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Evaluating wetlands within an urban context

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Abstract

Coastal regions are among the most rapidly urbanizing places on earth. The numerous effects of urbanization on hydrology, geomorphology, and ecology make wetlands in urban regions function differently from wetlands in non-urban lands. Furthermore, wetlands in urban regions may take on human-related values that they lack in non-urban areas, as they provide some contact with nature, and some opportunities for recreations that are otherwise rare in the urban landscape. Evaluations of the success of restorations in urban regions require criteria first to determine the kinds, and intensities of urban influence on the site, and secondly to assess functional performance. The development of success criteria, at both the levels of assessment, depends on the proper definition of a reference domain (the set of wetlands to which success criteria will apply), and the documentation of a set of reference sites within the domain; both must be based within the urban context appropriate for the region of interest. An example is presented from a study of urban wetlands in New Jersey of a procedure for establishing the reference domain, the reference set of wetlands, and criteria for the assessment of urban influence. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The growth of urban, and suburban areas has been a dominant demographic characteristic of the 20th century. During this time urban population has increased ten-fold, and the proportion of the human population living in urban areas has risen from 14 to over 50% (Platt, 1994). Much of this expansion of urban land, and citizenry has occurred along coasts, as port cities have expanded, coalesced, and engulfed neighboring undeveloped lands. Between 1960 and 1990, coastal counties in the US increased in population by 43%, a faster rate of growth than in the country as a whole. Likewise, between 1970 and 1989, nearly half of all building activities took place along the coasts (Anon., 1994). As of 1981, 28% of municipal areas were coastal, but they accounted for 55% of the US population (Walker, 1990). Elsewhere in the world, the story is similar: of cities with populations over 1 million, 100% of those in South America are coastal, as are 75% of those in Asia and Africa (Berry, 1990).

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Not surprisingly, the effects of this burgeoning coastal development on natural resources have been profound (Walker, 1990; Nordstrom, 1994). Damage to and loss of wetlands have been extensive (Tiner, 1984; Dahl and Johnson, 1991). A recent survey by the US Department of Agriculture found that urbanization was implicated in wetland loss in nearly all surveyed watersheds (96%) and may account for as much as 58% of the total wetland loss (Anon., 1997; Opheim, 1997). Yet wetlands remain an integral part of the developed landscape, particularly along coasts, where salt marshes surround oil tanks and abut summer homes, and riparian forests persist along streams as they meander through dense development and industrial campuses (see, for example, Greiling, 1993).

Restoration of coastal wetlands often must take place within urban regions. In order to evaluate the success of such restorations, it is necessary to establish criteria that reflect both the ecological qualities of the wetland and the realities of the urban context. Below, I discuss several ways in which the context of urban environments affects the process of determining success criteria in restoration. These comments are based on a consideration of the nature of urban environments, supplemented by the observations of urban/suburban wetlands in New Jersey.

2. Adapting success criteria to cities

While the human dimension in restoration has been stressed repeatedly, (Jordan, 1994), its importance is best expressed in urban regions. Restoration projects necessarily affect many people in their daily lives by altering the places in which they walk the dog, commute to work, do a bit of fishing. Such places often constitute the only 'natural' habitats that urban residents experience. The multiple aesthetic, emotional, and practical values that people ascribe to trees have been ably described by Dwyer et al. (1994), many of the same values accrue to natural landscapes. Since the commitment and involvement of local citizens are critical to the success of a project, these values must be taken into account in urban restoration more explicitly and more fully than in non-urban projects.

This point is well illustrated by recent controversies surrounding ecological restoration in Chicago (Shore, 1997; Gobster, 1997). A long-term collaborative effort by many agencies and organizations sought to restore prairie and oak savanna. The effort provoked harsh public opposition when some newspapers and local residents realized that re-establishment of these ecosystems involved removing large numbers of trees. Conflicting values — the amenities provided by trees versus the re-creation of the pre-settlement 'natural' landscape, local determination of the fate of land versus the science-based wisdom of professionals, the use of public funds for restoration versus acquisition of land for conservation has thrown this extensive urban restoration project into confusion. Its goals and success criteria were developed primarily, if not exclusively, in terms of the ecological characteristics of native prairie and oak savanna. But the local opposition suggests that the goals of a restoration project in a densely populated area must take into account factors unique to that area, including the historical and contemporary landscape to which the local citizens are accustomed. Urban restoration projects in Florida and New York City have generated similar controversies (Shore, 1997).

