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Restoration of an Urban Salt Marsh: An Interdisciplinary Approach

David G. Casagrande

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Restoration of an Urban Salt Marsh: An Interdisciplinary Approach

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David G. Casagrande
Volume Editor

Preface

This is an exceptionally informative, innovative, and relevant *Bulletin* in a number of important respects, all captured by its carefully chosen title. Of critical and timely significance is its interdisciplinary approach. The restoration of damaged and disturbed environments represents more than a technical challenge. We cannot, of course, accomplish ecological restoration lacking basic biophysical knowledge and management tools. Yet, these technical and scientific issues represent only the beginning of the restoration task, typically omitting the necessity of precisely identifying what we are trying to accomplish, articulating a compelling vision of this goal, and developing a comprehensive methodology for achieving this end.

These latter considerations inevitably require the additional knowledge and practice of a wide range of disciplines, including economics, sociology, political science, and others. We must confront, for example, the basic question of just what we are hoping to restore. This latter consideration ultimately constitutes a question of values, a determination of what attributes of worth and benefit from nature we are striving to restore and render available to people and society. This issue becomes especially prominent when trying to restore damaged environments where large numbers of people live, most particularly in the modern city. Whenever large numbers of people are involved, we must address in specific, persuasive, and precise ways that goods and services are provided by restored environments, as well as the costs and sacrifices people may be required to make to achieve this end. We must also recognize that restoration cannot be accomplished lacking the understanding, appreciation, and support of local communities. At the least, this necessitates a deep and sympathetic knowledge of the characteristics, interests, attitudes, and needs of varying human populations.

In my opinion, one of the tragic assumptions of contemporary life is the wide-spread belief that city people no longer require an abundant, diverse, and healthy natural environment to lead lives rich in satisfaction and meaning.

An additionally important facet of this *Bulletin* is its focus on the modern city. In my opinion, one of the tragic assumptions of contemporary life is the widespread belief that city people no longer require an abundant, diverse, and healthy natural environment to lead lives rich in satisfaction and meaning. Most urban dwellers are repeatedly reminded of the presumed unimportance of nature in the urban context. Environmental considerations are routinely omitted from matters of urban building design, siting decisions, road building, industrial development, shopping center construction, and various other land and water planning and management choices. The average developer and politician typically views with indifference remaining pockets of open space, and often regards environmental expenditures as the lowest of budgetary priorities. Likewise, few city officials recognize the links between a city's long-term economic and social viability and the quality of its natural landscape.

For reasons beyond explaining in this preface, these assumptions are false and ultimately self-defeating. The long-term health and vitality of the modern city will depend on opportunities for affiliating with nature in aesthetically attractive, ecologically sound, and materially sustainable ways. The prevailing urban malaise of widespread air and water pollution, habitat destruction, and denaturalized environments represents neither a necessary nor an inevitable reality. This *Bulletin*, thus, constitutes a commendable and important attempt to point the way toward identifying how damaged and degraded natural areas can be restored within the context of striving for more economically, socially, and psychologically rewarding urban neighborhoods and communities.

Finally, this *Bulletin*'s emphasis on restoring wetland environments is significant. Most cities occur along aquatic habitats such as rivers, lakes, and seashores. This prevalence reflects the many fundamental ways wetland ecosystems provide people with a wide range of physical, material, emotional, intellectual, and even spiritual benefits and opportunities. These aquatic environments offer a geographically organizing way for people to connect physically and visually with their natural landscapes. In New Haven, this feature is especially revealed by its three rivers converging at the city's estuarine harbor on the Long Island Sound. By focusing on the restoration of wetland habitats, this *Bulletin* emphasizes not only reviving important environmental services, but also a means for urban people to improve their emotional and intellectual connection with a city's most salient natural feature.

The Yale School of Forestry and Environmental Studies is especially proud to be associated with this pioneering effort. This *Bulletin* reflects the interdisciplinary, problem solving character of our School, as well as our location in an urban environment. The School has projects on every continent, and prides itself on its long history of national and international scholarship and professional activity. Yet, we regard the work on the West River in New Haven as central to the mission and long-term impact and relevance of our School.

Stephen R. Kellert
Professor of Social Ecology
Yale School of Forestry and Environmental Studies

Introduction

The great 19th century landscape architect, Frederick Law Olmsted, envisioned cities with park systems designed to rejuvenate weary urbanites and bring social classes together. In 1910, Cass Gilbert and Frederick Law Olmsted, Jr. released their *Civic Improvement Plan* for New Haven, Connecticut – an industrial city on the New England Coast (Fig. 1). The philosophy of the senior Olmsted was evident in the plan, which included a recommendation for a series of contiguous parks to be located along New Haven's West River, a tidal tributary of Long Island Sound. Park development was to provide open space and eradicate the salt marshes that dominated the area. Tide gates installed at the southern end of what would become West River Memorial Park (Fig. 2) were intended to reduce mosquitoes and reclaim the land upstream. Later, a long straight channel was dredged through the length of the park to create a pool reminiscent of that in front of the Washington Monument. Dredge spoil was deposited on the marsh to create upland recreation area. The tide gates, which restricted the flow of salt water and tidal fluctuation, combined with the dredge spoil dumping, successfully eradicated the salt marsh in the park.

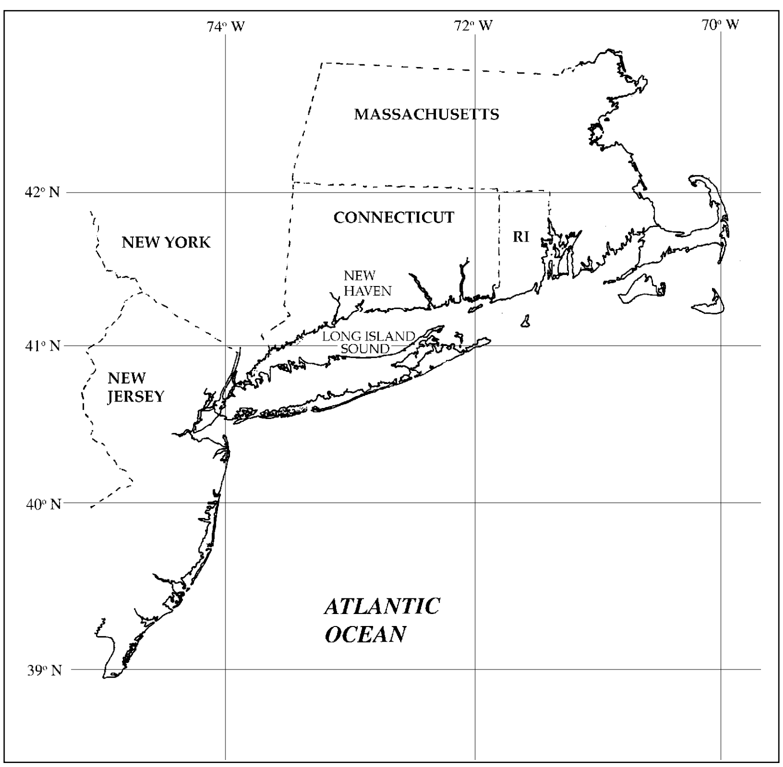

Figure 1. New Haven on the New England Coast.

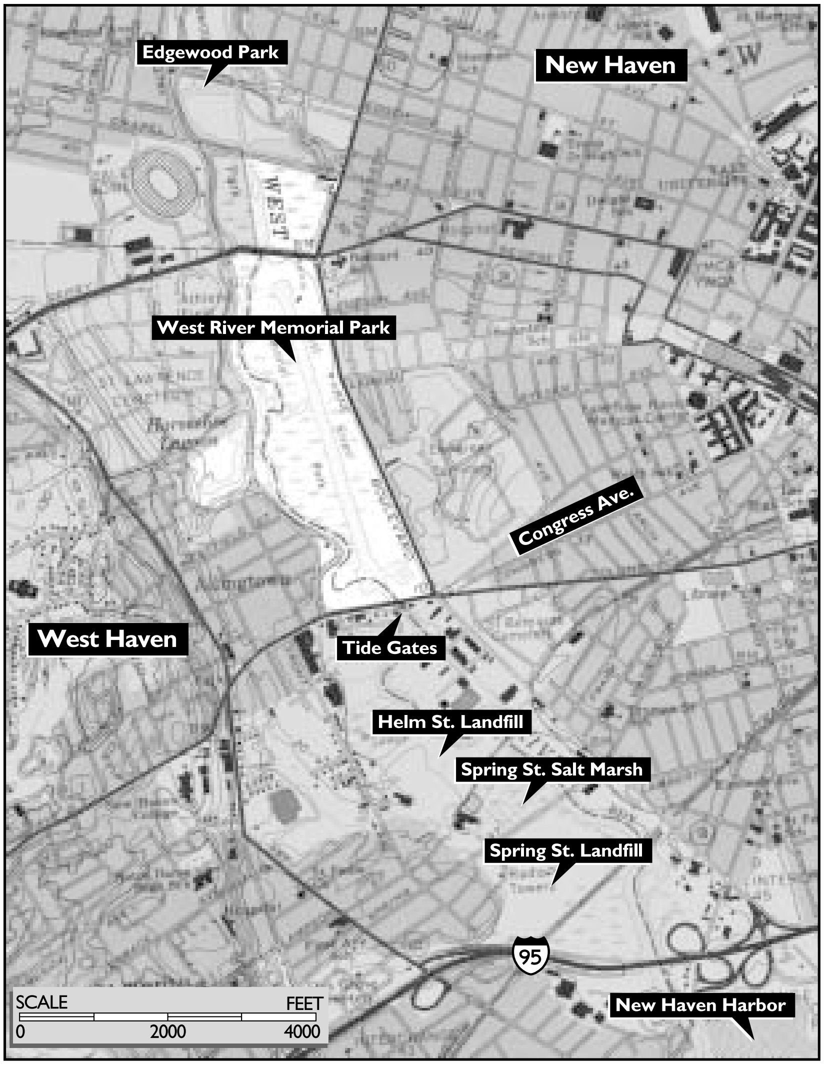

Figure 2. West River Memorial Park (white) and other features along the West River in New Haven and West Haven, Connecticut.

Unfortunately, the vision of West River Memorial Park as an area of spiritual rejuvenation and social integration was not achieved. The amount of dredge spoil was insufficient to create uplands. The result was an ecological no-man's land dominated by dense stands of common reed (*Phagmites australis*), which form visual and physical barriers to the water. The park now serves to segregate neighborhoods.

Many urban salt marshes have met similar fates resulting in degradation of habitat, water quality, and quality of human life. Now, we are in the midst of a national movement to restore such degraded wetlands. Connecticut's natural resource managers and researchers have been among the pioneers of salt marsh restoration. In this *Bulletin*, we draw upon this experience to expand the scope of restoration ecology to include the social realm, using West River Memorial Park as a case study.

Humans rely on ecosystems for their survival. In our culture this requires large inputs of energy and nutrients by humans to re-direct ecological processes, as in the case of agriculture. Restoration could be defined as restoring ecological processes suited to a landscape's climate, topography, geology, and hydrology, that provide human benefits with minimal inputs. The human/salt marsh relationship of the colonial period provides an example of humans benefiting from the ecosystem with minimal inputs. The exact colonial relationship cannot be recreated because the ecological and social contexts have changed. However, the authors in this *Bulletin* suggest that it is possible to recreate a system in the West River that provides increased human benefits with minimal inputs by restoring ecological processes.

Ecological restoration that explicitly includes a human component requires an interdisciplinary approach, including biophysical and social science. This *Bulletin* presents a case study in which researchers were free to explore across academic paradigms to investigate the human-environment relationship.

Interest in an interdisciplinary approach to the West River restoration project grew from the West River Symposium held by the Yale School of Forestry and Environmental Studies' Center for Coastal and Watershed Systems (CCWS) in October 1994, with funding provided by the Connecticut Department of Environmental Protection's (CT DEP) Long Island Sound License Plate Program. The symposium brought community leaders together with a diverse group of academics and natural resource managers to discuss potential river improvements within a watershed context. Hydrological research by Paul Barten and William Kenny that began in 1992 (Kenny and Barten 1993) provided a firm foundation for discussion. The gathering produced imaginative ways that restoration could breach disciplines to achieve ecological and social improvements (McDiarmid et al. 1995). With support from the Connecticut Department of Environmental Protection and other sponsors (see acknowledgments), CCWS brought together a team of researchers who began conducting a biological and social inventory of the lower West River watershed in 1995.

As the first step of an interdisciplinary approach to restoration of an urban wetland, this *Bulletin* presents the development of a baseline scenario. Sociologists, economists, biologists, hydrologists, landscape architects and ecologists provide the context in which community leaders can work with natural resource managers to establish restoration goals and methods for monitoring success. The baseline data presented here also provide an unprecedented opportunity to investigate the role of humans as components of ecosystems using an experimental approach to restoration.

This *Bulletin* is important because it addresses a degraded tidal marsh in the heart of an urban environment. Until recently, most salt marsh restoration has occurred in areas with lower human population density where ecological functions such as wildlife habitat and biomass production are more easily restored. Also, non-urban communities have been more likely to request restoration projects. This is unfortunate because most salt marsh degradation and eradication in the northeast U.S. have occurred in urban areas. Also, restoration benefits such as improved aesthetics, recreation, mosquito control, and pollution remediation would have the greatest impact in areas of high human population density.

The proximity of urban human communities to the marsh complicates restoration, but it also provides opportunities. There is a growing recognition of the need to incorporate humans, their values, and their behavior in ecosystem analysis (McDonnell and Pickett 1993). Until recently, the success of restoration has been determined primarily by measurements of vegetation. Early attempts to include other disciplines were generally limited to monitoring vertebrates such as birds, with some studies monitoring macro-invertebrates. More recently, researchers (e.g., Kentula et al. 1993, and authors in this *Bulletin*) have argued that restoration success is better judged using measurements of ecosystem function such as primary productivity, indices of biotic integrity, or survival rates of certain species. Equally important are the effects of restoration on human communities.

Because this is a preliminary investigation of an on-going project, not all disciplines are represented in equal detail. In some cases (e.g., insects and mammals) sampling was limited to the taxa most likely to be impacted by restoration. As such, tables and appendices are not meant to be definitive species lists and not all ecological parameters regarding water quality, soils, and human behavior were available at publication. Nevertheless, the information included is adequate for deciding which functions are desirable for restoration and what parameters are appropriate for monitoring.

Caution is also advised for interpreting the biological and social data because of the small sampling period, which was mostly limited to 1995 and 1996. 1995 was the third consecutive year of rainfall well below average. The data, therefore, reflect anomalous conditions associated with reduced stream flow and a corresponding increase in salinity. Also, the tide gates were not functioning properly because floating debris had accumulated and prevented the gates from closing completely. This increased water salinity within the park.

These events illustrate the need for long term monitoring. They also exemplify some of the factors that contribute to the instability and unpredictability of the system in its current condition, a situation that likely suppresses biological diversity as well as recreation opportunities. However, the data from 1995 do provide a limited preview of early salt marsh restoration including anglers targeting salt marsh species and salt marsh organisms colonizing the proposed restoration area.

Frederick Olmsted could be considered the first applied social ecologist because he attempted to manipulate landscapes to improve social conditions. Unfortunately, he lived during the peak of the industrial revolution when man was considered the agent through which God could improve on nature. During the century that has followed Olmsted's death, we have been humbled by the vast complexities of ecosystems and the unanticipated effects of altering ecological processes. We have also accrued sufficient knowledge of ecological and social processes to attempt anew experiments such as those initiated by Olmsted. This *Bulletin* presents an interdisciplinary approach for inquiry intended to deepen our understanding of humans as components of ecosystems.

David G. Casagrande
Volume Editor
New Haven, Connecticut

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Section I: Social Context

> *"I had a strong taste for angling, and I would sit for any number of hours on the bank of a river or pond watching the float."*
>
> *– Charles Darwin*

Establishing restoration goals and evaluating success requires an understanding of the historical, cultural, and economic trends that shape ecosystems. This is especially true in urban areas where landscapes have been severely altered and many people will be directly impacted by restoration projects. In this section, the authors explore the trends that have led to environmental degradation, the current social context, and the potential impacts of restoration on human communities.

The Full Circle: A Historical Context for Urban Salt Marsh Restoration

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ABSTRACT
New England salt marshes were highly valued by early colonists for hay and aesthetics, but these values diminished with the introduction of European grasses and industrial development. Many marshes were eventually filled to accommodate development and eradicate mosquitoes. Filling was driven by the dominant cultural worldview of the industrial era that humans were exempt from ecological processes. A new ecological worldview emerged during the 1960s and provided the basis for environmentalism. The economic value of salt marshes was restored during the early 1960s when scientific theory linked them with fishery productivity. Additional ecological and socioeconomic values that resulted from scientific research throughout the 1960s led to legislation to protect salt marshes. Regulation of tidal lands for the common good had a strong historical and legal precedent that fit well with the new worldview. This led to a rapid decline in salt marsh filling after 1970. The movement to restore salt marshes, which began in the late 1980s, has been driven by the ecological worldview, increasing recognition of salt marsh value, and a weakening of social trends such as population growth and the industrial development that drove marsh eradication. The restoration movement is likely to survive periodic set-backs, because the ecological worldview continues to deepen in the American, social consciousness and the economic value of salt marshes continues to increase as a result of ecological and economic research.

The perception that humans are a part, not masters, of the environment was central to the daily lives of Native Americans and early European colonists whose survival depended upon the generosity of the land. This view was swept aside by the three hundred year rush toward industrialization. Salt marshes, as well as other natural resources, came to be viewed as wastelands in need of reclamation for economic development. The recent restoration movement shows that we have reclaimed our respect for tidal wetlands as a life-supporting resource.

This paper provides a historical context for salt marsh restoration using West River Memorial Park in New Haven, Connecticut as a case study. The history of our relationship with salt marshes exemplifies a process in which our culture has come full-circle to appreciate that we only survive as members of ecological communities. A review of this evolution of thought is essential for understanding both the social trends that have driven salt marsh eradication and how West River Memorial Park has arrived at its present, degraded condition.

An analysis of social trends also enhances the predictability of near-term future trends that are likely to impact restoration policies locally and nationally. Policy decisions should recognize those negative values that continue to permeate perceptions of salt marshes as well as social developments responsible for the restoration movement. Ahistorical perspective can show how positive values such as wildlife habitat or aesthetics are balanced against negative perceptions within a changing society. This will allow us to hypothesize how communities bordering West River Memorial Park are likely to judge the success of the proposed salt marsh restoration. Community approval is essential for achieving the ultimate restoration goal of re-connecting humans with nature (Jordan 1995).

EARLY COLONIAL SURVIVAL

When John Davenport and Theophilus Eaton arrived in 1638 to establish the colony that would become New Haven, the area was inhabited by only the few Quinnipiac who had survived recent epidemics and wars with the Pequots (Lambert 1838, Osterweis 1953). Quinnipiac attitudes toward salt marshes were not documented, but there is no doubt that early English colonists saw the marshes as a blessing. While searching for a site to establish their puritan colony in 1637, Davenport and Eaton were delighted with the "rich and goodly meadows" of the Quinnipiac area (Farnham 1981, p. 10; Osterweis 1953, p. 8).

Availability of salt marsh hay, along with good harbors, were major factors in the selection of locations for many coastal New England towns settled in the early 17th century. New Haven's founders were delighted with the "rich and goodly meadows" of the Quinnipiac.

Indeed, availability of salt marsh hay, along with good harbors, were major factors in the selection of locations for many coastal New England towns settled in the early 17th century (Bidwell 1925; Russell 1976, p. 47). Early colonists were accustomed to the open rolling landscapes of England where most forests had been eradicated and European mythology portrayed forests as refuges of evil (Nash 1976; Russell 1976, p. 47). Fear of forests is easily learned given the human evolutionary preference for open landscapes (Appleton 1988, Ulrich 1993). Hence, "For the first Americans . . . the forest's darkness hid savage men, wild beasts, and still stranger creatures of the imagination" (Nash 1976, p. 24). Compared to the dense forests that dominated New England's coast, the openness of salt marshes would have appealed to early settlers.

More importantly, salt marshes were immediately recognized as a critical subsistence resource. The primary task of the early colonial farmer was to convert forest to agricultural land, a task that required horses or oxen. Early colonial farmers took readily to harvesting salt hay for their livestock because many had harvested marsh hay in England (Russell 1976, p. 31) and American upland grasses made poor fodder (Eliot 1760, Bidwell 1925). As a result, the ability to clear forests using animal power was largely dependent on the availability of salt marsh hay for fodder. Transporting hay from salt meadows to the farm also reduced the need to graze livestock in open areas where they were vulnerable to predators (Russell 1976, p. 31).

Figure 1. Harvesting hay from the West River salt marsh (Frederic Edwin Church, "West Rock, New Haven," 1849, courtesy of the New Britain Museum of American Art).

The soil of the fledgling New Haven colony was poor for crops, the forest animals yielded little fur, and most commercial ventures prior to 1670 were failures (Farnham 1981). Nevertheless, the region maintained the ability to export livestock products (Bidwell 1925), an industry that relied heavily on salt marsh hay (Eliot 1760; Russell 1976, p. 44). In addition, salt hay contributed to vegetable productivity through the use of livestock manure as fertilizer (Russell 1976, p. 126).

The relationship between livestock and salt marshes continued to be a component of New England's agricultural economy through the 19th century. As agriculture spread west, grain production in New England became less important (Bidwell 1925). New England farmers shifted to producing more milk and horses for export using grazing practices supplemented with salt marsh hay. Rhode Island farmers harvested 1,717 tons of salt marsh hay from 2,506 acres of marsh in 1875 (Nixon 1982). From 1638 through the beginning of the 20th century, salt hay was harvested from marshes in New Haven's Quinnipiac River, Mill River, and West River (Fig. 1).

Remnants of these marshes are still dotted with abandoned staddles (structures erected to store the hay above the tidal reach), and many existing dikes and tide gates were originally constructed to facilitate harvesting.

Although salt marshes were highly appreciated, positive values were underlain by negative values. Salt hay was the best and least expensive fodder available at the time, but its nutritional value and palatability are not very high (Burkholder 1956, de la Cruz and Poe 1975). Harvesting salt marshes was also labor intensive and biting insects plagued colonial farmers.

Attempts to introduce upland European grasses began immediately with colonization (Russell 1976, p. 129). One year after founding New Haven, the colonial assembly ordered that all citizens were required to plant English grasses (Hoadley 1857). By 1700 several varieties of timothy and clover were being successfully cultivated throughout New England (Eliot 1760, Butler 1821) and some farmers began reclaiming salt marshes for upland agricultural uses (Olson 1935). The successful introduction of European grasses greatly reduced the economic value of salt marshes, opening the gates for salt marsh eradication. This condition persisted until the 1950s when ecologists linked salt marsh productivity with the economic health of estuarine fisheries.

Population growth increased the pressure to convert salt marshes to parks, dumps, or industrial areas. The industrial era also included the application of new technologies, such as the steam engine, to marsh reclamation.

THE RISE OF INDUSTRIALISM

Between 1815 and 1861, and again after the Civil War, New Haven's industrial economy grew rapidly and the region's population swelled (Gilbert and Olmsted 1910; Osterweis 1953, p. 279; Kuslan 1981). The combination of the demise of agriculture and an increasing immigrant population yielded a citizenry with little sense of connection with the land. Population growth increased the pressure to convert salt marshes to parks, dumps, or industrial areas. This era also included the application of new technologies such as the steam engine to marsh reclamation (Siry 1984, pp. 36-37). These historical trends were typical of the industrial northeast.

In justifying the creation of Edgewood Park in 1889, New Haven's mayor, Henry Peck, called for dredging and filling of the West River's tidal wetlands, referring to them as "breeders of disease" (Peck 1889). This theme was pursued by his successor, J. B. Sargent, who initiated public acquisition of tidal marshes though eminent domain.

Mayor Sargent's proposal was to fill the marshes at public expense, then "sell them for manufacturing sites and lumber and coal yards, and for storage sheds." This would eventually "free the City from this constant menace to health and life, without loss to the finances of the city" (Sargent 1891). The public policy to eliminate the West River's tidal marshes was further promoted in 1910 by the nationally renowned urban planners Cass Gilbert and Frederick Olmsted Jr. who stated, "There is no reason why the West River Marshes can not be made into excellent park meadows, broad, smooth, fertile, and dry enough at most seasons to be freely used for every park purpose" (Gilbert and Olmsted 1910, p. 69).

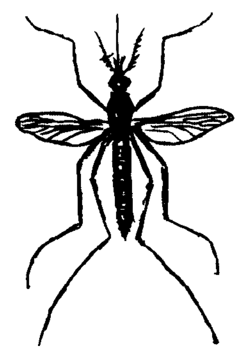
By the turn of the century the value of New Haven's salt marshes for dumping space began to override any remaining agricultural interests. While justifying public land acquisition for West River swamp reclamation in 1923, New Haven's superintendent of parks, G. X. Amrhyn, stated, "Even if funds are not at hand for its development in a general way . . . it will at least afford a good dumping place of which the city is sadly in need," specifically, "A number of properly kept dumping places along the Boulevard can be established" (Commissioners of Public Parks 1923, p. 37).

"The wind comes from the south and southwest, loaded with the miasmatic exhalations of the marshes over which it has passed, and deposits them in the dwelling places and lungs of the inhabitants dwelling in its course."

–New Haven's mayor, J.B. Sargent, 1891

MOSQUITOES

Throughout history, mosquitoes have been an annoying and often deadly component of the human environment. The first scientific evidence that mosquitoes spread disease was provided in 1878 (Gillett 1972, pp. 194-195). Subsequent discoveries of mosquito transmitted diseases have undoubtedly fueled the hatred of this insect. In a survey rating the popularity of 33 well known animals, mosquitoes (and cockroaches) were found to be the most reviled, surpassing even rats (Kellert 1996, p. 101).



Aedes sollicitans, *a common salt marsh mosquito*

By 1900, the eradication of mosquitoes in America was considered a mission of moral rectitude, and eradication of Connecticut's salt marsh mosquitoes was pursued with fanatical zeal. The most abundant salt marsh mosquito species of the northeast are *Aedes sollicitans, Aedes cantator, Anopheles bradleyi* and *Culex salinarius* (Chapman et al. 1954). *Aedes* mosquitoes were a particular nuisance in New Haven at the turn of the century because much land area was occupied by salt marshes and *Aedes* species are capable of dispersing many miles from their hatching site (Carpenter and LaCasse 1955). A survey of mosquitoes in New Haven's residential areas prior to 1912 found nine out of ten mosquitoes to be salt marsh species (Civic Federation of New Haven 1913).

Prominent New Haven citizens formed the New Haven Anti-Mosquito Committee in 1912 to raise funds for draining and spraying New Haven's marshes. After raising $5000, the committee contracted the United States Drainage and Irrigation Company to begin digging mosquito ditches in New Haven's salt marshes (Civic Federation of New Haven 1913). The ditches were intended to drain standing water from the marsh surface.

The New Haven Anti-Mosquito Committee also lobbied to improve state legislation to eradicate breeding habitat. Connecticut's *Nuisance Arising From Swampy Places* law, passed in 1895, had declared all marshes a threat to human health. The Public Acts of 1913 further stated, "Any accumulation of water in which mosquitoes are breeding is hearby declared to be a public nuisance" (Chap. 143, Sec. 1). These words were put into action in 1915 via *An Act Providing for the Elimination of Mosquito Breeding Places or Areas* (Chap. 264, Public Acts of 1915), which was strengthened in 1917 (Chap. 402, Public Acts of 1917). These latter statutes mandated that towns were responsible for the maintenance of mosquito control ditches or tide gates and charged the director of the Connecticut Agricultural Experiment Station with enforcement.

The 1915 and 1917 statutes gave the director of Connecticut's Agricultural Experiment Station authority to enter any marsh for the purpose of eliminating mosquito breeding habitat. Any person obstructing the director's mosquito control efforts was subject to a fine. These laws partly resulted from conflicts with farmers, who often refilled mosquito ditches to restore access to hay (Britton 1916). These laws show how non-agricultural values were superseding both the agricultural value of salt marshes and the rights of private owners.

"An act providing for the elimination of mosquito breeding places or areas" gave the director of Connecticut's Agricultural Experiment Station authority to enter any marsh for the purpose of eliminating mosquito breeding habitat.

By 1921, 750 acres of marsh in New Haven had been drained to reduce mosquitoes.[1] Ditching accelerated under federal work creation programs of the early 1930's (Britton 1935), and by 1937 all salt marshes in New Haven had been ditched.[2] The New Haven experience was not unique. Ninety percent of tidal wetlands between Maine and Virginia had been ditched by 1938 (Nixon 1982, p. 53). Meanwhile researchers were beginning to question the effectiveness of marsh ditching for mosquito control. They were also expressing concern about effects on wildlife, particularly loss of habitat for salt marsh birds (Bradbury 1938).

Nevertheless, ditching, tidal restriction, and spraying remained the primary mosquito control measures in Connecticut until 1985 when they were replaced with Open Marsh Water Management (OMWM)(Rozsa 1995). OMWM involves enhancing habitat for mosquito predators (primarily fish of the genus *Fundulus*) while maintaining the ecological integrity of the marsh (Daiber 1987). The effectiveness of using predators to control mosquitoes was recognized as early as 1904, and it was utilized in some states during the 1930's (Daiber 1987). However, the lack of any economic value of salt marshes, the desire to eradicate mosquitoes entirely, and the reliance on chemical biocides after World War II resulted in OMWM being largely ignored. It is now widely used only because the ecological and socio-economic value of salt marshes outweigh society's hatred of mosquitoes.

[1] Oct. 31, 1921 letter from Agricultural Experiment Station Deputy in Charge of Mosquito Work to William Bennett, New Haven Corporation Counsel.

[2] June 28, 1937 letter from R. C. Botsford, Deputy in Charge of Mosquito Elimination to Joseph I. Linde, Health Officer, City of New Haven

EARLY SALT MARSH CONSERVATION

Early American conservation tended to focus on charismatic species (particularly birds) and outstanding landscapes (e.g., Yosemite National Park), or on consumable resources such as forests, fisheries, or wildlife for hunting. However, a vocal minority also lamented the loss of marshes, and a salt marsh conservation movement began during the late 1800s (Siry 1984, pp. 44-61).

Bird advocates figured prominently in conservation efforts at the turn of the century when many species were being driven to extinction. A particular problem of this period was the widespread hunting of charismatic birds to supply the insatiable international demand for hats adorned with plumage (Ehrlich et al. 1988, p. 37). Many salt marsh species were slaughtered *en masse* between 1880 and 1900. Their feathers were sent to milliners in New York and New England (Bent 1921, pp. 270-273; Bent 1926, p. 153). Egrets were often shot in their nests, their plundered carcasses left to rot, and their nestlings left to starve. Whole breeding colonies were eliminated and bird populations declined precipitously.

Feather collecting provided substantial income for coastal residents. In Virginia, individuals were reported to have collected as many as 2800 least terns in a day and to have sold them for 10 cents each (Bent 1921). Milliners also provided many jobs and were reaping large profits producing feathered hats (Ehrlich et al. 1988, p. 39). Connecticut (especially Danbury) was an important millinery center, but many state residents were outraged by the possible extinction of native birds. Connecticut's *Act For The Protection Of Fish And Game* (Public Acts of 1901, Chap. 140) made the sale of plumage from many birds illegal, set seasons for collecting, and imposed daily bag limits of fifty birds per day for "snipe, plover, rails, gallinules, mud hen, and other shorebirds." This law clearly reflects non-consumptive values beginning to override direct economic exploitation of salt marsh resources. It also continued the trend of state regulatory power over tidal wetlands. As with mosquitoes, regulation was in response to ecological realities; in this case, the limits of bird populations.

Adorning women's hats with bird plumes was popular during the late 19th and early 20th century.

Other salt marsh bird species were being hunted to extinction for food or sport. John James Audubon wrote that it was not uncommon for one individual to take home up to "one hundred dozen" Clapper rail eggs from a New Jersey salt marsh in a single day (Bent 1926, quoting Audubon, p. 277). Rails and ducks were commonly taken using hunting practices that slaughtered entire migratory flocks (Bent 1926, p. 281; Collins 1960, p. 91).

Nationwide opposition to atrocities associated with feather collection and over-hunting led to the federal *Lacey Act* of 1900, which gave the U. S. Secretary of Agriculture responsibility for the "preservation, distribution, introduction, and restoration of game birds and other wild birds." This law effectively ended interstate trade of wild bird products. In combination with the *Migratory Bird Act* of 1913 and the *Migratory Bird Treaty* of 1916, the protection of birds was firmly placed within the public trust by allocating management to the federal government (Bean 1983). These federal laws withstood court challenges, and eventually provided the legal foundation for federal preservation of habitat, including vanishing wetlands such as salt marshes, under the *Endangered Species Act* (Hutton 1964, Bean 1983).

The late 19th century was also a time of increasing non-consumptive recreational activities such as bird-watching and amateur botany, which influenced public policies. These recreational trends were largely influenced by the romantic movement in art, music, literature, and philosophy (Siry 1984, p. 44). The Connecticut Botanical Society was founded in 1903 to explore local flora, while the New Haven Bird Club, founded in 1907, lobbied against the plume trade and sponsored bird-watching trips in the New Haven area. The popularity of bird-watching in New Haven at the turn of the century is indicated by the high attendance of up to 100 people at weekly bird club meetings.[3] In 1936 New Haven's superintendent of parks declared, "The area between the river and Yale Avenue from Whalley to Edgewood Avenues should be left in its present swamp and brush condition. It forms a beautiful bird sanctuary and attracts many people, especially members of bird clubs, who study the various forms of wildlife found there" (Commissioners of Public Parks 1936, p. 23). This statement indicates a major policy shift away from marsh eradication, although the superintendent was compelled to add that "it is necessary that we dig a few ditches for better drainage to prevent to a great extent the breeding of mosquitoes."

The collapse of bird populations led to greater concern for habitat loss, and a national movement to conserve habitat was spearheaded by organizations like the American Ornithologists' Union, the Audubon Society, and Ducks Unlimited.

[3] Gary Lemmon, Archivist, New Haven Bird Club, personal communication, Sept 25, 1996.

The collapse of bird populations led to greater concern for habitat loss manifested in a national movement to conserve habitat spearheaded by organizations like the American Ornithologists' Union, the Audubon Society, and Ducks Unlimited during the 1930s (Nash 1989, Beck 1994). These organizations, which valued birds either for aesthetics, scientific potential, or hunting, began to acquire land and lobby for legislative protection of habitat.

Modest attempts were made during the 1930s to preserve salt marshes in Connecticut through private acquisition (Rozsa 1995). More ambitious acquisition programs were initiated by the state, The Nature Conservancy, and local land trusts during the 1960s

(Dreyer 1995). Some marshes have been preserved by farmers who found new markets for salt hay including use as mulch (Rozsa 1995). But the amount of acreage in agricultural use since 1900 has been small. Federal legislation was enacted in 1906 to create the national wildlife refuge system, but Connecticut's first national wildlife refuge – a salt marsh – was not established until 1971 (Dreyer 1995).

Salt marsh preservation efforts prior to 1960 were based on an appreciation of marshes for wildlife, recreation, agriculture, and biological research, and focused mainly on preserving habitat for charismatic birds and for waterfowl for hunting. Although these ideals laid the groundwork for future conservation, they represented a minority opinion, and tidal marshes were quickly disappearing despite conservation efforts.

The industrial worldview considered humans exempt from ecological constraints.

THE INDUSTRIAL WORLDVIEW AND URBAN DEVELOPMENT

Accelerated habitat destruction after World War II, the profusion of chemical biocides, and increased personal mobility are but a few manifestations of the industrial worldview[4] that technology had freed the human race from ecological constraints. This exemptionalist attitude developed in concert with the industrial revolution (Caldwell 1990). During this era of unprecedented growth and prosperity, improvement to human quality of life was perceived to rely exclusively on economic growth. Economic growth was not considered to be bounded by natural resources since technology would allow the circumvention of ecological constraints (Catton 1980, p. 187).

Salt marshes, perceived as having no economic value, but having the negative reputation of mosquito habitat, were regarded as impediments to economic growth and became targets for technological remedies such as reclamation. The post-war economic expansion, coupled with technological advances such as hydraulic dredging (Darling 1961), led to an explosion of tidal wetland filling (Fig. 2). During the 1950s and 1960s tidal wetlands were filled for highways, airports, marinas, parking lots, and housing developments, or simply became repositories of garbage and dredge spoil (Darling 1961, Kavenagh 1980, Metzler and Tiner 1992). By 1970, 30% of Connecticut's tidal marshes had been destroyed (Rozsa 1995).

The industrial worldview was probably stronger in urban areas where nature had been reduced to an abstract concept and pressure for real estate was intense. As a result, urban wetlands were filled most rapidly. New Haven had lost over 60% of its tidal wetlands by 1970 (Rozsa 1995).

[4] The term "worldview" is used here in the anthropological sense – the way in which members of a culture perceive their status in relation to the natural environment, supreme powers, and external economies. Methods of inquiry, personal decisions, and public policy are based on this fundamental cultural perception.

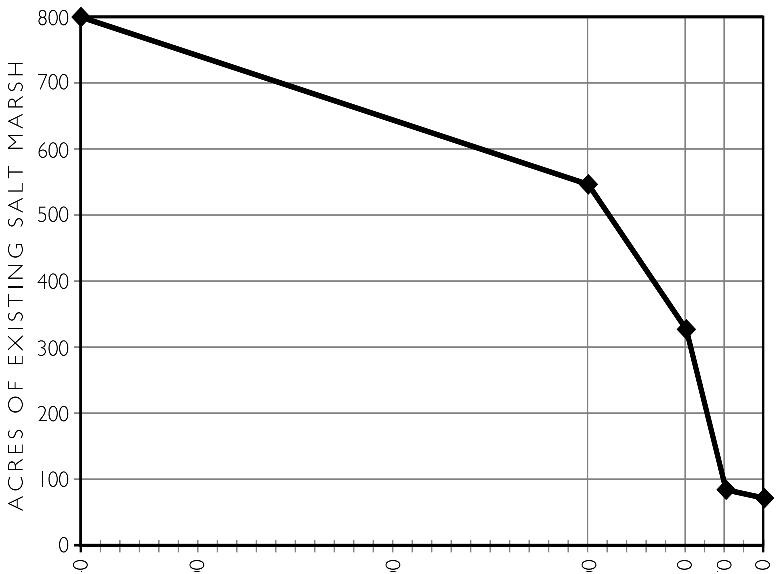


Figure 2. History of salt marsh reclamation in the West River watershed compiled from a review of the Sterling Memorial Libray map collection at Yale University.

Most of the West River tidal marsh filled prior to 1950 was used by the city for parks or sold for commercial use. The role of the city is clearly illustrated by the large amount of filled marsh that remains as parkland (Table 1). The area filled within West River Memorial Park was about 130 acres.

Private developers and the federal government were primarily responsible for marsh eradication after 1950 when filling accelerated (Fig. 2). The total loss of tidal marshes in the West River watershed today exceeds 90% (Kenny 1995). Tidal marsh originally covered an area of approximately 800 acres[5]. Of the original 800 acres, only 74 acres remain unfilled. Of these unfilled acres, twenty remain as highly disturbed salt marsh, but a 17 acre salt marsh near Spring Street in West Haven (see Fig. 2, p. 8) is relatively undisturbed (Orson et al., pp. 136-150, this volume). Another 40 acres of salt marsh were never

[5] These calculations result from a review of the Sterling Memorial Library map collection at Yale University. The estimate of original salt marsh area is based on the U.S. Geological Survey of 1877 and 19th century records referring to tidal marsh in the vicinity of Whalley Ave.

Table 1. Current use (1995) of filled salt marsh areas in the West River watershed compiled from aerial photos, visual surveys, and municipal records.

Land Use	Acres
City Parks	328
Commercial, Industrial, and Cemeteries	179
Landfills for waste	143
Roads and Railroads	63
Residential	19
Remaining unfilled (as salt marsh)	74 (37)

filled, but tidal restriction has eradicated all salt marsh vegetation. Twenty three acres of salt marsh appear to have been unintentionally created on former mud flats near the mouth of the river as a result of filling and hydrological alteration between 1930 and 1942.

ECOLOGY, SOCIO-ECONOMIC VALUE AND THE COMMON GOOD

How is it that social trends shifted so quickly that by the 1970s the destruction of salt marshes was halted and scientists were considering the possibility of re-creating marshes? Most of the destruction occurred only within the previous 30-40 years and social trends began to change. Population growth in Connecticut slowed with the industrial emigration that began in the 1960s, causing urban populations to decrease. Recreational tastes continued to become more naturalistic, a post-industrial economy developed, and new and alarming scientific information weakened the industrial worldview that humans are exempt from ecological processes. However, the *rapidity* of the deceleration of salt marsh filling since the late 1960s is largely the result of a legal infrastructure that facilitated the rapid institution of new social values; in particular, the legal precedent treating tidal lands as common property (Siry 1984, p. 6).

The rapidity *of the deceleration of salt marsh filling since the late 1960s is largely the result of a legal infrastructure that facilitated the rapid institution of new social values.*

The legal precedent for treating tidal wetlands as common property can be traced back to the Magna Carta of 1215, which barred the King of England from granting private use of tidal waters (Kavenagh 1980, Bean 1983). Eventually (in 1667), tidal lands were deemed the property of the king, but to be held in trust for the good of the populace (Kavenagh 1980). British law carried over to the American colonies, and in many cases the proprietary rights and responsibilities of the King, including those regarding tidal lands, were ultimately transferred to the general assemblies of the new American states (Siry 1984, p. 39).

Since many colonies established during the 1630s were somewhat autonomous, and the issue of private control of tidal lands was still not settled, colonies were essentially free to set land tenure systems for salt marshes. Many New England communities maintained public rights to salt marshes by considering them common pastures (Bidwell 1925). In Huntington, New York (Long Island) the tidal marshes were placed in public trust, and the rights to harvest hay were auctioned annually (Kavenagh 1980).

New Haven's leaders, however, opted for private ownership, and the "goodly meadows" were quickly divided up among the proprietors of the colony (Hoadley 1857). Nevertheless, as with the king, private owners were ultimately beholden to the common good, and ecological phenomena that transcended private boundaries eventually constrained proprietary use. The gradual transfer of authority to the state for mosquito control, for example, resulted from the ecological reality that mosquitoes have no respect for property boundaries.

In 1766 the Connecticut Colony General Assembly passed an act regarding the "preservation of oysters and clams and regulating the fishery thereof" with special reference to New Haven and Fairfield (Osterweis 1953, p. 104). This law granted regulatory authority over tidal waters to individual towns, and New Haven promptly established an oyster harvesting season and banned destructive harvesting methods. The right of the state to regulate oysters, and the exclusion of any individual to lay claim to private use of oyster beds, was upheld by the United States Supreme Court in 1842 in the case of *Martin vs. Waddell* (Bean 1983). This legal precedent resulted from a combination of economic foresight and recognition of the ecological reality of a limit to oyster reproduction. The regulation of fisheries, in combination with marsh bird protection and anti-mosquito legislation of the 1900s, laid a firm foundation for state control of lands below the high tide line.

Ecological concepts were largely unappreciated outside of the scientific and philosophical communities until Rachel Carson published The Sea Around Us *in 1951. By the early 1970s, books such as* The Limits to Growth *boldly disputed the industrial worldview.*

The public trust character of navigable water, including tidal lands, was institutionalized at the federal level with Section 10 of the *River and Harbor Act* of 1899, which allocated the right to regulate lands below the high tide line to the Army Corps of Engineers (ACOE). This law was the basis for Section 404 of the federal *Water Pollution Control Act* of 1972, which specifically charged the ACOE with regulation of dredging and filling of tidal marshes. In 1900, federal control of wildlife (including tidal marsh species) was relegated to the Secretary of Agriculture as a result of the *Lacey Act*. As these laws withstood court challenges they set the legal precedent for federal regulation of tidal lands.

By 1950, the philosophical rationale for conservation had steadily matured (Nash 1989), and recognition of the interconnectedness of life was evolving within the field of ecology (Cronon 1993). Yet, ecological concepts were largely unappreciated outside of the scientific and philosophical communities until Rachel Carson published *The Sea Around Us* in 1951. A best seller, *The Sea Around Us* brought ecological concepts to the general public for the first time. Another of Carson's books, *Silent Spring*, published in 1962, was followed by a steady stream of "environmental" works by other writers. By the early 1970s, books such as *The Limits to Growth* (Meadows et al. 1972) boldly disputed the industrial worldview that humans were exempt from ecological constraints. This literature inspired a wave of environmental legislation that regarded natural resources such as clean water, clean air, and endangered species as common property of finite supply. The ecological rationale embodied in Connecticut's 1971 law that created the Department of Environmental Protection exemplifies this radical shift: "The air, water, land and other natural resources, taken for granted since the settlement of the state, are now recognized as finite and precious. It is now understood that human activity must be guided by and in harmony with the system of relationships among the elements of nature" (PA 872 of 1971, Sec. 1).

An important theory illustrating the role of salt marshes in larger ecosystems is commonly referred to as the Outwelling Hypothesis and dates back to the late 1950's (Kalber 1959). Salt marshes had long been appreciated as highly productive communities (Rankin 1961), but the Outwelling Hypothesis proposed that salt marsh biomass was flushed out to sea where it contributed significantly to the productivity of marine fisheries. The relative importance of this process has recently been questioned (Peterson and Turner 1994). Nevertheless, this theory linking salt marshes to the economic value of fisheries was quickly brought into conservation arguments. Such arguments were institutionalized in 1964 by the Superior Court of Suffolk Massachusetts when Judge Horace T. Cahill ruled that "Broad marsh is a 'salt marsh' necessary to preserve and protect marine fisheries" (Hutton 1964). This decision was the first to place the ecological value of a salt marsh above private development by recognizing the biological importance of salt marshes for estuarine fisheries. Citing ecological values, Judge Cahill validated public control of tidal land in Massachusetts by maintaining the right of the state to regulate the salt marsh.

The links between salt marshes, fishery productivity, and water quality, discovered during the 1960s, led quickly to legal protection of salt marshes.

Meanwhile, other socio-economic values of wetlands continued to accrue. Repeated damage to property located in filled wetlands led many to begin questioning the logic of building on filled wetlands. The Army Corps of Engineers began considering wetland conservation as a flood protection strategy during the early 1970's (Metzler and Tiner 1992). This strategy was based on the economic value of reducing flood damage.

The potential for wetlands to remove waterborne sediments and pollutants became another powerful argument for salt marsh conservation. This socio-economic benefit was documented by researchers during the 1960's (Postma 1967, Boyd 1970, Grant and Patrick 1970). By the 1970s, researchers were evaluating the use of salt marshes to treat waste water (Valiela et al. 1973, Sloey et al. 1978).

Based on these increasing socio-economic values, Connecticut's *Act Concerning the Preservation of Wetlands and Tidal Marsh and Estuarine Systems* was passed in 1969 (PA 695). The intent of this law went well beyond protecting wildlife and plants. It recognized the ecological role of tidal wetlands as "sources of nutrients to fin-fish, crustacea and shellfish of significant economic value" (PA 695, Sec. 2). Salt marshes were also recognized for reducing flood damage and keeping navigation areas silt-free. Recreational and aesthetic values were specifically cited. In general, the law considers tidal wetlands to be of benefit to "public health and welfare" (PA 695, Sec. 2). This language differs dramatically from the negative language used to describe salt marshes at the turn of the century, although mosquito control activities conducted by the Department of Health were still specifically exempted from regulation by the Department of Environmental Protection.

It is no coincidence that comprehensive federal protection would eventually be enacted as part of pollution control legislation once the scientific link between wetlands and water quality was documented.

Federal recognition of human dependence on estuarine health, including salt marshes, was institutionalized in the *National Estuary Protection Act* of 1968 (PL90-454). This legislation was meant to increase conservation cooperation among federal agencies, encourage watershed planning, and fund wetland acquisition, but it fell short of comprehensive regulation of tidal wetlands (Siry 1984, p. 183).

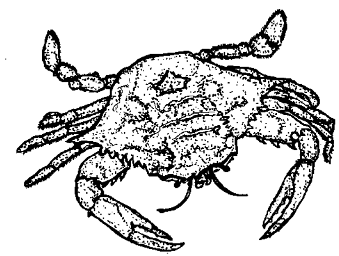
Comprehensive federal protection was eventually enacted as part of pollution control legislation as a result of the scientific link between wetlands and water quality. Federal legislation concerning the effects of water pollution on human health date back to the *Water Pollution Control Act* of 1948 (PL80-845,). The federal *Water Pollution Control Act* Amendments of 1972 (PL92-500), now called the *Clean Water Act*, expanded the scope of water pollution legislation dramatically by seeking to "restore and maintain the chemical, physical, and biological integrity of the nation's waters." This ecological approach reflected the view that human well-being was inextricably linked to ecosystem health. Tidal wetlands were now recognized as an important part of ecosystems to be treated as common property. Section 404 of the *Clean Water Act* created federal protection of tidal wetlands by giving the Environmental Protection Agency and the U. S. Army Corps of Engineers authority to deny permission to fill tidal wetlands if such fill would have an "adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreation areas."

The language of these laws illustrates how ecology and environmentalism have re-directed American thought to once again recognize the importance of salt marshes for economic stability and personal well-being, just as they were appreciated by the original colonists. Legal protection of tidal wetlands as common property was supported by the collapse of the industrial worldview.

CURRENT AND FUTURE TRENDS

Salt marshes were never disliked *per se*. Their eradication resulted from their association with mosquitoes and a failure to value them economically. Now, economic and ecological value are widely appreciated, and scientific, aesthetic, and wildlife habitat values remain strong. In addition, the recognition of the role salt marshes played in the location and subsistence of early colonial settlements indicates their historical and cultural value (Siry 1984, p. 188).

The persistence of the aesthetic appeal of salt marshes since they first beckoned European explorers is well documented by American artists (Fig. 1)(Siry 1984, p. 45). Even during the peak years of eradication they were cited for their pleasing visual character (Pough 1961). Indeed, the aesthetic quality of salt marshes was recognized as a valuable resource under Connecticut's *Tidal Wetland Act* of 1969. This value is not lost on home-owners who pay high prices for the sweeping vistas provided by marshes. Given the human psychological preference for such landscapes (Appleton 1988, Ulrich 1993), the aesthetic value of salt marshes is not likely to diminish and may even increase real-estate values.



Blue crab – an economically valuable species of estuaries.

Non-consumptive wildlife recreation, such as observing, feeding, and photographing wildlife, has grown into a multi-billion dollar industry. In 1991, 76 million Americans pursued non-consumptive wildlife activities and spent $17 billion on lodging, food, transportation, user fees, and the purchase of equipment such as binoculars, film, and special clothing (U. S. Department of the Interior 1993). Twelve million Americans traveled to wetlands, marshes, and swamps in 1991 specifically to experience wildlife. The majority of those trips were to see birds. An estimated one quarter of Americans are casual bird watchers, and 3% are considered committed enough to purchase expensive equipment (Kellert 1985). This level of interest in bird-watching is expected to continue in the 21st century (Kelly 1987).

Since salt marshes provide good habitat for large charismatic wading birds (Lewis and Casagrande, this volume), and low salt marsh grasses provide good visibility, they will continue to be valued as outstanding wildlife viewing areas. Duck hunting also remains a popular activity (U. S. Department of the Interior 1993), and salt marshes continue to provide good hunting opportunities.

The most frequently cited economic value of salt marshes continues to be for fisheries (Miller 1992). At first this was limited to oysters (Hutton 1964), but research has indicated that salt marshes are also important for other harvestable species including fin-fish, shrimp, and blue crabs (Peters et al. 1978). Economic value also includes cost savings of reduced siltation in navigable waterways, profits to the outdoor recreation industry, and reductions in pollution. New methods of economic valuation will raise the value of salt marshes further by placing dollar values on services such as habitat for threatened species (Udziela and Bennett, this volume).

Nevertheless, there continues to be a slow loss of tidal marshes in Connecticut (Connecticut Department of Environmental Protection 1994), largely because state and federal regulations still permit filling under certain conditions. Recognition of the inability to stop net losses of wetlands has resulted in a movement to restore degraded marshes and create new marshes (Beck 1994). Connecticut's *Tidal Wetlands Restoration Act* of 1993 (PA 93-428) directs the Department of Environmental Protection to restore and enhance marshes. Wetland restoration is also being promoted nationally by judicial decisions in which polluters are directed to restore wetlands as a penalty (Beck 1994).

If there is one caveat for salt marsh restoration, it is the persistent problem of mosquitoes.

Restoration may become even more important if court decisions require governments to compensate land owners who are denied permission to destroy wetlands (Beck 1994). These decisions may encourage regulators to grant permits to fill. Restoration would likely continue to be seen as a strategy for off-setting net losses (Beck 1994).

If there is one salt marsh restoration caveat, it is the persistent problem of mosquitoes. Specimens of *Aedes* infected with Eastern Equine Encephalitis were discovered in Rhode Island and Connecticut salt marshes in 1996 (Hartford Courant, Sept. 22, 1996). Although this disease is rarely transmitted to humans, Connecticut's governor declared a health risk and ordered aerial spraying of marshes (Hartford Courant, Sept. 25, 1996). A news article suggested that wetland restoration and wildlife habitat improvements were responsible for increasing occurrences of diseases transmitted to humans from wildlife (Hartford Courant, Sept. 22, 1996). This argument is based on research that linked increases in occurrences of diseases such as Eastern Equine Encephalitis with reforestation and increases in residential developments in or near wetlands (Komar and Spielman 1994).

Under current laws such as the *Tidal Wetland Act* and the *Wetland Restoration Act* designation of activities that will be allowed on tidal wetlands is contingent on the common good. Mosquito control activities are exempt from these regulations and outbreaks of diseases linked with salt marsh mosquitoes could threaten the restoration movement. Restoration of degraded marshes using Open Marsh Water Management (OMWM) often decreases mosquito breeding (Rozsa 1995). Nevertheless, the recent negative press regarding salt marshes indicates that positive perceptions of salt marshes are still balanced against the tenacious perception of marshes as breeders of disease.

The future of salt marsh preservation and restoration will be determined by the strength of the ecological worldview against challenges such as a revitalized perception of salt marshes as sources of disease. The strength of the ecological worldview, in turn, rests on its pervasiveness and level of understanding among the general public. Increasing environmental concern has been attributed to a growing acceptance of the ecological worldview, and the inter-connectedness of life is now appreciated throughout American society (Kempton et al. 1995, pp. 9-11). Environmental concerns deepened during the 1980s as repeated energy crises and environmental disasters such as Love Canal, Three Mile Island, Bhopal, and Chernobyl appeared to validate the environmental literature of the 1960s and 70s. Recent environmental problems such as global warming, ozone depletion, biodiversity loss, and tropical deforestation have led a majority of Americans to believe that environmental problems have increased in frequency, scale, and seriousness (Dunlap and Catton 1994). Surveys reveal that a majority of Americans believe environmental quality continues to decrease (Dunlap and Catton 1994). They overwhelmingly support increased government spending and regulations for environmental protection (Kempton et al. 1995, p. 4). Furthermore, environmental concern is strongest among younger populations, suggesting a continuing historical shift toward environmentalism (Kempton et al. 1995, p. 7).

The future of salt marsh preservation and restoration will be determined by the strength of the ecological worldview against challenges such as a revitalized perception of salt marshes as sources of disease.

The trend toward environmentalism and ecological thinking in combination with increasing documentation of salt marsh functions and economic value suggest that public support for salt marsh preservation and restoration will remain strong. Americans are likely to call for a technical solution to the threat of mosquito transmitted disease rather than a return to salt marsh eradication.

CONCLUSION

American perceptions of salt marshes as valuable resources appear to have come full circle, returning to the appreciation shown by early colonists. The history of West River Memorial Park reflects this process (see select chronology below). The park was created largely out of desire to eradicate salt marshes that were once essential to the survival of the agricultural economy. The environmental movement of the 1970s helped thwart further ecological degradation of the area, and a movement now exists to restore the salt marsh. These trends reflect national historical shifts in cultural perceptions, which result from a process of balancing negative against positive values on both an individual and societal level. An appreciation of salt marshes exists only because positive socio-economic values once again dominate negative perceptions of marshes as sources of mosquitoes and disease.

Salt marsh restoration goals for West River Memorial Park should consider how urban neighbors balance negative and positive perceptions . Mosquitoes, aesthetics, and visible wildlife (especially birds) will strongly influence perceptions (Casagrande 1996). Pollution remediation may be particularly valued due to the urban setting. Ecological concepts such as fishery productivity may be less appreciated because urban residents tend to have low knowledge of ecological concepts (Kellert 1984). A comprehensive restoration program could be used to improve urban ecological knowledge through neighborhood participation.

The national trend toward salt marsh restoration reflects the ecological worldview and may accelerate because positive values of salt marshes are expected to continue to accrue and legal decisions are likely to encourage restoration. The salt marsh restoration movement is likely to survive periodic set-backs since the ecological worldview and environmentalism continue to deepen in the American social consciousness.

"The world lies east: how ample the
marsh and the sea and the sky!
A league and a league of marsh-grass,
waist high, broad in the blade,
Green, and all of a height, and
unflecked with a light or a shade,
Stretch off, in a pleasant plain,
To the terminal blue of the main."

– from The Marshes of Glynn*, Sidney Lanier, 1878*

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SELECT CHRONOLOGY OF EVENTS
WEST RIVER MEMORIAL PARK
NEW HAVEN, CONNECTICUT

1638 New Haven Colony founded. All land including that of the park was purchased from the Quinnipiac tribe. The West River salt marshes were divided among settlers for agricultural use.

1638-1910 The area within the future park was used mostly for salt marsh hay. At some point during this time tide gates were installed near Congress Ave. (Fig. 3) to facilitate harvesting.

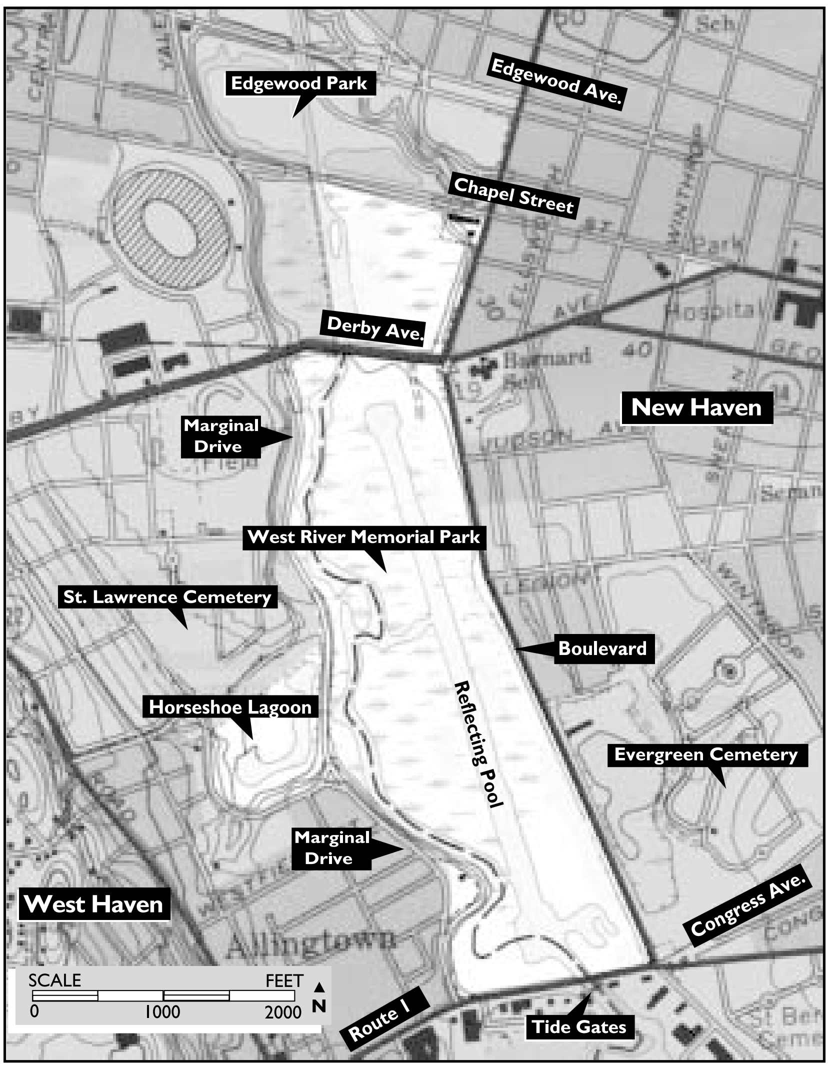

Figure 3. West River Memorial Park in West Haven and New Haven, Connecticut.

1641	The first bridge over the West River was constructed at the current location of Congress Ave.
1886-1893	The river course was straightened north of Congress Ave. to facilitate drainage.
1910	Gilbert and Olmsted's civic improvement plan called for a series of parks to extend along the West River from West Rock through Edgewood Park to the New Haven Railroad bridge just north of Spring St. The plan also noted that the tide gates at Congress Ave were in need of replacement.
1917	All 134 acres of salt marsh within the future West River Memorial Park were ditched to reduce mosquitoes. The Director of the Agricultural Experiment Station ordered New Haven to install new tide gates to accompany the mosquito ditching efforts.
1919	The New Haven Civic Improvement Association contracted the Olmsted firm to design a memorial to World War I veterans in what would be West River Memorial Park. Salt marsh eradication was clearly the intent of E. C. Whiting, the principal designer. The park plan was based on dredging a long pool and using the spoil to reclaim marshland. The City of New Haven began constructing new tide gates at Congress Avenue with the intention of reducing mosquitoes and reclaiming the marsh upstream.
1920	Tide gate construction was finished.
1923	Land was purchased for the park through private sales. Land acquisition and dredging were funded by municipal bonds.
1924	The remaining land was acquired through eminent domain. The city began to dispose of ashes and rubbish on the banks along the Boulevard.

1924	Dredging began on Oct. 10 with material being deposited along what would be Marginal Drive (Fig. 3), and the westerly banks of the Boulevard over the existing dumps. Playing fields at the Boulevard and Congress Ave. were filled and graded. An additional 12 acres between St. Lawrence cemetery and Derby Avenue were donated by Yale University.
1926	Most of the material excavated from the sand banks and in the making of the lake south of St. Lawrence Cemetery was used for Marginal Drive and to create an island in the center of the lagoon. This left little fill to reclaim marsh land. The city continued to dispose of ashes and rubbish on the banks along the Boulevard.
1927	Marginal Drive was finished. The next step was to dredge the straight main channel. A dredge was used to cut out the banks and solids, while a pump transferred the liquid mud over the adjoining marshes. Fires in the Boulevard dumps were a recurrent problem.
1928	Marginal Drive (still unpaved) was opened to the public at its own risk.
1929	Dredging continued and some additional fill was brought from an unrelated tunnel excavation at Tower Parkway.
1930	Oak Street, which bisected the park, was closed and removed within the park, and the fill was used to build dikes across the old river beds.

