Wetland Loss and Biodiversity Conservation

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Abstract: *Most species of wetland-dependent organisms live in multiple local populations sustained through occasional migration. Retention of minimum wetland densities in human-dominated landscapes is fundamental to conserving these organisms. An analysis of wetland mosaics was performed for two regions of the northeastern United States to assess the degree to which historical wetland loss alters the metrics of wetland mosaics and to assess potential future effects mediated by differently structured wetland regulations. These analyses indicated that profound reductions in wetland density and proximity are associated with increased human populations and that protections for all wetlands >1 acre (0.4 ha) are likely required to retain wetland densities minimally sufficient to sustain the wetland biota.*

Pérdida de Humedales y Conservación de la Biodiversidad

Resumen: *La mayoría de los organismos de especies que dependen de humedales viven en múltiples poblaciones locales sostenidas mediante migraciones ocasionales. Para conservar estos organismos es fundamental la retención de densidades mínimas de humedales en paisajes dominados por humanos. Para evaluar el grado al cual la pérdida histórica de humedales altera las dinámicas de los mosaicos de humedales se llevó a cabo un análisis de mosaicos de humedales en dos regiones del noreste de los Estados Unidos, así mismo, se evaluaron los futuros efectos potenciales mediados por regulaciones de humedales estructuradas de diferente manera. Estos análisis indicaron que las reducciones fuertes en la densidad de humadales y en la proximidad estan asociadas con incrementos en la población humana y que posiblemente se requiere de protecciones para todos los humedales >1 acre (0.4 ha) para retener la densidad mínima suficiente de humedales para sostener la biota que los habita.*

Introduction

Wetland Mosaics and Metapopulations of Wetland Organisms

The high biological productivity of wetlands and strong selection pressures of an aquatic existence have produced a rich biota associated only with wetlands (Gibbs 1995). Wetlands typically occur in discrete patches in a matrix of upland habitat, such that most local populations of wetland species are small and isolated and thus vulnerable to extinction (Møller & Rørdam 1985; Dodd 1990; Sjögren 1991). Many species of wetland-dependent organisms consequently live in multiple local populations sustained through occasional migration—that is, in metapopulations (Hanski & Gilpin 1991; Semlitsch 1998).

Our present understanding is minimal, however, of how those traits of wetland mosaics most important to sustaining metapopulations of wetland organisms—that is, wetland density and wetland isolation—are altered by mounting wetland destruction and by the regulations intended to restrict it (Semlitsch & Bodie 1998). These metrics of wetland mosaics are not independent in that higher numbers of wetlands in a landscape generally equate to reduced isolation among wetlands. Variability in the shape, size, and spatial dispersion of individual wetlands, however, makes the relationship a complex one. Digital maps of wetlands, developed for much of the United States under the authority of the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI), have recently become available (Wilen & Bates 1995) and provide an unprecedented opportunity for examining human effects on the metrics of wetland mosaics.

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Historic and Future Wetland Losses

Because the local population is the primary unit of population and community dynamics that maintains genetic and species diversity in wetlands (Semlitsch & Bodie 1998), forces that alter the abundance and distribution of wetlands will affect the diversity and persistence of the wetland biota. The most powerful forces currently shaping the metrics of wetland mosaics are the dredging, draining, and filling associated with human activities; these forces have seriously depleted wetland resources in the United States. Total wetland area in the conterminous 48 states, totaling 89 million acres in the 1780s, decreased by 53% to 42 million ha by the 1980s (Johnson 1994). These losses affected the wetland biota: a disproportionate fraction of species listed as endangered or threatened in many states and the nation are wetland obligates (Boylan & MacLean 1997; Wilcove et al. 1993). Given increasing human pressures on wetlands (Johnson 1994), metapopulations of wetland organisms will persist only through creation and enforcement of biologically relevant wetland-protection laws that conserve functional wetland mosaics.

To address the question of how human activities alter the metrics of wetland mosaics, I conducted an analysis of NWI data (Wilen & Bates 1995) that focused on wetland mosaics along an urban-rural gradient (cf. McDonnell & Pickett 1990) in the New York City region, an area that includes distinct and measurable gradients of population density and land use frequently used in studies of anthropogenic landscape change (e.g., Medley et al. 1995). This analysis provided a historic perspective on how human activities have altered the metrics of wetland mosaics.

