5 pts
> 5 species of recommended nectar plants	10 pts
Total (of maximum possible 10 pts)	__ pts
3. Native plants (Choose one from each of the 2 following groups)	
1 species of recommended native plants	1 pt
2-5 species of recommended native plants	3 pts
> 5 species of recommended native plants	5 pts
Recommended plants from 1 category (grasses, grasslikes, herbaceous, vines, small shrubs, tall shrubs, small trees, large trees)	1 pt
Recommended plants from 2-3 categories (grasses, grasslikes, herbaceous, vines, small shrubs, tall shrubs, small trees, large trees)	3 pts
Recommended plants from >4 categories (grasses, grasslikes, herbaceous, vines, small shrubs, tall shrubs, small trees, large trees)	5 pts
Total (of maximum possible 10 pts)	__ pts
4. Bird feeders (Choose one)	
1 feeder without black oil sunflower seeds	2 pts
1 feeder with black oil sunflower seeds	5 pts

Appendix 1. Site Evaluation Checklist -- This checklist can be used to determine the ecological value and site suitability for certain species at any urban site.

COMPONENTS	POINTS
>1 feeder without black oil sunflower seeds	3 pts
>1 feeder with black oil sunflower seeds	10 pts
Total (of maximum possible 10 pts)	__ pts
COVER COMPONENTS	
1. Bird houses (Choose one; numbers of houses are for each half acre or half of a soccer field)	
1 house of recommended specifications for 1 species	1 pt
2-3 houses of recommended specifications for 1 species	3 pts
>3 houses of recommended specifications for 1 species	4 pts
2-3 houses of recommended specifications for 2-3 species	6 pts
>3 houses of recommended specifications for 2-3 species	7 pts
>3 houses of recommended specifications for >3 species	10 pts
Total (of maximum possible 10 pts)	__ pts
2. Treefrog houses (Choose one; numbers of houses are for each half acre)	
1 house in appropriate location	3 pts
2-5 houses in appropriate locations	7 pts
>5 houses in appropriate locations	10 pts
Total (of maximum possible 10 pts)	__ pts
3. Bat houses (Choose one)	
1 house of recommended specifications and placement per half acre	5 pts
>1 house of recommended specifications and placement per half acre	10 pts
Total (of maximum possible 10 pts)	__ pts
4. Vertical dead trees (Choose one; at least 1 foot in diameter and 10 feet high)	
1 per acre	5 pts
2 per acre	7 pts
3 per acre	10 pts
Total (of maximum possible 10 pts)	__ pts
5. Burrows (Choose one from each of the 3 following groups)	
4 inch diameter opening	3 pts
> 4 inch diameter opening	4 pts

Appendix 1. Site Evaluation Checklist -- This checklist can be used to determine the ecological value and site suitability for certain species at any urban site.

COMPONENTS	POINTS
Depth of 1-3 feet	3 pts
Depth > 3 feet	4 pts
Vegetation at least 1 foot tall within 1 foot of entrance	2 pts
Total (of maximum possible 10 pts)	__ pts
6. Brush piles (Choose one)	
1 brush pile	5 pts
> 1 brush piles	10 pts
Total (of maximum possible 10 pts)	__ pts
7. Rock piles (Choose one)	
1 rock pile	5 pts
> 1 rock piles	10 pts
Total (of maximum possible 10 pts)	__ pts
WATER COMPONENTS (Choose one only if it contains water for at least 1 month)	
Above ground bird bath(s)	2 pts
On ground, < 3 inches deep bird bath(s)	3 pts
Installed pond with steep sides and no areas < 3 inches deep	3 pts
Installed pond with sloping sides and some areas < 3 inches deep	4 pts
Installed pond with marsh or swamp plants from recommended list	5 pts
Installed pond with marsh or swamp plants from recommended list and connected to a restored or natural upland area	6 pts
Natural body of water (pond, lake, stream, or river) with native marsh or swamp plants	8 pts
Natural body of water with native marsh or swamp plants and connected to a restored or natural upland area	10 pts
Total (of maximum possible 10 pts)	__ pts
SPACE COMPONENTS	
1. Size of Site (Choose one)	
Less than 1 acre	1 pts
1 to 5 acres	2 pts
5 to 10 acres	3 pts

Appendix 1. Site Evaluation Checklist -- This checklist can be used to determine the ecological value and site suitability for certain species at any urban site.

COMPONENTS	POINTS
10 to 20 acres	4 pts
20 to 50 acres	5 pts
50 to 100 acres	6 pts
100 to 500 acres	7 pts
500 to 1000 acres	8 pts
1000 to 5000 acres	9 pts
more than 5000 acres	10 pts
Total (of maximum possible 10 pts)	__ pts
2. Connected to > 1 acre of good habitats on adjacent properties	
Yes	10 pts
Total (of maximum possible 10 pts)	__ pts
3. Natural succession area	
Natural succession area set aside as recommended	10 pts
Total (of maximum possible 10 pts)	__ pts
4. Annually mowed area	
Annually mowed area set aside and maintained as recommended	10 pts
Total (of maximum possible 10 pts)	__ pts
Grand Total (of maximum possible 160 pts)	__ pts

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Chapter 9: Invasive Plants and the Restoration of the Urban Forest Ecosystem[1]

Hallie Dozier[2]

Abstract

Many ornamental species spread from gardens to natural areas where we do not welcome them. These plants out of place, or weeds, threaten the integrity of our natural systems. As gardeners we demand access to thousands of exotic species, unaware of side effects some have on natural systems. The tale of public expectation of gardening choice and variety began centuries ago. Early colonists worried mostly about food security, but from 1700 to the early 1900s Americans witnessed extensive plant exploration and introductions. Technological advances facilitated the change, as did growing public interest in gardening and growing prosperity found in nursery trade. Early colonists introduced invaders such as Scotch broom and common privet. Later explorers brought in other ornamentals-turned-invaders including China-berry and Norway maple. Welcoming non-native species into our landscapes for centuries has created a multi-billion dollar ornamental plant industry and a gardening public that takes this largesse for granted, selecting primarily on basis of color, shape, and size. Today's public is unaware of the origins of most ornamental plants and of the danger some species pose to natural areas.

Introduction

Today conservationists are concerned about the impacts invasive non-native plants have on our natural landscapes. In North America, thousands of non-native plant species succeed outside the confines of cultivation (Randall and Marinelli 1996), that is, they have naturalized. Most naturalized species are not thought to harm or disrupt the ecosystems where they are found, however, in roughly 300 cases, naturalized plant species have had a demonstrably negative effect in urban and rural natural areas - they have become invasive (Marinelli 1996). Invasive plant species can have direct impacts on natural areas, when they form monocultures, exclude native plants or change ecosystem functions. These changes may, in turn, cause indirect changes to ecosystem processes (c.f. Center et al. 1991; D'Antonio and Vitousek 1992; Mooney and Drake 1986). Of the recognized plant invaders introduced in North America, deliberately and accidentally, over the last 500 years, roughly half were brought in for ornamental purposes (Marinelli 1996). Species that have become invasive include every plant form and they vary in site requirements. They differ in degree of aggressiveness; some take over soon after introduction while others slowly build their

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populations to a critical mass after which they quickly expand into a full-blown invasion (Usher 1988). Spread may be cosmopolitan, affecting similar ecosystems throughout a latitudinal band, or spread may be somewhat limited in range. In North America most invaders are terrestrial herbaceous species, though many are woody (Center et al. 1991), and still others thrive in waterways (Nelson and Richards 1994). Urban forest managers should be concerned about biological invasions for two reasons: 1) urban parks and natural areas may be especially vulnerable to invasion because of high levels of use (disturbance) and close proximity to ornamental plantings; and 2) urban areas, with heavy concentrations of ornamental plantings and potentially heavily infested natural areas may serve as jumping off points for invasion into natural areas.

Although existing infestations remain to be dealt with and pose managers considerable challenges, it would be of tremendous benefit if the movers of plant materials (e.g., landscapers and home gardeners) were more discerning in selecting the plant materials they put into the landscape. Many people, however, even environmentally sympathetic people and experienced gardeners, have little information that would allow discerning plant selection, such as knowledge of a plant's range of origin or potential to be invasive (Colton and Alpert 1998; Dozier 1999). Moreover, though interested in the topic, people generally are unaware of and do not understand the issue of biological invasions, either plant or animal (Colton and Alpert 1998). Among gardeners and landscapers, though, the public traditionally has been better informed. History reveals that our knowledge of landscaping plants has changed since the time when botanical introductions were a topic of intense public interest and discussion. Today, the variety of plants we have seems a matter of course (see **History Section**) to many gardeners whose interest has shifted from the full story of the plant and how it came to our shores to a more functional interest, that is, how a particular plant performs in terms of color, shape, texture and growth potential **(Figure 1)**.

We have, as gardeners, become accustomed to having a tremendous variety of species from all over the world at our disposal, and restricting ourselves to using only native ornamental species would eliminate nine in ten of our most common landscape species (Van de Water 1995), that is, most of our manipulated landscapes are comprised of non-native species. When one of these species becomes invasive we must ask ourselves what are the ecological results of biological invasions? How should we manage invaded sites? How can we prevent future invasions? This chapter discusses the ecology of plant invasions, some general approaches to managing these invasions, and offers suggestions for approaching education efforts regarding invasions. Further, it briefly describes the history of ornamental plants with particular attention to species that have subsequently become invasive.

