National Capital Region
Natural Resources and Science
Center for Urban Ecology

National Park Service
U.S. Department of Interior

VALUES & CHALLENGES IN URBAN ECOLOGY

On the cover: *In the Potomac River, Theodore Roosevelt Island (George Washington Memorial Parkway) is a memorial park that preserves forest and wetlands from the surrounding development of metropolitan Washington, D.C.*

VALUES AND CHALLENGES

IN URBAN ECOLOGY

Natural Resources and Science Program

An archipelago of parks, woodlands, and other green spaces occurs throughout the mid-Atlantic. Vestiges of greater natural landscapes are steadily being reduced through human development. These remnant green spaces occur in varying shapes, sizes, and extent of connectivity. The status of their protection is as diverse as their intended purpose and ownership. The National Park Service's National Capital Region oversees nationally significant areas, including historic sites, battlefields, and parkways. These green islands protect significant natural resources amid metropolitan Washington, D.C.

The Region's Center for Urban Ecology in cooperation with park resource managers and its academic and other partners is striving to learn more about the natural resources within these remnant parks and how threats can be better understood and mitigated. The articles within this booklet provide a sample of some of these endeavors. While the focus is on the National Parks of the National Capital Region, the resources and threats extend throughout the mid-Atlantic area.

While much is already known about the natural resources of the parks, unique species and habitats are still being discovered and described. The Region's small, urban parks hold and protect biological richness in the form of a surprising number of species and communities. Recently, scientists working in the Region have found species new to science in groups as diverse as dragonflies and amphipods (subterranean, shrimp-like animals); these stories are included in this booklet.

Continued research in urban parks develops an integrated understanding of how to protect damaged or stressed systems. For instance, protecting federally listed species, such as a small wild carrot, harperella (*Ptilimnium nodosum*), means determining biological requirements in the face of changing riparian habitats along the Potomac River. Some native species, such as white-tailed deer (*Odocoileus virginianus*) and Canada geese (*Branta canadensis*), become overabundant in urbanizing landscapes and damage the park ecosystems, which no longer support natural predators of these larger species. Scientific studies offer insights into restoring population dynamics and minimizing threats to natural resources.

Extensive and expansive urban growth poses monumental challenges to practical resource management. As development intensifies, it is increasingly difficult for many native species and natural communities to survive. Many parks are surrounded by intensive development right up to their borders. Accompanying this urbanization is an expanding and interconnected array of resource threats, including air and water pollution and the increasing diversity and magnitude of invasive non-native species. Impervious surfaces, like parking lots and roads, are major urban challenges, creating hydrological havoc by increasing the amount of water channeled through fragmented, natural habitats.

The National Parks offer valuable ecosystem services. Air flowing through stream beds, urban forests, and meadows create reservoirs of fresher air and microhabitats for beleaguered species. Precipitation and water moving through the parks are filtered through the vegeta-

Dr. Jim Sherald, Chief of Natural Resources and Science, National Capital Region

tion and soil, removing some pollutants and providing habitats for subterranean animals. Such ecosystem services are illustrated within this booklet; one article describes scientists and the parks sampling the urban forest and measuring its contributions to the health and well-being of the urban-suburban environment and its citizens.

Protecting natural resources sustains the natural processes that provide these ecological services. We hope that encouraging and conducting studies in urban National Parks will create greater awareness about the resource values of these and other viable remnants of natural landscapes. Sharing information gained from collaborative and integrated scientific studies provides the land managers with more options and allows them to collectively protect and restore these valuable resources.

Natural Resource Challenge Congress is interested in the management of the National Parks. Interested enough to take an unprecedented step in 1998 and give a legal mandate for research within the National Park System to support management decisions, as well as broader scientific values. The National Parks Omnibus Management Act (Public Law 105-391) directs the National Park Service to encourage others to conduct research in the parks for the benefit of park management. Further, Title II of the act requires superintendents and other park officials to base decisions upon sound, research-based information. This ensures the full use of the results of science studies.

To put the mandate into action, Congress passed the Natural Resource Challenge: The National Park Service's Action Plan for Preserving Natural Resources in 2000, beginning a five-year, funded initiative to address the general lack of knowledge about natural resources and to enhance their management. In the National Capital Region, the Natural Resource Challenge provides funding for scientific professionals who support park managers. The Challenge funds an Air Resource Specialist, an Aquatic Ecologist, the National Capital Region Network (an Inventory and Monitoring network), the Exotic Plant Management Team, Chesapeake Watershed Cooperative Ecosystem Studies Unit, and the Urban Ecology Research Learning Alliance (a Research Learning Center). All of these entities work to increase the role of science in the management of park resources.

NATIONAL PARK SERVICE · NATIONAL CAPITAL REGION

CENTER FOR URBAN ECOLOGY

The Center for Urban Ecology is an interdisciplinary team that provides scientific guidance, technical assistance and education for the preservation, conservation and enhancement of park resources within urbanizing landscapes.

The Center for Urban Ecology serves 14 parks in the National Capital Region

1 Antietam National Battlefield
2 Catoctin Mountain Park
3 Chesapeake & Ohio Canal National Historical Park
4 George Washington Memorial Parkway
5 Harpers Ferry National Historical Park
6 Manassas National Battlefield Park
7 Monocacy National Battlefield
8 National Capital Parks - East
9 National Mall & Memorial Parks
10 Potomac Heritage National Scenic Trail (Headquarters)
11 Prince William Forest Park
12 Rock Creek Park
13 President's Park
14 Wolf Trap National Park for the Performing Arts

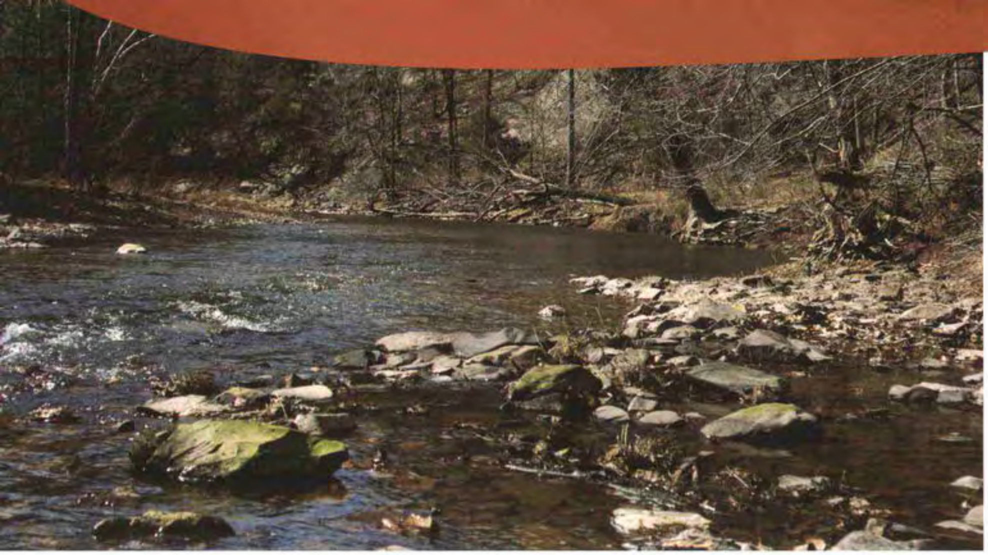
The National Capital Region is home to harperella (*Ptilimnium nodosum*), a federally endangered plant species with only 14 populations known worldwide. Harperella is a short, mostly annual (i.e., it lives only one year) member of the carrot family with a small cluster of white flowers. Its hollow, needle-like leaves blend into the surrounding grasses and rushes, making it inconspicuous. Harperella is found in seasonal ponds and along streams in western Maryland, Arkansas, North Carolina, Virginia, and West Virginia.

DECIPHERING

LIFE'S ESSENTIALS *for* A RARE PLANT

Sunny, cobble bars in gravelly streams that become exposed during mid- to late summer are ideal sites for population establishment. But this small plant is caught in a "habitat dilemma:" the habitat is created when strong stream currents strip away vegetation, including harperella, and toss gravel around. However, when the currents subside, perfect places are left behind for harperella seed dispersal and germination, which are essential to its survival.

Harperella is a pioneer species on these freshly exposed gravel cobble bars. But if the flooding and currents are too strong, last too long, or occur too frequently, the habitat and plants are washed away before seed germination. Many of these riverine habitats have been altered by development that has hardened surfaces and removed the trees, which changes the hydrology of an area. Because of the increase in development, rain that falls on open or paved surfaces rushes more



Cobble bars in gravely streams are ideal sites for harperella.

"As the sediment settles out of the water and onto vegetation and gravel bar alike, it robs harperella of sunlight by covering its leaves with mud and algae."

swiftly into streams and then into the Potomac River. This change increases the frequency and velocity of the high water events. These "flashy" or sudden and frequent high water events also increase erosion, which in turn contributes more sediment to the water. As the sediment settles out of the water and onto vegetation and gravel bar alike, it robs harperella of sunlight by covering its leaves with mud and algae (MDNR 1995). Increased water impoundments or retention sites in the watershed coupled with more dramatic draw-downs of the Potomac River by consumer use may further stress this rare plant, which needs damp sand and gravel to grow.

Collections of harperella have been made for nearly a century in the National Capital Region. Harperella has been documented at Harpers Ferry National Historical Park, but it has not been seen there for more than 25 years. Harperella was found on three separate, recent occasions on cobble bars along the Potomac River within the Chesapeake and Ohio (C&O) Canal National Historical Park. Unfortunately, following each discovery, the species was extirpated (lost) because of severe flooding. The loss of these subpopulations and their habitats is ecologically important because these are the most northerly harperella populations.

As a federally endangered species, harperella is one of the highest conservation priorities for C&O Canal National Historical Park and the National Capital Region. In 1988, the species was federally listed as endangered by the U.S. Fish and Wildlife Service. Threats to the species and its habitat are severe due to hydrologic alterations caused by landscape use changes, the spread of non-native invasive plant species, and the Park's recreational use by more than 3 million people visiting annually. All of these factors contribute to habitat degradation. The U.S. Fish and Wildlife Service Recovery Plan outlines tasks for the restoration and recovery of harperella populations throughout the eastern United States (FWS 1990).

The Nature Conservancy and the Maryland and West Virginia State Natural Heritage Programs surveyed extensively for harperella between 1981 and 1994. Botanists found populations of harperella along five streams and the Potomac River (Bartgis 1997). These surveys revealed that harperella remains a very local species within the Potomac River drainage.

Dr. Elizabeth Wells, a botanist at George Washington University, began restoration efforts in 2001 at the C&O Canal National Historical Park, working first to pinpoint when harperella is most vulnerable and what has the greatest effect on its survival. The National Capital Region funded Dr. Wells's preliminary survey to locate harperella populations and to assess their size and vigor. Dr. Wells surveyed the shore of the Potomac River along the C&O Canal from Cumberland to Williamsport, Maryland (Wells 2002a). Although she did not find harperella populations on Park land, four populations exist in the Sideling Hill Creek Wildlife Management Area, Maryland. From these populations, Dr. Wells collected three hundred seeds in fall of 2001 to use in germination and transplant experiments.

Needle-like leaves of harperella make it inconspicuous.

Dr. Wells sent two hundred harperella seeds for cryopreservation (freezing in liquid nitrogen) to the USDA National Center for Genetic Resources Preservation, Fort Collins, Colorado. The Center has joined with the National Park Service to preserve the seeds of our parks' most imperiled plants. The seeds are protected and available for use in future reintroductions.

The goal of Dr. Wells's research is to decipher the narrow range of unique requirements for harperella's survival in order to establish new populations on Park land and to provide accurate information about the species, increasing the ability of C&O Canal National Historical Park to establish and protect harperella populations. Dr. Wells conducted work on harperella's breeding requirements in the growth chamber and greenhouses at George Washington University. She hand pollinated flowers to ensure seed set. Dr. Wells conducted greenhouse and growth chamber trials to identify the micro-environmental parameters needed for germination of harperella seeds and growth of young plants. Additionally, she carefully recorded details about the life cycle of harperella.

Harperella lives a life of moderation when it comes to flooding. This study has demonstrated that harperella tolerates flooding to moderate depths and for moderate lengths of time. The consequences of seasonal flooding during various stages of harperella's life cycle are not well understood. Harperella appears to require some flooding during the winter and spring to scrape away plant competitors on the gravel bars. Flooding during seed maturation in late summer and autumn has mixed consequences for harperella. Minor floods of low volume have a seemingly beneficial role in seed dispersal through the establishment of new populations downstream. Yet, major floods of extended duration during the fall months kill the seeds and wash plants away.

Over two years, Dr. Wells transplanted small plants and planted seeds into eight marked

Dr. Wells, George Washington University, conducts greenhouse studies of harperella.

plots at several sites along the western side of the Potomac on land managed by the C&O Canal National Historical Park (Wells 2002b). Because harperella plants require specific site characteristics, including full sun, erosion protection, and scouring by water, few sites are ideal for transplants. During the first year, Dr. Wells transplanted young harperella seedlings and planted seeds into open plots cleared of all vegetation. The National Capital Region Exotic Plant Management Team worked with the investigator to eradicate non-native invasive plants from each of the plot sites. However, flooding wiped out the plots, killing the harperella.

The following year, Dr. Wells compared the survival of young harperella plants in four plots with all vegetation removed to four plots with intact vegetation. Thick stands of a herbaceous plant, American water-willow (*Justicia americana*) dominated the vegetated plots. American water-willow is a small, woody, deeply rooted plant that is common along the rocky Potomac shores. The Exotic Plant Management Team assisted Dr. Wells again by removing non-native invasive plants.

Relatively speaking, harperella did survive better in plots with American water-willow than in areas with no surrounding vegetation. The greater survival of harperella suggests that American water-willow may offer protection for the young transplants from the rapidly moving water. In one plot where the American water-willow had been cut to the ground, the entire plot was badly eroded, a major flood wiped out most of the water-willow plants and all of the harperella transplants. Eventually, severe flooding by three major flood events spaced three weeks apart killed the harperella in all plots demonstrating the incredible challenge of protecting this vanishing plant.

Harperella makes new populations by its seeds and plantlets washing downstream (TNC 1993). Plantlets are small pieces of

Transplantation studies at C&O Canal National Historical Park have yielded very low survival rates.

"Understanding the ecological dilemmas that lead to the loss of such plants may help us understand the effects of broader ecological changes in the Potomac River watershed."

broken plants that root at leaf nodes. This nodal rooting happens after harperella is submerged in shallow water for a while, and it is a form of vegetative reproduction. Dr. Wells has observed nodal rooting in the wild populations. If a small flood event happens during the late winter or early in the summer, harperella plantlets may be a primary means of dispersal instead of its very small, hard-coated seeds (less than 0.08 inch (2 mm)). Dr. Wells is continuing this restoration project by investigating harperella vegetative reproduction in the greenhouse. She will collect additional viable harperella seeds and locate other suitable sites for the reintroduction of young plants on the C&O Canal and off of the main stem of the Potomac River.

The possibility of losing all our harperella populations forever is real. Understanding the ecological dilemmas that lead to the loss of such plants may help us understand the effects of broader ecological changes in the Potomac River watershed. Although few of us have seen this small plant, its survival could foretell the future for other residents of the Potomac.

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Harperella is a federally endangered species.