Urban environments place a number of constraints on evaluating the success of restoration in urban regions (Table 1). These include the considerable differences in the physical conditions that limit the kinds of restoration that are possible and may preclude some kinds of ecosystem from being the goal of a restoration program. For example, intense disturbance events such as major floods and hot forest fires obviously cannot be tolerated in densely settled areas; ecosystems that depend on such disturbances may thus be impossible to restore. Air pollution and storm-water runoff introduce high concentrations of nitrogen; species and communities characteristic of very nutrient-poor habitats would be unrealistic targets for restoration in N-enriched sites. Species near the limits of their geographic ranges may be intolerant of the altered climate within cities. Thus, the cultural and physical environment in cities places some a priori constraints on the development of goals and success criteria for restoration.

Criteria for the evaluation of success usually based on qualitative or semi-quantitative expressions of wetland functions. Brinson et al. (1995), for example, have shown how simple equations can be derived to evaluate a variety of biological and physical functions such as wildlife support, nutrient cycling, flood storage, or biodiversity, from readily observable and measurable properties. Zedler (1996) similarly describes assessment methods that depend on measurements of indicators of identified functions in California tidal marshes. Many other assessment methodologies have been proposed and utilized (e.g. Hruby et al., 1995; Weinstein et al., 1997); all are based on the assumptions that separate wetland functions can be identified and evaluated relative to measured performance in unaltered reference sites, and that indicator variables reliably reflect the rate or magnitude of these functions. These approaches to determining restoration success make sense for non-urban areas, and they are also useful for regulatory situations in which the replacement of specific functions is required by a permit.

Table 1
Constraints on the specification of success criteria in natural vs. urban environments

Natural	Urban
Watershed-based approach is ideal	Municipality-based approach is often necessary
Ecological characteristics and functions are readily identified and are primary	Ecological functions may be less important than human values, which may be difficult to specify
Natural disturbance regimes are critical	Natural disturbance regimes may be impossible to restore
Restoration work is implemented by professionals or consultants, possibly supplemented by volunteers	Volunteers are extensively involved
Nutrient limitations are the norm	Nutrients are often present in abundant or over-abundant amounts, and cannot be reduced
Habitat patches can vary greatly in size and connectedness	Habitat patches are often small and isolated; connections are difficult or impossible to re-establish
Climate and microclimate reflect regional geography	Climate and microclimate are significantly altered from the geographically based expectations
Hydrology is a function of regional climate, geology, physiography	Hydrology is usually highly altered, in amounts, sources, and flow rates of water

In urban areas, however, a two-tiered approach to evaluation of restoration success may be more appropriate. Appraisal of functional capacity and replacement is clearly one necessary facet of evaluation, but this level of appraisal should take place within a framework of social expectations, wetland capacities, needs for active management, and values unique to the particular urban context. This enveloping framework affects the definition of the reference domain, the identification of reference sites, and the establishment of indicator variables for function and their expected ranges of values.

3. The establishment of 'reference domains' specific to urban wetlands

The development of success criteria depends fundamentally on the establishment of the reference domain. This concept (developed by Kentula et al., 1992; Brinson, 1993; Rheinhardt et al., 1997) refers to the identification of those attributes that define a particular class of wetland. A wetland class is usually defined by the plant community composition in conjunction with the hydrogeomorphic setting; for example, a reference domain might be defined as wetlands occurring in depressions, with mineral soils, a canopy of hardwood trees, and a dense understory of woody shrubs. Criteria for evaluating the condition or functional properties of a given wetland are then developed, which are specific for this class and are based on analyses of a reference set of sites that are deemed to be most representative of the 'best' ecological state currently possible for this class. Various objective and subjective criteria can be

Table 2
Likely effects of urbanization on wetland hydrology and geomorphology

Hydrology
Decreased surface storage of stormwater results in increased surface runoff (= increased surface water input to wetland)
Increased stormwater discharge relative to baseflow discharge results in increased erosive force within stream channels, which results in increased sediment inputs to recipient coastal systems
Changes occur in water quality (increased turbidity, increased nutrients, metals, organic pollutants, decreased O_2, etc)
Culverts, outfalls, etc. replace low-order streams; this results in more variable baseflow and low-flow conditions
Decreased groundwater recharge results in decreased groundwater flow, which reduces baseflow and may eliminate dry-season streamflow
Increased flood frequency and magnitude result in more scour of wetland surface, physical disturbance of vegetation
Increase in range of flow rates (low flows are diminished; high flows are augmented) may deprive wetlands of water during dry weather
Greater regulation of flows decreases magnitude of spring flush
Geomorphology
Decreased sinuousity of wetland/upland edge reduces amount of ecotone habitat
Decreased sinuosity of stream and river channels results in increased velocity of stream water discharge to receiving wetlands
Alterations in shape of slopes (e.g. convexity) affects water-gathering or water-disseminating properties
Increased cross-sectional area of stream channels (due to erosional effects of increased flood peak flow) increases erosion along banks