Figure 1.1

Ecology of Invasions

Definitions

It is important to define commonly used terms before discussing plant invasions. They are:

Weed - a plant out of place.

Exotic - not native to place where found. Typically we consider exotics to be those plants that

Figure 1.2

Figure 1.3

Figure 1.4

Figure 1. Classic non-native landscape choices such as this camellia (1.1), hydrangea (1.2), impatiens (1.3) and lantana (1.4) give gardeners reliable lasting color and interesting textures and shapes.

came to North America with Europeans after 1500 (FLEPPC 1999).

Colonizer - species that enter unoccupied or sparsely occupied habitats, perhaps following major disturbance.

Naturalize - to establish as if native, to escape cultivation and successfully recruit to the next generation.

Invader - invasiveness has many definitions but the common themes are ecosystem dominance, displacement of native species and disruption of system functions. Invaders are:

- Species that proliferate out of control and degrade our ecosystems, make us ill or devour our crops (Devine 1998);
- Species that have a significant effect on native plants and animal; species that modify habitats extensively or those that alter ecosystem structure or rearrange the biology of a system on a large scale (Mooney and Drake 1986);
- Species that can establish in relatively intact sites and come to dominate or replace the native flora (Bazzaz 1986); and
- Species whose introduction does or is likely to cause economic or environmental harm or harm to human health (Office of the President 1999).

Site Invasibility

For the most part, disturbed sites are thought to be the most vulnerable to invasion. Disrupting natural processes in a site puts it at risk for aggressive species to enter the system, become established, and supplant native species (Hobbs and Huenneke 1992). Disturbance does not only imply vegetation clearing or soil disturbance - altered drainage patterns, fire suppression, waste dumps, and storm water runoff filled with fertilizers or pesticides - are all examples of disturbances (see **Chapter 4 - Disturbances and Succession**). Undisturbed sites are rare, however, particularly in urban settings where many invasions tend to occur in disturbed but intact (eg., closed canopy) settings or along the edges of such sites.

Site degradation is not the only factor contributing to invasion: an area must be a suitable site for the invader to succeed and there must be a source of propagules (e.g., seeds, stems, etc.) for the site to be compromised. In heavily landscaped urban areas, propagules abound. Birds may deposit seeds eaten from an invasive shrub, vine or tree in neighboring yards, or bits of a plant may wash down the stream after a heavy rainfall. A plant lover may even opt to toss an unwanted plant into the wooded lot behind the house because he or she cannot bear to throw it on the trash heap. Depending on the species, though, even a plant thrown on the trash heap may be the starting point for an invasion.

Species invasiveness

Not all species are equally invasive, but invaders often share several characteristics that give them the advantage in a native ecosystem. They may be fast growers, have high reproductive allocation (e.g., heavy flowering and fruiting), have easily dispersed seeds and high germination rates, they may tolerate a variety of site conditions, and they may be hard to eradicate (Baker 1965). In other words, they are easy to start and grow, and they are difficult to kill - good landscape plants for urban gardens (Dozier 1999; Koller 1992).

One example of an ideal invader is the common privet (*Ligustrum vulgare* L.), one of the earliest (1500s) European arrivals in North America. In addition to its landscape value, this multi-purpose shrub served for dyeing, tanning, fiber, ink, and it had medicinal applications (Haughton 1978). Until the early 1800s it was the only privet grown in America, but by the early 1900s this deciduous shrub, susceptible to twig blight, had been replaced in landscaping largely by Japanese privet (*L. japonica* L.) **(Figure 2)** and Chinese privet (*L. sinense* Lour.) (Wyman 1969).

These are but three introduced privets in modern nursery trade - where there is confusing mislabeling among dozens of privets (Bender 1998; Brown 1945; Odenwald and Turner 1987). Together, these three species have become nuisance plants in natural areas across the country from New England to Texas (Randall and Marinelli 1996). The characteristics that make privets the most commonly planted shrubs in North America today translate into characteristics that contribute to their invasiveness (**Table 1**).

Figure 2.1 Photo by Charles Fryling

Figure 2.2 Photo by Charles Fryling

Figure 2.3 Photo by Charles Fryling

Figure 2. Common ligustrum (2.1) was one of the earliest introductions, brought in for its multiple uses. Together with Chinese ligustrum (2.2) and Japanese ligustrum (2.3), this genus has become extremely invasive in forests and open areas across the country.

Table 1. Landscape characteristics and invasiveness of privets.

Landscape Worthy Characteristics	Invasive Characteristics
Propagates easily from seeds and cuttings	Sexual and asexual reproduction strategies
Long flowering period, abundant flowers	High reproductive allocation
Abundant flowers	High reproductive allocation
Flowers attract bees	High reproductive allocation
Abundant and conspicuous fruit display	Appealing to dispersers
Late summer to winter fruit display	Appealing to dispersers
Attracts wildlife and provides habitat	Appealing to dispersers
Prunes well	Tolerates above ground damage
Evergreen (except L. vulgare)	Continuous growth
Thrives in sun or shade	Generalist habit
Grows easily in any soil	Generalist habit
Tolerates difficult conditions	Generalist habit
Moderate to fast growth rate	Outgrows slower growing species

Ecological Impacts of Invasion

Not all invasions are created equal, but the speed with which ecosystem changes occur when invasive non-native species establish populations in natural areas is alarming (Usher 1988). In severe cases, invaders may form monocultures and completely exclude native species, such as has occurred with purple loosestrife in northern wetlands (Blossy 1996; Mal et al. 1992; Mercer 1990). In cases where rare plants are endangered, loss (from direct competition with invaders) is a serious impact. Loss of rare species is not the only impact of non-native plant invasions, however. Plant invasions may also cause ecosystem structure to shift from herbaceous to woody, as when Chinese tallow tree invades southeastern coastal areas (Bruce et al. 1995). In other cases forests may be reduced to herbaceous systems when vines, such as kudzu (*Pueraria logbata* (Willd.) Ohwi) and English ivy (*Hedera helix* L.) **(Figure 3),** cover hectares of canopy trees (Bennett 1993; Reichard 1996a) and prevent the next generation of trees from establishing (see **Chapter 4 - Disturbances and Succession**).

Figure 3.1

Figure 3.2

Figure 3. Invasive vines can smother mature forests, preventing recruitment of seedlings to adulthood. Most kudzu (3.1) was brought in for erosion control in the southeast, though it has also been used as an ornamental species. English ivy (3.2), introduced before 1750, invades mature forests in the Pacific Northwest and is easy to propagate as a house or garden plant from rooted cuttings.

Conversions in vegetation due to invasion, in turn, drastically alter ecosystem functions when they change hydrologic, fire or nutrient cycles (Neil 1983; Vitousek and Walker 1989; Whisenant 1990).

Changes in plant assemblage have another effect: Plants are the starting point for all food webs - shifts in plant community composition affect food quality or availability, leading to changes, beneficial and detrimental, to the health of dependent animal populations. Invasive plants may grow so thickly that small mammals, for example, are effectively screened from overhead predators, leading to a shift in their population which, in turn, causes other changes in the system. When changes occur over a short period of time, it may be too rapid for other organisms in the system to adjust.

In the southwestern United States salt cedars (*Tamarix* spp.) have invaded riparian areas and changed the composition and function of those systems. The story of salt cedar is unique in that managers have been working to control it for almost half a century. This small tree was brought into the United States early in the 19th century and used for decoration and erosion control (Kennay 1996) **(Figure 4)**.

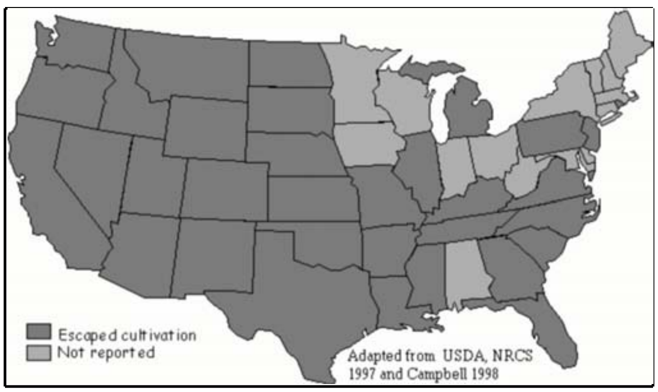


Figure 4.1

Figure 4.2 Photo by Charles Fryling

Figure 4.3 Photo by Cotton Randal

Figure 4. Salt cedars have plagued land managers for over 50 years (4.1). Originally introduced for ornament and erosion control, these small trees have naturalized across the country (4.2). In the southwest they invade riparian zones and stabilize riverbed formation, crowd out native plants, and lower water tables (4.3).