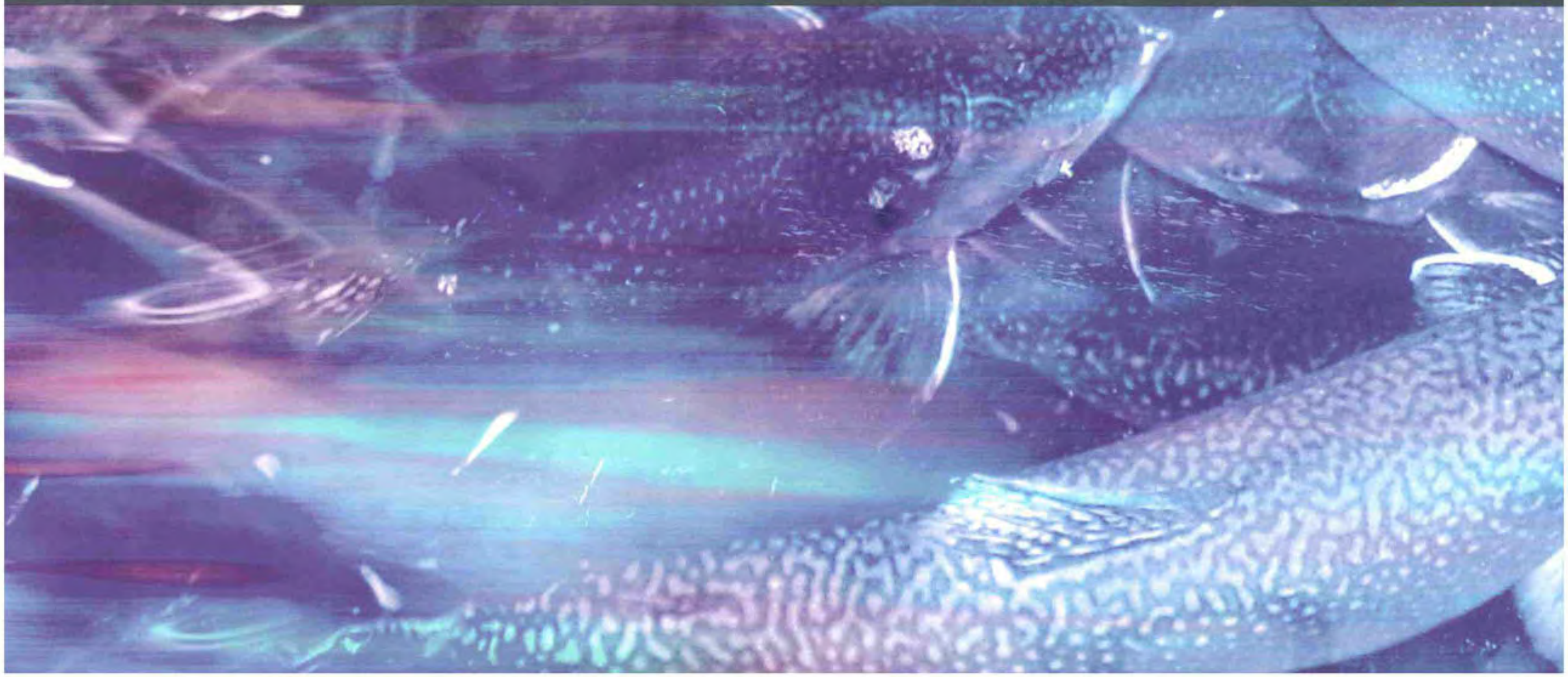
CENTER FOR URBAN ECOLOGY

Exotic Plant Management

The spread of invasive non-native plants is one of the major threats to the survival of harperella and other endangered native plants. The Exotic Plant Management Team at the Center for Urban Ecology is responsible for controlling invasive plants within the parks of the National Capital Region. As one of seventeen established teams within the National Park Service, the Exotic Plant Management Team inventories and maps non-native vegetation and develops strategies for controlling these plants. Regional management of invasive plants species encompasses approximately 65,000 acres (26,300 hectares) that span the District of Columbia, Maryland, Virginia, and West Virginia. Due to the numerous and varied habitats of the National Capital Region, eradication methods and/or strategies for control are developed specifically for individual species and sites. The successful management and restoration of disturbed areas are accomplished through partnerships between the Exotic Plant Management Team, park staff, and numerous volunteer groups that are concerned with invasive exotic plants. The Exotic Plant Management Team engages in an active outreach program, providing biological and control information to interested volunteers, community groups, and land management professionals.

Situated at the eastern end of the Blue Ridge Mountains and within 60 miles (96.6 km) of Washington, D.C., two high gradient streams and their tributaries support 17 known species of fish in Catoctin Mountain Park. The fantail darter (*Etheostoma flabellare*), mottled sculpin (*Cottus bairdii*), cutlips minnow (*Exoglossum maxillingua*), and dace (*Rhinichthys* and *Clinostomus* spp.) are commonly found, while elusive species like the American eel (*Anguilla rostrata*) often escape even the most careful observer. However, it is the Park's populations of trout that attract the most attention.

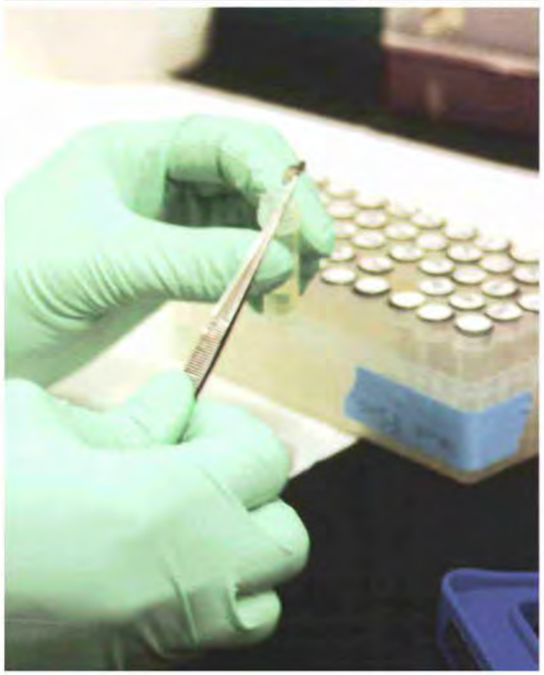
THEY'RE



Big Hunting Creek in the Park has played a prominent role in the development of recreational trout fishing in Maryland. The stream has long been popular among fly fishermen, who are attracted by brook (*Salvelinus fontinalis*), brown (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*). Big Hunting Creek was the first in the State of Maryland to be designated as a "Fly-Fishing-Only" stream. Later, it became Maryland's first "Catch-and-Release" trout stream. Outside the Park and below the dam that forms Hunting Creek Lake, the Maryland Department of Natural Resources stocks limited numbers of hatchery-raised rainbow and brook trout to enhance the stream's recreational fishing. The lake is managed by Cunningham Falls State Park, which is adjacent to Catoctin Mountain Park.

The population of brook trout is very special because it is the only trout species native to this region. Both brook and brown trout spawn in the headwaters of Big Hunting and Owens Creeks, but only brook trout spawn in the headwaters of Still Creek, which is a tributary to Big Hunting Creek. The Park does not stock brook trout into its creeks; its fish are wild and naturally occurring. Brook trout inhabit pristine stream environments, and its presence or absence is often perceived as an indicator of ecosystem integrity. Owens Creek is located on the northern side of the Park and contains populations of brown and brook trout, but the brook trout are more abundant.

NATIVE BROOK TROUT
NOT ALL THE SAME



Top: Staff at Leetown Science Center, U.S. Geological Survey, prepares samples for genetic analysis; ***Bottom:*** *Small amounts of tissue collected from brook trout fins are used for analysis of variation in microsatellite DNA;* ***Opposite page:*** *Large samples allow for comparison of genetic variation within and between populations.*

Natural resource managers in the National Park Service respond to many different management needs, including meeting the recreation needs of the American people while maintaining and enhancing the integrity of our ecosystems. Our goal is to provide for sustainable use of natural resources for recreation while preserving the resources.

Maintaining the genetic integrity of native, wild populations is very important in the conservation biology of a species. The genetic variation that exists in a population is the product of thousands of years of evolution and is critical to a population's ability to adapt to changes to its environment. Heritable genetic information offers an objective means of depicting management units and provides an evolutionary framework from which to develop and evaluate conservation priorities. Conserving biological diversity helps preserve species and prevents the disruption of natural processes such as species interactions and evolution.

The number of wild brook trout populations in the United States has been dramatically reduced as a result of overexploitation, competition from non-native fish, and habitat loss from such human-caused factors as deforestation, hydroelectric power development, and acid rain. The Air Resources Program at the Center for Urban Ecology works with the Park to monitor pollutants such as mercury and sulfur dioxide threats to the aquatic wildlife within the Park's streams. As a result of declining numbers of fish, the management and restoration of wild brook trout populations are important goals throughout their native range.

> "Maintaining the genetic integrity of native, wild populations is very important in the conservation biology of a species."

While anecdotal accounts from the 1930's indicate that brook trout were once abundant in the Park, some fisheries reports indicate the absence of brook trout from Owens Creek in the 1970's. It is difficult to pinpoint what happened to the brook trout at that time; there is no historical documentation of restocking. Finding clues to the origins of current brook trout populations requires the Park to identify the genetic variation in the brook trout and to understand the DNA variation of brook trout populations outside of the Park. Relatively large genetic differences can occur over short geographic distances because brook trout are territorial and live in local breeding groups in various watersheds, streams, and pools (Perkins et al. 1993).

Genetics Studies of Brook Trout in National Parks

The native range of brook trout (*Salvelinus fontinalis*) originally extended throughout eastern Canada and the northeastern and central United States. Brook trout is native to 18 National Parks in the United States, including Catoctin Mountain Park. With the exception of Great Smoky Mountains National Park, little was known about the ecological and evolutionary relationships among brook trout found in streams within or outside of park boundaries. Traditionally, National Parks based brook trout management practices on geographic location and did not take genetic relatedness among populations into account. To address this research need, the National Park Service collaborated with the U.S. Geological Survey, Biological Resources Discipline to survey the genetic variation in over 5,000 brook trout. These wild brook trout were collected from the major drainages within five National Parks: Acadia National Park, Catoctin Mountain Park, Shenandoah National Park, Great Smoky Mountains National Park, and Isle Royale National Park, and from several other populations located outside park boundaries. This survey identified a high degree of genetic diversity and differentiation at three different levels studied: populations, Parks, and drainages (King 2005).

Increased interest in restoring and enhancing brook trout requires a better understanding of the partitioning of genetic variation among different Park drainages and the effects of any past restoration effort.

The traditional method of addressing the decline of native populations has been hatchery supplementation. However, mixing genetically divergent stocks of brook trout has serious potential problems, including the loss of local adaptation, disruption of locally-adapted gene combinations, and the spread of pathogens. Declines in the number of breeding individuals in populations can result in reduced levels of genetic diversity among wild brook trout populations. It is estimated that less than 5% of brook trout populations in the many inland streams of the northeastern United States may still contain wild fish (Quattro et al. 1990, McCracken et al. 1993, Perkins et al. 1993). With this in mind, three important questions arise: is the population of brook trout in the Park still wild, and what are the genetic relationships among populations within the Park and those populations adjacent to the Park?

Obtaining genetic information is crucial for brook trout management. Future needs may call for using existing populations to expand the range of brook trout in Park streams or reintroducing brook trout following an environmental disaster. Brook trout were missing from Owens Creek in the Park in the 1970's; this loss could happen again. Wild brook trout remained in upper Big Hunting Creek and in its tributary, Still Creek. It is important to know the genetics of existing populations before any of these actions occur. For instance, if the genetic diversity is significantly different among populations, then maintaining separate populations may be better than mixing them.

The Unrooted Tree

This unrooted, Neighbor-Joining tree (or phenogram) shows the genetic distances between brook trout *(Salvelinus fontinalis)* from nine locations in Maryland, encompassing the drainage systems in and around Catoctin Mountain Park. It was possible to identify each population examined; that is, there is not one homogeneous gene pool for all brook trout inhabiting Catoctin Mountain Park or the other drainages in Maryland. The most genetically different populations are those along the Atlantic slope drainage (Bear Creek of the Youghiogheny River) and those within the interior basin drainage (Big Hunting Creek, Still Creek, and Owens Creek at Catoctin Mountain Park) (King and Julian (2000). King and Julian identified the collections from Fishing Creek and Owens Creek as the most genetically similar populations. In fact, they observed distinctly different branches on the tree for all collections except for those two streams.

To determine genetic diversity across the range of brook trout, Dr. Tim King with the U.S. Geological Survey, Biological Resources Discipline, Leetown Science Center conducted a survey within the Park and compared these Park populations and others. The Park and Maryland Department of Natural Resources staffs collected small amounts of tissue (fin clips) nondestructively from brook trout in three Park streams: Owens Creek, Big Hunting Creek upstream of Route 77, and Still Creek. Outside of the park, they also collected tissue samples from Fishing Creek, which is located just south of Cunningham Falls State Park. In addition, Dr. Ray Morgan from the Appalachian Laboratory, University of Maryland, Frostburg, Maryland, collected tissue samples from five populations in Maryland streams. These included Bear Creek (Youghiogheny River), Savage River (Potomac River), Gunpowder River, the left fork of Fishing Creek (Monocacy River), and Tuscarora Creek (Monocacy River).

Genetic diversity was measured as variation in microsatellite DNA. These are short pieces of DNA that occur as variable numbers of repeated DNA sequences. Molecular genetics has recently achieved an important place in contemporary conservation biology as a robust tool for identifying fine-scale population structure and determining the degree of reproductive isolation among populations. The molecular survey was completed in 2004. This study represented the first survey of microsatellite DNA variation in Maryland brook trout.

Dr. King's genetic analysis revealed a high degree of population subdivision and large genetic distances among all watersheds studied. Scientists at Dr. King's lab screened 325 brook trout from the nine locations for eight microsatellite DNA loci. Furthermore, the resulting data set contained sufficient allelic diversity to reveal unique multilocus genotypes for all individuals sampled. The pattern of genetic variation observed suggests a series of phylogeographic breaks that correspond to the major drainages surveyed, which may indicate local (or regional) adaptive significance and may reveal diverging evolutionary pathways.

The genetic analysis showed that Owens Creek within the Park was genetically closest to Fishing Creek located outside of the Park. The genetic data from this study support the reports of reintroductions of wild brook trout into Owens Creek from Fishing Creek sometime in the recent past. And, since considerable genetic differentiation exists between Still Creek and Big Hunting Creek, it may be that Cunningham Falls and the park reservoir dam serve as physical barriers to gene flow.

From this study, we learned that Catoctin Mountain Park is still home to a remarkable population of wild, native brook trout. This is key information for park managers to use when reviewing plans for restoration, road and trail construction, responding to hazardous materials spills, and for routine Park maintenance practices. This information will better direct the long term monitoring of the fish populations of the Park.