1932	The entire 130 acre salt marsh area of the Park had received its primary fill as a result of moving over 1,000,000 cubic yards of material. Further improvement, requiring more material and larger equipment, was to wait until the city could grant another bond issue.
1932 - 1940	Federal Emergency Relief Administration crews continued grading the banks and constructing walking and bridle paths.
1934 - 1940	A total of 213 white and pink dogwoods, 486 laurels, 43 hemlocks, and 21 red cedars were donated by the New Haven Garden Club through annual gifts of $500. The plantings were mostly along the Boulevard.
1936	Street-side concrete walks were installed at Congress and Derby Avenues. More fill was placed in the area bounded by Derby and Legion Avenues and the Boulevard.
1937	An unexplained pollutant led to a massive fish kill (mostly Alewives) in Edgewood and West River Memorial Parks, indicating the problem of pollution from upstream industrial areas.
1940	City park department finances were unable to supply federal relief workers with equipment.
	Thousands of swimmers used the West River within the park.
1944	Due to lack of funds, park development had still not been completed and the large expenditure had failed to yield the desired landscape.
	Toilets and dressing sheds were installed for swimmers.
1946	Swimming instruction was provided at West River Memorial Park and 25,136 people swam in the river, and another 6,002 visited as spectators. One youth drowned in the lagoon.

1946	Influential citizens began a movement to extend the channel north to Edgewood Ave. and south to Washington St. to accommodate crew races. The channel was never extended.
1947	Yale University began using the channel for crew practice.
1956	A playground, baseball field, and softball field were built along the Boulevard. The only other public use authorized for the park was fishing.
1964	Two boys drowned in the lagoon, leading to limited attempts to fill in the lagoon. This was never completed.
1967	A larger baseball field was constructed along the Boulevard to be the home field for Lee High School's varsity team.
1969	The International Rowing Course Foundation proposed building an Olympic standard course and other park improvements (mostly ball fields) in return for a 40 year lease of the park. The course was to extend from Congress Ave. to just south of Edgewood Avenue. The western lagoons were to be kept for wildlife, boating, and fishing. The plan required removal of the Chapel Street Bridge and a new bridge at Derby Ave. The rowing area was to be open for public boating and the Foundation would provide rowing shells to local high schools. A public hearing held on December 10 drew a capacity crowd.
	The parks department discontinued use of DDT.
1971	After much negotiating with the IRC Foundation, the New Haven Parks Commission approved the rowing course and sent a revised contract to the Board of Aldermen for approval.
1972	The rowing course plan eventually languished amid increasing public opposition and an inability to secure state funds.

1979	Friends of the Tidal Marsh (a grassroots organization) accused the St. Lawrence cemetery of illegally filling the lagoon.
1980	Marginal Drive was closed to vehicular traffic as a result of illegal dumping. The area was cleaned of tons of debris and remained open for fishing, jogging, hiking and bicycling.
1983	A soccer field was installed at Derby Ave. and the Boulevard.
1986	Peter Davis began a voluntary organized removal of trash from New Haven rivers including within West River Memorial Park. Davis was eventually designated the city River Keeper in 1993.
1992	The City of New Haven received a grant from the Connecticut DEP to study the feasibility of restoring the salt marsh in the park; Yale researchers William Kenny and Paul Barten found the restoration feasible.
1994	West River Memorial Park was included in the Connecticut DEP's list of potential salt marsh restoration sites.
	Two bodies were found in the river within the park; one found Sept. 2 had been murdered, the other found Sept. 12 appeared to have drowned.
	The West River Symposium was sponsored by the Yale School of Forestry and Environmental Studies with funding from the Connecticut DEP Long Island Sound License Plate Program. Community members, academics, and policy makers discussed current environmental knowledge of the river and possible restoration scenarios for the park.

1995	Large quantities of construction spoil that precluded access to the original viewing area at the south end of the park were removed.
Present	Park use includes some fishing and very little walking or swimming. The northern end of the park is covered with gravel for use as a parking lot for sporting events at nearby stadiums.

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Contingent Valuation of an Urban Salt Marsh Restoration

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ABSTRACT
This paper discusses the validity of the contingent valuation method (CVM) and presents the results of a CVM survey we conducted to estimate the nonmarket value of restoring a salt marsh in New Haven, Connecticut. The literature suggests that CVM is valid, but results are often biased by poor survey design. Using a survey that was extensively pretested, we addressed potentially problematic issues such as payment vehicle bias, information bias, and hypothetical bias. We also combined techniques from conjoint analysis. Fifty-one households near the West River in New Haven were surveyed on Saturdays in March and April 1996. The households represented a wide range of socio-economic characteristics. Survey respondents were provided with background information including the current condition of the river and possible costs and benefits of restoration. Respondents were asked if they supported or opposed the restoration. Their maximum willingness to pay either for the restoration, or to keep the river in its current condition was solicited.

The contingent valuation survey performed well and was effective in educating participants about the current condition of the West River, the restoration measures proposed, and the possible impacts of the restoration; it was also effective in obtaining willingness to pay responses from people interviewed. Over three-quarters of people interviewed supported the proposed opening of the tidegates. Moreover, this support extended to a willingness to pay considerable amounts of money for the restoration. People clearly have high values for nonmarket and even nonuse environmental resources. Without a means to estimate their economic value, these significant amenities will be ignored and thus not protected. Contingent valuation can be an effective method of obtaining price estimates for non-market values that would be excluded from consideration in traditional economic decision-making because they have no associated price. Consequently, economic valuation has a crucial role to play in preserving and restoring priceless environmental resources. We conclude that a carefully designed contingent valuation survey is a promising method for bringing nonmarket economic values into the cost-benefit analysis of restoring the West River salt marsh.

The West River and its flood plains occupy approximately 35 square miles in New Haven and West Haven, Connecticut. Historically, 800 acres of this area were salt marsh (Casagrande, pp. 13-40, this volume). It was a highly productive estuarine ecosystem with an associated biological community.

In 1919 tidal gates were installed where Route 1 crosses the river in New Haven for the purpose of marsh reclamation. The gates stopped Long Island Sound's saltwater from traveling upstream, thus reducing upstream salinity and tidal inundation. As a result, *Phragmites australis* have aggressively colonized the area north of the tide gates. Such large, man-made stands of *Phragmites* provide poor wildlife habitat.

There is currently significant interest and some controversy with regard to restoring about 70 acres of the historic salt marsh located just upstream of the gates within West River Memorial Park. Both the interest and the controversy revolve around the effects of opening some of the 12 tide gates to increase tidal flushing. Other restoration projects in Connecticut have shown that restored tidal flushing reduces *Phragmites* and allows a salt-marsh community to return (Steinke 1986, Rozsa and Orson 1993). However, opening the tidal gates could also have negative impacts such as flooding.

For a policy decision regarding the restoration to be balanced and objective, it is helpful to aggregate economic benefits and costs. Economic valuation is complicated, however, by the fact that restoration benefits include salt-marsh resources that do not have a market price (e.g., scenic views and wildlife). In other words, *value* is not determined or set by the market. Although scenic views and wildlife have a significant value to the public, they risk being excluded from economic analysis because they appear to have no economic value. The historic eradication of salt marshes provides evidence that the exclusion of nonmarket values can result in environmentally destructive policies (Casagrande, pp. 13-40, this volume). For this reason, we have focused on the nonmarket benefits and costs of restoration.

For a policy decision regarding the restoration to be balanced and objective, it is helpful to aggregate economic benefits and costs. Although scenic views and wildlife have a significant value to the public, they risk being excluded from economic analysis because they appear to have no economic value.

The most widely recognized method for the valuation of nonmarket resources is the contingent valuation method (CVM). CVM involves presenting survey respondents with a hypothetical market for the resource and eliciting a willingness to pay for that resource.[1] Using CVM to value natural resources is not new. CVM has been used in several studies of endangered species.[2] Other studies have focused more generally on wildlife preservation (Stevens et al. 1994, Desvousges et al. 1993).

CVM has been the subject of debate among economists and others for the last decade. Even though a panel of experts convened by the National Oceanic and Atmospheric Administration (NOAA) in 1993 concluded that contingent valuation could produce reliable estimates of some types of values, critics have stated that CVM has failed to produce reliable and accurate measures of value (Diamond and Hausman 1994, McFadden and Leonard 1993, Diamond et al. 1993). Others emphasize that most (or even all) of CVM's perceived failures have been due to surveys that were inadequately planned or poorly structured, and that CVM works when properly executed (Portney 1994, Hanemann 1994). This study helps to alleviate some concern. We argue that a careful survey design can eliminate many of the biases that have caused the controversy.

[1] See Portney 1994, Cummings et al. 1986, and Mitchell and Carson 1989 among others for details of methodology.

[2] See for example Samples et al. 1986, Boyle and Bishop 1987, and Stevens et al. 1991.

We used the CVM method to assess the nonmarket economic value of restoring the salt marsh in West River Memorial Park. Our goal was to produce a reliable estimate by adhering to survey methods that recent studies suggest can reduce bias.

SURVEY DESIGN

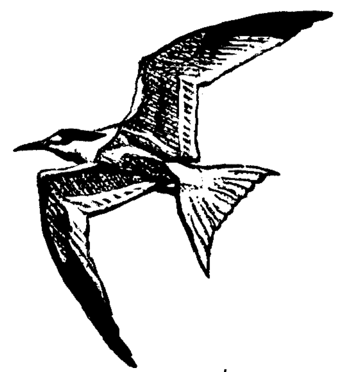
The survey instrument was carefully designed and pre-tested using focus groups and practice interviews. The survey is presented in the Appendix. The survey was conducted as personal interviews and consisted of four key components.

A DESCRIPTION OF THE CONTEXT AND THE COSTS AND BENEFITS TO BE VALUED

An important factor in the effectiveness of a contingent valuation survey is that the survey respondent must have a clear and accurate idea of the specific good that is being valued. In the case of natural resources, this is often a difficult concept to convey, because there are countless ways of viewing the resource. As a result, respondents could be considering their willingness to pay for a good that is different from the one being asked about in the survey. Careful survey design can help to avoid this information bias.

For example, the West River provides foraging habitat for the least tern, a threatened species in Connecticut that dives for fish (Lewis and Casagrande, this volume). The degraded condition of the marsh, however, reduces the habitat value for the tern. Least terns are common visitors to salt marshes in the northeast (Post 1970), and have been shown to benefit from salt-marsh restoration (Bontje 1987). Opening the tide gates and restoring the salt marsh may benefit the least tern by increasing fish abundance and improving water quality. Nevertheless, a survey question that asked for the value of the least tern only could have been ambiguous. Could the question be referring to the bird itself, reduced chance of extinction for the bird, probability of viewing a least tern during a visit to the West River, or the habitat it lives in?

Related to this is an issue known as "part-whole bias" or the "embedding effect," in which respondents produce equal values of willingness to pay for two goods, one of which is a subcomponent of the other (Brown et al., 1995). A good of interest, known as α, is valued by one set of subjects. Then, a larger good (Σ), which includes α, is valued by another set of subjects. Since studies of this type have obtained results that $\alpha \approx \Sigma$,[3] the conclusion is that either Σ is not valued at all (which is unlikely), or that respondents value α as a component of Σ. In our case, people may express a desire to preserve



Least tern

[3] The CV study of migratory waterfowl by Desvousges, et al. (l993) is commonly cited as an example of the severity of the embedding effect, because respondents failed to distinguish between 2,000, 20,000 and 200,000 birds. However, Hanemann (1994) has noted that when the data were trimmed to remove the extreme 10% of the values, the willingness to pay for each of the three quantities of birds was different.

the least tern because they value the habitat it lives in. In addition, respondents may be valuing other benefits of the restoration, such as enhanced aesthetics. Again, careful survey design can reduce the magnitude of this effect or eliminate it entirely.

This research addressed the embedding effect by phrasing the WTP question so that the good offered was a restored salt marsh that contained several benefits, including a specific number of acres (70) of habitat for the least tern, habitat for other wildlife, "naturalness" of salt marshes, and reduced fire hazard. Likewise, costs such as increased risk of flooding were included. Thus, respondents were considering an entire bundle of costs and benefits, all of which derive from the salt-marsh restoration. Pretesting of the survey had indicated that it would be beneficial to present respondents with all of the advantages and disadvantages of both conditions. They could then decide which "bundle" of benefits and drawbacks they preferred. This technique is called conjoint analysis and has been used extensively in marketing and transportation economics and more recently in natural resource valuation (Roe et al. 1996). Thus our survey not only incorporated CVM questions, but included conjoint analysis questions as well.

A panel of experts convened by the National Oceanic and Atmospheric Administration (NOAA) in 1993 concluded that contingent valuation could produce reliable estimates of values.

If information is comprehensive and properly presented, bias can be reduced. Therefore, we used visual aids extensively including photographs and maps to present a detailed description of current conditions and the effects of restoring tidal flushing.

Interviews began with questions about environmental attitudes and behavior. Respondents were asked how often they used the West River, where along the river they went, and what activities they did there, or why did they not use the river. Respondents were also asked about their perceptions of the West River's water quality, recreation potential, and habitat value. This allowed people to express their opinions and become comfortable with the survey.

Respondents were then asked whether they preferred the West River in its current state or as a restored salt marsh. This question was based on two photographs, one of each condition. Therefore, initial preference was based largely on aesthetics. A series of questions then gave successive information about the two river types. After each new fact was presented, respondents were asked which river they preferred. Finally, respondents were handed a list of all the advantages and disadvantages of each river type and asked to state a final preference based on all the information.

Interviewers next described the restoration proposal. The restored salt marsh would have both benefits (e.g., habitat for the least tern) and costs (e.g., increased flooding). Respondents were then asked if they supported or opposed the restoration.

THE WILLINGNESS TO PAY QUESTION

Economic value can be elicited with a CVM survey either using a question of willingness to pay (WTP) for a resource or willingness to accept (WTA) the loss of a resource. WTP is a measure of the maximum amount that a person would pay for a particular good or service, such as environmental quality or species existence, or for an incremental change in the amount of an environmental service provided. WTA refers to the minimum level of compensation that person would accept for losing those resources. Traditional economic theory suggests that the two should be equivalent. But studies have often found WTA to be larger than WTP (in some cases orders of magnitude larger). The NOAA panel (1993), among others, recommend using WTP since it elicits more conservative responses of value.

WTP is a measure of the maximum amount that a person would pay for a particular good or service, such as environmental quality or species existence, or for an incremental change in the amount of an environmental service provided.

Furthermore, a WTP response implies the respondent has no property right to the resource being valued. Alternatively, willingness to accept compensation for the loss of a resource would suggest that the respondent has a property right to the resource. We did not feel WTA applied to the West River situation and we elicited economic value using WTP.

The WTP question can be open-ended or presented as a dichotomous choice. In an open-ended question, respondents are asked for the maximum amount they would be willing to pay to obtain a particular environmental amenity. With dichotomous choice, respondents are presented with a price and asked to indicate whether or not they would be willing to pay the stated price. The NOAA panel recommended dichotomous choice in CVM surveys, because respondents are asked to make a familiar decision similar to voting or deciding whether or not to buy something. An open-ended question, the panel argued, places respondents in the unfamiliar situation of determining a value. However, recent comparative studies have revealed dichotomous choice WTP bids that are much higher than those from open-ended questions (see for example, McFadden and Leonard 1993). We used the open-ended format in order to obtain a more conservative estimate of New Haven's residents' values of salt-marsh restoration. We also chose open-ended questions in order to eliminate starting point bias, which is typically associated with dichotomous choice methods.

If respondents in our survey expressed support for the restoration, they were asked the maximum amount they would pay to ensure that it was implemented. If respondents opposed the restoration, the next question asked how much they would be willing to pay to ensure that the restoration was not implemented. Thus, the WTP question measured the economic value both for and against the restoration. If a respondent gave a range of values, the lowest value was used for analysis.

WTP can be biased if respondents do not think in the framework of economic choices that they make with their own money. There may be an overestimation of price if they ignore what they will sacrifice by paying for the environmental amenity. When interviewing people, we kept the realism level high by making the scenario very specific: payment would only occur once; it would occur within the next year; and subjects were required to make their decision on the basis of their present income, not their expected future income. Respondents were also reminded that any amount they were willing to pay would reduce their ability to purchase other goods and services.

In order not to bias WTP estimates, protest bids must be identified and removed. A protest bid is a stated response of $0 to a willingness to pay question even though actual value might be greater than zero. Protest bids occur when respondents are protesting something other than the good in question. Since these responses are not valid "zeros," they must be eliminated from the sample. A common example of a protest bid is the objection to the type of payment mechanism, such as a tax. This type of protest bid creates what is called vehicle bias. To test for vehicle bias, half of our surveys were conducted with a one-time tax as the payment mechanism. The other half included a one-time private donation.

Protest bids can also result from a moral objection to placing a price on the environment. At the end of interviews, we asked respondents to give the reasons for their WTP value. This question was included to identify protest bids, though it also provided other useful information, such as confirmation that respondents understood the restoration scenario.

SOCIOECONOMIC QUESTIONS

Socioeconomic data were solicited confidentially. Respondents were asked to fill out a form about their age, education, income, and race. They folded the form and sealed it in an envelope, which was attached to the survey by the interviewer. This information was used to determine the range of socioeconomic characteristics within our sample, and to test for influence of income on WTP.

FOLLOW-UP QUESTIONS

We asked follow-up questions to ensure that respondents understood the scenario and the payment format and believed the information presented. Respondents were also asked to give reasons for answers of "$0" WTP, so that we could identify protest bids.

SAMPLING DESIGN

Three neighborhoods were selected to represent the greatest range of socio-economic characteristics adjacent to the West River. The Hill is located in southern New Haven and borders the lowest stretch of the West River downstream from the tide gates. Households in the Hill are mostly Hispanic or African American and represented the lowest income. Edgewood is located to the north of the Hill, and is upstream from the tide gates. Edgewood is racially mixed, and incomes are higher than the Hill. Westville is in the north of New Haven; residents are mostly White and have high incomes.

Land use adjacent to the river differs for the three neighborhoods. Land use along the river in the Hill is mostly commercial, landfill, or junkyards. Adjacent to the Edgewood neighborhood, the West River flows through Edgewood Park. Westville is bisected by the river, and some homes are located close to the river. Westville suffers major flooding about every 30 years. The most recent flood in 1982 caused substantial loss of property.

Interviews were conducted with teams of two. This was initially done for safety, but it was also found that one interviewer could ask questions while the other handled the numerous visual aids. As soon as the interview was completed, interviewers filled out a short evaluation form to record time, date, address, payment mechanism, and their impression of the interview.

Interviewers went door-to-door to survey people in their homes during four Saturday afternoons in March and April. Each interview team was assigned a block and called at every house. People who were home and willing to participate were interviewed. In order to reduce voluntary response bias, subjects were offered $5 in cash to be interviewed. A total of 51 households were surveyed.

Interviewers who were native speakers of Spanish conducted impromptu translations of the survey for Spanish-speaking respondents. This enabled a wider cross-section of the population to be interviewed.

Table 1. Number of respondents in income groups by neighborhood.

Income	Hill	Edgewood	Westville	Total	% Total
$10,000-$19,999	4	2	0	6	14
$20,000-$29,999	4	3	1	8	19
$30,000-$39,999	2	2	1	5	12
$40,000-$49,999	1	2	2	5	12
$50,000-$59,999	0	2	0	2	5
> $60,000	0	6	7	13	30
not indicated	2	0	2	4	9

RESULTS

Of the 51 surveys, 19 were conducted in the Hill, 19 in Edgewood, and 13 in Westville. Household income of respondents was diverse, with an increasing gradient from the Hill (lowest), to Edgewood and Westville (highest, Table 1). Respondents were also racially diverse – 53% were Hispanic or African American (Table 2).

We removed protest bids in order to compute willingness to pay (WTP). A protest bid was considered a bid of $0 that was due to a protest against the payment mechanism (tax or donation) or moral objection to placing a dollar value on an environmental amenity. Protest bids were identified using follow-up questions. Nine protests to the tax mechanism were identified and removed. We did not detect any moral protests.

There were three respondents who were unable to determine their WTP. These were not protest bids, but were removed in order to calculate mean WTP. Respondents who wanted to pay, but were not able to pay anything were considered to have given valid bids of $0, and were included in mean WTP.

Of the seven responses that opposed opening the tide gates (Table 3), five were protest bids. This left two responses: a $20 tax bid and a $50 donation bid. The two bids against opening the tide gates were included in mean WTP for salt-marsh restoration as negative values. Of the 39 responses that favored opening the tide gates (Table 3), 4 of the tax responses were protest bids. There were no protest bids by respondents who favored opening the gates who took the donation survey. Three others were unable to determine WTP. Thus, there were 32 responses with valid WTP bids for opening the tide gates; 17 by donation and 15 by tax.

Table 2. Race of respondents.

	Number	Percent
Hispanic	14	25
Black	13	28
White	22	43
Asian	1	2
not indicated	1	2

Table 3. Responses to the proposal to open tide gates.

For the TAX survey, with 26 people surveyed:		
	3 people were against opening the tidegates	(11%)
	22 people were for opening the tidegates	(85%)
	1 person had no opinion	(4%)
For the DONATION survey, with 25 people surveyed:		
	4 people were against opening the tidegates	(16%)
	17 people were for opening the tidegates	(68%)
	4 people had no opinion	(16%)
For the TOTAL:		
	7 people were against opening the tidegates	(14%)
	39 people were for opening the tidegates	(76%)
	5 people had no opinion	(10%)

Table 4. The contingency table for the χ^2 test for the relationship between income and WTP.

Income	WTP ≤ Med	WTP > Med	Total
Low	14	5	19
High	5	8	13
Total	19	13	32

The expected values are:

Income	WTP ≤ Med	WTP > Med
Low	11.28	7.72
High	7.72	5.28

There were many \$100 bids (and a few \$200 bids) and many bids of \$25 or less. Only one value occurred between \$25 and \$100. As a result, there is a wide difference between mean WTP (\$61.41) and the median value (\$25.00), and the standard deviation is large (\$100.22). We used chi-square (χ^2) tests of two-way contingency tables to determine if WTP was influenced by income or payment mechanism (tax vs. donation). A χ^2 test was used because the WTP values had a discrete probability distribution rather than continuous (people tended to bid \$25 or \$100, but not values in between). Tests were conducted at the 5% significance level.

WTP bids were divided into two categories: bids less than the median, and bids greater than the median. Respondents were grouped as those having household income below the median for the survey, and those above (Table 4). The null hypothesis (H_o) was that income and WTP are independent. There was one degree of freedom because we used two-by-two contingency tables. Values for χ^2 were obtained from a reference table. WTP was dependent on income ($\chi^2 = 3.97$).

Respondents' bids were also grouped by payment mechanism (Table 5). WTP bids were grouped as above. The null hypothesis (H_o) was that payment mechanism and WTP were independent. Final WTP values appeared to be independent of whether the purchase mechanism was by tax or donation ($\chi^2 = 0.43$).

Table 5. The contingency table for the χ^2 test for the relationship between payment mechanism and WTP.

Payment mechanism	WTP ≤ Med	WTP > Med	Total
Tax	8	7	15
Donation	11	6	17
Total	19	13	32

The expected values are:

Payment mechanism	WTP ≤ Med	WTP > Med
Tax	8.91	6.09
Donation	10.09	6.91

DISCUSSION

Given that our sample size was relatively small, we view this as a "pilot project" for what will ultimately be a survey of a larger number of households. Testing our survey design for a small sample allows us to determine whether or not to proceed with a larger group.

The survey's overall performance was satisfactory. People generally understood the content, purpose, and logic, and respondents tended to make WTP bids in terms of real economic decisions. One respondent mentioned goods he would sacrifice in his determination of WTP by deciding to "give up a couple of twelve-packs." Other comments included: "I know my budget for April, and this is the amount I have free." "I'm bringing up three children; this is all I can spare." "I can't pay anything because I'm not working right now."

Respondents often anticipated questions. For example, when asked, "Do you think the restoration project is a good idea?" respondents often asked how much it would cost. Respondents were also curious as to why the initial photo with *Phragmites* was unnatural, when it looked natural. They appeared satisfied to learn a few questions later how the landscape had been altered by humans. Such synchronization within the survey provides evidence that its structure was cognitively sound; it made sense; it flowed well. Nevertheless, some considerations need to be discussed.

PAYMENT MECHANISM

The χ^2 test indicated that the amount respondents were willing to pay for the restoration was independent of payment mechanism. Protest bids, however, appeared to be more prevalent among tax payment mechanism surveys (almost one-fifth of all tax surveys). One respondent who was willing to make a donation of $500-$1000 told interviewers that had the question been in the form of a tax increase, his bid would have changed to $0. The statement, "I'm sorry, but if its dealing with taxes, then I can't support it," occurred several times.

Nevertheless, the proportion of people who were willing to pay a positive amount for the restoration with taxes (73%) was similar to those willing to pay with donations (71%). Therefore, it does not appear as though the subset of people who were willing to pay for the restoration was biased by payment mechanism, and our mean WTP value was not biased in this way.

GENDER BIAS

More males (53%) than females (37%) were interviewed. (Some respondents left this portion of the follow-up written questionnaire blank, explaining the discrepancy from 100%). More males than females answered the door. Also, men tended to participate when both men and women were present in the house. But the decision whether or not to make a donation or support a new tax is often a household decision, and our data analysis focused on households. Often, surveys with individuals were quickly transformed into household discussions. For example, a couple debated how to rate the current condition of the river for wildlife habitat. In another home, a wife convinced her husband to change his preference to the salt-marsh photo because she was concerned about the least tern. These decision-making processes are common, and thus represent appropriate responses to this survey.

UNCERTAINTY

Most economic surveys, CVM and otherwise, focus on demand for goods that are certain with regard to quantity, quality, and timing of availability. For environmental goods such as wildlife, however, these are not always certain. Threat of extinction may decrease for a rare bird, but the extent of decrease may not be defined. Respondents in a contingent valuation survey must determine willingness to pay even though they may not know if the species will survive long enough for them to experience a benefit.

Whitehead (1993) studied the effects of uncertainty on existence values of marine and coastal wildlife in North Carolina. His two main findings were that (1) there is evidence that "total economic values under uncertainty are theoretically valid", and (2) omitting consideration of uncertainty from CVM studies will produce a distorted value for willingness to pay. The first conclusion lends support for the use of CVM as a tool to elicit nonuse values for wildlife; the second implies that inclusion of uncertainty is necessary for a valid CVM survey.

Uncertainty became a factor in the West River survey. For example, even if the salt marsh was restored, respondents did not know the probability of seeing a least tern during a visit to the river. Thus, there was a risk involved in making a payment for that resource. Respondents were also told that the restoration would increase risk of flooding. But interviewers, as part of the survey design, would not give specific details regarding where flooding would occur, or how much more likely it would be. Respondents thus had to weigh uncertain harms against uncertain environmental benefits.

WARM GLOW AND FAIR SHARE EFFECTS

Stevens et al. (1994) studied the change of existence values for wildlife over time and found that they were stable. The reason for this stability, they found, was not due to the respondents' economic valuation of wildlife. Instead, the WTP was for something other than the wildlife. One such value is the satisfaction of contributing to a "worthy cause." Since giving to "good causes" and charities tends to be stable for individuals and households over time, this would be reflected in the stated willingness to pay for wildlife.

Kahneman and Knetsch (1992) have termed this the "warm glow effect," in which people derive value from knowing they have contributed to a good cause. Such respondents are purchasing the price of moral satisfaction, and one cause may be just as worthy as another.

Some of the responses to the West River survey suggest that the warm glow effect might have influenced respondents. When asked to state why they were willing to pay money to restore the West River, many people gave responses such as "to help the bird" or "to improve the community". These statements could imply the subjects viewed their WTP as a "charitable" donation to a "worthy cause."

Another factor that may influence WTP for environmental amenities is the tendency to calculate WTP based on the perceived total cost of the project divided by the assumed population of people who would have to contribute. Instead of constructing an individual existence value, respondents figure what their "fair share" would be. The rationale is, if everyone had to pay, it would only cost me a minimal amount. Survey respondents calculate this in two ways: out of a sense of duty to do their fair share (Stevens et al. 1994), or from belief that a certain amount is the maximum they should have to pay (Schkade and Payne 1993) because total cost is spread out over numerous individuals.

A few respondents in our survey gave WTP responses as the maximum cost of the project divided by the population they figured would be taxed. "If everyone in New Haven and West Haven was charged for this, it couldn't be more than $10 per person," one respondent concluded. The "fair share effect" has been offered as evidence that WTP bids are invalid because they do not represent a person's true value for an environmental good. However, an alternate interpretation could be that individuals motivated by their perception of fairness would not be willing to pay more for an amenity, because they would then bear an unjust proportion of the costs.

Rather than concluding that warm glow and fair share effects render CVM unable to obtain the monetary amount of nonuse values, it should be noted that individuals create their own valuation priorities. Hanemann (1994) argues that people have a wide variety of motives that help them determine their values for both market and nonmarket goods. Why a person would be willing to pay a certain price to restore the West River is perhaps less important than the fact that they would be willing to pay. Such values still would indicate a level of support for the restoration, and could be incorporated into a cost-benefit analysis.

COSTS AND BENEFITS

Respondents placed an economic value on the nonmarket environmental benefits of the West River salt-marsh restoration. Mean WTP could be aggregated over the population of households that would benefit from the restoration to approximate the value of the restoration. How would that value compare to the costs of the restoration? The major potential costs of the project would be associated with mitigating potential flooding. Fortunately, no residential areas are likely to be affected by the minimal water elevation increase needed to eradicate the *Phragmites* (Barten and Kenny, this volume). Most land use adjacent to the restoration zone is nonresidential (Page, this volume), and the few residential areas are much higher than the marsh. Of greater concern would be potential impacts to recreation facilities in the immediate flood plain, such as playgrounds, sport fields, and the Connecticut Tennis Center.

One option to eliminate potential damage to recreational areas as a result of opening tide gates at Route 1 would be to install an additional tidal control structure at Route 34. Thus, salt marsh could be established between Route 1 and Route 34, while recreational facilities north of Route 34 would be protected. Another option would be to build dikes around areas of concern. (Dikes for a similar project in Fairfield Connecticut cost $250,000, Steinke 1986.) Finally, self regulating tide gates that allow tidal flushing – but close during very high tides – could be installed to replace the existing tide gates at Route 1 (Barten and Kenny, this volume). Self regulating tide gates cost around $30,000 (Steinke 1986).

Other costs associated with the project would include a design study and, possibly, removal of earth to lower the marsh surface so that restoration could occur with less increase in water elevation. These tasks would be performed under the Connecticut Department of Environmental Protection's (CT DEP) Wetland Restoration Program.

CONCLUSION

The contingent valuation survey performed well and was effective in obtaining willingness to pay (WTP) and thus *value* estimates. There was strong public support for the restoration project: over three-quarters of people interviewed supported the proposed opening of the tide gates. These results suggest a large nonmarket value associated with restoration benefits.

Yet this nonmarket value would be excluded from consideration in traditional economic decision-making, because there is no associated price. Without a means to estimate their value, significant amenities would be excluded from policy decisions. Contingent valuation is an effective method for obtaining price estimates for nonmarket values, thus balancing the decision-making process. Consequently, contingent valuation has a crucial role to play in preserving and restoring environmental resources.

The end of the road with regard to the West River restoration has not yet been reached. Further public discussion and debate lie ahead, and there are opportunities for further research. This study, which comprised a small-scale contingent valuation survey, could be expanded in scope to increase its accuracy. This type of survey should also be periodically repeated over the long term, so that nonmarket environmental values are updated. In the case of the West River, it would be useful to determine if economic values of nonmarket benefits that accrue from restoration change as the restoration proceeds.

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APPENDIX. WEST RIVER SURVEY - TAX PAYMENT VEHICLE[1]

This is a survey that will be asking for your opinions and ideas about the West River, in New Haven, Connecticut. I appreciate your taking the time to assist me and help complete it.

1. Do you ever visit the West River or walk along roads that cross it?

   Yes (*go to question 2*)　　No (*go to question 6*)

2. Where along the river do you go to when you visit it? If you walk along roads that cross it, which roads do you see the river from?

3. What do you do when you visit the West River?

4. Where along the river do you do these things, and how often?

5. Do you ever see birds or other wildlife when you are at the West River?

   Yes　　No

   (*After completing question 5, please skip to question 7)*

6. Why don't you visit the West River?

7. On a scale of one to ten, how clean do you think the water in the West River is? A one means you think the water is so dirty you wouldn't even feel safe boating in it. A three means you think it is clean enough to boat on it. A five means you would feel safe eating a fish caught in the West River. A seven means you would feel the water in the river is clean enough to swim in. A ten means you think the water is clean enough to drink straight out of the river.

   Nothing　Boat　Fish　Swim　Drink

   1　2　3　4　5　6　7　8　9　10　don't know

8. On a scale of one to ten, how good do you think the West River is as a recreational site? A one means you think it has no value at all for recreation. A ten means you feel it is the best recreational site in Connecticut.

   1　2　3　4　5　6　7　8　9　10　don't know

9. On a scale of one to ten, how good do you think the West River is as a place for wildlife and birds to live? A one means you think no birds or animals can live there. A ten means you think the West River is better than any other place in Connecticut for birds and animals.

   1　2　3　4　5　6　7　8　9　10　don't know

[1] Only the survey format that used a one time tax as the willingness to pay vehicle is included here. The donation vehicle survey differed only in the wording of questions 17, 18, 20, 21, 22, and 24, in which language regarding a one-time donation was substituted for the one-time tax. Also, the sentence that stated, "Everyone would pay their fair share, and the tax would be no greater than the costs of the project." was not included in questions 17 and 21 of the donation survey.

Here are pictures of the lower stretches of two Connecticut rivers.

(*Show Picture A, which shows a river with a* Phragmites *monoculture*)

(*Show Picture B, which shows a* Spartina *salt marsh*)

Most rivers in coastal Connecticut resemble either Picture A or Picture B.

10. Based on what you see in the pictures, do you prefer a river that looks like the one shown in Picture A or Picture B?

Picture A Picture B no preference

The two rivers in the picture provide different types of habitat for wildlife and birds. Here is a photo of a bird called the least tern. It is an endangered bird species.

(*Show photo of least tern*)

11. Have you ever seen a least tern before?

Yes No

If yes, where and when?

The least tern can make its home in River B, but not in River A.

12. Now that you know that River B supports the least tern, which river do you now prefer?

River A River B no preference

River B can sometimes cause flooding problems for houses and buildings that are located along the river.

River A does not cause flooding problems.

13. Now that you know that River B can cause flooding problems and River A does not, which river do you prefer?

River A River B no preference

Historically, the lower part of most rivers in Coastal Connecticut looked like Picture B. In other words, Picture B shows the natural state of these rivers. People have altered the natural state of these rivers in several ways. As a result of these human actions, many rivers in Connecticut now look like the river shown in Picture A.

14. Now that you know that River A has been altered by humans and River B is in its natural state, which river do you prefer?

River A River B no preference

Here is some more information about River A and River B. (*Hand list to interviewee.*) Each of the rivers has both advantages and disadvantages, which are listed on your sheet. (*Read list out loud.*)

River A	River B
Is protected from flooding.	Can cause flooding to adjacent properties.
Has playgrounds and soccer fields by it.	Is a productive and diverse salt marsh.
Has been altered by humans.	Is in its natural historic state.
An aggressive grass called *Phragmites* has taken over the river. It grows 12-15 feet high and crowds out other plants and animals.	Is not dominated by Phragmites.
The *Phragmites* breeds more insects, like ticks and mosquitoes.	Provides habitat for many types of animals and birds, including endangered species like the least tern.
The *Phragmites* burns frequently in the summer in intense fires.	Has very little fire danger.

15. Now that you know these things about the two rivers, which river do you prefer?

River A River B no preference

This next question will be about the West River. Historically, the lower part of the West River looked like the river in Picture B. Here is a map of the area that used to look like Picture B.

(S*how map of historic salt marsh.*)

In 1919, tide gates were installed at the point where Route 1 crosses the West River

(*Point to this on the map.*)

These tide gates changed the West River and caused it to look like Picture A.

Suppose there was a proposal to restore the West River to its historic condition so that it would look like the river in Picture B. The restoration would affect about 70 acres along the lower part of the river.

(*Show map again.*)

The restoration would restore the river to its natural, historic state, and it would also provide habitat for the least tern, an endangered bird species. This restoration would be done by opening the tide gates. When this was tried in other rivers along the Connecticut coast, the rivers were successfully restored to where they looked like Picture B.

16. Do you think this project is a good idea?

Yes No no opinion

Why or why not?

(*Note, if they answered Yes to question 16, go to question 17. If they answered No to question 16, go to question 21. If they answered no preference, go to question 25.*)

17. You had answered that you think this restoration project is a good idea. Suppose that in order to pay for this project, there would be a one-time tax next year. Everyone would pay their fair share, and the tax would be no greater than the costs of the project. However, I am interested in finding out how much restoring the West River to its natural state is worth to you. Would you be willing to pay additional taxes next year to restore the West River? Keep in mind that any money you pay in additional taxes will not be available for you to spend on other things. Also keep in mind that this tax would occur only once, during next year.

    Would you be willing to pay additional taxes to restore the West River?

    Yes (*go to question 18*) No (*go to question 20*)

18. What is the maximum amount that you would be willing to pay in additional taxes?

19. Why did you choose this amount?

    (*After completing question 19, go on to question 25.*)

20. Why did you say you would not be willing to pay additional taxes to restore the West River?

    (*After completing question 20, go on to question 25.*)

21. You had answered that you do not think the restoration project is a good idea. Suppose that the only way to avoid doing the restoration project was to do additional construction and repair of the tide gates where the West River crosses Route 1.

    In order to pay for this repair, there would be a one-time tax next year. Everyone would pay their fair share, and the tax would be no greater than the costs of the project. However, I am interested in finding out how much keeping the West River in its current condition is worth to you. Would you be willing to pay additional taxes next year to repair the tide gates? Keep in mind that any money you pay in additional taxes will not be available for you to spend on other things. Also keep in mind that this tax would occur only once, during next year.

    Would you be willing to pay additional taxes to repair the tide gates?

    Yes (go *to question 22*) No (*go to question 24*)

22. What is the maximum amount that you would be willing to pay in additional taxes?

23. Why did you choose this amount?

    (*After completing question 23, please go to question 25.*)

24. Why did you say you would not be willing to pay additional taxes to restore the West River?

25. *At this point, reconfirm that the respondent either*

    1) expressed support for the restoration project.

    2) expressed opposition to the restoration project.

    3) were indifferent about the restoration project.

    If they have changed their minds, ask why, and note response.

Also reconfirm their willingness to pay, either 0, or if greater than 0, the amount they stated. Again, allow changes if they change their mind.

26. You are almost at the end of the survey. Please tell me in your own words why you think we are doing this survey.

27. Is there anything else you would like to say about the West River?

The last few questions are for demographic purposes. The answers are private and confidential. I am now giving you this page to fill out yourself. When you are done, please fold it and I will seal it. (*Hand the next page to them.*)

28. Age (please circle one)

A Under 20

B 20-29

C 30-39

D 40-49

E 50-59

F 60-69

G Over 70

29. Gender

M F

30. Household income (please circle one)

A Under $10,000

B $10,000-$19,999

C $20,000-$29,999

D $30,000-$39,999

E $40,000-$49,999

F $50,000-$59,999

G $60,000 and over

31. Number of years of education (please circle one)

A Less than 12 years

B Completed high school

C Attended college

D Completed college

E Attended graduate school

F Completed graduate school

32. How would you describe your ethnicity?

A Hispanic

B Black and Hispanic

C Black, non-Hispanic

D White and Hispanic

E White, non-Hispanic

F Asian

G Native American/American Indian/ First Nations

H Other (please specify)

Now, please fold this paper and the interviewer will seal it.

Those are all the questions. Thank you very much for your time in completing this survey!

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Values, Perceptions, and Restoration Goals

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ABSTRACT
Salt marsh restoration goals should reflect perceptions and values of residents, especially in areas having high population density. Households along the length of the West River in New Haven and West Haven, Connecticut were surveyed to determine how residents perceived and valued the river. Findings indicated that residents' perceptions were visually oriented. Pollution was the greatest concern of respondents – especially visual pollutants such as trash. The area near the river was perceived as somewhat dangerous due to crime. Highest value was placed on the river for aesthetics, quality of habitat for wildlife, and ability to relax and see wildlife. Residents valued passive activities such as walking, relaxing, and enjoying views. They tended to place lower values on active uses like fishing and boating.

Anglers were also surveyed to develop a user profile for fishing – the dominant use within West River Memorial Park. Most anglers were African American or Hispanic and often fished in family groups. They traveled to the river by car, and indicated little preference for species, or for saltwater or freshwater fish.

Cleaning up garbage and reducing common reed (*Phragmites australis*) by restoring the salt marsh would serve local values, would enhance public perception of the river, and might increase park use. Pollution remediation benefits of a salt marsh system would probably not be recognized by residents without an accompanying education program, because improvements in water quality would not be visual. Salt marsh restoration in the park would benefit anglers by improving fish habitat. Periodic sampling of perceptions and behavior could be used to evaluate restoration success from the perspective of local residents.

The West River meanders through the cities of New Haven and West Haven, Connecticut, and is the primary feature of West River Memorial Park, located 2.4 km (1.5 miles) upstream from Long Island Sound. Installing tide gates on the river in 1919 and dumping dredged material on marsh surface during the 1930s converted West River Memorial Park from a salt marsh to a brackish marsh dominated by common reed (*Phragmites australis*)(Orson et al. pp. 136-150, this volume). Common reed is a native species normally confined to the upland edges of salt marshes in New England, but often forms large, dense stands when tidal flow is restricted (Niering and Warren 1977, Roman et al. 1984). The height and density of reed stems can form physical and visual barriers. Unaltered salt marshes generally include a mix of saltwater cord grass (*Spartina alterniflora*), salt-meadow cord grass (*Spartina patens*), spike grass (*Distichlis spicata*), and black grass (*Juncus gerardii*). These grasses are shorter and form open landscapes.

The Connecticut Department of Environmental Protection (CT DEP), neighborhood residents, and researchers from Yale University are interested in restoring the salt marsh in West River Memorial Park by restoring tidal inundation (CT DEP 1994, Kenny 1995). The tall, impenetrable common reed would be replaced by short, salt marsh grasses creating a landscape with greater visibility and accessibility. Enhanced visibility would increase wildlife viewing opportunities and discourage perceptions of danger. Neighborhood leaders consider common reed eradication important for neighborhood revitalization[1]. Human preferences for high-visibility, short-grass (savanna) landscapes are well documented and may result from human evolution (Ulrich 1993). Restoration would also increase the density of charismatic wildlife such as wading birds (Lewis and Casagrande, this volume). Local ecologists are also interested in using the restoration as an experiment to learn more about salt marsh ecology. Ideally, the restoration would provide opportunities to restore biological diversity, improve environmental health and quality of life, and increase natural beauty, while improving our scientific understanding of salt marsh ecology.

Typical restoration goals are pollution remediation, improving habitat for specific species, aesthetic improvements, and increasing productivity of estuarine fisheries. Although these goals are not mutually exclusive, final restoration design must favor some goals over others. For example, pollution remediation and mosquito control are best achieved with a low marsh that is frequently inundated by tides. However, a less frequently flooded high marsh would provide better habitat for salt marsh sparrow species of concern. A further complication is the broader goal of the New Haven Department of Parks Recreation and Trees to increase park use.

Development of public policy (e.g., establishing restoration goals) requires an understanding of human values and perceptions in order to insure that policies are effective and justified (Lasswell 1971, Kellert and Clark 1991). But the need to understand values associated with natural resources is often overlooked during the process of policy development (Kellert and Clark 1991). Understanding values is particularly important for restoration projects in urban areas where many people will be affected. The opinions of the people who live near the park should play a critical role in setting restoration goals if the project is to succeed. It is, therefore, necessary to gather information about how the residential communities along the West River value the river, or how they perceive its condition.

*Tall, dense stands of common reed (*Phragmites australis*) in disturbed salt marshes can form physical and visual barriers.*

[1] At the annual meeting of the West River Neighborhood Association, Oct. 15,1996, the Association's president, Jerry Poole, stated that a primary goal of neighborhood revitalization would be to "see the river" as a result of *Phragmites* eradication.

The specific goals of this study were to (1) establish what values and perceptions are assigned to the river by the people, and (2) determine what types of improvements in West River Memorial Park would best fulfill the values of the residents and increase park use. Values and perceptions were determined by conducting door-to-door surveys of households (Appendix 1). A profile of recreational fishing was developed by conducting surveys of anglers (Appendix 2).

SURVEY METHODS

HOUSEHOLD SURVEY

Sixty-seven door-to-door surveys of households located within 160 m (0.10 miles) of the river were conducted. Six neighborhoods that border the river were selected to represent a range of socio-economic characteristics (Table 1). Surveys were conducted on Saturdays between 11:00 A.M. and 4:00 P.M. in October and November, 1995.

Table 1. Social and economic characteristics of the six neighborhoods sampled during the household survey (source: 1990 Census). All neighborhoods are adjacent to the West River in New Haven and West Haven, Connecticut.

Neighborhood	% Hispanic or African American	Per-capita Income	% Housing Owner Occupied	Number Households Sampled
Allingtown	16	$15,810	56	15
West River/Boulevard	63	$9,606	22	17
Westville/Edgewood	41	$16,302	20	9
Hill	81	$7,775	34	8
Westville Center	44	$8,197	18	9
West Hills	51	$14,575	50	9
Average (Total)	49	$12,044	33	(67)

Surveys required approximately six minutes to administer. Respondents were asked both closed and open-ended questions regarding their perceptions of crime, pollution, human impacts, and the general condition of the river (Appendix 1). They were also asked to rank a series of hypothetical general improvements and specific recreational improvements (Tables 2 and 3). Finally, they were asked to identify activities that household members had undertaken in or near the river during the past year (Table 2). The survey was designed to avoid bias toward positive nature values by beginning with questions about crime and pollution and "burying" nature-related questions among questions regarding recreation.

Responses to the improvement categories were ranked by assigning a value of two to the response "very important," a value of one to "somewhat important," and zero to "not important." These values were summed for the category, and the sum was divided by the number of responses to obtain a score. The categories were ranked according to scores. Significant differences among improvement and use categories were determined using single-factor analysis of variance (*F*, Zar 1974). Significant differences between other variables were tested using a *t*-test assuming equal variances (*t*, Zar 1974), and correlation between variables was determined using regression analysis (*r*, Zar 1974).

Gender and race of survey respondents were compared to census tract data from the 1990 census (U. S. Department of Commerce) to determine if residents were equally represented in the survey. Correlation of respondents' recreational preferences with household use (Table 2) was tested using Spearman ranked correlation (r_s, Zar 1974) to determine the validity of stated preferences.

ANGLER PROFILE

Brief surveys of anglers (Appendix 2) were conducted to determine preferences for species of fish, fish consumption, angler group composition, and methods of travel to fishing sites. The surveys were conducted by visiting all known fishing spots in West River Memorial Park, and along the river south to New Haven Harbor, on Saturdays in early October. Interviewers questioned a representative of every group of anglers encountered. The fishing survey was also administered to household survey respondents who indicated that they fished in the West River.

Table 2. Household survey respondents' scores and ranks for recreational improvements, and numbers and ranks of use by households.

	Desired improvements		Household use	
Activity	**Score**	**Rank**	**Number**	**Rank**
Escape and relax	1.50	1	39	1
Walking and jogging	1.44	2	36	3
Enjoy views	1.43	3	38	2
Watching wildlife	1.33	4	34	4
Picnicking	1.05	5	9	6
Fishing	1.02	6	14	5
Boating and canoeing	0.93	7	4	7
Swimming	0.61	8	2	8

RESULTS AND DISCUSSION

The gender distribution of household survey respondents (53% male, 47% female) approximates that of the city (47% male, 53% female), although minorities may be underrepresented in the survey (32% interviewed vs. 49% living in the six census tracts surveyed). This bias probably results from the variation of racial concentrations within census tracts. For example, Whites may tend to live closer to the river. It also may result from the small sample size (67 households). The survey is generally representative of the population, but socio-economic and race-specific results should be viewed with caution.

The respondents' ranked priorities for desired recreational improvements were significantly correlated with their reported use of the river and shoreline ($r_s = 0.95$, $P < 0.002$; Table 2). This suggests that they were sincere in their response to the question about desired improvements, and that bias in survey responses was low.

Most respondents wanted improvements to the river and its shoreline. They placed highest priority on cleaning up pollution and garbage.

Table 3. Household-survey respondents' scores and ranks for desired general improvements to the West River.

Improvement	Score	Rank
Clean up pollution and garbage	1.86	1
Reduce crime	1.77	2
Improve environment for plants and animals	1.71	3
Improve recreation opportunities	1.30	4
Improve personal access to the river	0.90	5

VALUES AND PERCEPTIONS

Most respondents (78%) wanted improvements to the river and its shoreline. There were significant differences ($F = 25.0$, $P < 0.001$) in priorities for improvements (Table 3). Respondents placed highest priority on cleaning up pollution and garbage, and second highest on reducing crime near the river. They placed third highest priority on improving the environment for plants and animals and fourth highest on improving recreation. Scores for improving the environment for plants and animals were significantly higher than scores for improving recreation opportunities ($t = 3.33$, $P = 0.001$). Respondents placed the lowest priority on improving personal access to the river.

Table 4. Perceptions of pollution, crime, and natural condition of the West River.

Perception	% Yes	% No	Rank
The river is polluted	75	25	1
The river has been altered by humans	74	26	2
The river area is dangerous due to crime	48	52	3

Differences in respondents' priorities for recreation improvement categories (Table 2) were also significant ($F = 9.90$, $P < 0.001$). Respondents placed the highest priorities on passive recreation, such as the ability to escape from the city and relax, walking and jogging, enjoying nice views, and watching wildlife. Lower priority was placed on active recreation like fishing and boating. These results indicate the importance of passive recreation, perceived security, and aesthetics.

Household survey respondents placed higher priority on improving the environment for plants and animals than they did on improving their own access to the river.

Most respondents (75%) answered "yes" when asked if they thought the West River was polluted (Table 4). Udziela and Bennett (this volume) also found that residents perceived the river as polluted. The most common type of pollution cited by respondents in this survey was dumped garbage (70%, Table 5). The emphasis on garbage suggests a visual orientation to the perception of pollution in the river. There was a significant correlation ($r = 0.28$, $n = 56$, $P = 0.05$) between those respondents who rated improving views as important and cleaning up pollution as important. Those respondents who were not interested in nice views were less likely to want pollution cleaned up.

Other types of pollution that were commonly cited (Table 5) also tended to be visually oriented. The most important pollution problems in the West River are nonpoint sources (i.e., surface run-off), combined sewage overflows, and past deposition of heavy metals from manufacturing (Benoit 1995; T. Rozan and J. Albert, Yale F&ES, personal communications). These forms of pollution were poorly represented in survey responses. This suggests that residents are not well informed about pollution mechanisms.

Table 5. Types of pollution associated with the West River by household-survey respondents.

Type of pollution	Number respondents
Trash and garbage	26
Sewage	3
Landfill and junkyard	3
Oil	2
Factories	1
Mud and siltation	1
Run-off	1

It is widely believed that crime is the largest deterrent to park use in New Haven (New Haven Department of Parks, Recreation, and Trees 1981). Results of this survey, however, indicate other phenomena that are influencing behavior. Only 48% of respondents thought that the area near the river was dangerous because of criminals. Respondents who placed a high priority on reducing crime were not correlated with those who said the river area is dangerous because of criminals ($r = 0.20$, $n = 57$, $P = 0.27$). Although crime is generally perceived as a problem, it is not necessarily associated with the West River and its shoreline.

Respondents generally perceive the river as being altered by humans and therefore unnatural. Seventy-four percent indicated that humans have changed the kinds of plants and animals that can live in or near the river. This finding may be related to the tendency for respondents (70%) to cite garbage dumping as the most significant pollution problem. Also, 53% of respondents indicated that development close to the river has somehow damaged the river. Unnatural landscapes can significantly degrade recreational experiences (Robertson and Burdge 1993). Recreational improvements without beautification can be insufficient to increase user satisfaction (Kaplan 1983). Udziela and Bennett (this volume) also found that residents near the West River highly value landscapes free of human intervention. The perceived unnaturalness of the river may partially explain low use of public areas adjacent to the river for passive recreation, such as relaxing, walking, and enjoying views (Page, this volume).

The perceived unnaturalness of the river may partially explain low use of public areas adjacent to the river for passive recreation, such as relaxing, walking, and enjoying views.

Clearly, there are barriers to the use of West River Memorial Park (Page, this volume). However, personal decisions to use the park are complex and are continually re-evaluated (Casagrande 1996). Barriers such as busy streets and cultural perceptions are somewhat fixed, but improvements in personal perceptions can increase park use (Casagrande 1996). This study indicates that improving natural aesthetics and wildlife habitat by cleaning up garbage and reducing common reed (*Phragmites australis*) might increase use of West River Memorial Park.

THE WEST RIVER ANGLER

Although fishing is a low priority for residents near the river, there are many people who drive to the river from the greater New Haven area to fish. Surveyors encountered and interviewed 78 people fishing in 33 groups. Most groups (78%) traveled to fishing sites by car, 19% arrived by foot, and 3% rode bicycles. Successful development of fishing areas will require safe parking.

Table 6. Saltwater and freshwater fishing preferences of West River anglers by race.

	Number of Respondents				Percent
	Black	Hispanic	White	Total	Total
No preference	9	8	3	20	54
Saltwater	4	3	4	11	30
Freshwater	3	1	2	6	16
Total	16	12	9	37	100

Most anglers (54%) indicated no preference for either saltwater or freshwater habitats (Table 6). African Americans and Hispanics expressed the least tendency to prefer particular habitats. When respondents did express a preference, it was usually for saltwater. This could result from the higher quality of saltwater fishing (i.e., for striped bass and bluefish) in the lower West River. Freshwater sections of the West River in New Haven provide poor habitat for popular freshwater species such as trout or freshwater bass (Moore, this volume).

Table 7. Fish species preferences of West River anglers by race.

	Black		Hispanic		White			
Species	No.	Rank	No.	Rank	No.	Rank	Total	Rank
Bluefish	8	2	7	1	4	1	19	1
White perch	9	1	3	3	1	4	13	2
No preference	4	3	4	2	1	4	9	3
Striped bass	1	5	1	5	3	2	5	4
Eel	2	4	1	5	0	0	3	5
Bass (freshwater)	1	5	0	0	1	4	2	6
Blue crab	0	0	1	5	1	4	2	6
Catfish	1	5	0	0	1	4	2	6
Porgy	0	0	2	4	0	0	2	6
Sunny (bluegill)	1	5	1	5	0	0	2	6
Trout	0	0	0	0	2	3	2	6
Flounder	0	0	0	0	1	4	1	7
Carp	1	5	0	0	0	0	1	7

The requirement of a license for freshwater fishing may influence fishing behavior. Some respondents indicated that they did not fish in freshwater because they could not afford a license. None of the anglers observed fishing in freshwater (north of Route 1) displayed licenses. Those who do purchase freshwater licenses may be more likely to seek the benefit of higher quality fishing areas to offset the cost of a license.

The most popular fish species were bluefish and white perch (Table 7), although many anglers indicated they fished for "anything." It should be noted that this survey was conducted during October. Responses are likely to be biased toward fall species such as bluefish and striped bass, and against spring and summer species such as flounder, trout, and blue crab.

Most angler groups (78%) consisted of African Americans or Hispanics (Table 8). The 1990 Census indicates that the population of the census tracts bordering the river is 49% African American or Hispanic, and the total population for New Haven is 46% African American or Hispanic. This indicates a disproportionate representation of minority anglers along the lower West River. In fact, no White anglers were encountered north of the tide gates at Route 1, despite the high percentage of White residents (84%) in the adjacent neighborhood of Allingtown. Since the household survey indicated that African Americans and Hispanics were no more likely to fish than Whites, the high proportion of minority anglers in West River probably results from decisions by White anglers to fish elsewhere.

In general, anglers showed little preference for particular species, or for either freshwater or saltwater fish.

Table 8. Group composition of West River anglers by race.

	Black		Hispanic		White	
Group Description	**No.**	**%**	**No.**	**%**	**No.**	**%**
Adult men alone	7	44	1	10	3	43
Two or more men	1	6	4	40	4	57
Adult women alone	2	13	1	10	0	0
Two or more women	0	0	0	0	0	0
Adult men and women	1	6	0	0	0	0
Adult(s) with child(ren)	5	31	4	40	0	0
Total	16		10		7	

White anglers were more likely than minority anglers to prefer trout fishing, and African Americans showed little preference for salt or freshwater habitat or species (Tables 6 and 7). However, African Americans were most likely to prefer white perch (a freshwater-brackish species). The predominant use of cars to access fishing spots indicates that anglers are free to choose among fishing sites within a large geographic area. Therefore, the lower West River probably satisfies the cultural preferences of African American and Hispanic anglers, but not the preferences of White anglers.

Another possible explanation for high use of the West River by minorities is that individuals tend to seek outdoor recreation areas occupied by others they perceive as similar to themselves (Lee 1973). As a result, recreation sites tend to assume distinct, ethnic compositions (Carr and Williams 1993). Minorities may not feel comfortable fishing in suburban and rural communities outside of New Haven.

Most West River anglers are members of minority groups, who are more likely than White anglers to fish in family groups.

There were distinct, ethnic patterns in angler group composition (Table 8). White anglers were most likely to be in groups of adult males; African Americans and Hispanics were more likely to be in groups of adults with children. No children were encountered without parents. Women were rarely alone or in groups without men. These results are consistent with other studies (Carr and Williams 1993, Floyd and Gramann 1993).

Most respondents (62%) indicated that they eat the fish they catch. Only two respondents voluntarily mentioned the possibility of fish being contaminated by pollutants, and they both indicated that they consume the fish they catch.

In summary, African American and Hispanic anglers are the dominant user groups in the lower West River and are less likely to show a preference for species or habitat. Therefore, it is African American and Hispanic anglers who will benefit mostly from fish habitat restoration or improvements to fishing sites.

Since most West River anglers do not prefer freshwater fishing, restoration of tidal flow and salinity in West River Memorial Park would not reduce fishing opportunities. Successful salt marsh restoration would increase densities of blue crabs and allow saltwater sport species farther upstream into the park where public access is assured. In its current condition, the park does not provide good habitat for either the fresh or saltwater species targeted by most anglers (Moore, this volume).

CONCLUSION

Respondents' values and perceptions of the river are highly influenced by what they see. They generally perceive the river to be polluted by garbage, altered by development, and somewhat dangerous due to crime. However, they value the river for its wildlife and potential natural beauty and want to see it improved. Residents are more interested in passive activities such as relaxing, walking, and seeing wildlife. They are less interested in active interaction with the river through fishing, boating, or swimming. Improving aesthetics and wildlife habitat by cleaning up garbage and reducing common reed (*Phragmites australis*) would serve local values, enhance public perception of the river, and would encourage park use if combined with other park improvements (Page, this volume).

The results of this survey clearly indicate the importance that local residents place on aesthetics, naturalness, and wild plants and animals. Restoration goals should place a high priority on reducing common reed to increase visibility, including the opportunity to see charismatic wildlife. Although pollution remediation is desired by residents, it would not be recognized by local residents without an accompanying education program, because improvements in water quality would not be visual. Restoration should also include efforts to clean up garbage in the river.

The results of this survey clearly indicate the importance that local residents place on aesthetics, naturalness, and wild plants and animals. Restoration goals should place a high priority on reducing common reed to increase visibility, including the opportunity to see charismatic wildlife.

Success of restoration should be measured by periodically sampling perceptions and behavior. Perceptions would be expected to become negative during preliminary restoration, because of excavation and initial sedimentation. As the marsh assumes a more natural state, perceptions of the river should improve.

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APPENDIX 1. WEST RIVER HOUSEHOLD SURVEY

Date: Time: Surveyor: Address:

Hello my name is ____ and I am a student at Yale. We are conducting a survey of people's attitudes toward the West River. Can you take 5 minutes to answer some questions?

(*If the river is not in view*) The area I'm going to ask about is the river right over there and the shoreline. Are you familiar with this area? (*if no, explain it or stop the survey*)

1. Do you think the area is dangerous because of criminals? (Y / N)

2. Do you think the river is polluted? (Y / N) If yes:
   a. What kind of pollution is in the river? (any other type of pollution?)
   b. Do you think the pollution is harmful to you? (Y / N)
   c. Do you think it can it be cleaned up? (Y / N)

3. Do you think that humans have changed what kinds of plants and animals can live in or near the river? (Y / N)

4. Do you think that building parking lots, houses or buildings close to the river has damaged it? (Y / N)

5. Do you think there is anything else wrong with the river besides what we have talked about? (Y / N)

   If yes, what?

6. Do you think something should be done to improve the condition of the river and its shoreline? (Y / N)

7. The city or state may make improvements to the river and the shoreline. I'm going to read you a list of possible improvements. Please tell me if you think each possible improvement is very important, somewhat important, not important, or you have no opinion.

A. Is improving recreation opportunities. . .	very	somewhat	not	n.o.
B. Is cleaning up the pollution and garbage. . .	very	somewhat	not	n.o.
C. Is improving the environment for plants and animals. . .	very	somewhat	not	n.o.
D. Is improving your access to the river. . .	very	somewhat	not	n.o.
E. Is reducing crime near the river. . .	very	somewhat	not	n.o.

8. I'm going to read you a list of recreation activities that may be improved. Please tell me how important you think each activity is to you or other members of this household.

A. Is improving the opportunity for fishing or crabbing in the river. . .	very	somewhat	not	n.o.
B. Is improving the opportunity for swimming in the river. . .	very	somewhat	not	n.o.
C. Is improving the opportunity for picnicking near the river. . .	very	somewhat	not	n.o.
D. Is improving the opportunity for watching wildlife. . .	very	somewhat	not	n.o.
E. Is improving the ability to enjoy nice views along the river. . .	very	somewhat	not	n.o.
F. Is improving the ability to escape from the pressure of city life. . .	very	somewhat	not	n.o.
G. Is creating the opportunity for canoeing or boating on the river. . .	very	somewhat	not	n.o.
H. Is improving the opportunity for walking or jogging in the area. . .	very	somewhat	not	n.o.

APPENDIX 1 (CONTINUED)

9. Please tell me if you or anyone else in this household has used the river or the area near the river for any of the following activities so far this year?