used to identify the reference sites; these include historical accounts of the ecosystem of interest by early naturalists, existing ecological data, criteria derived from ecological theories such as island biogeography, and the judgment of ecologists with extensive experience in the region. Thus, the definition of a reference domain circumscribes the choice of sites that can be used to set boundary conditions for indicating ecosystem status, and also the choice of variables used to index function.

The urban environment is physically and biologically different from the non-urban environment (Gilbert, 1989; Adams and Dove, 1989; Platt, 1994) Tables 2 and 3 summarize some of the salient differences. The hydrology of regions is changed by urbanization, as Leopold (1968) first documented. All these hydrological changes have indirect effect on wetland structure and function (Table 2). In addition, direct hydrological changes in wetlands commonly occur by filling, ditching, diking, draining, and damming. For example, 90% of a sample of suburban cedar swamps in New Jersey had been so modified (Ehrenfeld and Schneider, 1991). Physical changes to the shape of the land, wrought by massive land movement associated with road and building construction, also cause geomorphological changes both in the wetlands and adjacent areas (Table 2).

Climate and air quality are also altered by urbanization. In addition to increased concentrations of oxidants (O_3, SO_2) and nutrients (nitrates, cations in dust), net radiation and average wind speed decrease, cloudiness and precipitation increase, and temperature rises by 1–3°C (‘heat

Table 3
Likely effects of urbanization on wetland ecology.

Vegetation
Large numbers of exotic species present; large and numerous sources for continuous re-invasion of exotics
Large amounts of land with recently disturbed soils suitable for weedy, invasive species
Depauperate species pool
Restricted pool of pollinators and fruit dispersers
Chemical changes and physical impediments to growth associated with the presence of trash
Small remnant patches of habitat not connected to other natural vegetation
Human-enhanced dispersal of some species
Trampling along wetland edges and periodically unflooded areas
Fauna
Species with small home ranges, high reproductive rates, high dispersal rates favored
Large predators virtually non-existent
‘Edge’ species favored over forest-interior species
Absence of upland habitat adjacent to wetlands
Absence of wetland/upland ecotones
Human presence disruptive of normal behaviors

island' effect), (Berry, 1990). These changes imply that urban sites cannot be directly compared with non-urban sites, any more than sites in different climatic zones.

Biological and ecological changes accompany the physical effects of urbanization (Table 3). The pool of species available to form communities, dispersal ability, and mutualistic interactions (e.g. pollination, mycorrhizae) may all be limited or altered. Rare or unusual types of microhabitats, especially forest or wetland interiors, may be very limited or non-existent in extent. Both animal behavior and plant reproductive ecology may be strongly affected by the size, shape and heterogeneity of habitat patches. Thus, the possible states for the flora and fauna in urban areas are qualitatively different from those of non-urban areas.

Physical and biological changes in urban areas can be both large in scope and permanent, which in turn may constrain the kinds of communities that can be restored and the level of success attainable. A good example is the Hackensack Meadowlands in northern New Jersey. It occupies an area of about 7000 ha in close proximity to New York City, and is currently brackish to saline marsh. It is traversed by numerous large highways and railroads, has many closed and active landfills, contains a large sports stadium complex, hotel/condominium developments and mega-stores, and is surrounded by industry. As recently as 1896, the Meadowlands supported freshwater forested wetlands, including Atlantic white-cedar (*Chamaecyparis thyoides*) swamps (Heusser, 1963; Sipple, 1972). Mixed with these trees was a rich flora of bog species. In 1819, the noted botanist John Torrey said, "Few places have afforded us more plants, than in the vicinity of Hoboken and Weehawk, and the neighboring marshes" (Torrey, 1819). Freshwater marshes, supporting large stands of wild rice (*Zizania aquatica*), were also present. Extensive ditching and diking occurred early in the 20th century, which, combined with the rising sea level and the impoundment of freshwater in several large reservoirs upstream, converted the area to brackish and saline marsh. The freshwater marshes were taken over by *Phragmites australis* and other salt and brackish marsh species by 1919; today pure *Phragmites* stands fill the basin. Although, there have been discussions and some attempts to restore freshwater cedar swamps in the region (Schmid, 1987), most of the current restoration work aims to establish *Phragmites*-free salt marsh; freshwater wetlands are no longer physically realistic. In an analogous way, cottonwoods (*Populus* spp.) cannot be restored on floodplains of western cities because permanent hydrological changes associated with urbanization prevent movement of river channels, and therefore, the creation of suitable habitat for tree seedlings (Auble et al. 1997).