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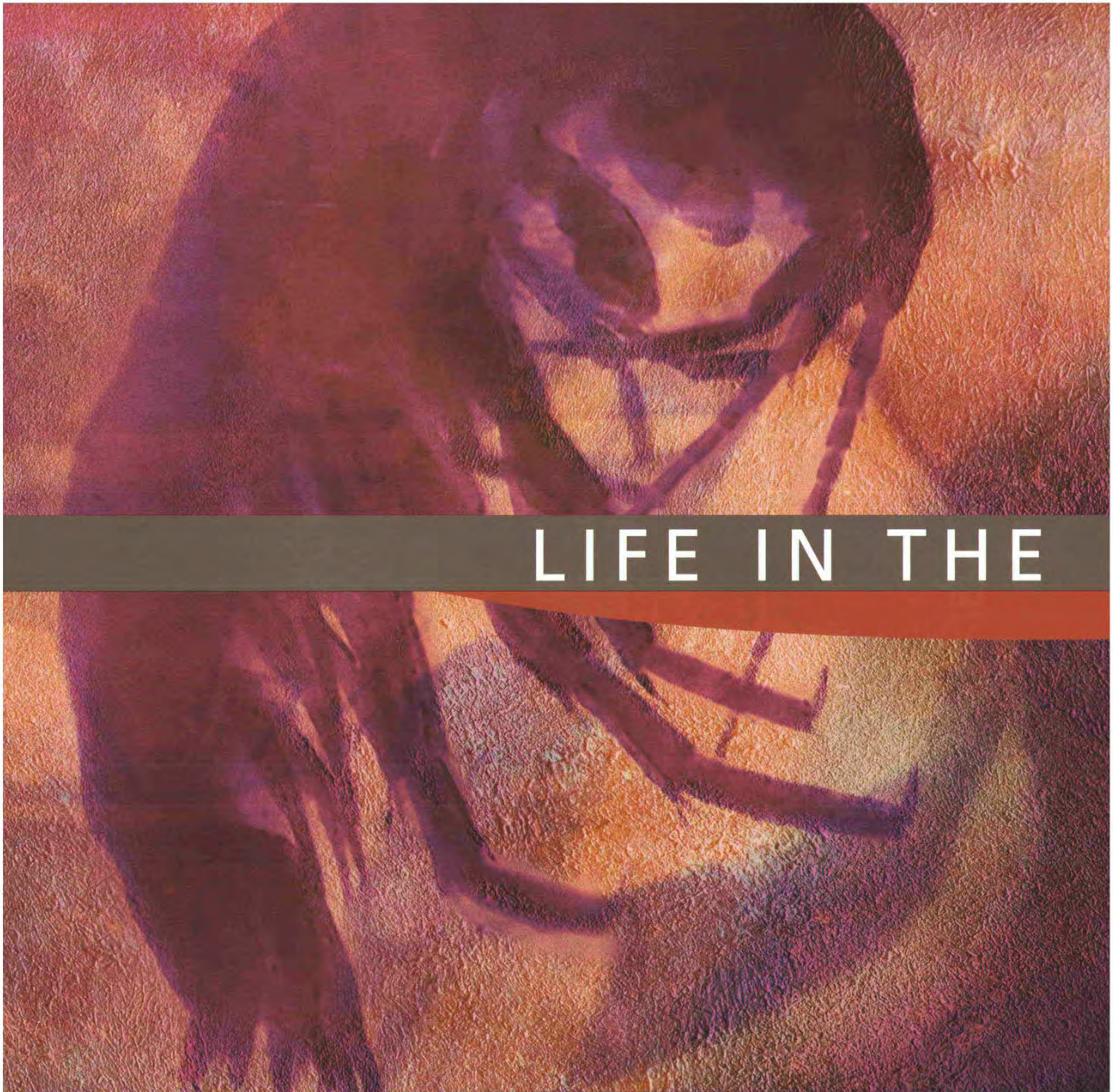
Air Resources Program Air pollutants do not just make the air murky and unhealthy to breathe. They also can harm ecosystems by acidifying and enriching both soils and water bodies (via nitrogen and sulfur deposition), by damaging and retarding growth in plants (via ozone deposition), and even by poisoning fish and the organisms that feed on them (via mercury deposition). Thus, air pollutants are a threat to brook trout populations. To protect park resources and predict effects of air pollutants on natural resources in the National Capital Region, the Air Resources Program at the Center for Urban Ecology coordinates with national-scale air quality monitoring programs both within and outside the National Park Service. These include:

- Interagency Monitoring of Protected Visual Environments (IMPROVE)
- Clean Air Status and Trends Network (CASTNET)
- National Atmospheric Deposition Program (NADP).


LIFE IN THE

To effectively protect animals, we must protect their habitats. However, for animals that live underground and are not easily found or seen, protecting their habitats is especially important and difficult. In and around the nation's capital, urban development over the past 100 years has obliterated many subterranean aquatic habitats by water contamination, fill, pavement, and entombment in pipes or concrete. As a result, development has eliminated or so disturbed many groundwater systems that unknown numbers of interesting and potentially significant species are lost.

UNDERGROUND

The National Parks of the National Capital Region protect fragile and fragmented groundwater habitats that house truly remarkable creatures. Along the Potomac River and its tributaries, including Rock Creek, the groundwater is home to a diverse community of animals without backbones (invertebrates), such as snails and several kinds of crustaceans. Amphipods are among the largest groups of freshwater invertebrates in North America (Culver and Sereg 2004). These blind, colorless, shrimp-like animals only live underground. Remarkably, work by Culver and Sereg (2004), biologists from American University, revealed that the Region's parks are one of the hotbeds of amphipod biodiversity for the genus *Stygobromus*. Seven *Stygobromus* species are known to occur in the groundwaters of the parks.

Protection of *Stygobromus* species of amphipods is challenging because they live underground in scattered small habitats. Understanding the distribution of these subterranean species is important for Park managers to ensure that resource management practices protect the invertebrate habitat. Management practices that address the protection of groundwater habitat are especially needed because the federally endangered Hay's Spring amphipod (*Stygobromus hayi*) and other *Stygobromus* amphipod species of conservation concern occur in several of the Region's parks.

The Hay's Spring amphipod and Kenk's amphipod (*Stygobromus kenki*) are endemic to Rock Creek. This means that those two amphipods are found only along Rock Creek and nowhere else in the world. Hay's Spring amphipod reaches 0.4 inch (10 mm) in length.

Above: *Dr. Culver and students, American University, sample amphipods from the Rock Creek stream underflow.*

Little is known about its biology, ecological community, or population dynamics. Kenk's amphipod is half the size of Hay's Spring amphipod, and less is known about this species. Kenk's amphipod is highly rare and critically imperiled within the District of Columbia.

The life histories of many underground dwelling animals are still a mystery. Amphipods and other invertebrates live in seeps and small springs, which are fed by precipitation, surface flows, or groundwater. Amphipods are also found in small, clay-lined, perched aquifers, as much as 39 inches (1 meter) deep. Since the clay prevents the downward movement of water, the water becomes perched. The clay layer may also serve as a refuge for amphipods to burrow into during drought.

Amphipods move within the water as it percolates among sand grains and gravel. Seeps may have semi-isolated areas of saturated soil and gravel where amphipods live. The seep environment is a complex

"The life histories of many underground dwelling animals are still a mystery. Amphipods and other invertebrates live in seeps and small springs, which are fed by precipitation, surface flows, or groundwater."

area of upwellings and downwellings of water that produce pockets of low and high oxygen content within just a yard (meter) of one another (Mestrov 1962). In seeps and springs, large volumes of water may flush the animals up and out. Although amphipods may be found washed out into the fallen leaves and debris around a spring or seep, these outflow areas do not support survival or dispersal. Because perched aquifers are usually isolated underground, they provide limited opportunity for dispersal.

While it is not entirely clear where amphipods live, the most likely habitat for survival and dispersal is along the underflows of the river, streams, and spring runs, where they probably inhabit two types of underflow habitats: (1) bedrock fractures that are flooded [called stream underflow habitat], and (2) in the surface soil, gravel, and rocks above the bedrock [called seep underflow habitat]. These are all called interstitial habitats, which are narrow spaces filled with water among the rock, gravel, and sand (Culver and Sereg 2004).

Rock Creek's Amphipods

Examples of the two types of underflow habitats where amphipods may live occur in Rock Creek Park. The stream underflow habitat is found beneath and along Rock Creek's stream bed and beneath the upland springs in the park. The seep underflow habitat is scattered throughout the Park and is found where subsurface water is retained at shallow depths below the soil layer in loose rock piles or in fractures within superficial rock layers.

Culver and Sereg began surveying ground-water habitats located in Rock Creek Park in 2000 to ascertain the presence and composition of the groundwater inverte-

brate community. Sampling for amphipods is usually restricted to monitoring spring outflows by baiting with shrimp or searching through dead leaves for invertebrates. For this study, they used a special pump designed by French biologists, Claude Bou and Raymond Rouch, to extract invertebrates in the stream underflow habitat. Bou-Rouch pumping proved to be a very successful sampling technique. It pulled up more species of groundwater invertebrate fauna than baiting with shrimp or searching beneath leaves at spring outflows did. However, the pump could not be used in spring runs associated with storm drains because it clogged from the high amounts of fine sediments. In addition to counting and identifying all amphipods found, Culver and Sereg evaluated environmental threats, identified ecological tolerances of the amphipods, and described the ecological diversity and health of groundwater habitats in nine springs and four sites along Rock Creek.

Five of the nine springs in Rock Creek Park (stream underflow habitats) have two or more amphipod species and show the fewest signs of anthropogenic influences, indicated by lower amounts of dissolved solids (a measure of pollution) and nitrate (0.26 to 4.4 mg/L). It is important to define the recharge areas for these sites and designate them as Special Protection Areas within the Park. The remaining four springs contained low numbers (0 or 1) of amphipod species and showed signs of high anthropogenic influence with greater degradation in water quality. These springs are close to a heavily traveled city street and highly developed urban neighborhoods. Culver and Sereg measured extremely high nitrate values, ranging from 8.87 to 30.8 mg/L. High nitrate values may be a result of runoff of lawn chemicals and fertilizers from the surrounding neighborhoods.

Culver and Sereg (2004) found that the seep underflow habitats supported 22 invertebrate taxa total. The list included the Potomac Groundwater amphipod (*Stygobromus tenuis potomacus*).The Potomac Groundwater amphipod is widespread in the Park and needs no special protection, although it remains a Watch List species for Maryland and the District of Columbia.

Rock Creek Park Natural Resource Manager examines preserved specimens of amphipods.

Urban Parks Host Rare Species

Rock Creek Park is one of the oldest National Parks, established in 1890, and one of the largest urban parks in the United States. It encompasses 1,754 acres (709.8 ha) of Rock Creek's rugged stream valley, protecting significant natural resources. The Park has survived urban development pressures from the surrounding neighborhoods of Washington, D.C. and provides valuable plant and wildlife habitat. Nestled in the nation's capital, Rock Creek Park has a surprisingly rich diversity of native species, including species listed as rare and imperiled within the District of Columbia: six invertebrates, 53 plants, and one bird. Rock Creek is a wildlife corridor, descending from 165 feet (50.3 m) at the Maryland border to approximately sea level where it enters the tidal Potomac River. Continuous threats to the Park's natural resources challenge managers to distribute funds based on conservation need and importance.

Top: *Seeps are very vulnerable to degradation caused by hikers diverging from trails.*
Bottom: *Amphipods washed out into fallen leaves and debris do not survive.*

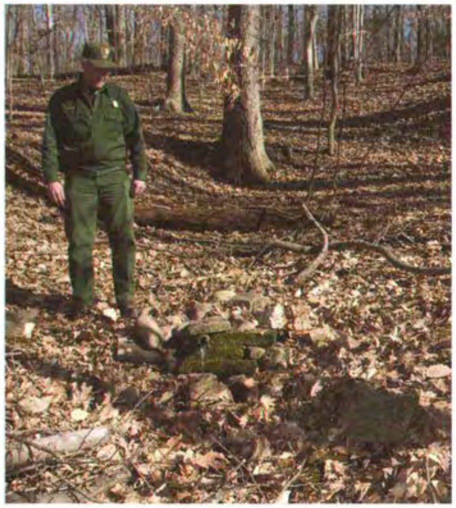
The stream underflow habitats of the springs had the greater number of invertebrate taxa at 25, demonstrating that it is in better condition compared to the stream underflow habitat of Rock Creek, which had only 13 taxa total (Culver and Sereg 2004). Culver and Sereg (2004) found three species endemic to the wider Rock Creek Park area at four or fewer sites. Kenk's and Hay's Spring amphipods occurred in the stream underflow habitats and less frequently in the seep underflow habitats. They found Hay's Spring amphipod, but not Kenk's amphipod in the Rock Creek stream underflow habitat. An undescribed amphipod species was more rare and found only once in each of the stream underflow habitats of Rock Creek and the upland springs.

This study demonstrated that Kenk's amphipod has a smaller range (1.9 miles (3 km)), stretching along one side of Rock Creek drainage than the federally listed Hay's Spring amphipod (6.2 miles (10 km)), which extends along both sides of Rock Creek drainage. It is unlikely that Kenk's amphipod uses the Rock Creek stream underflow habitat to disperse; it may have very limited dispersal ability (Culver and Sereg 2004). Habitat degradation may be the most important factor in the rarity of Kenk's amphipod.

Amphipods have little capability to respond to environmental degradation, which makes them extremely vulnerable to impacts like storm water runoff, pollution from road runoff, and soil compaction from trails. The seeps, their underground flows, and their catchment basins face several kinds of direct threats. Walkers on trails through seep areas compact the soil, reducing the amount of suitable habitat. To protect the subterranean fauna in the stream underflow habitat of seeps and springs, creating new trails and the widening of existing trails in these areas need to be avoided. Runoff from nearby streets may be especially harmful because of the elevated levels of heavy metals such as selenium and lead from tire residue. Pesticide applications that could harm subterranean invertebrates should be prohibited in all spring and seep recharge areas.

> “The persistence of amphipod populations in the National Capital Region is testament both to the protection of habitat set aside in National Parks and to the critical importance that the Park has placed on preserving these species.”

An additional concern is that the current practice of routing storm water into small stream channels in the parks clogs the streambeds with very fine particles, such as clay and silt. Clogging by sediments has



Bill Yeaman, Rock Creek Park Natural Resource Manager, shows one of the many seeps scattered throughout Rock Creek Park, which provide habitat for rare amphipods.

effectively eliminated these streams as dispersal paths for amphipods and isolated the seeps along the stream, degrading groundwater habitat. It is important to remove or divert storm drains that impact spring sites.

The persistence of amphipod populations in the National Capital Region is testament both to the protection of habitat set aside in National Parks and to the critical importance that the Park has placed on preserving these species. Detailed information on the distribution of these amphipod species has resulted in changes in resource management, including rerouting of storm water runoff, changing road maintenance practices, altering the location of new trails away from seeps and springs, building small foot bridges over seeps, and restoring vegetation around some seep areas.

The small parks in the Region are protecting wildlife habitat, as well as the interrelationships among the natural processes and the species they support. Baseline studies like Culver and Sereg (2004) are very important for understanding how to manage park resources and to ensure the persistence of a rich diversity of amphipod species that face continued threats from urban development pressures. Dr. Culver expanded the survey in 2004 to include George Washington Memorial Parkway, and in 2006 he and his students will continue along the Parkway and begin studying amphipods in three more national parks on the Coastal Plain: the Chesapeake and Ohio Canal National Historical Park, Manassas National Battlefield Park, and Prince William Forest Park. Parks of the National Capital Region provide some of the few remaining places where these small, special habitats, and the wildlife they support, can be found.

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CENTER FOR URBAN ECOLOGY

Threatened and Endangered Species Program The Threatened and Endangered Species Program at the Center for Urban Ecology supports conservation efforts for threatened and endangered species of the National Capital Region. The Threatened and Endangered Species Program protects five federally listed species along with State-listed species through research, reintroduction, monitoring, and invasive plant management. The Region has two federally threatened species: bald eagle (*Haliaeetus leucocephalus*) and small whorled pogonia (*Isotria medeoloides*) and three endangered species: harperella (*Ptlimnium nodosum*), Hay's Spring amphipod (*Stygobromus hayi*), and shortnose sturgeon (*Acipenser brevirostrum*). The Threatened and Endangered Species Program assists parks with compliance under Section 7 of the Endangered Species Act. The National Capital Region cooperates with the lead biologists for these listed species in state and federal agencies, working toward the species' recoveries. Conservation strategies are necessary to sustain healthy populations and recover listed species within the parks. Parks provide information annually to Congress on the status of the parks' listed species and the amount spent on monitoring and recovery efforts.