In the Rio Grande Valley conditions that facilitated salt cedar invasion came about from human manipulation of the river, including flow diversion and livestock grazing. These activities, and the ensuing environmental degradation, set the stage for salt cedar domination of riparian vegetation (Taylor and McDaniel 1998). Salt cedars stabilize river sand bars and prevent natural channel movement. They also induce degradation by tapping into the water table and altering natural hydrology (Muzika and Swearingen 1997)

Natural system structures may change when invaders such as Chinese tallow tree (*Sapium sebiferum* (L.) Roxb.) arrive **(Figure 5)**. Tallow tree, introduced in the late 1700s, was brought here for the practical applications it afforded - it provides an excellent source of oil used for candle and soap making, and it can provide shade under harsh conditions, like those in a farm's chicken yard (hence a regional name "chicken tree"). During the expansion of the petroleum industrial complexes near Houston, Texas during WWII, landscape experts recommended this fast-growing tree to give quick shade and reliable fall color to the new subdivisions that sprang up near refineries (J. Griffith, Louisiana State University, 1999, personal communication). These refinery towns are located in the Gulf Coastal Prairie - the remnants of which today are seriously threatened by Chinese tallow invasion (NWRC 1999). Chinese tallow tree's impact in this area and elsewhere has been to convert grasslands to forest, a structural change that also affects function. For example, natural fire regimes change because tallow tree burns less easily than native grasses, it shades out natives, and rapid breakdown of its leaves is believed to alter soil solution composition, contributing to faster eutrophication of wet systems where it grows (Cameron and Spencer 1989). Its leaves also release tannins which have a negative impact on some invertebrate populations (Cameron and LaPoint 1978). This species is not restricted to wet sites, though, it also invades upland sites (F. Lorenzo, Southern University, 1999, personal communication). After centuries of cultivation and improvement in its native Asia, this species is essentially pest-free (Jubinsky 1995). Worse yet, it also sprouts vigorously after cutting and is a prolific seeder with high germination success, making management extremely challenging.

Figure 5.1

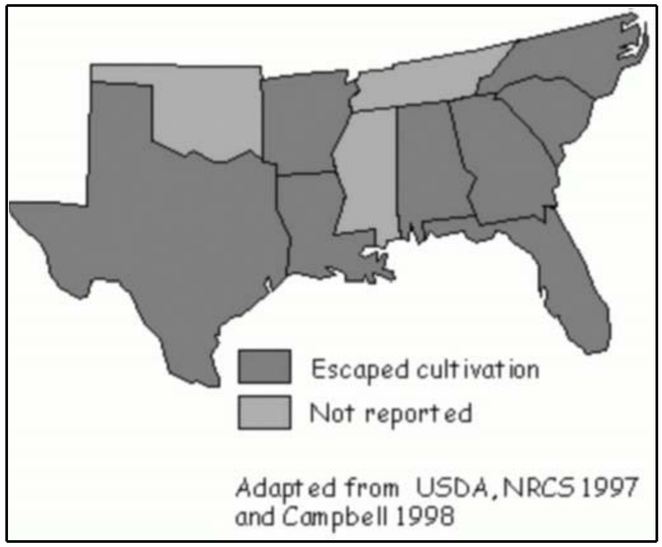


Figure 5.2

Figure 5. Chinese tallow tree (5.1) invasions convert grasslands to forests, changing landscape structure and shading out natives (5.2). It continues to be a popular landscape plant in the southeast, due to its reliable, brilliant fall color.

Management: Technical

How do we handle current invasions and how can we prevent future invasions from occurring? Managing invasions can be prohibitively expensive (MacDonald and Wissel 1989; Taylor and McDaniel 1998), therefore managers must carefully decide which invasions to tackle, weighing cost, feasibility and likelihood of success. Using volunteers may make management and control more practical when otherwise it would be too costly (Bradley 1988).

Using a mixed approach that employs chemical and mechanical methods may be the best means of insuring long-term success (Dozier et al. 1998), but to do so, it is helpful to understand some critical aspects of the invasive species' life history (e.g., ability to coppice, reproductive strategies, response to herbicides, etc.). Several volumes have been published that are instructive to managers seeking to control a variety of invasive species, including those introduced for ornamental purposes (see **Suggested Readings and Other Information**).

Chemical Control

The key to long-term chemical management of perennial weeds is to deliver a lethal dose of the appropriate chemical to the underground tissues. Translocatable herbicides follow the movement of photosynthates, that is, sugars manufactured during photosynthesis. It is essential, therefore, to time herbicide application to coincide with movement of photosynthates to storage organs so the herbicide is transmitted to a plant's underground tissues. Technical parameters determining management success of invasive species include type of herbicide used, strength, and number of applications. While source/sink movement is the main physiological parameter affecting chemical management success, others include leaf developmental stage and point of delivery. Careful consideration of environmental conditions and an understanding how these conditions affect physiological parameters of the invader are also important for successful control (Dozier et al. 1998). For example, some species may require multiple applications to inhibit regrowth from hard-to-kill underground tissues.

Developmental stage of an invader may influence herbicide efficacy (Lee 1986; Willard 1988), and herbicide absorption may vary with location of contact (Townson and Butler 1990). Physiological responses to changing environmental conditions can affect delivery of herbicide to underground tissue in perennial invaders and therefore influence management success. Seasonal changes, for example, may have an impact on control. Periods of low rainfall, and thus low available soil moisture, may allow for greater concentration of herbicide in underground tissues. Also, late summer to early fall applications, when carbohydrates are being shunted to storage tissues, may increase translocation to underground tissues.

Mechanical Control

In some cases mechanical methods (cutting, mowing, uprooting, burning, etc.) are effective for controlling an invader. Mature plants may be cut down or whole seedlings removed. For persistent perennial species, though, one round of treatment usually does not suffice, and repeated physical removal may be required to free a site of an invader. Usually such intensive management is not practical or affordable, though biomass reduction will result (Gaffney 1996; Willard 1988), aiding in the short-term recovery of the treated site.

Norway maple (*Acer platanoides* L.) **(Figure 6)** was introduced in 1762 (Wyman 1965), and since has naturalized across the eastern region of the United States.

One of the most commonly planted street trees across North America, there are over 20 varieties available in retail nurseries. Its ability to displace native maples in natural areas may be linked to its resource allocation to a heavy foliar display which, in turn, enhances its shade tolerance and ability to shade

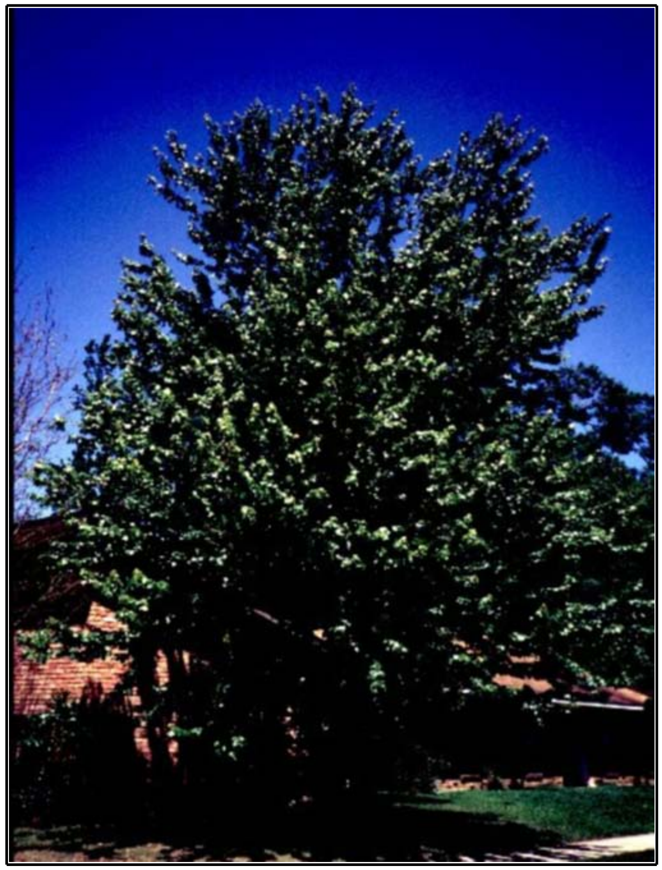


Figure 6.1

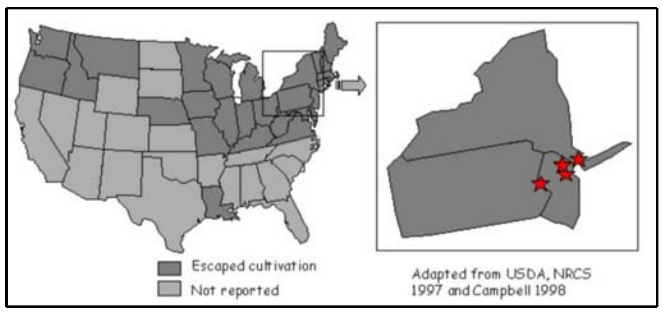


Figure 6.2

Figure 6. Norway maple successfully competes with native maples due to greater allocation of resources to foliar display (6.1). It is the most planted street tree in the country, which may explain, in part, its spread in natural areas across the nation, especially in the northeast (6.2).

out understory vegetation (Niinemets 1998; Randall and Marinelli 1996). The Norway Maple Removal Experiment in the Drew University Forest Preserve near Madison, New Jersey employs only mechanical methods. In an effort to restore native ecology in the forest preserve, volunteer students and faculty, and paid grounds crews from Drew University used machetes and chain saws to remove and girdle the trees in January 1998. Thus far they have been able to avoid using chemical control and are hoping that natural regeneration will eliminate the need for replanting native species. Ongoing monitoring suggests that planting will be necessary to restore native species, though large herbivores (e.g., deer) will make replanting a special challenge.