These considerations lead to the conclusion that urban wetlands need to be defined as reference domains separate from non-urban wetlands. Furthermore, local reference sites need to be established within each urban region as the basis for establishing criteria and standards for judging restoration success. For example, the structure and function of coastal marshes within large port cities may be very different from those of marshes occurring on coasts intensively developed for summer recreation.

4. Criteria for defining reference domains and selecting reference sites

Reference sites for evaluating restoration success can be chosen based on criteria that reflect the factors discussed above (Table 4). I illustrate the process by describing how a reference domain and reference set of sites has been developed for northeastern New Jersey, an extensive urban/suburban region.

Clearly, the first step in defining a reference domain should be the delineation of urban land-use (Table 4). In northern New Jersey, the urban/suburban core is easily definable by the density of major highways, municipalities with population sizes $>10\,000$, and a known long history of dense settlement. Surrounding this core is a band of rapidly developing suburbia which fringes Interstate 287 (Fig. 1). This road also delimits major physiographic regions. The northeast/southwest leg of the road (Fig. 1) follows the boundary

Table 4
Proposed procedure and criteria for identifying reference sites within an urban context

1	Definition of reference domain, based on a combination of municipal or demographic criteria and hydrogeomorphic criteria
2	Survey of wetland resources (given available databases) to identify appropriate wetland classes (e.g. vegetation types) and to locate all the possible sites of each class within the domain
3	Characterization of each site with respect to size (area), proximity to urban land use, likelihood of hydrological modifications (either on-site or off-site), evidence of physical disturbance (e.g. bike trails, large amounts of trash)
4	Stratification of the study region to ensure representative sampling
5	Selection of the largest unfragmented wetland in each subsection of the region that is surrounded by urban land-use but that has the least evidence of direct disturbance or hydrological alterations.

between the Piedmont physiographic province (east) and the Highlands Province (west), while the east/west leg of the road separates the more urban northern portion of the state from the less densely settled areas south of the Raritan River. It was assumed that the hydrogeomorphic settings of wetlands would be similar within each physiographic province, so the interstate highway was used as a convenient delimiter of the reference domain.

The delineation of an urban reference domain necessarily involves arbitrary decisions about boundaries between urban and suburban, and between suburban and rural areas. Urban and suburban land-use form a continuum, because much urban land area is occupied by dense-to-moderate residential housing. In New Jersey, this continuum extends from high densities of housing within the oldest developed areas, along the Hudson River and the Arthur Kill, to low densities in the wealthy suburbs in the central and western parts of the study area (Fig. 1). Formerly agricultural land, within the matrix of roads and towns, has filled with housing, commercial, and office-park development during the past three decades. Thus, there are no clear physical boundaries between suburban lands and rural lands, or between the urban cores of the larger cities and suburbia. However, the region west of Interstate 287 has only been subjected to intense development pressure in the past few years, so the highway forms a convenient if somewhat arbitrary boundary between older suburbs and rural/newly suburban land.

The second step in the process (Table 4) should be a survey of the wetland resources within the defined domain, for which existing maps and information can be used. From the New Jersey Department of Environmental Protection Freshwater Wetland Maps, a database was created by identifying 20 largest areas of deciduous forested wetlands (wetland class 'PFO1') within each of the 80 maps which covered the region. Sites $<$ 300 m across were excluded, except in the area around the city of Newark, which contained <20 sites per map, all very small.

Preliminary inventory of the range of characteristics of the mapped sites can provide a basis for selecting the reference set. Each wetland that was identified on the maps was characterized in terms of the number and types of Cowardin wetland classes occurring within the contiguous wetland area, its location relative to roads, railroad beds, town centers, or other landmarks and urban features, the occurrence of open water within or adjacent to the site, and the presence of public open space (municipal, county or state-owned lands) within or adjacent to the wetland area. The NJDEP GIS system was then used to determine the area and perimeter of each wetland polygon, and the total area of each wetland patch. Two-hundred-sixty-two forested wetland areas were thus identified and characterized.