THE VALUE

When we think of a forest, most of us usually think of natural, thick stands of mature trees. There are, however, many kinds of forests. One kind of forest that we often neglect to appreciate is the diverse array of trees growing in a city in parks and on streets. These urban forests provide fundamental benefits to urban environments, enhancing local environments. Trees reduce air pollution by trapping particulates and absorbing gases such as ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide.

of URBAN TREES

They reduce storm water runoff and soil erosion by filtering and absorbing water. Urban environments are cooled by trees shading streets and releasing water vapor into the air. Trees reduce noise pollution by providing sound screens. They also provide habitat for wildlife that would otherwise have a difficult time surviving in urban areas. Trees provide us with a sense of well being amidst the hectic lifestyle that accompanies urban settings.

The parks managed by the National Park Service, National Capital Region within the city of Washington, D.C. play a significant role in sustaining the visual and environmental quality of the nation's capital. For example, two parks—the National Mall and Memorial Parks and the President's Park, which surrounds the White House—maintain over 16,000 trees. Besides their environmental contributions, sustaining these trees is important because many trees, such as the American elms (*Ulmus americana*) of the National Mall and the delicate Japanese cherry trees (*Prunus* species) that surround the Tidal Basin, have cultural significance and are major assets of Washington, D.C.

Developing management strategies designed to protect and enhance urban trees and education strategies to make the public aware of the need for wise management, depend upon understanding and quantifying the resource values of the urban forest. In 2004, the National Capital Region partnered with the U.S. Forest Service, the Casey Trees Endowment, and the University of Maryland,

Cooling Effects of Trees

Trees can have many energy-saving benefits for buildings by providing shade and evaporative cooling, which reduces energy costs in the summer. They can also block winter winds, reducing heating costs in the winter. The UFORE model estimates that trees in Washington D.C. reduce building energy costs by $2.6 million each year; these are savings to residents in heating and cooling costs. In addition, lower energy use reduces the carbon emissions from power plants for an annual $96,000 savings through decreased use of fossil fuels.

In addition to reducing storm water runoff, trees have a significant cooling effect.

Urban Forestry Program (a member of the Chesapeake Watershed Cooperative Ecosystem Studies Unit) to assess the urban forest of Washington, D.C. The purpose of this study was to provide resource managers, city planners, urban foresters, and the public with baseline information on species diversity, tree size and condition, and the ecological services provided by the urban trees.

Field crews composed of trained seasonal rangers, university interns, and volunteers collected information about the urban forest during the summer of 2004. Teams collected data from 201 field plots throughout the District of Columbia, which included a mix of woodlands, city parks, National Parks and other federal installations, developed urban sites, commercial property, and residential yards. Each circular field plot was one-tenth of an acre (0.04 ha) in size, and crews inventoried all vegetation within the plot. They identified trees and took measurements such as diameters at breast height, tree heights, and crown volumes and condition. Crews collected site information data such as existing land use and ground and tree cover.

U.S. Forest Service researchers also used local hourly air pollution concentrations and meteorological data for the year 2000 in conjunction with the field data. They analyzed all the data using the Urban Forest Effects (UFORE) computer model, which quantifies ecological services, forest structure, and capital asset value (Nowak et al. 2006). A unique outcome of the UFORE model is that the capital value of the urban forest can be expressed in dollar amount in terms of their replacement costs and the ecological services they provide, including their contribution to pollution removal, carbon sequestration, and energy savings.

Trees: A Valuable Resource

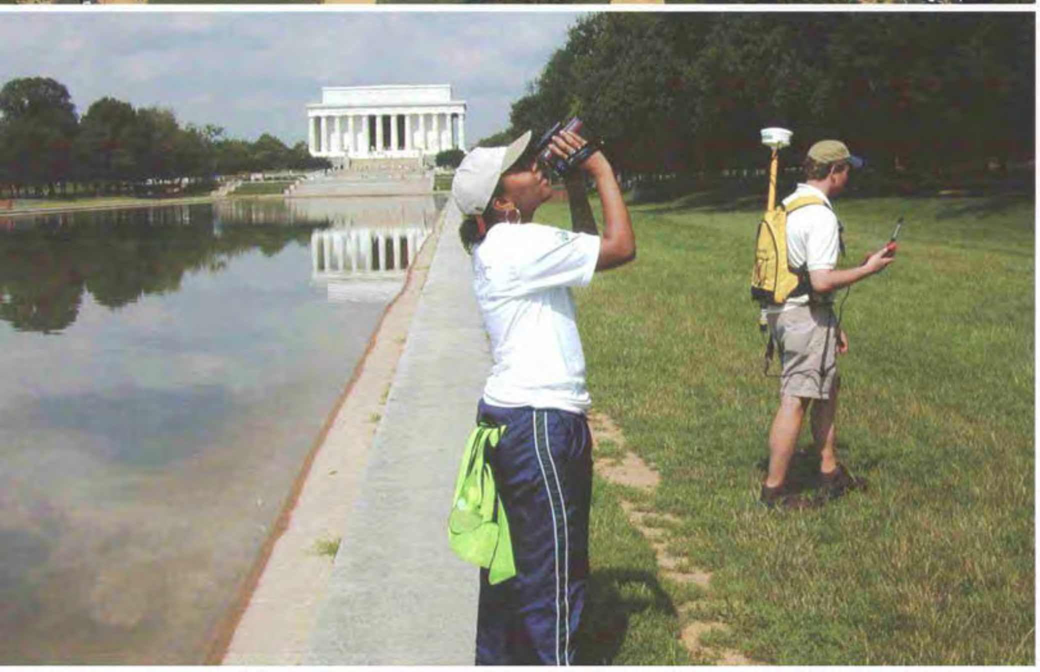
Within Washington, D.C. are an estimated 1,928,000 trees with an overall tree canopy cover of 28.6%. Slightly over half of those trees (56.3%) are less than 6 inches (15.2 cm) in diameter at breast height. The most common tree species are American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), boxelder (*Acer negundo*), tulip tree (*Liriodendron tulipifera*), and flowering dogwood (*Cornus florida*).

Our urban forest appears to be in good standing: Washington, D.C. ranks fifth in total number of trees when comparing tree coverage among seven cities in the Northeast (Atlanta, Georgia; Baltimore, Maryland; Boston, Massachusetts; Brooklyn and New York City, New York; Jersey City, New Jersey; and Philadelphia, Pennsylvania). It places third in tree densities (49 trees/acres (121 trees/ha)) following Baltimore with 51 trees/acre (126 trees/ha) and Atlanta with 112 trees/acre (276 trees/ha). One major contributor to the urban forest is Rock Creek Park, a National Capital Region unit located in the middle of the city. Rock Creek Park occupies approximately 7% (2,876 acres (1,164 ha)) of Washington, D.C. and contains large areas of uncultivated, dense forest. Other National Park units are also significant components of Washington, D.C.'s urban forest.

Although many environmental and social benefits remain to be quantified, the UFORE model has allowed us to calculate several benefits of the urban forest in our nation's capital. The benefits are very significant. As an example, poor air quality is a common problem in cities and leads to human health problems, damage to structures, reduced visibility, and alteration of ecosystem

"Within Washington, D.C., an estimated 1,928,000 trees provide an overall tree canopy of 28.6%... The most common tree species are American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), boxelder (*Acer negundo*), tulip tree (*Liriodendron tulipifera*), and flowering dogwood (*Cornus florida*)."

American elms are a distinctive feature of the National Mall's landscape.



Top: The National Mall in Washington, D.C. houses a large population of trees.

Bottom: Forestry interns measuring tree height (left) and gathering GPS information (right).

> "The urban forest can help improve air quality by removing pollutants from the air and reducing air temperature. Yearly pollution removal by trees in Washington, D.C. was estimated at 492 tons, an ecological service with an associated value of $2.5 million."

processes. The urban forest can help improve air quality by removing pollutants from the air and reducing air temperature. Yearly pollution removal by trees in Washington, D.C. was estimated at 492 tons, an ecological service with an associated value of $2.5 million. The ecological services that the Washington, D.C. urban forest provides amount to more than 523,000 tons of carbon storage, a value estimated at approximately $9.6 million. Carbon stored in trees and other plants can help mitigate atmospheric effects of carbon dioxide released into the environment by motor vehicles. Thus, urban trees can actually help mitigate climate change by storing atmospheric carbon and turning it into new tree growth each year. The UFORE model determined that the difference in carbon storage abilities of the trees between different years (or carbon sequestration) is 16 tons per year, worth an annual value of $297,000. Across the city, the urban forest provides savings in annual building energy use equal to $2,616,000, according to the UFORE modeling results.

Urban forests have a structural replacement value based on the tree itself, which is the cost of replacing the tree with a similar tree or compensating for its loss. The value is based on the location of the tree, the species, size, and condition. Structural values tend to increase with an increase in the number of healthy trees and as the trees grow larger. The UFORE study estimated that the structural value of the trees in Washington, D.C. is approximately $3.5 billion. Clearly, these ecological and compensatory values show the significant capital asset of urban trees.

Looking into the Future

Because of the relatively harsh conditions of the urban environment in Washington, D.C., these trees require special attention and exceptional care to ensure successful growth and maintenance. City environments differ greatly from natural habitats. The health and survivorship of trees in a city are most affected by air pollution, poor soil quality, and physical damage. In many cases when trees are stressed, they become more susceptible to infestation by insect pests and diseases.

In order to track changes in the urban forest over time, field crews will reassess 10% of the Park trees every year to detect overall changes and trends. This means that every 10 years the Parks will complete a new inventory. The information will facilitate planning efforts directed at maintaining and increasing the number of healthy trees.

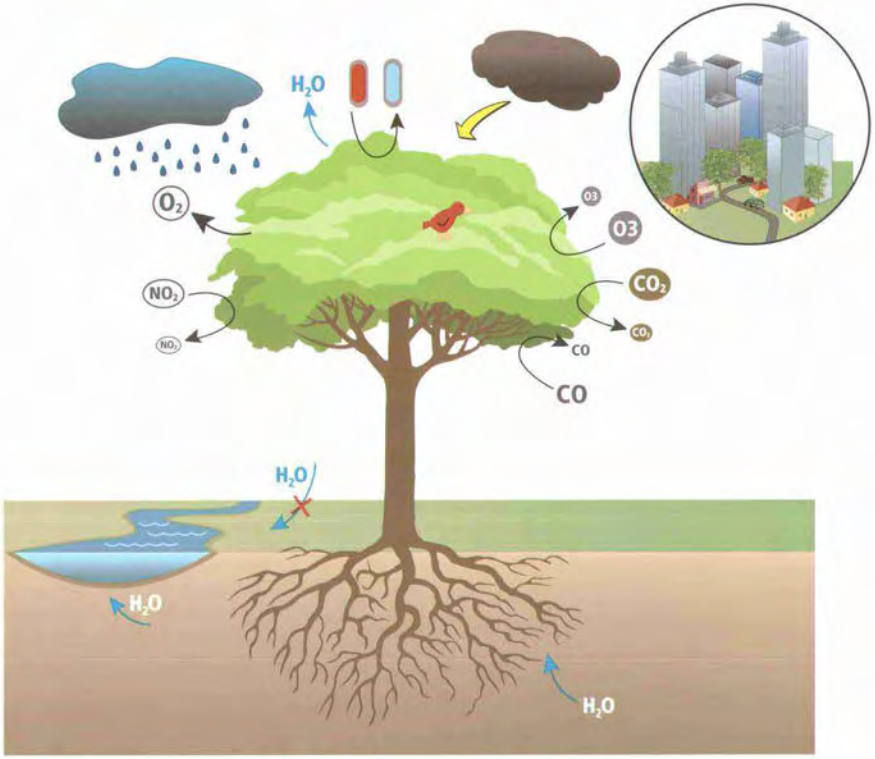
Although the National Capital Region is quick to replace street and park trees that have died, we also recognize the importance of sustaining large, healthy trees to further improve the area's air quality. Researchers have found that healthy trees greater than or equal to 30 inches (76 cm) in diameter remove 70 times more pollution per year than healthy trees that are less than or equal to 3 inches (7.6 cm) in diameter. This fact should persuade all municipalities to take greater interest in sustaining their older trees.

“The UFORE study estimated that the structural value of the trees in Washington, D.C. is approximately $3.5 billion.”

The urban forest improves air quality by reducing air temperature and removing pollutants. Images are from air quality webcam at the Netherlands Carillon.

Right: Street trees are part of the urban forest in Washington, D.C.

Using the baseline data collected in a comprehensive inventory of all their trees, resource managers at the National Mall and Memorial Parks are developing a maintenance-based data collection tool and GIS program to better address management needs. Future data applications will include identifying where trees are missing in accordance with site planting plans, tracking diseases throughout the Park, identifying survivorship of tree species in different areas, creating a historic tree preservation plan, and directing maintenance efforts. Managers will continually update this database with information about new tree plantings, removals, and causes of removal.



Ecological Benefits of Urban Trees

Urban forests provide many benefits to society. Trees in cities improve air quality by directly removing urban pollutants from the air such as ozone O3, carbon monoxide CO, carbon dioxide CO_2 and nitogen dioxide NO_2. Some of these pollutants CO_2 CO are integrated to the trees' tissue as they grow. Because of their shading benefits and evapotranspiration, trees reduce air temperature contributing to energy savings for city dwellers. They contribute to the quality of a watershed by reducing storm water runoff with the consequence of reduced erosion and reduced transportation of sediments and pollutants to streams. Trees also provide habitat for urban wildlife.

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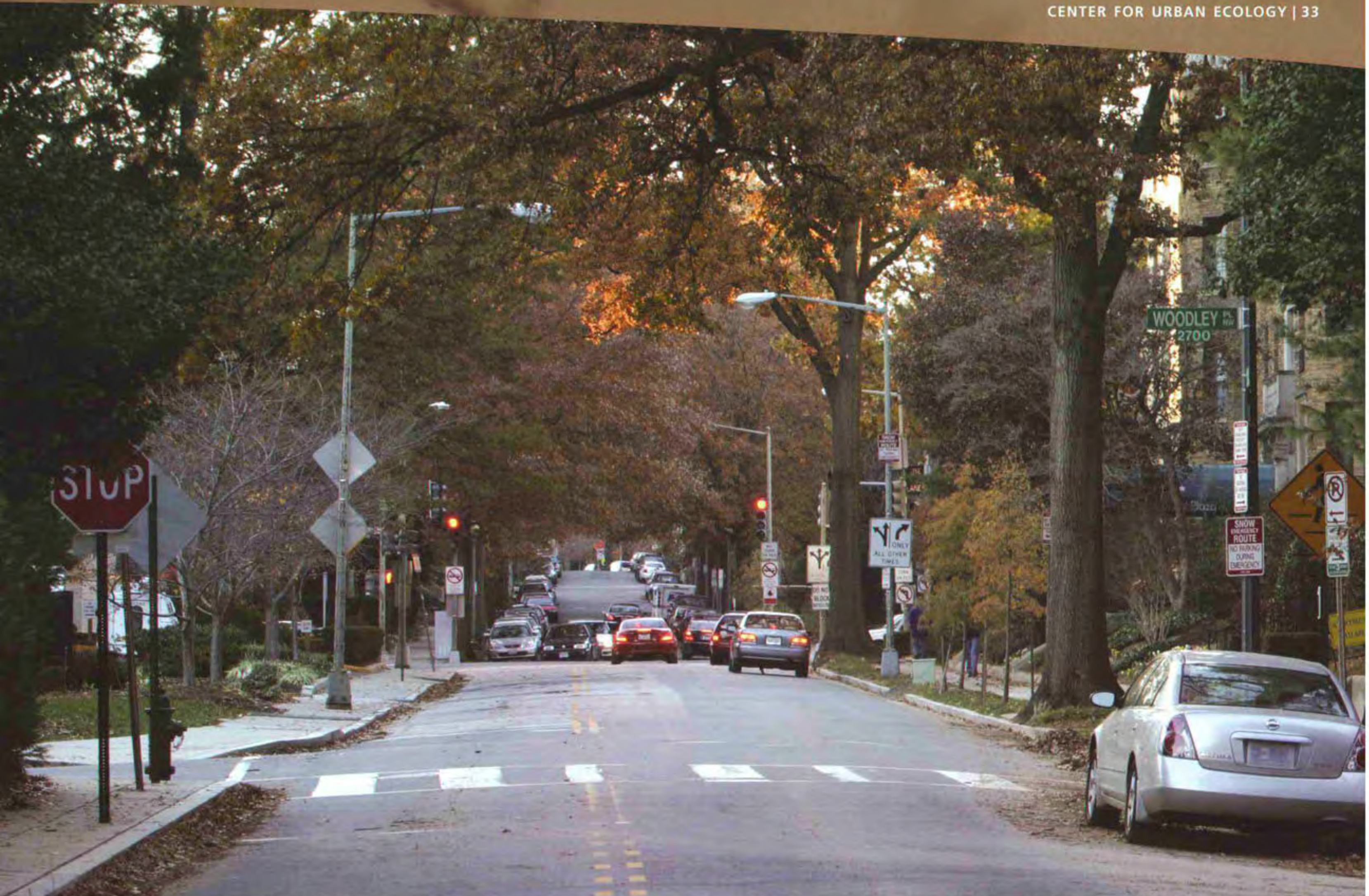


CENTER FOR URBAN ECOLOGY

Horticultural Landscape Program The Horticultural Landscape Program provides technical assistance to the parks of the National Capital Region in the design, development, and maintenance of horticultural landscapes. Assistance is provided in the diagnosis of plant disorders, selection of plant material, and the design of sustainable planting environments. The Program collaborates closely with the Integrated Pest Management, Exotic Plant Management Team, and Soils and Geology Programs. We engage in studies to protect and describe the urban forest by participating in city-wide efforts such as Dutch elm disease (*Ophiostoma ulmi*) and gypsy moth (*Lymantria dispar*) management and in surveys describing the extent, health, and ecological values of the urban forest. The Horticultural Landscape Program collaborates with the District of Columbia's Urban Forestry Administration, the Casey Trees Endowment, and other groups interested in sustaining the urban forest of the National Capital Region and the Washington, D.C. metropolitan area.