   Has anyone used the river for:

   fishing ***If yes, follow up with angler survey*
   hunting
   swimming
   picnicking
   watching wildlife
   enjoying the view
   just relaxing
   walking/running
   boating or canoeing

Thank you!

POST-INTERVIEW NOTES
Interviewee gender: M F
Race: White Black Hispanic Asian
Age group: youth middle-age elderly
Interest level: high medium not too interested
Other comments/observations:

APPENDIX 2. WEST RIVER ANGLER SURVEY

Date: Time: Surveyor: Location of interview:

1. When you fish in this river, what do you try to catch? (anything else?)
2. Do you eat what you catch? yes no

   comments:
3. How many years have you been fishing in this river?
4. How often do you fish in this river? (e.g., times per year)
5. Did you get here by car, bicycle, or on foot?
6. Do you live in New Haven?
7. In general, when you fish do you prefer to fish for freshwater or saltwater fish?

   fresh salt no preference

Thank you!

POST-INTERVIEW NOTES
Interviewee gender: M F
Race: White Black Hispanic Asian
Age group: youth middle-age elderly
Description of group (e.g., alone, family, how many children, etc.):

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Predicting the Social Impacts of Restoration in an Urban Park

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ABSTRACT
Analysis of potential impacts of a proposed salt marsh restoration in West River Memorial Park (New Haven, Connecticut) on surrounding human communities was conducted using resident surveys and behavioral sampling along the West River, a literature survey of recreational trends and behavior, and a geographic information system (GIS) of biophysical and demographic features. Current and potential use and perceptions of West River Memorial Park are influenced by physical and social barriers to access, but the demographics of human communities around the park are not the central factor barring use. Rather, physical barriers and the arrangement of residential and nonresidential space, roads with busy traffic, and municipal boundaries are among the main reasons for the park's current state. Large, strip-like areas such as West River Memorial Park that are distant from downtown and blocked by busy roads are easily abandoned. Current barriers to use will not vanish by restoring the salt marsh alone. However, well-planned attempts to ameliorate the effects of barriers, as part of the restoration can act as a catalyst for generating greater local and regional use of the area. The diversity of communities within a relatively small geographical area and the regional, multi-use potential of West River Memorial Park suggest that the area could attract a varied collection of users to sustain and enliven the park and the surrounding landscape. If the initial investment of resources and time is to generate sustainable use of the area, careful attention and effort must be invested in removing barriers to access.

West River Memorial Park, a 200-acre public open space in New Haven, Connecticut, boasts a rich historical past and stunning natural beauty within its boundaries. The park holds tremendous potential to become the kind of place that landscape architect Frederick Law Olmsted believed all urban parks should be (and what his son intended when he recommended the park's creation) – a place of recreation and public enjoyment for a diverse and democratic body of people. Instead, it is an underutilized resource, plagued by physical, social, and political barriers. It is invisible to the vast majority of people living and traveling around its borders; its existence and location are a mystery to many. Incidents of murder associated with the park hang heavy in the public imagination and create an image of a sinister and crime-ridden place. Instead of being a resource and benefit to all, the park attracts only a few loyal users. For the rest, the area is a black hole sitting squarely along the border between West Haven and New Haven (Fig. 1).

Many urban parks suffer from problems similar to those of West River Memorial Park, even though the need for accessible, safe parks and usable, clean rivers is growing. Increasingly, people in the United States are recreating closer to home; within the boundaries of their cities and along coastlines. A Connecticut Department of Environmental Protection (CT DEP) report indicates that Connecticut residents travel no more than 12-15 minutes to recreate (1993). Between 1978 and 1985, while visitation to rural National Park Service units increased by only two percent, visitation rates in urban areas doubled (Hornback 1989). Seventy-one percent of all people surveyed nationally rated neighborhood parks and recreation areas (those within a 15 minute walk of home) either 'very' or 'somewhat' important. Types of activities that tended to have the highest national estimates of activity-days per participant over the course of a year were those easily done near the home: bird-watching, team sports, and biking (Van Horne 1996). Forty-seven percent of people surveyed in another study of fishing, hunting, and wildlife recreation reported engaging in nonconsumptive wildlife-related activities within one mile of their home, compared with 17% who engaged in such activities further from home (U.S. Department of the Interior 1982). These figures indicate a strong national demand for experiencing the natural world close to home.

"Conventionally, neighborhood parks or park-like open spaces are considered boons conferred on the deprived populations of cities. Let us turn this thought around, and consider city parks deprived places that need the boon of life and appreciation conferred upon them. *This is more nearly in accord with reality, for people do confer use on parks and make them successes – or else withhold use and doom parks to rejection or failure."*

– *from* The Death and Life of American Cities, *Jane Jacobs*

These trends offer a multitude of opportunities if we take the initiative to revive our city parks and urban rivers. Currently, plans are underway to restore the salt marsh in West River Memorial Park that was eradicated during the 1920s and 1930s in attempts to create upland recreation areas. The intent of this chapter is to identify the larger social and physical characteristics of the surrounding area that will constrain or enhance potential benefits of the salt marsh restoration.

Effective management of open space and rivers must address the relationship between human behavior and the environment. To do so requires an interdisciplinary, integrated understanding of urban watersheds. Recreational needs and issues of non-point source pollution reflect the increasing pressures that people place upon watersheds. At the same time, flooding, water quality, and aesthetic factors can have a direct impact upon human behavior. Management of a restoration project must strive to quantify patterns of human behavior and demographics as rigorously as traditional biological and chemical assessments of watersheds (Burch and DeLuca 1984). The quantification of social patterns can be facilitated by categorizing data as measures of stress, supply, or demand, as described below. These categories are not mutually exclusive, because some data (e.g. income) can be used to measure stress, supply, and demand depending on the biophysical and social context.

STRESS AND BARRIERS TO PARK USERS

The interaction of human populations and public open spaces can result in stresses upon both park and people. The social and biophysical characteristics of an area continually influence one another. In the case of West River Memorial Park, an abandoned open space can contribute to a lowering of housing values and perceived safety of already vulnerable adjacent neighborhoods. In turn, levels of income or density of populations reflect different kinds of stresses a community places upon an open space. Disenfranchised neighborhoods may lack the political power to lobby for maintenance and revitalization of a park. Such processes serve to reinforce each other (Logan and Molotch 1987, Grove 1996), leading to social stratification – separation of people along social and cultural lines into varying levels of wealth and power – which in turn causes or prevents further degradation of the biophysical environment. In densely settled urban areas, such patterns tend to be magnified. For example, lower levels of participation in outdoor activities have been strongly linked with residence in large urban areas, particularly those of one million or more people (Van Horne 1996).

In this context, stress refers to any factor or process that hinders a positive, stable interaction between people and open space.

Other types of stress are more intuitive. For example, increased recreational activity might cause biophysical stress to a river in the form of trail erosion and littering, while a lack of use could increase perception of crime and cause people to shun the area. Also, development throughout the watershed can increase the actual or perceived risk of flooding to those who live in developed areas adjacent to the river. In addition, residents near greenways, riverways, and converted rail-trails frequently express concern that activity in those areas will bring stress to their communities by increasing crime and reducing property values. Such problems are further complicated when abandoned or nonresidential areas create barriers between neighborhoods with different racial and economic characteristics. Although studies have shown that proximity to greenways often increases property values (Alexander 1994), the perception of risk must be addressed.

Income can affect both patterns of recreational use and the way different populations will be affected by changes to recreational resources, such as those caused by the salt marsh restoration. Income can also create stress by acting as a barrier to recreational activities. In a national survey, lack of money was the second most frequently cited constraint to outdoor recreation activities after lack of time (Van Horne 1996). Income barriers would have less effect on lower-income populations if usable local public spaces were nearby.

cycles. Usually, "a pattern of spatial and temporal 'ordered competition' develops among different user groups in any particular urban recreational setting" (Hutchison 1993, p. 8). Individual activities take place in the morning hours, family activities in the afternoon, and peer groups in the evening. A Santa Monica survey of coastal anglers noted that anglers over sixty years of age were more likely to fish during the week, avoiding weekend crowds of under-60-year-olds (Southern California Coastal Water Research Project 1994). In the words of urban planner Jane Jacobs, "it takes a wide functional mixture of users to populate and enliven a neighborhood park through the day" (Jacobs 1961, p. 99). It is therefore important to quantify the diversity of potential users in adjacent neighborhoods in order to predict how restoration and enhancement can mobilize human resources needed to sustain the park.

Patterns in demand for open space can vary as a result of social characteristics such as age, income, ethnicity, population density, and proximity to open space. These characteristics can be measured to predict demand.

Assuming that a restored West River Memorial Park will make the area more attractive to a diverse population, the larger numbers of people using the park at most times of day may help to dispel its reputation as an unsafe area and increase its desirability as a regional recreational resource. Also, greater diversity increases the potential for a broader advocacy base.

DEMAND FOR OPEN SPACE

Finally, population patterns will indicate the demand for open space – both the amount and types of demand present, and when use is likely to occur on a daily, seasonal or multi-year cycle. Types of demand can vary depending on age, ethnicity, income of a population, density of population, density of single-unit and multi-unit housing, and proximity to open space. Resources such as time, recreation equipment, or transportation all affect amounts and patterns of human demand. Information about populations can help a park manager anticipate future demand or pinpoint potential user groups that are underserved.

Demographic groups with high levels of demand for open space include those people under 18 and over 65 (Van Horne 1996, Godbey et al. 1992). These are the primary populations that engage in passive recreation. They are also the ones most likely to be affected by problems of accessibility owing to health limitations, dependency upon parents or caregivers, or safety. The elderly comprise an important and growing recreational user group. By the year 2000, more than 40% of the United States population will be over the age of 60 (Alexander 1994).

In one survey, individuals between the ages of 65 and 84 were more likely to use parks frequently than respondents from any other age group (Godbey et al. 1992).

Age classes can represent a process as well as categories of users. The most common reasons cited for change in time spent in outdoor recreation nationally were related to changes in life cycle stages, either due to aging or passing through child-rearing years (Van Horne 1996). While participation in outdoor activities generally tends to decrease with age, some activities remain constant. Fishing is a consistently popular activity among older populations. Nature study was the only activity in the most recent national recreation survey that actually increased among all age groups (Van Horne 1996).

People least likely to have a yard in which to recreate included those living in the central city, especially smaller, non-White, lower income households living in multiple-housing units (Van Horne 1996). Thus, multiple-housing units could be considered a consistent indicator of demand for open space, in addition to simple density of population.

The presence or absence of trees and grass also influences demand for public open space. If a residential area has a large number of street trees and spacious back yards, residents may be less likely to take advantage of nearby, public green space. If a residential area is largely covered by impervious surfaces such as parking lots and streets, residents may be more likely to visit an open space and may value it more. Grove (1996) used percent of vegetative cover and percent of impervious surface as indicators of a residential area's well-being. These biophysical measures can be combined with sociological data to construct an index of demand for open space.

It is also worth examining current and potential demand for fishing along the West River, because fishing is currently one of the few activities consistently pursued in the park (see below). Restoration may increase use of West River Memorial Park by anglers as a result of changes to the landscape, water quality, and fish populations within the park (Moore et al., Orson et al., pp. 123-135, this volume). Nationally, more fishing trips took place in "strongly man-modified environments" than any other recreation activities (Van Horne 1996). This seems to support the idea that, although peace and quiet, getting away from day-to-day living, and enjoying nature and the outdoors were the most frequently cited reasons for fishing, it is an activity that is flexible enough to flourish within the confines of a highly urbanized setting.

METHODS

This study sought to quantify the categories of stress, supply of human resources, and demand for open space discussed above as they relate to West River Memorial Park in its current and potential restored condition. Existing census data, satellite images, behavioral sampling, and data from interviews were used.

There are many potential sociological and biophysical measures for estimating stress, demand, and supply as defined above. However, analysis was limited by what block level data were available from the U.S. Census. A coarser grain of resolution, such as the block group or tract level, would have allowed a wider choice of variables. However, landscape heterogeneity in urban areas is such that characteristics of the population unique to the area around West River Memorial Park might have been lost. Therefore, age, population density, and multi-unit housing data were used to measure sociological patterns at the block level. Patterns of impervious and vegetative land cover, major roads, and nonresidential areas were used as biophysical measurements, also at the block level. Larger block group level data regarding income and car ownership were included as a descriptive, qualitative part of the analysis.

U.S. census data, satellite images, behavioral sampling, and data from interviews were used to quantify stress, supply of human resources, and demand for open space as they relate to West River Memorial Park in its current and potential restored condition.

GEOGRAPHIC INFORMATION SYSTEM

Socioeconomic data from the 1990 U.S. Census, land use/land cover data, hydrologic features, and municipal and state open space for the municipalities of New Haven and West Haven were collected and analyzed using PC-ARC/INFO and ArcView 3.0.

Two kinds of open space stress were measured by comparing West River Memorial Park and Edgewood Park. Edgewood is an adjacent park of similar size, but receives more use and maintenance (Fig. 1). First, data regarding nonresidential and industrial areas were used to compute the percentage of each park perimeter that did not border on a residential area (P) using the equation

$$P = \frac{l_{nonres}}{l_{total}} \times 100$$

where l_{nonres} = length of the perimeter of the park that is adjacent to a nonresidential area, and l_{total} = total length of the perimeter around the park.

Second, adjacent populations were calculated by selecting residential block groups within 0.3 miles of each park. Sums of the populations were computed to compare the number of potential local users for the two parks. Then, a GIS map of major roads was used to determine and compare the percentage of people in each adjacent population that would have to cross a major road in order to reach that area's park.

To measure potential supply of human resources from populations surrounding the parks, diversity of age within a block population (H′) was measured using the Shannon-Weaver diversity index (Odum 1971):

$$H' = -\Sigma P_i \ln P_i$$

where P_i = the proportion of individuals within age group *i*. Three age classes were used, based on age information available at the census block level: individuals under 18, individuals between the ages of 18 and 65, and individuals over 65.

The demand index (N) was developed with data from an MSS composite satellite image and block level data from the 1990 United States Census, and was computed for each block as

$$N = \frac{(D+H+A+V)}{4}$$

where D = density index, H = housing index, A = age index, and V = vegetation index. The density index was computed as

$$D = \frac{(p/a)}{m_d} \times 100$$

where p = population of block, a = area of block, and m_d = maximum density value among all blocks for both cities. The housing index (H) was computed from census data as

$$H = \frac{h_{10+}}{h_{total}} \times 100$$

where h_{10+} = housing units in structures containing 10 or more housing units in a block, and h_{total} = total housing units in a block. The age index (A) was computed from census data as

$$A = \frac{(p_{age}/p)}{mp_{age}} \times 100$$

where p_{age} = population over 65 or under 18, p = total population, and mp_{age} = maximum proportion of population over 65 or under 18.

Impervious surface area and vegetative surface were determined by overlaying census block boundaries on top of a composite satellite image of land use and land cover. The vegetation index (V) was then computed as

$$V = \frac{(a_{imp}/a)+(1-(a_{veg}/a))}{2}$$

where a_{imp} = area of impervious surface within each block, a = area of each block, and a_{veg} = area of vegetative surface within each block.

Although intended to be uniform, homogenous units of measurement, census blocks can vary widely in both area and population size. To test for bias, a second set of demand and supply indices was calculated in which each index was weighted according to either the block's area or population. The mean of both indices was then calculated for West River Memorial and Edgewood Parks, and then for the total area of West Haven and New Haven combined. For example, the mean demand index for the area around West River Memorial Park was

$$N_{wrmp} = \frac{(D_m + H_m + A_m + V_m)}{4}$$

where D_m = mean density for all blocks adjacent to West River Memorial Park, and H_m = mean housing index, A_m = mean age index, and V_m = vegetation index for the same area. Means were tested for significant differences using paired *t*-tests.

BEHAVIORAL SAMPLING

Supply of human resources was also estimated by tallying actual users within West River Memorial Park. Visitors to the area were observed and recorded on four separate dates in September and October 1996. Sampling was conducted in late morning, early afternoon, and late afternoon on two Saturdays and two weekdays to account for differences in temporal use patterns. The sampling process attempted to simulate a "snapshot" of park use at a certain time. Sampling consisted of moving through the entire park, recording each individual's observed activity as well as his or her estimated age, ethnicity, and gender. Although the area to the south of Orange Avenue along the river below the tide gates is not within park boundaries, it is an active spot for fishing closely associated with the park. Therefore, activities in that area were included in observations. Some bias may have resulted from the fact that most of the park along Ella T. Grasso Boulevard was surveyed by an observer sitting in the passenger seat of a stopped car. Marginal Drive observations were conducted on foot. Since the usable area of the park along Ella T. Grasso Boulevard is very open, individuals were easy to spot and it is unlikely that large numbers of user groups were missed. Sampling was done on foot along Marginal Drive because vegetation is dense and more intensive searching was required to find users. This difference in sampling may result in some bias, so these numbers should be considered approximations.

ANALYSIS OF RESIDENT SURVEY

Demand for recreation in West River Memorial Park was also measured at the neighborhood scale. Responses to the resident survey discussed earlier in this volume (Casagrande, pp. 62-75) were analyzed to determine whether attitudes and perceptions towards the park differed significantly between six neighborhoods. For each neighborhood, chi-squared (χ^2) tests were conducted on the means of responses to survey questions regarding the park. If answers differed significantly between neighborhoods, the characteristics and locations of the neighborhoods were compared to identify relations between attitudes and perceptions, levels of potential supply, demand and stress, and distance of neighborhoods from the park. The results were used to increase understanding of attitudes and responses among neighborhoods to the proposed restoration.

RESULTS AND DISCUSSION

STRESS AND BARRIERS TO PARK USERS

Unlike the problems of overuse in some of the nation's more popular wilderness areas, urban parks are often confronted with stress generated by underuse. While crowds do provide their share of erosion and littering, a city park that no one visits will rapidly fall into neglect and disuse. Infrequent human traffic through an area will generate both the perception and often the reality that the place is unsafe. To the extent that physical, perceptual, and political barriers prevent or reduce use of an area, they generate stress upon that park by short-circuiting the reciprocal relationship of supply and demand. GIS analysis and behavioral sampling revealed that barriers between residential areas and West River Memorial Park limit accessibility, and that the park in turn functions as a barrier between neighborhoods.

Barriers between residential areas and West River Memorial Park limit accessibility, and the park in turn functions as a barrier between neighborhoods.

Although West River Memorial Park is often considered a southern extension of the popular Edgewood Park, the two parks are separated by busy Derby Avenue (Fig. 1). To the east, Ella T. Grasso Boulevard (a four-lane state route) bars access by foot to West River Memorial Park's playing fields. Several neighborhoods are separated from the park by the presence of nonresidential areas: Evergreen Cemetery to the east and the Connecticut Tennis Center and Saint Lawrence Cemetery to the northwest (Fig. 1). South of the park, the river flows through a swath of nonresidential and industrial land. It is clear that heavy traffic and pedestrian-unfriendly roads on three of West River Memorial Park's four sides severely curtail pedestrian use. Vehicular access is equally limited; most park users that arrive by car use nondesignated parking places either along Ella T. Grasso Boulevard, in the Dunkin' Donuts parking lot on Orange Avenue, or on Marginal Drive outside the southern entrance to the park. There is a closed gate at Marginal Drive's northern end at Derby Avenue, and a small parking lot at the park's northeast corner (Ella T. Grasso Boulevard and Derby Avenue) is usually closed and locked. Thus access from the north is particularly difficult. Although the northeast parking lot is supposed to be left open most of the time, the gate can remain closed for several days, frustrating casual use of the fields and perpetuating the park's image as a closed and abandoned place. Parking is plentiful in Edgewood Park to the north, but no established corridors exist between the two parks to take advantage of this fact.

West River Memorial Park's size and shape may also further limit its accessibility. Large parks possess boundaries, absent in small parks, that can act as barriers to travel (Jacobs 1961). The perimeters of large parks tend to be the locus of most activity rather than the interior for reasons of safety or proximity. Although some of the most desirable locations for fishing and viewing wildlife are fairly deep within the confines of the park, potential users may opt not to enter or are unaware of interior opportunities. The eastern edge of West River Memorial Park is dominated by tall reeds (*Phragmites australis*) that block the view of the water from the heavily used playing fields along the Boulevard. Salt marsh restoration designed to replace *Phragmites* with shorter salt marsh grasses may open up water-based recreational opportunities.

Salt marsh restoration designed to replace Phragmites *with shorter salt marsh grasses may open up water-based recreational opportunities.*

Whyte (1968) emphasized the importance of the edge effect in achieving maximum contact between a park and adjacent neighborhoods. Since concern over the safety of areas removed from streets and human activity may cause people to shun the inner reaches of large parks, Whyte argues, more edge means greater, more concentrated opportunities for use. The predominance of nonresidential areas and busy roads around the perimeter of West River Memorial Park, however, effectively neutralizes the "edge effect" potentially offered by the park's long, strip-like borders. Measurement of park perimeters revealed that fully 54% of areas adjacent to West River Memorial Park's border are nonresidential, either industrial areas or cemeteries, as opposed to Edgewood Park's 31%. Nonresidential areas are a no-man's land that pedestrians in particular are often unwilling or unable to pass through. Thus, difficulty of travel to a park surrounded by nonresidential areas may be greater than that suggested by linear distance.

Jacobs noted that any single-use area that dominates the landscape around a park will result in a limited diversity of potential users. In a strictly residential area, the largest user groups will be mothers with children, who are able to occupy the area a maximum of five hours a day with severe restrictions imposed by the weather (Jacobs 1961, p. 96). In a homogeneous business district, a park will be used exclusively by office workers during lunch hours. Much of the nonresidential lands adjacent to West River Memorial Park are cemeteries, and these spaces add little to the supply of people using the park. Only two residential areas – New Haven's West River and West Haven's Allingtown neighborhoods – are adjacent to the park (Fig. 1).

Because of the greater prevalence of nonresidential areas enveloping West River Memorial Park, the number of people within one-third of a mile from the park (5,314) was smaller than the number within the same distance around Edgewood Park (15,469). Of the population adjacent to West River Memorial Park, 30% lived in Allingtown, the one neighborhood from which it is not necessary to cross a major road to reach West River Memorial Park (Fig. 1). This supports the notion that the relatively densely populated neighborhood of Allingtown, the neighborhood closest to and with the least obstructions to West River Memorial Park, represent a considerable portion of the park's likely user population. Thus, the perceptual barriers that limit use of the western side of the park must be overcome in order to generate an adequate supply of local use.

The Allingtown neighborhood is closest to West River Memorial Park and has the least obstructions to access. It therefore includes a considerable portion of the park's likely user population.

Although the western area of the park is the most accessible, it remains vulnerable to abandonment and neglect. Because of its relative isolation from major traffic, the west side of West River Memorial Park has been plagued over the years with the stress of illegal dumping, allegedly from the neighboring cemetery (Board of Parks Commissioners 1980). While the effects upon water quality are uncertain, the aesthetic effects are considerable (Casagrande, pp. 62-75, this volume). Again, limited human use of the park may allow such practices to become commonplace due to a low probability of getting caught in the act.

Safety concerns may pose an equally daunting barrier to use. Sensational newspaper accounts of bodies found in the river, a double murder in the St. Lawrence Cemetery, and occasional drownings may account for negative perceptions of West River Memorial Park.

Other researchers (Brantingham and Brantingham 1984) have noted that crimes were more likely in areas with a "medium intensity of use." These are areas that have enough potential victims to make criminal behavior worthwhile, but not enough people that there are many witnesses present. Currently, human traffic in West River Memorial Park seems to occupy that "critical zone" where crime is a possibility. Increasing human use above the critical zone is a desirable strategy for reducing this stress.

Because much as the park is underutilized, potential visitors may see desirable areas for fishing as "taken", particularly if those fishing are outside their ethnic group (Suttles 1968; Casagrande, pp. 62-75, this volume). Opening up the eastern shoreline of the river by reducing *Phragmites* may provide space for more groups, thereby reducing this type of stress (Suttles 1968).

Since increased fishing opportunities (Moore et al., this volume) will increase single or small-group activity, and since anglers typically arrive by car, access to parking will become a larger problem. At present, the handful of sports teams and spectators that use the park generally arrive in groups. Parking along Ella T. Grasso Boulevard – already a safety concern due to busy traffic – will increase as individual use increases on the eastern side. Residents may be affected by an increase in nonresidential, unregulated parking in their neighborhoods.

It is important to anticipate the potential, negative, short-term effects of the restoration upon current park users, so that the restoration process itself does not become a stress.

It is important to anticipate the potentially less positive short-term effects of the restoration upon current park users, so that the restoration process itself does not become a stress upon human park activity. It is essential, for example, that the restoration design reduces habitat of pestiferous insects (Pupedis, this volume), so that recreational facilities such as the athletic fields and the playground in the northeast corner of the park remain as attractive as before the restoration.

Some concern has been expressed regarding potential health effects of eating fish caught in the West River (Moore et al., this volume). Increased fishing opportunities could lead to more anglers fishing in and eating catch from West River Memorial Park. A large percentage of West River anglers surveyed indicated they ate what they caught (Casagrande, pp. 62-75, this volume). Studies on the impact and demographics of subsistence fishing have concluded that it is difficult to define subsistence fishing and accurately measure levels of fish consumption; difficult to generate a standard of consumption behavior that can be used to predict health effects; and difficult to identify a national demographic profile of who is likely to engage in subsistence fishing (Ebert et al. 1996). The specific risks of the fish in the river and the behavior patterns of West River anglers deserve closer scrutiny, especially if West River Memorial Park becomes a popular regional park because of increased fishing opportunities.

Socioeconomic differences among the areas surrounding the park are most evident when comparing per capita income of adjacent block groups. Here, the river and the park act as a buffer between the comparatively affluent block groups that contain the Westville and Allingtown neighborhoods, where income ranges from $15,000 to $28,000 per capita, the poorer Edgewood/West River neighborhood block groups ($7,827-$11,847), and the even poorer Hill neighborhood ($5,314-$7,826). The park's role as a buffer between less and more advantaged populations will inevitably provoke strong feelings among local citizens should the status quo of the park be altered in any way. Similarly, when two adjacent block groups possess drastically different racial compositions, that area may have a heightened degree of tension due to distrust, suspicion, and fear. Decisions to increase connectivity via proposed improvements should anticipate the possibility of conflict between communities currently separated by the river and park.

Political boundaries can also be the cause of stress to a public open space. West River forms the border between New Haven and West Haven from Derby Avenue south to New Haven Harbor. The western portion of the park lies within the town of West Haven, although it remains under the control of New Haven's Department of Parks, Recreation, and Trees. Ironically, the residential area closest to the park is the West Haven neighborhood of Allingtown. Thus, those people who would likely have the most interest in the health of the park and the river are residents of another municipality. As such, the ability of these people to influence New Haven's park policies are small. An advocacy base is most effective when it is able to directly influence those making decisions. West River Memorial Park's advocacy base is quite literally split down the middle (Fig. 1).

Political boundaries can also be the cause of stress to a public open space. The western portion of the park lies within the town of West Haven, although it remains under the control of New Haven's Parks Department. As a result, West River Memorial Park's advocacy base is reduced.

Jacobs (1961) refers to such areas as "border vacuums." According to Suttles (1968): "All of them are sections where people do not live permanently and over which no one exercises a personal surveillance" which creates "a kind of social vacuum where the usual guarantees of social order and control are lacking." Such places are viewed as dangerous: "On either side, residents take some comfort in knowing they are safely separated by a border of moral chaos" (Suttles 1968, p. 35).

SUPPLY OF HUMAN RESOURCES

Safe, frequently-used and well-maintained parks are frequently the products of a strong community advocacy group. Edgewood Park to the north has this kind of support, but West River Memorial Park has no equivalent advocacy group, perhaps because of a lack of accessibility. Also, the popularity of Edgewood Park may draw the

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and below the tide gates (Fig. 1), this location attracts consistent use. The western side of West River Memorial Park along Marginal Drive and near Horseshoe Lagoon, also attracts anglers.

The athletic fields on the east shore attract a small but regular supply of weekend and afternoon use in the fall and spring by athletic teams (L. Amendola, New Haven Department of Parks, Recreation and Trees, personal communication). At the time of the behavioral sampling, over 98% of activity on the eastern side of the park was related to either participating in or watching an organized sport. Over 50% of individuals using the park were engaged in such activities. Group size associated with soccer games averaged 30. Activities such as fishing, walking, jogging, or biking involved groups of between one and four people. Individual activity on the eastern side was limited to a few joggers and walkers. The latter seemed to be using the area as a shortcut rather than for the deliberate purpose of recreating, as did the handful of bikers along Marginal Drive.

Although various barriers prevent full potential use of the park, it attracts a diverse and consistent number of users even in its current state.

Organized sports tend to occupy public open space for a discrete period of time, leaving it empty during off-times and seasons. Individual activities are scattered throughout the day according to individual schedules. Although various barriers to use prevent the park from realizing its full potential, it attracts a diverse and consistent number of users even in its current state.

DEMAND FOR OPEN SPACE

The mean demand index value for Edgewood Park ($D_m = 1.74$) was significantly higher ($t = -2.16$, $p = 0.03$) than for West River Memorial Park ($D_m = 1.19$). This was true for both weighted and unweighted means. Demand varied widely across the larger area of New Haven and West Haven (Fig. 3). The largest difference between the area around the two parks was found in values from the vegetation index. The mean vegetation index for the residential area surrounding Edgewood ($V_m = 0.008$) was higher ($t = -12.21$, $p < 0.001$) than for West River Memorial Park ($V_m = 0.004$). Thus, the residential areas surrounding West River Memorial Park have on average a lower amount of impervious surface and a higher amount of vegetative cover than Edgewood. Part of the demand for and success of Edgewood Park is the attraction of a large green space to residents who lack sufficient trees and lawns in their private surroundings. Future studies might conduct an analysis of percent land cover by neighborhood, since the averaging of results may have masked a significant difference in landscape between Allingtown and the Hill.

Means of the housing, density, and age indices were not significantly different for the two parks (t = -0.97, -0.24, -0.17, respectively). Hence, demand for open space based on these characteristics of the surrounding populations is not significantly different for the two parks. The discrepancy between the current states of the two parks, then, more likely comes from a combination of other factors, such as amount of unvegetated landscape around homes, supply of users from many age groups, or barriers to access.

In part because of cemeteries and nonresidential space, the overall density of census block groups adjacent to the park is far less than that of New Haven and West Haven as a whole. West Haven has 105 people per acre, and New Haven 62 (CT DEP 1993). The West River/Edgewood neighborhood has only 18 people per acre, and Allingtown has four.

Low demand for use of West River Memorial Park most likely comes from a combination of landscape around homes, lack of user age diversity, and barriers to access.

West River Memorial Park has the potential to meet many of the most common recreational demands. In a 1986 national survey, pleasure walking was the most widespread activity, having no less than 35% participation from any socioeconomic group. Only swimming matched walking in terms of popularity, with identical participation levels (Van Horne 1996). The universal appeal of these two activities suggests that demand should exist for both of them within West River Memorial Park. There is less likely to be a strong demand for swimming, given current perceived and actual pollution levels (Casagrande, pp. 62-75, this volume), but swimming's widespread popularity is noteworthy for the restoration process. Indeed, swimming in the park, especially in Horseshoe Lagoon, was highly popular in the 1940s when as many as 25,00 people swam over the course of a year (Casagrande, p. 34, this volume). Salt marsh restoration targeted at pollution abatement, together with education programs stressing reduction of non-point source pollution, could go a long way toward increasing the possibility of swimming.

Regarding demands from specific age groups, residential populations near West River Memorial Park having the highest concentration of juveniles (under 18) are found mostly in the Hill neighborhood and to the southeast of the park, in the City Point neighborhood. Individuals under 18 years of age comprise between 28% and 52% of the population in these areas. In the early 1980s, the city of New Haven targeted the Hill neighborhood as an area in dire need of more park and recreational opportunities for young people (Department of Parks, Recreation, and Trees 1981). But the high volume of traffic along Ella T. Grasso Boulevard poses a particular concern in terms of safe passage to the park for young people. Any attempts to increase attractiveness and use of the park must

Residents of the Hill were particularly emphatic regarding the importance of reducing crime; all respondents ranked it highest in importance. Neighborhoods adjacent to the park also gave improvement of the river for fishing and crabbing a significantly higher response ($\chi^2 = 5.34$, $p = 0.02$) than neighborhoods further north. Hill and West River residents assigned a greater importance to viewing wildlife than Allingtown residents ($\chi^2 = 6.43$, $p = 0.001$).

These differences suggest that residents near the stretch of river flowing through West River Memorial Park have a stronger interest in restoration and improvement for specific activities than residents who live further away. This may be due to the degraded and unsafe nature of the river or the higher incidence of crime overall within this area, or perhaps residents further away from the park have access to other areas for recreation such as fishing and viewing wildlife. A weaker interest in improving wildlife viewing among Allingtown residents may be due to the fact that the dense vegetation on the west side of the park already provides habitat for wildlife.

Greater use of the park as a result of restoration may be complemented by future development on the east side of the park. If a proposed biotechnology facility is built in the West River neighborhood, there will be an increase in potential use by employees during weekday business hours. Demand would be enhanced if the developers were to build a pedestrian bridge over the Boulevard.

POTENTIAL EFFECTS OF RESTORATION

Eliminating *Phragmites* will probably have the greatest physical effect upon the eastern shore of the river, opening up a vista from the Boulevard and improving access for fishing, boating, and viewing wildlife, especially birds (Lewis and Casagrande, this volume). Improved wildlife viewing was a priority for West River/Boulevard residents (Casagrande, pp. 62-75, this volume).

If earth must be moved for salt marsh restoration (Orson et al., pp. 123-135, this volume), park anglers will be affected because of sedimentation and loss of aesthetic quality. But these effects will be temporary. The composition of fish species is likely to change as well (Moore et al., this volume). But given the general lack of preference for fish species (Casagrande, pp. 62-75, this volume), changes to the fish community are unlikely to discourage anglers.

Often, a small population of advocates can have a disproportionate influence upon the future of an open space. Residents of the West River neighborhood (Fig. 1) have expressed interest in restoration of the park. An interdistrict environmental magnet school has been proposed by Barnard Elementary School, which is opposite West River Memorial Park on Derby Avenue and Ella T. Grasso Boulevard.

The project plan includes using the West River as a field laboratory. The park has larger potential for similar efforts; 25 schools within New Haven alone are situated within one mile of the park. Potential strong support of the community and use by schoolchildren may provide the park with an advocacy base with influence far greater than the neighborhood's size might suggest.

Restoration of the salt marsh may catalyze additional interest in and use of the park in particular and the West River in general. Use, in turn, could help to deter undesirable activities. For example, promotion of off-hour family activities at some public facilities has successfully reduced vandalism (CT DEP 1993). To the extent that West River Memorial Park is able to attract multi-use activity, that use will mitigate the barrier effects of "that troublesome border between land and water" (Jacobs 1961, p. 268). By increasing traffic and reducing safety concerns, restoration could make existing recreational opportunities (the athletic fields, for one) more desirable as well.

CONCLUSION

Kevin Lynch (1960) referred to large, strip-like parks that act as "a seam rather than a barrier" when successful. A park that is able to attract and sustain a healthy and diverse level of use becomes "a line of exchange along which two areas are sewn together" (p. 65). West River Memorial Park and the stretch of the West River within its boundaries suffer the ill effects of various political, social, and biophysical stresses and barriers that hamper access to and awareness of a truly unique area. Access to the park from the north, east, and south is hampered by busy roads with several lanes of traffic. The park is either unknown to most people or suffers from a poor reputation as an unsafe, crime-ridden area. Unlike Edgewood Park to its north, West River Memorial Park has failed to garner the support and advocacy of local residents who might demand better maintenance and staffing from the city. Data indicate that this results from a lack of residential neighborhoods immediately adjacent to the park, socioeconomic conditions that reduce the political influence of the residents of adjacent neighborhoods (particularly the Hill), and the fact that the park is bisected by the municipal boundary between West Haven and New Haven.

Findings suggested that other barriers to West River Memorial Park's well being, and the factors that distinguish it from the more successful Edgewood Park, were a smaller supply of current and potential users, as measured by actual use and age diversity; the presence of major roads; and entrenched negative perceptions of the area. Demand for the resources of the park in terms of characteristics of the surrounding population do not seem to be as significant a reason for lack of current and potential use. Since the restoration effort can serve to mitigate some of the physical and perceptual barriers to use, it is likely that demand from the local population will increase human use of the area.

Given that the population near enough to use West River Memorial Park on a regular basis is significantly smaller than the population around Edgewood, visitation to West River Memorial Park will be lower than in Edgewood even following the restoration. In order to encourage a higher level of diverse use, restoration planners should investigate ways of cultivating regional use of and interest in West River Memorial Park. Its size, potential for boating, and unique history make it an ideal candidate for a regional park. By drawing users from outside the immediate area, the park will attract a broader range of activities at different times of the day. As park popularity increases, so will awareness of the area, use, human traffic, and hopefully, greater safety.

West River Memorial Park's size, potential for boating, and unique history make it an ideal candidate for a regional park. Restoration of the salt marsh with federal and state money can catalyze the park's revitalization.

Restoration alone will not remove many of the factors contributing to neglect of the area. Ella T. Grasso Boulevard, Orange Avenue, and Derby Avenue will remain daunting obstacles unless infra-structural changes such as crosswalks or pedestrian bridges are implemented. The expanses of nonresidential areas along the park borders is also expected to remain. Also, lack of parking will continue to reduce potential use.

Restoration will probably have a positive public relations effect on the park. *Phragmites* on the east side of the park will be replaced by salt marsh grasses, making the river visible from Ella T. Grasso Boulevard. On the west side, however, plant composition is principally woody herbaceous plants. But the enclosed feeling created by trees and shrubs between Marginal Drive and the river will remain unchanged by the restoration, and so will existing perceptions of risk.

In its favor, West River Memorial Park has a small but vital and enduring population who use it regularly for fishing and other recreation, a growing number of advocates from the West River neighborhood who have the capacity to influence the future of the park and the river, and historical and physical features that give it the potential for a diversity of uses. Finding ways to cultivate this potential, while ensuring that restoration of the park includes the infrastructure necessary to maintain current use, are vital steps to the long-term success of the park. Making both regional and local use of West River Memorial Park possible, convenient, and attractive will generate a sustainable supply of human use of the area. Restoration of the salt marsh with federal and state money can act as an initial catalyst to revitalize the park. But use by people with diverse interests is necessary to generate greater safety within the park through a constant stream of people with different daily and seasonal recreational patterns. Likewise, more people who are aware of the park and willing to speak on its behalf can create an advocacy base necessary for maintenance and programming to ensure that the park remains in a usable condition. Anticipating the effects of physical and social factors upon the restoration will help to insure that public investment yields the highest return.

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Section II: Ecological and Hydrological Context

*"Praise be, my Lord, for Sister Water.
Who is most useful, humble, precious
and chaste."*
– St. Francis of Assisi

Planning and implementing urban, wetland restoration requires an understanding of the biophysical context. Development throughout the watershed, pollution, and physical impediments to water flow all constrain potential restoration alternatives and goals. The three papers in this section describe some of the ways in which the landscape sets the context for salt marsh restoration in New Haven's West River.

The Hydrologic Structure and Function of the West River Marsh

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William L. Kenny
Jay Fain and Associates

ABSTRACT
This paper updates earlier hydrologic studies of the marsh in West River Memorial Park, New Haven, Connecticut. Throughout the 1800s and 1900s, drainage, filling, and the installation of 12 tide gates (in 1919) progressively transformed the park's original salt marsh ecosystem into a system dominated by common reed (*Phragmites australis*). In 1992, we conducted a hydrologic study to assess the feasibility of salt marsh restoration in the park. Experimental openings of tide gates were used to quantify the increase in tidal inflow and salinity to the marsh. Average water surface elevation range was 79 cm with one gate open and 91 cm with two gates open. By contrast, average accumulation of fresh water in the marsh when all gates were closed was approximately 27 cm. Increases in salinity were detectable as far as 2.1 km upstream when two gates were opened. Salinity near the gates ranged from 9 $g \cdot l^{-1}$ at water surface to 20 $g \cdot l^{-1}$ at a depth of 150 cm. These concentrations approach the salinity required to extirpate common reed and provide favorable conditions for salt marsh vegetation. A detailed topographic survey and field measurements of tidal inflow were used to develop and validate a water surface elevation-water storage function for the site. This function can be used, in concert with hydrodynamic models, to estimate the gate openings needed to meet ecological goals and safeguard property and infrastructure. When combined with ecological and socioeconomic data and information, this study of the hydrologic structure and function of the West River Marsh provides a foundation for constructive, community-based change.

This paper updates earlier hydrologic work presented in Kenny and Barten (1993), Kenny (1995), and Barten (1995). The application of our results to the preliminary design of a salt marsh restoration project in West River Memorial Park (New Haven and West Haven, Connecticut) is discussed in the context of the biological and socioeconomic studies presented in this bulletin. Although additional hydrologic measurements and monitoring would be helpful, and may be necessary for final engineering design, our results clearly demonstrate the opportunity to convert at least a portion of the common reed (*Phragmites australis*) monoculture back to a vibrant assemblage of salt marsh plants and animals. There is a coincident opportunity to restore some of the social benefits traditionally associated with New England salt marshes (see Figure 1, p. 15, this volume).

OBJECTIVES

The primary objectives of this study were to:

1. quantify the hydrologic regime of the West River Marsh;
2. measure changes in water level and salinity associated with experimental manipulations of tidal exchange;
3. develop a detailed topographic map of the marsh surface; and
4. relate the hydrologic and topographic data to determine the feasibility of salt marsh restoration.

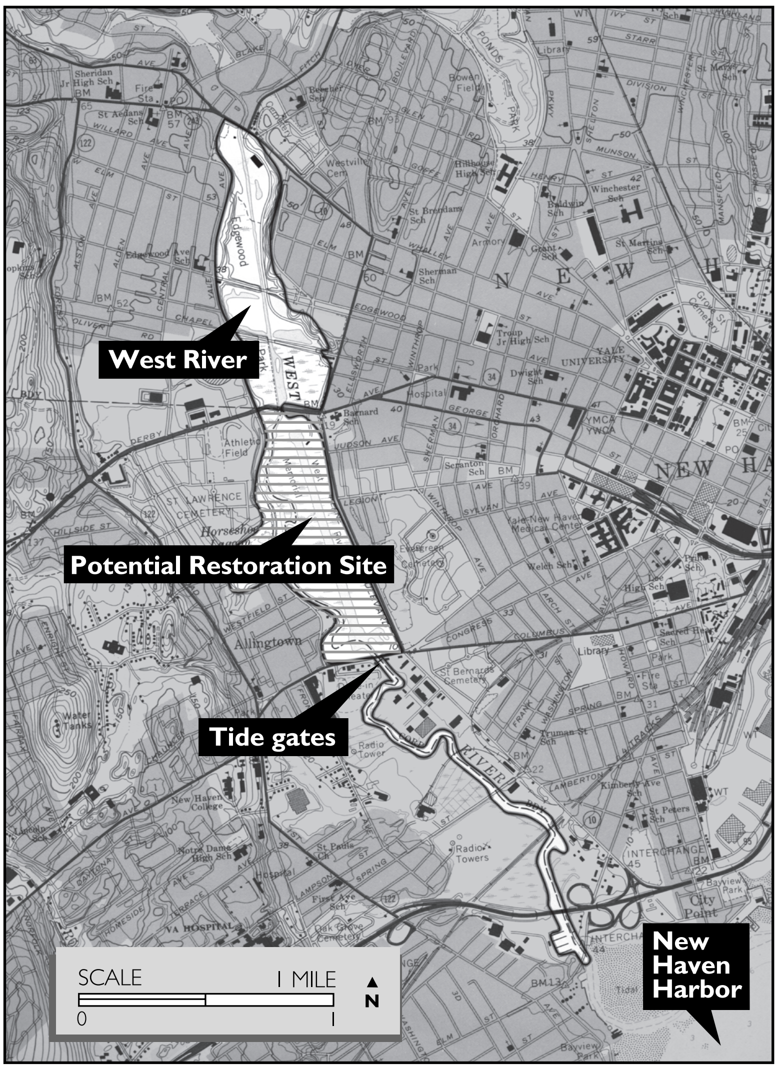


Figure 1. A portion of the New Haven, Connecticut U.S. Geological Survey 7.5 minute quadrangle (1984) showing the West River hydrological study area, the potential restoration site in West River Memorial Park, and the surrounding urban area.

SITE DESCRIPTION

West River Memorial Park is located within a 4.4 km (2 mi) long floodplain corridor, that was a salt marsh less than a century ago, of the West River along the New Haven-West Haven, Connecticut boundary (Fig. 1). The West River Marsh occurs at the estuarine interface between a 91 km^2 (22,400 acre) watershed and Long Island Sound. The West River watershed includes portions of New Haven, West Haven, Hamden, Woodbridge, Bethany, and Prospect. Barten (1995) and Benoit (1995) describe this diverse landscape, changes in its condition over time, and subsequent effects on the quantity and quality of water entering the marsh, New Haven Harbor, and Long Island Sound.

WATERSHED CONDITIONS

Development has changed watershed conditions so that larger quantities of lower quality water are delivered more rapidly to tributary streams and the estuary – in this case the West River tidal marsh.

Land cover and land use in the West River watershed exhibit patterns that are typical of the New England coastal zone. The headwater area (Bethany and Woodbridge) is largely forested with widely scattered single family houses. Several large tracts of forest land are protected as a part of the regional water supply system and in the West Rock Ridge Regional Park. During the post-World War II era, many farms and forests in the middle reaches (Hamden) were converted to residential subdivisions and associated commercial development. The lower reach of the West River (New Haven and West Haven) traverses densely populated urban neighborhoods.

Hydrologic and hydraulic changes associated with development in the watershed such as (1) conversion of deep-rooted forest vegetation to shallow-rooted grasses, (2) increased impervious areas (e.g., roads, parking lots, roofs, and compacted soil), (3) construction of extensive storm drain systems, (4) filling and drainage of freshwater wetlands, (5) construction of reservoirs, and (6) the installation of tide gates have altered the quantity, quality, and timing of water flow. Reducing the density and vigor of vegetation (forests . . .farms . . . suburbs . . .urban areas) means more rain and snowmelt reaches the surface and less is returned to the atmosphere by evaporative processes. Hence, more water is available for overland flow, streamflow, or groundwater flow. Water flows over, instead of through, compacted soils and directly off impervious surfaces. This short-circuits the natural pathways of flow and limits the opportunity for contaminant assimilation and transformation. Therefore, larger quantities of lower quality water are delivered more rapidly to tributary streams and the estuary – in this case the West River tidal marsh.

GEOLOGIC SETTING

The marsh substrate consists of glacial lake sediments that were deposited over arkosic bedrock during the Pleistocene. These sediments were subsequently buried beneath a delta of outwash sand during the melting of the late Wisconsin period ice sheet about 15,500 to 17,000 years ago. When glacial meltwater flowed down the valley, 6 to 18 m (20 to 40 ft) hills of sand remained along its margin (Flint 1930, pp. 178-179; Flint 1965; Lewis and Stone 1991). The end of the Pleistocene was marked by a global rise in sea level that led to the development of a salt marsh ecosystem in the lower West River. The mixing of saltwater with freshwater in the floodplain caused the deposition of silt and organic matter. Plants colonized the area, and a silty peat developed on the site. Orson et al. (pp. 123-135, this volume) describe the formation of salt marshes, including those in the West River, in more detail.

Tide gates were often installed along the Eastern Seaboard in order to enhance public safety. They reduce, but do not eliminate, the risk of flooding during severe storms.

THE RESTRICTION OF TIDAL EXCHANGE

In 1919, tide gates were installed 1.8 km (1.1 miles) upstream from the confluence of the West River with New Haven Harbor and Long Island Sound. Before they were installed, the tidally influenced zone extended approximately 5 km (3 miles) inland from the harbor. The tide gate structure consists of 12 top-hinged gates that are constructed of heavy timbers to cover 5.0 ft. wide by 7.6 ft. high openings in a massive concrete bulkhead. During flood tide, when pressure exerted on the seaward (downstream) side of the gates exceeds total force (pressure plus momentum) on the upstream side, the gates close against the bulkhead. As the tide ebbs, downstream water level falls below upstream water level. The pressure difference pushes the gates away from the bulkhead, and seaward flow resumes.

As described by Casagrande (pp. 13-40, this volume) and MacBroom (1995), tide gates were installed on this site and many others along the Eastern Seaboard in order to enhance public safety by: (1) reducing or eliminating tidal flooding of coastal zone rivers, (2) draining, filling, and otherwise reclaiming [*sic*] land, and (3) eliminating mosquito breeding habitat. Tide gates are simple, effective, devices for transforming salt marshes, but they rarely, if ever, meet these broad objectives.

Tide gates substantially reduce water level fluctuations and virtually eliminate the flow of salt water into marshes. Tide gates reduce, but do not eliminate, the risk of flooding during severe storms. When the storm surge caused by a hurricane closes the gates, stormflow from the watershed – as much as 250 mm (10 inches), frequently associated with hurricanes in New England – can inundate the area behind the gates.

MacBroom (1995) lists 20 possible combinations of tidal conditions and river water levels that may influence the operation of tide gates. It is necessary to use a hydrodynamic computer simulation model to accurately predict the functioning of tide gates over this diverse range of scenarios. A model, calibrated and verified with field data, can be used to quantify existing conditions and explore restoration alternatives.

SELF REGULATING TIDE GATES

Adjustable floats can be attached to the seaward side of conventional tide gates to alter their buoyancy and thereby influence quantity and timing of flow (flood and ebb) through the structure. These Self Regulating Tide Gates (SRTs) have been successfully deployed for marsh restoration projects elsewhere in Connecticut (Bongiorno and Trautman 1992), most notably in Fairfield, where they were developed (Steinke 1986). Their application to this project is discussed in the last section of this paper and by MacBroom (1995). Changes in the flora and fauna of the West River and other salt marsh ecosystems that occur in association with the restriction of tidal flow are described by Cuomo (1995), Niering and Warren (1980), and throughout this volume.

METHODS

Water level, tidal flow, and salinity data were collected during spring tide events with (1) all tide gates closed, (2) one tide gate open, and (3) two tide gates open (Table 1). Spring tides are the highest tides during each lunar cycle; they occur twice each month. The periodic inundation of a marsh during spring tides is sufficient to kill plants that are not salt tolerant (e.g., *Phragmites australis*) and to allow for re-colonization by salt marsh vegetation (e.g., *Spartina* spp.).

Table 1. Dates (1992) of flow data collection and predicted tide ranges[1] for New Haven Harbor (Eldridge Tide and Pilot Book 1991).

Tide gates closed (existing)		One gate open (treatment 1)		Two gates open (treatment 2)	
Date	Range (m)	Date	Range (m)	Date	Range (m)
4 June	2.22	18 July	2.13	12 Sept	2.16
17 June	2.07	30 July	2.50	30 Sept	2.34
2 July	2.32	17 Aug	2.19		

[1] Average tide range for New Haven Harbor is 1.89 m (1 ft = 30.48 cm; 1 m = 3.281 ft). Dates of new moon: May 31, June 30, July 29, September 26, 1992. Dates of full moon: June 15, July 14, August 13, September 11, 1992.

Tidal flows and corresponding water levels were measured through a complete tidal cycle (low to high to low tide). Salinity measurements were made at high tide (the maximum concentration during the tidal cycle).

TOPOGRAPHIC SURVEY MEASUREMENTS

A detailed topographic survey of the study site was conducted with a Spectra-Physics laser level. All elevations are referenced to the National Geodetic Vertical Datum (NGVD) of 1929. The City of New Haven benchmark number 85 has a designated elevation 50.336 feet above NGVD. All references to vertical elevation in this chapter are registered to the NGVD. Elevations were confirmed throughout the field survey phase with level loops (starting and returning to the same benchmark) within accepted errors of closure. Horizontal locations were registered to known map features. Transect azimuths were established with a Suunto hand compass and distances measured with a fiberglass measuring tape. Transects across the marsh and river were spaced at 122 m (400 ft) intervals. Elevations were measured at changes in surface topography along each transect. Elevations within the river channel and other water bodies were taken at 1.5 to 4.6 m (5 to 15 ft) intervals along each transect.

Elevation data from earlier surveys around the periphery of the marsh supplemented field data for map compilation. These survey data were entered into the SURFER software (version 4.0) as three dimensional (x,y,z) coordinates (Golden Software, Inc. 1989). SURFER was used to create detailed contour maps and cartographic projections. The site was divided into six sections to contend with the input array constraints of SURFER, while producing maps of the necessary accuracy and spatial resolution (10 by 10 ft. grid cells) for possible restoration and landscape design. Vertical variation of water storage volume was calculated at 0.5 foot intervals (from 1.5 ft below to 5.0 ft above NGVD) of water surface elevation. These data were used to develop a water surface elevation-water storage function for the site.

WATER SURFACE ELEVATION MEASUREMENTS

Continuous water surface elevation (level) measurements were made with two Stevens Type F chart recorders. One recorder was located along the dredged channel approximately 610 m (2,000 ft) upstream of the tidal gates (Fig. 2). The other was located along the West River approximately 1,740 m (5,700 ft) upstream of the tidal gates. Water level data from the charts were entered into a spreadsheet and referenced to the NGVD survey datum for graphical presentation and analysis.

Supplementary water surface elevations were obtained from staff gauges located at strategic points throughout the site (Fig. 2). The NGVD datum for the staff gauges was established by a level survey with a precision of 3 cm (0.1 ft.). Staff gauge readings were made at 30-minute intervals during spring tide data collection. A perforated PVC pipe containing a crest-stage gauge was attached to the bulkhead immediately downstream of the tide gates to record maximum elevation at high tide.

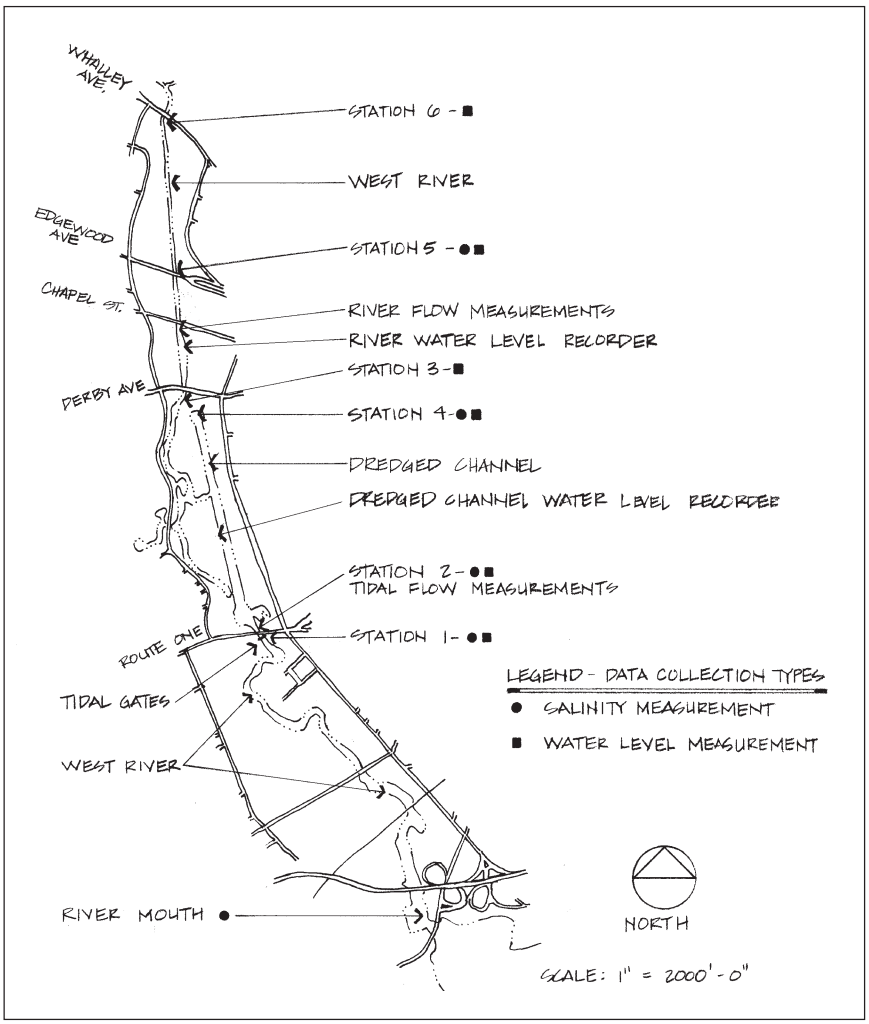


Figure 2. Sampling stations for water level, salinity, and flow in the West River Marsh, New Haven, Connecticut. Solid circles indicate sites of salinity measurements. Solid squares indicate the location of staff gauges for water level measurements.

STREAMFLOW AND TIDAL DISCHARGE MEASUREMENTS

Flow velocity was measured with a General Oceanics mechanical impeller flow meter (minimum threshold velocity of approximately 0.3 $ft \cdot sec^{-1}$). Discharge was determined as a function of flow velocity, cross-sectional area of the channel, and the continuity equation $Q = AV$; where Q is discharge ($ft^3 \cdot sec^{-1}$), V is mean flow velocity at 0.6 x flow depth ($ft \cdot sec^{-1}$), and A is the cross-sectional area of the channel segment (ft^2).

Tidal flows were measured approximately 55 m (180 feet) upstream of the tide gates in a reach with uniform flow conditions. Measurements were made from a canoe secured to a rope that was suspended across the river. The flow depth and velocity were measured at 5.0 foot (1.5 m) intervals across the West River. This section width allows for the efficient measurement of rapidly changing tidal flows as well as an accurate depiction of the channel cross-section. This method for tidal flow measurements was originally developed by Lickus and Barten (1990) and refined by Marchesi and Barten (1992) at bridge openings to the Tivoli Bays (freshwater tidal marshes in the Hudson River National Estuarine Research Reserve). The dry weather streamflow (baseflow) of the West River was measured south of the Chapel Street bridge on August 5, August 25, and September 25.

SALINITY MEASUREMENTS

Water column salinity was measured using the YSI Model 33 S-C-T meter; a portable instrument designed to measure salinity, conductivity, and temperature. Salinity measurements were calibrated to water temperature in the field. Three standard NaCl solutions, spanning the expected range of tidal inflow (5, 10, and 20 $g \cdot l^{-1}$ or parts per thousand [ppt]), were used to verify the calibration accuracy of the YSI meter. Measurements were made throughout the study period from downstream of the tide gates to Edgewood Avenue (2.1 km [1.3 mi] upstream of the tide gates, Fig. 2). At each sampling site, measurements were made at 30 cm (1 ft) increments from the water surface to the channel bottom. An average of three hours, centered on the time of high tide, was required to collect the salinity data across the entire study site.

RESULTS AND DISCUSSION

WATER SURFACE ELEVATIONS

Daily average high and low tide water surface elevations measured with the Stevens recorder located along the West River are shown in Figure 3. Figure 3 also shows daily precipitation as recorded by the South Central Connecticut Regional Water Authority at Lake Dawson in Woodbridge (3.7 km [2.3 mi] north of the site). Precipitation recorded at Lake Dawson during the study period exceeded the long-term average.

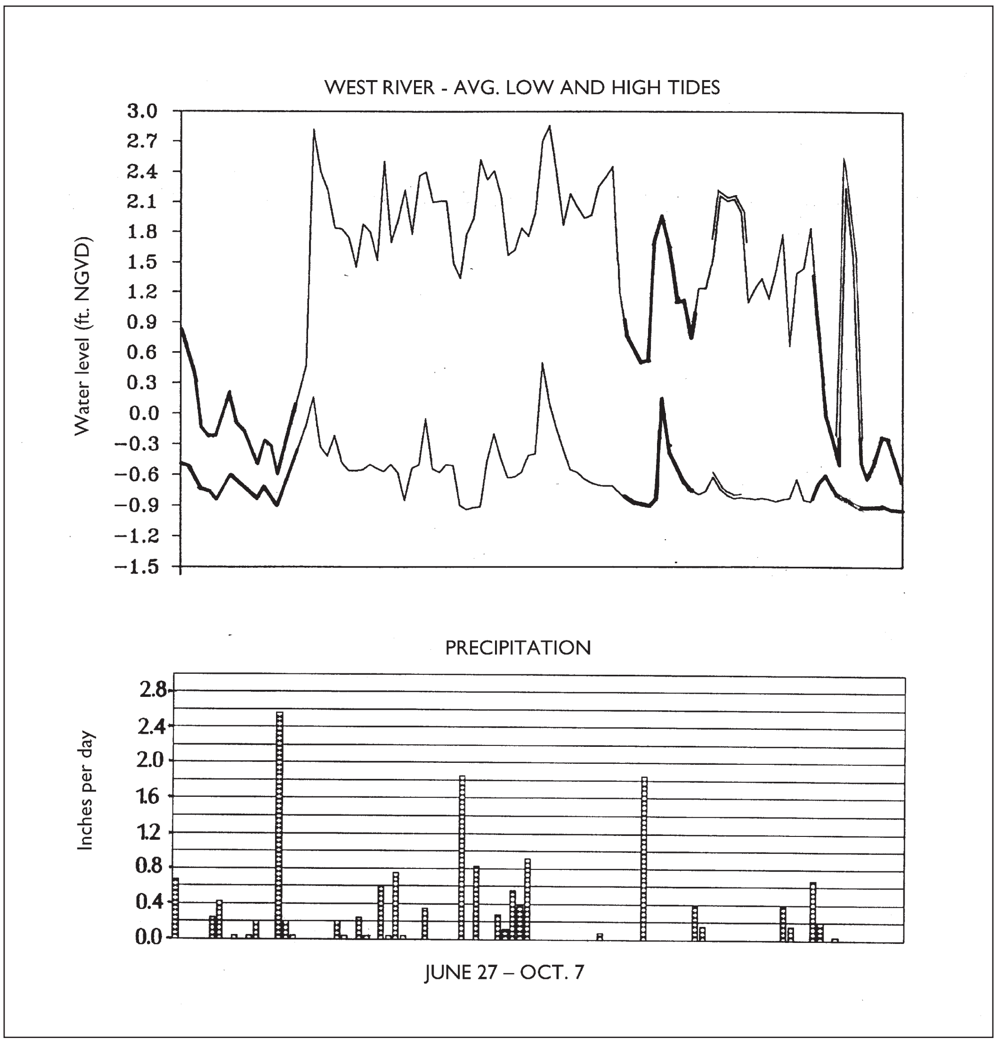


Figure 3. (a) Mean low and high water level in the West River marsh between Chapel Street and Derby Avenue for the period June 27 to October 7, 1992 with all tide gates closed (dark solid line), one gate open (solid line), and two gates open (double line); (b) histogram of daily rainfall.