These data were then used to determine the frequency distribution of wetland sizes (Fig. 2), the distribution of wetland classes (Fig. 3), and the number of wetland classes within each site (Fig. 4). In addition, about 120 of the sites were briefly inspected in the field. These analyses suggested that although many classes of wetland were present in the region, most sites were dominated by saturated wetlands (PFO1B), and many con-

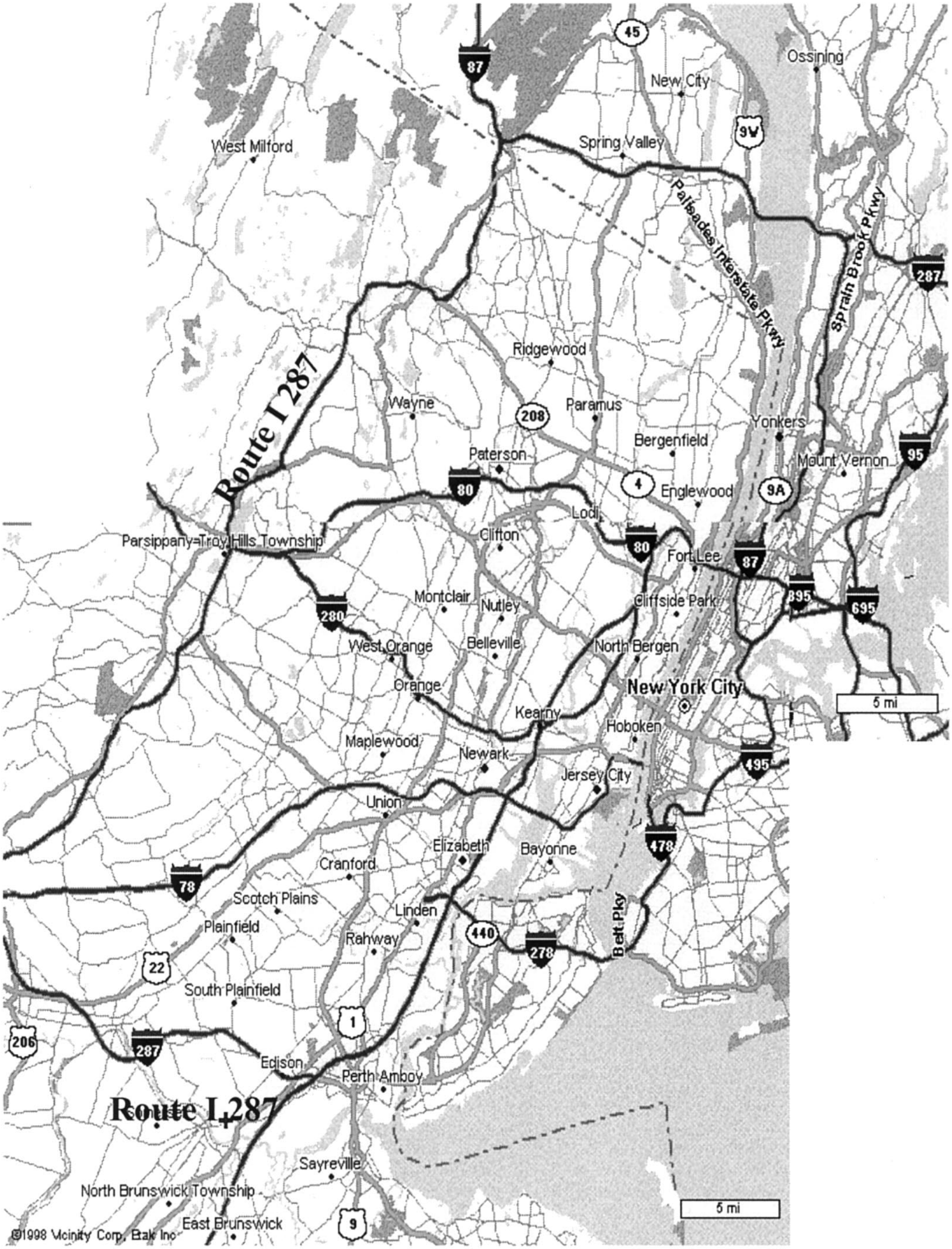

Fig. 1. Map of northeastern New Jersey, showing the density of municipalities, roads, and city centers. The urban wetland study area is delimited by Interstate 287.