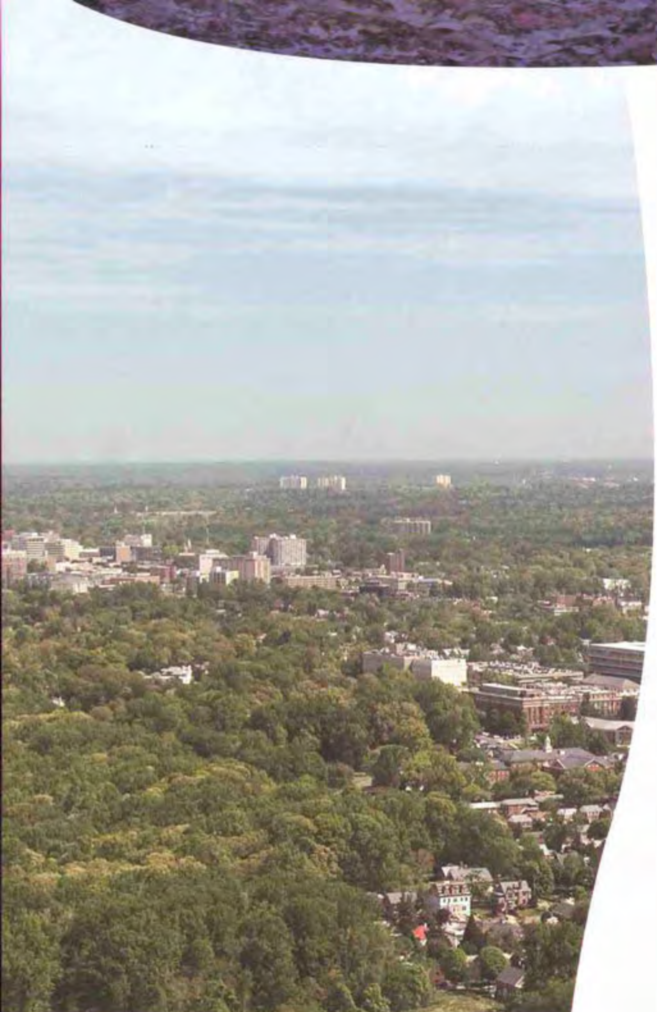
PERMEATING

The rivers and streams entering the parks of the National Capital Region provide an impressive combination of natural, scenic, cultural, historical, and recreational value. Along the Potomac River, paddlers, fishermen, bird watchers, and many others take advantage of the many recreational opportunities offered by the parks. With the continued development and population growth throughout the Washington, D.C. metropolitan area, the integrity and health of our rivers and streams are seriously compromised. Some of the impacts of this accelerated development on streams are readily noticed, others are hidden.

CHALLENGES

National Park areas sit within a landscape matrix made up not only of forest, grassland, agricultural lands, but also of roadways, buildings, and residential and commercial development. Areas surrounding the Parks range from relatively little development to highly developed cityscapes. The gradual conversion of lands surrounding the National Parks into roadways, buildings, and parking lots has increasingly adverse impacts on water resources, according to the Water Resources Program at the Center for Urban Ecology. What is the culprit? Impervious surfaces--because they prevent the infiltration of water into the soil. Unfortunately, it may take years or even decades for the cumulative, detrimental effects of impervious surfaces to become apparent.

The challenge for the National Park Service is to protect resources threatened by development and to mitigate and restore resources already impacted. This is particularly difficult when threats and impacts to the resources within the parks originate outside the park boundaries. For example, three of our parks are long, skinny ribbons with large perimeter areas. One of these, the Chesapeake and Ohio Canal National Historical Park, is 184 miles (296 km) long and includes over 109 streams that are potentially affected by pollution from the surrounding developed lands in Maryland and the District of Columbia. Seven other parks are either entirely inside cities or abutting development from one or more directions. Rock Creek Park is an island of green forest within a sea of impervious surfaces (Figure 1).



When it comes to impervious surface, it does not take much coverage to affect water resources. Generally, impaired water quality is detectable when the impervious surface area rises above 5% of the total area within the watershed. When impervious surface area rises above 30%, the water resources are permanently degraded (Brabec et al. 2002, Goetz et al. 2003). Forests are very beneficial to a watershed, but a residential development with only one house per two acres (0.8 ha) contains enough impervious surface to produce a detectable decrease in stream water quality (Figure 2). Roadways and parking lots have the most detrimental effects and are the largest contributors to impervious surfaces associated with development. However, the roofs on buildings are also a major contributor to the total impervious surface of an area.

We use watersheds as frames of reference when describing the effects of impervious surface area on water resources such as the water quality of a stream. Impervious surface area values are calculated for an entire watershed. For example, if there is a watershed with one-half of the area

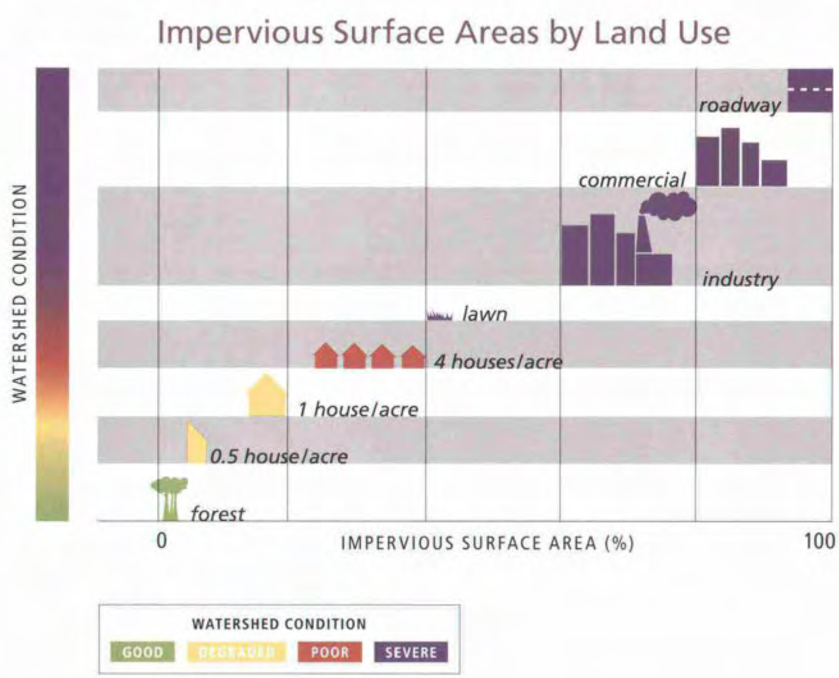


Figure 1 (above)
Rock Creek Park (dark green center), located in the Washington, D.C. metro area, is a forested island surrounded by a sea of impervious surfaces created by residential and commercial development.

Figure 2 (right)
Impervious surface areas associated with different land uses. The colors represent the predicted levels of water quality condition for a watershed comprised entirely of each land use category (compiled from Anacostia 1991, CWP 1998, NVPDC 1980).

> "Impervious surfaces interfere with the percolation of water into the soil layer. In a natural system, rain water soaks into the soil and replenishes both shallow and deep groundwater reservoirs."

in medium-density residential land use equaling 40% impervious surface area and the other half is a forest with 1% impervious surface area, then the average impervious surface area for that watershed is 20.5%. The 20.5% indicates that the water resources are degraded, but the adverse effects may still be reversible.

Where does the water go if it is not percolating downward due to the impervious surfaces? First, the rain water gets concentrated into roof downspouts, roadside gutters, and storm water drain pipes and is quickly transported into city distribution systems such as the storm sewers. From there, the water is dumped into unprotected gullies or directly into streams and rivers, resulting in severe erosion (Figure 3). In a natural setting, streams develop over decades and commonly take a meandering form. This process is a balance between the force of the running water versus the resistance of the soils and rocks in the valley. Urbanization disrupts this balance by changing the amount and speed of the water that flows through the watershed. Increased flows force the stream to change its path and down-cut the stream channel, erode the bank, or straighten and widen the stream. Ultimately, this affects the habitat quality both in and out of the stream for fish and other organisms. Eroded urban streams can lose all their fish and turn into breeding grounds for aquatic worms, nuisance flies, and mosquitoes.

Impervious surfaces interfere with the percolation of water into the soil layer. In a natural system, rain water soaks into the soil and replenishes both shallow and deep groundwater reservoirs. Streams often are partially fed by groundwater; therefore, decreases in the volume of groundwater can dramatically change stream water flows. Many streams become dry during part of the year as a direct result of the lowering of the groundwater levels. In addition, the lack of percolation also increases the frequency and severity of flooding—the water needs to go somewhere. Flooding is a particular problem for the parks in the National Capital Region because of the proximity of many historical and cultural resources along waterways.

Urban sprawl generates large quantities of seemingly innocuous chemicals (e.g., salt, nitrogen, and phosphorus), as well as known hazardous materials (e.g., oils, metal contaminants, and bacteria). When impervious surfaces displace the natural landscapes that filter and retain contaminants, these chemicals and materials are easily transported directly into streams and rivers. In urban systems, direct input of excess nutrients can stimulate algae and aquatic plant growth to

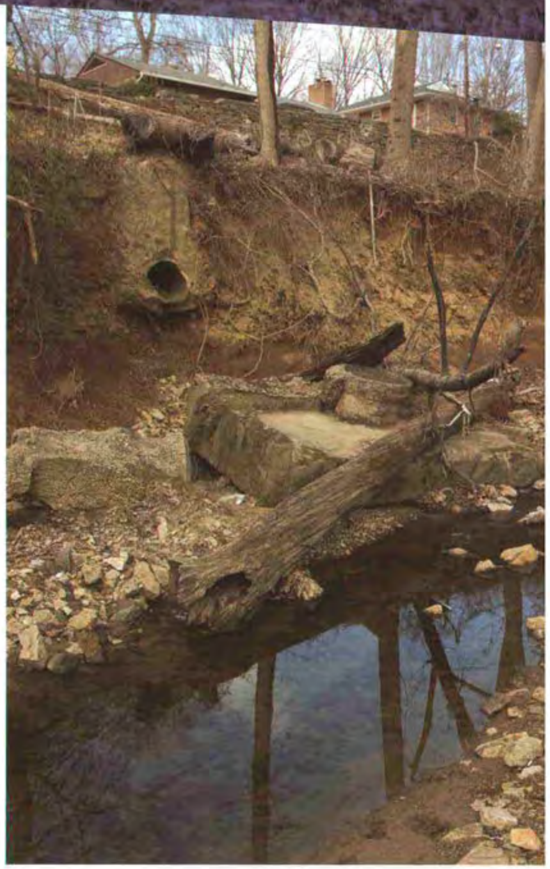
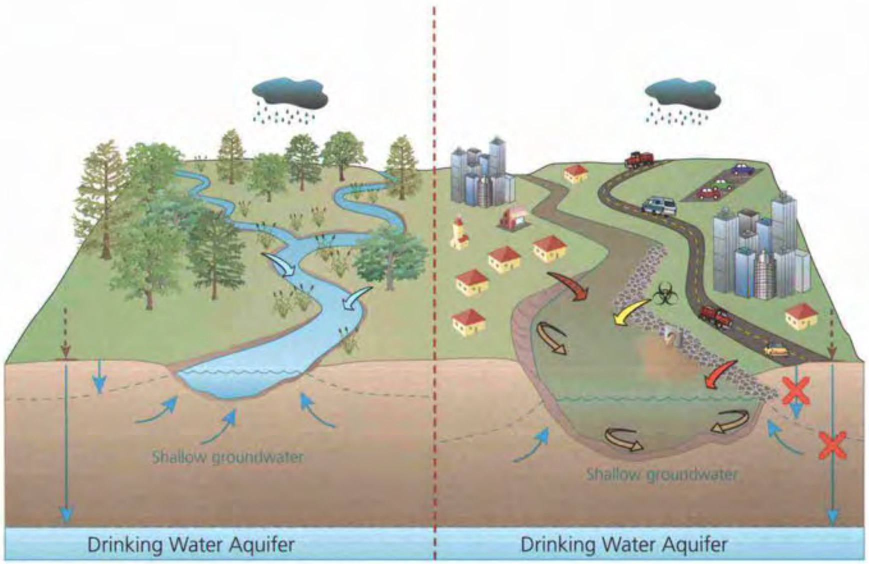


Figure 3
Storm water flowing into an unprotected gully causes massive erosion.



Natural System

Forests, grasslands, wetlands, and meandering streams represent the natural state of the environment. Rainfall permeates natural surfaces and recharges the shallow groundwater layer and the deeper drinking water aquifer. Groundwater supplies a baseflow for streams by percolating through stream banks and stream bottoms. Forests and wetlands provide a natural buffer for absorption of pollutants and interception and storage of rainfall. Overland flow is slowed by vegetation.

Urbanized System

City and suburban development increase impervious surfaces. Impervious surfaces provide pathways for direct transport of pollutants and sewage into streams and rivers. Impervious surfaces also prevent rainfall from penetrating into the groundwater and drinking water aquifer. Lowered groundwater levels provide less input for stream flow. Increased water flow from development causes stream erosion from both the banks and the stream bottom, causing the stream to widen and deepen.

> "To interpret the potential threat of impervious surface area to watersheds, we need to demonstrate the relationship between impervious surface area and water quality in a stream."

harmful levels. Each year in the Chesapeake Bay, plant and algae decay create areas of such low oxygen that beneficial aquatic organisms die.