Figure 3 illustrates changes in water level as a function of precipitation and tidal flow under three conditions: (1) all gates closed, (2) one gate open, and (3) two gates open. The direct effect of stormflow events can be differentiated from tidal inflows by noting the times when the water level rises even though gates were closed. Water level increases caused by tidal inflow and stormflow from the watershed (125 mm [4.93 inches] of rainfall occurred from August 9 to 18) were omitted from subsequent calculations in order to illustrate tidal inflow only or stormflow only.

The average water surface elevation range at station 3 was 27 cm (0.9 ft) with all gates closed, 79 cm (2.6 ft) with one gate open, and 91 cm (3.0 ft) with two gates open. Supplementary measurements were made every 30 minutes during spring tide events. On days when the gates were closed (June 4, Fig. 4), water levels at station 5 and 6 remained constant throughout the day, while average water surface elevation range at station 3 was 25 cm (0.8 feet). When one gate was open, elevations affected at stations 5 and 6 had an average tide range of 6 cm (0.2 feet). When two gates were open (Sept. 12), the tide range at station 6 was 21 cm (0.7 feet, Fig. 4).

The dredged channel that led to the degradation of the salt marsh may facilitate its restoration by increasing the flow of saline water to interior sections of the site.

As expected relative to their position in the estuary, water surface elevations at the recorder in the dredged channel (station 4, Fig. 2) ranged from 0.15 ft above and 0.15 ft below elevations recorded at the river recorder (station 3, Fig. 2). This illustrates the more direct communication with New Haven Harbor and the potential benefit of the dredged channel for the restoration of the West River Marsh. The result is not surprising, because tidal flow into a marsh is dependent upon the size, location, and morphometry of channels (Myrick and Leopold 1963). It is somewhat ironic, however, that the same dredged channel that led to the degradation of the salt marsh may facilitate its restoration by increasing the flow of saline water to interior sections of the site.

TIDE LAG

Flood tides are progressive waves moving up tidal rivers (MacBroom 1992). Therefore, high tide at the mouth of the river occurs earlier than high tide upstream. This phenomenon leads to differences in elevation along the length of an unrestricted tidal river at any given time. Upstream river levels are also limited by three factors: the nearly horizontal bed or adverse (relative to the flood tide) slope of the river channel, streamflow from the watershed, and friction losses along the channel (MacBroom, 1992).

Two tide lags occur along the West River. The first occurs immediately downstream of the tide gates. During spring tides observed, the tide lag averaged 19 minutes – with a range of 6 to 38 minutes – from the predicted high tide at New Haven Harbor entrance

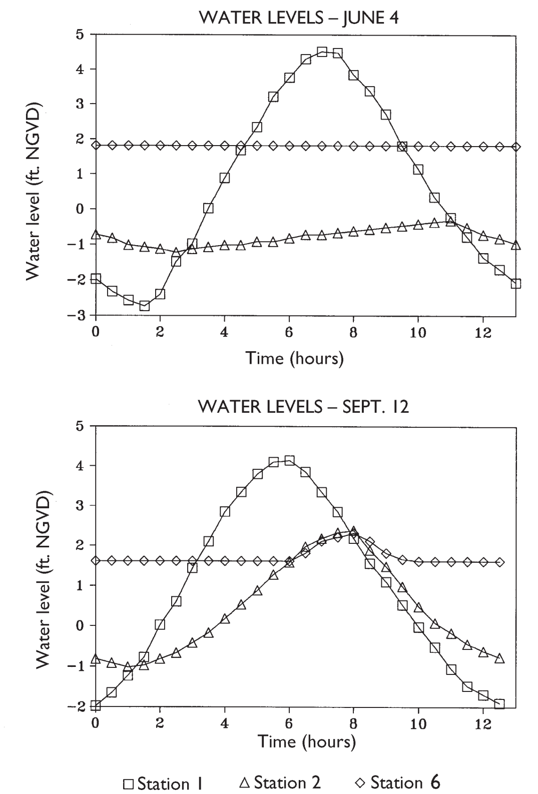


Figure 4. Water levels at station 1 (immediately downstream from the tide gates), station 2 (30 m upstream from the tide gates), and station 6 (at the Whalley Avenue bridge) (see Figures 1 and 2), on June 4, 1992 with all gates closed and September 12, 1992 with two gates open, West River, New Haven, Connecticut.

(Eldridge Tide and Pilot Book 1991). The observed tidal range downstream of the gates was an average of 18 cm (0.6 feet) less than predicted tidal range at the New Haven harbor entrance (Eldridge Tide and Pilot Book 1991). The average spring high tide elevation at Station 1 determined from eight direct measurements and another eight crest-stage gauge measurements was 154 cm (5.1 feet).

The second lag occurs upstream of the tide gates. As noted earlier, when the flood tide progresses up the river, gates are forced shut and remain closed as long as downstream water elevation is greater than upstream elevation. The gates function as a dam until the water surface elevations downstream are less than those upstream. The highest water surface elevation in the marsh occurs at the moment when elevations on both sides of the gates are equal. This occurs during ebb tide on the seaward side (Fig. 4). Average lag time on the upstream side of the tide gates was three hours and 50 minutes with all gates closed, two hours and 40 minutes with one gate open, and two hours and 13 minutes with two gates open.

TIDAL FLOWS

The results of flood tide discharge measurements on June 4, July 18, and September 30 are shown in Figure 5. They illustrate the typical flow regime we observed with all gates closed, one gate open, and two gates open, respectively. Maximum rates of tidal flows increased from a negligible quantity with all gates closed, to nearly 300 $ft^3 \cdot sec^{-1}$ with one gate open, and nearly 600 $ft^3 \cdot sec^{-1}$ with two gates open. Similarly tidal prisms (total volume of inflow) ranged from a negligible volume with gates closed, to 4.2×10^6 ft^3 with one gate open, and 6.8×10^6 ft^3 with two gates open. Streamflow in the West River south of the Chapel Street bridge was measured, and a rating curve was developed (Fig. 6). The rating curve was needed to estimate streamflow into the marsh during the tidal flow measurements. It will also be needed to estimate baseflow and stormflow inputs when a hydrodynamic model is used for restoration planning and design. The median streamflow of approximately 30 $ft^3 \cdot sec^{-1}$, and corresponding volume of 6.5×10^5 ft^3, is an order of magnitude smaller than the tidal inflow with just one or two gates (of 12) open.

Median streamflow and corresponding volume is an order of magnitude smaller than the tidal inflow with just one or two gates open.

When all gates are closed, a negligible quantity of water leaks into the marsh. Occasionally, debris is lodged in the gates causing them to remain partially open. When this occurs, the flood tide seeps through the gates. Although it cannot be accurately measured with conventional instruments, it may exceed the minimum freshwater inflow (approximately 10 $ft^3 \cdot sec^{-1}$) we observed during the study period.

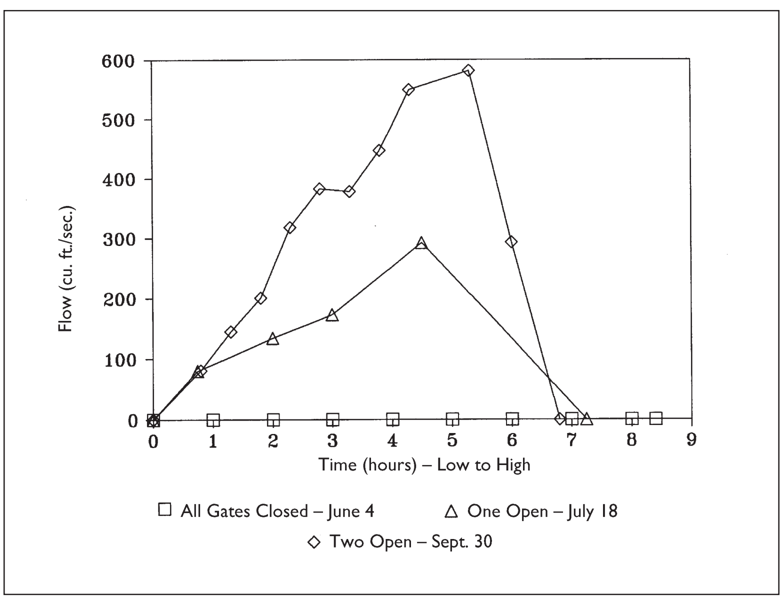


Figure 5. The flood tide on June 4,1992 with all gates closed, July 18,1992 with one gate open, and September 30,1992 with two gates open, West River, New Haven, Connecticut.

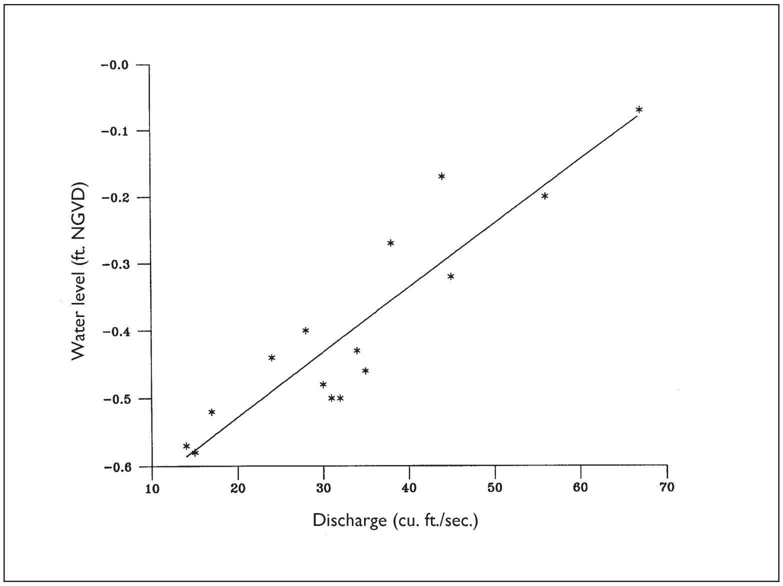


Figure 6. Rating curve for baseflow conditions on the West River south of the Chapel Street bridge, New Haven, Connecticut.

Salt concentrations measured 100 ft upstream from the tide gates when two gates were opened ranged from 9 $g{\cdot}l^{-1}$ at the water surface to 20 $g{\cdot}l^{-1}$ at a depth of 5 feet.

Tidal prism volumes were combined with river flow volumes to determine the total quantity of water in the marsh. Groundwater inflow and outflow and evapotranspiration losses were assumed to be minimal, relative to the large tidal volume, for this site. Lickus and Barten (1990) determined that evapotranspiration accounted for less than one percent of measured outflows in a similar tidal wetland system along the Hudson River. In a study of two tidal marshes in Virginia, Harvey and Odum (1990) found that groundwater flowing into the marsh soils was negligible relative to the tidal flows.

SALINITY

The West River salinity regime exhibited characteristics of a slightly stratified estuarine system, where both river flow and tidal mixing are important, and a well-mixed estuarine system, where tidal flows dominate (Berner and Berner 1987). Figure 7 shows salinity under different flow conditions at the sampling stations shown in Figure 2. At the mouth of the river, characteristics of a well-mixed system were exhibited throughout the study period (Fig. 7a). Note the overall salinity increase of about 5 $g{\cdot}l^{-1}$ during the field sampling period.

Water column salinity increased throughout the site during the study period. Typical late-growing season reductions in freshwater inflows (of the Mill, Quinnipiac, and West Rivers, and local tributaries) to New Haven Harbor may have contributed to higher salinity measured later in the study period (Fig. 7a).

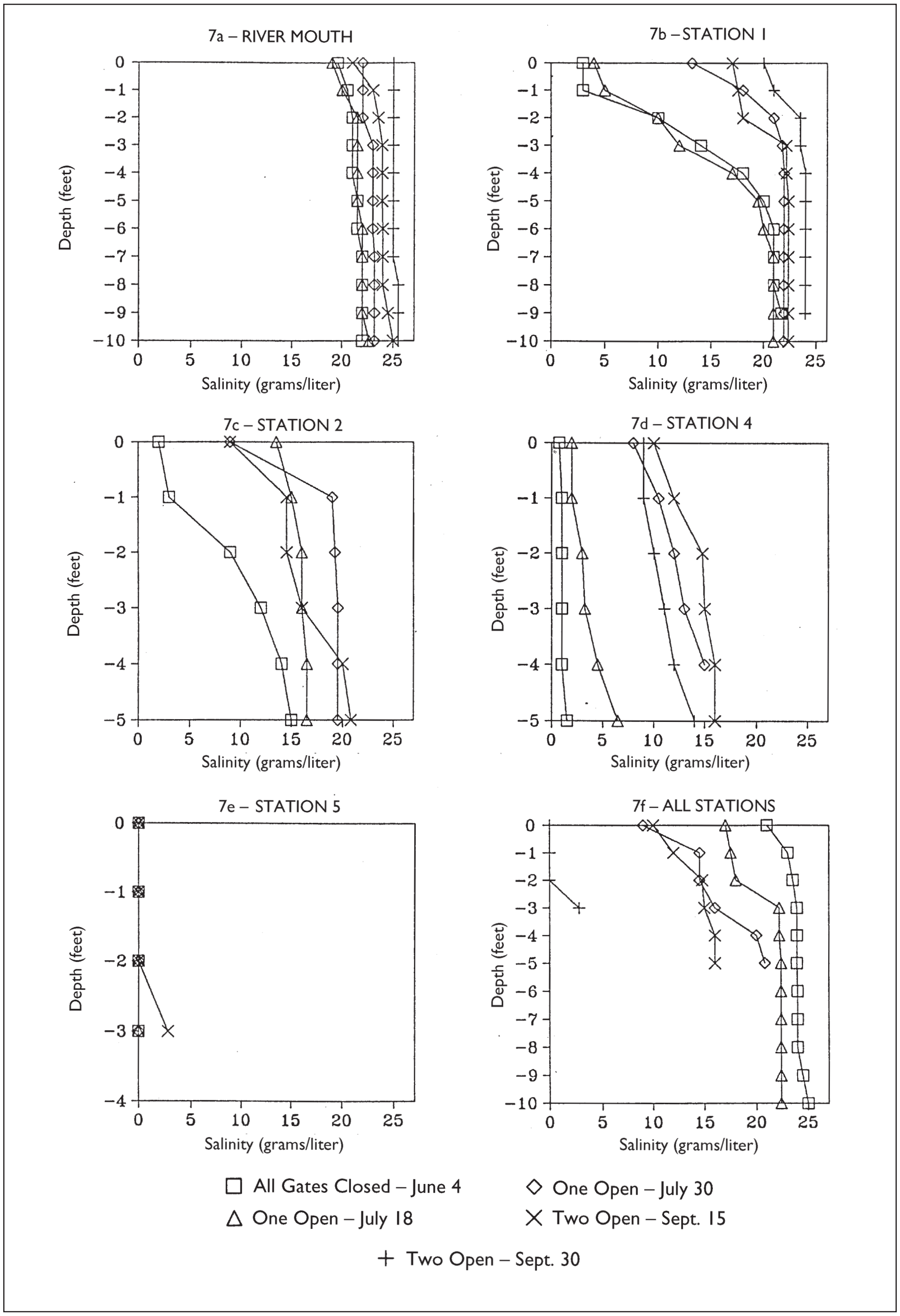


Figure 7. Salinity (g·l⁻¹) versus depth (ft) at the confluence of the West River with New Haven harbor (7a) and stations 1(7b), 2(7c), 4(7d), and 5(7e)(see Figure 2) on June 4,1992 with all gates closed, July 18,1992 and July 30,1992 with one gate open, September 15,1992 with two gates open, and September 30,1992 with two gates open. Figure 7f shows all five sampling sites on September 15, West River, New Haven, Connecticut.

Salinity profiles in the dredged channel were representative of a well-mixed estuarine system (Figure 7d). This may result from persistent on-shore winds mixing water in the long, straight channel. By comparison, salinity profiles were stratified where river flows had greater influence, and along the steeply sloping, forested section of the site that is protected from the wind (Figures 7b, 7c, 7e, and 7f).

As expected, highest concentrations were measured when two gates were opened. Thirty meters (100 ft) upstream of the gates, salinity levels ranged from 9 $g \cdot l^{-1}$ at the water surface to 20 $g \cdot l^{-1}$ at a depth of 150 cm (5 feet). At a sampling site 2.1 km (1.3 miles) upstream from the gates, levels ranged from 0 at the water surface to 3 $g \cdot l^{-1}$ at a depth of 122 cm (4 feet). Elevated salinity caused an increase in turbidity throughout the site, most evident at high tide.

TOPOGRAPHY

Water channel, marsh, and upland surface elevations are recorded on the six, supplementary topographic plans (Sheets T-1, T-2, T-3, T-4, T-5 and T-6).[1] Spot elevations measured in the field are indicated with an asterisk (*). Most of the marsh area within the study site has been altered over time. Historic maps clearly show drainage ditches that existed in 1877. Since then, some areas of the marsh have been filled. Filled areas of the marsh can be grouped into two categories. In the first, marsh surface elevation ranges from 1 to 1.2 m (3.5 to 4 feet) NGVD, about 30 cm (1 ft) above the natural, marsh surface elevation of 0.6 to 0.9 m (2 to 3 feet) NGVD. In the second category, where the marsh has been filled to a greater extent, elevations range from 1.5 to 2.4 m (5 to 8 feet) NGVD. A vibrant salt marsh along the reach of the West River, between the tide gates and New Haven Harbor, has a median surface elevation of approximately 0.8 m (2.8 ft). Some areas of the West River Marsh may have subsided when drainage produced aerobic (oxygenated) soil conditions and accelerated the decomposition of organic material.

Levees are present along most of the length of the dredged channel. Because the levees are less than 3 m (10 feet) in width, they do not appear distinctly on our topographic maps. However, several spot elevation measurements indicate their position and elevation.

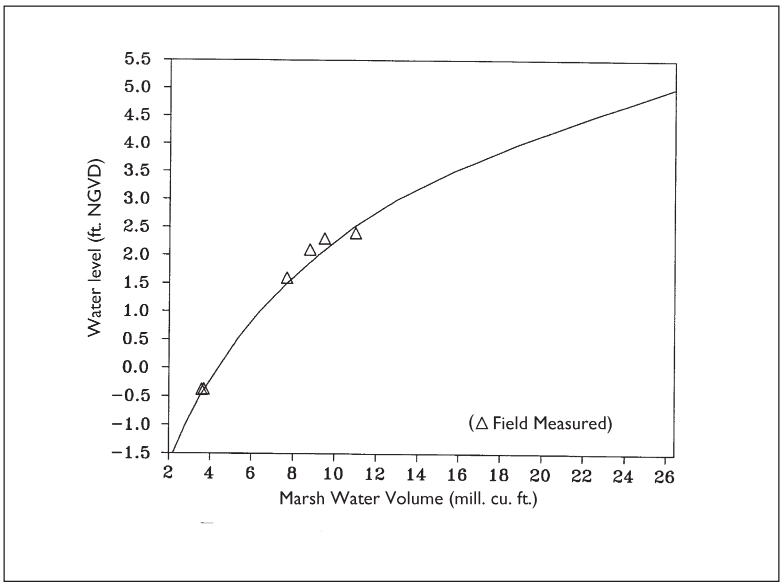
[1] Topographic plans are on file at the Center for Coastal and Watershed Systems, Yale School of Forestry and Environmental Studies, in New Haven.

DERIVATION OF AN ELEVATION-STORAGE FUNCTION

Water storage volumes for the West River Marsh were calculated from the topographic data with SURFER. Volumes were calculated as a function of 15 cm (0.5 ft) elevation increments over an elevation range of -0.45 to 1.5 m (-1.5 to 5 feet). This matrix of elevation and volume data was used to derive the logarithmic equation

$$Y = 2.65(\ln X) - 3.8$$

where Y is the water surface elevation (ft) and X is the corresponding water storage volume (10^6 ft^3) (Fig. 8). We then used numerical integration to determine the total volume of flow for the six tidal events we measured. The volume of water storage resulting from tidal plus freshwater inflow to the marsh was plotted against corresponding, high tide elevation. These data points are shown with triangles superimposed on the elevation-storage function. Close agreement between the equation derived from topographic data and volume calculations and data points developed independently from field measurements validates the accuracy of the regression model.



Close agreement between the equation derived from topographic data and volume calculations and data points developed independently from field measurements validates the accuracy of the regression model.

Figure 8. A function [Y = 2.65 (ln X) - 3.8] relating water surface elevation (Y, ft) to water storage volume (X, 10^6 ft^3) developed from topographic data for the West River Marsh, New Haven, Connecticut. The triangles superimposed on the function show the water surface elevation at high tide versus total volume of inflow calculated by numerical integration from tidal discharge data collected for six events during July through September, 1992.

The West River elevation-storage function can be used to guide hydraulic design of modifications to the tide gates. After a supplementary survey to locate potential flood damage points (e.g., the elevation of the athletic fields on the east side of the park), a target water surface elevation can be designated (2.7 ft., for example). Solving the elevation-storage function with Y = 2.7 yields a corresponding storage (X) of 11.6 x 10^6 ft^3. Dividing this volume by the six hour duration of the flood tide yields an average, required tidal inflow rate of approximately 540 $ft^3 \cdot sec^{-1}$ to reach the target water surface elevation of 2.7 ft. (0.82 m). Median and maximum tidal flow rates can be estimated from the tidal hydrograph data presented in Figure 5. Once design discharge has been determined, the required number of gates and the total cross-sectional area can be accurately estimated (MacBroom 1995).

Field trials and modifications to the position of flotation devices can be used to complete adjustments to Self Regulating Tide (SRT) gates retrofitted to the existing bulkhead. Periodic monitoring of changes in plant and animal communities would aid in the refinement of restoration plans and the systematic adjustment of tidal inflow to the site. SRT gates would protect the existing infrastructure along the West River (e.g., The Connecticut Tennis Center and the Edgewood Park Pond) from storm surges, while allowing the re-establishment of a relatively natural, hydrologic regime and, with time, a salt marsh ecosystem. Alternatively, moving the tide gate structure upstream to the Derby Avenue bridge would protect existing facilities while making virtually all of the marsh available for restoration.

Our field data from the gate opening treatments demonstrate the ability to manage the rate, areal extent, and salt concentration of tidal flooding in the marsh.

The combination of appropriate salt concentrations and tidal flooding is needed for a successful marsh restoration. Hellings and Gallagher (1992) have determined that the growth of common reed is restricted, or terminated, when salinity has reached 30 $g \cdot l^{-1}$ and the site is regularly inundated at high tide. As common reed dies, salt marsh vegetation can become established (Cuomo 1995). During our field experiments, maximum water surface elevation was 2.3 feet (0.7 m) and the tidal inflow was largely confined to the unvegetated channels. Milone and MacBroom (1987) noted that saline water may not reach all marsh surfaces before the tide ebbs, even though the marsh surface lies below the high tide water surface elevation in nearby channels. This disparity occurs because of increased resistance to flow caused by marsh vegetation (relative to smooth tidal channels), the existence of channel edge levees, and shallow overland flow (subject to the frictional resistance of the marsh vegetation) that occurs when the water reaches the marsh surface. Therefore, it may be necessary to lower the marsh surface elevation in some sections. A study by Price and Barten that is in progress will use the topographic data to quantify the area flooded with respect to tidal water level under existing conditions and one or more restoration scenarios.

Our field data from the gate opening treatments demonstrate the ability to manage the rate, areal extent, and salt concentration of tidal flooding in the marsh. The elevation-storage function for the West River Marsh coupled with hydrodynamic models (MacBroom 1995) provide analytical tools for evaluation of restoration alternatives by the community with the help of social scientists, ecologists, landscape architects (Balmori 1995), and engineers.

CONCLUSIONS

Our feasibility study of the tidal zone of the West River indicates that a salt marsh restoration project has a high likelihood of success. Engineers and landscape architects can protect existing infrastructure while providing new amenities to the community. Detailed topographic maps can be used to design modifications of the marsh surface that will maximize the effectiveness of tidal inundation to extirpate the common reed and allow re-colonization by salt marsh plants. A water surface elevation-water storage function and tidal hydrographs measured with one or two gates open provide the basis for hydraulic analyses of gate and flow regime modifications. When combined with ecological and socioeconomic data, and information presented in the balance of this *Bulletin*, our study of the hydrologic structure and function of the West River Marsh provides a biophysical foundation for constructive, community-based change.

ACKNOWLEDGMENTS

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Soils, Sediments, and Contamination

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ABSTRACT
Tidal flow has been restricted from the West River Marsh between Routes 1 and 34 in New Haven, Connecticut for the better part of this century. This has resulted in drier, less saline conditions within West River Memorial Park. Additional impacts to the system include placement of fill on the marsh surface and urban development along the borders and throughout the watershed. Changes in hydrology and the addition of fill have degraded the habitat and changed the system from a tidally flushed salt marsh to a poorly-drained, brackish wetland dominated by reedgrass (*Phragmites australis*). Our analysis of soils and sediments indicates that West River Memorial Park was a well-developed salt marsh system prior to tidal restriction. Sediments are not contaminated with high levels of metals, and the marsh system can be restored without negative impacts to water quality. Sediments that were placed as fill can be moved to create upland islands within the restored marsh system. This will allow for the re-establishment of salt marsh areas while creating a more diverse habitat and reducing costs of removing fill. Discussion in this chapter focuses on the soils, sediments, and water quality changes associated with the restoration of the West River Memorial Park tidal marsh.

Substrate characteristics are very important for the development of a wetland system. The structure and composition of the substrate will determine water holding capacity, nutrient cycling processes, and filtering capacity of the marsh system. The type of sediments and their salt concentrations influence soil chemistry and biogeochemical pathways. The rate at which these sediments accumulate also influences development of the plant community and, in combination with soil characteristics, controls the cycling and sequestering of pollutants within these systems (Orson et al. 1992a).

Substrates in tidal salt marshes are typically silts and clays mixed within an organic peat matrix. Accumulated plant remains form the most important component of salt marsh substrates. The roots, rhizomes, and culms of marsh grasses are well preserved due to wet, oxygen-depleted conditions and salts. Because this material is slow to decompose, it accumulates over time and forms the basis for vertical marsh development (McCaffrey and Thomson 1980, Orson and Howes 1992). Although most peat forms from accumulation of the *in-situ* organic fraction (plant remains), a portion of the substrate is dependent on external sediment sources. When tidal marshes are located along the open coast, much of the mineral sediment comes from the reworking of near shore areas (erosion and resuspension). However, when the marsh is located along a river, such as the West River system, mineral sediments also come from local upland sources as well as mineral sediments of the watershed that are carried downstream (both suspended and bedload).

Since marshes occupy the lowest elevations of the landscape, and their substrates accumulate from both local and regional sources, the substrates record the depositional history of a watershed, its land use patterns (i.e., periods of erosion), and its pollution history. These marshes act as sinks in the landscape (Nixon 1980, Simpson et al. 1983); they retain sediments, thereby keeping river channels from filling with muds, and they sequester and retain pollutants from the open water column, thus reducing negative impacts to downstream aquatic environments.

When tides are restricted from flowing over salt marshes, the marsh substrates not only lose the ability to remove pollutants, but can release pollutants into the aquatic ecosystem.

POLLUTION CONTROL

The mechanisms by which tidal marshes retain and sequester pollutants are only beginning to be understood (Orson et al. 1992a). Some pollutants accumulate in vegetation and are transferred to the substrate as plant material is buried and decomposes (Giblin et al. 1980, Simpson et al. 1983, Orson et al. 1992a). Uptake of pollutants by vegetation can be seasonal. During the growing season, plants can actively limit the uptake of heavy metals. But, when plants are dormant during fall and winter months, their culms and roots absorb higher concentrations of pollutants directly from the water column and transfer it to the substrate (Simpson et al. 1983, Orson et al. 1992a).

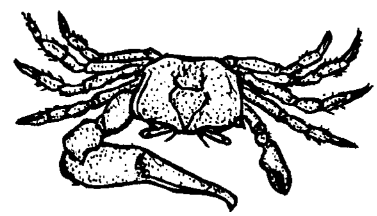
Other pollutants that are carried on highly reactive clay and silt particles can accumulate in sediments. Pollutants carried on clays and silts settle too slowly to be removed from moving water. However, when these suspended particles flow over a vegetated surface water movement slows down. Grasses act as baffles in the water column, and particles have time to settle out of the water on to the marsh surface.

Suspended particles may also accumulate in the marsh system as a result of flocculation. Flocculation occurs as freshwater bearing suspended matter mixes with saltwater. Positive salt cations reduce the natural negative charge of the particles, allowing them to combine into aggregates. The aggregates grow in size, and eventually settle out of the water column.

Coastal tidal marshes are nutrient limited systems (Valiela and Teal 1974, Mendelssohn 1979, Simpson et al. 1983). Because of this, they can remove large concentrations of nitrogen and phosphorus from the water column (DeLaune and Patrick 1980, Aziz and Nedwell 1986, Wiegert and Penas-Lado 1995) by processes in their sediments and substrates (Thompson et al. 1995). Thus, tidal marshes are important for maintaining the health of the estuary by limiting impacts of enriched upland runoff and problems associated with nutrient enrichment of adjacent water bodies.

Tidal marsh substrates are also important sites for many biogeochemical pathways. For example, sulfuric acid, a principal constituent of acid rain, can be cycled to a less acidic form (hydrogen sulfide, pyrite) in salt marsh substrates, thus mitigating the influences of acid precipitation on coastal waters (Dent 1986).

Tidal marsh sediments and substrates also provide habitat for many species of coastal invertebrates including economically important crabs and shellfish. Mussels require a muddy substrate within specific elevations on a vegetated marsh surface (Olmstead and Fell 1974). The distribution of many crab species is also dependent on sediment grain size. Other benthic organisms (i.e., tube worms) are sensitive to grain size as well as rates of sedimentation within stream channels. Because many fish and birds feed on benthic organisms, sediments and substrates are important for maintaining trophic food webs.



*Fiddler crab (*Uca *spp.), an abundant benthic invertebrate that depends on salt marsh substrates.*

TIDAL RESTRICTION

When tides are restricted from flowing over salt marshes, as in the case of West River Memorial Park, a number of changes occur. Some of the pollution remediation processes described above are reversed. As saltwater is excluded, freshwater inputs from rain and upstream drainage reduce substrate salt concentrations. Tidal restriction also lowers water tables and increases the exposure of substrates to air. Subsequent dewatering of sediments and increases in the decomposition of organic matter preserved in the peat often result in compaction of the substrate and a corresponding loss of elevation of the marsh surface (Roman et al. 1984).

The increase in freshwater and oxygen penetrating further into the substrate can alter biogeochemical pathways as well. For instance, reduced sulfur compounds (i.e., pyrite, hydrogen sulfide) that were stable in the salt marsh may oxidize and produce sulfuric acid that is released back into the water column (Dent et al. 1976). Releasing acids can also remobilize heavy metals that have been bound to clay and organic particles. Oxidized sediments can also degrade organic matter and contribute to changes in metal complexes that can then be released into the water column (Allen et al. 1990). As a result, oxidation of marsh soils and the remobilization of heavy metals and other pollutants due to tidal restriction can negatively impact water quality.

SALT MARSH RESTORATION AND WATER QUALITY

Experience has shown that when tides are returned to a formerly restricted marsh system there is a decline in water quality within the first few months due to flushing of stored contaminants out of the peat. In time, however, constant tidal flushing usually reverses the impacts of restricted flow and restores the former water quality of the system.

Marsh systems that have been drained or restricted often show a marked increase in anoxic or hypoxic conditions, which may negatively impact fish and benthic organisms. After tidal flushing has been restored, the effects of oxygen depletion can be reversed, and the habitat can return to more stable oxygen conditions.

A well inundated tidal salt marsh is very effective as a sediment sink within the landscape. In systems where saltwater has been restricted, the loss of flocculation and an increase in peat decomposition will increase the amount of suspended load available to the river system. When tides are reintroduced to a marsh there may be an immediate flush of clays and silts out of the system. But this flush is temporary. As tidal flushing continues, flocculation will increase, decomposition will decrease, and the salt marsh benthic community can become reestablished. These changes will decrease the amount of suspended load available to the river and aid in reducing sediment deposition downstream. Within a few growing seasons after the reintroduction of tides, the negative effects of tidal restriction can be reversed and improvements to water quality achieved.

METHODS

Preliminary sampling of soils and sediments was necessary to identify the type and depth of fill deposited on the marsh surface, characterize the marsh community prior to tidal restriction, and identify potential problems associated with soil chemistry that might result from salt marsh restoration within West River Memorial Park. Heavy metal contamination of existing substrates was of concern, because of the watershed's industrial history and because the source of fill was uncertain.

To characterize the marsh substrates and determine the depth of the former marsh surface, sediment cores were taken using a Russian peat sampler (a manual side chambered coring device). Continuous cores were removed in sections from two locations on the north peninsula. The first core was considered a preliminary sample, and only the second, more detailed core (Fig. 1) is discussed here. The core extended down to a depth of 2.5 m and represented the zone that will be most affected by the reintroduction of tides. Each core

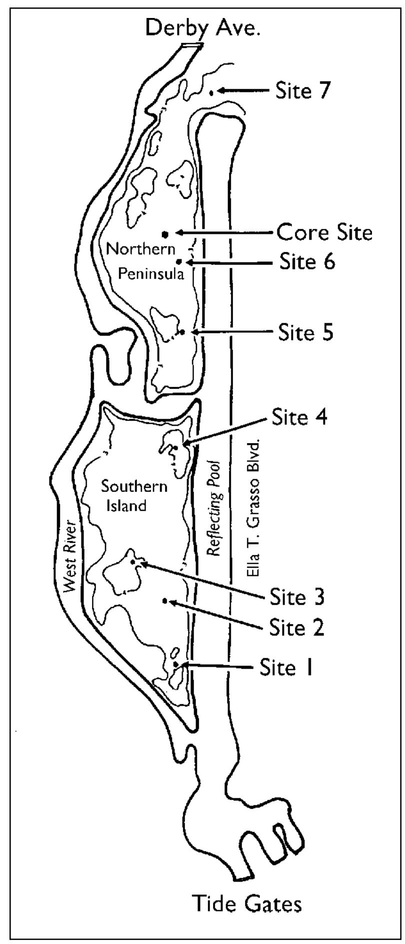


Figure 1. Soil sample and core locations in West River Memorial Park, New Haven, Connecticut.

Table 1. Location of soil sample pits and core in West River Memorial Park by vegetation category and elevation.

Elevation (NGVD)	*Solidago* spp. *Rubus* spp.	*Phragmites* spp.	*B. populifolia* *Q. palustris*
2.5-3.5	Site 1 & 5	Site 6 & 7	
3.5-4.5		Site 2 & Core	Site 3
4.5+			Site 4

section was analyzed for color, texture, and plant remains. Dominant substrate color changes were noted immediately upon removal of the sediments by comparisons to a Munsell Color chart (Orson et al. 1992b). To characterize changes in dominant plant communities through time, we determined the relative abundances of plant taxa at various depths using roots and rhizomes preserved within the peat (Niering et al. 1977, Orson et al. 1987, Orson and Howes 1992). Changes in grain size, plasticity, stickiness, and mineral content and texture were determined using field identification techniques described by U.S. Soil Survey Staff (1975).

Metals analysis and preliminary characterization of fill material were conducted by hand-digging eight pits. Pit locations (Fig. 1) were chosen to represent observed variations in elevation and vegetation. According to field observations, elevation differences corresponded well with vegetative cover and provided a good estimator for locating pits that would represent a variety of conditions (Table 1). (Elevations relative to National Geodetic Vertical Datum were based on maps compiled by Kenny and Barten 1993.)

We dug pits with a shovel until the water table was reached (usually within the first 36 cm), then continued with a bucket auger. Soil horizons were designated based on observed shifts in color, texture, or amount of preserved organic matter. Samples were taken from most horizons for laboratory analysis of metal concentrations, organic fraction, color, and texture. Samples were sealed in Ziploc bags and transported back to a laboratory for storage and analysis.

To determine the presence of pollutants, samples were ashed and analyzed for heavy metals including cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). Approximately 0.5 g of sample was air dried, sieved, and then oven dried at 100°C for two days. Samples were then re-weighed and ashed overnight at 500°C. Organic content was estimated from weight loss on ignition (LOI) and was calculated as

$$\% \text{ LOI} = \frac{(\text{oven dry weight - 500°C weight})}{(\text{oven dry weight - crucible weight})} \times 100$$

Table 2: Sediment characteristics and metal concentrations of soil samples taken from the potential salt marsh restoration area in West River Memorial Park, New Haven, Connecticut.

Site	Depth (cm)	Texture[1]	%LOI	Cd mg/kg	mg/kg	mg/kg	mg/kg
Site 1	0-8	SLTCLY	16.8%	0.4	12.0	87.1	37.7
	8-17	SLTCLY	8.5%	0.6	4.4	14.1	35.1
	17-30	SLTCLY	10.5%	0.4	4.6	10.9	52.0
	>30	SLTCLY	5.7%	0.2	5.1	6.7	19.0
Site 2	0-8	SLTCLY	41.7%	0.6	27.6	174.5	35.8
	8-24	SNDY	1.5%	0.3	2.1	26.4	29.7
	>24	SLTCLY	6.6%	0.2	4.8	6.7	24.0
Site 3	13.5-26	SLTCLY	6.9%	0.4	6.4	31.5	27.8
	26-36.3	SNDY	2.5%	0.1	3.0	7.2	6.7
	36.3-46.5	SLTCLY	5.1%	0.3	5.9	17.5	27.2
Site 4	8-43.5	SNDY	1.9%	0.3	3.4	15.2	6.5
	43.5-56	SNDY	2.7%	0.1	5.8	16.5	7.0
	56-70.8	SLTCLY	6.3%	0.3	15.7	64.3	24.4
	>70.8	SNDY	0.7%	0.1	3.4	1.7	9.5
Site 5	5-9	SLTCLY	9.9%	0.4	3.3	20.2	21.5
	10-15	SLTCLY	11.7%	0.4	4.8	23.6	19.2
	15-18	SLTCLY	7.0%	0.3	2.5	19.3	17.1
	18-23	SLTCLY	9.4%	0.3	2.5	13.8	20.6
	54	SLTCLY					
	108	SLTCLY					
Site 6	0-6	SLTCLY					
	6-14	SLTCLY					
	62	SLTCLY					
	100	SLTCLY					
Site 7	30.5	SLTCLY	11.09%	0.4	9.2	24.6	27.7
	75	SLTYSND	4.96%	0.2	18.5	45.5	27.3
	105	SNDY	1.49%	0.1	5.9	9.6	12.7
Connecticut[2] Residential Criteria		N/A	N/A	34.0	2500.0	500.0	2000.0

[1] SLTCLY = silty clay, SNDY = sandy, and SLTYSND = silty sand.

[2] These criteria are from the *Connecticut State Remediation Standards*. Regular, direct contact with these levels of contamination in residential areas would pose a risk to human health. Although the restoration area is not residential, these state criteria are presented to represent minimum acceptable levels of contamination. A mass-analysis extraction method is used to estimate the state criteria exposure levels. We also used mass-analysis, but our reaction strengths were much more aggressive then those used by either the state or US EPA. Therefore, our method would result in higher estimates of contamination. Nevertheless, our results remain well below the state criteria.

Ashed samples were digested with 50 ml 6N HNO_3 and analyzed for Cu, Cd, Zn, and Pb using inductively coupled plasma emission spectroscopy (Perkin Elmer).

To estimate the area within West River Memorial Park that can be restored through the reintroduction of tides, topographic surveys from 1924 (City of New Haven Parks Department) and a preliminary survey from 1993 (Kenny and Barten 1993) were compared for differences in elevation. The area to be restored was estimated based on a preliminary approximation of areas of fill and subsidence.

RESULTS AND DISCUSSION

The soil core indicated that salt marsh existed at the site for many centuries[1] prior to construction of tide gates within the last 100 years. Evidence of a salt marsh system extended from a depth of approximately 2.5 m to 0.9 m (not adjusted to NGVD). More recent material taken between 1.3 m and 0 .9 m indicated the decline of salt marsh and establishment of a mixed community. Between 0 .9 m and 0.5 m there was evidence that the organic material was highly decomposed, and suggested a shift toward drier conditions. Sand dominated the sediments above 0.5 m, showing the depth of fill at that location. *Phragmites* rhizomes were identified within the upper 0.5 m of vertical development, indicating recent establishment of a *Phragmites* community. Due to compaction as a result of surface drying and placement of fill, it is not possible to assign precise dates to these horizons without further research.

Our preliminary analysis of metals did not indicate high concentrations of Cd, Cu, Pb, or Zn at any site or depth (Table 2). Contamination is typically assessed using U.S. Environmental Protection Agency (US EPA) methods and criteria (US EPA 1979). Our metal extraction method was more aggresive than the US EPA method, and this complicates direct comparison with regulated contaminant levels. However, comparison of our results with other New England sites tested using our method indicated that metal concentrations in the sediments from West River Memorial Park were low (Gaboury Benoit, Yale F&ES, personal communication). In most instances, our samples had lower concentrations of heavy metals than many upland forested areas within the region (Thomas Siccama, Yale F&ES, personal communication). Furthermore, metal concentrations in our samples were well below Connecticut's standards for residential areas (Table 2).

A complex mosaic of sediment types and layering is typical in areas affected by severe, spatially heterogeneous disturbances. Thus, we sampled to characterize a variety of observed sediment types and presumed sediment sources. This is reflected in the variation

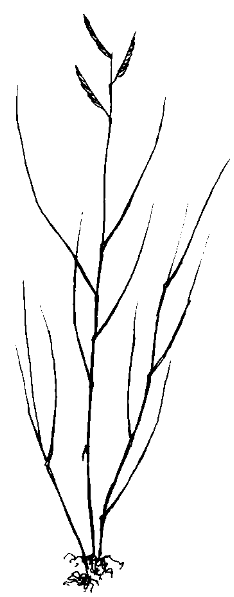
[1] Radioisotope analysis was not performed on the core sediments. Rather, Dr. Orson relied on his experience dating other New England estuarine sediments to estimate age within the West River core.

Table 3. Preliminary marsh area calculations for the West River Memorial Park study site. Sheet numbers refer to those noted in Kenny and Barten (1993). Percent area is based on total area of marsh per sheet. These estimates are not meant to be used for purposes other than discussion.

Sheet	Approx. Area of Fill (sq ft)	Approx. Volume of Fill (cu yds)	% Area at or below 2.5 ft NGVD
T-4	310,000	16,500	40
T-5	640,000	31,000	80
T-6	120,000	6,500	98

of metal concentrations within and among pits. Sediment metal concentrations show expected correspondence with texture class and organic matter content (estimated using LOI). Where textures were finer (silty-clays), and organic matter higher (e.g., 42% for a sample from Pit 2), metal concentrations were highest. The opposite was true for the coarser sediment fractions (sands) with lower organic matter (<10%). We would expect these patterns to occur throughout the area we did not sample. Calculating metal levels more precisely would require more detailed mapping of soil types throughout the park.

A preliminary approximation of the area which can be restored using area below 2.5 ft National Geodetic Vertical Datum (NGVD) is shown in Table 3. Only the areas between the dredged channel and the West River were considered, because the athletic fields and other developed perimeter areas will not be restored to salt marsh. The estimates presented here are based on surveys conducted by Kenny and Barten (1993) and represent a preliminary estimate of the potential area to be restored. Before restoration plans can proceed further, a more detailed topographic survey of the site should be conducted.



*Saltmeadow cordgrass (*Spartina patens*) found in soil cores indicated the former existence of a high salt marsh.*

HISTORIC CONDITIONS

Based on core analysis, West River Memorial Park includes an area that began developing as an open mud flat thousands of years ago. Salt marsh vegetation became established during the time represented within the 2.5 m depth of our core. Material taken from the core between 2.3 m and 1.3 m indicated that a mature salt marsh community, complete with low and high marsh, had developed. Material above 1.3 m indicated subsequent changes to the system. Salt marsh grasses were replaced by other species, which suggests some hydrologic manipulation at the time. These observations are consistent with those from other sites that have been subjected to hydrological manipulations and agriculture, both on the sites and throughout the watersheds.

The shifts in vegetation and the highly decomposed nature of the organics between 0.9 and 0.5 m may correspond to the period when tide gates were installed at the mouth of the marsh system. Drying would have increased decomposition and led to compaction of the marsh surface. When sandy fill was added to the marsh surface (indicated within the uppermost 0.5 m) substrates were further compacted. This probably led to additional lowering of the marsh surface, somewhat offsetting increases in elevation due to the placement of fill on the marsh. Conditions which favored the colonization of reedgrass during the last fifty years include lowering of the marsh surface (flooding kept other upland species from invading the site), the addition of sand (better drainage), and the reductions in salts in the sediments (from continual freshwater flushing).

Surface topographic surveys will be important in estimating how much area can be restored in West River Memorial Park by increasing tidal flushing alone. Surveys conducted by New Haven's Department of Parks, Recreation and Trees in 1924 showed that the elevation of these "meadows" was 2.0 to 2.5 ft NGVD. Recent surveys by Kenny and Barten (1993) showed that a reference salt marsh located downstream near Spring Street has an elevation between 2.5 and 3.0 ft NGVD. Therefore the target elevations for restoration at West River Memorial Park should be about 2.5 ft NGVD. Restoration may require lowering the surface of areas identified by Kenny and Barten (1993) to be above 3.0 ft NGVD. Areas situated between 2.0 and 2.5 ft. NGVD may be left intact depending on the water elevations achieved after tides have been reintroduced. Areas significantly lower than 2.0 ft NGVD may be too low for restoration and will revert to open water unless additional fill is used to raise the surface to at least 2.0 ft NGVD. Using these estimates of elevation, complete tidal flushing would restore 45% of the present marsh area located on the center island. If, on the other hand, the fill is removed and the surface regraded, the area of marsh restoration can be doubled.

The Connecticut Department of Environmental Protection's Wetland Restoration Unit could move sediments and regrade the marsh surface using their amphibious equipment. Although the methods and the technology to move the fill are available, there are economic considerations that must be included in the final analysis. Removal and dewatering of marsh sediments can be very expensive. An alternative to removal of sediments from the site is moving the fill into piles to create upland islands on the marsh surface (Rozsa and Orson 1993). Creating islands would reduce costs of fill disposal and increase habitat diversity.

HEAVY METAL POLLUTION AND WATER QUALITY

Results of the metals analysis show that concentrations of heavy metals are low and will not be of concern when tidal flushing is restored to the system. Although there may be a slight decrease in water quality as flushing begins (i.e., oxygen content, Portnoy 1991; nutrient mobilization, Seitzinger et al. 1991), this should be limited and will probably only last for the first few months. Restoration of the West River Memorial Park should result in better water quality within the first few years of the project.

RESTORATION PROBLEMS AND GOALS

Reestablishing surface elevations will be contingent upon the final goals of the restoration effort. We suggest that the system be restored to an elevation capable of supporting low marsh habitat (ca. 2.25 to 2.75 ft. NGVD). This will help increase the pollution filtering capacity of the site, because low marshes are inundated on all high tides, not just spring tides. A low marsh design will also protect against invasive plant species. Some of the plant species currently growing at the site are tolerant of saline conditions, but only salt marsh grasses are tolerant of both salts and extensive flooding. By considering tide height and surface elevations in the restoration plan, the amount of active management (e.g., planting *Spartina* spp. or removal of invasives) can be greatly reduced.

Restoration of the salt marsh in West River Memorial Park will result in better water quality within the first few years of the project.

The best substrate for the growth of the plants will be the former salt marsh peats. However, in areas where the peats have subsided and are below the flooding tolerance of salt marsh plants, fill can be used to raise the surface elevations. This fill can be taken from existing areas where the elevations are too high.

The reintroduction of tidal flushing will eventually return the substrate in the West River Marsh to a highly reduced, saline condition. The rate of recovery and the time required to return the function of the system will depend upon the ability to control surface elevations in relation to flooding and to replace the biological processes of the system. Past experience with restoration projects in Connecticut suggests that, depending on factors such as funding and the amount of active management, restoration can begin almost immediately, although it will require five to fifteen years to be complete (Rozsa 1995). As the system is restored, its function will also return. Eventually the system will act as a sink for sediments and pollutants within the watershed and provide habitat for coastal biota. Based on other restoration projects, the system should stabilize within two decades and remain a healthy ecosystem if its hydrology is not further altered.

CONCLUSIONS

The West River Memorial Park was a salt marsh system for many centuries before it was degraded. Salt marsh restoration will return the habitat to its former function in the landscape and improve the water quality of the West River ecosystem. Since levels of metal contaminants found within the sediments were low, it will be possible to use existing sediments and fill to create upland habitats (islands) while restoring large portions of marsh habitat. The system is restorable, and plans should proceed to reverse years of neglect and damage to a very important urban, salt marsh habitat.

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Ecological Context and Vegetation Restoration

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ABSTRACT
Baseline information on flora is critical for planning salt marsh restoration in New Haven, Connecticut's West River Memorial Park. This information will be important for evaluating existing site conditions and success or failure of the restoration. This chapter presents results of a plant inventory and addresses the ecological considerations necessary to return salt marsh plants to the site. Aerial photographic interpretation and ground reconnaissance indicate that the potential restoration area is dominated by plant species common to coastal marshlands that have been cut off from tidal exchange for a number of years. The salt marsh community has been replaced by a community dominated by common reed (*Phragmites australis*) with mixes of woody vegetation, cattail (*Typha latifolia*), and a variety of herbaceous dicots such as goldenrod (*Solidago* spp.) and smartweed (*Polygonum* spp.). Restoration at this site is complicated by the presence of fill that was placed on the marsh surface during the 1920s. The fill has raised surface elevations and allowed trees to grow over some areas of the former tidal salt marsh surface. Restoration efforts, therefore, will require a combination of techniques, including the reintroduction of tidal exchange, the removal of fill, and regrading of the surface. Based on similar sites throughout Connecticut, the restoration effort will require ten to twenty years for completion. Periodic ground surveillance and interpretation of future aerial photographs will be required to monitor the success of the restoration.

Tidal salt marshes have been shown to be very important to the health and quality of the coastal zone (Gosselink et al. 1974). Marshes provide habitat for many birds, migratory waterfowl, and a number of macroinvertebrates. These systems are also extremely important in providing spawning grounds and nurseries for many of our commercial fisheries. Tidal salt marshes play a major role in filtering river and coastal waters of sediment and pollutants, thus protecting adjacent bodies of water from damage. They absorb energy from coastal storms and store large volumes of water during storm events. Tidal salt marshes are second only to tropical rain forests in the amount of biomass (organic matter) that they produce. They are among the most biologically productive habitats in nature (De la Cruz 1973).

There are three types of tidal marshes in New England, each defined by the concentration of salt in the water. These three marsh types (salt, brackish, and fresh) can be readily identified by the plants that grow in them (Chapman 1960). Tidal salt marshes are located in areas along the coast regularly inundated by sea water. Because salt concentrations remain above 23 ppt (parts per thousand), this type of tidal marsh is dominated by salt tolerant grasses belonging to the genus *Spartina*, such as saltwater cordgrass

(*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*, typically referred to as salt marsh hay). Other plants that can grow in these saline (salty) areas include spikegrass (*Distichlis spicata*) and blackgrass (*Juncus gerardii*)(Niering and Warren 1980).

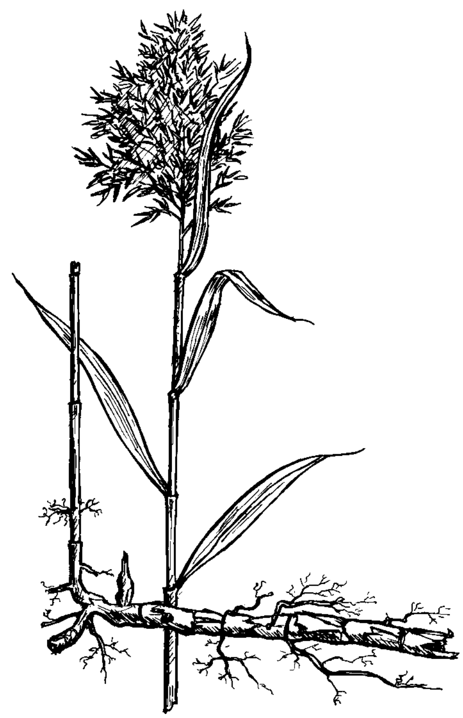
As one moves up a river away from the sea, the influence of freshwater increases and saltwater becomes diluted, creating brackish and eventually freshwater conditions. When salt concentrations are below 20 ppt, tidal brackish marshes form over accumulated sediments. This marsh type typically contains many of the same plants found in the salt marsh (blackgrass and saltmeadow cordgrass), although they are mixed in a community of herbaceous plants such as goldenrod (*Solidago* spp.), silverweed (*Potentilla anserina*), fleabane (*Pluchea purpurascens*), and a variety of sedges (*Carex* and *Scirpus* spp.), rushes (*Eleocharis* and *Juncus* spp.), and some grasses (e.g., *Agrostis stolonifera*). As freshwater inputs continue to dilute saltwater, plants such as common reed (*Phragmites australis*), cattail (*Typha* spp.), and prairie cordgrass (*Spartina pectinata*) become important (Warren and Fell 1995). Tidal freshwater marshes occur in those areas still influenced by tides, but where salt concentrations are close to zero. Here the plant community is commonly dominated by wild rice (*Zizania aquatica*), pickerel weed (*Pontederia cordata*), arrow arum (*Peltandra virginica*), water lily (*Nuphar* sp.), jewel weed (*Impatiens capensis*), bur-marigold (*Bidens frondosa*), and smartweeds (*Polygonum* spp.)(Rozsa and Metzler 1982, Simpson et al. 1983). Although all three types of marshes can be found in Connecticut, the focus of this report will be on the degraded, tidal salt marsh system of the lower West River watershed.

Ecological Restoration *is defined as the intentional alteration of a habitat to reestablish the approximate biological, geological and physical conditions that existed in the predisturbed indigenous habitat.*

PLANT COMMUNITY CHANGES AND COMMON REED

For many centuries, the area today known as West River Memorial Park supported a mature tidal salt marsh community dominated by saltmeadow cordgrass (*Spartina patens*) in the high marsh and salt marsh cordgrass (*Spartina alterniflora*) in the low marsh areas (Orson et al., pp. 123-135, this volume). Within the last few hundred years, human activity has changed the system, culminating with the construction of tide gates and the placement of fill on the marsh surface during the earlier part of this century. The combined impacts of development, agriculture, and hydrological manipulations, both on site and within the watershed, have changed the habitat from tidal salt marsh, to brackish marsh, to a freshwater marsh/upland complex within a relatively short period of time. Within the last 100 to 150 years the system has become brackish to fresh. As the system changed from a salt marsh to a brackish marsh complex, its function as a salt marsh declined accordingly.

Once tides were eliminated from the system and fill was placed on the marsh surface, changes in hydrology and elevation favored colonization by common reed. Common reed is a native plant typically found along the upper, high marsh border (Orson et al. 1987). In the past, this plant was often found in association with cattail and switchgrass (*Panicum virgatum*), and rarely formed the monocultures that we see today. Common reed is generally not tolerant of sea water and grows best in salinities between 0 ppt and 18 ppt (Bjork 1967, Haslam 1973), although recent investigations have found it inhabiting areas with salinities over 22 ppt, suggesting that a genetic variant may be occurring (R. Scott Warren, personal communication, 1997). Common reed has a worldwide distribution and can grow in areas a few feet below sea level to over 10,000 feet above sea level (Haslam 1973). Reed is colonial, rarely spreads by seed, and is an aggressive colonizer. It has been known to expand laterally as much as three meters within a single growing season (Haslam 1973). Its vegetative reproductive structures are highly lignified and strong enough to break through asphalt paving (personal observations). The combination of the strength of the rhizomes, the height of the culms (Buttery and Lambert 1965), and its aggressive nature makes common reed a difficult plant species to remove once it becomes established.



Phragmites australis *(common reed)*

Although native to the area, the recent surge of common reed across Connecticut has been cause for concern. In tidal marshes where tides have been interrupted and/or the soils have been disturbed, this plant has displaced many of the more common species and formed dense monocultures, sometimes covering hundreds of square hectares. Indeed, by 1974 this plant was estimated to have covered over 10% of Connecticut's coastal salt marshes (Niering and Warren 1974, Orson et al. 1982). The impacts of monocultures of common reed on the environment are still being debated. Although it is commonly accepted that monocultures tend to be less biologically productive than more diverse plant communities, recent work along the Connecticut River has suggested that common reed communities may be used by birds as much as the more diverse cordgrass communities (R. Scott Warren, personal communication, 1997). However, the Connecticut River research looked at small stands of reed interspersed with cordgrass communities and did not include areas where reed forms dense monocultures over many hectares.

MARSH RESTORATION

The restoration of a tidal marsh is a slow process, generally requiring one to two decades to complete (Rozsa and Orson 1993). Restoring a system by reintroducing tides is often complicated by a number of factors, including indirect changes to the hydrologic system and reductions in surface elevations within restricted tidal systems. The construction of multiple road crossings can significantly reduce the ability to reintroduce adequate tidal flushing to the site, since inadequate and/or malfunctioning culverts limit the tidal prism upstream. Each successive bridge or crossing may then limit the salt water available to the system to be restored. For this reason, detailed hydrologic investigations are important in designing the vegetation restoration plan (Barten and Kenny, this volume). In addition, many tidally restricted marshes presently dominated by common reed often experience subsurface compaction due to drying and high organic decomposition rates (Roman et al. 1984). Thus, when tides are reintroduced, some of the marsh areas are too low to support salt marsh grasses and convert to open water habitats (Rozsa and Orson 1993). Although loss of elevation due to subsurface compaction at West River Memorial Park may be of concern, at least in some areas, the addition of fill may partially offset surface elevation reductions and aid in the restoration effort. Until a more detailed topographic survey can be completed, it is not possible to estimate the true extent of the problem.

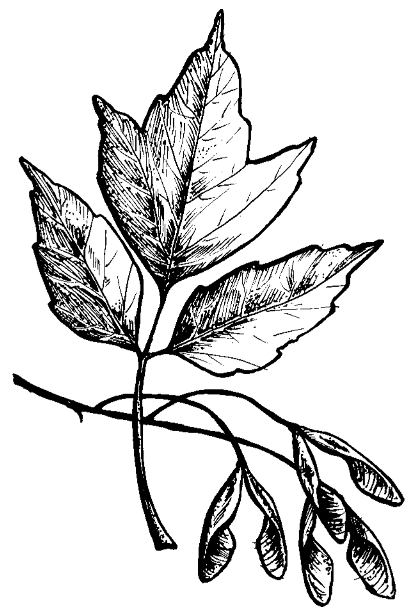
In order to overcome some of the problems associated with marsh restoration, a number of alternative restoration techniques have been employed, among them innovative gate designs (i.e., self-regulating tide gates), acquisition of low lying properties, and multiple plant control techniques (i.e., mowing or burning of reed) (Rozsa and Orson 1993, Rozsa 1995). The time frame to restore the system can be reduced by combining various techniques, such as using reed control measures while increasing tidal flushing. However, these techniques can raise the cost of restoration considerably.

PURPOSE AND GOALS OF THIS INVESTIGATION

The purpose of this study was to establish a baseline vegetation description, document the dominant plant communities, and utilize this information to assess the restoration plans for West River Memorial Park in New Haven, Connecticut. The description of existing plant communities will be important to allow for comparisons in determining the eventual success or failure of the restoration. Since vegetation can be used to evaluate growing conditions, the inventory will provide an estimate of former disturbance and the conditions necessary to restore the area to its pre-twentieth century condition – a cordgrass dominated tidal salt marsh. Because this site not only has been restricted from tidal flow, but also has been subject to the placement of fill, the vegetation inventory will help identify those areas where additional grading may be required.

METHODS

The area of the West River watershed considered for this project lies between the tide gates at Route 1 and Derby Ave (Route 34)(Fig. 1). Existing plant community structure and species inventories within the study area were conducted by Lauren Brown, Penelope Sharp, and members of the Connecticut Botanical Society between April and September, 1995. Since the site was disturbed and the vegetation varied greatly within short distances, traditional plant sampling techniques (i.e., line intercept or quadrat sampling) were not appropriate for describing the marsh system, and alternate methods of analysis were employed. The vegetation was analyzed using remote sensing techniques (aerial photograph interpretation) coupled with ground reconnaissance, because the West River site is a relatively small area and high-quality aerial photographs were available. This enabled the study team to map the vegetation and to identify types and locations of dominant plant communities. Vegetation mapping with this technique is commonly used in similar projects and is typically very accurate. To determine community changes and estimate successional phases, the 1996 plant inventory was compared to a vegetation map prepared in 1965 by Aero Service Corporation.



Acer negundo *(box elder)*

RESULTS

West River Memorial Park is dominated by either common reed, mixed herbs and shrubs, or areas of woody vegetation (Fig.1). Smaller emergent pond fringes and cattail communities were also found. A number of areas are dominated by Japanese knotweed, a recently introduced species. A detailed plant species list can be found in the Appendix.

Woody communities along the river's edge are typical of riparian environments and include box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), red maple (*Acer rubrum*), and silky dogwood (*Cornus amomun*). The remaining uplands are dominated by young oak/hickory forests or include other upland hardwoods such as oaks, Norway maples, and black cherry. On more recently disturbed uplands and sections of the filled marsh, woody plants include black locust (*Robinia pseudoacacia*), tree-of-heaven (*Ailanthus altissima*), and quaking aspen (*Populus tremuloides*). The peninsula of fill that extends south of Derby Avenue contains pin oak (*Quercus palustris*) and gray birch (*Betula populifolia*), two species that rarely grow together, but are not uncommon in areas where marshes have been filled.