Mechanical control alone may work best in the early stages of invasion such as in the case of English holly (*Ilex aquafolia* L.) **(Figure 7)**. This beloved holly of songs and holiday festivities was introduced in the eastern United States prior to 1750, and in the Pacific Northwest, in the 1860s (Lang et al. 1997; Wyman 1969). In climates somewhat similar to its native Mediterranean range, this small tree has since naturalized in forested areas of California, Hawaii and Oregon (USDA and NRCS 1997). Conservationists concerned about English holly populations developing in rare old-growth forests in the northwest have incorporated its removal into restoration projects that target other invasive species. The city of Arcata, California is taking advantage of existing restoration work in forest remnants to remove shade tolerant English holly before the problem gets out of hand (G. Ammerman, City of Arcata, 1999, personal communication). With a no-use chemical policy, all removal efforts are manual - volunteer workers concentrate on hand pulling young plants during Invasion Removal days. Larger trees are rare, but each is hand dug carefully to prevent excessive disturbance to the site. Given the concern about protecting old-growth forests (Reichard 1996b), Arcata's early intervention approach to English holly is sensible, particularly in light of the expense and difficulty managers face when invasions expand rapidly or are ignored during initial stages (Hiebert and Stubbendieck 1993; Hobbs and Humphries 1995; MacDonald and Wissel 1989).

Figure 7.1

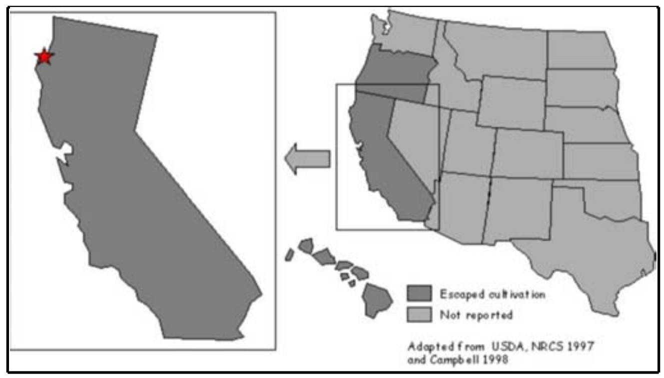


Figure 7.2

Figure 7. English holly (7.1) has begun to show up in old growth coastal forests (7.2) where managers remove whole seedlings and carefully excavate mature plants.

Integrated management

Reliance on a single means of control may be prohibitively expensive or result in failure for aggressive species. A practical approach may be to use mechanical control followed by chemical application. For example, a woody species that sprouts after cutting may be cut and herbicide immediately painted onto all cut surfaces. A species that responds to cutting by sprouting along the length of its surface roots may be treated with herbicide *before* cutting or treated and left standing. Invasive species also may be mechanically treated, allowed to grow new photosynthetic tissues, and then treated with herbicides. The benefit of this approach is that chemicals are applied to plants which have been weakened by drains on carbohydrate reserves (starch allocated to new shoot growth). Additionally, herbicide application to the flush of new plant tissues may maximize absorption and result in greater efficacy.

Integrated management also includes replanting the site with suitable species, for if the space freed by removal of the invader is not filled with another plant, the invader may return. After suppression of the invader, the establishment of desirable plant species is essential for long-term control of the site (Dozier et al. 1998; Taylor and McDaniel 1998). The strategy should be to replace the invader, not temporarily remove it.

An example of such integrated management is a salt cedar removal project in New Mexico. A variety of methods have been used over the last half century to control salt cedar, and researchers continue to look for the combination of techniques that yields the best result while lowering costs. Recent restoration research in the Bosque del Apache National Wildlife Refuge suggests that traditional clearing (mechanical and chemical) followed by planting native cottonwood and black willow poles can give excellent results (Taylor and McDaniel 1998). In addition to the integration of traditional control methods, that is, removal of the invader and replanting native vegetation, a new component has been tried in these sites: timed irrigation is used to contribute to natural regeneration of native species while reducing salt cedar to a minor community component. It appears that reactivating or mimicking *natural* water flow may prove essential to long-term management of this species in riparian systems.

Management: Social

Tastemakers

Educating the public about the benefits and pleasures of gardening was the task of the 19th and 20th century tastemakers (see **History Section**). Our challenge today is to inform people about environmentally wise gardening as a means to reducing biological invasions. History identifies the groups who in the past have influenced the public to become gardeners. They are the same as those who are instrumental in landscaping trends today - garden writers for popular publications **(Figure 8)**. For the modern media of television and radio, this group also includes broadcast writers, producers and hosts. It would benefit conservationists to recruit the efforts of garden editors of top selling journals such as *Sunset Magazine, Ladies' Home Journal, Better Homes and Gardens*, and *Southern Living*, for each of these popular magazines reach millions of readers (Wissenfeld 1998) and regularly influence people's choices of landscape plants. If the tastemakers feel concern about this issue they will undoubtedly add this focus to their work. Opening lines of communication between garden writers and biological conservationists can only improve the quality of information reaching gardeners.

Figure 8. Many popular magazines feature gardening articles, which may promote invasive species. This 1994 article from Southern Living touts Chinese tallow for its superior, early, and reliable fall color - a quality missing in many native southern trees.

Landscapers, Horticulturalists, and Nursery Owners

Customers rely heavily on nursery and garden center personnel for gardening advice (Safley et al. 1993), however, nursery personnel are unable to identify the native range of most of the plants they sell, the majority of which are not native (Dozier 1999). If ornamental horticulture and landscape design courses touched more on this topic, students who go on to work in the nursery or landscaping trades would be better equipped to understand this issue. This, in turn, would have a positive effect on how they conduct their businesses and how they pass on information to their customers. People also turn to their local Cooperative Extension agents for advice. They too, could benefit from exposure to the subject during their training.

Community Groups

Direct observation is a powerful tool in teaching the public about non-native invasions. In a survey of retail nursery customers (Dozier 1999), those familiar with invasions were most likely to know about the invasions as a result of personal experience with the species or personal observation. Putting restoration work in the public eye can be a means to teaching people about invasions.

Today several projects across the country are tackling non-native plant invasions, and many of the restoration projects are in high traffic, high profile parks and preserves. Highly visible projects, particularly those that deal with landscaping favorites, should include interpretive materials that clearly outline the problem in that particular site, the breadth of the problem in general, and the importance of restoration activities and prevention. These messages, however, are not always easy to convey, and project organizers must take public sensitivity and attachment to favorite plants into consideration. Organizers of a Chinese tallow tree replacement campaign in Gainesville, Florida, learned hard lessons about public reaction to tree removal - any tree removal (Putz et al. 1999). This well planned campaign was supported by a variety of critical stakeholders, including local nurseries, government officials and educators, and it provided educational components and incentives for home gardeners. Despite these excellent efforts, though, press coverage of the removal of a rather large specimen on Arbor Day (a local newspaper ran a color photo of one of the project planners next to the tree, chainsaw in hand) sparked critical backlash from the public. Thoughtful planning and careful implementation are crucial to success, but they may not garner desired results if public sentiment is underestimated.

A project that had better public reception was a miconia (*Miconia calvescens* DC.) eradication project in Hawaii (Loope 1996; Mesureur 1996) which employed (with considerable effort and expense) television broadcasts, extensive press releases, articles in major daily and weekly publications, and distribution of hundreds of "most wanted" posters. The efforts were so successful, in fact, that citizens reported previously unknown populations to authorities allowing them to implement early control measures. The cost was high in terms of effort, but it resulted in a public more attuned to the issue of non-native plant invasions and more vigilant about personal gardening practices.

Another way to teach these lessons is through involving community members directly in restoration work (Bradley 1988; Devine 1998). When volunteers or other members of the public help remove exotics and revegetate with natives, it gives them the opportunity to have a real impact on their (public) natural areas. It also gives managers the opportunity to teach participants about wiser plant selection for their personal gardens. The physically challenging task of grubbing out small trees and shrubs makes a lasting impression that may influence a person's future choices in landscape plants.

Non-native plant invasions are going to occupy land managers for years to come. The contribution to this problem from urban areas, in the form of ornamental species, is considerable, and urban managers should pay special attention to addressing this issue. Ornamental gardening history gives us a glimpse of how modern fashions in landscaping developed, and suggests how best to reach the gardening public to reshape those tastes. The gardening public, as well as those who work in nurseries and as landscapers, clearly can be instrumental in stemming introduction of invasive species; managers should concentrate on demonstrating to these groups - directly and through gardening tastemakers - the damage invasions cause. There are many opportunities for teaching people about the issue of non-native plant invasions: popular articles (including radio and television) on gardening, highly visible restoration projects, and education of resource people such as nursery personnel, landscapers and extension agents. Just as taking advantage of these opportunities enamored the country with ornamental gardening (See **History Section**), these paths will allow us to develop into a country of environmentally conscientious gardeners.