In 2004, Dr. Jeff Runde in the National Park Service Water Resources Program collaborated with the Woods Hole Research Center, Woods Hole, Massachusetts and the Mid-Atlantic Regional Earth Science Applications Center, University of Maryland, College Park to obtain satellite maps for the years 1986, 1990, 1996, and 2000 that showed impervious surfaces for parts of Maryland, Virginia, West Virginia, and the District of Columbia. These maps allowed Dr. Runde to calculate the percent impervious surface area for watersheds in the National Capital Region parks. Figure 4 shows the highest impervious surface area value for each park measured in any single watershed during the year 2000.

Knowing the magnitude and growth (trend) of impervious surface area is the first step in understanding their effect on water resources. To interpret the potential threat

The Anacostia River receives trash and contaminants from urban streams in the Washington, D.C. metro area, some of which flow through National Parks.

Figure 4

Year 2000 data from satellite maps. Shown here are the highest value of impervious surface area for each park.

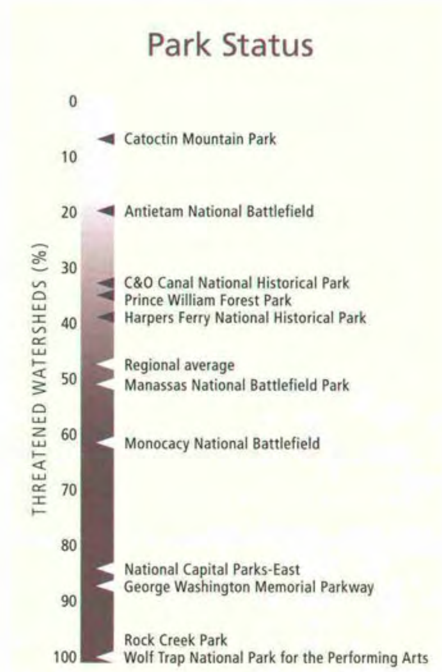


Figure 5

Percent of threatened watersheds for each park based on the percent of impervious surface area, year 2000 data.

of impervious surface area to watersheds, we need to demonstrate the relationship between impervious surface area and water quality in a stream. This relationship is called a potential threat assessment, and it has been divided into four categories. If a watershed has less than 5% impervious surface area it has "good" water quality, 10% impervious surface area is rated as having "impaired" water quality, between 11% and 30% impervious surface area is rated as "poor" water quality, and over 30% impervious surface area, the water quality is ranked as "severely degraded" (Brabec et al. 2002, Goetz et al. 2003). The satellite imagery from 2000 shows that the parks range from less than 10% potentially threatened watersheds in Catoctin Mountain Park to 100% threatened in Rock Creek Park (Figure 5).

Based on satellite imagery from 1986, Dr. Runde estimated that 68% of the National Capital Region's waterways had a potential threat assessment of "good" back then. By 2000, the imagery showed a decrease, and only 53% of the waterways rated "good." Of most concern was a 75% increase from 1986 to 2000 in the proportion of the waterways rated as "severely degraded."

> "The goal of the NPS Water Resources Program is to continue assessing the effects of development located both inside and outside of park boundaries to better understand potential threats to water resources. We are giving special attention to assessing the potential threat of increased impervious surface around the parks."

It is important to note that the percent of impervious surface area in a watershed is used to predict the potential condition of the water quality in streams; the data used come from across the country (Brabec et al. 2002, Goetz et al. 2003). In 2006, the NPS Water Resources Program began water quality testing, which will help verify or ground-truth the relationship between impervious surface area and water quality for the individual watersheds within the parks.

Figure 6 shows a potential threat assessment case study for Manassas National Battlefield Park, comparing the years 1986 and 2000. Over the 14 years, development pressures outside the Park degraded the condition of five of the Park's 17 watersheds. One primary contributor was the Virginia highway system. The park is bisected by two heavily traveled highways (Virginia Routes 29 and 234) and is bordered on the south by a commuter freeway, Highway 66. The most threatened watershed is in the southeastern corner of the Park; it has doubled in impervious surface area from 20% to 40% during this period. The threat assessment predicts that water quality in this particular watershed will remain permanently degraded.

Looking into the Future

The goal of the National Park Service Water Resources Program is to continue assessing the effects of development located both inside and outside of park boundaries to better understand potential threats to water resources. We are giving special attention to assessing the potential threat of increased impervious surface around the parks. Monitoring the park waterways will quantify water quality and compare it to the predicted level of water quality from the satellite maps, which showed the amount of impervious surface within a park. This will allow the National Park Service to direct resource management efforts that will protect and improve stream quality.

Watershed Condition: Manassas National Battlefield Park

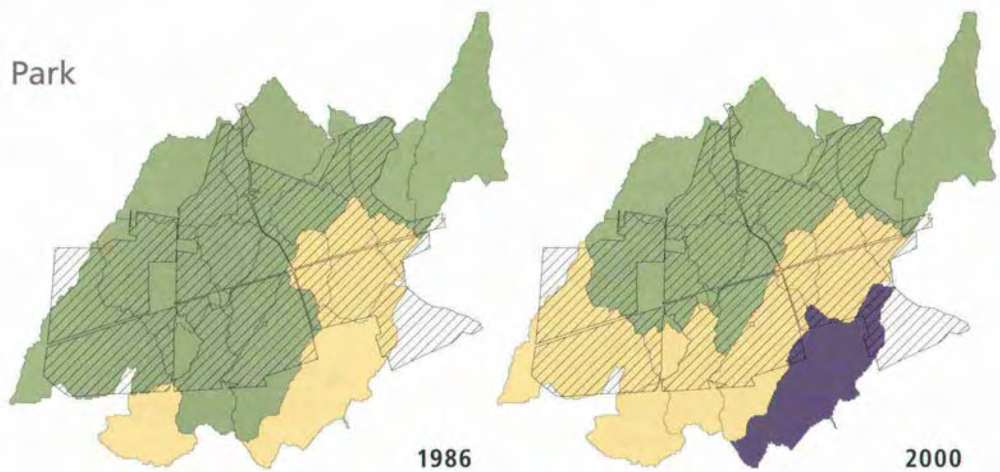


Figure 6

A comparison of threatened watersheds for Manassas National Battlefield Park during the years 1986 and 2000. The Park property is represented by the hatching. The most impacted watershed had 20% impervious surface area in 1986 (yellow) and more than 40% in 2000 (purple). Other watersheds moved from a good (green) to a degraded (yellow) condition.

WATERSHED CONDITION

GOOD | DEGRADED | POOR | SEVERE

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Staff from the National Capital Region Network Inventory and Monitoring program collect samples for water quality analysis.

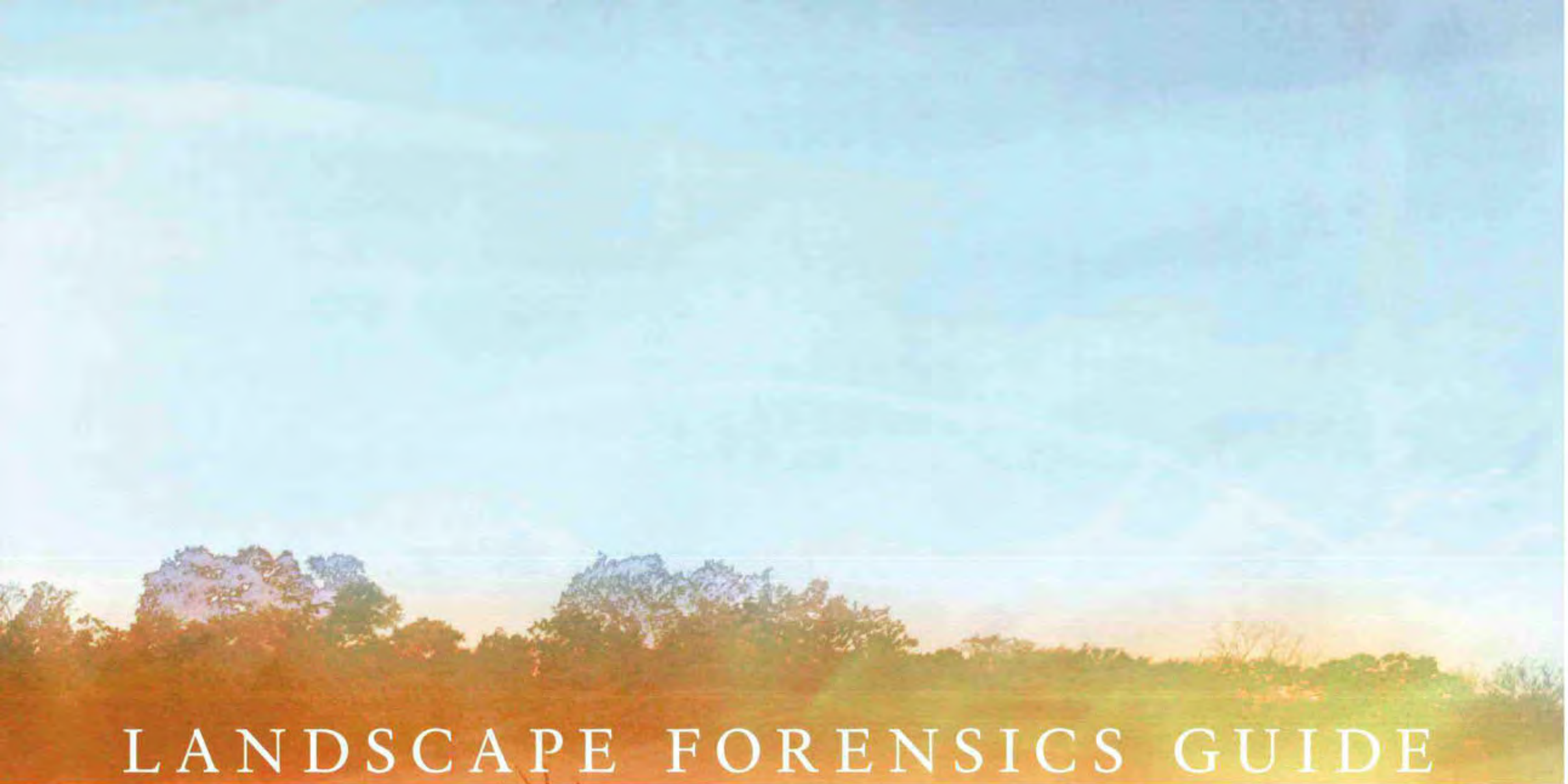
CENTER FOR URBAN ECOLOGY

Water Resources Program The Water Resources Program at the Center for Urban Ecology provides technical assistance on water resource issues to protect the natural, cultural, and historical resources of the parks within the National Capital Region. Human-caused impacts such as urban development have seriously degraded aquatic ecosystems. Innovative approaches toward restoration and protection, such as long-term ecosystem monitoring, water quality assessment, and data analysis are used by scientists to address aquatic habitat health.

Protection of aquatic habitats is also accomplished through the management of the region's streams, wetlands, floodplains, riparian corridors, and groundwater systems. The Water Resources Program promotes best management practices and green infrastructure to reduce the amount of impervious surface area in the Region. They worked with Rock Creek Park to plan and place a green roof on the building that houses the Center for Urban Ecology. Green roofs have many benefits, including decreased storm water runoff. Following best management practices, the Water Resources Program assisted Rock Creek Park with creating bioengineered storm drains in the Park Maintenance Yard to reduce pollution and protect aquatic habitats in the Park. Effective water resource preservation, protection, and management are improved through research and partnerships between the Water Resources Program and other organizations concerned with the water resources of the Washington, D.C. metropolitan area.

WETLAND

The loss of wetland habitat is one of the biggest challenges facing America. Losing wetlands means losing species, which decreases biodiversity and ecosystem services such as pollution filtering and erosion control. By law, wetland loss due to development and construction requires mitigation to replace the lost habitat. The following story of a wetlands restoration project at Manassas National Battlefield Park is a unique story of collaboration and history informing science. It is also an interesting example of how natural and cultural resource preservation interact in the parks of the National Capital Region.



LANDSCAPE FORENSICS GUIDE

RESTORATION

In 1996, the National Park Service and the Smithsonian Institution began to develop a wetland mitigation and landscape restoration project at Manassas National Battlefield Park. The Park acquired adjacent battlefield land, called the Stuart's Hill tract in 1988, where a private developer had previously destroyed wetlands. The Park lacked funding to restore the construction site. In another part of the county, the Smithsonian planned to build a new museum, causing the removal of wetlands, which required mitigation by law. Both of these activities set the stage for collaboration. A wetland mitigation and restoration project had to satisfy the Smithsonian's need to mitigate sufficient acres of wetland and the Park's desire to restore historic landscape features and the ecological integrity of the acquired battlefield site. The project brought about a fusion of historical research and restoration science to address the management needs of both the Smithsonian and the National Park Service.

Wetlands Lost

Stuart's Hill tract, located in the southwestern portion of the Park, incorporates part of the battlefield of the Second Battle of Manassas. Previously owned by a private housing development company, one fifth of the 558 acres (226 ha) was altered for a combined residential and commercial development. Extensive site preparations excavated and graded nearly 125 acres (50.6 ha) down to shale or bedrock and filled and contoured wetland areas, creating a drainage network that changed the hydrology of the area. The resulting public outcry led the U. S. Congress to a legislative taking of the property, and the Park received it in the fall of 1988.

In keeping with its mission to preserve Civil War battlefields, the National Park Service contracted in 1992 with the School of Environmental Design at the University of Georgia to develop a general plan

Restored wetlands provide a diversity in foliage.

Battlefield Provides Habitat to Many Species

Manassas National Battlefield Park is located in Prince William and Fairfax Counties, Virginia, approximately five miles north of the city of Manassas. The Park was established in 1940 to interpret and preserve the sites of the First and Second Battles of Manassas. The Park protects the large tracts of land that represent the scene as it existed at the time of the battles in 1861 and 1862. The open fields, wooded areas, ridges, valleys, and streams help define the battlefields. These different habitats are home to many plants and animals, including four different species of state listed plants. Chris Lea, National Park Service Botanist, recently identified a highly rare wetland sedge, false hop sedge (*Carex lupuliformis*) in the Park, which was previously undocumented. Surrounded by explosive urban growth, the Park provides protection for unique native biodiversity.

for the restoration of the site. This cultural landscape restoration study used historical maps to document the appearance of the property and to propose a plan for restoring the site to its condition in 1862 when the former plantation witnessed skirmishing and maneuvering by both armies during the Second Battle of Manassas, 28 to 30 August 1862 (Morris et al. 1993, Galke 1992).

The National Archives military records held critical information for planning the restoration. After the Second Battle of Manassas, Major General Fitz John Porter of the Union Army was accused of disobeying orders, court martialed, and found guilty (U.S. Congress 1879). In 1878, the President appointed a Board of Generals to review the initial testimony, and a retrial was scheduled. To facilitate the analysis of the testimony for the retrial, the Secretary of War requested that the Chief of Engineers produce a set of battlefield maps of the Second Battle of Manassas. General Gouverneur K. Warren conducted an on-site survey of the battlefield area. He prepared 22 maps with contours in 5-foot widths (1.5 m) and described the vegetation (National Archives Record Group 77, file marked Va., G-281). The battlefield survey information helped overturn Major General Porter's conviction, allowing his reinstatement into the United States Army. This historical knowledge about the Stuart Hill's vegetation communities and landscapes was the key to the site's restoration plan. However, the restoration plan was not implemented due to a lack of funds.

> "The mitigation-restoration may be on the disturbed site or elsewhere in the same or another watershed."