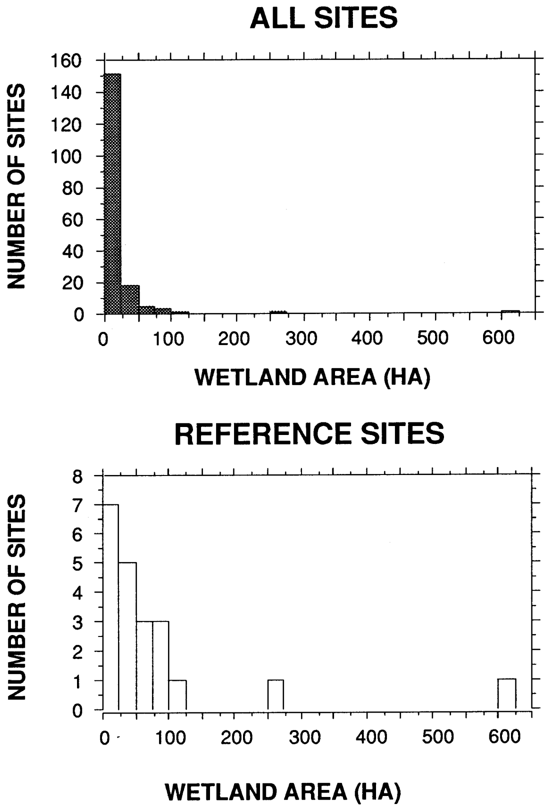

Fig. 2. Frequency distributions of areas (ha) in (a) the 262 wetlands identified in the survey of forested wetlands in the study area and (b) the 20 reference sites.

tained either seasonally flooded (PFO1C), seasonally saturated (PFO1E), or temporarily flooded (PFO1A) forested wetlands (Fig. 3). These classes could be used as a primary filter to select reference sites by assuming that sites with similar general hydrology (as mapped) would have broadly similar hydrogeomorphic settings. This assumption will be tested with well and piezometer measurements in the course of characterizing the reference set.

This preliminary work suggested that the cultural and physical settings of the wetlands were extremely heterogeneous, and could not be readily classified using a priori criteria. Therefore, in the absence of detailed information about the biota, hydrology or function of these wetlands, wetland size was chosen as the most useful criterion for identifying the set of reference sites. This decision was based in part on the assumptions that the larger the site, (1) the larger the area of 'interior' habitat; (2) the more protected the interior areas would be from direct human impact (e.g. road runoff and storm sewer outfalls, roadkill of animals, dumping of trash, etc.); (3) the more likely that it has not been substantially altered in the past, since it is still a wetland habitat; (4) the greater the amount of microhabitat heterogeneity, and therefore, the larger the species pool that may be present and (5) the greater the likelihood that animal species with large home ranges could be present. This reasoning is similar to that used for other area-based criteria for restoration planning (Zedler 1996).

The heterogeneity within an urban region in the history and intensity of development necessitate some method of stratification to ensure representative sampling of the range of conditions within the defined domain. The USGS quadrangles offer a convenient device for blocking large areas. For northeast New Jersey, 20 quandrangles cover the region, and one reference site is established within each quadrangle. This ensures that all portions of the area are represented by a site that is the largest wetland in that block. The inclusion in the reference set of small sites within the heavily urbanized areas as well as large sites from more

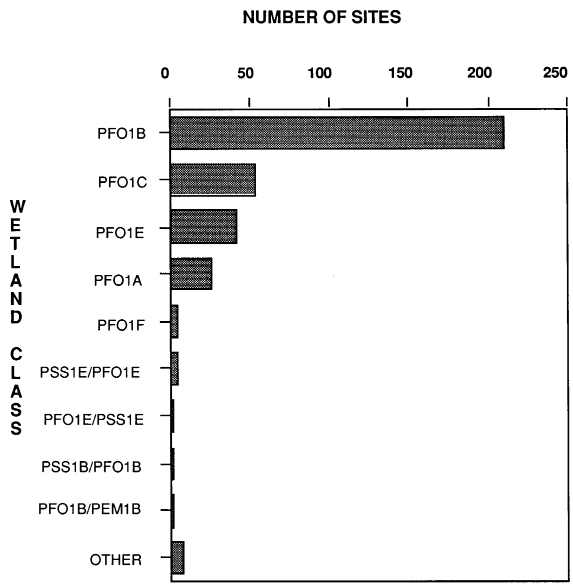

Fig. 3. Number of sites containing each class of forested wetland. Classification follows Cowardin (1979); see text for details.