Wise Gardening Choices

What is the best educational message to give those who decorate the urban landscape with ornamental plants? It will not work simply to pass out lists that inform people which plants are "bad." While extremely useful, lists of invasive plants may be difficult to compile and maintain - the lists necessarily changing as scientists recognize more invasions. Moreover, such lists may not indicate exactly where a particular species is problematic (FLEPPC 1995; FLEPPC 1999) which reduces the list's usefulness. Nor will it work to teach people simply to "plant natives" - most popular landscape species are not native, and some natives can be as aggressive and weedy, or as finicky, as non-natives. Not only that, people may not respond well to a simplistic approach that dictates what to plant and what not to plant. Guilt over selecting a non-native plant should not be a side effect of education.

A more feasible and beneficial course of action is to teach people to gather as much information as they can about the species they select. Learning about landscape species gives gardeners interesting information about the plants they use, and it will give them the opportunity to make environmentally sound choices in their gardening. In addition to asking for information that will help them pick the right plant for their landscape needs, gardeners can ask the following:

1. What is this plant's native range?
2. How does the plant reproduce?
3. Is this a plant that needs a lot of maintenance to keep it in check?
4. Is it an aggressive grower?
5. Does it attract birds?
6. Is it known to be invasive anywhere?
7. Is it known to be invasive in areas similar to where I want to plant it?

Answering these questions will allow gardeners and landscapers to have a better idea how their choices may impact (if at all) areas outside of the site they intend to change. This, in turn, should lead to wiser choices on the part of gardeners and landscapers.

History

Ornamental Plant Introduction

Our gardens are crowded with an amazing wealth of exquisite plants both ornamental and economic; our lawns are studded with superb trees and shrubs satisfying in form, color, flower, and often, fragrance; our orchards bear fruit in such variety as to lengthen their seasons far beyond those of only a short time ago. Our annual crops of garden catalogues are filled with long, awesome lists, incredible illustrations, and Baron Munchausen descriptions. As a result, our minds are confused by numbers and beauty and wearied by the labor of making choices. Surely our notion of "bigger and better" has run riot in gardens, their catalogues and their books. Do we even wonder or speculate as to how this has come about? Or do we lazily accept the largesse?

-Ann Dorrance, 1945, p.73

Age of Function: Early Colonial

Spices and medicines derived from plants were commodities important enough to drive the vast world explorations conducted by 15th century explorers (Dorrance 1945). Men and women who settled in North America had little time for gardening except that which was necessary to insure an adequate supply of food, flavorings, medicines and fiber. Naturally, they brought with them plants from home including fruit trees and medicinal herbs (Leighton 1986; Manks 1968; Martin 1988; van Ravenswaay 1977; Wyman 1968) **(Figure 9)**.

Some of the plants they brought were not native to Europe, but adopted from other areas already

Figure 9.1

Figure 9.2

Figure 9. Early settlers brought important medicinal and culinary herbs and food plants with them when they arrived in North America. Tansy (9.1) has naturalized in several states and is considered invasive in the Pacific Northwest and elsewhere. Figs (9.2) have escaped plantations in California's central valley to invade riparian zones (Randall and Marinelli 1996).

explored; peaches, native to Asia, were brought here by Spaniards in the 16th century (Crosby 1986; Manks 1968) **(Figure 10)**.

Well into the 17th century colonials had so little leftover from their harvests that they relied, for the most part, on Europe for most of their goods, including each year's seed supplies, thus regular intercontinental transport of plant materials began early.

Figure 10.1 Photo by Larry Korhnak

Figure 10.2 Photo by Charles Fryling

Figure 10. Peaches have been in cultivation for thousands of years (10.1 and 10.2). Native to Asia, they first came to North America with early Spanish explorers. Adopted by native tribes, later European settlers initially believed peaches native to the New World.

Some of the plants deliberately introduced during the 16th and 17th centuries have naturalized; a few are considered problem species in our landscapes today. They include Scotch broom (*Cytisus scoparius* L.) **(Figure 11)** and common privet (Wyman 1968; Wyman 1969).

Age of Exploration: Eighteenth & Nineteenth Centuries

Though colonists settling into their new environment continued to be interested primarily in gardening for function, the 18th century was a time of great feats of plant exploration, export and

Figure 11. Scotch broom was brought into the U.S. for practical and ornamental purposes. Here the shrub colonizes areas leveled by the 1992 fires near Berkeley, CA. Photo by Susan Gabbard

introductions (Hedrick 1950; Manks 1968). Botanists John Bartram and André Michaux, among others, actively exchanged plant materials between the world's continents, particularly North America, Asia and Europe. Bartram, who became the American botanist to King George III, enthusiastically sent native American plants to England in exchange for European and other species that had performed well in Europe. Michaux also helped populate European gardens with native North American plants; during a ten-year period he sent more than 60,000 live plants back to Europe (Hedrick 1950; Manks 1968). His contributions to North America include the China-berry tree (*Melia azedarach* L.) **(Figure 12)**, which came from Asia via France, several popular species of azalea (*Rhododendron* spp.), and crape-myrtle (*Lagerstroemia indica* L.), which he introduced to the Charleston, South Carolina area (Hedrick 1950). The work of these two men and their contemporaries formed the basis of our current knowledge of North American species, and we regard them as great visionaries for their spirited investigation and dissemination of American natives.

Commercial plant trade tended to de-emphasize the value of native plants while promoting non-native species. Robert Prince, who established the first commercial nursery in Flushing, New York in 1737, mostly promoted European novelties (Manks 1968). An early advertisement from Prince Nursery included dozens of species of apples and stone fruits as well as ornamental species such as silk-tree (*Albizia julibrissin* Durazz.) **(Figure 13)**, European Snowball (*Viburnum opulus* L.), and tree

Figure 12. An early introduction brought from Asia to North America by French botanical explorer, André Michaux, Chinaberry tree has been used extensively as a farm tree. Though many across the southeastern states consider it a weed tree, it is also is useful for quick shade and fuel wood (Haughton 1978). Photo by Charles Fryling

of heaven (*Ailanthus altissima* (Mill.) Swingle) **(Figure 14)** (Hedrick 1950; McGourty 1968b).

Figure 13. Gardeners enjoy the mimosa, or silk tree, for its shape, texture and fragrant pink blossoms. Introduced in 1745, this species since has become naturalized from New York to California (USDA and NRCS 1997).

Notable introductions of the 18th century which are with us today and which are, in some areas, invasive, include English holly, Norway maple, a troublesome species in northeast and northwest that came in 1762, and English ivy (*Hedera helix* L.), introduced in 1736 and now a major invader in natural areas along the northern Pacific coast Randall and Marinelli 1996; Wyman 1965; Wyman 1968).

Age of Adornment

By 1837 when Victoria ascended the British throne, several events had occurred in the United

Figure 14. Another early introduction (1784), the tree of Heaven is valued in colder regions of the country for its tropical-looking foliage and its ability to withstand harsh urban conditions (Wyman 1968). In the southwest, it is appreciated for its medicinal properties (Cheatham et al. 1995). Photo by Charles Fryling

States and abroad making way for the whirlwind of horticultural activity that continued into the 20th century. During the short span of 100 years, global exploration increased, international trade became less burdensome, the number, quality and availability of printed materials increased, and industrialism stimulated a prosperity that allowed the widespread novelty of leisure time. These elements combined to create a climate where pleasure gardening became fashionable, accessible, affordable, and profitable.

Transportation, domestic and international, improved dramatically during the early part of the century. The opening of new post roads, the Erie Canal (1825), and the Long Island Railroad (1836) not only increased people's mobility, it facilitated movement of gardening stock, especially by mail order (Manks 1968). The historically famous M'Mahon Nursery was just one of many eastern sellers offering seeds and bulbs through the mail.

Early in the century, most plants were brought in by botanical explorers, who commonly were sponsored by wealthy patrons and botanical clubs. With improvements in oceanic transit, world travel became more common, and commercial nursery owners interested in obtaining new or rare plants by a faster route appealed directly to travelers to carry home starting stock (Manks 1968).

Improved transatlantic travel had another impact on gardening in the United States as well: one upmanship. With increasing numbers of Americans traveling to Europe and Europeans traveling to the United States, a competition grew up between the two continents, especially in the highly visible areas of economy, social politics, and horticulture. Europeans wrote prolifically about inferior American landscapes and Americans shared with each other impressions of beautiful and extensive European gardens. According to 19th century horticulture historian, Tovah Martin (1988), the situation for Americans was not unlike Adam and Eve discovering their nakedness, "The shame...was infinitely confounded by the realization that the rest of the world was clothed" (p. 51).