During the construction from 2000 to 2003 of a new National Air and Space Museum (the Steven F. Udvar-Hazy Center) in Virginia, the Smithsonian unavoidably impacted 7 acres (2.8 ha) of wetlands. The 1972 Clean Water Act mandates "no net loss" of wetlands (Public Law 107-303). All land development that impacts wetlands must have mitigation plans to construct and/or restore the same amount of wetland area destroyed or manipulated during construction. The mitigation-restoration may be on the disturbed site or elsewhere in the same or another watershed. Any developers disturbing wetlands must seek regulatory approval (i.e., a permit) through the U.S. Army Corps of Engineers.

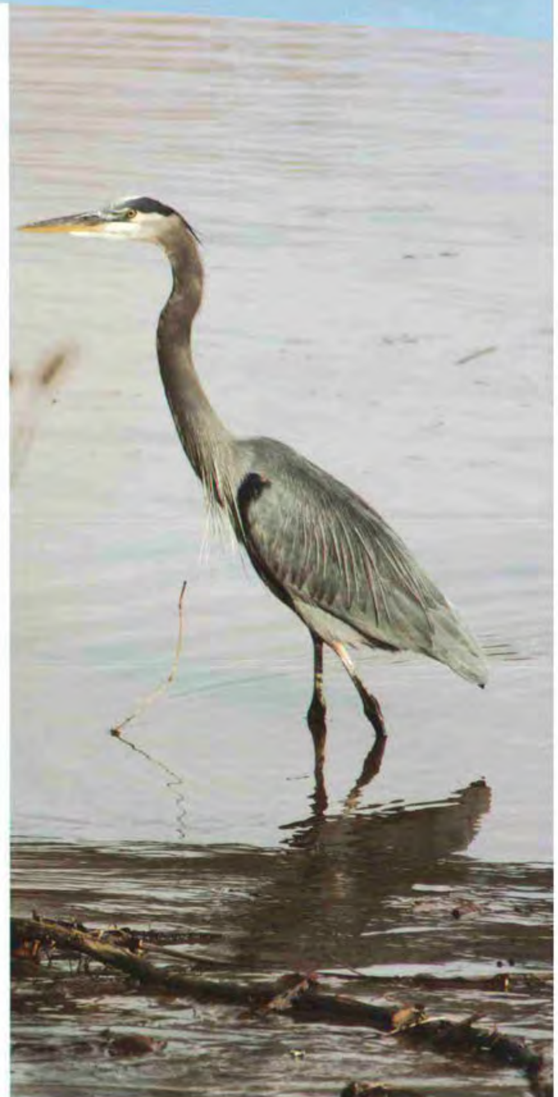
In 1996 the Smithsonian contacted Park staff to determine the feasibility of a wetland compensation mitigation project within the Park's boundaries. The Smithsonian permit stipulated, as compensation mitigation, 15.6 acres (6.3 ha) of wetlands needed to be built or restored. As the permit-holder (Department of the Army ASP-18-Permit No. 97-V1832 issued in 2000), the Smithsonian was responsible for the design, construction, monitoring, and ecological success of a compensatory mitigation site for a minimum of five years, in addition to ensuring the site's long-term protection.

Wetlands Gained

The Smithsonian brought together a mix of partners and contractors to fund, plan, and implement the restoration. The team included environmental consultants (Dames and Moore Group, Los Angeles, California) and the National Air and Space Museum project architect. The Park's natural resource manager and historian provided guidance throughout the planning and construction phases. The Smithsonian team developed and refined the plans for restoring the Stuart's Hill landscape and its wetlands by using the University of Georgia's studies that identified the area's 1862 woodlots, fencerows, meadows, and fields (Galke 1992, Morris et al. 1993). The Park reviewed the proposed locations to recreate wetlands. For example, if the site was historically a meadow or field, any wetland restoration/mitigation was designed as herbaceous (marsh) wetland.

Restoration began in 2003 after this extensive planning. The Dames and Moore Group refined contours from the military map used in Porter's 1878 retrial by incorporating three other sources of information: the private housing developer's initial survey made just before the Stuart's Hill tract was excavated, a map from Prince William County that was made during the same period (just prior to 1988), and aerial photography of the area from the 1930's, which showed topographic changes since the Civil War. Thus, the Dames andMoore Group had an excellent rendition of the historic landscape including detailed contours.

The restoration area at Stuart's Hill has seven major drainage areas that contain 19 wetland creation sites, ranging in size from 0.07 to 1.3 acres (0.03-0.51 ha). Each of these sites is a wetland mitigation unit with specific site prescriptions for hydrologic condition and a detailed planting prescription. Reliable wetland hydrology was established in the sites by measuring dry season groundwater levels and setting the bottom of the wetlands 1 foot (0.3 m) higher.



Right: *Manassas National Batlefield supports many bird species and has been designated as an* **Important Bird Area** *in the State of Virginia.*
Bottom: *More than a hundred acres were excavated and contoured to former 1862 conditions.*

The Mandate to Restore Wetlands

U.S. Army Corps of Engineers issues permits under 1972 Clean Water Act, Section 404 after environmental reviews of impacts. The permit conditions may require that any unavoidable wetland impacts be compensated by creating new wetlands. Clean Water Act U.S.C. Title 33 as amended, P.L. 107-303.

Forensic Wetlands Restoration

Table 1. Species planted in herbaceous wetlands and the understory of forested wetlands (Anonymous 2005).

Life Form	Common Name	Scientific Name
fern	cinnamon fern	*Osmunda cinnamomea*
	marsh fern	*Thelypteris palustris*
sedge	fringed sedge	*Carex crinita*
	shallow sedge	*Carex lurida*
rush	blunt spikerush	*Eleocharis obtusa*
	green bulrush	*Scirpus atrovirens*
	wool-grass	*Scirpus cyperinus*
	soft rush	*Juncus effusus var. brunneus*
grass	switchgrass	*Panicum virgatum*
	wood reed	*Calamagrostis perplexa*
forb	Joe-Pye weed	*Eupatorium fistulosum*
	monkey flower	*Mimulus spp.*
	swamp milkweed	*Asclepias incarnata*
	false-nettle	*Boehmeria cylindrica*
	purple-stemmed aster	*Symphytum puniceum*
	swamp smartweed	*Polygonum hydropiperoides*
shrub	silky dogwood	*Cornus amomum*
	southern arrowwood	*Viburnum dentatum*
	swamp rose	*Rosa palustris*
	winterberry	*Ilex verticilliata*

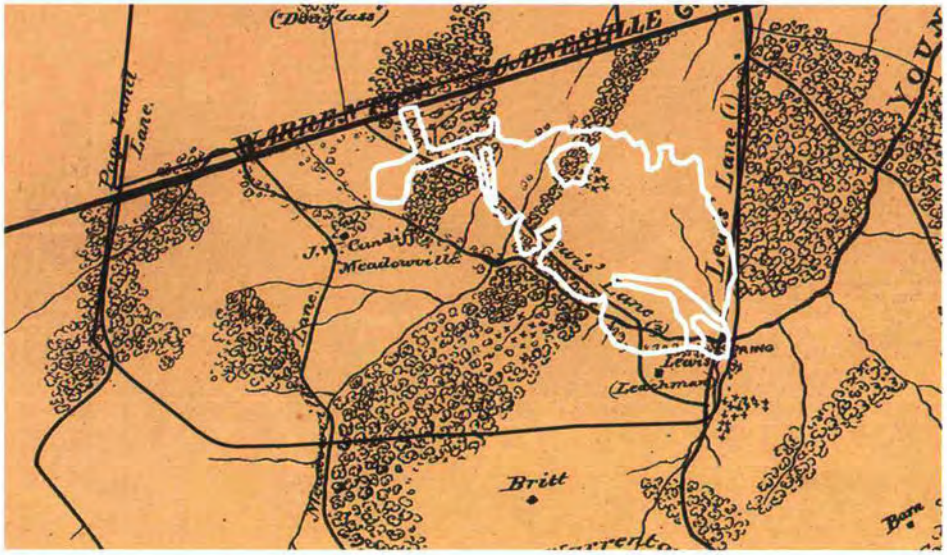
This ensures water year-round for plants. Implementing the plan required excavating and grading 104 acres (42 ha) back to the 1862 contours. Stuart's Hill restoration had over 3 million cubic feet (95,000 cubic meters) of material moved around the site by rebuilding ridges, removing soil, concrete, culverts, pipes, and non-native plants. Once the earthwork was completed, contractors installed approximately 57,000 plants of 24 hydrophytic (or water-loving) native species (Table 1). In some areas, intact soils and hydrology allowed direct planting of native hydrophytic plants.

Upland Restoration at Stuart's Hill

In 2003 the Park received Natural Resources Preservation Program (NRPP) funding to augment the restoration project in the upland areas at Stuart's Hill. The Park managers wanted to create upland forest and meadow habitat to benefit a variety of wildlife and plant species, while maintaining the open vista present during the Civil War. They planted native warm season grasses and native forbs. The forb mix enhanced species diversity and provided nitrogen-fixers to the meadow. The native forbs and grasses planted include Indian grass (*Sorghastrum nutans*), tall coneflower (*Rudbeckia laciniata*), black-eyed Susan (*Rudbeckia hirta*), partridge pea (*Chamaecrista fasciculata*), round-head lespedeza (*Lespedeza capitata*), and marsh blazingstar (*Liatris spicata*). In addition, the Park restored trees to historically wooded areas at the site. The target plant community was "Basic Oak Hickory Forest" type. The Park planted over 450 native trees, including northern red oak (*Quercus rubra*), willow oak (*Quercus phellos*), swamp white oak (*Quercus bicolor*), red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), green ash (*Fraxinus pennsylvanica*), and tulip poplar (*Liriodendron tulipifera*) (Gorsira 2004).

Looking into the Future

Compensation for the loss of wetlands is challenging. With three years remaining in the 5-year monitoring and maintenance period, more engineering, hydrology, and vegetation work remain. Data from the vegetation and hydrology monitoring in 2004 shows that the Smithsonian has established 8.5 acres (3.4 m) of wetland areas that meet the wetland hydrology criteria in the approved compensation mitigation plan. The Park and the Smithsonian are discussing how to achieve the remaining mitigation acreage requirement.



A map produced in 1878 for the trial of Major General F.J. Porter of the Union Army guided restoration of a wetlands. The restored area is shown in white.

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CENTER FOR URBAN ECOLOGY

Vegetation Program Park managers base management decisions on scientifically defensible data. The Vegetation Program at the Center for Urban Ecology provides expertise on experimental designs and analysis of vegetation studies and long-term data sets within the parks of the National Capital Region.

The classification and subsequent mapping of vegetation communities in National Capital Region parks is a primary Program goal and is one of the 12 required data sets that parks must develop. The Vegetation Program at Center for Urban Ecology has developed a time and cost efficient mapping strategy that is simultaneously mapping all of the parks in the National Capital Region. Preliminary field work and data analysis have identified 150 plant communities in the parks.

The vegetation mapping project is conducted in cooperation with NatureServe, the Virginia Department of Conservation and Recreation—Natural Heritage Program, the National Capital Region Geographical Information Service and Inventory and Monitoring Programs, and the National Park Service Vegetation Mapping Program.

DRAGONFLIES

Preserving the resources of the National Parks for the enjoyment of future generations is the fundamental purpose of the National Park Service. In the landscape of accelerated development and population growth in the mid-Atlantic region, National Parks and other protected areas contain the last remnants of habitats critical for the survival of many species. Inventories produce the baseline information that park managers need to effectively protect these resources. As we continue our inventories of natural resources in the parks of the National Capital Region, many species not previously recorded are revealed, and the value of our urban parks is even more apparent.

PRECIOUS JEWELS:
AND DAMSELFLIES

The story of how we came to learn about the impressive diversity and value of our dragonflies and damselflies (the odonates) is one of ecological connections and shared interest in preserving biodiversity and protecting human health. The National Capital Region manages important wetlands, which is habitat for the odonates. The National Capital Region also serves more than 40 million visitors annually, which accounts for 20% of the total National Park Service annual visitation (NPS 2001). West Nile Virus is established in the Washington, D.C. area and efforts are underway to monitor for the vectors and the disease throughout the National Capital Region.

How are dragonflies and West Nile Virus connected? The connection is ecological because West Nile Virus is a mosquito-borne virus. Both the mosquitoes that transmit West Nile Virus and the odonates share the same aquatic habitats. If there is a need in the future to aggressively control mosquito populations, this could adversely affect other aquatic organisms. Dragonflies and damselflies play an important role in freshwater aquatic environments. The immature stages (nymphs) live totally under water, occupying all types of aquatic habitats, including both moving and still water, where they spend most of their early life feeding on various sorts of small aquatic organisms. When a nymph is fully grown, it crawls up out of the water, usually on a plant stem or rock, and undergoes its final molt. Once out of the last nymphal skin (exuvia) the adult expands to its full size and goes on to a life on its wings.

Odonates are excellent indicator species, which means that the odonate community composition of a given aquatic environment reflects the overall health of that system (Corbet 1999). Changes in aquatic systems are quickly reflected in changes in the odonate species

The lives of odonates are connected to water; the immature stages are aquatic and the adults are usually found near water. The wide variety of habitats along the Potomac River contribute to odonate diversity; these habitats include tidal marshes (top), slow flowing channels (middle), and streams with moderate flow (bottom).

composition, which are often at faster rates than can be monitored for most other plant or animal groups. Odonate species are currently at risk from a number of environmental threats, including habitat destruction and contamination.

Richard Orr (Versar, Inc., Columbia, Maryland) conducted a study of dragonfly and damselfly populations in multiple parks of the National Capital Region from 2002 to 2004. He designed the study to provide critical life history information for park managers so that future West Nile Virus vector control management practices could be developed or modified to reduce the risk to these species and their habitats from pesticide spraying and other park activities. The project had the added value of providing a comprehensive list of the dragonflies and damselflies found in our parks and an assessment of their conservation status and needs, allowing parks to better address rare species issues.

> "The immature stages (nymphs) live totally under water, occupying all types of aquatic habitats, including both moving and still water, where they spend most of their early life feeding on various sorts of small aquatic organisms."

The meticulous and intensive sampling conducted by Mr. Orr included Rock Creek Park, Harpers Ferry National Historical Park (West Virginia, Maryland, and Virginia sections), the Potomac Gorge (Theodore Roosevelt Island to Bealls Island; including property managed by George Washington Memorial Parkway and Chesapeake and Ohio (C&O) Canal National Historical Park, District of Columbia, Maryland, and Virginia), and the C&O Canal National Historical Park (from Bealls Island to Antietam Creek, Maryland; including the Potomac River). The investigator sampled all permanent and temporary wetland habitats including the Potomac River, the C&O Canal, marshes, seeps, ponds, and tributaries within the boundary of each park.

Because many odonate species are rare and their aquatic habitats are difficult to access and sample, species data come from the identification of adults observed using binoculars or caught with nets, and collections of exuviae (the cast exoskeleton remains left by emerging adults). Since exuviae are ephemeral (time sensitive), their presence provides important life history information such as emergence times and distributions of some of the rare adult species. Mr. Orr's final analysis also included data from a detailed study of the dragonflies and damselflies of the Potomac River and C&O Canal that he conducted from 1994 through 1996.

A very important component of the survey effort was the participation of 23 volunteers working through Partners-in-Parks who

Science Informing Management

With the introduction of the mosquito-borne West Nile Virus to the Washington, D.C. area in 2000, aquatic ecosystem management in the National Capital Region also addresses human health concerns. The descriptions, life histories, and locations of rare dragonflies and damselflies are now known for each of the parks that Mr. Orr studied. Park managers are able to use the information to minimize adverse effects on odonate populations. Care will be taken to prevent significant population-level impacts on rare odonate species.