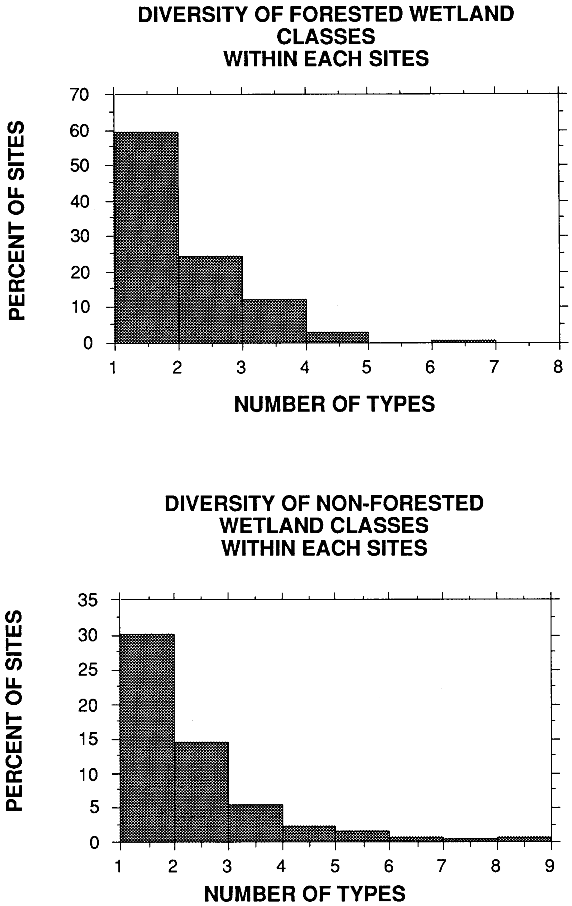

Fig. 4. Frequency distributions of the number of wetland classes found in each site, for (a) forested wetland classes and (b) non-forested wetland classes.

suburban areas provides the range of values that could be considered characteristic of urban wetlands in the study region. As Kentula et al. (1992) and many others emphasize, temporal and spatial variability can be high even among sites initially thought to be uniform, so it is crucially important to capture the potential range of variation within the reference set of sites.

5. Assessment protocols in an urban context

Assessment protocols are intended to identify potential or replacement functional capacity. Such protocols for urban wetlands, should include two levels of assessment: first, an assessment of the extent of urban influence which sets bounds on the potential for the performance of the conventionally defined functions and identifies social valuation, and second, within that context, a modified assessment for functional capacity. Table 5 presents possible components of an assessment protocol for urban influence. It relies primarily on the available geographic data to describe the urban environment and utilizes readily observable indicators within the wetland site itself (e.g. presence of trash, ditches, etc.). The variables listed in Table 5 include continuous, quantitative data (e.g. wetland area, distance to nearest other habitat), categorical data (e.g. presence/absence of contiguous wetland or upland habitat; presence/absence of ditches, dams, drains), and qualitative data (residents' stated values; current use). However, an overall index of urban influence could be constructed from the data from the reference set of sites. The potential urban influence for a new site can then be indexed relative to the range of impact observed for the reference wetlands within the same urban region.

The assessment of ecological functions can follow the models developed for non-urban wetlands (e.g. Brinson et al., 1995). The same range of functions is possible within urban wetlands, with the same constraints set by overall hydrogeomorphic setting (Brinson, 1993; Smith et al., 1995). However, the range of values of indicator variables may differ in several ways from their counterparts in non-urban settings (Table 6). First, the range of variability, both within and between wetlands, is likely to be much higher in urban areas than non-urban areas. This pattern was observed in a range of biotic and environmental descriptors of suburban and undisturbed wetlands in the New Jersey Pinelands (Ehrenfeld and Schneider 1993; Zampella 1994).

Second, indicator values may receive weightings in an urban context that are different from those in a non-urban area. For example, isolated wetlands often support fewer species than sites within a regional complex of wetlands (Weller, 1990). But in an urban area, an isolated patch may provide essential habitat in a large region with no natural habitat. Small wetlands have been shown

Table 5
Proposed components and indicator variables for assessing the degree of urban impact on wetlands, prior to functional assessment