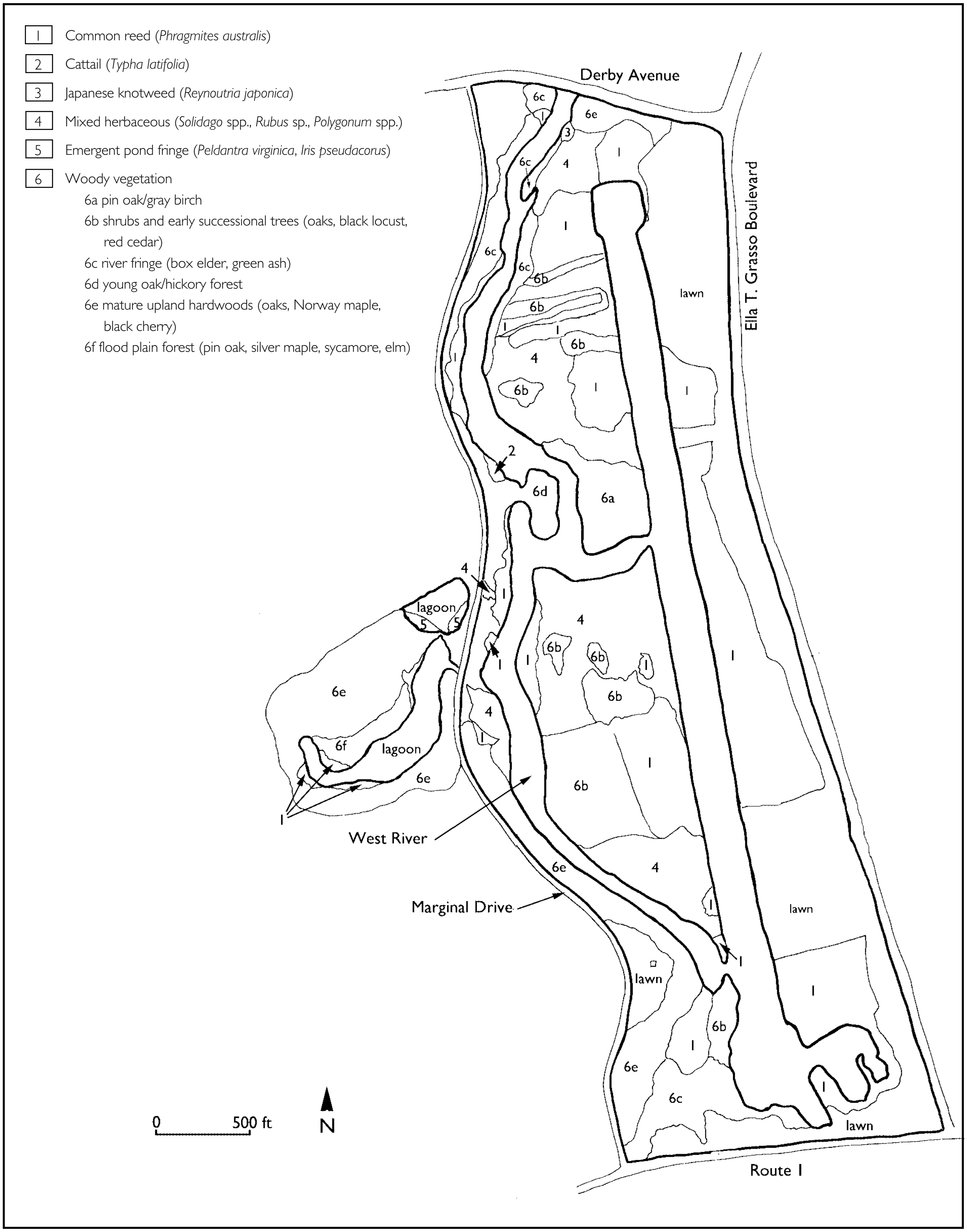
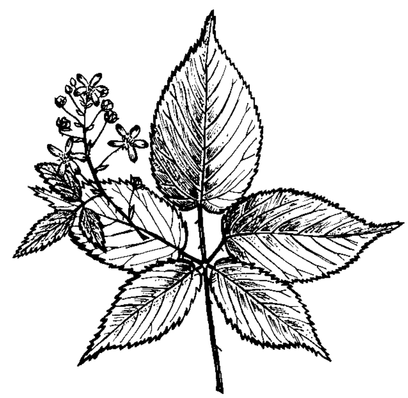


Figure 1. Plant communities of West River Memorial Park, New Haven, Connecticut.

A number of areas in the system are neither woody nor dominated by common reed. These mixed herbaceous and shrub communities are dominated by blackberry (*Rubus* spp.) and goldenrod (*Solidago* spp.). Interspersed within this vegetation are open sandy areas dominated by bayberry (*Myrica pennsylvanica*), meadow sweet (*Spiraea latifolia*), prairie cordgrass (*Spartina pectinata*), and little bluestem (*Schizachyrium scoparium*); and low wet areas dominated by sedges (*Carex stricta*, *Scirpus cyperinus*), Joe-pye weed (*Eupatorium* spp.), and purple loosestrife (*Lythrum salicaria*).

No natural salt marsh communities occur upstream of the tide gates. Since the reed communities are mixed in many places and woody and other herbaceous plants are found on the surface, it is evident that the site has been subjected to multiple disturbances and therefore cannot be defined as a single plant community. However, the combination of plants are typical of systems where tides are restricted and fill has been placed on the marsh surface. No plant species considered by the Connecticut Department of Environmental Protection to be endangered, threatened, or of special concern were found.



Rubus alleghaniensis *(blackberry)*

The closest surviving salt marsh to West River Memorial Park is located downstream at Spring Street in West Haven. This marsh is dominated by a high marsh community. Species found in this marsh include saltmeadow cordgrass, spikegrass, and a variety of herbaceous dicots such as sea lavender (*Limonium nashii*) and salt marsh aster (*Aster tenuifolius*). Marsh elder (*Iva frutecsens*) can be found along the stream channels and levees. Saltwater cordgrass dominates the ditch and stream channel banks. The salt marsh at Spring Street will be a source of seed and propagules for restoration in West River Memorial Park.

Comparison of the present vegetation in the park with a vegetation map prepared during the 1960s showed that the system has changed over the last 30 years. Woody vegetation has increased in the central portion of the site and mixed herbaceous communities have increased toward Route 34. Common reed has declined, woody plants have increased, and Japanese knotweed has become established.

DISCUSSION

PLANT COMMUNITIES

Loss of tidal flushing from a system reduces salinity, changes nutrient exchange rates, and alters microbial communities. These changes typically result in the invasion of non-salt marsh species that outcompete the salt marsh plants. However, reductions in flooding only rarely produce conditions that allow for the colonization of woody plants on the marsh surface as observed at West River Memorial Park. The combination of reduced water flow and increased surface elevations due to the placement of fill has resulted in the distribution of plant species we see today. These conditions will be an important consideration in the successful restoration of this tidal marsh habitat.

Although the distribution of plant species does not allow for a simple classification of plant communities in this system, the vegetation changes observed at West River are comparable to other areas with similar histories of disturbance. The plant community, therefore, accurately reflects recent land-use history in an area of extensive urban development.

MARSH RESTORATION

Restoration of the tidal salt marsh system will require removing fill, reestablishing target surface elevations, and reintroducing tides. Once the fill has been removed and the proper surface elevations have been achieved (Orson et al., pp. 123-135, this volume), tidal flushing can be restored.

With proper elevation and tidal regime reestablished, restoration of salt marsh vegetation can proceed. Reestablishing salt marsh plants can be accomplished using either passive or active management techniques. Passive restoration lets nature restore itself. Once the elevations have been established, and the appropriate number of tide gates have been opened, seeds and propagules from the Spring Street salt marsh may float in on tides and reestablish salt marsh plants to the area. Passive restoration is less expensive and allows nature to select the plants most suited for local site conditions.

In large urban systems such as West River Memorial Park, passive restoration has disadvantages as well. Passive restoration takes time. Seeds and/or propagules must first wash into the system, begin to germinate, and compete for space. Since many areas of the system will not be restored, non-salt marsh plants can continually reinvade the site and slow the spread of desirable plant species. Further, since soil removal may be required, there may be areas on the marsh devoid of vegetation that will require stabilization to prevent erosion. Open soil is also subject to invasion by a number of less desirable plant species that grow faster than some salt marsh grasses. Though passive restoration is often the preferred method, this technique may be less desirable in sites where alteration of the substrate is required.

Distichlis spicata *(spikegrass), a typical grass of high salt marshes.*

Active management restoration is more costly, but it generally reduces the time frame of restoration and increases the chances of success in achieving a target plant community. A number of techniques can be used to promote restoration success. One method is to purchase whole plants and plant them at about 12 inch intervals into the marsh substrate. This is the most expensive active management method, and tends to have the highest rate of success, particularly in areas where erosion is a consideration. It is possible to reduce costs by substituting purchased plants with those collected from other salt marsh systems. However, this technique tends to be labor intensive and will require permission from the Connecticut Department of Environmental Protection. Also, it is important to consider the source salt marsh's size and structure so that collection does not degrade existing habitat. Another active management plan would be to plant seed instead of whole plants. Though less expensive than planting, this method is typically less successful.

Salt marsh restoration in West River Memorial Park may require a combination of techniques: active planting of whole plants, seeding regraded spots, and passive restoration in areas where fill is not removed from the marsh surface or the original salt marsh surface has been exposed. This combination of techniques would insure that target communities are established while reducing costs and impacts to water quality. Using the techniques described above, full marsh restoration will probably require about ten to fifteen years. It is generally best to let restoration proceed at a relatively slow pace (except where exposed soils may erode) so that the system can adjust to the newly established growing conditions. An attempt to restore the entire system within a shorter time frame will likely require unnecessary additional expense.

MONITORING AND FUTURE RESEARCH

Monitoring of the plant community should be conducted annually for the first five years and biannually for the following ten years. To monitor the restoration, it is suggested that a number of standard plant sampling techniques be employed, such as permanent line transects, random quadrat analysis, and remote sensing techniques. Three permanent transects may be established at random points across the islands and marked with pipes driven deep into the sediments. These transects can be sampled annually for elevation changes and plant community composition and density using the line intercept method. This will provide a detailed account of the annual changes to the marsh surface and can be used to monitor success of the restoration. To estimate community changes away from the transects, random sampling with 1/4 m^2 quadrats can be utilized. These measurements should include plant biomass by species (both living and dead), and estimates of species composition. Aerial photography should be conducted at least once every five years, but if money is available, once every two or three years. Remote sensing can be used to qualitatively assess plant community development and aid in determining system-wide impacts of the restoration. Restoration of the aesthetics or visual component of the marsh does not necessarily result in restoration of the biological function of the system. Careful and continual monitoring will help guide future restoration efforts as well as provide an understanding of how the West River tidal marsh system functions.

It will be important to define the parameters that determine success of the restoration. Due to the nature of the system and uncertainty of the final restoration plan, defining success of the restoration cannot be standardized. For example, if the restoration only included opening or replacing the tide gates, restoration success would have to be considered as a return to a dominance of salt marsh vegetation within a mixed community, only in those areas where elevations will permit. By contrast, if the restoration included regrading of the surface and planting with whole plants or seed, initial success could be judged on an 85% survival rate of the target plant communities over a five-year period and establishment of a salt marsh community after 15 years. Once the final restoration plan has been decided, success can be defined and monitoring can be adjusted to determine success.

Careful and continual monitoring will help guide future restoration efforts as well as provide an understanding of how the West River tidal marsh system functions.

Future areas of research may include a long-term monitoring plan (50 to 100 years), biogeochemical analysis of the soils and organic components, and estimates of the filtering capacity of the system. The proximity of West River Memorial Park to Yale University will make it possible to monitor the system well into the future. Since detailed, long-term monitoring results are lacking in restored systems, this would significantly aid in our understanding of biologic systems. Monitoring can be completed once every ten years after the initial 15 to 20 year monitoring phase has passed. Analysis of biogeochemical pathways and processes that occur as the system is restored can be useful in relating the restored marsh to the reference system located at Spring Street. It will be important that a program of sampling be established to determine the filtering capacity of the marsh system. Since filtering the water column is an important function of a healthy salt marsh, estimates of the marsh as a sink will be important in judging the functional success of the restored system.

CONCLUSIONS

The plant community structure in the West River Memorial Park is typical of highly disturbed, partially filled, tidally restricted marsh systems. The presence of common reed and woody vegetation indicates that this disturbance has been present for a number of decades. Restoration of the system will result in a decline in reed and the eradication of woody plants in lower elevations on the marsh. Removal of the fill, adjustments of the elevations, and reintroduced tides will be required for complete salt marsh restoration in West River Memorial Park. Depending on the ability to adjust surface elevations and control tidal flushing, there is reason to believe that salt marsh restoration can be successful. Restoration efforts in other systems along the coast of Connecticut have been very successful when properly planned. Such planning requires a baseline plant inventory and careful hydrologic modeling (Barten and Kenny, this volume). Restoration efforts usually take 5 to 15 years to complete depending on the level of financial support and human resources dedicated to the effort.

The advantages of restoring the salt marsh are numerous and should be pursued. In urban areas these habitats are important for maintaining water quality, providing wildlife habitat, and improving aesthetics. Natural habitats are rare in many urban areas, which diminishes human quality of life. Restoration of the West River system will improve water quality of the river and provide the people living in this urban environment with an important and educational natural resource.

ACKNOWLEDGMENTS

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APPENDIX: PLANT SPECIES OF WEST RIVER MEMORIAL PARK[1]

Pinaceae (Pine Family)
- *Juniperus virginiana* (red cedar)

Typhaceae (Cattail Family)
- *Typha latifolia* (common cattail)

Gramineae (Grass Family)
- *Agropyron repens*[2] (quack grass)
- *Calamagrostis canadensis* (bluejoint grass)
- *Dactylis glomerata*[2] (orchard grass)
- *Phragmites australis* (common reed)
- *Poa pratensis*[2] (Kentucky bluegrass)
- *Schizachyrium scoparium* (little bluestem)
- *Spartina pectinata* (freshwater cordgrass)

Cyperaceae (Sedge Family)
- *Carex crinita* (sedge)
- *C. stricta* (tussock sedge)
- *C. spp.* (sedges)
- *Fimbristylis autumnalis*
- *Scirpus cyperinus* (wool-grass)

Araceae (Arum Family)
- *Peltandra virginica* (arrow arum)

Juncaceae (Rush Family)
- *Juncus effusus* (soft rush)

Liliaceae (Lily Family)
- *Smilacina racemosa* (false spikenard)

Iridaceae (Iris Family)
- *Iris pseudacorus*[2] (yellow iris)
- *I. versicolor* (blue flag)

Salicaceae (Willow Family)
- *Populus deltoides* (cottonwood)
- *P. tremuloides* (trembling aspen)
- *Salix babylonica*[2] (weeping willow)
- *S. nigra* (black willow)

Myricaceae (Wax Myrtle Family)
- *Myrica pensylvanica* (bayberry)

Juglandaceae (Walnut Family)
- *Carya glabra* (pignut hickory)
- *C. ovata* (shagbark hickory)

Corylaceae (Hazel Family)
- *Alnus sp.* (alder)
- *Betula populifolia* (gray birch)
- *B. lenta* (black birch)

Fagaceae (Beech Family)
- *Fagus grandifolia* (American beech)
- *Quercus alba* (white oak)
- *Q. bicolor* (swamp white oak)
- *Q. coccinea* (scarlet oak)
- *Q. palustris* (pin oak)
- *Q. rubra* (red oak)
- *Q. velutina* (black oak)

Ulmaceae (Elm Family)
- *Ulmus americana* (American elm)
- *U. rubra* (slippery elm)

Moraceae (Mulberry Family)
- *Morus alba*[2] (white mulberry)

Urticaceae (Nettle Family)
- *Urtica dioica*[2] (stinging nettle)

Polygonaceae (Buckwheat Family)
- *Polygonum sagittatum* (arrow-leaved tearthumb)
- *P. scandens* (climbing false buckwheat)
- *Reynoutria japonica*[2] (Japanese knotweed)
- *Rumex crispus* (curled dock)

Chenopodiaceae (Goosefoot Family)
- *Chenopodium album*[2] (lamb's quarters)

Phytolaccaceae (Pokeweed Family)
- *Phytolacca americana* (pokeweed)

Caryophyllaceae (Pink Family)
- *Saponaria officinalis*[2] (bouncing bet)
- *Silene alba*[2] (white campion)

Papaveraceae (Poppy Family)
- *Chelidonium majus*[2] (celandine)

Cruciferae (Mustard Family)
- *Hesperis matronalis*[2] (dame's rocket)

Platanaceae (Plane Tree Family)
- *Platanus occidentalis* (American sycamore)

[1]This list is meant to be comprehensive, but not all-inclusive.

[2]Alien species that are not indigenous to Connecticut.

Rosaceae (Rose Family)
- *Agrimonia gryposepala* (hairy agrimony)
- *Amelanchier canadensis* (shadbush)
- *Geum canadense* (white avens)
- *Pyrus communis*[2] (common pear)
- *P. malus*[2] (apple)
- *Rosa multiflora*[2] (multiflora rose)
- *R. palustris* (swamp rose)
- *Rubus alleghaniensis* (blackberry)
- *Spirea latifolia* (meadowsweet)
- *S. tomentosa* (steeplebush)

Leguminosae (Pulse Family)
- *Gleditsia triacanthos*[2] (honey locust)
- *Robinia pseudo-acacia*[2] (black locust)

Rutaceae (Rue family)
- *Phellodendron amurense*[2] (cork tree)

Simaroubaceae (Quassia Family)
- *Ailanthus altissima*[2] (tree-of-heaven)

Anacardiaceae (Cashew Family)
- *Rhus coppalina* (shining sumac)
- *R. glabra* (smooth sumac)
- *R. typhina* (staghorn sumac)
- *Toxicodendron radicans* (poison ivy)

Aquifoliaceae (Holly Family)
- *Ilex verticillata* (winterberry)

Celastraceae (Staff-tree Family)
- *Celastrus orbiculatus*[2] (oriental bittersweet)

Aceraceae (Maple Family)
- *Acer ginnala*[2] (Amur maple)
- *A. negundo* (box elder)
- *A. Platanoides*[2] (Norway maple)
- *A. rubrum var. rubrum* (red maple)
- *A. rubrum var. trilobum* (red maple)
- *A. saccharum* (sugar maple)
- *A. saccharinum* (silver maple)

Balsaminaceae (Touch-me-not Family)
- *Impatiens capensis* (jewelweed)

Vitaceae (Grape Family)
- *Parthenocissus quinquefolia* (Virginia creeper)
- *Vitis sp.* (wild grape)

Malvaceae (Mallow Family)
- *Hibiscus palustris* (rose mallow)

Eleagnaceae (Oleaster Family)
- *Elaeagnus umbellata*[2] (autumn olive)

Lytheraceae (Loosestrife Family)
- *Lythrum salicaria*[2] (purple loosestrife)

Onagraceae (Evening Primrose Family)
- *Epilobium sp.* (willow herb)
- *Ludwigia alterniflora* (seedbox)
- *Oenothera biennis* (evening primrose)

Umbelliferae (Parsley Family)
- *Daucus carota* (Queen Anne's lace)
- *Osmorhiza claytonii* (sweet cicely)

Cornaceae (Dogwood Family)
- *Cornus amomum* (silky dogwood)
- *C. racemosa* (gray dogwood)

Ericaceae (Heath Family)
- *Vaccinium corymbosum* (highbush blueberry)

Oleaceae (Olive Family)
- *Fraxinus americana* (white ash)
- *F. pennsylvanica var. subintegerrima* (green ash)

Verbenaceae (Vervain Family)
- *verbena hastata* (blue vervain)

Solanaceae (Nightshade Family)
- *Solanum dulcamara* (climbing nightshade)

Bignoniaceae (Bignonia Family)
- *Catalpa bignonioides* (common catalpa)

Rubiaceae (Madder Family)
- *Cephalanthus occidentalis* (buttonbush)

Caprifoliaceae (Honeysuckle Family)
- *Lonicera japonica*[2] (Japanese honeysuckle)
- *Sambucus canadensis* (common elderberry)

Compositae (Composite Family)
- *Arctium minus*[2] (common burdock)
- *Artemesia vulgaris*[2] (common mugwort)
- *Aster* spp. (asters)
- *Chicorium intybus*[2] (common chicory)
- *Cirsium vulgare*[2] (bull thistle)
- *Eupatorium* sp. (Joe-pye weed)
- *Mikania scandens* (climbing hempweed)
- *Solidago altissima* (tall goldenrod)
- *S. graminifolia* (grass-leaved goldenrod)
- *S. juncea* (early goldenrod)
- *S. rugosa* (rough-stemmed goldenrod)

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A paleoecologist with over 15 years experience in tidal marsh restoration and environmental management, Dr. Orson has degrees in biology and botany and received his Ph.D. in Ecology at Rutgers University in 1989. A former Assistant Professor of Geography and Environmental Sciences, he has had his own environmental consulting firm since 1995. His research interests include impacts of sea level rise on coastal marsh development, modelling heavy metal accumulations in wetland systems, and applications of paleoecology to managing coastal habitats. Dr. Orson was a member of the original team that helped establish the State of Connecticut's coastal marsh restoration program.

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Section III: Biological Indicators

> *"Biological diversity is the key to the maintenance of the world as we know it. Life in a local site struck down by a passing storm springs back quickly: opportunistic species rush in to fill the spaces. They entrain the succession that circles back to something resembling the original state of the environment."*
>
> *– from* The Diversity of Life*, Edward O. Wilson*

An important design goal of urban restoration is to enhance ecological functions within existing ecosystems, rather than attempt to restore all pre-disturbance functions, which is impossible in urban landscapes. Using the existing biota of West River Memorial Park in New Haven, Connecticut the authors in this section describe the difficulties confronting urban restoration. They also recommend design criteria that would maximize habitat restoration within an urban context, and discuss methods for monitoring restoration using biotic communities.

Benthic Invertebrates of the Lower West River

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ABSTRACT
The purpose of this study was to document existing benthic organisms of the lower West River in New Haven and West Haven, Connecticut, in order to enable monitoring of salt marsh restoration. Seventeen sites were sampled between the Chapel Street Bridge and the mouth of the West River during the month of July 1995. All sites contained polychaete worms and other organisms typical of estuarine systems. The northernmost sites also contained some freshwater organisms, the most abundant of which were chironomids and freshwater snails. The presence of estuarine fauna within tide-restricted portions of the West River is attributed primarily to the malfunctioning of tide gates during the sampling season in combination with a regional drought. These conditions provided a favorable environment for estuarine organisms to colonize and provided an opportunity to determine that restoration of the estuarine benthos would occur if estuarine water flow was returned to the river as a part of salt marsh restoration. Periodic sampling of the benthic community would be an effective component of restoration monitoring.

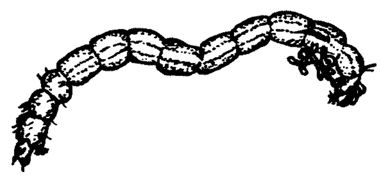
Benthic invertebrate communities are integral components of both freshwater and estuarine systems. The benthos – those organisms that live on or within sediments – influence sediment and bottom-water chemistry (Rhoads et al. 1977, Aller 1980, 1982), alter sediment organic content (Pearson and Rosenberg 1978) and structure (Rhoads and Young 1970, 1971, Bokuniewicz et al. 1975, Rhoads et al. 1978, Rhoads and Boyer 1982), and serve as major prey species for crustaceans and fish (Virnstein 1977). Although freshwater and estuarine benthos perform similar ecological functions, organismal composition is quite different. Common members of freshwater benthic communities include oligochaete worms, chironomids (dipteran larvae), numerous other insect larvae, insect adults, leeches, freshwater gastropods (snails), and freshwater bivalves (e.g., clams). Estuarine benthos typically include nematode worms, polychaete worms, amphipods, crustaceans, marine gastropods, and marine mollusks.

Rhoads and Germano (1982) documented a series of predictable, successional stages for estuarine benthic communities. These successional sequences (Stages I, II and III) are characterized by particular, functional types of benthic organisms. One functional type succeeds another over time if all else remains stable. Organisms comprising Stage I estuarine assemblages colonize newly available seafloor, such as that which becomes available when a freshwater habitat is inundated by saline water. A change in benthic community composition from freshwater benthos to a Stage I estuarine benthic assemblage can be expected to occur with salt marsh restoration. As saline estuarine waters are introduced into a freshwater marsh environment, freshwater organisms such as chironomids, leeches, and oligochaetes will be replaced by salt-tolerant Stage I organisms such as polychaete worms and amphipods.

The purpose of this study was to document the existing benthic organisms and habitat characteristics (e.g. salinity, sediment type, dissolved oxygen) of the lower regions of the West River. These data were intended to form the basis for monitoring changes as a result of salt marsh restoration.

METHODS

Field collections were undertaken during July, 1995, at 17 sites within the lower region of the West River (Fig. 1). Sites were chosen to represent a cross-section of the variety of benthic conditions and to include areas likely to be impacted by restoration. Primary criteria included proximity to vegetation, proximity to shoreline, depth, freshwater inflow, and bottom sediment type. The northernmost site was located under the Chapel Street Bridge, and the southernmost site was located at the mouth of the West River, where it enters New Haven Harbor.



Chironomid – a typical freshwater benthic organism.

Three, and sometimes four, grab samples were taken at each site using a small (0.25 m^2) Van Veen grab. Samples were placed in 2-liter Nalgene jars, fixed with 10% formalin, stained with rose bengal, covered, and labeled with site identification. Upon return to the laboratory, all samples were decanted and sieved through a 125 µm sieve. Materials retained on the sieve were examined under a dissecting microscope, and all organisms were removed and placed in labeled glass vials. Samples were later transferred to 70% ethanol and identified. Some organisms were identified to species, but the majority of identifications were to genus. This level of identification was adequate for a preliminary study, given sampling and time constraints. It is recommended that long-term monitoring include species-level identification whenever possible in order to provide a more detailed record of restoration.

Dissolved oxygen, sulfide, salinity, and water temperature were measured from bottom-water samples taken concurrently with benthic samples. Dissolved oxygen and sulfide were measured using standard chemical titration methods (Campbell and Wildberger 1992). Sediment characteristics such as grain size, organic content, and degree of cohesion were determined visually and recorded at the time of collection.

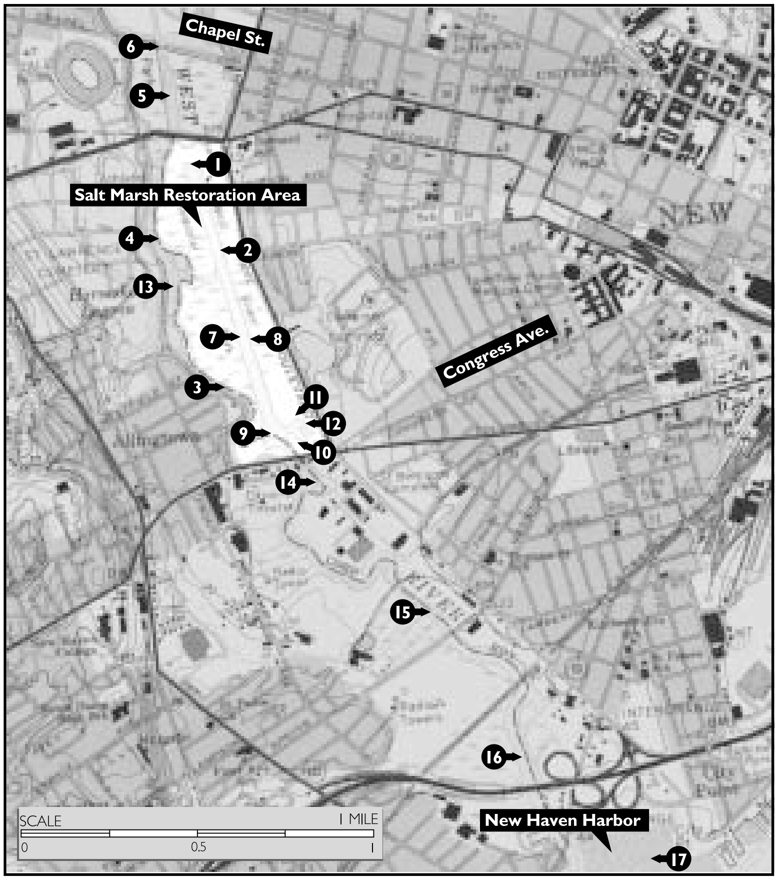


Figure 1. Benthic invertebrate sampling locations in the lower West River, July, 1995.

RESULTS

All sites contained fauna typically associated with estuarine systems (Table 1). Benthic polychaete worms, nematode worms, and tubiculous amphipods dominated the samples. Few sites (i.e., 2, 4, 5, and 6) contained benthic organisms such as chironomids, leeches, gastropods, and insect larvae typically associated with freshwater systems, and estuarine fauna dominated even these samples. No endangered, threatened, or species of special concern were found in any samples.

Polychaetes were dominated by capitellids, which were found at all but one site (site 16). Ampeliscid amphipods (small tube-dwelling crustaceans) were also present throughout the lower River. Free-swimming gammarid amphipods were identified at some sites. Benthic fauna collected at the mouth of the River resembled background estuarine communities typical of New Haven Harbor (McCusker and Bosworth 1981).

Table 1. Benthic organisms of the lower West River, New Haven, Connecticut, sampled during July, 1995.

Site 1
40 *Capitella* spp.
6 *Gammarus* spp.
2 *Streblospio benedicti*
1 *Stenothoe* spp.

Site 2
15 *Capitella* spp.
8 *Ampelisca abdita*
5 *Streblospio benedicti*
2 Chironomidae
Uca sp. (fiddler crab)[1]

Site 3
36 *Capitella* spp.
20 *Ampelisca abdita*

Site 4
15 Nematoda
7 Chironomidae
6 *Capitella* spp. (plus abundant fragments)
1 Amphipoda
1 Ostracoda
2 fish eggs

Site 5
887 *Capitella* spp.
144 Chironomidae
99 Nematoda
22 Nemertinea
12 *Notomastus* sp.
12 Ostracoda
11 Amphipoda
5 fish eggs
4 fly larvae
2 Copepoda
2 Ophelidae
1 *Stenothoe* sp.
1 Leech

Site 6
15 *Capitella* spp.
4 *Streblospio benedicti*
1 Chironomidae

Site 7
17 *Capitella* spp.
12 *Ampelisca abdita*
6 *Ophelia* sp.
1 *Streblospio benedicti*

Site 8
24 *Capitella* spp.
10 *Ampelisca abdita*
5 *Gammarus* spp.
1 *Streblospio benedicti*

Site 9
16 *Capitella* spp.
13 *Streblospio benedicti*
5 *Gammarus* spp.
Callinectes sapidus (blue crab)[1]

Site 10
10 *Capitella* spp.
6 *Gammarus* spp.

Site 11
12 *Ampelisca abdita*
7 *Streblospio benedicti*
6 *Ophelia* sp.
5 *Capitella* spp.
1 *Gammarus* sp.

Site 12
12 *Capitella* spp.
7 *Ampelisca abdita*
4 *Streblospio benedicti*

Site 13
45 *Ampelisca abdita*
16 *Capitella* spp.
3 *Pectinaria gouldii*

Site 14
23 *Capitella* spp.
14 *Ampelisca abdita*
10 *Steblospio benedicti*
3 *Ophelia* sp.

Site 15
11 *Capitella* spp.
2 *Streblospio benedicti*
2 Sabellidae
2 *Gammarus* spp.
1 *Ampelisca abdita*
Uca sp. (fiddler crabs)[1]

Site 16
34 *Ampelisca abdita*
30 *Streblospio benedicti*
2 *Scolecolepides* spp.

Site 17
18 Nematoda
12 *Streblospio benedicti*
11 *Ampelisca abdita*
10 *Gammarus* spp.
7 *Capitella* spp.
7 *Corophium volutator*
7 unidentified benthic foraminifera
4 Mysid shrimp
2 Copepoda
1 Isopoda
1 *Polydora ligni*
Numerous polychaete fragments

[1] Collected by Moore et al. during their study of West River fish communities.

Table 2. Physical parameters and bottom water dissolved oxygen and sulfide at West River sampling sites, New Haven, Connecticut during July, 1995.

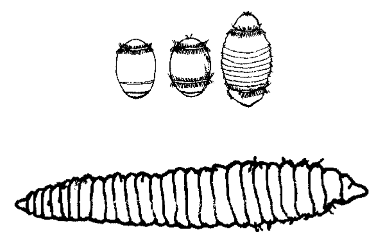
Site	Salinity (ppt)	Temperature (°C)	Sediments	Dissolved Oxygen (mg/l)	Dissolved Sulfide (ppm)
1	na	22.5	black mud, leaf litter	0.00	0.25
2	20.6	21.7	muddy sand	0.00	0.20
3	7.7	23.6	black mud	4.80	0.00
4	3.9	20.3	sandy black mud	6.50	0.00
5	3.2	19.3	muddy sand	na	na
6	1.9	19.7	sand	7.80	0.00
7	25.5	23.5	rocky with a distinct odor of H_2S	15.80	0.00
8 [1]	3.2	23.3	black mud with leaf litter	6.40	0.00
9	16.3	24.0	fine, black mud with H_2S odor	9.40	0.00
10	na	na	large rocks	5.20	0.00
11	13.5	na	rocky sand	17.20	0.00
12	17.1	24.0	black mud	10.00	0.00
13	4.6	23.8	black mud	4.30	0.00
14	10.3	27.5	muddy shell hash	6.50	0.00
15	14.9	na	muddy peat	4.70	0.00
16	27.5	26.0	watery black mud	6.50	0.00
17	na	na	mud with *Ulva* sp. (sea lettuce)	13.10	0.00

[1] Storm sewer outfall or groundwater flow.

Salinity measurements ranged from 1.9 parts per thousand (ppt) to 27.5 ppt (Table 2). Overall, there is a decrease in salinity as one moves up river. Low salinity readings from downstream (e.g., site 8) are attributed to groundwater percolation and/or presence of storm sewer outfalls. Bottom-water temperatures ranged from 19.3°C to 27.5°C. The range can be attributed to differences in water depth, as well as relation to local groundwater influx and storm sewer outflows. Sediments ranged from mixed pebbles and silty sands to black, colloidal, sulfidic muds. The majority of sites sampled contained muds and sands typically associated with river systems. The larger rocks and hardground areas are believed to be areas of fill. Dissolved oxygen and sulfide measurements also varied over the sampling region (Table 2). Organic content of the sediments appeared to be rather high, as evidenced by black color of the sediments, abundance of plant debris, and the distinctive odor of H_2S detected at many sites. Low dissolved oxygen levels and/or presence of H_2S can be directly related to the abundance of organic matter present and the relative amount of water movement. High organic content, such as that near sewer outfalls, increases decomposition resulting in lowered dissolved-oxygen levels in bottom-waters. Species tolerant of low levels of dissolved-oxygen and high levels of organic matter, such as capitellids, rapidly and abundantly colonize such areas (McCall 1977, Pearson and Rosenberg 1978).

DISCUSSION

The benthic fauna of West River above the tide gates at Congress Avenue were expected to represent a New England freshwater system. Indeed, since a primary purpose of tide gates is to eliminate saltwater inflow, only freshwater-tolerant benthic organisms should have been found. However, the tide gates failed to function properly during the sampling period. We regularly observed one gate wedged open by debris and at least one other malfunctioning. Thus, a significant amount of saltwater exchange was able to occur upstream of the tide gates, reaching as far north as the Chapel Street bridge, where salinity was 1.9 ppt. Further complicating the situation was a drought that persisted throughout the spring and summer of the sampling year. At one point, freshwater flow from the headwaters ceased, as evidenced by the dry river bed observed north of Whalley Avenue (J. Cunningham, Foote School Science Program, personal communication). The only freshwater input to the lower reaches of West River during this period came from overland runoff, groundwater percolation, and storm-sewer discharge.



Life stages of Capitella capitata *– a typical polychaete of the lower West River (not to scale).*

These factors provided favorable conditions for studying the potential estuarine benthic recolonization of West River that would result from restoration of estuarine water flow. Rather than providing baseline data on the freshwater benthic communities of West River, this study showed that estuarine restoration of the West River benthos could be readily accomplished given increased exchange with Long Island Sound. Tracking changes in benthic organisms appears to be a viable method for detecting whether or not the system under restoration is responding to salinity shifts, such as would be expected by opening existing tide gates or installing self-regulating tide gates.

Rhoads and Germano (1982) have described a characteristic, estuarine, benthic pioneering community (Stage I) that inhabits recently disturbed and/or newly created estuarine sedimentary environments. These assemblages initially consist primarily of small, surface deposit-feeding, tubiculous polychaetes, oligochaetes, and/or mactrid bivalves, such as *Mulinia lateralis.* Such organisms are frequent and abundant prey species for commercially important fish and crustaceans that inhabit Long Island Sound, such as flounder and blue crabs (R.Whitlatch, Director, Department of Marine Sciences, University of Connecticut, Groton, Connecticut, personal communication). Species composition of the Stage I community depends on sediment type, disturbance frequency, larval availability, and organic/pollutant load. Certain polychaetes, such as *Capitella* spp., are extremely tolerant of organically-loaded and/or polluted systems and low-oxygen, highly sulfidic environments. These organisms are frequent colonizers of dredge-spoils, sediments near sewage outfalls, and other polluted environments (Pearson and Rosenberg 1978). *Capitella* spp. were the most common organisms found above the tide gates (Table 1).

Benthic fauna of the potential salt marsh restoration area in the West River represent a dynamic system that will respond readily to changing salinity of the overlying water.

Pioneering organisms are joined by small, tubiculous amphipods (e.g. *Ampelisca abdita*) and/or shallow-dwelling bivalves (e.g. *Tellina agilis*)at a slightly later time. This assemblage comprises Stage II of the developing community. If no disturbance occurs to reset the successional process, the intermediate Stage II community will eventually be succeeded by organisms, such as maldanid polychaetes and/or nuculid bivalves and/or *Molpadia oolitica* (sea cucumbers), that feed and burrow deeper in the sediment. Estuarine sediments located at or above mean storm wave base rarely develop communities beyond Stage II, because they are subjected to frequent sediment disturbance (McCall 1978). Such disturbance resets the successional sequence and maintains the system in a Stage I-early Stage II assemblage (Rhoads and Germano 1982). This is also true for areas receiving large amounts of sewage and/or dredge spoil (McCall 1977, 1978, Pearson and Rosenberg 1978, Rhoads and Germano 1982).

Most of the sampling sites within West River fit the Stage I-Stage II descriptions of the Rhoads and Germano (1982) model. Sites 4, 5 and 6, located in the upper reaches of the lower West River (Fig. 1), were dominated by capitellid polychaetes and can be characterized as early Stage I communtities. These sites also contained some relict freshwater fauna such as chironomids, as well as some brackish-water tolerant gastropods. The sites located within the reflecting pool (sites 1, 2, 7, and 8), as well as those located in the side channel and the lower part of the main channel (sites 3, 9, and 10-13) can be classified as being in late Stage I-early Stage II of estuarine benthic succession. Interestingly, no purely freshwater, benthic community was documented within the lower West River. Sites below the tide gates (sites 14-17) also contained organisms characteristic of a late

Stage I-early Stage II evolving nearshore, organic-rich, estuarine community. Such communities are typically representative of benthic communities located on fine-grained sediments above mean storm wave base in this region of Long Island Sound (Rhoads and Germano 1982).

The sampling scheme employed in this study worked quite well. It is recommended that such a scheme be used as one method for gauging the progress of estuarine restoration. This study has shown that organism identification down to the genus level, supplemented by occasional species-level identification, is more than adequate for monitoring restoration. The presence of Stage I assemblages can be taken as early indicators that the benthos is responding to salinity change. The ultimate, successional stage reached by benthic communities in any salt marsh restoration effort, however, is going to be dependent on many factors, not the least of which is the successional stage of the larger estuarine system in immediate contact with the restoration area. For example, the successional stages present in a restored salt marsh in the lower reaches of the West River should, at maximum development, be functionally identical to those located below the tide gates, although individual species composition and abundance may vary somewhat.

A common argument for salt marsh restoration is that it will reduce downstream pollution loads. Whether or not Stage I and Stage II organisms bioaccumulate sediment contaminants is under study by the authors, but is not known at the present time. It is also uncertain whether establishment of Stage I and Stage II estuarine benthic communities contributes more to pollution remediation than the presence of a freshwater benthic community.

CONCLUSIONS

Benthic fauna of the potential salt marsh restoration area in West River represent an early, successional, estuarine community. Freshwater benthic species are rapidly displaced by Stage I, estuarine colonizers such as those sampled in the West River upon introduction of estuarine waters. This indicates that the potential restoration area is a dynamic system that will respond readily to changing salinity of the overlying water. Monitoring of the benthos is an excellent way to gauge whether or not the estuarine component of a salt marsh restoration is successful. Additionally, since many commercially important species feed upon Stage I and Stage II organisms, the presence of such communities should enhance local fisheries. Thus, a recorded shift toward estuarine, Stage I organisms can be taken as a leading-edge indicator that other non-benthic estuarine species (e.g. fish) may follow.

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Aquatic Insects of the West River and Salt Marshes of Connecticut

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ABSTRACT
The insect survey of West River Memorial Park in New Haven, Connecticut shows that freshwater aquatic communities are currently restricted to portions of the river above Chapel Street. The extensive shoreline insect communities were documented to provide a baseline for determining future changes caused by a salt marsh restoration. No endangered species were found in the park. Collections from nearby Connecticut salt marshes indicate that potential salt marsh colonizers of the proposed restoration area in the West River are present at a site downriver at Spring Street. Recommendations are to survey immediately the species of true flies (Diptera) in the West River, plan for additional monitoring of the shoreline communities during restoration attempts, and monitor for the introduction of exotic and pest insect species. The salt marsh biota at Spring Street Marsh should be preserved and maintained.

Two goals were set for the insect survey. The first was to document species of insects found in the fresh and saltwater areas of the aquatic and semiaquatic environments of the lower West River. These targeted communities represent environmentally restricted groups that disappear or change species composition as salinity levels change. The insect members of these communities are also relatively easy to collect and identify. These features make insects ideal as indicators of environmental change as, for example, when a freshwater environment reverts to a salt marsh. Efforts were also made to search the West River for the presence of local species considered by the Connecticut Department of Environmental Protection to be endangered, threatened, or of special concern.

As the majority of insect species currently found in the West River or on its banks will probably disappear or be displaced as their habitats change due to increasing salinity levels and accompanying vegetative change, the second goal was to document potential, salt marsh, insect colonizers present in Connecticut. This involved sampling of three different salt marshes located at varying distances from the West River. These data can be used in two ways. Colonization of the West River by salt marsh insect species can be taken as evidence that the conversion of the river is proceeding towards the anticipated salt marsh community. These data also will predict the composition of a potential insect community in the West River marsh.

METHODS

Collecting sites at West River Memorial Park were restricted to that area from the Chapel Street Bridge to the tide gates at Columbus Avenue, and to the reflecting pool constructed along the east side of the park (Fig. 1). The specific ecological zones sampled were the benthic region of river and reflecting pool, and the associated shorelines and mudflats. Six collecting trips were conducted in the park.

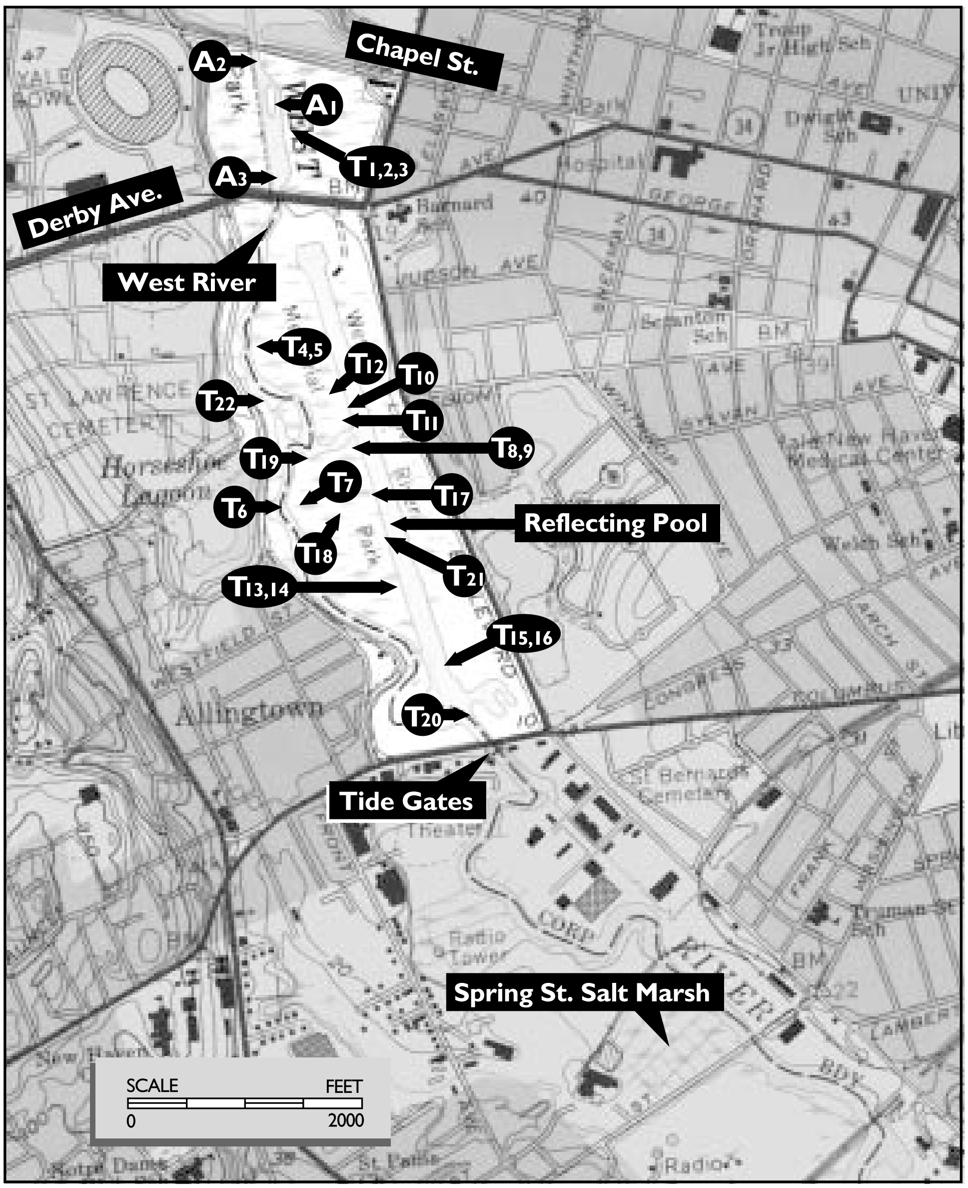


Figure 1. Insect collecting sites in West River Memorial Park and location of the tide gates and Spring Street Salt Marsh. "T" designates a shoreline site; "A" signifies an aquatic site. Only sites from which specimens were retained are shown.

Three salt marshes were selected for identification of potential insect species that may be available for colonization of restored salt marshes in south central Connecticut. Separate collections of insects were made from the various vegetative zones (e.g. *Spartina patens*, *S. alterniflora*, etc.) and distinctive mud pans of the three marshes.

The first marsh, Spring Street Marsh, is on the West River between the Helm Street landfill and Spring Street in West Haven 1 km south of West River Memorial Park (Fig. 1). It will probably serve as the major source for many of the colonizing salt marsh insects in the new marsh. The relatively small size of this marsh (6.9 ha) and the degree of encroachment by development may limit its species diversity. One collection was made at this site.

The second marsh, Hoadley Marsh, is located at the Yale Peabody Field Station in Guilford, Connecticut, 16 km east of the West River, in New Haven. Hoadley represents a less disturbed salt marsh environment. The insect community at this site can be compared with the Spring Street Marsh in order to determine whether Spring Street can supply West River Memorial Park with insects normally associated with a salt marsh system. Two collections were made at Hoadley Marsh.

The third marsh, Pine Creek Marsh, is located in Fairfield County, Connecticut, 32 km west of the West River. Pine Creek, a restored salt marsh, demonstrates that recolonization by salt marsh insects does occur in restored salt marshes and that a normal salt marsh community can be reestablished. One collection was made at this site.

At the West River, aquatic collecting consisted of kick sampling with seines and sweeping of aquatic vegetation with D-frame nets. Shoreline sites were sampled using aspirators. Pitfall traps were set initially, but the method was abandoned as not sufficiently productive. In the three salt marshes, sampling with aspirators and sweeping with aerial insect nets accumulated insects living on the grasses, shrubs, and underlying substrate.

The inferences drawn from this survey must be carefully delimited for two reasons. First, the collecting period was restricted to summer months, between June 1 and July 27, 1995. A substantial number of insect species may not have been collected because of limited sampling methods, and daily, monthly, or seasonal population fluctuations.

Secondly, not all available insect communities were investigated. In two initial collecting trips during June, aquatic insect communities were practically nonexistent south of the Chapel Street bridge (Fig. 1). The largest aquatic insect accumulations were found in an isolated side channel of the river, a short distance below Chapel Street, and in the submerged rubble beneath the Chapel Street bridge. Possibly, the aquatic insect community was being adversely affected by increased salinity levels produced as a consequence of daily tidal fluctuations of the river at this point. In addition to salinity effects, the sandy bottom of the river bed and the large packs of decaying organic matter undoubtedly contributed to a decreased diversity of aquatic insects in the river and reflecting pool. However, shoreline populations of insects appeared rich in species and easily inventoried. For these reasons, emphasis was placed on an inventory of the semiaquatic shoreline communities, with less emphasis placed on the completely aquatic communities.

Insect taxa to be included in the survey were based on the insects that were accessible, the time available for collection and curation, and the experts available for identifying specimens. Collecting focused on the Coleoptera and Hemiptera. Insects from other groups were collected when encountered, but they were not purposely targeted. The final species list undoubtedly lacks key species that may appear at different seasons or in zones not sampled adequately. A voucher collection of insect specimens from the four sites, field notes, and collecting maps have been deposited in the Entomology Division at the Yale Peabody Museum of Natural History.

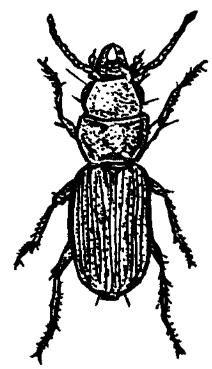
RESULTS

WEST RIVER MEMORIAL PARK

Approximately 87 species representing 41 insect families from eight orders were collected in West River Memorial Park (Appendix 1). There were few aquatic insects in the river. At the Chapel Street bridge, species of mayfly nymphs (Ephemeroptera: Baetidae), adult and larval riffle beetles (Coleoptera: Elmidae), caddisfly larvae (Trichoptera: Hydropsychidae), larval black flies (Diptera: Simuliidae), midge larvae (Diptera: Chironomidae), and an adult sialid (Megaloptera: Sialidae) were found. Each of these groups was represented by only one or two individuals.

A numerically larger and more diverse aquatic community was centered in a small side channel of the river that was somewhat isolated from the main river channel and tidal influences (Site A1, Fig. 1). Here, larval and adult specimens of dragonflies and damselflies were collected along with various heteropterans, such as the pygmy backswimmers (Pleidae), shore bugs (Saldidae), water boatmen (Corixidae), and creeping water bugs (Naucoridae). Beetles (Coleoptera) were represented by species from several aquatic families: water scavenger beetles (Hydrophilidae), predaceous diving beetles (Dytiscidae), whirligig beetles (Gyrinidae), and crawling water beetles (Haliplidae). The site exhibited insects that were typical of a freshwater environment.

Aquatic sites lower on the river within West River Memorial Park yielded only chironomid larvae (Diptera: Chironomidae) and a few water scavenger beetles (Coleoptera: Hydrophilidae). Other researchers involved in the West River biological survey also found only chironomid larvae in the lower West River (C. Cuomo, Geology Department; J. Moore, Biology Department, Yale University, personal communications). The restriction of freshwater organisms to upper parts of the river was consistent with concurrent water salinity data recorded by Cuomo and Zinn (this volume). Rainfall data indicate an area-wide drought that began in 1993. The resulting lower water levels, coupled with the effects of an open tide gate during 1995, undoubtedly contributed to elevated salinity levels. This effectively shifted the communities of freshwater insects farther upstream, beyond the reach of tidal influence. Possibly, the current aquatic community predicts the future insect community that will be found when salinity levels rise to those sustaining a salt marsh.



Bembidion *sp. (redrawn from Greene 1968)*

The shoreline communities on the mud and clay banks along the river and reflecting pool were host to a diverse group of beetles and other insects. Thirty-two species from nine beetle families were discovered at the waters' edge. Of these, the species of the coleopteran genus *Bembidion* are well-known inhabitants of salt marshes (Olmstead and Fell 1974). On the eastern side of the central island, a large colony of tiger beetle larvae *Cicindela duodecimguttata* Dejean (Cicindelidae) were discovered inhabiting clay banks adjacent to the reflecting pool. No tiger beetles were seen on the other sand bars in the river during the collecting period.

Taxa found at West River Memorial Park had little in common with the salt marsh communities. Nonetheless, several salt-associated insects were found in the park. Two carabid beetle species, *Bembidion contractum* Say and *B. versicolor* LeConte, and one clerid beetle (*Enoclerus rosmarus* Say), collected in the park were also found in one or more salt marshes. Among the Diptera collected at the West River, one *Notiphila* species (Ephydridae) was found also at the Hoadley and Pine Creek salt marshes. No new species or those considered by federal or state agencies to be endangered, threatened, or of special concern were encountered at the West River.

NEW RECORDS

During our collecting, a new state record was established for the seed bug *Chilacis typhae* (Perris) (Heteroptera: Lygaeidae). This exotic from Europe is restricted to the heads of cattails (*Typha* spp.). The first record of this species in North America was from Pennsylvania in 1986 (Wheeler & Fetter 1987). In the West River, it was discovered in a small patch of broad-leafed cattail (*Typha latifolia* Linneaus) growing in a river bend (Fig. 1, site T22). Later in 1995, the species was also found on cattails in Gilman and Willimantic, Connecticut (O'Donnell and Pupedis, MS in prep.). Another rarely reported species collected from the West River was a heteropteran in the family Gelastocoridae (toad bugs). The nymph we found is only the second specimen of its kind ever collected in Connecticut.

Several of the Carabid beetle specimens from the West River represent significant additions to Connecticut records (W. Krinsky, entomologist, personal communication). The specimen of *Bembidion impotens* Casey, collected just above the tide gates, represents only the third specimen collected in Connecticut. Although *Elaphropus saturatus* (Casey) was previously reported from Connecticut, the ten specimens from the West River are the only specimens available for verification. Twelve other beetles species represent new records for West Haven (W. Krinsky, personal communication). The staphylinid beetle, *Ochthephilum fracticorne* (Paykull), collected at Hoadley Marsh, is also a new record for Connecticut (M. Oliver, entomologist, personal communication).

Gelastocoris *sp. (toad bug, redrawn from Usinger 1956)*

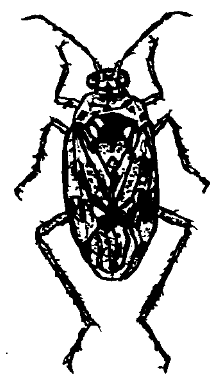
SALT MARSHES

The brief survey of salt marshes revealed the presence of six insect orders representing 33 families and 50 species (Appendix 2). This probably represents only a small fraction of the true diversity that occurs in Connecticut salt marshes. For example, the results from a sweep-net survey of North Carolina marshes (Davis and Gray 1966) produced 250 species representing 48 families in six orders. Another detailed survey of Gulf Coast marshes identified 585 morphospecies in 20 insect orders (Rey and McCoy 1997).

Our survey of local marshes detected many of the more common groups reported in Olmstead and Fell (1974) and Weiss (1995). Species at the Pine Creek Marsh indicate recolonization by insects typical of a salt marsh insect community. There were few direct matches of species between Spring Street Marsh and the other two marshes (Appendix 2). Four shore bug species (Saldidae) have been reported for Connecticut salt marshes [*Micracanthia hungerfordi* (Hodgen), *Saldula palustris* (Douglas), *Pentacora sphacelata* (Uhler), *P. hirta* (Say)(Polhemus 1976)]. However, only *P. sphacelata* was found in all three marshes and *P. hirta* only at the Hoadley Marsh and from the side channel (site A1) of the West River. Additional matches between the Spring Street Marsh and the other salt marshes were in the three coleopteran species *Bembidion contractum* (Carabidae), *Coccinella septempunctata* (Linneaus)(Coccinellidae), and *Collops nigriceps* Say (Melyridae). A common salt marsh species, *Trigonotylus uhleri* (Reuter)(Heteroptera: Miridae), was collected at the other salt marshes, but not the Spring Street Marsh. Although the common salt marsh insect *Heterocerus* sp. (Coleoptera: Heteroceridae) was found at Hoadley Marsh, it was not found in the Spring Street Marsh. Because heterocerids live mainly in mud galleries (Olmstead and Fell 1974), they may be easily overlooked.

One species of beetle, *Rypobius marinus* (LeConte) (Corylophidae), was collected only at Spring Street. It has been recorded from Connecticut and is common in salt marshes in New York (Downie and Arnett 1996). Corylophids are typically found in detritus and decomposing vegetation (Arnett 1973, White 1983). This species was found in very high concentrations in the Spring Street Marsh. An association may exist between insect density and the proximity of land fills adjacent to the marsh.

At Spring Street, one specimen was collected of the weevil *Sphenophorus pertinax pertinax* (Olivier)(Coleoptera: Curculionidae); its known host plants are the salt grasses *Spartina cynosuroides* (Linneaus) and *S. alterniflora* Loesener (Agricultural Research Service 1983). It has been reported as breeding in roots of *Typha latifolia* (Blatchley and Leng 1916).



Pentacora signoreti *(redrawn from Usinger 1956)*

DISCUSSION

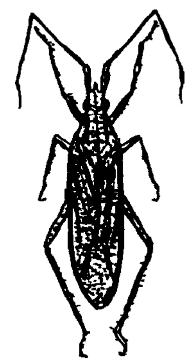
Introducing a tidal-driven influx of marine water will have several effects on the insect community. Locations of marine and freshwater communities on the West River will shift continuously in response to the tidal-driven boundaries of freshwater and saltwater. Loss of freshwater species in the upper park due to temporary incursions of marine waters, caused by low rainfall levels or storms, can be offset by recolonization from communities further upstream, through passive stream drift or active migration. Aquatic groups restricted to the upper section of the river will undergo little change, since these are already at the upper edge of tidal influence.

In the lower reaches of the West River below Derby Avenue, elevated salinity levels have had a strong impact on the aquatic insect community. The species of aquatic Diptera now present such as the craneflies (Tipulidae), mosquitoes (Culicidae), biting midges (Ceratopogonidae), and midges (Chironomidae) will probably be replaced by species more adapted to saline conditions. The same will probably occur for the aquatic beetle *Berosus peregrinus* Herbst (Coleoptera: Hydrophilidae). Although our salt marsh sampling was not designed to evaluate biting Diptera, high densities of these pestiferous insects in salt marshes is well documented.

The greatest changes will come with the replacement of *Phragmites australis* and terrestrial vegetation with salt marsh vegetation. Barten and Kenny (this volume) indicate that the rate and extent of tidal flooding can be controlled in West River Memorial Park. The impact on insect communities will depend greatly on the degree to which tidal flooding is limited and how plant communities will respond to salinity changes.

If the central island in the park is not inundated during periods of high tide, insect shoreline communities will shift inland as new, salt marsh vegetation is established. Existing species will probably continue to persist in a boundary between a completely terrestrial environment and the leading edge of the high marsh (Ranwell 1972). However, if the central island is completely inundated, then the existing insect community will be exterminated and an entirely new community will be established. New species will be either facultative or obligate salt marsh species. The existing shoreline communities may disappear entirely.

As salt marsh grasses (i.e., *Spartina* spp. and *Distichlis spicata*) and shrubs, such as high-tide bush (*Iva frutescens*), establish themselves and spread, they will in turn be colonized by insects immigrating from outside salt marshes. These colonizers will undoubtedly come from salt marshes located on the West River below the tide gates and from salt marshes associated with rivers emptying into New Haven Harbor. The community of salt marsh insects that exists at Spring Street Marsh will provide the initial colonizers for the new marsh.



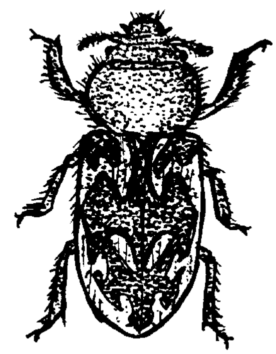
Trignotylus pulcher *(redrawn from Froeschner 1949)*

RECOMMENDATIONS

A number of salt marshes have already been restored successfully in Connecticut (see reviews in Dryer & Niering 1995). Insect samples from the restored Pine Creek Marsh indicate that salt marsh insects are fully capable of colonizing restored salt marsh habitats without human intervention. With the establishment of salt marsh vegetation and the presence of a nearby source of insect colonizers, West River Memorial Park will eventually come to resemble a typical salt marsh insect community. Natural processes of migration and colonization will adequately populate the habitat.

A program of consistent monitoring of selected insect groups is strongly recommended. Insects can and have served as excellent biological indicators for the health of an ecosystem. In addition to detecting community changes, entomological monitoring of the restoration represents an excellent opportunity to observe the dynamics of shifting community structure, colonization capability, and colonization rate of insects associated with salt marshes. These observations, coupled with baseline data, can predict or assess the success of other, local restoration attempts. They will serve to measure the effectiveness of salt marsh mitigation projects, the condition of marshes, and marsh productivity (Peck et al. 1994).

If the decision is taken to change the tidal regime of the West River, insect collections must be taken to monitor changing distribution and species composition of shoreline communities on the banks of the West River. This will provide quick assessment of the immediate impact of changes in salinity and hydrology of the West River. Biotic community change can be quantified with various community and diversity indices. The collecting techniques described herein will be sufficient for monitoring purposes. A pictorial checklist can facilitate a quick assessment, although a curated sampling must be collected for verification of species identity. The species checklist in Appendix 2 can serve as a baseline for determining change in species composition.



Heterocerus *sp. (redrawn from Greene 1968)*

During restoration, the newly forming marsh must also be monitored for introduction of exotic species. The international, commercial shipping traffic in New Haven Harbor and the incidence of major storms moving from the south can be sources of exotic insects that can more readily gain a foothold in a developing community where niches may be temporarily available. The current presence of the exotic true bug *Chilacis typhae* is such an example. Although most introduced species are innocuous, the possible establishment of economic pests is always a concern.

A recommended, longer-term project will be to monitor the appearance of insect species colonizing new *Spartina* grass communities. The checklist for the three salt marshes and published accounts of Connecticut salt marsh insects can be used to indicate whether a typical salt marsh insect community is being established. At present, detailed checklists of Connecticut salt marsh insects are lacking, and a separate initiative will be necessary to produce these lists.

Because Diptera have a high profile as potential pests, blood-feeding species must be monitored. Common pest species include deerflies (Tabanidae), such as the common saltmarsh greenhead *Tabanus nigrovittatus* (Macquart); "no-see-ums" or biting midges (Ceratopogonidae) of the genera *Culicoides* and *Leptoconeps*; and the salt marsh mosquito, *Aedes sollicitans* (Walker)(Culicidae). If control measures are not implemented in a timely manner, all three groups can pose significant discomfort and possible health risks to recreationists and residents adjacent to the marsh. The present study did not concentrate on biting Diptera. Therefore, West River Memorial Park must be surveyed to determine specifically the resident species of culicids, tabanids, and ceratopogonids. Salt marsh restoration will include Open Marsh Water Management (Daiber 1987) to control mosquito populations. However, the effectiveness of this type of management should be monitored; Open Marsh Water Management does not address the control of tabanid or ceratopogonid populations. As the West River restoration evolves, regular surveys are recommended for monitoring changes of species composition and densities of these pestiferous insect families.