Newfound prosperity from industrialism allowed Americans the leisure time to indulge in horticulture as a pastime. This was especially true for girls and women who used botanical pursuits as a socially acceptable way to express themselves intellectually and artistically (Martin 1988). Leisure time also allowed for pleasure reading, and by the 1830s gardening magazines were common, including those that featured articles describing tropical regions of the world, where plant hunters busied themselves collecting ever new and interesting specimens for return to the United States. Authors wrote articles specifically to educate and entertain a public eager for sophistication and to encourage the American public to become enamored with pleasure gardening. These articles also served as a way to bring the exotic world into the homes of everyday Americans.

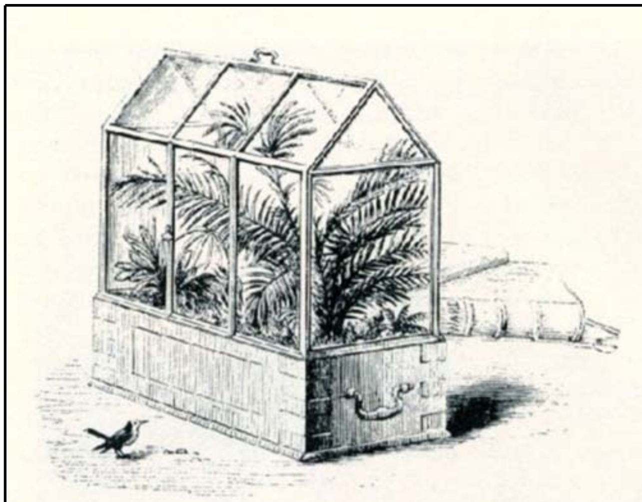
Throughout the century, gardening advocates inundated the press, garden clubs and speech circuits with encouragement for fledgling gardeners (Martin 1988). They were the "tastemakers of the times [who] saw their tasks primarily as a battle against widespread ignorance," and thus, from the 1830s onward, "Americans were subjected to an onslaught of consciousness raising publicity aimed at educating the masses about the pleasures of ornamental gardening." To ensure that citizens did not forsake these new pleasures and return to their traditionally puritan ways, they were "continually coached by vigilant gardening advocates" (p. 52).

Nursery owners joined others in promoting pleasure gardening to an increasingly interested public. A growing number of gardening journals provided readers with detailed instruction on how to plant and care for the variety of plants becoming available across the country. Many of the guides were written, edited, and published by large nurseries and seed houses. Nurseries and seed houses also frequently financed gardening books. With the sponsorship of nursery and seed house owners, Edward Sayers published three editions of *The American Flower Garden Companion* (1838). Such publications also served commercial nursery owners as advertisements - most consumers preferred getting their gardening advice from experts. One publisher unfortunately promoted his book with claims of objectivity, for he had no connection to any nursery, and made such a poor impression that his magazine failed in its first year (Hedrick 1950).

Over the century, the popular press continued to bring the thrills and excitement of plant exploration into American homes. The ongoing adventures of botanical explorer Robert Fortune in China were published, in serial form, in the influential horticultural journal, *The Horticulturist and Journal of Rural Art and Rural Taste* (1846-1852), edited by premier landscape architect, A.J. Downing. Other publications provided subscribers with colorful accounts of jungle treks in many far away places, sometimes including detailed illustrations of exotic queens and kings to captivate the American reader (Martin 1988).

Independent horticulture societies (the first was established in New York in 1818) began appearing in addition to those that had branched from larger, older agricultural societies formed during the previous century (Hedrick 1950). These clubs, which frequently relied on the support of wealthy, horticulturally inclinded community leaders, began to encourage nursery owners to import and develop more and more ornamental specimens (Manks 1968). In 1827, President John Adams made an official request to foreign consuls to send seeds and specimens of rare plants back to Washington for later circulation, beginning a long period of government-sanctioned plant introductions that continues today (Wyman 1968).

Mid-century found America's obsession with non-native plants widespread and unstoppable (van Ravenswaay 1977). Lawns which had been dominated by lush green were now neatly trimmed with newly developed lawn mowers. Gardens featured a variety of color from easily available, tender (e.g., cold sensitive), tropical plants brought to North America in Wardian Cases **(Figure 15)** and raised in larger, improved glass houses **(Figure 16)**.



104. A Wardian case, as depicted by Nathaniel B Ward (1791–1868) in his book on the subject.

Figure 15. English botanist Nathaniel Bagshaw Ward (b. 1791 d. 1868) found a way to defeat lethal salt water and sea spray that commonly decimated entire live cargoes when, in 1832, he successfully shipped live seedlings from England to Australia in closed, glazed glass cases - changing forever the business of plant import (Dorrance 1945).

Figure 16.1 Photo by Charles Fryling

The trend of using tropicals as bedding plants, which clearly allowed for the continuous introduction and sale of new plant material, continues today **(Figure 17)**.

Writers in the 1860s continued urging Americans to adorn their estates with color and bloom. Those who actively promoted gardening

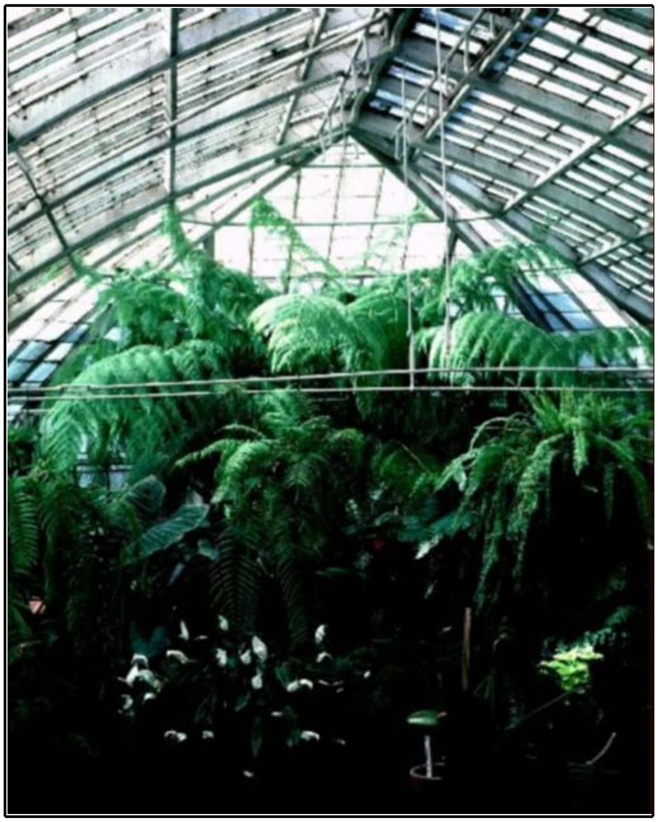


Figure 16.2 Photo by Charles Fryling

Figure 16. By the 1840s, glass making had improved greatly and manufacturing techniques for cast iron made it possible to construct large, stable glasshouses for growing every variety of plant. Pictured here, the Palm House at Kew Botanical Garden in London (16.1) and the interior of the Golden Gate Park Conservatory in San Francisco (16.2).

Figure 17. Nineteenth century gardeners began using cold tender tropical plants as houseplants and as warm season annuals, practices that continue today.

believed that most Americans could benefit from expert help in order to develop their skills as landscape designers. To ease the transition from novice to experienced gardener, F.J. Scott addressed the gardening needs of average families who lived on small (~ 1/2 acre) suburban lots. This work appealed to a large audience and helped "induce every family" to explore the satisfaction of gardening and raptures of tropical plants (Martin 1988). Private homes were not the sole domain of horticulture. For a period of several years, A.J. Downing used his journal to supply a steady stream of editorials in which he implored Americans to convince their local governments to establish and fund public parks for pleasure and recreation (Hedrick 1950). Due to his efforts, those who did not own their own property where they could enjoy the physical, psychological, and moral benefits of gardening were able to enjoy the new urban park systems designed and developed by men like Frederick Law Olmstead, designer of New York City's Central Park and Boston's Emerald Necklace (Eisner 1994), and Thomas Meehan who spearheaded the acquisition of lands for Philadelphia's city parks (McGourty 1968a). Gardening for pleasure became not only vogue, it was on its way to becoming common, and the effect on the plant trade was enormous. Scott's continued bombardment of the American public with articles promoting the knowledge of gardening and the enjoyment of using tender tropical plants as annuals perpetuated plant introduction in two ways: nurseries had to scramble to provide customers with a constant source of new plants from foreign places, and they had to continue to stimulate the demand for new plants. Plant hunters continued outbound with the goal of introducing new and rare specimens to the gardening public.

Following the Civil War, which temporarily slowed horticultural progress, the opening of the Arnold Arboretum in Boston (1872) renewed the stimulus for introducing non-native plants, particularly Asian flowering shrubs (Wyman 1968). In the late 1890s the federal government established the Office of Plant Introductions, which facilitated a steady stream of plants into the country (Fairchild 1928).