Category	Indicator variables to be assessed	Significance
Size	Area, perimeter, fractal dimension ranking of site with respect to reference set	Ecological expectations, given parcel with given dimensions
Connectedness/fragmentation	Presence of contiguous other habitat (wetland and/or upland) distance to nearest other habitat (both wetland and upland)	Likelihood of animal and plant dispersal, presence of a species pool, habitat heterogeneity; regional significance as available habitat island
Hydrogeomorphic alterations	On-site: ditches, dams, diversions, drains, fill off-site: percentage of impervious surface; groundwater withdrawals; upstream impoundments and flow control structures; changes in basin drainage density, channel shape, storm hydrographs	Likelihood that the hydrology of the site has been altered; what permanence of hydrological changes
Urban setting	Percentage of land in residential, commercial, industrial use road density population density rate of population growth presence of trash, trails within the wetland, percentage impervious surface	Residential: likelihood of trampling, trash; commercial: likelihood of trash; industrial: likelihood of pollutants; road density: likelihood of road runoff; population density and growth rate: index of urban intensity and likelihood of changing impact in the future
Human values	Current and potential future human uses of site values ascribed to site by neighboring residents values ascribed to site by professional resource managers, scientists	Range of current and future human uses (positive and negative); potential for conflicts between local residents and professionals

to have high habitat value for some wetland fauna (Gibbs 1993; Semlitsch and Bodie, 1998). Conversely, species richness of both plant and animal groups may be higher than in comparable non-urban wetlands, due to the incursion of exotic and weedy species, the presence of microsites that allow more upland and facultative-upland species to become established, and the removal of nutrient limitations due to pollutants in both air and water (Ehrenfeld and Schneider 1993). Weighting of species richness variables must be done in conjunction with an analysis of the species list in order to determine to what extent the value of the variable indicates ecological health versus degradation.

Third, urban wetlands often have unusual physical features which are the result of human intervention. Disturbed soil profiles, mounds of soil from old ditch-digging or channel-widening activities, heterogeneous materials, etc., are not uncommon. Sandy surficial deposits from storm water runoff may overlie organic sediments. Provision needs to be made in sampling protocols to document the presence and extent of these features.

Fourth, indicator variables for direct human influence are essential. Measures of the presence of trash provide useful indicators of human proximity and pathways of human influence. For example, stream corridors, even small first-order creeks, often serve as conduits of both trash and sediments, which are deposited in a narrow belt along the channel. The presence of a stream corridor, can thus, indicate the potential for extended human influence into the interior of a site. In addition, trails may become established on slightly higher ground, giving access to the wetland. Finally, indicators of positive human uses are also needed; the existence of local 'Save our Swamp' organizations are an example.

Table 6
Characteristics of indicator variables and of variable values in urban settings

High variability both within and between sites
Indicator values differently weighted in urban and non-urban settings
Frequent occurrence of outlier values (both qualitative and quantitative)
Presence of unusual, anthropogenic landforms that have no counterparts in non-urban settings
Presence of soil profiles that are unlike those in non-urban wetland
Increased presence of upland species, disturbance-associated species
Increased dominance of nitrophilous, fertile-site species, and absence or paucity of poor-site species
Total species richness possibly higher than expected
Riverine-influenced areas sometimes different from adjacent areas
Indicators of function include indices of human usage (presence of trash; observations of people, etc.)

Functional assessment using a set of reference wetlands is currently accomplished by setting the value of the mathematical expression describing each function equal to 1.0 for the reference site(s), and evaluating the expression for a sample site relative to that value (Brinson et al., 1995; Rheinhardt et al., 1997). In urban regions, it may be necessary to modify this approach by subdividing the reference set into classes, based on the characteristics of a particular urban region, and developing separate mathematical expressions for each function within each class. Such flexibility would allow differential weighting of variables within each expression, to take into account the variations within the urban region in question. For example, the New Jersey metropolitan region currently being studied contains areas with large wetland complexes resulting from two extensive glacial lake basins, and other areas outside the lake basins with only small wetland areas. The region also contains areas that have been densely settled since the 1600s, and areas that have become densely settled only in the last 20–30 years. These geological and demographic subsets are overlapping but not completely congruent. The set of reference sites being developed for the entire region, described above, will capture this range of variation for the region, but may need to be subdivided to establish assessment criteria for the different subregions.

In summary, urban areas may retain large numbers of wetlands, both as remnants of the natural environment, and as the inadvertent result of human activities (for example, fringing wetlands on dredge spoil deposits). These wetlands continue to provide important ecological services and may be of particular importance to both people and wildlife because of their remaining presence within concrete landscapes. Measures of restoration success and functional performance must start with an appreciation and assessment of the particular conditions imposed by the urban environment. These conditions can be identified, measured, and incorporated into assessment protocols for individual wetland functions.

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