Finally, insect colonization of West River Memorial Park will be facilitated by the Spring Street Marsh. Though the scope of insect sampling at Spring Street was limited and does not allow for extensive comparison with other salt marshes, the insect survey and the botanical survey (Orson et al., pp. 136-150, this volume) appear to indicate that the marsh is a relatively healthy and typical salt marsh. Efforts must be undertaken to preserve this marsh and to prevent any disturbances that degrade the salt marsh biota.

ACKNOWLEDGMENTS

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APPENDIX 1. WEST RIVER SPECIES CHECKLIST[1]

COLEOPTERA

ANTHICIDAE
- *Malporus formicarius* Laferte[2]

BUPRESTIDAE
- *Eupristocerus cognitans* (Weber)

BYRRHIDAE
- *Syncalypta tesselata* (LeConte)[2]

CARABIDAE
- *Agonum excavatum* Dejean[2]
- *Agonum melanarium* Dejean
- *Agonum ferreum* Haldeman[2]
- *Amara angustata* Say
- *Amara familiaris* (Duftschmit)
- *Amara rubrica* Haldeman
- *Anisodactylus harrisi* LeConte
- *Bembidion affine* Say[2]
- *Bembidion americanum* Dejean[2]
- *Bembidion contractum* Say[2]
- *Bembidion impotens* Casey[2]
- *Bembidion nigrum* Say[2]
- *Bembidion patruele* Dejean[2]
- *Bembidion versicolor* LeConte[2]
- *Callida punctata* LeConte
- *Chlaenius impunctifrons* Say
- *Chlaenius pennsylvanicus* Say[2]
- *Chlaenius sericeus* Forster[2]
- *Clivina americana* Dejean[2]
- *Dyschirius integer* LeConte[2]
- *Elaphropus incurvus* (Say)[2]
- *Elaphropus saturatus* (Casey)[2]
- *Elaphropus vernicatus* (Casey)[2]
- *Elaphropus vivax* (LeConte)[2]
- *Elaphropus xanthopus* Dejean[2]
- *Leptotrachelus dorsalis* Fabricius
- *Pterostichus caudicalis* Say[2]

CHRYSOMELIDAE
- *Chaetocnema confinis* Crotch[2]
- *Exema byersi* Karren
- *Labidomera clivicollis* (Kirby)
- *Metachroma* sp.
- *Paria* sp.[2]
- *Trirhabda virgata* LeConte

CICINDELIDAE
- *Cicindela duodecimguttata* Dejean[2]

CLERIDAE
- *Enoclerus rosmarus* Say

CURCULIONIDAE
- *Auletes* sp.
- *Barypeithes pellucidus* (Boheman)[2]
- unidentified sp. A
- unidentified sp. B

DYTISCIDAE
- *Laccophilus maculosus* Say
- unidentified sp. A
- unidentified larvae

ELMIDAE
- *Ancyronyx variegatus* (Germar)
- unidentified larvae

GYRINIDAE
- unidentified larva

HALIPLIDAE
- *Haliplus borealis* Crotch
- *Haliplus* sp.
- *Peltodytes edentulus* (LeConte)

HYDROPHILIDAE
- *Berosus peregrinus* Herbst[2]
- *Tropisternus lateralis nimbatus* Say
- *Tropisternus natator* d'Orchymont

SCYDMAENIDAE
- *Euconnus ?semiruber* Casey[2]

STAPHYLINIDAE
- Aleocharinae - 5 unidentified specimens[2]
- *Aleocharis* - 18 unidentified specimens[2]
- *Anotylus* sp. A[2]
- *Homaeotarsus bicolor* (Gravenhorst)[2]
- *Neobisnius paederoides* (LeConte)[2]
- *Paederus littorarius* Gravenhorst[2]
- *Stenus* - 4 unidentified specimens[2]

[1] All specimens represent adults unless otherwise noted.
[2] Species collected from shoreline communities.

APPENDIX 1 (CONTINUED)

DIPTERA
CHIRONOMIDAE
    23 unidentified specimens[2]
    unidentified larvae
DOLICHOPODIDAE
    Dolichopus sp.
    Pelestoneurus sp.
    4 unidentified specimens
EPHYDRIDAE
    Notiphila sp.
SIMULIIDAE
    unidentified larva
TIPULIDAE
    2 unidentified specimens[2]

EPHEMEROPTERA
BAETIDAE
    unidentified nymphs

HETEROPTERA
ALYDIDAE
    Alydus pilosulus (Herrich-Schaeffer)
ANTHOCORIDAE
    Orius insidiosus (Say)
BELOSTOMATIDAE
    unidentified nymph
CORIXIDAE
    28 unidentified specimens
GELASTOCORIDAE
    unidentified nymph
HEBRIDAE
    Merragata hebroides White[2]
LYGAEIDAE
    Chilacis typhae (Perris)
    Ischnodemus falicus (Say)
MESOVELIIDAE
    Mesovelia mulsanti White[2]
MIRIDAE
    Lopidea sp.[2]
    Phytocoris sp.[2]
    Poecilocapsus lineatus (Fabricius)
NAUCORIDAE
    1 unidentified adult
PLEIDAE
    Neoplea striola (Fieber)
SALDIDAE
    Pentacora hirta (Say)
    Salda lugubris (Say)

MEGALOPTERA
SIALIDAE
    1 unidentified specimen

ODONATA
ANISOPTERA
    unidentified nymphs
  AESHNIDAE
    Anax sp.
  LIBELLULIDAE
    Libellula pulchella Drury
ZYGOPTERA
    unidentified nymphs
  COENAGRIONIDAE
    Chromagrion conditum (Hagen)
  LESTIDAE
    Ischnura verticalis Say

ORTHOPTERA
ACRIDIDAE
    Chorthippus curtipennis (Harris)
TETTIGONIIDAE
    Nomotettix crustatus Scudder

TRICHOPTERA
HYDROPSYCHIDAE
    unidentified larva

APPENDIX 2. SALT MARSH SPECIES CHECKLIST[1]

COLEOPTERA

ANTHICIDAE	SS[2]	H[3]	PC[4]
Anthicus sp.	X	-	-
CANTHARIDAE			
2 unidentified specimens - 1 species	-	-	X
CARABIDAE			
Amara apricaria Paykull	-	-	X
Bembidion contractum Say	X	-	X
Bembidion constrictum LeConte	-	X	-
Bembidion versicolor LeConte	X	-	-
CHRYSOMELIDAE			
Ophraella notulata (Fabricius)	-	-	X
unidentified sp. A	-	-	X
unidentified sp. B	-	-	X
unidentified sp. C	-	-	X
unidentified sp. D	-	X	-
CLERIDAE			
Enoclerus rosmarus Say	-	X	-
Isohydnocera tabida LeConte	-	X	X
COCCINELLIDAE			
Coccinella septempunctata (L.)	X	-	X
Coccidula lepida LeConte	-	-	X
Harmonia axyridis Pallas	X	-	-
Naemia seriata seriata (Melsheimer)	-	-	X
Propylea quaduordecimpunctata (L.)	-	X	X
CORYLOPHIDAE			
Rypobius sp. (? *marinus* LeConte)	X	-	-
unidentified sp. A	X	-	-
CURCULIONIDAE			
Sphenophorus pertinax pertinax (Olivier)	X	-	-
HETEROCERIDAE			
5 unidentified specimens - 2 species	-	X	-
HYDROPHILIDAE			
Enochrus perplexus LeConte	-	X	-
2 unidentified specimens	-	-	X
5 unidentified specimens	-	X	-
MELYRIDAE			
Collops nigriceps Say	X	X	-

1 X denotes presence. All specimens are adults unless otherwise noted.
2 SS – Spring Street Marsh, New Haven.
3 H – Hoadley Marsh, Peabody Field Station, Guilford.
4 PC – Pine Creek Marsh, Fairfield.

APPENDIX 2 (CONTINUED)

PSELAPHIDAE	SS	H	PC
Pselaphus sp.	X	-	-
SCARABAEIDAE			
Phyllophaga sp.	X	-	-
1 unidentified specimen	-	-	X
STAPHYLINIDAE			
Ochthephilum fracticorne (Paykull)	-	X	-
Aleocharinae - 18 unidentified specimens	X	-	-
DIPTERA			
CANACIDAE			
Canacea macateei ?	-	X	-
EPHYDRIDAE			
Ephydrya spp.	-	X	-
Notiphila sp.	-	X	X
MUSCIDAE			
1 unidentified specimen	-	X	-
OTITIDAE			
30 unidentified specimens	-	X	X
SCIOMYZIDAE			
2 unidentified specimens	-	-	X
STRATIOMYIDAE			
1 unidentified specimen	-	X	-
SYRPHIDAE			
1 unidentified specimen	-	-	X
TABANIDAE			
19 unidentified specimens	-	X	X
HETEROPTERA			
CORIXIDAE			
28 unidentified specimens	-	X	-
MIRIDAE			
Trigonotylus prob. *uhleri*	-	X	X
PENTATOMIDAE			
Chlorochroa (*Rhytidolomia*) *senilis* (Say)	-	X	-
SALDIDAE			
Pentacora hirta (Say)	-	X	-
Pentacora sphacelata (Uhler)	X	X	X

APPENDIX 2 (CONTINUED)

	SS	H	PC
HOMOPTERA			
CICADELLIDAE			
28 unidentified specimens	X	X	X
DELPHACIDAE			
67 unidentified specimens	-	X	X
MEMBRACIDAE			
Micrutalis calva (Say)	-	-	X
2 unidentified specimens	X	-	-
ODONATA			
ANISOPTERA			
LIBELLULIDAE			
Erythrodiplax berenice Drury	-	X	X
ORTHOPTERA			
ACRIDIDAE			
Melanoplus femur-rubrum (DeGeer)	-	X	-
Orphulella olivacea (Morse)	-	X	-
GRYLLIDAE			
Oecanthus sp.	-	-	X
TETTIGONIIDAE			
Conocephalus fasciatus (DeGeer)	-	X	-
Conocephalus saltans (Scudder)	-	X	-

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Fish Communities as Indicators of Environmental Quality in the West River Watershed

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ABSTRACT
The West River bordering New Haven and West Haven, Connecticut, is under evaluation for potential restoration of a former salt marsh. As part of a larger survey of biota associated with this river, the fish fauna was examined in the estuary and adjacent freshwaters. The results provide baseline data for monitoring restoration efforts and indicate the environmental health of the river. The fish communities lacked intolerant species, included significant numbers of individuals of non-native fishes, and showed low abundance and diversity of the native species, all indicating that this stretch of the river represents poor fish habitat with significant ecological disturbances. Some sites contained individuals with excessive parasites, tumors, ulcers, and fin erosion, which suggests physiological stress and potential human health hazards. These problems are localized in the vicinity of combined sewage outflows and/or storm sewer runoff from streets. They are exacerbated by periodic low flow or stagnant waters caused by the tide gates. Salt marsh restoration with tide-gate modification could improve habitat for species with commercial and recreational value and improve movement of diadromous fishes.

The West River, a coastal watershed system on the New Haven-West Haven border in Connecticut, once included a thriving salt marsh in the area of the present day West River Memorial Park. In 1919, installation of tide gates restricted the flow of marine water upstream (Kenny 1995). The tide gates were installed in order to limit tidal flow for agricultural, flood control, and mosquito control projects (MacBroom 1995). The ensuing degradation of the salt marsh upstream from the gates brought many ecological changes to the area. High tide levels of the original marsh were reduced, and the salinity concentration generally became lower, although it still remained brackish (Kenny 1995). These physical factors caused a change in the vegetation of the park, allowing common reed (*Phragmites australis*) to thrive. Lower water levels also caused an increase in wildfires due to the frequent dryness of the environment (MacBroom 1995). With restricted water movement, soil settlement became common, changing the chemistry of the river water and bottom. These environmental changes continue to affect the aquatic and terrestrial life of the watershed ecosystem. Moreover, the tide gates restrict the passage of diadromous fishes, physically preventing some of them from entering the estuarine and freshwater areas upstream.

The main goals of this study were to inventory species of fishes in the West River watershed, particularly those of the estuarine and adjacent freshwater portions, and to assess the environmental health of the watershed. Fish distribution is discussed with regards to habitat and ecology. It is our hope that this inventory will establish a baseline for measuring changes that may occur from future actions to improve the West River watershed. This survey represents one of the first detailed examinations of fish fauna in a coastal Connecticut river. As an example of urban-river ecosystems with identifiable disturbances, it can be compared with studies of other coastal, New England rivers. The degradation of water resources is a concern to society.

The West River flows through a very urbanized area and shows many diverse river-habitat alterations. Examinations of fish community structure in rivers and streams has become a way of investigating the kinds of stresses introduced by anthropogenic changes. One method involves the calculation of an Index of Biotic Integrity (IBI; Karr 1981, Karr et al. 1986, Karr 1991). Biotic integrity is defined as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of a natural habitat of the region" (Karr and Dudley 1981). Changes in the structure of the fish community, such as abundance and diversity of species, can reflect the effects of various stresses on the biotic integrity of the river as a whole (Fausch et al. 1990).

Fish communities are excellent indicators of the biological integrity of watershed systems.

Fishes have a number of advantages as biological-integrity indicators of a watershed system (Plafkin et al. 1989). Because of their multiyear life-spans and mobility, most fish species are good indicators of long-term effects and larger-scale habitat conditions. Fish communities include a range of species and trophic levels, which can reflect relative degree of environmental disturbance. Some species of fish are very sensitive to changes in water chemistry, such as pH or dissolved oxygen, which may be caused by pollutants, tidal flow, natural change, or other factors. Compared with many small invertebrates, more life-history information exists for fishes and they are easier to collect and identify. Fishes are of greater immediate concern to people due to their potential for food and sport.

Using data from fish communities, one can compare changes in water quality with degree of disturbances in the West River watershed system. With these results, recommendations can be made for the management of the watershed ecosystem, and the progress of implemented plans to alter the ecosystem, such as restoration of the salt marsh, can be monitored.

DESCRIPTION OF THE STUDY AREA

The main study area consists of brackish waters found throughout the entire West River Memorial Park and the southern portion of Edgewood Park (Fig. 1). In addition, two fully freshwater sites near West Rock Park were sampled to examine the freshwater fish fauna. Depth of the river ranges from 0.3 to 3 m; width ranges from 1.5 to 10 m. Vegetation along the banks of the West River within the main study area is predominantly common reed, with a variety of deciduous trees bordering the river in a few places.

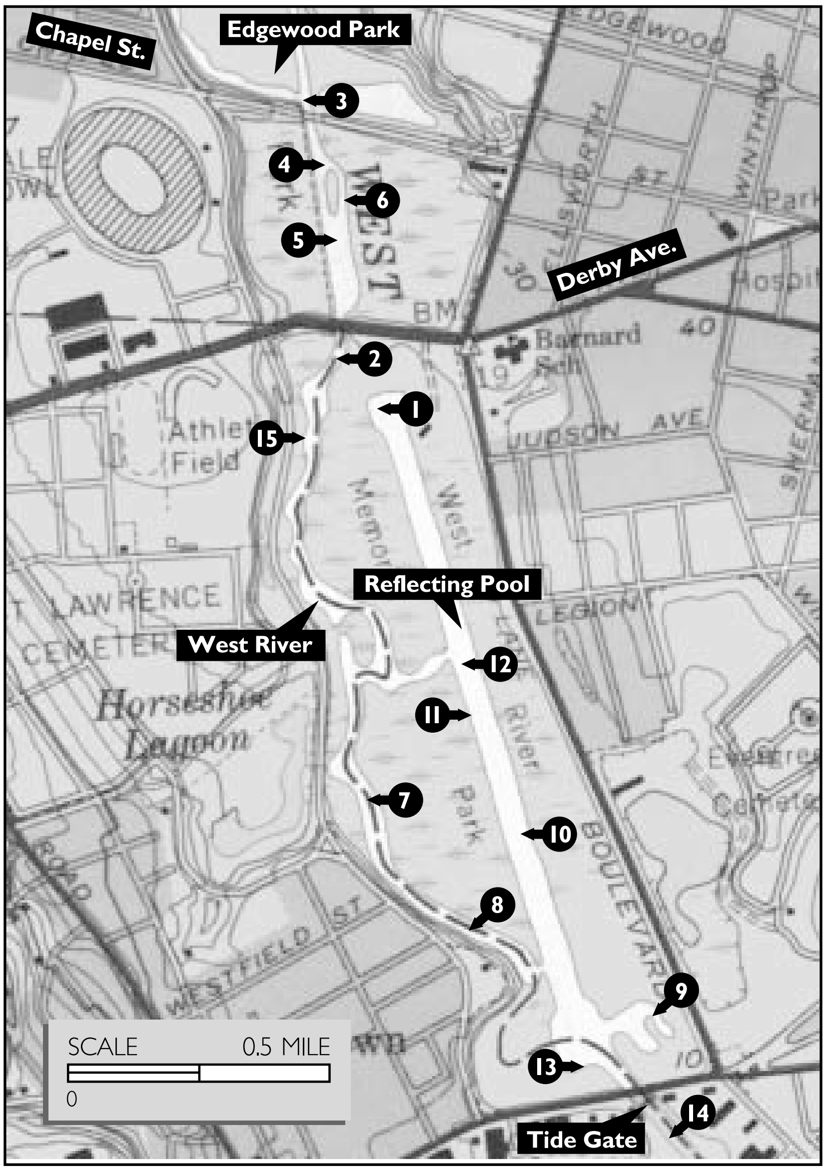


Figure 1. Lower West River fish sampling locations in West Haven and New Haven, Connecticut.

Just below the tide gates, the river consists of a 3 m-deep, steep-sided tidal channel with a shell hash bottom and moderate salinity of up to 17 parts per thousand (ppt). Within West River Memorial Park, there is a dredged river channel and a parallel reflecting pool, both with shallow marsh edges and a bottom of either mud, muddy sand, or sand. Frequently the bottom contained high levels of organic matter, which was often undergoing anaerobic decomposition. Salinity varied from 2 ppt near Chapel Street to 17 ppt near the tide gates. Estuarine conditions were found within the study area below the tide gates, throughout the reflecting pool (where salinity varied from 16 ppt near the tide gates to 10 ppt near Derby Avenue), and in the lower reaches of the river downstream from the cross-channel connection between the river and the reflecting pool (where salinity varied from 9 ppt in the river closest to the southern end of the reflecting pool to 5 ppt near the cross channel). Predominantly freshwater conditions (salinity < 5 ppt) existed upstream from the cross channel, with occasionally higher salinity due to tidal influences and the irregular occurrence of debris keeping one or more tide gates partially open. Lower salinity is also sometimes found near site 7 due to the occasional high flow of freshwater drainage from Horseshoe Lagoon into the river.

Two other sampling sites in shallow, fully freshwater runs and riffles were located at the entrance to West Rock Park, near Stone Street, and the area where Ramsdell Street crosses the river. For purposes of evaluating the environmental health of the main study area, the habitats sampled were confined to shallow marsh edges and river banks with sand or muddy sand bottoms. This similarity of habitats should reduce the differences in fish species and abundances that result from large habitat differences.

Some unusual conditions during the sampling period should be noted. Drought conditions during the summer of 1995 reduced freshwater inflows to very low levels. Unusually higher salinity (unpublished data) was found in the latter part of the summer. Drought conditions were evident when salt marsh grass (*Spartina* sp.) germinated on normally submerged mud flats along the lower river. Sampling at the Ramsdell Street site had to stop when the river bed dried up. Conversely, heavy snowmelt and torrential rains in March 1996 caused unusually severe flooding, effectively washing out a number of collecting sites and ending much of the collecting effort. The severity and timing of these floods may lead to poor recruitment of early spawning fishes, such as alewife (*Alosa pseudoharengus*) and white suckers (*Catostomus commersoni*).

HABITAT QUALITY OF COLLECTION SITES

As a general observation, practically the entire study area has been physically altered. The river was rerouted in the course of dredging out the reflecting pool, which was envisioned as a centerpiece for the originally planned West River Memorial Park (Balmori 1995). The tide gates have altered the flow regime of salt water and, in turn, caused a change in the flora bordering the river (Kenny 1995). Major streets cross the river at Chapel Street, Derby Avenue and Orange Avenue. Formerly, a trolley line also crossed the river. Combined sewage overflows (CSO) empty into the river in a number of localities (e.g., near the intersections of Derby and Boulevard and near Orange Avenue and Boulevard). This has probably introduced hydrocarbons, other surface run-off pollutants, and sewage during periods of moderate to heavy rains (Benoit 1995). Trash was commonly found throughout the study area in 1995-1996, and was sometimes brought up in our sampling nets.

The entire study area has been physically altered. The river was rerouted, combined sewage overflows empty into the river, and trash was commonly found throughout the study area. Industrial waste formerly entered the river upstream.

During summer, portions of the river's surface included floating masses of blue-green algae, which indicated nutrient-enriched water. When this algae dies it falls to the bottom, where decomposition by bacteria can deplete the dissolved oxygen and lead to fish kills (Benoit 1995). Industrial waste formerly entered the river upstream, and the river may be contaminated with heavy-metals (G. Benoit, Yale F&ES, personal communication).

Site 3, immediately upstream from the Chapel Street bridge (Fig. 1), exhibits additional problems resulting from the outflow of a small pond. This pond has a large population of resident waterfowl, the excrement from which alters the water chemistry of the pond. Altered pond water occasionally enters the West River in sufficient amounts to affect water chemistry in the river. Dissolved oxygen was at times reduced to 5 ppm and potentially less, while pH and nitrates were elevated in the river adjacent to the pond outflow. Also, a sewer pipe underneath the Chapel Street bridge was observed discharging into the river on at least one occasion. This likely affects habitat quality at sites just downstream from the bridge such as site 4, where unusually high numbers of parasites and lesions were found on some fishes.

The upper end of the reflecting pool also exhibited a number of major problems. First was the lack of flow, which caused an accumulation of organic matter. No dissolved oxygen was detected on the pool's bottom, and sulfides were present. Also, two sewer outflows empty into this area, which brings in a great deal of sediment and potential pollutants. Fishes were only found on the very margins of the pool in this region, where oxygen diffused into the water from the marsh plants and the surface. Some fishes in this area exhibited chemically eroded fins and excessive parasites.

At site 8, a large storm-water outflow has brought in sediment and pollutants from the surrounding community of West Haven. This was another site where some fishes exhibited problems with parasites, lesions, and tumorous growths.

METHODS

Fishes and habitat information for all sites were collected from May 1995 to March 1996, representing spring (May-June), summer (July-Aug.), fall (Oct.-Nov.), and winter (Dec.-March) samplings in the southern portion of the West River watershed in New Haven and West Haven, Connecticut. Notes were recorded at each sampling station concerning the air and water temperature, tide stage, state of the environment around the site, bottom type, time, and date. Habitat quality for each site was assessed according to a number of physical and water quality criteria established by Plafkin et al. (1989).

Fish samples were taken from 15 different sites along the lower West River (Fig. 1) and two sites along the upper river. Between the cross channel and site 15 the bottom of the river was extremely mucky with hydrogen sulfide, which was given off any time the bottom was disturbed, even by the passage of large carp. For practical reasons, this area was nearly impossible to sample for fishes with the equipment at hand. Sampling of all sites was undertaken about once every two months during the spring, summer, and fall. During winter months, sampling could not be conducted because major portions of the river's surface were completely frozen. Sampling was limited to near-shore habitats, where the majority of species can be collected. In doing so, some deeper water and pelagic species may have been undersampled. However the data are most likely sufficient to assess habitat quality (Plafkin et al. 1989).

Sampling was primarily conducted with a 30 ft. seine net. At shallower stations, one person held one end of the seine close to shore while the other end was moved offshore perpendicular to the bank. The person offshore swept upstream in an arc towards the shore. As both persons reached shore, the seine net was pulled in, and the fish caught in the net were collected by hand. The area sampled was roughly a quarter circle, approximately 66 m^2. At deeper sampling stations, a canoe was utilized to sweep in a similar arc towards shore. The seine net was then pulled in and the fishes were examined.

As a test of sampling efficiency, a few of the freshwater stations were also sampled with an electrofisher backpack. This resulted in the addition of larger individuals, greater abundances, and individuals of one cryptic species, ammocoete larvae of sea lamprey (*Petromyzon marinus*), that were never collected in the seine. To avoid sampling bias, electrofished samples were not considered in assessing environmental health.

Immediately after collecting, fishes were put into a pan of river water for identification and counting. Some specimens were preserved in a 4% formaldehyde solution as voucher specimens or for later identification. Voucher specimens can be found in the ichthyology collection of the Peabody Museum of Natural History, Yale University (YPM). Most of the fishes caught were released back into the river in order to minimize disturbance of the population numbers of various species.

Abnormalities were noted as (1) excessive parasites, defined as fishes with four or more parasites per individual or more than two types of parasites, (2) ulcers, defined as any open sores, (3) tumors, defined as any abnormal or enlarged growths, and (4) fin erosion, which consisted of any holes in the fin membranes or abnormal truncations of the fins.

SPECIES DIVERSITY AND EVENNESS

The Shannon-Weaver Index of species diversity (H′) is the most widely used index of heterogeneity, that is, an index that combines species richness with equitability of abundance (Cox 1985). This index describes the average degree of uncertainty of predicting the species of an individual chosen randomly from the biotic community. As the value of the index increases, the probability of randomly picking two fish of the same species decreases. Thus, the greater the value of the index, the greater the diversity of the community. The formula of this index is

$$H' = -p_i \log p_i$$

where p_i is the fraction of individuals of species *i*. Equitability of abundance is then calculated as

$$J = H'/H'_{max}$$

where H'_{max} is the value of H′ computed with the same number of species, but equal p_i values. As J approaches 1.0, abundances of species are more evenly distributed.

The Simpson Index of species diversity was also calculated. This index corresponds to the number of randomly selected pairs of individuals that must be drawn from a community in order to have an even chance of obtaining a pair of the same species (Cox 1985).

The greater the value of the index, the greater the diversity of the community. The Simpson Index is calculated by

$$N_2 = [N(N-1)]/[n(n-1)]$$

where N is the total number of individuals of every species and n is the number of individuals of one species. The equitability of abundance can then be derived by

$$V = N_2/N_{2\ max}$$

where $N_{2\ max}$ is N_2 calculated for the same number of species and individuals, but equal abundances for each. The species abundances are more evenly distributed as V approaches 1.0.

Both of these indices of species diversity were calculated because each had advantages over the other. The Shannon-Weaver Index is more sensitive to the addition or loss of rare species but assumes a non-clumped distribution (Cox 1985). The Simpson Index is better for sampling without replacement but is sensitive to sample size (Cox 1985).

RESULTS AND DISCUSSION

None of the species collected (Appendix) are considered threatened, endangered, or of special concern in Connecticut. Table 1 gives counts for the collections made in late July and early August and depicts the number of individuals of each species captured at each site. Deegan et al. (1993) indicate that fishes collected at this time of year are most representative of the resident fauna within estuaries and, therefore, are best for assessing environmental quality. These data are published for the benefit of future studies in the West River. Site 6 is not included in the table because it was completely dried out in July and August. Site 14 is not included because that site, just downstream from the tide gates, was not successfully sampled during this period. Table 2 gives the calculated diversity and equitability indices for the late spring, mid summer, and winter sampling series.

SEASONALITY OF FISHES

The highest abundances of nearshore fishes were in mid-to-late summer. By winter, there was a drastic decrease in the number of fish caught in nearshore habitats; a total of 1138 fish in July-August compared with only 18 in December-March. Furthermore, the 18 fish caught were of only two species, striped killifish (*Fundulus majalis*) and inland silversides (*Menidia beryllina*). These two species appear more tolerant to cold temperatures than the other West River fishes. One possible reason for the absence of fish during the

Table 1. Number of fish specimens collected at sampling sites[1] in the lower West River, New Haven, Connecticut during July and August 1995, and life history notes.

	Site Number																	
Species	**1**	**2**	**3**	**4**	**5**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**Total**	**Spawn**	**Nursery**	**Resident**	**Benthic**
Fundulus diaphanus	8		1		1	165	1	1	1	122	29	267	16	612	YES		YES	YES
Fundulus majalis	3		1	1		4	7	6	7	4			16	49	YES		YES	YES
Fundulus heteroclitus	2					6	4	1	3	19		150		185	YES		YES	YES
Catostomus commersoni		23	5	11	23								75	137	YES		YES	YES
Menidia sp.							1							1				
Menidia menidia	1					3		1				31		36		YES		
Menidia beryllina	6							2		1				9	YES		YES	
Morone americana	5					5				6		3		19			YES	YES
Apeltes quadracus		19	1	7	5			1	1				4	38	YES		YES	YES
Alosa spp.	6							5				25		36	YES			
Lepomis macrochirus	1					2						1		4	YES		YES	
Pseudopleuronectes americanus								2						2		YES		YES
Trinectes maculatus												1		1	YES		YES	YES
Ictalurus nebulosus			3											3				YES
Cyprinidon variegatus						2								2	YES		YES	YES
Micropterus salmoides						3								3				
Sample Size	32	42	11	19	29	190	13	19	12	152	29	478	111	1137				

[1] Sites 6 and 14 are not included because of difficulties when sampling.

winter season of 1995-96 may be the limitations of the sampling method. During the winter season, fishes often move to deeper waters where it is warmer. There was no suitable equipment on hand for deeper sampling in estuarine waters.

Table 2. Diversity indices of near-shore fish sampled in the West River, New Haven, Connecticut during 1995-1996.

	H′	J	N_2	V
late spring	0.976	0.929	8.014	0.501
mid-summer	0.672	0.558	2.986	0.184
winter	0.196	0.651	1.417	0.667

Abundance and diversity of fish species were low. This probably results from poor environmental conditions.

BIOTIC INTEGRITY AND HEALTH OF THE WEST RIVER

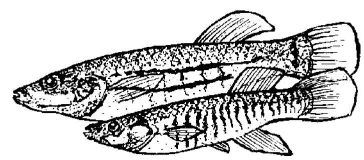
The Index of Biotic Integrity (IBI) was originally utilized for assessment of freshwater stream and river habitats (Karr 1981). Since it was first introduced, various modifications have been made to accommodate regional faunal differences (Miller et al. 1988) and, more recently, the application of this concept to other environments. The Estuarine Biotic Integrity Index (EBI) is one of those recent outgrowths of the IBI and has been applied to estuaries in Cape Cod, Massachusetts (Deegan et al. 1993).

Unfortunately, it was not feasible to apply these indices to our project. The definition of biotic integrity depends on fish-community data from similar, undisturbed habitats within the region. No warm water coastal rivers in Connecticut have been previously examined (R. Jacobson, Connecticut Department of Environmental Protection, personal communication), so no comparable baseline data exist. While developing their EBI, Deegan et al. (1993) decided not to test it for lower-salinity, estuarine habitats, because of the poor quality of those areas in the estuaries they studied. They concluded that, within their study area, seagrass habitat best reflected habitat quality in the EBI values. This kind of habitat, however, was not documented within our study area.

Although it was not feasible to explicitly calculate an IBI or EBI for the estuary and adjacent freshwater portions of our study area, a number of parameters from Plafkin et al. (1989) and Deegan et al. (1993) were examined. Taken together, they indicate generally poor environmental health of the lower watershed and the study area.

A total of 32 species were collected from the estuarine and adjacent freshwaters of the West River during this study. The publications by Whitworth et al. (1968) and Thomson et al. (1971) show a cumulative total of 49 fish species in estuarine and adjacent freshwaters of nearby watersheds in coastal, central Connecticut. The lower number of species collected in the West River probably represents three factors: (1) a sampling bias introduced by limited collecting techniques, which underrepresented the pelagic and deeper-water species, (2) a reduction in pelagic species due to obstruction by the tide gates and degraded habitat quality, and (3) a reduction in the diversity of nearshore, shallow-water fishes in the West River due to degraded habitat quality.

Diversity of species within the study area was at times quite low; no more than eight species were collected at any given site in July and August (Table 1). Total number of species collected within the study area at this time was 16. Calculations of the Shannon-Weaver (H′) and Simpson (N_2) indices revealed that species diversity was greatest in the spring (Table 2). This reflects the timing of the sampling, which was at the height of the spawning season when nonresident species of fish migrate upriver to breed. Species diversity remained moderate during mid-summer. However, there is a steep drop in diversity during the winter months. Plafkin et al. (1989) and Deegan et al. (1993) recommend that samples be taken in mid-to-late summer to reduce the effects of seasonality in water levels and migrations. Measurements of abundance equitability from spring and mid-summer showed abundance was concentrated in just a few species: killifishes (*Fundulus* sp.), silversides (*Menidia* sp.), white sucker, and four-spined stickleback (*Apeltes quadracus*).



*Striped killifish (*Fundulus majalis*)*

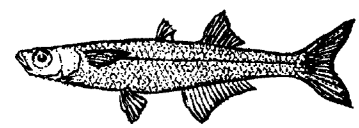
Abundance

The overall abundance of fishes was rather low at most sites (usually less than 1 fish per m^2 and no more than 7 fish per m^2). Banded killifishes (*Fundulus diaphanus*) were numerically the most abundant species. Mummichog (*F. heteroclitus*), striped killifishes, white suckers, four-spined sticklebacks, and Atlantic silversides (*Menidia menidia*) were also abundant. These six species made up almost 93% of the fishes caught during the July-August period.

Number of spawners

Most of the fishes collected in the study area spawn within the estuary or in slightly brackish waters just upstream from the cross channel. Some suitable spawning habitat must be available for these species to continue. Spawning activity was observed from April to June for alewife and blue-backed herring (*Alosa aestivalis*) at site 3 just upstream from the Chapel Street bridge. Bluegill (*Lepomis macrochirus*) nesting has also been observed in May, just downstream from that same bridge, and many carp (*Cyprinus carpio*) were seen apparently spawning on submerged vegetation along the eastern bank between Chapel Street and Derby Avenue.

Other indications of spawning consisted of gravid female fishes or larval individuals of resident species. Gravid, female four-spined sticklebacks were caught at sites 2, 4, 5, and 8 in the river in May and June, and small juveniles were collected at site 8 in June. Postflexion larvae and juvenile inland silversides were found at site 7 in June. Silversides are known to breed during the early summer (Whitworth et al. 1968). This site along the main channel could be a possible breeding site or nursery area for inland silversides. Juvenile white suckers were collected at sites 3, 4, 5, and 8 between May and July 1995, indicating these areas may include breeding grounds. White suckers typically spawn in early spring, moving upstream to breed in river riffles (Whitworth et al. 1968). Suckers are generally benthic spawners that choose an area of gravel or rocks to breed (Moyle and Cech 1988). The stretch of river between sites 3 and 5 is a particularly suitable breeding area, because of its shallow depth and sandy bottom with rocks. Killifish juveniles were found at sites 5, 6, and 7 during the late spring and early summer.



*Inland silverside (*Menidia beryllina*)*

Although spawning of numerous fishes was evident, spawning success itself was not measured. The low abundances of adult fishes within the study area may indicate that spawning failure is higher than usual, or juvenile mortality may be unusually high. Possibly, environmental disturbances contribute to high mortality. This would need to be tested in the future.

Number of nursery species

Besides the estuarine spawners, only two other species use the estuary as a nursery ground for juveniles, Atlantic silversides and winter flounder (*Pseudopleuronectes americanus*). Young individuals of these species were collected at a number of sites in the reflecting pool and, for silversides, in the lower river.

Number of intolerant species

The presence of fishes intolerant to chemical or physical perturbations to the environment is a sign of moderate to high quality habitats. Intolerant fishes are typically the first species to disappear following disturbances to the environment. No intolerant fishes were collected. Even the freshwater sites near West Rock Park contained only intermediate and tolerant species. Within the study area the dominant species discussed above are all tolerant species.

This seems to indicate low-quality habitats. It should be noted that brook trout (*Salvelinus fontinalis*), an intolerant species, were collected as dead or dying individuals within the park. However, these likely came from upstream of West River Memorial Park and had probably succumbed to effects of the drought conditions that summer.

Abnormalities

According to various indices, any more that 5% of the individuals in the population having abnormalities indicates low-quality habitat (Miller et al. 1988, Plafkin et al. 1989). Abnormalities are defined as discolorations, deformities, eroded fins, excessive mucus, excessive external parasites, fungus, poor condition, reddening, tumors, and ulcers (Plafkin et al. 1989). At a number of sites in the study area, abnormalities in the form of eroded fins, excessive parasites (leeches on body and fins, copepods in gills, and unidentified cysts), tumors, and ulcers were found in 9% to 29% of individuals. The worst sites were in the reflecting pool (1, 9, 10, 11, 12, 13); and lesser, but still poor sites, were near sewer outlets (4, 8). Particularly affected were larger, presumably older, individuals of resident species. This would seem to indicate sublethal stresses to these fishes that are accumulating over time and compromising their ability to resist parasites and diseases.

At a number of sites, abnormalities were found in 9% to 29% of fish. Larger, presumably older, individuals of resident species were particularly affected.

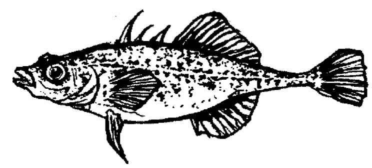
Introduced species

Three introduced species were found in the study area during this investigation: bluegills, largemouth bass (*Micropterus salmoides*), and carp. Historically, a fourth introduced species, black crappie (*Pomoxis nigromaculatus*), has also been taken from the pond in Edgewood Park that empties into the West River at site 3 (Yale Peabody Museum collections). While bluegills and bass were in low numbers and often the targets of the local fishermen, carp represented a significant amount of fish biomass in the study area and were apparently not targeted by fishermen (Casagrande, pp. 62-75, this volume). Although few carp were sampled, visual counts included over 110 individuals in one day, all of which appeared to be over 30 cm in length. Large carp are also significant in that they disturb the bottom to a great degree, potentially resuspending any toxins and destroying habitat for other benthic fishes.

Distribution of species

The different life-history groups found within the area were: diadromous fishes, marine transients, freshwater residents, and estuarine residents. Diadromous fishes are those that move from marine to freshwater or vice versa for spawning. Included in this group are the alewife and blueback herrings which migrate upstream to spawn. Marine lampreys apparently move into the river to spawn, since electrofishing revealed the presence of filter feeding larvae at site 3 and further upstream. Also found were American eels (*Anguilla rostrata*); a number of juveniles (elvers) were observed arriving from spawning grounds in the Atlantic and migrating through the estuary into freshwater upstream. The tide gates likely reduce the number of migrant fishes moving through the estuary and can potentially cause significant decreases in the reproductive success of these fishes. Salinity changes in the upper estuary caused by the gates has altered the area's suitability for spawning and may have had an effect on reproductive success. Restoring tidal flushing of the estuary could restore the former spawning areas of some of these fishes.

Marine transients collected or observed in this survey include the smooth dogfish shark (*Mustelis canis*) and the Atlantic needlefish (*Strongylura marina*), both of which occasionally enter estuaries (Thomson et al. 1971).

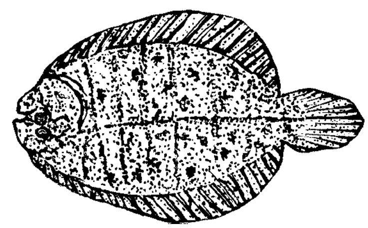


*Four-spined stickleback (*Apeltes quadracus*)*

Freshwater resident fishes were collected at site 3 and the two upstream sites near West Rock Park. These include brook trout, chain pickerel (*Esox niger*), spottail shiner (*Notropis hudsonius*), blacknose dace (*Rhinichthys atratulus*), golden shiner (*Notemigonus crysoleucas*), brown bullhead catfish (*Ictalurus nebulosus*), tesselated darter (*Etheostoma olmstedi*), redbreast sunfish (*Lepomis auritus*), pumpkinseed (*Lepomis gibbosus*), and largemouth bass. Largemouth bass were also collected at site 7 near the outflow from Horseshoe Lagoon, a freshwater pond where this species also resides. The individuals from site 7 were juveniles, and probably escaped from Horseshoe Lagoon.

Estuarine residents showed a number of distributional trends. Some fishes, such as four-spined sticklebacks, bluegills, and banded and striped killifishes, were found throughout the study area. The sticklebacks were, however, more abundant in fresher waters, while striped killifish and bluegills were never very abundant. The banded killifishes were most abundant closer to the tide gates. Carp and white suckers were found residing only in brackish to fresher waters (< 10 ppt), usually showing greater abundances in fresher waters. Many species were limited to the saltier portions (> 10 ppt) of the study area in the reflecting pool and the river itself downstream from the cross channel. These species included mummichogs, Atlantic silversides, inland silversides, white perch (*Morone americana*), winter flounder, and hogchokers (*Trinectes maculatus*).

A number of typically estuarine fishes were not found within the study area during this survey, but were collected or observed just downstream from the tide gates. These included bay anchovy (*Anchoa mitchilli*), Atlantic menhaden (*Brevoortia tyrranus*), striped bass (*Morone saxatilis*), and bluefish (*Pomatomus saltatrix*). The latter two species are highly regarded food and game fishes (Casagrande, pp. 62-75, this volume) that may largely be excluded from West River Memorial Park by the tide gates. According to fishermen, these fishes are much more frequently caught immediately downstream from the gates. These fishes could add economic and recreational importance to the park, if the tide gates are modified to allow easier passage for them. Menhaden and anchovies are usually consumed by other larger fishes and birds, including threatened least terns, which were often seen hunting in the area just downstream from the tide gates (J. Moore, personal observation).



*Hogchoker (*Trinectes maculatus*)*

RECOMMENDATIONS FOR FUTURE RESEARCH

A number of people were observed fishing during this study. Some of those questioned were sport fishing, but most intended to eat the fish they caught (Casagrande, pp. 62-75, this volume). Given the poor environmental health of the West River indicated by this study, especially in the reflecting pool and near the tide gates, the possibility exists that fishes, particularly top level carnivores (white perch, largemouth bass) and resident fishes (bluegills), may be accumulating toxins. It is imperative that toxicity studies be conducted on the prime target fishes of subsistence fishermen, e.g. bluegills, white perch, largemouth bass, American eel, striped bass, and bluefish.

For an IBI or EBI to be calculated, comparative information regarding fish fauna from relatively undisturbed habitats in the region is required. A faunal analysis should be conducted on a less impacted estuary and river system, potentially one of the smaller, less disturbed systems to the east of New Haven. Other salt marsh channels should also be sampled in anticipation of salt marsh restoration in the West River. This comparative information would then allow an explicit calculation of an IBI or EBI for the West River and would also provide a measure of any progress in improving the West River's environmental quality.

Alterations to the tide gates that would increase salt water intrusion to the West River Memorial Park would most likely cause salt water to enter the currently freshwater Horseshoe Lagoon. This pond should be sampled to determine resident fishes there and to test the habitat quality of the pond, which receives significant runoff from a nearby cemetery and surrounding community.

No quantitative analysis was made of the effect the tide gates have on the passage of fishes. It is apparent that the gates represent a physical barrier to some, if not all, of the diadromous fishes and may also reduce the numbers of amphidromous fishes, which would regularly pass back and forth between fresh and salt waters. Study of the actual effect of the gates on fish passage may enable some determination as to how to modify the gates to allow for freer movements.

CONCLUSIONS

The West River contains depauperate freshwater and estuarine fish faunas that reflect the high degree of anthropogenic disturbance to the river. No rare or threatened fish species were found in the river, and it is unlikely that any occur within the study area. Parameters indicate stressful conditions within portions of the river as a result of low-quality habitats and significant environmental perturbations. At present, the fish data may also be pointing to potential human health hazards.

Improvements to the estuarine habitats in the river could enhance the number of fish species and abundance of individuals within West River Memorial Park.

Improvements to the estuarine habitats in the river could enhance the number of fish species and abundance of individuals within West River Memorial Park. Modifications to the tide gates that would allow for easier passage of fishes and tidal waters would likely contribute to improved environmental health in the West River Memorial Park, without detrimentally affecting the freshwater fauna upstream. Salt marsh restoration may result in the strictly freshwater fauna being pushed further upstream in Edgewood Park as a result of salt water reaching further upstream during high tides.

Future replication of our sampling method could be used to monitor progress in restoring salt marsh fish communities and improving environmental quality of the West River. Sampling in the spring would aid in monitoring spawning migrants. Summer samples appear adequate to assess the anthropogenic effects on resident communities. More comparative baseline data, in the form of multiyear sampling in the West River and sampling from relatively undisturbed estuaries elsewhere in Connecticut, would improve the nature of the data and the strength of conclusions drawn from them.

As seen during the drought, only a small change in salinity is necessary for salt marsh grasses to reestablish. Changes to the tide gates should achieve a result similar to the drought and maintain those grasses beyond the first year. Reintroduction of salt marsh grasses to the West River Memorial Park would provide better cover for smaller nearshore fishes, more varied habitats, and food resources for small fishes and invertebrates. All of these changes would enhance the food resources and habitat for bluegill, white perch, striped bass, and bluefish, which in turn could provide added economic and recreational value to West River Memorial Park.

APPENDIX. FISH SPECIES COLLECTED OR OBSERVED DURING 1995-1996 IN THE WEST RIVER, NEW HAVEN, CONNECTICUT.

Family Petromyzontidae
- *Petromyzon marinus* (Sea lamprey)

Family Carcharhinidae
- *Mustelis canis* (Smooth-hound shark)

Family Anguillidae
- *Anguilla rostrata* (American eel)

Family Clupeidae
- *Alosa pseudoharengus* (Alewife)
- *Alosa aestivalis* (Blueback herring)

Family Engraulidae
- *Anchoa mitchilli* (Bay anchovy)

Family Cyprinidae
- *Cyprinus carpio* (Carp)
- *Notemigonus crysoleucas* (Golden shiner)
- *Notropis hudsonius* (Spottail shiner)
- *Rhinichthys atratulus* (Blacknose dace)

Family Catostomidae
- *Catostomus commersoni* (White sucker)

Family Ictaluridae
- *Ictalurus nebulosus* (Brown bullhead catfish)

Family Esocidae
- *Esox niger* (Chain pickerel)

Family Salmonidae
- *Salvelinus fontinalis* (Brook trout)

Family Atherinidae
- *Menidia beryllina* (Inland silverside)
- *Menidia menidia* (Atlantic silverside)

Family Belonidae
- *Strongylura marina* (Needlefish)

Family Cyprinodontidae
- *Cyprinodon variegatus* (Sheepshead minnow)
- *Fundulus heteroclitus* (Mummichog)
- *Fundulus diaphanus* (Banded killifish)
- *Fundulus majalis* (Striped killifish)

Family Gasterosteidae
- *Apeltes quadracus* (Fourspine stickleback)
- *Gasterosteus aculeatus* (Threespine stickleback)
- *Pungitius pungitius* (Ninespine stickleback)

Family Moronidae
- *Morone americana* (White perch)

Family Centrarchidae
- *Lepomis macrochirus* (Bluegill)
- *Lepomis auritus* (Redbreast sunfish)
- *Lepomis gibbosus* (Pumpkinseed)
- *Micropterus salmoides* (Largemouth bass)

Family Percidae
- *Etheostoma olmstedi* (Tessellated darter)

Family Pleuronectidae
- *Pseudopleuronectes americanus* (Winter flounder)

Family Soleidae
- *Trinectes maculatus* (Hogchoker)

ACKNOWLEDGMENTS

We would like to thank Emly McDiarmid whose work on promoting study of the West River was invaluable and whose trusty canoe was our main method of transportation on the river. We would also like to thank those who helped with our sampling: Jen Beck, David Casagrande, Guido Casagrande, Hank Demers, Katie Dodd, Laura Nachiem, and the science students from the Foote School. Rick Jacobson and Lauri Friedenburg kindly reviewed this manuscript and provided helpful comments. This research was supported by the Connecticut Department of Environmental Protection's Long Island Sound License Plate Program and the Norcross Wildlife Foundation.

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Amphibians and Reptiles of the Lower West River

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ABSTRACT

We surveyed West River Memorial Park in New Haven, Connecticut to determine which amphibian and reptile species are present within the park's available habitats and to assess the potential effects of salt marsh restoration on the herpetofauna. A variety of aquatic and terrestrial census methods were used. We recorded seven species of amphibians and reptiles, all of which are either described as habitat generalists or able to persist in highly disturbed urban areas. We conclude that plans for restoration of wildlife populations and future wildlife monitoring efforts in West River Memorial Park should be based on other taxa.

Connecticut is inhabited by 45 species of reptiles and amphibians (Klemens 1993). Most of these species are widely distributed across the state, but have limited distributions among the diversity of available habitats. As examples, many amphibians require the presence of non-permanent freshwater habitats, and many reptiles require dry, well-drained uplands (Klemens 1993). We surveyed West River Memorial Park to determine which amphibian and reptile species are present within the park's available habitats and to assess the potential effects of salt marsh restoration on the herpetofauna. We used an array of aquatic and terrestrial survey techniques in order to evaluate presence and absence of species.

METHODS

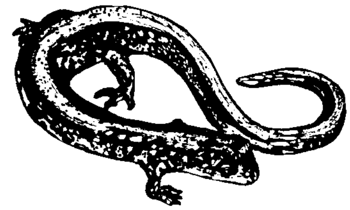
Between April and August of 1996, we surveyed West River Memorial Park to document the presence of amphibian and reptile species. The park is located on the lower reaches of the West River in New Haven, Connecticut, at the border with West Haven (see Fig. 3, p. 31). Our survey area was bounded on the north by Derby Avenue and on the south by Route 1 (Congress Avenue). Park land to the east of the reflecting pool was not surveyed. The three small ponds feeding into Horseshoe Lagoon, although not part of the park proper, were surveyed. Two ponds enter the lagoon on the eastern horn, and one enters on the western horn. The ponds are located west of Marginal Drive and north of the lagoon.

QUADRAT SAMPLING

Quadrat sampling was used to survey woodland salamanders and fossorial snakes (eastern worm snake and ringneck snake) in large patches of homogeneous habitat. Four 3 m by 6 m quadrats were randomly selected along a 50 m transect perpendicular to the slope. Two transects were searched, one in the hardwood forest on the southern edge of Horseshoe Lagoon, and one in the wooded riverbanks between Route 1 and the southern park gate. Within each quadrat, all ground cover, particularly large woody debris and rocks, was overturned, and all leaf litter was thoroughly searched. Searches were conducted within 24 hours of a thunderstorm or other soaking rainfall event.

CASUAL LEAF LITTER SEARCHES

On several occasions, thorough examinations of the ground cover were made in the woods bordering Horseshoe Lagoon on the north, the woodlands on either side of Marginal Drive and north of Horseshoe Lagoon, the isthmus just above the northwest corner of the island, and around the ditches located west of Marginal Drive and north of the isthmus connection. Examinations were conducted by picking through leaf litter until reaching the soil surface. Large woody debris and rocks were overturned to check for woodland salamanders and snakes. Quadrat sampling was not used in these areas.



Redback salamander

DIP NET SAMPLING

We walked the margins of the West River and Horseshoe Lagoon and visually surveyed for suitable amphibian habitats such as beds of submergent and emergent vegetation in the littoral zone as well as amphibian eggs, larvae, and adults. Submerged leaf litter and vegetation were sampled with a dip net. The two feeder ponds on the eastern horn of Horseshoe Lagoon, the feeder pond at the western horn of the lagoon, and the small backwater in the northeast corner of the Route 1-Marginal Drive intersection were similarly investigated.

PITFALL TRAPS

An array of pitfall traps was installed at the bottom of the slope between Marginal Drive and the backwater at the Route 1-Marginal Drive intersection. Traps were constructed from two, No. 10 aluminum cans attached at one end with duct tape, the bottom of the top can having been cut out. Each trap was installed so that the upper lip was approximately 3 cm below the ground, and traps were installed at 3 m intervals. Guide curtains made of heavy brown paper were erected between the traps, but not over the trap openings. The curtains were approximately 0.75 m high, and the bottoms were buried in a shallow trench in the ground.

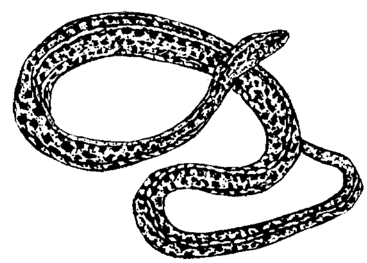
Traps were arranged in a "T"-shaped configuration. Four traps were installed in a line perpendicular to the slope, and two traps were installed parallel to the slope.

CALLING SURVEYS

Four surveys of frog and toad breeding calls were conducted. Two surveys were made in April, one in May, and one in June. The surveys were conducted at dusk and lasted 60 to 90 minutes. Surveys were conducted within 48 hours of a thunderstorm or other soaking rainfall event. The surveys were conducted by walking Marginal Drive between the park gates.

OBSERVATIONAL SAMPLING

Binoculars were used to scan riverbanks and water surfaces for frogs, turtles, and snakes. We searched Horseshoe Lagoon, its feeder ponds, the main river channel, and the reflecting pool on approximately 10 occasions. Observations were made either during the mornings, one to two hours after sunrise, or during the calling surveys (see above). Marginal Drive and the gravel parking lot were checked for basking snakes at the same times.



Eastern garter snake

RESULTS

Despite the use of several sampling methods, we recorded just seven species of amphibian and reptiles in West River Memorial Park (Table 1). None of the recorded species are listed as endangered, threatened, or of special concern (Connecticut Department of Environmental Protection 1995).

No individuals were revealed during quadrat sampling. Despite an abundance of prey (earthworms, sowbugs, etc.) and ground-level moisture (as measured by the authors' touch), no woodland salamanders or fossorial snakes were found. No individuals were found on the isthmus or in the woods north of Horseshoe Lagoon during the causal leaf litter searches.

An area adjacent to the ditches near the north end of Marginal Drive revealed a small population of redback salamanders. Both red and lead forms were found in equal numbers. The salamanders were concentrated in one 75 m^2 area. Other areas along the ditch with similar tree and ground covers (e.g., leaf litter and amount of large woody debris) failed to yield additional individuals. A single, eastern garter snake was captured in this area in late April.

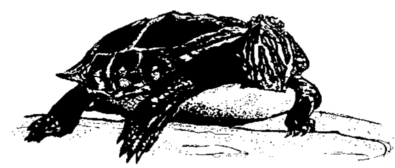
Table 1. Current records of amphibians and reptiles in the towns of New Haven and West Haven, Connecticut (Klemens 1993, J.P. Gibbs, Columbia University, personal communication). Species found during this survey of West River Memorial Park are denoted by an "X".

SALAMANDERS AND NEWTS	
Four-toed salamander (*Hemidactylium scutatum*)	
Marbled salamander (*Ambystoma opacum*)	
Northern dusky salamander (*Desmognathus f. fuscus*)	
Northern two-lined salamander (*Eurycea bislineata*)	
Redback salamander (*Plethodon cinereus*)	X
Red-spotted newt (*Notophthalmus v. viridescens*)	
Spotted salamander (*Ambystoma maculatum*)	
FROGS AND TOADS	
Bullfrog (*Rana catesbeiana*)	
Eastern American toad (*Bufo a. americanus*)	X
Fowler's toad (*Bufo woodhousii fowleri*)	
Gray treefrog (*Hyla versicolor*)	
Green frog (*Rana clamitans melanota*)	X
Northern spring peeper (*Pseudoacris c. crucifer*)	
Pickerel frog (*Rana palustris*)	
Wood frog (*Rana sylvatica*)	
TURTLES	
Common snapping turtle (*Chelydra s. serpentina*)	X
Eastern box turtle (*Terrapene c. carolina*)	
Painted turtle (*Chrysemys picta*)	X
SNAKES	
Eastern garter snake (*Thamnophis s. sirtalis*)	X
Eastern milk snake (*Lampropeltis t. triangulum*)	
Northern black racer (*Coluber c. constrictor*)	
Northern brown snake (*Storeria dekayi dekayi*)	
Northern copperhead (*Agkistrodon contortrix mokasen*)	
Northern ringneck snake (*Diadophis punctatus edwardsii*)	
Northern water snake (*Nerodia s. sipedon*)	X
Smooth green snake (*Opheodrys vernalis*)	

Dipnetting and searching along the banks revealed green frog tadpoles in the pond on the western horn of Horseshoe Lagoon and in the northernmost pond on the eastern horn. Green frog tadpoles were regularly found in both ponds from late May to mid-July. One adult was observed in the western pond in June. Several adults were found around the margin of both eastern feeder ponds and the eastern horn of the lagoon throughout the study period.

Several hundred (visual estimate) American toad tadpoles were found in the backwater at the corner of Route 1 and Marginal Drive. One large adult toad and several dozen neomorphs were captured adjacent to the backwater in the pitfall traps. These toadlets were abundant in the woodlands around the backwater throughout July and August.

Remarkably, no frogs were heard during the calling surveys despite the presence of robust choruses and breeding activity of a number of species during the same period at the nearby Yale Preserve. Scanning the surface and margins of the water revealed a snapping turtle and a northern water snake in the pond on the western horn of Horseshoe Lagoon in late June. Painted turtles were observed in this location, in Horseshoe Lagoon, and in the southernmost pond on the eastern horn throughout the study period. No turtles, snakes, or frogs were ever observed in the river channel or reflecting pool.



Painted turtle

DISCUSSION

Over half of Connecticut's 45 amphibian and reptile species have been recorded within New Haven and West Haven (Table 1; Klemens 1993). Given this diversity, the number of species (n=7) recorded at West River Memorial Park is low. Quite probably, additional sampling effort would uncover more species (e.g., northern ringneck snake, bullfrog). However, many species are likely to be absent because the park does not provide suitable habitat. There is little in the way of necessary breeding habitats for amphibians, such as ephemeral ponds, small streams, and seeps. Most of the standing water is permanent, intermittently saline (Cuomo and Zinn, this volume), inhabited by predatory fish (Moore et al., this volume), and has a largely unvegetated littoral zone. This combination of attributes makes the park extremely inhospitable to most aquatic-dependent amphibians (Kats et al. 1988, Klemens 1993, Holomuzki 1995).

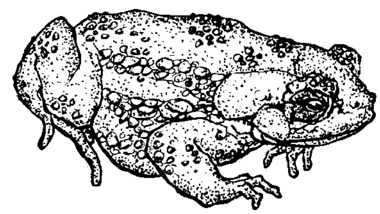
Among primarily terrestrial species, there is an entire complement of regionally common amphibians and reptiles (e.g. Fowler's toad, eastern box turtle) that favor dryer uplands or rocky habitats. The park does not provide such habitats. The small size and isolation of the park within an urban landscape probably contributes to the low number of species (Minton 1968). In Campbell's review (1974), he emphasizes the poor dispersal ability of reptile and amphibian species through urbanized landscapes. Gibbs (1995) notes that many locally abundant Connecticut amphibians are unable to traverse urban landscapes in order to exploit suitable habitats within the urban matrix.

CONCLUSIONS

The herpetofaunal diversity of West River Memorial Park is extremely low and comprised entirely of common species that can persist in urban environments (Klemens 1993). Our results are consistent with the findings of Campbell (1974) and the several urban herpetofaunal surveys that he describes. Restoration of the salt marsh is unlikely to improve habitat for most of these species. Just two, the snapping turtle and the American toad, are routinely found in and around salt marshes (Klemens 1993). Others such as painted turtles, northern water snakes, and green frogs may be lost when salinity in the river and associated backwaters increases (Klemens 1993; Cuomo and Zinn, this volume). The remaining species (redback salamander and garter snake) are likely to persist in the wooded portions of the park (Minton 1968, Campbell 1974).

Salt marsh restoration is unlikely to promote the unaided immigration and establishment of new species. There is at least one species, the diamondback terrapin, that is a specialist within Connecticut's coastal habitats. However, the diamondback terrapin has been recorded only once[1] in New Haven and West Haven, despite intense local collecting evidenced by many historical records of rare (and now locally extinct) species (Klemens 1993).

Because of the lack of suitable freshwater and terrestrial habitats, the park has been, and will continue to be, unsuitable for most amphibians and reptiles. Fortunately, within the surrounding region there are other protected areas containing excellent habitat for amphibians and reptiles (e.g., West Rock Ridge State Park and the Yale Preserve). Wildlife monitoring efforts and plans for restoration of wildlife populations in West River Memorial Park should be based on other taxa.



Eastern American toad

[1] On May 31, 1996 Ray Pupedis and Celia Lewis of the Peabody Museum of Natural History caught, photographed, and released a diamondback terrapin in the Quinnipiac River in New Haven. Diamondback terrapins were once common in Connecticut salt marsh creeks, but are now less abundant.

ACKNOWLEDGMENTS

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Using Avian Communities to Evaluate Salt Marsh Restoration

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ABSTRACT

The objectives of this study were to document avian species inhabiting West River Memorial Park in New Haven, Connecticut and develop goals for restoration of a salt marsh bird community. Restoration goals were based on the breeding season bird community at the restoration site, breeding season communities of less disturbed salt marshes, and a literature review. Community descriptions included relative abundances of species and foraging guilds, nesting density, and obligate species. We conducted fixed-radius point counts and call-back surveys to develop a species list and estimate relative abundances. Nesting densities in less disturbed marshes were summarized from the literature. We also searched stands of common reed (*Phragmites australis*) at the restoration site to identify nesting species that would be affected by restoration.

The number of species using West River Memorial Park was high (n=99), and 11 species were endangered, threatened, or of special concern. This indicates the importance of the park for avian diversity within an urban area. No species of concern would be negatively impacted by the restoration, and many would benefit. The species we observed most often in common reed during the breeding season was the red-winged blackbird, and only red-winged blackbird nests were found in common reed stands.

The proportion of species shared by West River Memorial Park and the less disturbed marsh during breeding was high, and the relative abundance of foraging guilds was similar. However, relative abundances of species were different. Breeding bird densities of all species in *Spartina* spp. zones summarized from the literature suggest an average 2.5 breeding pairs ha^{-1} (1 pair $acre^{-1}$). These results suggest that restoration of a salt marsh bird community in West River Memorial Park is feasible. We discuss changes in species abundance that will be necessary to achieve restoration. We also recommend design criteria to address salt marsh bird habitat restoration problems in this park and urban areas in general.

The value of birds has played a significant role in the movement to conserve – and now restore – salt marsh habitat (Casagrande, pp. 13-40, this volume). Udziela and Bennett (this volume) have shown the value placed on salt marshes as habitat for endangered bird species. These values indicate the need to predict the effects of restoration on birds. Such an evaluation requires reviewing current knowledge of avian salt marsh habitat and assessing the condition of West River Memorial Park.