For example, Mr. Orr's study reveals that the larval habitats of the two mosquito species (*Culex quinquefasciatus* and *C. pipiens*) found in the mid-Atlantic region and pose the most risk to human health for the spread of the virus differ from those of the rare odonate species found in the parks (CDC 2003). Mosquito larvae prefer dark to semi-dark, highly organic (e.g., wetlands and sewage treatment plants effluent), and still-water habitats. However, the larval habitats for the odonates of special concern are rivers, streams, or clean-fresh water seeps. Therefore, applying larvicides to the specific habitats where mosquito larvae occur should not threaten odonates of special concern. On the other hand, the toxicological effects of mosquito-targeted sprays on adult dragonflies are not fully understood. As adults, mosquitoes feed actively during the early morning, evening, and night hours. The majority of dragonflies and damselflies found in the National Capital Region are diurnal. Therefore, proper application of treatments should occur when odonate species are not active.

provided 552 hours of additional field work. These volunteers searched for casts in 2003 and 2004 and collected nearly 2,000 dragonfly exuviae that they provided to Mr. Orr for identification and counting.

Impressive diversity

The results of this study revealed an impressive wealth of odonate species from a biodiversity standpoint. Equally impressive is the high numbers of dragonfly and damselfly species that have been identified as having conservation importance on State Heritage lists of threatened or endangered species.

In total, Mr. Orr found 101 species of dragonflies and damselflies utilize habitats within the surveyed units of the National Capital Region. Mr. Orr and volunteers collected over 100,000 individual data points. Forty-five of the species have conservation importance due to rarity in at least one or more of the political entities of the District of Columbia, Maryland, Virginia, and West Virginia and are represented within the surveyed area.

The discovery of the Potomac Snaketail (a new species of *Ophiogomphus*) and the Tiger Spiketail (*Cordulegaster erronea*) are worth mentioning because of their conservation stature. The Potomac Snaketail is a previously undescribed species known from a single male collected within the C&O Canal National Historical Park. Recently emerged, the male specimen matches the description of the rare Wisconsin Snaketail, *Ophiogomphus susbehcha*. The Wisconsin Snaketail is considered one of the rarest dragonflies in the world and is exclusively found along the St. Croix River in Minnesota and Wisconsin (Vogt and Smith 1993). To correctly identify this unknown species, Mr. Orr compared the specimen with four specimens preserved in the national collection at the Department of Entomology, Smithsonian Institution. Differences in many structural features suggest that it is a new species of *Ophiogomphus*. This is a very exciting finding and the search for additional specimens is currently underway.

Field Guide to Dragonflies and Damselflies

Over 100 species of dragonflies and damselflies (odonates) have been located within the National Capital Region. Forty-five species are of conservation concern and importance. Mr. Richard Orr included 15 common odonate species in a field guide to assist park managers and interested visitors in the identification of the dragonflies and damselflies of Rock Creek Park, Chesapeake and Ohio Canal National Historical Park, George Washington Memorial Parkway, and Harpers Ferry National Historical Park.

Dragonflies and damselflies are large insects with well-developed eyes. Like birds, odonates use distinctive color patterns to identify individuals within their own species. Males, females, and young adults of the same species may vary in color. Mature males are usually the most brightly colored and most likely to be seen since they commonly defend territories or wait in the open for the more secretive females. Therefore, the guide focuses primarily on the identification of mature males of the most commonly seen species.

Mr. Orr (Versar, Inc.) documented more than 100 species of odonates in National Capital Region parks. Almost half are species of conservation concern and importance.

The collection and identification of the Tiger Spiketail at Rock Creek Park is also noteworthy. Historical records indicate that the species was first found within the District of Columbia in 1922, but it was not recorded as present in the Park again until 2001. Listed as rare by the Maryland Department of Natural Resources, Natural Heritage Program, the Tiger Spiketail requires seeps and small permanent clean-water rivulets, which are very fragile ecosystems throughout the Park. Mr. Orr saw only a few adult males during the 2002 and 2004 field seasons of this study. Therefore, the Park's Tiger Spiketail population is considered small and threatened. Further monitoring is needed to determine the likelihood of the species continued existence within Rock Creek Park.

These discoveries attest to the uniqueness and importance of the Potomac River as a biodiversity resource. At present, the Potomac River corridor is highly regarded for its diversity of plant species. With these new invertebrate records, it should be clear that the unique biological value of the National Park Service sections of the Potomac River corridor and its tributaries is extraordinary. The high dragonfly diversity found in the study areas confirms the importance of the corridor for invertebrate conservation.

Urban development within the surrounding areas of the National Capital Region have caused changes to the Potomac River, its tributaries, and associated wetlands that contribute to the loss of dragonfly species. Mr. Orr found only small amounts of Spiketail and Gray Petaltail dragonflies, which is a change from the past when scientists found considerable numbers of these species in the study area. The Gray Petaltail was last recorded in the District of Columbia in 1898, and it currently exists in small isolated areas of the Potomac Gorge (NPS and TNC 2001). Likewise, the Spiketail has been reduced to isolated populations that are rarely observed.

Effective management of the aquatic ecosystems of the National Capital Region requires a wide knowledge base from multiple ecological disciplines. The newly gained knowledge of our dragonfly and damselfly populations increases our ability to better protect park resources. Our small urban parks house more than 100 different kinds of dragonflies and damselflies and almost half of them are of known conservation importance.

Targeted monitoring efforts and consideration of temporal and spatial patterns of biocide and insecticide applications must be considered when spraying is used to manage mosquito populations (CDC 2003). However, the story is not that simple. Although odonates are good indicator species for ecosystem health, their response to biocide and insecticide application should not be indicative of all non-target insects. Millions of stoneflies, caddisflies, and midges emerge from the Potomac and Shenandoah Rivers yearly. Some are likely more vulnerable to control methods than dragonflies and damselflies. Additionally, adult midges (chironomids) found throughout the National Capital Region are a major component of the food web in the Potomac River. Since odonates are closely related to mosquitoes in morphology and behavior, they are likely as vulnerable to control treatments as are the mosquito vectors for West Nile Virus (*Culex* species) (Orr 2005.)

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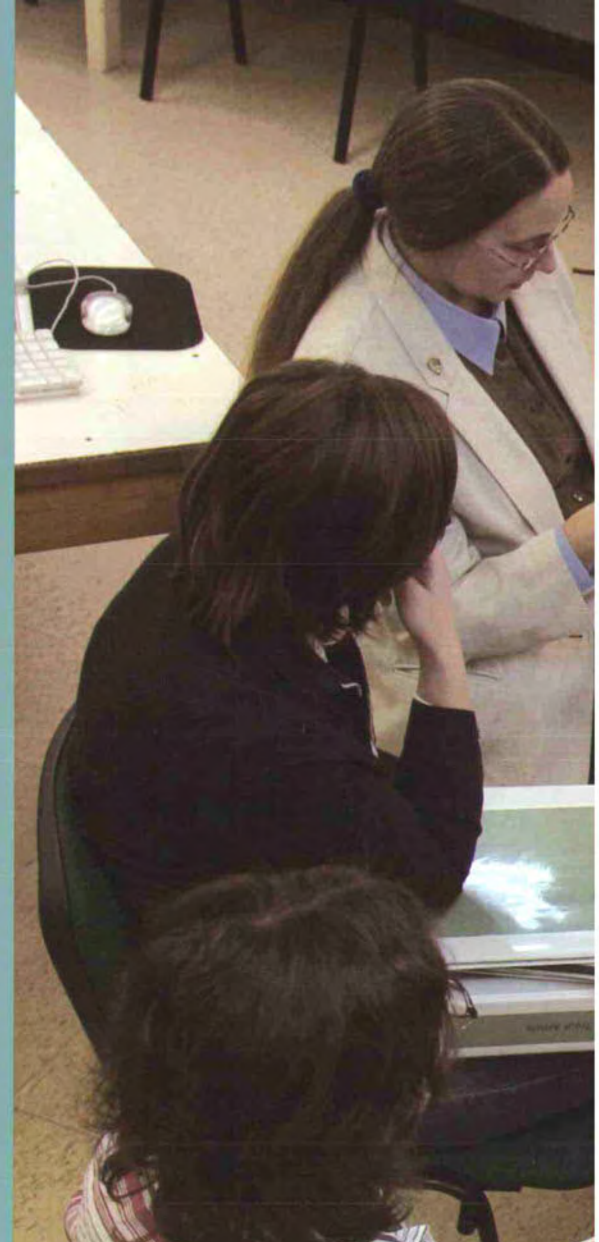
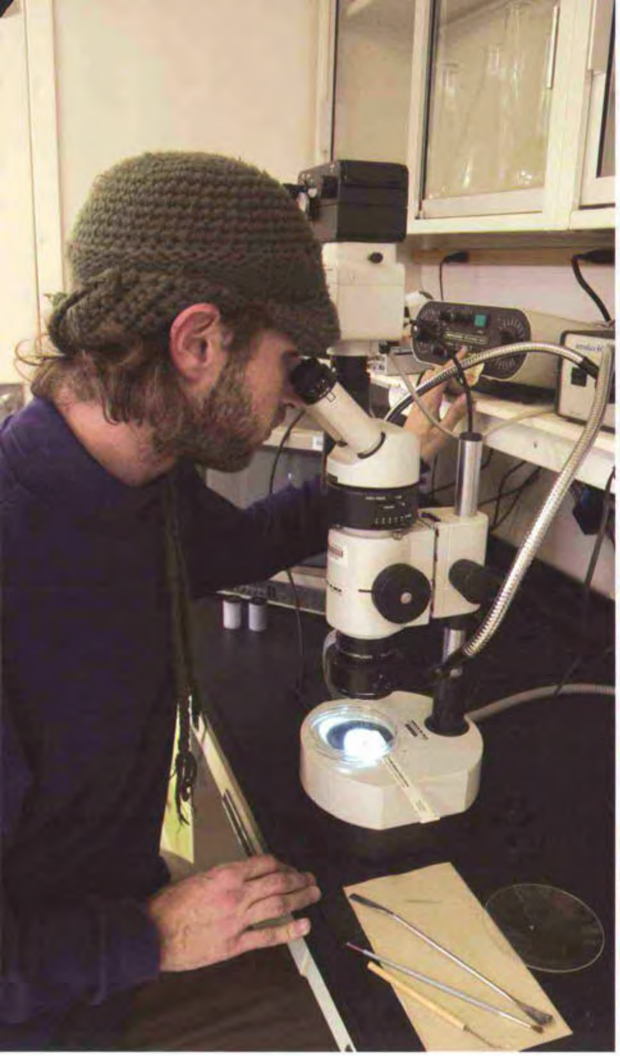
Integrated Pest Management The National Park Service implements a nationwide Integrated Pest Management Program to reduce risks to the public, park resources, and the environment from pests and pest-related management strategies. Integrated Pest Management is a decision-making process that coordinates the knowledge of pest biology, the environment, and available technology to prevent unacceptable levels of pest damage. Integrated Pest Management uses cost-effective means that pose the least possible risk to people, resources, and the environment. The National Capital Region Integrated Pest Management Program provides coordination and technical assistance to the Region's parks. Integrated Pest Management ensures that the management of identified pests is carried out according to National Park Service policy in an effective and responsible manner that alleviates pest damage and protects resources.

COLLABORATION





Promoting Science for Parks through Partnerships

The Urban Ecology Research Learning Alliance is the Research Learning Center for the National Capital Region. We sponsored this booklet, which supports our mission to synthesize and communicate research results, promote research in the parks, and increase research-related educational opportunities. The seven scientific studies and projects summarized in this booklet provide examples of the many natural resource values and challenges in the National Park units of the National Capital Region.

Right: Student photographer Emily Witman works in the field capturing images of harperella.

Left (clockwise): Student photographer Rob Brzostowski photographs amphipods with a camera equipped microscope; Editor Giselle Mora-Bourgeois travels in a U.S. Park Police helicopter for an aerial photo shoot; Diane Pavek collaborates with students to select article photography.

The common thread in these studies and projects is human influences on the natural resources in the Region's parks. Studies and research on natural resources in the National Capital Region include historical and ecosystems perspectives. With these perspectives, scientists explore the relationships of urbanizing landscapes and ecological processes. Examples of human pressures and their impacts on the ecology of parks are examined in the studies on impervious surfaces and the restoration of disturbed wetlands. The challenges illustrated in this booklet include restoring federally listed species, maintaining genetic variation in brook trout populations, identifying and preserving dragonflies, and protecting amphipods living underground. In addition, the articles emphasize ecosystem services that the urban National Parks provide, such as air and water filtration, regulation of microclimates, surface and subsurface water drainage, recreation, and the conservation of biodiversity.

Understanding the complex working of urban ecosystems relies on multi-disciplinary approaches. For this reason, the Center for Urban Ecology has an interdisciplinary team of scientists to address park and regional needs. As part of that team, the Urban Ecology Research Learning Alliance actively supports research on urban ecology and communicates research results to diverse audiences.

All aspects of this booklet, from the scientific content to its graphic design, are the result of collaboration among diverse partners. For example, for this publication the Urban Ecology Research Learning Alliance funded a graduate fellowship at George Mason University to assist with interviewing principal investigators and National Park Service staff, pulling together relevant materials, and crafting drafts of the articles. The Urban Ecology Research Learning Alliance and Center for Urban Ecology staff provided editorial guidance. We collaborated with the Graphic Design program at Shepherd University where students took photographs, created the graphic design for the booklet, and provided quality control during publication. By involving creative students with diverse backgrounds to develop science communication products like this publication, the students not only acquire real-world experience, but also increase their understanding about urban ecology issues.

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The Urban Ecology Research Learning Alliance will continue to look for innovative ways to develop and strengthen cooperation for scientific efforts to protect park resources and values. Our work is possible because of the diverse partnerships and collaboration between scientists, students, academic institutions, federal agencies, and National Park Service staff. We will continue building relationships with universities and other agencies committed to the stewardship of our national parks. The studies and projects contained in this booklet support the National Park Service mission to preserve resources so that all may experience our natural and cultural heritage.

VALUES & CHALLENGES IN URBAN ECOLOGY

EDITOR
Giselle Mora-Bourgeois, National Park Service, National Capital Region

EDITORIAL COMMITTEE
Diane Pavek, National Park Service, National Capital Region
Dan Sealy, National Park Service, National Capital Region
Jim Sherald, National Park Service, National Capital Region

CONTRIBUTORS
David Culver, Biology Department, American University, Washington, D.C.
Sean Denniston, National Park Service, National Capital Region
Kristy Garnett, George Mason University, Fairfax, VA and AMEC Earth and Environmental, Inc., Chantilly, VA
Bryan Gorsira, National Park Service, Manassas National Battlefield Park
Tim King, US Geological Survey-Biological Resources Discipline, Leetown Science Center, Kearneysville, WV
Gopaul Noojibail, National Park Service, Carlsbad Caverns National Park
Richard Orr, Versar Inc., Columbia, MD
Curt Ostrodka, AMEC Earth and Environmental, Inc., Chantilly, VA
Jeff Runde, National Park Service, National Capital Region
James Voigt, National Park Service, Catoctin Mountain Park
Elizabeth Wells, Biology Department, George Washington University, Washington, D.C.
Bill Yeaman, National Park Service, Rock Creek Park

DESIGN AND PRODUCTION
GRDS 450: Annual Report Studio, Department of Art, Shepherd University, Shepherdstown, WV

CREATIVE DIRECTOR
Stephanie Engle, Visiting Assistant Professor of Art

STUDENT CREATIVE TEAM
Project Manager: Michele Foshee
Graphic Designers: Jackie Harford, Adam Leviton, Tiffany Moreland, Lindsey Warf
Photographers: Rob Brzostowski, Krystal Tydings, Emily Witman

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Center for Urban Ecology
4598 MacArthur Blvd., N.W.
Washington, D.C. 20007