Hundreds of foreign plant species came into North America during the 1800s. Some have naturalized and persist in modern landscapes, including porcelain berry (*Ampelopsis brevipedunculata* (Maxim.) Trautv.), salt cedar, Japanese honeysuckle, coral ardisia (*Ardisia crenata*

Sims.) and Chinese wisteria (*Wisteria sinensis* (Sims.) Sweet) **(Figure 18)** (Wyman 1969)

Figure 18.1

Figure 18.2

Figure 18.3

Figure 18. Both Chinese wisteria (18.1) and Japanese honeysuckle (18.2) have long been known as aggressive vines that escape cultivation in the eastern portion of the United States. Almost 200 years after introduction (1804) nandina (18.3) is making the jump from garden to natural areas in northern Florida. Nevertheless, such old-time ornamental species appeal to gardeners for their fragrance, color and nostalgia (Dozier et al. In preparation).

Though the river of new plants introduced from abroad slowed to a comparative trickle by the early 1900s, our affection for landscaping and ornamental gardening did not. A new generation of plant explorers grew up and horticulturalists refined the art of breeding new varieties of well-loved species. Botanical explorer, David Fairchild, under patronage of Lathrop Barbour, introduced many species during the first half of the 20th century (Fairchild 1938). For over forty years, during most of which time he worked as chief of the Seed and Plant Introduction Section of the USDA (1898-1940), he collected thousands of seeds and live plant specimens and brought them into the United States. While Dr.

Fairchild considered the majority of species he introduced useful (Fairchild 1928,:3-11), he usually managed to procure several purely ornamental species during any collection expedition (Wait 1968).

In 1918, Plant Quarantine 37 became law after several damaging insects and diseases arrived with new plants (Wyman 1968). While making certain that new plants were free of insects or diseases lowered the chances that pests harmful to economic crops would enter the country, in some cases the practice effectively freed new plants from their natural controls and contributed to their invasiveness (Jubinsky 1996; Randall 1996).

Horticultural activity slowed for most Americans during the 1930s due to the Great Depression, dampening nursery sales, but post-World War II economic recovery in the late 1940s allowed tremendous regrowth in this area. In the period following the war, the garden center movement developed, which, in turn, revolutionized the retail plant industry (Schneider 1990). Homeowners soon were able to buy directly from nurseries without having to wait for mail order, and perhaps more importantly, they were able to buy all their supplies - tools, seeds, soil, fertilizer and pesticides - and obtain gardening advice, in one convenient location.

The Twenty-First Century: So Greatly Does Custom Prevail

Today countless images from daily newspapers, magazines, books, films and television continue to fuel our love for gardening. Enthusiasts can peruse pages of colorful photographic layouts and articles listing the multiple advantages of different plants, or they can wander about any of over 400 beautifully tended botanical gardens (B. Boom, New York Botanical Garden, 1997, personal communication) filled with flowering specialties from around the globe **(Figure 19)**.

Figure 19. Botanical gardens perform many services, including educating the public about the world of plants. A future path for botanical gardens and arboreta may be to take a lead role in educating people about biological invasions and the importance of preserving biodiversity.

Across the country, it is difficult to find a county that does not have at least one plant nursery, there is no postal route that does not carry seed and plant catalogues into homes, and most bookstores feature a whole class of gardening books. Most sizable towns boast gardening/horticulture societies as well, providing a venue for people to share their knowledge and passion for plants. In the absence of nurseries, large discount retail stores often have garden centers attached, and in the absence of book retailers and gardening clubs, gardeners can get information and advice from the World Wide Web. In addition, many television and radio stations broadcast gardening shows. The efforts of book and journal publishers, film, radio and television producers, and garden patrons continue to provide huge rewards for the nursery industry. The supply side of this well developed supply/demand relationship represents a minimum of $2.5 billion in annual wholesale trade (potted flowering, foliage or house, and bedding plants) (USDA 1996) **(Figure 20)**.

Figure 20.1

Figure 20.2

Figure 20. Landscape, house and annual plants are worth billions of dollars in trade every year. Indian azaleas (2031) and gardenias (20.2), both introduced species, are well behaved in the landscape - staying exactly where the gardener puts them.

Suggested Readings and Other Information

Managers can find more information for identifying and controlling specific weeds from a variety of sources.

Books

Invasive Plants: Weeds of the Global Garden - by John Randall (1996)

Identification and Biology of Non-native Plants in Florida's Natural Areas by Ken Langland and Kathy Craddock Burks (1998)

The Southern Living Gardening Book - by Steve Bender (1994)

The Sunset National Garden Book - by Lang et al. (1997)

Weed Handbook available from the Wyoming Weed and Pest Council

Private organizations and public agencies

California Exotic Pest Plant Council (CalEPPC) at http://www.caleppc.org

Florida Exotic Pest Plant Council (FLEPPC) at http://www.fleppc.org

Pacific Northwest Exotic Pest Plant Council (PNW-EPPC) http://www.wnps.org/eppclet.html

Southeast Exotic Pest Plant Council (SE-EPPC) at http://webriver.com/tn-eppc/

Tennessee Exotic Pest Plant Council (TN-EPPC) at http://webriver.com/tn-eppc/

Bureau of Land Management - in western states

Cooperative Extension Services

USDA Animal and Plant Health Inspection Service (APHIS) at http://www.aphis.usda.gov/ppg/weeds/weedhome.html

Weed Science Society of America (WSSA) at http://www.wssa.net

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Chapter 10: Glossary of Terms for Restoring the Urban Forest Ecosystem [1]

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Absorption: The uptake of water, other fluids, or dissolved chemicals by a cell or an organism (as tree roots absorb dissolved nutrients in soil or leaves absorb chemicals in a foliar herbicide application).

Age class: A group of individuals of a species that have the same age.

Anion exchange capacity (AEC): The total number of exchangeable negatively charged ions (anions) that a soil can adsorb.

Anthropogenic: Of human origin or influence.

Biodiversity: The variety of life and all the processes that keep life functioning. It includes the variety of different species (plants, animals - including humans, microbes and other organisms), the genes they contain, and the structural diversity in ecosystems.

Biomass: The dry weight of all organic matter in a given ecosystem. It also refers to plant material that can be burned as fuel.

Biosphere: That part of the earth and atmosphere which contains all of the life. All the ecosystems on earth form the biosphere.

Buffer zones: Semi-natural areas located around areas or ecosystems with higher natural value to minimize external influences.

Bulk density: The relative density of a soil measured by dividing the dry weight of a soil by its volume.

Canopy: The percent of land area covered by tree crowns.

Cation exchange capacity (CEC): The total number of exchangeable positively charged ions (cations) that a soil can adsorb.

Coarse woody debris: Any piece of dead woody material, including logs, snags and stumps. It provides habitat for plants, animals, and insects and is a source of nutrients in soil.

Colonizer: Species that enter unoccupied or sparsely occupied habitats, perhaps following a major disturbance.

Community: An assemblage of living organisms (plants, animals, microbes) that interact with each other in energy flow and nutrient cycling

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processes in an ecosystem. The biotic component of a particular ecosystem.

Compaction: An increase in soil bulk density caused by foot or motor traffic and/or heavy machinery.

Competition: Occurs when species attempt to utilize the same common resources (space, light, water, and nutrients) for survival and growth when these resources are in limited supply.

Connectivity: Ways of restoring broken connections between fragmented ecosystems in the landscape. Essentially the opposite of fragmentation.

Consumers: Organisms that cannot photosynthesize but instead feed directly on the producers (i.e., herbivores) and other consumers (i.e., carnivores, detritivores or decomposers). Consumers include non-photosynthetic bacteria, fungi, and animals, including humans.

Coppice: The ability of certain species to produce shoots when the main stem is cut but the root system is left intact.

Core area: The undisturbed interior area of an ecosystem fragment.

Corridor: Any area of habitat through which an animal or plant has a high probability of moving.

Cost-benefit analysis: Determination and comparison of the costs and benefits of an activity to evaluate its economic viability.

Cover: Plant and non-plant ecosystem components that provide protection from weather and predators for an animal species.

Decomposition: A large number of interrelated processes by which organic matter is broken down to smaller particles and soluble forms.

Detritus: All dead organic matter including litter, humus, soil organic matter, dead standing trees, and downed logs. Often an important source of nutrients in a food web.

Detrivore: An organism that obtains its energy by consuming dead organic matter: a decomposer organism, also called a sapotroph.

Disturbance: Any event, either natural or human-induced (anthropogenic), that changes the existing condition of an ecosystem.

Ecological management unit (EMU): The smallest treatable unit of land - the smallest restorable unit; the focus for restoration management activities; a human-defined area which may include one or more ecosystems.

Ecosystem health: An ecosystem in which structure and function allow the maintenance of biodiversity, biotic integrity and ecological processes over time while providing for human needs.

Ecosystem management: The use of an ecological approach to achieve productive resource management by blending social, physical, economic and biological needs and values to provide healthy ecosystems.

Ecosystem processes: Natural disturbances (e.g., fire), ecological succession, nutrient cycling and hydrological cycling.

Ecosystem services: Valuable functions that ecosystems provide free of charge to human societies, including maintenance of atmospheric gases, regulation of the hydrologic cycle, provision of potable water, fertile soil, wood, fish, and other consumable products, processing of wastes, pollination of crops, etc.

Ecosystem structure: Attributes related to the physical state of an ecosystem; examples include density, diversity, and biomass.

Edge:core ratio: The amount of border area in an ecosystem compared to its interior area.