Salt marshes provide habitat for obligate species, which breed and forage only in salt and brackish marshes, and facultative species, which breed or forage in other habitats as well. Obligate, salt marsh species in Connecticut include sharp-tailed sparrow,[1] seaside sparrow, and clapper rail (Greenlaw 1983, Robbins 1983, Craig 1990, Eddleman and Conway 1994). Both sparrow species have been

[1] Common names follow the American Ornithologists' Union system.

described as common but declining in numbers in Connecticut River salt marshes (Craig 1990), and are considered species of special concern by the Connecticut Department of Environmental Protection (CT DEP 1995). Alteration of salt marsh habitat in Connecticut has likely contributed to decreased populations (Robbins 1983). We chose not to rely exclusively on presence of obligate species to evaluate restoration success, because their presence is highly variable among undisturbed salt marshes and the relationships between their presence and site characteristics are poorly understood (Brawley 1995). Also, salt marshes provide important habitat for facultative species.

There are many facultative, salt marsh species in Connecticut, and their presence and abundance vary among marshes. Facultative, salt marsh species designated by the CT DEP as endangered, threatened, or species of special concern include the great blue heron, great egret, snowy egret, willet, least bittern, yellow-crowned night-heron, black-crowned night-heron, osprey, glossy ibis, least tern, and common tern (Daiber 1982, Craig 1990, Reinert and Mello 1995).

We chose not to rely exclusively on presence of obligate species to evaluate restoration success, because their presence is highly variable among undisturbed salt marshes. Also, salt marshes provide important habitat for facultative species.

Avian communities of salt marshes are affected by a number of habitat variables including water salinity, depth and frequency of flooding, heterogeneity of the plant community, competition between bird species, size of the marsh, and history of human impact (Poulson 1969, Daiber 1982, Brown and Dinsmore 1986, Craig and Beal 1992). Diversity and abundance of salt marsh birds have been linked to heterogeneity and juxtaposition of microhabitats (Greenlaw 1983, Craig and Beal 1992, Reinert and Mello 1995). Common reed (*Phragmites australis*) contributes to heterogeneity in undisturbed salt marshes where it is confined to a thin strip at the marsh edge, or occurs in small patches throughout the marsh. This pattern occurs because common reed is less tolerant of salinity and inundation than other marsh vegetation (Parrondo et al. 1978, Hellings and Gallagher 1992).

Human-induced reductions in water level and salinity, such as those of West River Memorial Park, often lead to vigorous expansion of common reed (Roman et al. 1984, Hellings and Gallagher 1992). These created reed stands tend to have low bird diversity and abundance (Bontje 1987). Obligate, salt marsh species tend to be absent from created reed stands (Bontje 1987), and the avian community is dominated by blackbirds or grackles (Post and Seals 1991). However, few studies have investigated avian use of large common reed stands in the United States. Anecdotal observations of avian use rarely include descriptions of stand characteristics such as reed stem density and stand size. Studies in Europe, where large stands of reed occur naturally, have found that common reed provides valuable habitat for birds (Frömel 1980, Tscharntke 1992). Hence, it is important to document existing use of common reed as a function of stand characteristics in West River Memorial Park, because salt marsh restoration would reduce common reed.

Our goals were to (1) develop a list of species occurring throughout the year at the restoration site and downstream, (2) document those species likely to be negatively impacted by eradication of common reed, and (3) compare profiles of breeding season bird communities at the proposed restoration site and a control salt marsh. We conducted fixed-radius point counts (Hutto et al. 1986) and call-back surveys between May 1995 and May 1996. We also searched intensively for nests along transects in stands of common reed in West River Memorial Park.

Foraging guilds are appropriate for describing the unique pattern in which an ecosystem's productivity is available to birds.

METHODS

For evaluating habitat, we used an avian community approach that included relative abundances of foraging guilds and individual species, nesting density, and obligate species. Foraging guilds are groups of bird species defined by what and how they eat. For example, birds that ground-glean only seeds are in a different guild from omnivorous ground-gleaners. Relative abundance indicates which foraging guilds dominate the habitat. This method is valuable for describing habitat, because it reflects the pattern in which ecosystem productivity is available to a foraging community. It is also valuable to include relative abundances of each species to reflect vegetation structure and level of disturbance. We developed community profiles for West River Memorial Park and a relatively undisturbed control site. The control site provided a target community profile (a profile of how the West River Memorial Park bird community should be composed after restoration). We also used published nesting density data in our target community profile.

The area of West River Memorial Park is approximately 81 ha (200 acres). Human alterations of the park have led to a mosaic of herbaceous plant communities, deciduous woods, stands of common reed, and open water (Orson et al., pp. 136-150, this volume). Approximately 12 ha (30 acres) of the park are dominated by common reed. Stands of reed are mostly less than 2 ha (5 acres); the largest stand is 3 ha (8 acres). The area of potential salt marsh restoration is approximately 25 ha (62 acres).

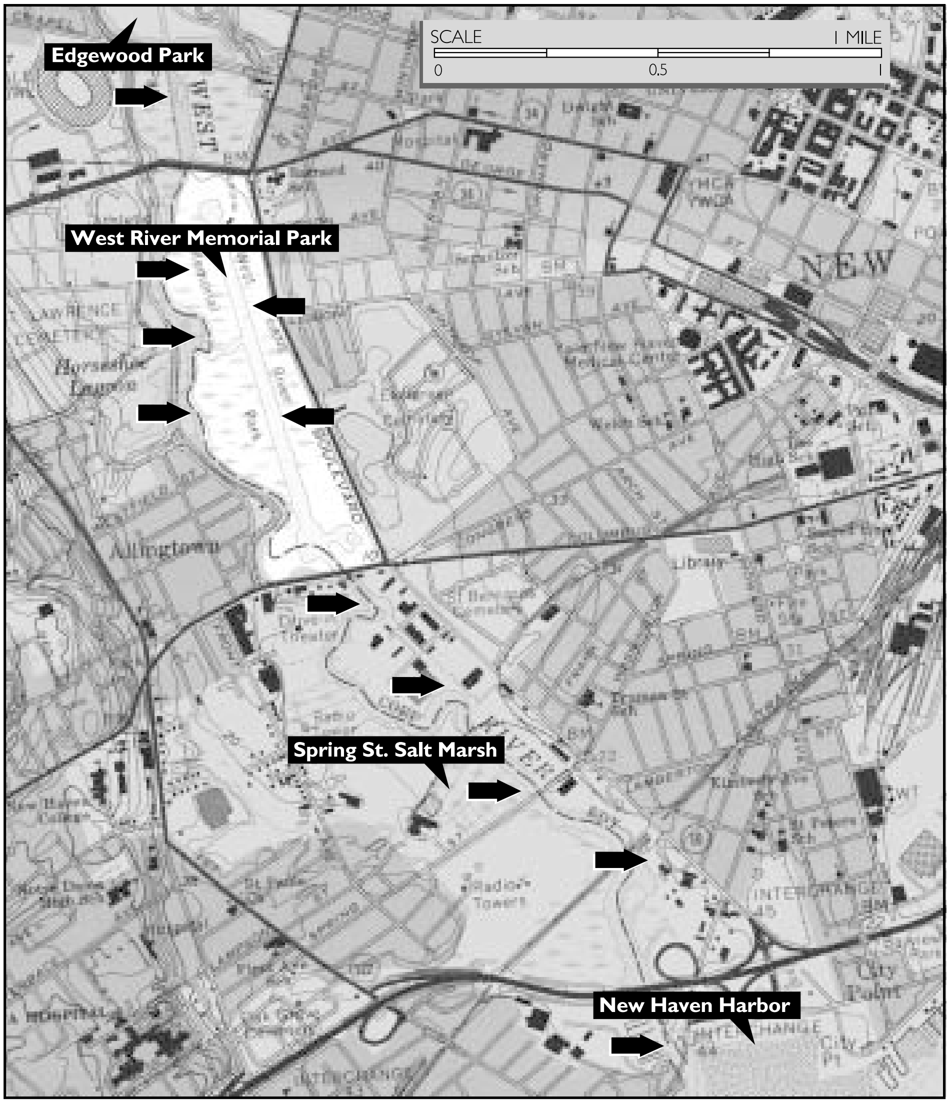


Figure 1. West River salt marsh restoration study area (white) and bird survey point locations.

Bird communities are influenced by surrounding habitats, and the urban areas east, west, and south of the park are heavily developed (Fig. 1). The river is separated from a dense residential area and large cemetery to the west by deciduous woods varying from 10 to 107 m (33 to 352 ft) in width. The river is separated from dense development to the east by stands of common reed and ball playing fields. Edgewood Park, an adjacent park to the north, is mostly deciduous forest.

We chose Hoadley Marsh in Guilford, Connecticut as a control site, because it is an isolated marsh of similar size (58 ha; 143 acres) surrounded by residential land use and upland deciduous forest. Hoadley Marsh is 18.7 km (11.6 miles) east of West River Memorial Park. This marsh is impounded by a dike close to the sea and by a raised railroad bed farther inland. These barriers are breached, but tidal flow is reduced. A typical result of such situations is that the tide ebbs more slowly, resulting in longer periods of tidal submersion. This might explain why Hoadley Marsh is dominated by *Spartina alterniflora*, which is more tolerant of submersion (Parrondo et al. 1978, Niering and Warren 1980). Stands of *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii* were not as dense as we have observed in other marshes. Hoadley Marsh includes many irregularly flooded salt pannes and is criss-crossed by mosquito ditches. The marsh was occasionally mowed for hay until 1970.

Eight point count surveys were conducted along the West River during each of the four seasons: the breeding season (May 15-July 17, 1995), fall (Sept. 1-Oct. 16., 1995), winter (Jan. 15-March 1, 1996), and spring (April 1-May 10, 1996). Six points were located within West River Memorial Park and five points were located along the lower river between the park and New Haven Harbor (Fig. 1). Two relict salt marshes were located near downstream survey points. Five survey points were located in Hoadley Marsh in Guilford. Eight point counts were conducted at Hoadley Marsh during the breeding season only.

Ralph et al. (1993) recommend 250 m (800 ft) distance between points to minimize double counting. However, other work we have done in similar habitats indicates that detection of most species drops off rapidly after 200 m (650 ft). We chose a minimum 200 m distance between points to maximize the number of points. Points could not be randomly located because access to West River was limited, especially below the tide gates. Therefore, selection of points was based on accessibility, view of the river, inclusion of the dominant habitat types, and distance between points. We surveyed each point for five minutes. This duration tends to maximize the number of species detected while minimizing bias due to double counting and allowing for more points to be counted (Gutzwiller 1993, Ralph et al. 1993). We randomized the order in which the points were surveyed each day to account for diurnal patterns of bird behavior.

All point counts conducted during spring and the breeding season were between 6:00AM and 10:00AM. In the fall, point counts were conducted between 6:30AM and 10:30AM, and in winter between 9:30AM and 3:00PM. No surveys were conducted in rain, snow, or strong winds. Birds were noted as being seen and/or heard within a 25 m (80 ft) radius or outside of a 25 m radius (unlimited distance).

Birds that moved into the fixed-radius during the count period were counted as inside the circle. Birds that flushed from the circle as we approached were also counted as inside the circle. We recorded the habitat in which birds were detected (i.e., air, water, undergrowth, canopy, open field, common reed, freshwater marsh, salt marsh, and edge of river).

Call-back surveys were conducted in the West River by canoe during the breeding season at ten points. Again, the points were at least 200 meters apart and were located between Chapel Street and New Haven Harbor. We surveyed all ten points five times between May 12 to June 21 between 4:00 and 9:00AM. The survey method followed that of the Connecticut Department of Environmental Protection (CT DEP) marsh bird call-back survey (J. Dickson, CT DEP, Wildlife Division, personal communication). We attempted to solicit calls from American bittern, least bittern, black rail, clapper rail, king rail, sora, willet, common moorhen, pie-billed grebe, and American coot.

We anticipated problems detecting all species with equal probabilities. For example, species that are more likely to be detected by call would be underrepresented at points near noisy city streets. Therefore, we determined differences in species abundance using relative abundances (Verner 1985). Relative abundances are easily obtained from point counts and are sufficient to compare communities (Verner 1985, Hutto et al. 1986).

We developed breeding community profiles using the relative abundances of foraging guilds, relative abundances of species, and published data for salt marsh breeding bird density (Table 1). We assigned species to foraging guilds based on the foraging descriptions of Martin et al. (1951) and Ehrlich et al. (1988). The proportion of birds in foraging guilds and relative abundances of species were calculated from frequency of detections during point counts during the breeding season (May 15 - July 17).

We tested for the ability to detect species with fixed-radius point counts by comparing the number of species detected during point counts to the total number detected in the area (Hutto et al. 1986). Total number detected in the area was the sum of species detected during point counts, call-back surveys, observations between points, and observations of other researchers during the survey period.

Estimates of relative abundance may be biased by distance. We used Spearman ranked correlation (r_s, Zar 1974) to determine differences in the relative abundances of species detected within 25 m and at unlimited distance.

We used the Kolmogorov-Smirnov goodness of fit test (D, Zar 1974) to determine differences in relative abundances of species and foraging guilds between Hoadley Marsh (expected) and West River Memorial Park (observed). The proportion of species shared between sites was estimated using the similarity index (*SI*, Odum 1971).

We sampled nesting behavior in common reed in West River Memorial Park by walking parallel transects through two dense stands of common reed. One stand was 1.4 ha (3.4 acres) in size; the other was 0.8 ha (1.9 acres). Both stands were adjacent to open water, but were infrequently flooded because stand elevation was 0.5 m (1.6 feet) above mean high water. We sampled 450 m (1476 feet) of transect during the first week of June, 1996, looking for nests in the vegetation and on the ground within 1 m (3.28 feet) on either side of the transect. This resulted in an effective sampling area of 900 m^2 (9683 ft^2). We identified bird species responsible for nests using eggs, nestlings, or other nest characteristics (Harrison 1975). To characterize vegetative structure we sampled reed stem density and height and presence of other plant species within 0.25 m^2 quadrats randomly distributed along the transects. Stem density measurements were taken at ground level and included both dead and live stems. Stem height measurements included stems of the previous year only (i.e., dead, but with seed heads).

It was important to document birds nesting in common reed, because salt marsh restoration would reduce common reed. Only red-winged blackbirds were found nesting in common reeds within West River Memorial Park.

Avian surveys were also conducted to the north of West River Memorial Park in Edgewood Park and around the reservoirs on the upper reaches of the watershed. Species observed in Edgewood Park and along the river downstream from West River Memorial Park are included in the Appendix. Upper watershed data are not included in this study, but are available upon request from the authors.

RESULTS

Ninety-five percent of all species were detected during point counts. This suggested that point sampling provided good coverage. No additional species were detected during call-back surveys. The relative abundances of species detected during point counts within 25 m and at unlimited distance were not different ($r_s = 0.94$, n = 145, $p < 0.05$). We used unlimited distance data to calculate proportion of birds in foraging guilds and species abundance.

We observed 99 bird species in West River Memorial Park over the course of the year, 11 of which are listed as endangered, threatened, or species of special concern by the CT DEP (Appendix). We found no obligate, salt marsh species in West River Memorial Park, and found only one obligate (clapper rail) in Hoadley Marsh. One obligate species (sharp-tailed sparrow) was observed breeding in a relict salt marsh downstream from West River Memorial Park. Results of the literature review indicated breeding bird density in salt marshes is 2.5 breeding pairs ha^{-1} for all species (Table 1).

Table 1. Published densities of breeding pairs in salt marshes, all species.

Source	Study location	Breeding pairs ha^{-1}
Leenhouts (1982a)	Florida	1.2
Leenhouts (1982b)	Florida	1.6
McDonald (1982)	Florida	2.1
Moller (1975)	Denmark	2.2
McDonald (1988)	Florida	2.3
McDonald (1983)	Florida	2.5
Jacobson et al. (1983b)	California	2.7
Jacobson et al. (1983a)	California	2.8
McDonald (1990)	Florida	3.3
Post (1970)	New York	3.4
McDonald (1985)	Florida	3.6
Spaans (1994)	Netherlands	1.9
	mean	2.5
	SD	0.7

The proportion of species shared by West River Memorial Park and Hoadley Marsh during the breeding season was high, ($SI = 0.70$), but the relative abundance of each species was different ($D = 0.28$, n = 32, $\alpha = 0.05$). The relative abundance of foraging guilds was not different between the restoration and control sites ($D = 0.14$, n = 31, $\alpha = 0.05$). Both communities were dominated by birds that glean insects on the ground (Fig. 2), primarily red-winged blackbirds, song sparrows and European starlings (Table 2). West River Memorial Park had fewer birds that forage for insects in the air. The most abundant aerial-foragers in Hoadley Marsh were barn swallows and tree swallows. Omnivorous ground-gleaners were less abundant in West River Memorial Park because of fewer common grackles, herring gulls, and blue jays. A larger representation of waterfowl that surface-feed on aquatic vegetation in West River Memorial Park was due to abundant mallards. The higher proportion of foliage gleaners in West River resulted mostly from an abundance of yellow warblers and common yellowthroats.

The species we observed most often using common reed (*Phragmites australis*) during the breeding season point counts was the red-winged blackbird (Table 3). Blackbirds often perched or foraged in reeds. Some willow flycatchers were observed foraging above reeds, but usually returned to branches of small trees to perch. Song sparrows were occasionally seen perched and singing on reed stems. We observed several species foraging for insects or seeds in reeds during winter (Table 3).

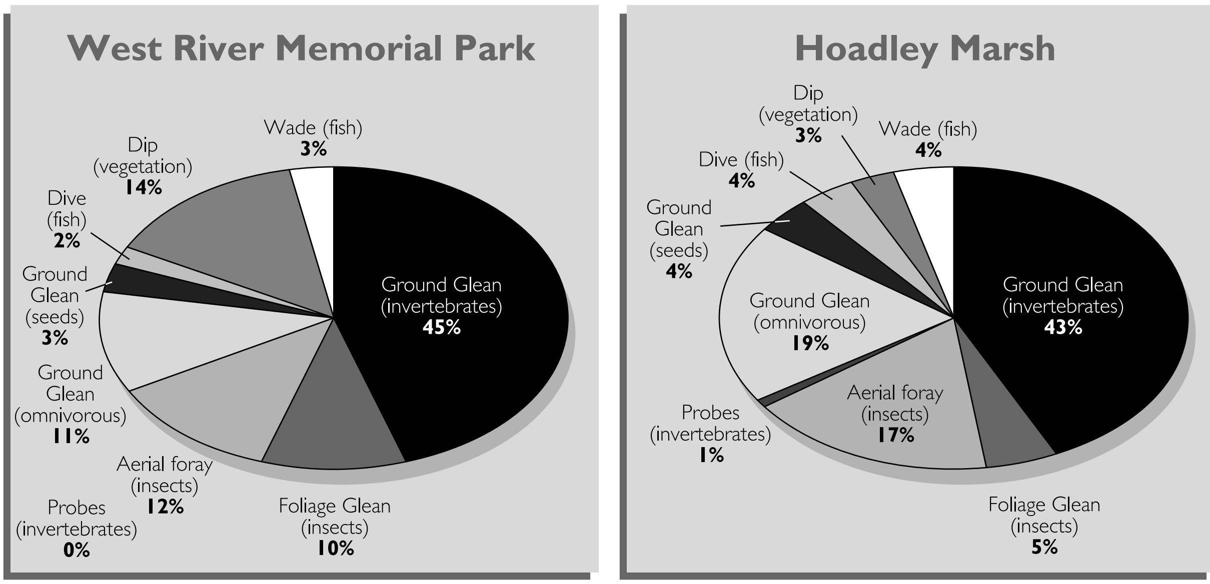


Figure 2. Relative abundances of foraging guilds in West River Memorial Park and Hoadley Marsh determined from point counts during the 1995 breeding season (May 15-July 17).

Interiors (more than 3 m from edges) of the common reed stands that we surveyed for nests did not include any vegetation other than common reed. Mean reed stem height (321 cm, ± 24 cm) and density (109 m^{-2}, ± 20 m^{-2}) indicated a vigorous reed community. Only red-winged blackbirds were observed within common reed stands during nest search transects, with the exception of one common yellowthroat. Thirty-three percent of nests contained eggs or nestlings of red-winged blackbirds; other nests were empty. All nests showed size, construction, and materials typical of red-winged blackbirds (Harrison 1975). Nests were cup shaped and had outer diameters of 11.5 cm (±1.7 cm), inner diameters of 7.7 cm (±1.1 cm), outer depths of 9.2 cm (±1.7 cm), and inner depths of 5.7 cm (±0.5 cm). Nests were woven into dead common reed stems 90.6 cm (±23.2 cm) above the ground. No nests were found on the ground. Red-winged blackbird nests were abundant in the common reed stands (105 nests ha^{-1}, 42 nests $acre^{-1}$).

Table 2. Observations per point visit during the breeding season for select species.

Common name	Hoadley Marsh	West River Memorial Park
blackbird, red-winged	6.3	5.4
cormorant, double-crested	0.4	0.3
crow, American	1.5	1.2
duck, black	0.4	0.1
egret, snowy	1.3	0.0
finch, house	0.9	0.2
flycatcher, willow	0.0	1.2
goose, Canada	0.2	1.9
grackle, common	2.1	0.8
gull, herring	1.8	0.6
heron, great blue	0.0	0.2
heron, green	0.3	0.0
ibis, glossy	0.1	0.0
jay, blue	1.0	0.2
mallard	0.4	2.1
night-heron, back-crowned	0.0	0.7
osprey	0.7	0.1
rail, clapper	0.1	0.0
robin, American	0.7	1.7
sparrow, song	0.4	2.9
starling, European	5.8	1.6
swallow, barn	2.9	0.7
swallow, rough-winged	0.3	0.6
swallow, tree	1.3	0.2
swan, mute	0.1	0.2
swift, chimney	0.8	0.8
tern, common	0.2	0.0
warbler, yellow	0.2	1.8
wren, marsh	0.6	
yellowlegs, greater	0.1	0.1
yellowthroat, common	0.2	0.7

Table 3. Number of sightings of birds using common reed (*Phragmites australis*) during point count surveys in West River Memorial Park, New Haven, Connecticut.

Summer (15 May – 10 July)	
red-winged blackbird	110
willow flycatcher	20
song sparrow	19
American goldfinch	4
yellow warbler	3
black-crowned night-heron	3
common yellowthroat	3
swamp sparrow	2
pheasant	1

Winter (15 Jan. – 26 Feb.)	
black-capped chickadee	8
downy woodpecker	6
American tree sparrow	6
song sparrow	5
American crow	1
blue jay	1
tufted titmouse	1
swamp sparrow	1

Spring (1 March – 12 May)	
red-winged blackbird	46
song sparrow	23
American goldfinch	7
yellow warbler	5
common grackle	3
downy woodpecker	3
northern Cardinal	2
brown-headed cowbird	1
European house sparrow	1
American tree sparrow	1
savannah sparrow	1

Fall (1 Sept. – 28 Oct.)	
song sparrow	9
red-winged blackbird	7
American goldfinch	5
black-capped chickadee	4
swamp sparrow	3
downy woodpecker	2
eastern phoebe	2
marsh wren	2
gray catbird	1
mourning dove	1
common yellowthroat	1
northern mockingbird	1
eastern towhee	1
hermit thrush	1

DISCUSSION

Given the history of New Haven and West River Memorial Park (Casagrande, pp. 13-40, this volume), we were not surprised to find West River Memorial Park dominated by species that have adapted to landscapes altered by humans. During the breeding season, red-winged blackbird is the most abundant species, followed by song sparrow, mallard, Canada goose, American robin, and European starling (Table 2). These species are tolerant of, or in some cases attracted to, human-altered landscapes (Dowd 1992).

Nevertheless, the number of species detected in West River Memorial Park (n = 99) was very high for an urban area (Beissinger and Osborne 1982, DeGraaf et al. 1991). The high number of species likely resulted from the range of vegetation types in the park (Orson et al., pp. 136-150, this volume), presence of water, size of the park, and proximity to other forested parks. Other researchers have also found the number of species in relict, urban, wetland forests to be high (Tilghman 1987, Dowd 1992).

The absence of obligate, salt marsh sparrows in Hoadley Marsh indicates the difficulty in using obligate species to evaluate restoration (Brawley 1995). We probably did not find sharp-tailed or seaside sparrows in Hoadley Marsh because the marsh is excessively flooded (Daiber 1982, Greenlaw 1983). Prolonged flooding would explain the paucity of *Spartina patens* and the predominance of *Spartina alterniflora* (Parrondo et al. 1978, Niering and Warren 1980). In addition, Hoadley Marsh was mowed until 1970, and mowing has been found to cause long-term changes in salt marsh bird communities (Moller 1975, Larsson 1976).

Although many species are shared by West River Memorial Park and Hoadley Marsh, relative abundances of each species indicate different bird communities. Restoration could change the existing bird community structure at West River to be more like Hoadley.

Although species similarity between West River Memorial Park and Hoadley Marsh was high, relative abundances of each species indicated different bird communities. Restoration could focus on shifting the existing avian community structure and composition of West River Memorial Park to be more like Hoadley Marsh (Fig. 2). This implies a need to increase the abundance of aerial insectivores and ground-gleaning omnivores. It would also require shifting the abundance of some species within foraging guilds.

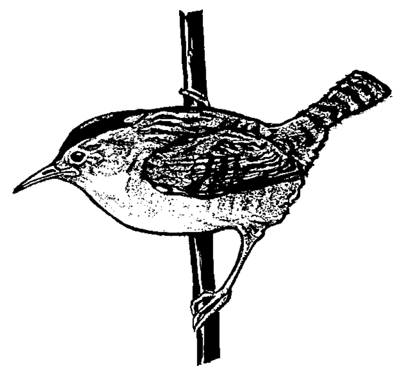
GROUND-GLEANERS OF INVERTEBRATES

Birds that ground-glean for invertebrates were the dominant foraging guild at both Hoadley Marsh and West River Memorial Park (Fig. 2). Relative abundance of this guild would probably not change much with successful restoration. However, species composition within the guild would probably change.

Song sparrows are abundant ground-gleaning insectivores in West River Memorial Park. Song sparrows are very common throughout Connecticut (Zeranski and Baptist 1994), and are adapted to a variety of habitat types, including forest edges, stream banks, and marshes (Delany and Mosher 1983, Bevier 1994). This species was observed in common reed during all four seasons and has been known to feed on common reed seeds (Marks et al. 1994). Song sparrows may be displaced by sharp-tailed and seaside sparrows with successful restoration. Sharp-tailed and seaside sparrows are more abundant than song sparrows in New England salt marshes (Post 1970, Clarke et al. 1984, Reinert and Mello 1995).

We did not detect sharp-tailed or seaside sparrows at West River Memorial Park or Hoadley Marsh, although both species were found in New Haven's Quinnipiac River marshes during a 1996 call-back survey (CT DEP, unpublished data). In addition, we found breeding sharp-tailed sparrows to be abundant in a 7 ha (17 acre) relict salt marsh 0.8 km (0.5 miles) downstream from West River Memorial Park at Spring Street (Fig. 1). Brawley (1995) found sharp-tailed sparrows to be more widely distributed than seaside sparrows in Connecticut salt marshes. These results suggest that obligate, salt marsh sparrows do not necessarily avoid urban salt marshes, but that sharp-tailed sparrows are more likely to colonize the restored site than seaside sparrows if vegetation structure is suitable.

One of the most abundant wetland breeding species in Connecticut is the red-winged blackbird (Craig 1990, Bevier 1994). The lack of preference for habitat (Craig 1990, Brawley 1995) and high relative abundance of red-winged blackbirds at both of our sites (Table 2) suggest that salt marsh restoration in West River Memorial Park would result in little change for this species.



Marsh wren

European starling was the second most common species at Hoadley Marsh, and may have replaced sharp-tailed and seaside sparrow as the dominant species that ground-gleans arthropods. A significant restoration challenge in West River Memorial Park will be to create habitat in an urban area that is more conducive to seaside and sharp-tailed sparrows than European starlings or song sparrows.

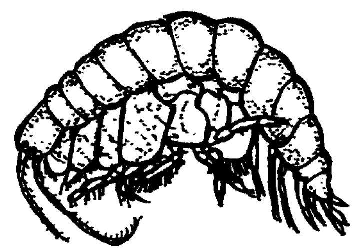
Marsh wrens typically nest in salt marshes (Post 1970, Daiber 1982, Burger 1985) and are abundant in transitional brackish marshes throughout Connecticut (Bevier 1994; Craig 1990; CT DEP, unpublished data). They nest in tall, emergent vegetation such as common reed and cattails, and are locally common migrants in spring and fall. We found marsh wrens in reed stands at Hoadley Marsh during the breeding season, but not in West River Memorial Park.

Marsh wrens have been observed using created stands of common reed in altered salt marshes (Bontje 1987), and abundance of common reed in West River Memorial Park suggests that emergent vegetation is sufficient for nest sites. More likely, the absence of marsh wrens results from the size and density of common reed stands (Brown and Dinsmore 1986), the absence of other grasses (Saunder 1922), lack of proximity to open water (Verner and Engelsen 1970), or interspecific competition with red-winged blackbirds (Picman 1980). Marsh wrens were quick to colonize restored salt marshes in California and New Jersey (Jacobson et al. 1983b, Bontje 1987), and we found marsh wrens to be abundant in recently restored salt marshes in Fairfield, Connecticut. Monitoring changes in marsh wren and red-winged blackbird abundance as a result of restoration could shed light on long-standing questions about marsh wren and red-winged blackbird nesting patterns (Saunder 1922).

GROUND-GLEANING OMNIVORES

All species of this foraging guild were more abundant in Hoadley Marsh than West River Memorial Park, but especially common grackle, herring gull, and blue jay (Table 2). The dense *Phragmites* may preclude foraging by these three species in West River Memorial Park. However, the abundance of ground-gleaning, omnivorous species in Hoadley Marsh may also be a result of upland habitat and proximity to breeding grounds.

Common grackles forage in salt marshes, but nest elsewhere (Post 1970, Craig 1990, Bevier 1994, Zeranski and Baptist 1994). They were not found to be a major component of salt marsh bird communities in Massachusetts (Clarke et al. 1984, Reinert and Mello 1995) or Connecticut (Brawley 1995). Blue jay abundance at Hoadley Marsh was probably unrelated to the salt marsh as well. Its abundance more likely results from surrounding upland habitat, particularly the presence of nearby oak trees.



Amphipods – abundant, tiny crustaceans of salt marshes – are important food for many salt marsh birds.

Herring gulls were the most abundant gull in one Massachusetts salt marsh (Reinert and Mello 1995), although they were much less common in another study (Clarke et al. 1984). In regions other than Connecticut, great black-backed gulls and herring gulls nest in salt marshes (Burger 1985). In Connecticut, these gulls usually nest on offshore islands and rarely nest in salt marshes (Bevier 1994). The abundance of gulls at Hoadley Marsh probably results from proximity to numerous, rocky offshore islands.

AERIAL-FORAGERS

We found swallows and other aerial insectivores to be a major component of the salt marsh bird community at Hoadley Marsh (Fig. 2). Aerial insectivores were also found to be the most abundant foraging guild of salt marshes in Massachusetts (Clarke et al. 1984) and Connecticut (Brawley 1995). These results imply that salt marshes provide an important foraging resource for these species.

Common salt marsh aerial-foragers of this region include northern rough-winged swallows, bank swallows, and barn swallows (Craig 1990, Bevier 1994, Zeranski and Baptist 1994). These aerial-foragers were more abundant in Hoadley Marsh than West River Memorial Park (Table 2). Restoration of a New Jersey salt marsh with common reed eradication led to an increase in barn and tree swallows (Bontje 1987). Swallows were also found to be abundant in a restored salt marsh in California (Jacobson et al. 1983b). Successful salt marsh restoration in West River Memorial Park should include an increase in the relative abundance of foraging swallows.

Willow flycatchers were more abundant in West River Memorial Park than Hoadley Marsh. This species is generally associated with freshwater wetlands and streams, and open areas with scattered shrubs and trees (DeGraaf and Rappole 1995). But they are also locally common in coastal wetlands in Connecticut (Bevier 1994). Depending on the extent of saltwater intrusion with the opening of the tide gates, the willow flycatcher population may decline, even though suitable, shrubby habitat may still be available on the uplands. This species is considered stable across its range and is increasing in the central United States (DeGraaf and Rappole 1995).

We found swallows and other aerial insectivores to be a major component of the salt marsh bird community at Hoadley Marsh, but not at West River. Salt marshes provide important foraging resources for these species.

INSECTIVOROUS FOLIAGE-GLEANERS

The higher proportion of foliage gleaners in West River Memorial Park resulted mostly from an abundance of yellow warblers and common yellowthroats. Common yellowthroats occur in a variety of marsh types (Daiber 1982, Craig 1990) and are common throughout the state (Bevier 1994). Yellow warblers are habitat generalists and are also quite common in Connecticut (Bevier 1994). We would expect a slight decrease in the relative abundance of yellow warblers and common yellowthroats in West River Memorial Park, because some upland-edge vegetation will be reduced with salt marsh restoration.

SURFACE-FEEDING AQUATIC HERBIVORES

Waterfowl that surface-feed for aquatic vegetation were more common in West River Memorial Park than Hoadley Marsh due to abundant mallards in the West River. Black ducks were more common in Hoadley Marsh than West River. Black ducks and gadwalls were found to be more common in salt marshes than freshwater marshes along the Connecticut River and black ducks were the only surface-feeder observed in a Massachusetts salt marsh (Clarke et al. 1984). Black duck populations may be declining along the Atlantic coast (Daiber 1982, Burger 1985, Craig 1990).

These results suggest that salt marsh restoration could increase black duck and gadwall abundance. The restoration would provide an opportunity to study the effects of changes in vegetation, salinity, amount of open water, and water quality on this poorly understood salt marsh foraging guild.

DIVING PISCIVORES

Connecticut bird species that dive for fish in salt marsh creeks during breeding season include the least tern, common tern, double-crested cormorant, pied-billed grebe, and belted kingfisher (Craig 1990, Bevier 1994). Terns were abundant visitors at a Long Island salt marsh (Post 1970) and at Massachusetts salt marshes (Clarke et al. 1984, Reinert and Mello 1995). We found this foraging guild to be somewhat more abundant at Hoadley Marsh than West River Memorial Park (Fig. 2).

The CT DEP has designated the least tern as threatened in Connecticut, and the common tern is considered a species of special concern. Least and common terns are known to nest in salt marshes (Daiber 1982, Burger 1985), but this rarely occurs in Connecticut (Craig 1990). Pied-billed grebes are known to nest in only one coastal marsh in the state (Bevier 1994) and are listed as endangered in Connecticut.

Least terns – a threatened species in Connecticut – were often observed foraging in the West River. Salt marsh restoration may benefit this species.

Foraging opportunities in West River Memorial Park might improve for this guild if fish abundance increases with restoration (Moore, this volume). Least tern abundance increased with restoration of a New Jersey salt marsh through reduction of common reed (Bontje 1987). However, tern abundance may not increase with restoration in West River because Connecticut populations of these species may be constrained by availability of suitable shorefront nesting areas (Safina et al. 1989, Craig 1990).

PROBERS OF INVERTEBRATES

The relative abundance of species that probe for invertebrates was quite low at Hoadley Marsh during the breeding season (Fig. 2). Rail species likely to occur in Connecticut salt and brackish marshes include clapper rail, king rail, and Virginia rail (Daiber 1982, Craig 1990). Other species that nest, or have nested, in Connecticut coastal marshes include black rail, sora, spotted sandpiper, and willet (Craig 1990; Bevier 1994; CT DEP, unpublished data). Visits to salt marshes by glossy ibis may be increasing in the northeast (Craig 1990).

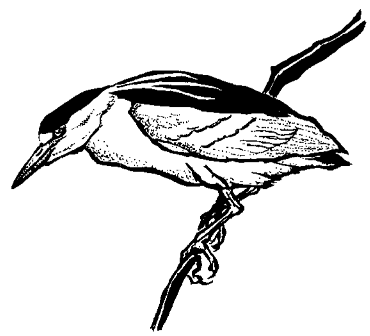
The only members of this foraging guild that we observed more than once at Hoadley Marsh during the breeding season were clapper rails, greater yellowlegs, and glossy ibis. Clapper rails, lesser yellowlegs, glossy ibis, least sandpipers, and semipalmated sandpipers were found by other researchers to be common at Connecticut and Long Island salt marshes during summer (Post 1970, Craig 1990).

Although this guild is not abundant in southern New England salt marshes during breeding season, salt marshes may provide important winter habitat and feeding stopover sites for migrating shorebirds. Overall avian abundance and diversity in a Massachusetts salt marsh was highest in fall and winter as a result of shorebirds (Reinert and Mello 1995), and this was the most abundant foraging guild in New Jersey and Massachusetts salt marshes when times of migration were included (Bontje 1987, Clarke et al. 1984).

Ideally, salt marsh restoration in West River Memorial Park would result in colonization by clapper rails, although we would not expect to see large changes in the abundance of members of this guild during the breeding period. However, we should expect increased abundances during migration. Sandpiper abundance increased dramatically with restoration of a New Jersey salt marsh through reduction of common reed (Bontje 1987).

WADING PISCIVORES

Connecticut bird species that wade and stalk fish in salt marshes include snowy egret, great egret, black-crowned night-heron, least bittern, and green heron (Post 1970, Craig 1990, Bevier 1994, Zeranski and Baptist 1994). Great blue herons have been reported as abundant in salt marshes in Massachusetts (Clarke et al. 1984, Reinert and Mello 1995), but they were absent from Connecticut River and Long Island salt marshes during summer (Post 1970, Craig 1990). Species of this foraging guild are charismatic, and would be appreciated by urban recreators in West River Memorial Park.



Black-crowned night-heron

We found the relative abundance of birds that wade and stalk fish to be slightly lower at West River Memorial Park than Hoadley Marsh (Fig. 2). Snowy egrets were more common in Hoadley, while black-crowned night-herons were more common in West River Memorial Park.

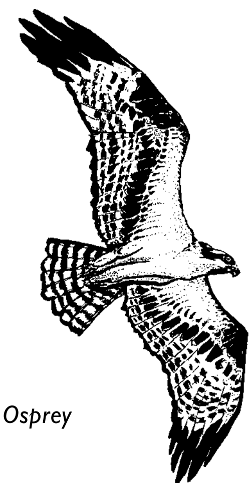
Snowy egrets are the waders most strongly associated with northeastern salt marshes during the breeding season (Post 1970, Clarke et al. 1984, Craig 1990, Master 1992). Snowy egrets may be more likely to take advantage of abundant salt marsh invertebrates such as shrimp, fiddler crabs, and snails than other waders (Ehrlich et al. 1988). This species would probably benefit from salt marsh restoration in the West River, because restoration tends to increase invertebrate populations (Cammen 1976, Kraus and Kraus 1986). Snowy egret abundance increased substantially with salt marsh restoration in New Jersey, where increases in abundance of great blue herons, green herons, and black-crowned night-herons were negligible (Bontje 1987).

Least bitterns are associated with common reed or cattails of transitional marshes in Connecticut (Craig 1990) and were observed in New Haven's Quinnipiac River marshes in 1995 (CT DEP, unpublished data). We found no evidence of least bitterns inhabiting the common reed in West River Memorial Park. Consequently, this species is unlikely to be negatively impacted by salt marsh restoration.

Black-crowned night-herons are commonly observed in salt marshes in the northeast (Post 1970, Clarke et al. 1984) and may be strongly associated with this habitat (Craig 1990). Populations of this species of special concern may be decreasing in Connecticut (Craig 1990). High relative abundance of this species in West River Memorial Park is probably a function of abundant upland perches near water or proximity to a suitable nesting site. The West River heron population will probably not be negatively impacted by salt marsh restoration. Upland forest edge will not be altered significantly, and this species often prefers salt marsh habitat. The species may benefit from increased fish abundance (Moore et al., this volume). Common reed eradication did not negatively impact black-crowned night-herons in a New Jersey salt marsh restoration (Bontje 1987).

RAPTORS

The northern harrier (marsh hawk) has been known to nest in Connecticut coastal marshes. Although harriers were common on Long Island as recently as 1970 (Post 1970), the species is rare now (Craig 1990, Bevier 1994), and none were detected during surveys in Massachusetts (Clarke et al. 1984). The DEP considers the northern harrier an endangered species in Connecticut. We observed a harrier once at West River Memorial Park in September, and once over the landfills in the lower West River in December. We never observed harriers at Hoadley Marsh. It is likely that this species requires large areas for foraging (Craig 1990). The small salt marsh restoration area in West River may provide limited foraging habitat for migrating or wintering harriers. Otherwise, restoration would have no effect on this species.



Osprey

Osprey are more common in salt marshes than other marsh types along the Connecticut River, and their numbers appear to be increasing (Craig 1990). We often saw osprey at Hoadley Marsh, because there were two occupied nesting platforms within view of survey points (Table 2). We occasionally observed osprey at West River Memorial Park. More recently, we frequently have seen a pair of osprey foraging at the park. A pair might occupy a nesting platform in the park, if it were installed in an area of restored salt marsh. Nesting success would depend on abundance of fish and water clarity, and would require efforts to limit disturbance by recreators. This charismatic species would provide outstanding educational opportunities in an urban setting.

HABITAT VALUE OF COMMON REED

Patches of common reed (*Phragmites australis*) in unaltered salt marshes are generally not wide, and soil salinity reduces stem density and height. Reeds probably provide protection from predators and flooding, display perches, and access to resources of the salt marsh (Verner and Engelsen 1970, Cody 1981, Daiber 1982, Burger 1985). Red-winged blackbird, marsh wren, least bittern, and several duck species are known to nest or forage in common reed in unaltered salt marshes (Post 1970, Daiber 1982, Burger 1985, Craig 1990). But these species also nest in, and often prefer, other vegetation (Saunder 1922, Verner and Engelsen 1970, Post and Seals 1991, Craig 1990).

Human-induced reductions in water level and salinity often lead to very large stands of increased stem density and height (Roman et al. 1984), as in the case of West River Memorial Park. Such conditions do not occur naturally and result in an altered bird community (Greenhalgh 1971, Moller 1975, Larsson 1976). Species observed by other researchers using created reed stands include blackbirds and grackles (Post and Seals 1991) marsh wren, mallards, and swamp sparrows (Bontje 1987). American robins have also been reported to nest in common reeds (Hudson 1994). We found only red-winged blackbirds nesting in the large, very dense and infrequently flooded man-made reed stands in West River Memorial Park.

Red-winged blackbird

The density of red-winged blackbird nests in reed stands of the park (42 acre^{-1}) can not be used to estimate abundance of breeding pairs, because red-winged blackbirds build multiple nests and some nests may have been from previous years. However, nest density did indicate that red-winged blackbirds can dominate the avian community when hydrological conditions allow common reed to completely dominate the vegetative community.

The species most likely to be impacted by reduction of common reed in the park is the red-winged blackbird. However, it is likely that red-winged blackbirds would remain abundant, because they are known to breed in a variety of wetland and upland habitats (Yasukawa and Searcy 1995). Other avian species seen in common reed in West River Memorial Park during the breeding season include American goldfinch, yellow warbler , black-crowned night-heron, common yellowthroat, swamp sparrow and ring-necked pheasant. These species were seen in a variety of habitats, with relatively few sightings in common reed. It is not likely that reducing common reed would negatively impact these species, unless increased salinity reduced shrub and woodland habitat as well.

Black-capped chickadees, downy woodpeckers, and American tree sparrows were seen feeding in common reeds on several occasions during winter. These three species are common winter residents in this region. Tree sparrows primarily feed on a wide variety of seeds in open fields during winter (Martin et al. 1951). We observed small flocks of American tree sparrows feeding on seed heads of common reed.

Chickadees are known to feed on the seed heads of emergent vegetation such as goldenrod (*Solidago* sp.) and ragweed (*Ambrosia* sp., Smith 1993), but we did not observe them eating common reed seeds. Both black-capped chickadees and downy woodpeckers in the park fed by poking holes in the stems of common reeds with their bills and extracting insects from inside the stem. Chickadees and downy woodpeckers are typically found in upland and riparian woods as well as in parks and suburban areas. It is not likely that the downy woodpecker, black-capped chickadee, or American tree sparrow will be significantly affected by restoration, because they can use many other resources in the park. Furthermore, salt marsh restoration will not entirely eradicate common reed.

In the park, we observed only a few of the shorebird species that normally use salt marshes as migratory stop-overs. Migratory shorebirds would likely benefit from salt marsh restoration.

MIGRATORY AND WINTER HABITAT

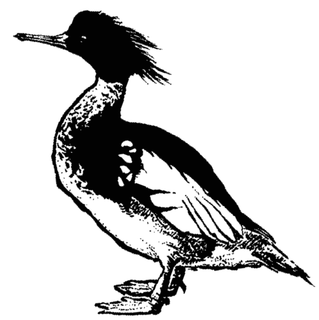
Salt marshes are important foraging habitat for migratory shorebirds (Glue 1971, Breininger and Smith 1990, Reinert and Mello 1995), especially least sandpipers (Clarke et al. 1984, Reinert and Mello 1995), but also spotted and solitary sandpipers, killdeer, greater and lesser yellowlegs, black-bellied, semipalmated and piping plovers, and dunlins. Salt marshes and their pools also provide important habitat for migrating waders and hawks.

West River was heavily used by migrating species in spring and fall. However, we observed only a few of the shorebird species that normally use salt marshes as migratory stop-overs. Shorebirds observed during migration in West River Memorial Park included 12 spotted sandpipers, 28 greater yellowlegs, six lesser yellowlegs, one semipalmated plover, and one solitary sandpiper. Migratory shorebirds would likely benefit from salt marsh restoration in the park.

An impressive number of migrating warblers and other songbirds are regularly seen by bird watchers in Edgewood Park and along Marginal Drive in West River Memorial Park. Continued protection of these parks provides stopover points for migrants, an important component of neotropical passerine conservation (DeGraaf and Rappole 1995). It also provides opportunities for bird-watching in an urban area.

The West River harbors a diverse community of waterfowl in winter. Along the Lower River (downstream from West River Memorial Park), rafts of greater and lesser scaup were seen regularly. At present there is concern over decreasing numbers of greater and lesser scaup in Long Island Sound (Bevier 1994). We also observed common goldeneyes, common, hooded and red-breasted mergansers, canvasbacks, and less frequently, ring-necked ducks, buffleheads, black ducks, mallards, pied-billed grebes, horned grebes, and red-throated loons.

Waterfowl observed over-wintering in West River Memorial Park included hooded, common, and red-breasted mergansers, pied billed grebes, ring-necked ducks, gadwalls, American black ducks, and mallards. We also frequently observed red-tailed hawks in West River Memorial Park during winter.



Red-breasted merganser

RELICT SALT MARSHES OF WEST RIVER

The West River shoreline south of West River Memorial Park is heavily developed. Only four salt marshes totaling 24 ha (60 acres) remain. We found sharp-tailed sparrows to be abundant in a 7-ha (17-acre), ditched salt marsh adjacent to Spring Street in West Haven (Fig. 1). Salt meadow cordgrass (*S. patens*) dominates this marsh and is very thick. The dense grass may explain why we observed only one seaside sparrow at this site (Post 1974, Sykes 1980). We never found clapper rails at this relict marsh. The marsh near Spring Street generally resembles Hoadley Marsh in species composition, although species tolerant of development such as mallard, mute swan, song sparrow, and starling were more abundant. Snowy egrets and herring gulls were less common, and tree swallows were absent.

The other three relict marshes of the West River are sparsely vegetated by salt marsh cordgrass (*S. alterniflora*), because the marshes are lower and more regularly flooded. Gulls, crows, and starlings visited during low tides.

DESIGN RECOMMENDATIONS

Avian habitat restoration in West River Memorial Park will be complicated by urbanization surrounding the park. The urbanized habitat bordering the park probably harbors low species diversity and a high abundance of species tolerant of humans (Emlen 1974, Beissinger and Osborne 1982, Tilghman 1987). Tolerant urban species often include predators and parasites such as blue jays, crows, cowbirds, red foxes, Norway rats, and raccoons. The restored salt marsh might turn out to be a small, isolated island within an urban area (Tilghman 1987) that has low potential for colonization (McArthur and Wilson 1967) and long-term survival of sensitive species (Lack 1976). Poor water quality in the West River (Benoit 1995) may impact salt marsh bird health directly (Eddleman and Conway 1994), as well as suppress potential food sources, such as aquatic invertebrates and/or fish (Cuomo and Zinn, Moore et al., this volume). To succeed, restoration of a salt marsh bird community will require improving habitat quality within the severe constraints imposed by water quality and the surrounding landscape.

Brown and Dinsmore (1986) have found that species richness drops off sharply with greater distance from other marshes and in marshes smaller than 5 ha (12 acres). In particular, the occurrence of marsh wrens decreases sharply for isolated marshes smaller than 5–11 ha (12–27 acres). Seaside sparrows tend to avoid areas closer than 50 m (164 feet) to dense stands of trees (Sykes 1980). Occurrence of sharp-tailed sparrows at an isolated 7-ha (17-acre) salt marsh nearby suggests that this species has an area threshold below 7 ha. Other species such as red-winged blackbird, Virginia rail, and sora are not area sensitive (Sykes 1980). We recommend that the restored salt marsh include at least 10 contiguous hectares (25 acres), and include ample habitat at least 50 m (164 feet) from upland vegetation.

The restoration should include at least 25 contiguous acres of salt marsh habitat at least 164 feet from upland vegetation. Recreation amenities should not intrude in this area. The design should include salt marsh pools and irregularly shaped, marsh-estuary edge.

Human recreation during the peak of breeding may negatively affect breeding success. Therefore amenities such as picnic areas, walkways, or fishing access areas should not intrude in large contiguous areas of salt marsh habitat.

Restoration design should include salt marsh pools, since bird abundance and diversity have been found higher in marshes with pools (Clarke et al. 1984). Mosquito breeding will have to be controlled due to the density of human residences nearby and the value of the park for recreation (Page, this volume). Mosquitoes can be controlled using Open Marsh Water Management (Daiber 1987), a practice whereby pools are maintained with a depth that allows survival of small fish that consume mosquito larvae (e.g., *Fundulus* spp.). Habitat for shorebirds and herons could also be enhanced by creating an irregularly shaped, marsh-estuary edge. Optimal habitat conditions occur where expansive areas of estuarine pond and emergent marsh habitats are juxtaposed (Craig and Beal 1992, Reinert and Mello 1995).

A major cause of nest failure for birds nesting in salt marshes is inundation during abnormally high tides (Post 1974, Eddleman and Conway 1994). Self-regulating tide gates installed at the southern terminus of West River Memorial Park could be adjusted to control abnormally high tides (Steinke 1986).

MONITORING RESTORATION SUCCESS

Our sampling method was rapid and inexpensive. The community profiles adequately described the similarities and differences in avian communities between the proposed restoration and control habitats. We suggest that meeting the following criteria would indicate successful restoration of an avian salt marsh community:

1) no significant difference in foraging guilds between the existing and target communities,
2) no significant difference in relative abundances of species between the existing and target communities,
3) species similarity index value > 0.8 between the existing and target communities,
4) nesting density of at least 2.5 pairs ha^{-1} for all species in the *Spartina* spp. zone, and
5) presence of at least one obligate species.

These restoration criteria could be met in West River Memorial Park. There is no significant difference between foraging guilds now, which suggests that the basic pattern in which marsh productivity is available to the avian foraging community has not been severely altered. However, vegetation characteristics preclude breeding and foraging by some salt marsh species. The presence of sharp-tailed sparrows downstream suggests potential colonization of at least one obligate species.

We recognize that community profiles can be heavily biased by selection of control site, because coastal marshes can vary in terms of species, diversity, and abundance. A better approach would be to develop standard community profiles using data from many marshes. Unfortunately, descriptions of salt marsh bird communities are lacking (Daiber 1982). The studies by Clarke et al. (1984), Craig (1990), Brawley (1995), and Reinert and Mello (1995) are the only comprehensive, quantitative descriptions of New England salt marsh bird communities, and differences in survey methods and contradictory results complicate comparisons among them. Profiles of avian, salt marsh communities in southern New England should be developed by sampling a large number of marshes. In the meantime, care should be taken that the chosen control site represents a habitat that can be reasonably replicated by restoration.

We recognize that community profiles can be heavily biased by selection of control site. Therefore, standard profiles of avian, salt marsh communities in southern New England should be developed by sampling a large number of marshes.

The community profile approach can also be applied to mitigation (i.e., a marsh is restored to compensate for another marsh to be destroyed). A target community profile could be developed from the marsh to be destroyed. The created, replacement marsh should meet the criteria above if mitigation is to be judged successful. Data for nesting density and recruitment of obligate species (if present) can be measured for the marsh to be destroyed instead of relying on published data.

GENERAL RECOMMENDATIONS

We recommend further study of the relict salt marsh on the lower West River near Spring Street. The reproductive success of sharp-tailed sparrows and the use of the marsh by seaside sparrows and marsh wrens remain unclear. The use of common reed by birds and the impact of common reed stands on bird diversity also deserve closer examination, considering the interest in controlling common reed (Marks et al. 1994). Also, the Horseshoe Lagoon area of West River Memorial Park (Fig. 1) was not included in our survey. We recommend surveying birds of the lagoon, because restoration may increase salinity and water level in the lagoon.

There is little documentation of the kinds of insects found in common reed in this country. Studies in Europe, where large reed belts occur naturally, suggest that insects associated with common reed are an important food source for birds (Frömel 1980, Tscharntke 1992). Given our observations of the use of common reed as a food source for insectivorous birds in winter, and the concern about common reed as an invasive plant in northeastern salt marshes (Marks et al. 1994), an entomological survey in common reed would be a valuable undertaking.

Perhaps the most important consideration for habitat conservation in West River Memorial Park is local community involvement. The public should be informed about the park's bird diversity and the potential for restoring salt marsh habitat, and access should be provided for recreation. West River Memorial Park is already a remarkable area for bird watching, though relatively few people are aware of it. Even without restoration, promoting activities like bird watching can enhance the value of the park for local citizens. As the park's popularity increases, the potential for park conservation for the benefit of people and wildlife will also increase.

CONCLUSION

Our results suggest a strong potential for restoring a salt marsh bird community in West River Memorial Park. Species similarity between the restoration area and the control site is already high, because many facultative salt marsh species occur in West River Memorial Park. With the introduction of a *Spartina*-dominated habitat, we expect a shift toward avian salt marsh community structure and composition. Species of concern in the park would either not be affected or would benefit.

The species most likely to be affected by reduction of common reed is the red-winged blackbird, which was the only species we found nesting in common reed. Red-winged blackbirds and other species that would be negatively impacted by restoration are common habitat generalists.

The community profile method is appropriate for evaluating restoration of avian communities because it captures a wide range of ecological functions quickly and inexpensively. However, the method can be biased by choice of control site. We recommend further development of this method using relative foraging guild and species abundance data from salt marshes throughout southern New England.

ACKNOWLEDGMENTS

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APPENDIX. AVIAN SPECIES OF THE WEST RIVER IN NEW HAVEN AND WEST HAVEN, CONNECTICUT DURING 1995-1996.

Common name	Area[1]			Season[2]	Abundance[3]	State Conservation Status
bittern, American	WRMP			SP	rare	endangered
blackbird, brewer's[4]			EP	SP		
blackbird, red-winged	WRMP	LR	EP	SP,SU, F	abundant	
bufflehead		LR		W	rare	
canvasback		LR		W	rare	
cardinal, northern	WRMP	LR	EP	SP,SU,F,W	common	
catbird, gray	WRMP	LR	EP	SP,SU,F	abundant	
chickadee, black-capped	WRMP	LR	EP	SP,SU,F,W	common	
coot, American			EP	SU	rare	
cormorant, double-crested	WRMP	LR	EP	SP,SU,F	abundant	
cowbird, brown-headed	WRMP	LR	EP	SP,SU	abundant	
creeper, brown	WRMP			W	rare	
crow, American	WRMP	LR	EP	SP,SU,F,W	abundant	
crow, fish	WRMP	LR	EP	SP,SU,F,W	common	
cuckoo, black-billed	WRMP		EP	SP,SU	rare	
cuckoo, yellow-billed[4]			EP	SP		
dove, mourning	WRMP	LR	EP	SP,SU,F,W	common	
dove, rock	WRMP	LR	EP	SP,SU,F,W	abundant	
duck, American black	WRMP	LR		SP,SU,F,W	common	
duck, ring-necked	WRMP	LR		SP,W	uncommon	
duck, wood	WRMP		EP	SP,SU,F	uncommon	
egret, great	WRMP	LR		SP,SU,F	common	threatened
egret, snowy	WRMP	LR		SP,SU,F	common	threatened
falcon, peregrine		LR		F	rare	endangered
finch, house	WRMP	LR	EP	SP,SU,F,W	common	
finch, purple[4]			EP	SP		
flicker, northern	WRMP	LR	EP	SP,SU,F	common	
flycatcher, Acadian			EP	SU	rare	
flycatcher, great-crested			EP	SU	rare	
flycatcher, least			EP	SU	rare	
flycatcher, willow	WRMP	LR	EP	SU	common	
gadwall	WRMP	LR		SP,SU,W	common	
gnatcatcher, blue-gray			EP	SU	rare	
goldeneye, common		LR		W	uncommon	

[1] WRMP – West River Memorial Park; LR – Lower river; EP – Edgewood Park (see Fig. 1). Edgewood Park surveyed only in spring and summer.

[2] SP – spring; SU – summer; F – fall; W – winter.

[3] Abundant – seen more than 75 times and at more than one point; common – seen more than 10 times and at more than one point; uncommon seen more than 3 times; rare – seen less than 4 times.

[4] Sightings recorded outside of survey period. Abundance not determined.

APPENDIX (CONTINUED)

Common name	Area			Season	Abundance	State Conservation Status
goldfinch, American	WRMP	LR	EP	SP,SU,F,W	abundant	
goose, Canada	WRMP	LR	EP	SP,SU,F,W	abundant	
grackle, common	WRMP	LR	EP	SP,SU,F	abundant	
grebe, horned		LR		W	uncommon	
grebe, pied-billed	WRMP	LR		SP,W	uncommon	endangered
grosbeak, rose-breasted	WRMP		EP	SU,F	uncommon	
gull, great black-backed	WRMP	LR	EP	SP,SU,F,W	abundant	
gull, herring	WRMP	LR	EP	SP,SU,F,W	abundant	
gull, laughing	WRMP	LR		F,W	common	
gull, ring-billed	WRMP	LR	EP	SP,SU,F,W	abundant	
harrier, northern	WRMP	LR		F,W	rare	endangered
hawk, cooper's		LR		F	rare	
hawk, red-tailed	WRMP	LR	EP	SP,SU,F,W	common	
hawk, sharp-shinned	WRMP	LR		SP	rare	threatened
heron, great blue	WRMP	LR		SP,SU,F,W	common	special concern
heron, green	WRMP	LR	EP	SU,F	uncommon	
hummingbird, ruby-throated			EP	SU	uncommon	
jay, blue	WRMP	LR	EP	SP,SU,F,W	abundant	
junco, dark-eyed	WRMP			F,W	uncommon	
kestrel, American		LR		SP,F	uncommon	
killdeer	WRMP	LR		SP,SU,F	common	
kingbird, eastern	WRMP	LR	EP	SP,SU,F	common	
kingfisher, belted	WRMP	LR	EP	SP,SU,F,W	common	
kinglet, golden-crowned	WRMP			F	rare	
kinglet, ruby-crowned	WRMP			F	uncommon	
loon, common		LR		F	rare	special concern
loon, red-throated		LR		SP	rare	
mallard	WRMP	LR	EP	SP,SU,F,W	abundant	
martin, purple[4]			EP	SP		
merganser, common	WRMP	LR		SP,F,W	common	
merganser, hooded	WRMP	LR		SP,F,W	common	
merganser, red-breasted	WRMP	LR		SP,W	common	
merlin		LR		F	rare	
mockingbird, northern	WRMP	LR	EP	SP,SU,F,W	common	
night-heron, black-crowned	WRMP	LR	EP	SP,SU,F	common	special concern
nighthawk, common[4]	WRMP		EP	SP,F		
nuthatch, red-breasted			EP	SU	rare	
nuthatch, white-breasted	WRMP		EP	SU,F,W	common	
oriole, northern	WRMP	LR	EP	SP,SU	common	
osprey	WRMP	LR	EP	SP,SU,F	common	special concern

APPENDIX (CONTINUED)

Common name	Area			Season	Abundance	State Conservation Status
ovenbird			EP	SU	rare	
parula, northern	WRMP		EP	SP	uncommon	special concern
pheasant, ring-necked	WRMP	LR	EP	SP,SU,F,W	common	
pheobe, eastern	WRMP	LR	EP	SP,SU,F	common	
pintail, northern[4]			EP	SP		
plover, black-bellied		LR		F	rare	
plover, semipalmated	WRMP			F	rare	
redstart, American			EP	SU	uncommon	
robin, American	WRMP	LR	EP	SP,SU,F	abundant	
sandpiper, least	WRMP			SP	rare	
sandpiper, solitary	WRMP			F	rare	
sandpiper, spotted	WRMP	LR	EP	SP,SU,F	common	
sapsucker, yellow-bellied[4]			EP	SP		
scaup, greater		LR		SP,W	uncommon	
scaup, lesser		LR		SU,W	uncommon	
snipe, common	WRMP			F	uncommon	
sparrow, fox[4]	WRMP			F		
sparrow, house	WRMP	LR	EP	SU,W,SP	common	
sparrow, savannah	WRMP			SP,SU	rare	
sparrow, seaside		LR		SU	rare	special concern
sparrow, sharp-tailed		LR		SU	rare	special concern
sparrow, song	WRMP	LR	EP	SP,SU,F,W	abundant	
sparrow, swamp	WRMP		EP	SP,SU,F,W	common	
sparrow, American tree	WRMP			SP,W	uncommon	
sparrow, white-throated	WRMP	LR		F,W	uncommon	
starling, European	WRMP	LR	EP	SP,SU,F,W	abundant	
swallow, bank	WRMP		EP	SU	rare	
swallow, barn	WRMP	LR	EP	SP,SU	abundant	
swallow, cliff	WRMP		EP	SP	rare	
swallow, northern rough-winged	WRMP	LR	EP	SP,SU	common	
swallow, tree	WRMP	LR	EP	SP,SU	common	
swan, mute	WRMP	LR		SP,SU,F,W	common	
swift, chimney	WRMP	LR	EP	SP,SU	common	
tanager, scarlet			EP	SU	rare	
teal, green-winged	WRMP			SP	rare	
tern, common		LR		SU,F	uncommon	special concern
tern, least	WRMP	LR		SP,SU,F	common	threatened
thrasher, brown			EP	SU	rare	
thrush, hermit	WRMP		EP	SP,F,W	uncommon	
thrush, swainson's[4]			EP	SP		

APPENDIX (CONTINUED)

Common name	Area			Season	Abundance	State Conservation Status
thrush, wood			EP	SU	rare	
titmouse, tufted	WRMP	LR	EP	SP,SU,F,W	common	
towhee, eastern	WRMP		EP	SP,SU,F	uncommon	
turkey, wild	WRMP			SP	uncommon	
veery			EP	SU	rare	
vireo, red-eyed	WRMP		EP	SU	uncommon	
vireo, warbling	WRMP	LR	EP	SU	common	
vireo, yellow-throated			EP		rare	
vulture, turkey		LR	EP	SU,F	rare	
warbler, bay-breasted[4]			EP	SP		
warbler, black-and-white	WRMP			SP	rare	
warbler, black-throated green	WRMP		EP	SU,F	uncommon	
warbler, blackburnian[4]			EP	SP		
warbler, blackpoll	WRMP		EP	SP,SU	rare	
warbler, blue-winged			EP	SU	rare	
warbler, canada[4]			EP	SP		
warbler, cerulean[4]			EP	SP		
warbler, chestnut-sided[4]			EP	SP		
warbler, hooded[4]			EP	SP		
warbler, kentucky			EP	SP,SU	rare	
warbler, palm	WRMP	LR		SP,F	uncommon	
warbler, tennessee			EP	SU	rare	
warbler, wilson's			EP	SU	rare	
warbler, worm-eating			EP	SU	rare	
warbler, yellow	WRMP	LR	EP	SP,SU,F	abundant	
warbler, yellow-rumped	WRMP			SP,F	common	
waterthrush, northern			EP	S	rare	
waxwing, cedar	WRMP	LR	EP	SP,SU,F	uncommon	
widgeon, American[4]			EP	SP		
wood-pewee, eastern			EP	SU	rare	
woodcock, American	WRMP			SP	rare	
woodpecker, downy	WRMP	LR	EP	SP,SU,F,W	common	
woodpecker, hairy			EP	SU	rare	
woodpecker, red-bellied	WRMP		EP	SU,F,W	uncommon	
woodpecker, pileated[4]			EP	SP		
wren, Carolina	WRMP	LR	EP	SP,SU,F	common	
wren, house	WRMP		EP	SU,F	rare	
wren, marsh	WRMP	LR		SP,SU,F	common	
yellowlegs, greater	WRMP	LR		SP,SU,F	common	
yellowlegs, lesser	WRMP	LR		SP,F	uncommon	
yellowthroat,common	WRMP	LR	EP	SP,SU,F	common	

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Mammals of West River Memorial Park

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ABSTRACT
A survey of the mammalian community of West River Memorial Park in New Haven, Connecticut identified 21 species of mammals representing seven taxonomic orders and 13 families. This community of mammals is dominated by resilient-generalist species commonly found in urban environments and/or associated with tidal salt marshes. The white-footed mouse (*Peromyscus leucopus*) was the most abundant small mammal captured. Rodents represented the greatest number of mammalian species (seven). The high species richness (diversity and relative abundance) of mammals in the park is believed linked to the area's vegetatively diverse patches of closely spaced habitat types. Deciduous woodland habitat, in particular, provides essential life requisites for many species of mammals. The effects of salt marsh restoration and urban development on mammal diversity and abundance are discussed. Mammals would be poor biological indicators of successful salt marsh restoration because of their generalist behavioral characteristics and high adaptability to a wide range of habitats. No mammals listed by the Connecticut Department of Environmental Protection as endangered, threatened, or of special concern will be adversely impacted by the planned restoration of the salt marsh.