Edge effects: Sharp borders between ecosystems which may have negative impacts on ecosystem structure and function, and on wildlife and their habitats.

Eutrophication: The nutrient enrichment of aquatic ecosystems. Symptoms of eutrophication may include algal blooms, nuisance growth of other aquatic plants, dissolved oxygen depletion, and altered species diversity and richness.

Evapotranspiration: Loss of water by evaporation from the soil, lakes and streams, and transpiration from plants.

Even-aged: A forest stand or forest type in which relatively small (10 to 20 year) age differences exist between individual trees.

Exotic: Plant or animal species introduced into an area where it does not occur naturally; either intentionally transplanted from another region or introduced accidentally. Typically we consider exotics to be those plants that came to North America with Europeans after 1500.

Fire dependent ecosystems: Ecosystems requiring one or more fires of varying frequency, timing, intensity, and size, in order to achieve optimal conditions for population survival and/or growth.

Fire suppression: Intentional exclusion of fires from ecosystems.

Food web: All the interactions of producers and consumers, included along with the exchange of nutrients into and out of the soil. These interactions connect the various members of an ecosystem, and describe how energy passes from one organism to another.

Forest succession: The change in species composition, age and size, and ecosystem structure and function over time.

Forest structure: The nature and abundance of the various vegetation layers (canopy, subcanopy, shrub layer and ground cover) and the presence of dead logs and snags.

Fragmentation: Landscapes become fragmented when natural ecosystems are broken up into remnants of vegetation that are isolated from each other.

Goals: Broad statements that give a project general direction.

Greenhouse effect: The warming of the Earth's atmosphere attributed to a buildup of carbon dioxide or other gases.

Greenways: A type of corridor designed to connect open spaces for ecological, cultural and/or recreational purposes.

Ground water: The water entering the soil which remains in the saturated soil and rock.

Habitat: The physical location or type of environment in which an organism or biological population lives or occurs.

Heavy metals: Elements, such as mercury, lead, nickel, zinc, and cadmium, that are of environmental concern because they do not degrade over time. Although many are necessary nutrients, they are sometimes magnified in the food web and in high concentrations that can be toxic to life.

Herbivores: Animals that only eat plants.

Hydrologic cycle: Also called the water cycle, including precipitation of water from the atmosphere as rain or snow, flow of water over or through the earth and evaporation or transpiration of water to the atmosphere.

Hydrophobic soil layer: Layer of soil that is water repellent, due either to natural or anthropogenic causes.

Impervious: Not easily penetrated by roots or water.

Infiltration: The movement of water from the soil surface into the soil.

Interception: The amount of precipitation that is held by living or dead plant material.

Invader: Species that have certain characteristics that give them an advantage in native ecosystems, such as being fast growers, having high flowering and fruiting, having easily dispersed seeds, exhibiting high germination rates and tolerating a variety of site conditions.

Landscape: An area where interacting ecosystems are grouped and repeated in similar form.

The traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic or social patterns.

Litter (leaf litter or forest litter)**:** The detritus of fallen leaves, branches and bark which accumulates in forests.

Microclimate: The climate of small areas. Especifically, the climate under a plant or other cover, differing in extremes of temperature and moisture from the climate outside that cover.

Monoculture: Even-aged, single-species forest stands, usually grown for commercial purposes.

Mortality: Rate of death as a result of competition, disease, insect damage, drought, wind, fire and other factors.

Naturalize: To become established as if native, to escape cultivation and successfully reproduce.

Nitrogen-fixing species: Biological fixation is accomplished by certain microorganisms that can reduce N_2 and combine it into organic molecules such as amino acids and proteins.

Non-point source pollution: Runoff washing over the urban landscape which transports nutrients and other chemicals into aquatic ecosystems.

Nutrient cycling: The transformation of chemical elements from inorganic form in the environment to organic form in living organisms, then back to inorganic form. It includes the exchange of elements between and among the biotic and abiotic components of an ecosystem.

Nutrient cycle: The exchange of elements between the living and non-living components of an ecosystem.

Objectives: Statements which provide specific destinations and time lines for different aspects of a project. Progress toward these objectives should be measurable.

Old-growth: A forest of very large trees or very old trees, or a forest that has reached its climax successional stage. Old growth is not a type of forest ecosystem, but rather a condition that a forest ecosystem can attain if sufficient time passes since the last disturbance.

Omnivores: Animals that eat both plants and animals.

Organic matter: Materials in the soil that were once living and are decomposing back into the soil.

Organic matter amendments: Organic materials which are added to the soil to improve soil properties such as cation exchange capacity and soil structure.

Photosynthesis: The manufacture by plants of carbohydrates and oxygen from carbon dioxide and water. The reaction is driven by the energy of sunlight and catalyzed by chlorophyll.

Plan: A predetermined course of action to meet a vision, goals and objectives.

Piedmont: A plateau in the Southeastern U.S. between the coastal plain and the Appalachian Mountains including parts of Virginia, North Carolina, South Carolina, Georgia, and Alabama.

Pioneer: A usually prolific, fast-growing and short-lived species, generally intolerant of shade. Pioneers are capable of invading bare sites (e.g. a newly exposed soil surface) and persisting there or "colonizing" them, until supplanted, by other successional species.

Pore space: Voids or spaces between solid soil particles in the soil; pores holding water and air.

Prescribed fire (or burning): The application of fire to an area to meet predetermined resource management objectives.

Primary production: The quantity of organic carbon fixed by photosynthesis per unit time.

Primary succession: Plant and animal establishment and development that occurs in environments that lack organic matter and which have not yet been altered in any way by living organisms. It includes the development over time of the original substrate into soil.

Producers: Mainly green plants that take light energy and store it through the process of photosynthesis.

Restoring the urban forest ecosystem: Reestablishing the ecological health of the urban forest ecosystem. Altering a site to a state which is more ecologically sustainable to the community. Restoration might reestablish ecological structure, functions, pathways and/or cycles.

Riparian forest buffers: Forests along creeks, streams and rivers that stabilize banks, take up nutrients, and provide shade, habitat, and food for aquatic ecosystems.

Runoff: Water from rain, snow melt, or irrigation water that runs off the land into streams or other surface-water. It can carry pollutants from the air and land into receiving waters.

Savanna: A type of woodland characterized by open spacing between trees and the intervening areas of grassland.

Secondary succession: Plant and animal establishment and development that occurs in an environment that has supported mature vegetation in the past, and where, after a disturbance, the substrate (i.e., soil) remains relatively intact.

Seepage: Water which enters the soil and moves down through the soil.

Shade tolerant: A plant that develops and grows better in the shade of, and in competition with, other trees or plants. Antonym is shade intolerant.

Site assessment: The first step in any restoration process to determine the site's resources.

Site context: A description of the potential restoration site; a site picture which assesses the site's current and past conditions.

Site evaluation checklist: A quick-and-easy instrument to assess the ecological value of a site. Used especially to estimate the suitability of a site for wildlife species.

Snag: A dead standing tree.

Soil aeration: The movement of atmospheric air into pores in the soil.

Soil assessment: An evaluation of the chemical, physical, and biological features of soil resources which can limit colonization, survival, and growth of living organisms.

Soil structure: The combination or arrangement of primary soil particles into secondary particles or units.

Soil texture: The relative percentage of sand, silt, and clay-sized particles in the mineral portion of the soil.

Space: The size of an area containing sufficient food, cover, and water for an animal species to survive.

Stakeholders: All parties who will be impacted by a restoration project, e.g., communities, government, NGOs, universities, private sector, investors, and others.

Stepping stones: Smaller habitats or ecosystems that permit the flow of some plants and animals to move across the landscape from one ecosystem fragment to the other.

Stocking: Releasing wildlife offspring or transplanting wildlife into suitable habitat areas.

Substrate: Supporting surface on which an organism grows. It may simply provide structural support or may provide water and nutrients. It may be inorganic, such as rock or soil, or it may be organic, such as wood.

Thinning: Cutting of parts of a tree or individual trees in a stand to improve average growth, health and form of the remaining trees.

Throughfall: Precipitation that is not intercepted by plants or that drips to the ground.

Transpiration: The evaporation of water from within living plant tissue through leaf openings called stomata.

Trophic enrichment of the soil: The addition, infection, contamination or repatriation of a site with various living organisms such as worms, arthropods, fungi, bacteria, and organic materials.

Understory vegetation: Any plant growing under the canopy formed by other plants, particularly herbaceous and shrub vegetation under a tree canopy.

Urban forest ecosystem: A collection of living organic matter (plants, animals, people, insects, microbes, etc.) and dead organic matter (lawn clippings, leaf-fall, branches) on a soil (with all its urban characteristics) through which there is a cycling of chemicals and water and a flow of energy.

Urban heat island: The increase in temperature in cities compared to the surrounding rural lands.

Vision: A desired future condition or state for a restoration site.

Weed: A plant out of place.

Wetlands: Ecosystems that are periodically inundated with water at a frequency and duration to support vegetation which is adapted for life in saturated soils.

Wildlife habitat: The area where an animal species lives or may potentially live because it provides all the live-sustaining requirements for that particular species.