The number and diversity of mammals within a given community can be influenced by many ecological factors, including inter- and intra-species competition, availability of suitable habitat, abiotic factors such as weather and atmospheric deposition, diseases and parasites, and human activities (Webster et al. 1985). Of these, suitable habitat probably is the most important factor regulating the distribution and abundance of terrestrial mammals within their geographic ranges (Vaughan 1972). Land-use patterns and disturbance regimes also can have profound effects on the abundance, distribution, and diversity of terrestrial vertebrates (Wilson 1988). Nearly all wetlands in the conterminous United States have been severely impacted by human activities (Frederickson and Laubhan 1996). Despite a history of human disturbances (Casagrande, pp. 13-40, this volume), West River Memorial Park, located within metropolitan New Haven, Connecticut, continues to support a diverse mammalian community with an interesting mixture of taxa. Some species are typically associated with urban environments while others, perceived by most people as residents of dense forest ecosystems, have become acclimated to civilization. Other species that usually inhabit either coastal wetlands or are common to fragmented woodlands also were found in the park.

Adaptability is the key to survival for terrestrial mammals. Nearly all mammals have a generalist mode of feeding and have become ecological opportunists that can occupy a variety of habitats in order to survive (Smith and Remington 1996). The distribution of mammalian species within the West River Memorial Park appears related to topographically controlled patterns of environment and vegetation (Orson et al., pp. 136-150, this volume).

This study of mammals is part of the Center for Coastal and Watershed System's and Connecticut Department of Environmental Protection's (CT DEP) evaluation of the impacts of the restoration of salt marsh habitat within West River Memorial Park. The objectives of the mammalian inventory reported here were to (1) identify the species that currently inhabit the park, (2) list additional species that could potentially inhabit or use the site (i.e., species not detected in the survey and transients), (3) discuss the possible effects of ecological change on selected mammalian species due to salt marsh restoration, and (4) consider the impact of restoration on mammalian species listed as threatened, endangered, or of special concern by the CT DEP.

METHODS

During 1995 and 1996 a survey was conducted to document the presence of mammalian species inhabiting West River Memorial Park. Details of the vegetation are described by Orson et al. (pp. 136-150, this volume). Briefly, the park is dominated by plant species common to salt marshes that have been highly disturbed and also influenced for years by the effects of impeded tidal flow. The area's diverse vegetation forms a mosaic of closely spaced habitat types, each with a distinct structure. For example, some areas are dominated by either reedgrass (*Phragmites australis*), cattail (*Typha latifolia*), herbs and shrubs, or by pockets of woody vegetation. Woody vegetation extends along the West River's upland edge and into some filled marsh areas.

A stratified sampling method was used to survey the mammals. Stratification, which ensures that the sample is representative of the area, permits heavier sampling in some areas and can provide separate estimates for individual strata within the study area (Bart and Notz 1996). The number of captures from various vegetation strata were normalized for comparative purposes (number of captures per 100 trap nights) and are presented in Table 1. A survey transect line was established adjacent to Marginal Drive (Fig. 1), with 10 trap stations located approximately 100 m apart. At each station, two to six traps were placed at various distances from each other according to vegetative type and stratum variability (i.e., reedgrass, woodland, grass)

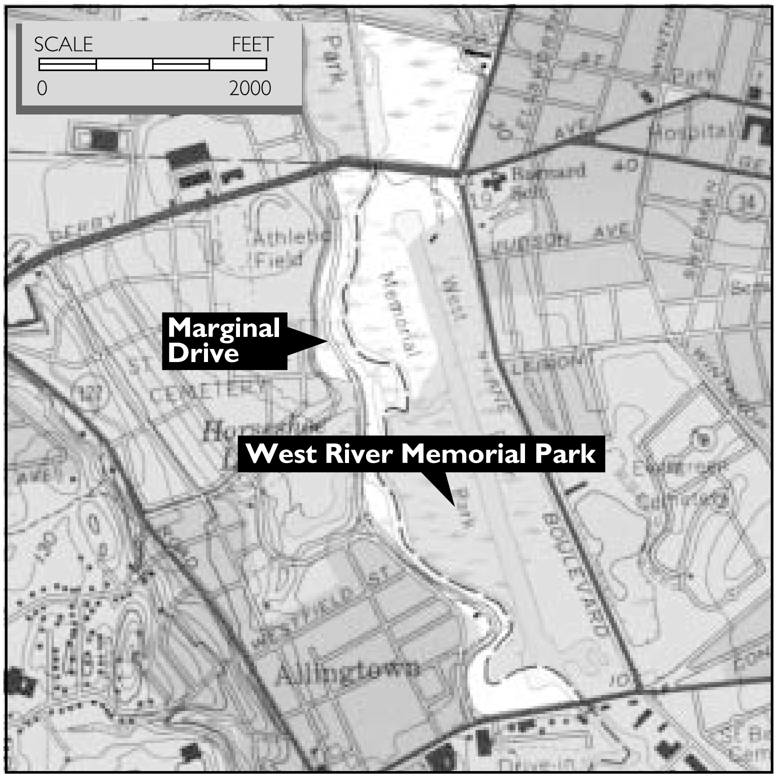


Figure 1. Area of mammal trapping (white) during 1995-1996 in West River Memorial Park, New Haven, Connecticut.

and the amount of physical evidence of mammalian activity. A few additional trap stations were established in selected areas of the park to ensure that samples were taken from all strata.

In 1995, 50 Sherman live traps (8 x 8 x 26 cm) and six Tomahawk wire live traps (three at 48 x 15 x 15 cm, three at 82 x 25 x 30 cm) were deployed on May 15 and June 12. Traps were checked once daily for three consecutive days. Sherman traps were baited with a peanut butter-oatmeal mixture, and cotton nesting material always was present. The Tomahawk traps were baited with a combination of sardines, cat food (chicken or fish), and apples. The number of trap nights was determined by subtracting the number of disturbed (sprung) traps from the total number that were set.

Twelve pitfall traps (28 cm diameter x 28 cm deep) were deployed during the summer of 1996 and checked biweekly. Pitfall traps are known to capture a greater number and diversity of small mammals than conventional traps (Mengak and Guynn 1987). They also sample continuously over an entire sampling period without requiring regular visits to collect samples. Also, on November 8, 1995, and April 4, 1996, 24 Sherman traps were set at selected trap stations and checked for three consecutive days. During the May 15 trapping sequence, captured small mammals were individually marked by toe-clipping and released at point of capture. During the June trapping period, captured small mammals were not marked. The animal's species, sex, age, and condition were recorded. Larger mammals were not marked during any trapping period and were distinguished from recaptures by individual characteristics (i.e., size, scars, and condition). Also recorded were observations by the author or other members of the biological inventory team of mammalian species that were not captured.

Relative abundance or commonness of species was estimated subjectively based on physical evidence (i.e., actual captures, suitable habitat, burrows, droppings, tracks, and feeding remains). Sampling effort was neither sufficient nor intended for use in estimating animal density, based on recapture data. Latin names for mammals are given in Tables 2 and 3.

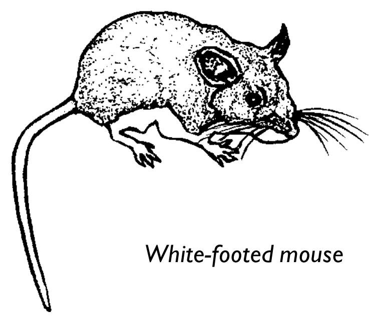
Table 1. Number of mammals captured per 100 trap nights (capture rate) within West River Memorial Park's habitats during the May and June 1995 sampling periods.[1]

	Habitat							
	Woodland		Wood edge		Reedgrass		Herbaceous	
Species	**May**	**June**	**May**	**June**	**May**	**June**	**May**	**June**
Opossum	2.9	2.8	5.0	2.2	3.4	6.7	—	—
Northern short-tailed shrew	5.9	—	5.0	6.5	—	—	—	—
Chipmunk	—	—	—	2.2	—	—	—	—
White-footed mouse	35.3	36.0	57.5	36.9	34.4	43.3	9.1	9.5
Meadow vole	—	—	5.0	—	—	6.7	—	—
Muskrat	—	—	—	—	—	3.3	—	—
Norway rat	—	—	—	—	6.9	3.3	—	—
Raccoon	5.9	—	—	—	—	—	—	
All species	50.0	38.8	72.5	47.7	44.7	63.3	9.1	9.5
May & June combined	88.8		120.2		108. 0		18.6	

[1] Values shown were normalized.

RESULTS

Forty-six individual mammals representing six species were captured (total captures = 61) on 125 trap nights (162-37=125) during the May trapping period. Rain occurred on the day of setup and also on day two following setup. Weather affects animal activity. Several species of rodents and insectivores are more active on warm, rainy nights (Gauthier and Bider 1987). The number and habitat distribution (vegetative stratum) of captured mammals is shown in Table 1. The white-footed mouse was the most frequently captured species; 32 numbered individuals accounted for 47 (77%) of the total captures. This species, most abundant in the woodland "edge" habitat, was the only species captured in all habitats (Table 1) and was the most abundant mammal captured in each zone. The number of individuals of other species captured and the percentage of total captures, in parentheses, included: four opossums (7%), four northern short-tailed shrews (7%), two meadow voles (3%), two Norway rats (3%), and two raccoons (3%). Although the mammals other than the white-footed mouse were captured in small numbers, the results clearly suggest increased activity along the salt marsh-woodland gradient and greatest activity along the edge of the woodland habitat (Table 1). The deciduous woodland had the next highest level of mammal activity.



White-footed mouse

During the June trapping period, seven species of mammals (56 total captures) were captured on 133 trap nights (162-29=133). These included 45 white-footed mice(80%), three opossums (5%), two meadow voles (4%), one Norway rat (2%), three northern short-tailed shrews (5%), one muskrat (2%), and one eastern chipmunk (2%). Rain occurred on the day after setup. In June, the white-footed mouse remained the only species captured in each habitat, and the habitat in which most of these mice were captured had shifted from the woodland edge to reedgrass. Because of this shift, the greatest level of mammalian activity (all species) for June (Table 1) was in the reedgrass habitat. Combined species capture rates for May and June continued to suggest increased activity along the salt marsh-woodland gradient, with the greatest activity along the woodland edge.

Except for the capture of a juvenile house mouse, efforts to capture additional unrecorded species in pitfall traps (e.g., masked shrew, star-nosed mole) during the summer of 1996 were unsuccessful. Also, traps set on November 8, 1995, and April 4, 1996, failed to capture any species different from those captured during the May and June, 1995 trapping periods. Mammals representing nine species were captured during the survey and representatives of 11 other species were observed by the author or by other members of the inventory team (Table 2). In June 1996, a single sighting of a river otter was reported by an area naturalist. These results confirm that at least 21 mammal species were using habitats within West River Memorial Park during the time of the survey. No mammals listed by the Connecticut Department of Environmental Protection as endangered, threatened, or of special concern were observed or captured during this survey.

Table 2. Mammals using West River Memorial Park, New Haven, Connecticut during 1995-96.

Species	Relative Abundance[1]	Captured[2]	Observed[3]	Reported[4]
Virginia Opossum (*Didelphis virginiana*)	C	x		
Northern Short-tailed Shrew (*Blarina brevicauda*)	C	x		
Eastern Mole (*Scalopus aquaticus*)	C		x	
Little Brown Myotis (*Myotis lucifugus*)	C		x	
Big Brown Bat (*Eptesicus fuscus*)	C		x	
Eastern Cottontail (*Sylvilagus floridanus*)	C		x	
Eastern Chipmunk (*Tamias striatus*)	C	x		
Woodchuck (*Marmota monax*)	C		x	
Gray Squirrel (*Sciurus carolinensis*)	C		x	
White-footed Mouse (*Peromyscus leucopus*)	A	x		
Meadow Vole (*Microtus pennsylvanicus*)	C	x		
Muskrat (*Ondatra zibethicus*)	C	x		
Norway Rat (*Rattus norvegicus*)	A	x		
House Mouse (*Mus musculus*)	C	x		
Red Fox (*Vulpes vulpes*)	U		x	
Domestic Dog (*Canis familiaris*)	C		x	
Raccoon (*Procyon lotor*)	C	x		
Striped Skunk (*Mephitis mephitis*)	C		x	
River Otter (*Lutra canadensis*)	R			x
Domestic Cat (*Felis catus*)	C		x	
White-tailed Deer (*Odocoileus virginianus*)	C		x	

[1] Based on physical evidence (i.e., actual captures, suitable habitat, burrows, droppings, tracks, and feeding remains). A = Abundant (plentiful); C = Common (occurring or appearing frequently); U = Uncommon (not ordinarily encountered); and R = Rare (seldom occurring or found).

[2] Trapped during survey.

[3] Sighted by author or other member of biological inventory team.

[4] Sighted by a local naturalist.

Table 3. Mammals that could potentially occur in West River Memorial Park.

Species	Probability of Occurrence[1]
Masked Shrew (*Sorex cinerus)*	Excellent
Least Shrew (*Cryptotis parva)*	Poor
Star-nosed Mole (*Condylura cristata)*	Excellent
Red Bat (*Lasiurus borealis)*	Fair
Hoary Bat (*Lasiurus cinereus)*	Fair
New England Cottontail *(Sylvilagus transitionalis)*	Fair
Southern Flying Squirrel *(Glaucomys volans)*	Excellent
Meadow Jumping Mouse *(Zapus hudsonicus)*	Good
Coyote *(Canis latrans)*	Good
Gray Fox (*Urocyon cinereoargenteus*)	Fair
Long-tailed Weasel *(Mustela frenata)*	Fair
Mink *(Mustela vison)*	Poor

[1] Based on species' requirements for suitable habitat and the author's research experience within similar habitats.

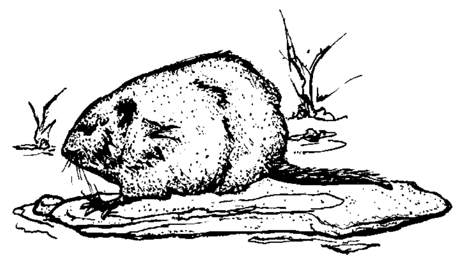
DISCUSSION

EFFECTS OF URBAN DEVELOPMENT

Despite extensive anthropogenic disturbances that have included tidal restriction, extensive ditching for mosquito abatement, dredging and filling, and urbanization, (Casagrande, pp. 13-40, this volume), West River Memorial Park remains host to a variety of mammalian species. The 21 mammal species identified during the survey (Table 2) represent seven taxonomic orders and 13 families. This diversity is possible because of existing habitat characteristics and the general adaptive behavior of terrestrial mammals. The mosaic of vegetation types, patch sizes, and strata provides adequate food and cover for this mammalian community, which is clearly dominated by resilient-generalist species commonly found in urban areas.

Paradiso and Handley (1965), Shure (1970), Holland and Smith (1980), and Weiss (1995) are among those who have enumerated the mammal species found in or associated with fringes of tidal marshes. Interestingly, no mammals appear unique to tidal marshes, given that each species has been reported to be distributed extensively in or along freshwater inland marshes or along the borders of ponds, lakes, or streams and into upland areas (Daiber 1982). However, nearly all of these species benefit from the rich aquatic and terrestrial food produced in the tidal marsh. Of the species identified in this survey, only the muskrat, which is able to satisfy its total food requirements from within the salt marsh, can be considered a marsh animal.

There are definite relationships between topographically controlled patterns of vegetation and animal abundance (Shure 1971). Because of the strict zonation of plant associations (Orson et al., pp. 136-150, this volume), increased habitat complexity represents increased availability of exploitable patches of habitat. Dueser and Brown (1980) suggested that this patchiness appears to promote increased species diversity for rodents. In this survey, rodents represented the greatest number of species (seven). It also is apparent that most of the species (Table 2) have been thoroughly acclimated to a mix of habitats and civilization and, therefore, would commonly be found within city limits. Dickman and Doncaster (1987) found that the species of small mammals they studied were strongly influenced by the density of vegetation at particular heights above ground, and more weakly by indices of habitat modifications and urban disturbance. They suggested that small mammals did not perceive the urban environment directly but responded to it directly if it modified the growth or structure of vegetation patches therein. Urban wildlife has the same needs as wildlife everywhere – water, food, cover, and adequate space to range and reproduce. Nearly all the mammals identified as inhabitants of West River Memorial Park are known to breed along the upper borders of wetlands (DeGraaf and Rudis 1986). Also, it is apparent that mammals that find suitable habitat in disturbed landscapes are becoming more abundant, hence, the increasing numbers of opossum, raccoon, and white-tailed deer in urban areas and the recent range extensions of the coyote (Smith and Remington 1996).



Muskrat

In urban areas of the eastern United States, only species with the most general habitat and resource requirements have remained in urban corridors (Murphy 1988). Likewise, open space in inner cities often supports only species that are particularly well adapted to human activities. Absent from or transient in the urban fauna within the park are species with large home ranges and/or sensitivity to human disturbance (e.g., mink and river otter). Nevertheless, it is desirable to provide and protect mechanisms for interpopulation movement of these species (Kent 1994), even though urban development in New Haven has destroyed most of the natural corridor along the West River which these species utilize. The river flows into New Haven in near-pristine condition from Lake Dawson, located approximately 6.7 km north of the park. The U.S. Department of the Interior, Fish and Wildlife Habitat Suitability Index (HSI) for mink assumes that a minimum strip of 100 m along the edge of a wetland enhances the value of that wetland to mink (Allen 1986). Rapid declines of mink populations along the shores of Lake Ontario were associated with small increases in the human population along the shoreline (Buchsbaum 1994). Notwithstanding restoration of the corridor within the West River Memorial Park, animals such as mink and river otter will remain only occasional visitors (transients) because of their "source-sink" population dynamic relationships. Populations maintained by immigration into habitats outside a species niche (which the park would be for mink and river otter) are "sink" populations (Pulliam 1988). A species has "source-sink" dynamics if local births exceed local deaths in "source" habitats (i.e., Lake Dawson), and if births do not match deaths in "sink" habitats (Holt 1996).

West River Memorial Park also is typical of urban environments characterized by the replacement of native by nonnative species through the actions of unusually high densities of cats and dogs as predators of small mammals. Both free-ranging dogs and feral and house-based cats are common in the park. These domestics (especially cats) may depress the distribution and abundance of many small mammals and birds. The result can be to reduce the availability of prey to specialist carnivores such as weasels that already are rare or perhaps even absent from the park. Unlike weasels, cats, due to their semidomesticated status, usually avoid regulation through variable prey abundance (Liberg 1984).

Open space in inner cities often supports only species that are particularly well adapted to human impact. Absent from or transient in the urban fauna within the park are those species with large home ranges and/or sensitivity to human disturbance.

Two introduced (nonnative) species of mammals that are common in the park are the Norway rat and the house mouse. It would be reasonable to hypothesize that, in a wetland ecosystem such as the West River Memorial Park, a muskrat population with restricted recruitment capabilities that was also subjected to depredation by Norway rats could experience deleterious impacts. The house mouse is relatively uncommon in undisturbed marshes. Though DeLong (1966) demonstrated that the meadow vole may limit house mouse populations in undisturbed areas, house mice have been shown to replace meadow voles in disturbed marshes as vole populations have declined (Baenninger 1973, Holland and Smith 1980).

SALT MARSH RESTORATION

Although restoration would result in significant changes in certain parts of this wetland ecosystem, it should have relatively little impact on the upland vegetative structure within West River Memorial Park. Vegetative structure (including vertical structure) and species composition are major determinants of microhabitat use by wildlife (M'Closky 1975, Yahner 1982). Species diversity of terrestrial vertebrates has been shown to be related to foliage height and diversity

(Miller and Getz 1976). It would appear that species richness of mammals within the park is closely linked to the remnant and fragmented upland, deciduous woodland that provides essential life requisites (e.g., suitable and abundant food, cover, and den sites) to many species of mammals. This woodland area also forms an important buffer zone that, with its tall vegetation, provides mammals with refuge from cold winds, high temperatures, high tides, and storms (Lewis 1994). In addition, the buffer also acts as a travel corridor and a shield from anthropogenic activity. The importance of this woodland buffer is reflected in the capture rates of species (Table 1). These observations, though limited, do agree with the classic ecological notion of an ecotone, i.e., wildlife tends to be more abundant at the wetland-buffer boundary between two distinct ecosystems such as rivers and upland (Leopold 1933, Mitsch and Gosselink 1986). In the park's wood edge, the association of animal abundance and diversity with the woodland habitats is quite clear (Table 1). Here, where two habitats coexist in close proximity, many mammals forage on the abundant invertebrates, fish, and wash-ups of the marsh but still require the surrounding wooded upland for den sites and refuge during high tides. The high level of mammalian activity shown in the reedgrass in June (Table 1) can be largely explained by animals (especially white-footed mice) extending or shifting their home ranges to forage in the reedgrass. Seasonal shifts in the activity of small mammals from woodland into reedgrass, possibly to exploit changing food availability, have been reported (Holland and Smith 1980).

Wildlife will tend to be more abundant at the boundary between two distinct ecosystems such as rivers and upland. The association of animal abundance and diversity with the park's wood-edge habitat is quite clear.

Despite the apparent strong relationship between the woodland-buffer and mammalian species richness in the park, restoration likely will affect the abundance of some species of mammals through changes in habitat. The species most likely to show a dramatic increase in number is the meadow vole, an important link in the food chain of several predators. Although captured in the reedgrass habitat during this survey, meadow voles are usually more common and often abundant in saltmeadow cordgrass (*Spartina patens*) zones of tidal marshes (Harris 1953). Shure (1971) found the meadow vole to be the most abundant small mammal in barrier beach vegetation of a New Jersey marsh habitat that was dominated by saltmeadow cordgrass. He also noted that meadow voles were most abundant in the drier, denser saltmeadow cordgrass vegetation than in the lower, wetter saltwater cordgrass (*S. alterniflora*).

The meadow vole, a major food for many birds of prey, represents an important link in mammal-bird relationships. Species-abundance relationships reveal information about the structure of the wetland community, and lead to theories about such issues as community stability, resource partitioning, and species-area relationships (Hutchinson 1959). For example, the return to a tidal marsh dominated by saltmeadow cordgrass would subsequently support a prey population of meadow voles and also might produce habitat for two permanent bird residents, the eastern screech owl (*Otus asio*) and red-shouldered hawk (*Buteo lineatus*), and two winter migrants, the rough-legged hawk (*Buteo lagopus*) and short-eared owl (*Asio flammeus*). Since the late 1960s, the occurrence of these species in West River Memorial Park has been extremely rare and coincides with the replacement of saltmeadow cordgrass by common reed (Noble Proctor, Professor of Biology, Southern Connecticut State University, personal communication).

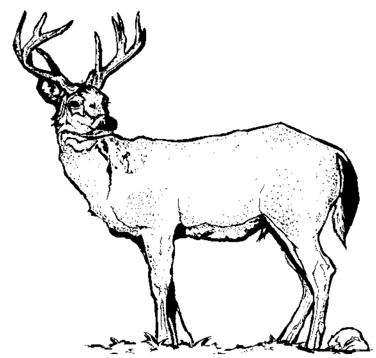
Restoration also should improve habitat for the meadow jumping mouse and the endangered (in Connecticut) least shrew. Although neither of these species was recorded during the survey, both are known to occur within saltmeadow cordgrass zones of tidal marshes in Connecticut. However, when these species are associated with tidal marshes, they are characteristically found along the high terrestrial borders of the marsh out of reach of normal tidewaters (Shure 1970). The failure to observe these species as well as others listed in Table 3 is likely to have resulted from natural animal fluctuations. As is typical of most small mammal populations, local populations increase when living conditions are ideal and decline when they are severe, resulting in great fluctuations in numbers from year to year and even from season to season (Webster et al. 1985). For example, the masked shrew was not captured during the survey, yet it has a distribution and choice of habitat greater than any other American mammal, ranging from salt marshes to high mountain slopes above timberline (Daiber 1982).

Small mammals like the meadow vole, meadow jumping mouse, and least shrew could benefit fram salt marsh resoration. These mammals are important prey for several bird species.

The distribution and abundance of the New England cottontail, known to inhabit salt marshes (Weiss 1995), have declined dramatically in response to land use changes and expanding human populations (Litvaitis and Villafuerte 1996), and competition with the eastern cottontail (Webster et al. 1985). Even though restoration would improve and provide habitat for the New England cottontail, it is most likely that the park would support only a few individuals. This is based on the availability of limited resources that would prevent the recruitment necessary to maintain a population above a "sink" habitat situation due to the metapopulation dynamics of this species (Litvaitis and Villafuerte 1996). The New England cottontail is currently listed as a candidate for federal threatened or endangered status (Federal Register Volume 54, No. 4: 553-579, Jan. 6, 1989).

Two species of "special concern" status, the red bat and the hoary bat, are unlikely to be affected by restoration. Both are tree-roosting species, and sightings are not uncommon in urban environments. West River Memorial Park provides suitable habitat for both of these species. The stressed urban trees in the woody buffer provide sufficient cavities, while the salt marsh provides a needed source of insect food. These species should be occasional visitors to the park in the fall (September) during southern migration rest stops.

West River Memorial Park is typical of disturbed tidal wetlands; that is, the park is characterized by extensive stands of common reedgrass. Although reedgrass-dominated habitats often are viewed as less valuable to wildlife than native salt marsh (Roman et al. 1984), it is important to consider the context in which this plant occurs within a landscape that includes both native and salt marsh vegetation, reedgrass, and surrounding upland. In the park, dense stands of reedgrass provide white-tailed deer with essential thermal protection, daytime resting cover and, most importantly, escape cover from free-roaming dogs. Consequently, through loss of cover, it is reasonable to assume that restoration would lead to a reduction in the park's deer population, which is unknown. Deer sightings were common during the survey and the observed variation in pellet and track size along heavily traveled paths throughout the reedgrass indicated a successful breeding population.



White-tailed deer

It is not anticipated that restoration would cause a noticeable reduction in the number of any other species listed in Table 2. Although muskrat numbers and their food sources are known to decrease as salinity increases (Daiber 1982), relatively little change in the abundance of this species should be anticipated because of the already very limited availability of optimum cattail (*Typha* spp.) habitat. Muskrats will remain most abundant in the upper reaches of the West River, where tidal influence is reduced and less saline tolerant types of vegetation predominate (e.g., cattail, *Typha* spp.) (Dozier 1947).

CONCLUSIONS

The mammalian community within West River Memorial Park is measurably diverse and it is reasonable to assume that additional sampling would verify that those species listed as "potentials" (Table 3) are also members of the community. In addition to identifying 21 species, the survey reinforced our understanding of the clear link between mammal species presence and habitat availability and use. Restoration of the salt marsh is likely to have little impact on mammalian species richness (diversity and relative abundance) within the park. Because of their generalist behavioral characteristics and their high level of adaptability to civilization, mammals would be poor biological indicators of successful restoration of West River Memorial Park. As generalists, none are sufficiently narrow in environmental tolerance that changes in species diversity or relative abundance would reliably indicate a particular change in habitat condition. A few exceptions might exist at the species level (e.g., least shrew and meadow vole). Although restoration would improve and create suitable habitat for the endangered least shrew, problems associated with establishment, monitoring (destructive sampling), and normal population fluctuation would likely preclude even this species from being a reliable indicator.

Wildlife use of wetlands is largely determined by the type, quality, and distribution of foods and cover. Therefore, restoration of the tidal marsh would result in some changes in species distribution within the marsh. For example, restoration would eliminate most of the cover provided by reedgrass which is necessary to shelter the current population of white-tailed deer. Consequently, deer would be forced to seek shelter in the remaining reedgrass and/or woody vegetation located along the upland edge.

Because of their generalist behavior and their high level of adaptability to civilization, mammals would be poor biological indicators of restoration success of West River Memorial Park.

The unlikely role for mammals as useful biological indicators for marsh restoration and the minimal effects that restoration would have on species richness within the park should not negatively influence further efforts to study mammals within the West River ecosystem. According to Frederickson and Laubhan (1996, p. 645), "Wetland complexes provide the greatest opportunity for management successes. Pristine systems should be protected, whereas those that have been modified by human activities should be managed to enhance their functional value for wildlife."

Professional wildlife biologists, conservationists, and ecologists have a responsibility associated with restoration of ecosystems that includes focusing on animal populations in decline through loss of habitat and environmental degradation. These professionals will be challenged to apply proper scientific methods and techniques in survey sampling in order to achieve desired ecosystem restoration goals. Continued research in the West River wetland ecosystem is encouraged to address important questions regarding issues of species associations (i.e., social spacing and interspecific competition) which are valuable for predicting the impact of habitat alterations on community composition and stability.

The purpose of this survey was to document species presence and to comment only subjectively on commonness (relative abundance). Considerably more effort would be required to measure population densities and to estimate numbers of individuals per unit area. Future analysis of restoration effects on species of mammals would require such population density estimates; also, it would be necessary to gather reliable age-structure data in order to assess population condition (i.e., declining, stable, or increasing). Results from this survey are too preliminary to form the basis for confident predictions. Monitoring of species should be done over a sufficient number of years to provide for identification of stochastic variation. Many other issues related to the enhancement, restoration, and creation of coastal wetlands would benefit from continued basic and applied studies of the mammalian community within West River Memorial Park.

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Section IV: Synthesis

> *"Improved understanding, not only among academics, but across the community at large, of human situations in terms of culture-nature interplay may well be a prerequisite for ecological sustainability and, hence, for the survival of the human species."*
>
> – *from* The Human Component of Ecosystems, *Stephen Boyden*

Our understanding of ecosystems has been enhanced by expanding the scope of variables used to monitor restoration success. In the case of salt marshes, ecological functions such as wildlife species survivorship, biomass productivity, and ability to sequester water-borne pollutants are being used to evaluate restoration. Social variables, however, are generally excluded from ecological analysis. This is unfortunate, because excellent methods exist for including humans in ecosystem analysis. This final paper draws on the research presented throughout this *Bulletin* to present methods for using restoration to expand our knowledge of the relationship between humans and ecosystems.

The Human Component of Urban Wetland Restoration

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ABSTRACT
Urban ecological restoration can produce important social benefits in addition to those biophysical improvements traditionally included in the evaluation of restoration success. Achieving social benefits requires local people to participate in planning, implementation, and evaluation of restoration. Restoration also provides experimental opportunities to study the interactions between human and non-human components of ecosystems. Existing sociological, psychological, and anthropological literature provide methods for analyzing effects of restoration on adaptive behavior, community structure, values, perceptions, knowledge, and personal efficacy.

Wetland restoration in urban areas is, in effect, restoration of human habitat. The process, goals, and evaluation of restoration success should all include a human component. Urban wetland restoration can restore the ecosystem to a condition that maximizes human benefits while minimizing inputs of energy. This is accomplished most easily and inexpensively, and achieves the longest-term results, by restoring ecological processes suited to the climate, topography, geology, and hydrological context of the restoration site. Such restoration does not require exact duplication of an historic landscape. However, it does imply altering the relationship between human and non-human components of the ecosystem.

The proposed salt marsh restoration in New Haven, Connecticut's West River Memorial Park – the subject of this volume – provides an opportunity to study this approach. During the colonial period, farmers derived economic benefits from the salt marsh system with little input of human energy (Casagrande, pp. 13-40, this volume). This was possible because farmers maintained or enhanced the ecological processes responsible for high biomass productivity. Between 1927 and 1934, a massive investment of energy was directed at eradicating the ecological processes that sustained the salt marsh in West River Memorial Park. This was so costly that the City of New Haven was forced to abandon the project before it was completed. But not before ecosystem processes were redirected to favor a *Phragmites australis* (common reed) dominated system (Orson et al., pp. 136-150, this volume).

Human energy required to maintain the current system is minimal, limited mostly to maintaining the tide gates. However, the system no longer provides benefits. Large stands of *Phragmites* block recreation access and views to the river, and provide for poor bird diversity (Lewis and Casagrande, this volume). Estuary biomass productivity and water quality are reduced, because the current system lacks the ability to sequester pollutants and sediments (Orson et al., pp. 123-135, this volume) and because the tide gates reduce upstream water oxygenation and free movement of fish and invertebrates (Moore et al., Cuomo and Zinn, this volume). Residents of adjacent neighborhoods generally perceive the river as polluted and appear psychologically and behaviorally disconnected from it (Casagrande, pp. 62-75, Page, this volume). They have indicated that they would value the area more if it were restored to a salt marsh (Udziela and Bennett, this volume).

Restoration can redirect ecological processes so that humans once again benefit from the system with minimum sustained input.

The goal of the West River restoration should be to redirect ecological processes so that humans once again benefit from the system with minimum sustained input. This would not require a large investment of energy if the targeted ecological processes are suited to the proposed restoration site. The proposed salt marsh restoration fits this criterion. Indeed, opening one or two tide gates can quickly initiate the desired successional process (Barten and Kenny, Cuomo and Zinn, this volume).

Inability of nearby residents to benefit from the marsh also results from cultural and physical barriers (Casagrande 1996; Page, this volume). Successful restoration will have to include activities other than landscape alterations that re-connect residents – cognitively, physically, and behaviorally – with the non-human ecosystem.

William Jordan (1997) distinguishes the process of ecological restoration from the science of restoration ecology. To him, ecological restoration is a constructive, functional, and self-aware human participation in the ecosystem being restored. Such participation could help link the human and non-human components of the West River ecosystem.

Jordan defined restoration ecology as restoration efforts undertaken specifically to develop and test hypotheses about the ecosystem being restored. Unfortunately, traditional definitions of ecosystems have excluded humans. This will have to change if we, as a society, are to sustain our collective adaptability to environmental change (World Commission on Environment and Development 1987).

Excluding humans from the science of restoration ecology leads to a disproportionate amount of restoration taking place in less densely populated areas. This effect is exemplified by Kentula et al. (1993), who recommend using the differences in quality between urban and non-urban wetlands to "direct wetland protection and restoration to areas with the greatest potential for ecological benefit" (p. 35). Ecological benefits, such as biomass productivity and wildlife habitat, are generally easier to restore in non-urban areas where wetlands are larger and less disturbed by humans. However, potential psychological and social benefits of restoration in densely populated areas are excluded from such an evaluation.

Hence, restoration that provides social benefits involves two approaches. Ecological restoration is the process of reconnecting the human and non-human components of ecosystems. Restoration ecology that includes humans is required for evaluating the success of restoration.

The effort to re-connect people – cognitively and behaviorally – with their urban ecosystem is a daunting yet essential task. American industrial culture is being transformed by science and technology into an ecological culture (Siry 1984, Merchant 1989). The focus on material satisfaction and the dominant perception of "man over nature" are gradually giving way to an appreciation of the inter-connectedness of life (Kempton et al. 1995, Metzner 1995). But this change lags behind in urban areas where knowledge of ecological concepts and participation in environmental activities are much lower than in suburban or rural areas (Kellert 1984, Taylor 1989). Impediments to inner-city participation in environmental activities include low personal efficacy,[1] lack of financial and political resources, lack of outdoor recreation, and cultural norms.[2]

Analyses of ecosystems will have to include humans if we are to sustain our collective adaptability to environmental change.

Despite impediments to environmental activities, urban residents strongly desire to interact with non-human nature and are concerned about environmental issues (Kaplan 1983, Kempton et al. 1995, Casagrande, pp. 62-75, this volume). Indeed, Knopf (1983) found that levels of desire to reduce stress through outdoor recreation were correlated with degree of urbanization. The gaps between the desire and ability to experience nature and between environmental concern and action result in a debilitating psychological tension (Metzner 1995). For the city-dweller, this stress is exacerbated by the cultural perception that nature is inherently non-urban, and the realization that we rely on ecosystem health, but are powerless to change our environmentally destructive lifestyles (Hartig et al. 1994). Psychologists are beginning to treat this stress using ecological restoration as therapy (Cahalan 1995, Shapiro 1995). This approach is not surprising if restoration is considered analogous to gardening, which has long been known to reduce stress and foster a sense of connection with the living world (Kaplan 1983).

[1] Mohai's (1985) definition of efficacy is used here: "The individual's perceptions of his or her abilities to affect his or her social and/or political environment."

[2] See for example Washburne (1978), Mitchell (1980), Van Liere and Dunlap (1980), Mohai (1985), and Mohai (1990). Disparate theories have been synthesized by Taylor (1989) and Casagrande (1996).

Ecological restoration can provide a bridge between the industrial and ecological cultures – easing the social unrest and personal anxiety of transition. But cities will continue to decay if urban residents do not benefit from this bridge. It is difficult, though not impossible, to psychologically re-connect inner-city populations with their ecosystems. Successful cases indicate that the following six approaches are helpful, and in most cases essential, for ecological restoration to produce maximum social benefits in urban areas.

LOCAL PARTICIPATION

The success of re-connecting local people with their ecosystems lies within the people themselves and their empowerment. They must feel a sense of ownership of the restoration site. The traditional approach, with neighborhood residents periodically commenting on a plan developed outside of their community, is insufficient. Neighborhoods, government agencies, private consultants, and/or industry must all participate in planning, implementation, and evaluation of the restoration as equals. Otherwise, the local community is not likely to develop a sense of ownership.

Lack of personal efficacy is a major impediment to involvement in community affairs and environmental activism (Mohai 1985, Taylor 1989). A key benefit of participation is improving personal efficacy (Kaplan 1983). Ecological restoration enables people to directly experience connections with the plants, air, water, wildlife, ecological processes, and other people of their environment. This promotes a sense of place within the ecosystem – a groundedness that is essential for mental health (Cahalan 1995). Environmental restoration also engenders a sense of dignity (Shapiro 1995) and may reduce stress by creating a sense of control (Hartig et al. 1994). Groundedness, dignity, and control all clarify the means by which disenfranchised urban residents can change their environment, which will enhance their personal efficacy. Hence, the individual is empowered through participation in restoration. Personal empowerment can carry over to other neighborhood revitalization efforts including economic development (Burch and Grove 1993).

Participation in planning activities is also an effective tool for communicating among stakeholders such as neighborhood groups and government agencies who may have fundamentally different perspectives of the local ecosystem. Examples of participatory planning activities include field trips to the restoration site and participatory mapping.[3] Local residents are more likely to be outspoken and think more seriously about environmental resources as a result of participatory activities. Observation of behavior during meetings, field trips, or other activities can also help environmental managers learn more about the needs and desires of local people.

"Barring love and war, few enterprises are undertaken with such abandon, or by such diverse individuals, or with so paradoxical a mixture of appetite and altruism, as that group of avocations known as outdoor recreation. It is, by common consent, a good thing for people to get back to nature."

– from A Sand County Almanac, *Aldo Leopold*

[3] Participatory mapping is a social forestry technique in which local people and environmental agencies collaborate to draw maps of the environmental resource in question. It is very effective at communicating the landscape attributes that are most important to various stakeholders. This, and other social forestry techniques that can be applied to urban areas, are described by Fox (1990), Mascarenhas (1991), Gibson (1994), and Jackson et al. (1994).

Local people can also participate in collection of water-quality, wildlife, and vegetation data (Holloran 1996). Data collecting can enhance local interest and sense of ownership of restoration projects. It serves to de-mystify science and technology, and builds community self-confidence. This is particularly effective when data collection is incorporated into local school curricula (Tanner et al. 1992).

Although inner-city, minority communities suffer a disproportionate amount of environmental degradation, they show the lowest rates of environmental activism (Mohai 1990). Research has indicated that outdoor activity, especially in a social setting, is a prerequisite to environmental activism (Taylor 1989). Inner-city residents generally do not pursue outdoor recreation because of limited access to high quality recreation settings and cultural norms. Because ecological restoration is a nature-based social activity, it can help break down these barriers to environmental activism.

Cooperation among stakeholders will also require environmental management agencies to help urban communities develop resource management capabilities (Poffenberger 1990). An excellent example is the community-based stewardship approach that the National Park Service is taking in San Francisco (Holloran 1996). This program uses volunteer participation to empower communities and help them develop a sense of resource ownership.

Incorporating ecological restoration into community-based initiatives aimed at economic development, neighborhood beautification, job training, and school improvements can help circumvent impediments to urban environmental action.

FOCUS ON COMMUNITY

A general disillusionment with the ability of government bureaucracies to address inner-city problems has encouraged the growing movement to take a community-based approach to problem solving (Gurwitt 1992, Gibson 1994). Across America, communities with few resources have made remarkable progress against poverty and urban blight. The community-based approach has become *de facto* anti-poverty strategy in many cities (Gurwitt 1992).

The basic concepts of community-based development also apply to ecological restoration. Government, philanthropic, and corporate resources can be channeled through small-scale community groups that set the agenda for their neighborhoods, and are free to discover benefits of ecological restoration themselves. Only through self-discovery and community empowerment can the full range of possible ecosystem benefits be retained.

Many inner-city neighborhoods have become repositories of environmental degradation because they have failed to act on environmental issues (Mohai 1990). Incorporating ecological restoration into community-based initiatives aimed at economic development, neighborhood beautification, job training, and school improvements can help circumvent impediments to urban environmental action.

The neighborhood is a logical scale of organization for consensus building, because it is small enough to be responsive to individuals yet provides the refuge and power of a group. Individuals are more likely to accept risks in groups than alone. Psychologists recognize the neighborhood (or rural village) as an ideal unit of participation (Cahalan 1995). A major problem in blighted, urban areas, however, is that social structure has deteriorated (Gibson 1994). Many neighborhoods lack basic communication, family function, and political leadership, which enhances criminal opportunities. Therefore, neighborhood revitalization is often a struggle to restore basic community structure.

External parties (including environmental agencies and activists) can help restore community structure by interacting with community leaders. This can enhance the legitimacy of leaders and increase the community's power base. Restoration activities also have the potential to encourage communication between generations, strengthen social bonds, improve perceptions of the neighborhood, and stabilize home values and ownership (Burch and Grove 1993). Hence, urban ecological restoration can help restore social structure as well as non-human ecosystem structure.

Urban ecological restoration can help restore social structure as well as non-human ecosystem structure.

In recognition of these potential benefits, the West River Neighborhood Association (WRNA) has included the West River salt marsh restoration in their neighborhood revitalization plan. This grassroots organization of residents from a neighborhood adjacent to the restoration site has successfully implemented revitalization efforts funded with government grants totaling over one million dollars. Marketing the neighborhood as a "Gateway to New Haven" has been central to their economic development plan. Community leaders recognized that *Phragmites* eradication would support this effort by opening views and access to the river. Another community goal is to rebuild an aging school by converting it to an inter-district environmental education school that uses the West River and the restoration as learning tools. Efforts are also underway to link the restoration with job creation and youth entrepreneur training. Ideas include aquaculture and urban eco-tourism. This high level of community participation will help restoration benefits flow to the community.

Establishing consensus between neighbors of the potential restoration area and the implementing agency can also help avoid opposition to restoration after the project has begun. The genesis of salt marsh restoration in Fairfield, Connecticut (Steinke 1986) came from homeowners adjacent to large stands of *Phragmites* who were suffering damage from periodic brush fires. The goal of *Phragmites* eradication was set by the community. Therefore, residents were prepared to accept temporary inconveniences of salt marsh restoration and were willing to negotiate compensation for permanent property losses caused by increased soil salinity.

THE ROLE OF FACILITATOR

Urban restoration can involve local community groups, researchers, industry, private consultants, and government agencies. These stakeholders may have fundamentally different perspectives, which are difficult to communicate and reconcile. Also, urban community groups or local politicians without environmental agendas may be unaware of ecological restoration benefits and may not be interested in participating in restoration.

Individuals who understand the perspectives of the various stakeholders can facilitate communication and promote agreement. A facilitator can balance technical possibilities with ecosystem constraints and community needs within the context of social goals, human and economic resources, and community desires (Burch and Grove 1993).

To be successful, a facilitator needs to be sympathetic to all perspectives and hold the trust and respect of the various stakeholders. Gaining the respect of environmental agencies often requires demonstration of experience in restoration or an appropriate technical education. Also, a facilitator must understand financial, policy, and procedural issues of the participating government agencies. Gaining the trust of community groups requires spending time in the community and participating in activities such as clean-ups and community meetings.

Even though inner-city people often care about environmental issues (Taylor 1989), their ability to take action can be constrained by a lack of resources including money and political knowledge (Mohai 1985). The facilitator can bring resources to the community by assisting with grant applications or providing knowledge about government agencies and programs or private foundations.

Private consultants, state government agencies, town officials, environmentalists, educators, and students can potentially act as facilitators. In the case of New Haven's West River salt marsh restoration, staff and students affiliated with the Center for Coastal and Watershed Systems (CCWS) are acting as facilitators between the Connecticut Department of Environmental Protection (CT DEP), city staff, and The West River Neighborhood Association (WRNA). CCWS is a research and public outreach center within the Yale School of Forestry and Environmental Studies. It is respected by the CT DEP because of its university affiliation and past research partnerships with government agencies. CCWS holds the trust of the neighborhood because its office is in New Haven, and its staff have lived in the West River neighborhood or have been involved in New Haven politics. More importantly, CCWS staff and students have attended community meetings regularly and contributed to other aspects of neighborhood revitalization efforts. This has included assisting with grant applications, collaborating with development of the environmental magnet school, and providing information about the science and politics of the proposed restoration.

EDUCATION

Environmental education through community-sponsored programs and school curricula is fundamental to enhancing the relationship between human and non-human components of urban ecosystems. Increased ecological knowledge can reduce barriers to environmental activism (Taylor 1989) and outdoor recreation so that benefits can flow to the community.

Incorporating ecological restoration into school curricula can stimulate interest in science and math (Tanner et al. 1992). This, in turn, contributes to personal efficacy and community empowerment. Children also provide an excellent way to involve adults in restoration (Tanner et al. 1992, Chow-Fraser and Lukasik 1995). Adults become interested by seeing children working at restoration and by talking about projects at home. Student presentations are valuable because parents are much more likely to come to a presentation about restoration and make the effort to understand restoration principles if their own children are presenting information. College and high school internships linked to environmental curricula have also been found to be valuable for restoration efforts (Holloran 1996).

Combining ecological restoration with education can reduce barriers to environmental activism and outdoor recreation, stimulate interest in science and math, enhance personal efficacy, and empower communities.

DEMONSTRATION PROJECTS

A fundamental concept of community-based development is that progress happens project by project (Gurwitt 1992). Neighborhood-based restoration projects that are highly visible can help build community development momentum because they display success (Burch and Grove 1993). It is also helpful to make field trips to restored urban ecosystems, so that community members can envision a finished product in their neighborhood.

EVALUATION

Urban, community-based, ecological restoration is becoming more common (Holloran 1996), and it would be prudent to evaluate the success of the various approaches. It has been argued that ecological restoration has the potential to promote democracy (Light 1994, Holloran 1996), reduce psychological stress (Shapiro 1995), and fulfill a basic human need for ritual that is currently expressed by our culture in destructive ways (Jordan 1997). These potential benefits imply that social goals can be set and that progress toward those goals can be evaluated using the social variables discussed below.

RESTORATION ECOLOGY: THE HUMAN COMPONENT

It is essential to include biophysical processes in the study of ecosystem restoration, and methods have been discussed throughout this volume and elsewhere.[4] However, ecologists' attempts to include humans in ecosystem analysis have mostly focused on one-way effects of humans on ecosystems (see for example McDonnell and Pickett 1993). Other disciplines such as environmental psychology, environmental history, and ecological anthropology are valuable for generating hypotheses of human-environmental interaction.[5] But these approaches do not allow experimental tests for cause and effect – a fundamental goal of ecology. Using the social variables described below, restoration ecology can provide experimental opportunities for studying human interactions with ecosystems.[6]

ADAPTIVE BEHAVIOR

It is through adaptive behavior that humans respond to continously changing ecosystems (Ulrich 1983, Smith 1992). Therefore, monitoring behavior is essential for analyzing the effects of restoration on humans. Human behavior can be monitored directly or indirectly. A rapid and inexpensive direct method is to travel line transects or visit points and record data about activities, group composition, gender, age, time of day, and duration of activities (Altmann 1974, Ås 1975). Indirect sampling involves observations of physical evidence of past behavior. For example, a survey of litter can be used to determine if an area is being used for picnicking, fishing, or taking illegal drugs.

Preliminary behavioral sampling by Page (this volume) indicated that recreation near the West River was mostly limited to organized sports in playing fields. Few people were observed walking, enjoying views, fishing, or observing wildlife, even though residents desired these activities (Casagrande, pp.62-75, this volume). Enhancement of recreation opportunities through improved aesthetics and fish and wildlife habitat is an important benefit of urban restoration (Kaplan and Talbot 1983, Knopf 1983). Passive and nature-based recreation could be monitored to evaluate behavioral response to restoration.

Observations of group size and composition can indicate social structure and cultural norms when combined with block level census data. Behavioral sampling can also be used to verify interview surveys of environmental resource use. However, other social variables must be monitored to evaluate restoration benefits, such as increased personal efficacy and non-use economic value (Udziela and Bennett, this volume).

[4] See for example Westman (1991), Kentula et al. (1993), and Shreffler and Thom (1994).

[5] Ulrich (1983) and Roszak et al. (1995) provide introductions to environmental psychology including effects of ecological restoration. Cronon (1983) and Merchant (1989) used environmental history to generate hypotheses of feedback mechanisms. Steward (1955), Rappaport (1968), Smith (1992), Bennett (1993) and Richerson (1993), provide examples of anthropological approaches to human-ecosystem relationships.

[6] For examples of ecosystem models that include humans, see Kowalewski et al. (1983), Burch and DeLuca (1984), Lee et al. (1992), and Boyden (1993).

KNOWLEDGE OF THE ECOSYSTEM

A prerequisite for adaptive behavior is sufficient knowledge of the ecosystem (Hunn 1982, Berlin and Berlin 1983, Heerwagen and Orians 1993). Ecological restoration provides a direct learning experience, although knowledge acquired through restoration is not confined to the participants. Humans are a social species and circulate knowledge throughout their community in order to enhance collective adaptability. Ideally, a restoration project would maximize the transfer of ecological knowledge by linking the project with education and other community-based initiatives.

A restoration project's effectiveness for enhancing knowledge can be evaluated using surveys before and after restoration. A preliminary survey of neighborhoods near the proposed West River restoration site suggested a low level of ecological knowledge (Casagrande, pp.62-75, this volume), which is typical for urban areas (Kellert 1984). It is possible that the residents possess a different kind of ecological knowledge than was tested for in the survey, which was not designed as a comprehensive test for ecological knowledge. For example, residents indicated poor knowledge of pollution processes, but some fishermen were very knowledgeable about the area's wildlife and history of environmental disturbance (Casagrande, unpublished data). A more comprehensive survey could be designed to specifically test for changes in ecological knowledge as a result of restoration.

Humans are a social species and circulate knowledge throughout their community in order to enhance collective adaptability. Ideally, a restoration project would maximize the transfer of ecological knowledge by linking the project with education and other community-based initiatives.

VALUES AND PERCEPTIONS

Although ecological knowledge is necessary for sustaining a beneficial human/environmental relationship, knowledge does not translate directly into adaptive behavior. Values, social norms, individual perceptions, and social institutions influence behavioral decisions and interpretation of knowledge (Casagrande 1996). Values and perceptions can be rapidly quantified using surveys.

Surveys in the West River area indicated that residents valued the potential restoration area for its naturalness and for wildlife habitat (Casagrande, pp. 62-75, Udziela and Bennett, this volume). But they perceived the river as polluted and aesthetically displeasing. As a result, they placed a high priority on restoring an environment suitable for relaxation and encountering wildlife. These data indicate that – in this case – values and perceptions would support changes in behavior (i.e., increased outdoor recreation) as a result of restoration. Continuous periodic surveys would be necessary for evaluating restoration effects on perceptions and values.

PERSONAL EFFICACY

Ecological knowledge and cultural values can encourage behavioral responses to environmental change. However, individuals may not act if they lack self confidence and/or a clear cognitive model[7] of how their action will result in benefits. Cognitive models can be based on personal experiences or, as in the case of religion, cultural influences (Holland and Valsiner 1988). Self confidence and cognitive models combine to shape personal efficacy. Increased personal efficacy could be a major benefit of urban ecological restoration.

Semi-structured interviews and photo-questionnaires used by anthropologists and environmental psychologists can be used for studying personal efficacy (Kaplan 1983, Kempton et al. 1995). These methods are time consuming and require special skills. But they are necessary for evaluating restoration projects that emphasize human behavioral change.

[7] Cognitive models are mental maps of our relationship with our social and physical environment. These models enable us to predict the results of our actions.

TIME AND MONEY

Exchanges between humans and ecosystems can also be measured using time and money. Municipal expenses required to maintain the West River tide gates, for example, represent current human inputs to the system. Volunteer time and municipal expenditures being considered for park clean-up and *Phragmites* mowing represent potential inputs aimed at increasing aesthetic benefits. Increases in expenditures of time or money to visit the restored area would indicate increased human benefits.

Restoration benefits, such as satisfaction from knowing wildlife exists or that future generations will have a cleaner environment, are difficult to value economically and are not reflected in behavior. However, they can be measured using economic techniques such as contingent valuation (Udziela and Bennett, this volume).

COMMUNITY STRUCTURE

Characteristics of the community can greatly influence the ability of restoration to increase ecosystem benefits. Demographic characteristics such as age distribution, population density, and race are easily obtained from census data (Page, this volume). Information regarding community leadership, cultural norms, and institutions (e.g., civic groups, churches) can be obtained from interviews and systematic observation.

Additional information about cultural norms and communication between residents can be acquired from behavioral sampling. For example, observations of West River anglers indicated that Hispanics were most likely to fish in family groups – a cultural norm (Casagrande, pp. 62-75, this volume). Perceptions of the river are probably communicated between generations of Hispanics more quickly than generations of other cultures.

WEST RIVER RESTORATION: A HYPOTHETICAL EXAMPLE

The following simplified, hypothetical example using the West River restoration illustrates how the human component can fit into ecosystem research. Collaboration between the CT DEP, neighborhood groups, and Yale University researchers could result in a mutual goal of reducing non-point source (NPS) pollution.[8] Water chemistry studies conducted by Yale researchers and funded by the CT DEP have identified NPS pollution as a problem in the watershed, and neighborhood residents indicated pollution as a major concern (Casagrande, pp. 62-75, this volume). Landscape and hydrological alterations to the marsh within West River Memorial park can be designed to restore ecological processes that remove NPS pollution (Barten and Kenny; Orson et al., pp. 123-135; this volume). But long-term pollution reductions require changes in the values and behavior of watershed residents, because much NPS pollution can be attributed to automobile use and maintenance, lawn care, and illegal dumping. Comprehensive ecological restoration with an educational component and widespread participation of residents could achieve additional water quality improvements through behavioral change (Table 1).

Baseline survey data indicate that residents have no knowledge of NPS pollution (Casagrande, pp. 62-75, this volume). If neighbors participated in salt marsh restoration with an educational component, they would learn about watershed hydrology, non-point source pollution, and their ability to affect the environment. As a result, they might limit their use of chemical lawn treatments, refrain from changing automobile oil in the street, or maintain automobiles to reduce leaking fluids. If community social structure were amenable, this behavior could spread from the participants to other residents. Increased water quality could enhance perceptions of the river and recreational opportunities – further strengthening the human bond with the river. Every step of this hypothetical, positive feedback loop could be measured using biophysical and social variables.

[8] Non-point source pollutants originate from activities conducted over broad areas, or through the cumulative effect of many, small activities (Benoit 1995). They are more difficult to regulate than point-sources, such as factories or sewage treatment plants. Lead and nitrates from surface run-off and combin-ed sewer outflows and copper from algae control are the major pollutants in the West River watershed (Gaboury Benoit, Tim Rozan, and Jeffrey Albert, Yale F&ES, personal communication). Orson et al. (this volume) discuss the potential for restored salt marshes to sequester pollutants.

Table 1. Differences in urban salt marsh restoration approaches using the hypothetical goal of nonpoint source pollution reduction.

BIOPHYSICAL APPROACH ONLY	APPROACH WITH HUMAN COMPONENT
Implementing agency designs marsh restoration.	Plans are developed through collaboration of local people and the agency.
Implementing agency restores hydrological function and plants vegetation.	Community participates in restoration work, and the project includes links to education and community revitalization.
Implementing agency monitors water quality, soils, and sedimentation rates.	Community participates in monitoring. Local behavior, perceptions, and values are also monitored.
Desired Result: improved water quality in estuary.	Desired result: additional water quality improvements through behavioral change within the watershed.
No knowledge gained regarding the human component.	Water quality improvements can be enhanced by calibrating education, recreation, and participatory activities, or additional social barriers to behavioral change can be identified.

The amount of time needed to detect social change is uncertain. Kentula et al. (1993) have proposed a method for evaluating biophysical changes using a performance curve. This concept can be expanded to include social variables, such as perceptions of marshes (Fig. 1). A salt marsh restoration in Fairfield, Connecticut provides an example of changes in perceptions after restoration. Steinke (1986) indicated that before restoration neighbors had a negative perception of the *Phragmites* dominated marsh, because brush fires were damaging their property. Immediately following restoration complaints increased because of negative effects such as snakes and rats migrating off the marsh and into yards. But several years later, perceptions were mostly positive, including an increased appreciation of wildlife.

Perceptions could be monitored by annual surveys and plotted on a performance curve (Fig. 1). The maximum increase in benefit would occur as the curve levels off and the system stabilizes. Ideally, stable post-restoration perceptions would be more favorable than the pre-restoration condition.

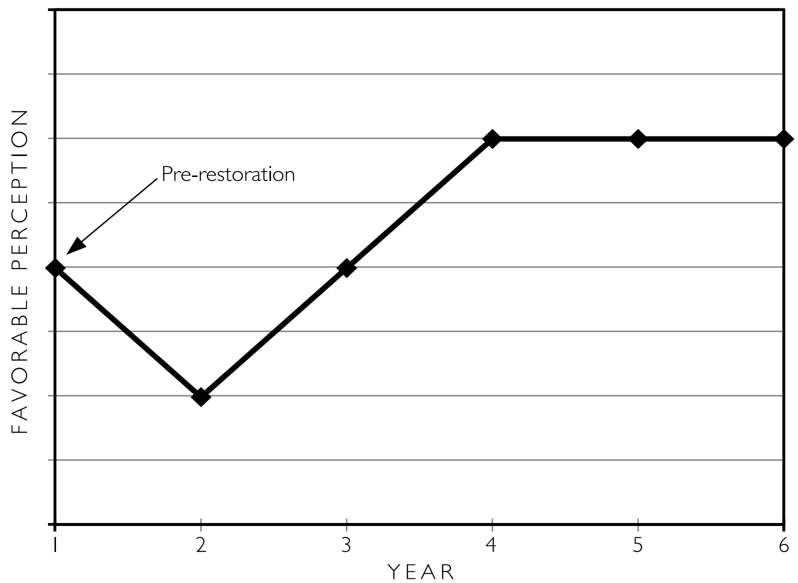

Figure 1. Hypothetical change in human perceptions of a marsh as a result of restoration.

CONCLUSION

Urban ecological restoration provides an opportunity to study the interactions between human and non-human components of ecosystems by taking an experimental approach. The sociological, psychological, and anthropological literature provide methods of analysis for determining the effects of restoration on adaptive behavior, community structure, values, perceptions, knowledge, and personal efficacy. Success of ecological restoration could be measured by the amount to which social benefits – as well as bio-physical benefits – exceed human inputs of time and energy necessary to maintain ecological processes.

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