I performed a related analysis to examine how differently structured wetlands regulations might affect future wetland losses. A highly contentious debate currently centers upon the topic, particularly regarding establishment of minimum size thresholds for wetland protection as part of nationwide permitting of activities in wetlands under provisions of the U.S. Clean Water Act administered by the U.S. Army Corps of Engineers (Kaiser 1998). The debate has been obscured by lack of empirical evaluation of the issue, a situation that could be addressed through an analysis similar to that described for the New York City region but one focused instead on landscapes where human effects on wetland mosaics have been minimal. In such landscapes, the metrics of future wetland mosaics can be predicted given different scenarios of regulated wetland loss. To this end, I performed a similar analysis for wetlands in largely unpopulated landscapes of central and western Maine (cf., Gibbs 1993) to examine how future wetland losses mediated by differently structured wetlands regulations might alter wetland mosaics. The current density and isolation of wetlands was estimated and contrasted with simulated mosaics for which wetlands of sequentially larger size classes (≤ 1, ≤ 2, ≤ 3, . . . ≤ 10 acres) were removed.

Methods

To examine historic effects of human activities on the metrics of wetland mosaics, I used two transects along the urban-rural gradient surrounding New York City to capture both the physiographic variability of wetlands and the varying intensity of human land use in the region. Both transects originated in New York City's Central Park. One transect extended along a northwest-southeast axis west of the Hudson River. The other extended along an east-west gradient along Long Island. Characteristics of wetland mosaics along the gradient were estimated from the NWI digital database. The data were converted into raster format at a map resolution of 0.1 ha to match the approximate minimum mapping unit of the NWI, and they were manipulated by metaprogramming of modules of the microcomputer-based geographic information system Idrisi.

Each NWI map corresponded to a U.S. Geological Survey 7.5′ topographical quadrangle (scale = 1:24,000) and was created in the mid- to late 1980s. Quadrangles were used as the sampling unit because the number of wetlands in each quadrangle (mean = 250.8 ± 242.6 SD) was sufficiently large to allow adequate characterization of the wetland mosaics within them. The analyses focused on palustrine wetlands, by far the dominant class of wetlands in the region. All mention of "wetlands" therefore refers to the mosaic of palustrine wetlands. Thirty NWI quadrangles were analyzed (15 arrayed along each of the two transects): Arthur Kill, Bellport, Brooklyn, Central Islip, Central Park, Flushing, Freeport, Goshen, Greenlawn, Hicksville, Huntington, Jamaica, Lynbrook, Maybrook, Middle Island, Mohegan Lake, Moriches, Mount Kisko, Mount Vernon, Park Ridge, Patchogue, Pine Island, Port Jefferson, Riverhead, Sloatsburg, Thiells, Wading River, West Point, White Plains, and Yonkers. Human population densities within each NWI 7.5′ quadrangle were compiled for all zip code units located within each quadrangle (U.S. Bureau of Census data for 1990).

The landscapes in Maine selected for analysis included those for which NWI data were available and those that included minimal human populations (<1 inhabitant/km^2 and no urban development). The NWI wetlands quadrangles (n = 25) included were Bar Mills, Black Nubble, Bridgton, Brownfield, Enchanted Pond, Fryeburg, Greenfield, Hiram, Jefferson, Johnson Mountain, Limington, North Whitefield, Pleasant Mountain, Popular Mountain, Quill Hill, Searsmont, Standish, Steep Falls, Sugarloaf Mountain, Tim Mountain, Union, Washington, Waterboro, Witham Mountain, and West Rockport.

Results and Discussion

The analysis revealed a clear relationship between human density and wetland density, proximity, and aggregate area (Fig. 1). As human settlement patterns shifted from rural to urban, wetland mosaics in the region shifted from consisting of many clustered wetlands (2–5 wetlands/km^2 some 200–400 m apart) to many fewer and more isolated wetlands (<1 wetland/km^2, generally >500 m from other wetlands). Aggregate wetland area also declined with increasing human density (Fig. 1), with the proportion of the landscape in wetland shifting from 5–8% in rural areas to <1% in many suburban and urban areas.

The implications of these trends are most apparent in the context of the dispersal abilities of wetland animals. Adaptation to an aquatic existence has imposed severe constraints on the ability of many wetland animals to disperse across the uplands separating wetlands (Gibbs 1995; Semlitsch 1998). Dispersal of aquatic plants is also highly dependent on transport by wetland animals (Sculthorpe 1967; Lowcock & Murphy 1990). Average dispersal distances for many wetland animals (Gibbons 1986; Gibbs 1993; Semlitsch 1998; Semlitsch & Bodie 1998) are generally <0.3 km for frogs, salamanders, and small mammals and <0.5 km for reptiles. Given these constraints on dispersal, all but the least populated areas of the New York City region now support wetlands too sparse (that is, <1 wetland/km^2 and >0.5 km from other wetlands; Fig. 1) to sustain metapopulations of many wetland organisms. This is particularly an issue for the smaller-bodied and poorly dispersing yet more abundant and arguably most functionally important groups, such as amphibians and small mammals. Reduced density and proximity of wetlands also has important energetic implications for larger-bodied animals, such as waterfowl, that must move daily among multiple wetlands to forage.

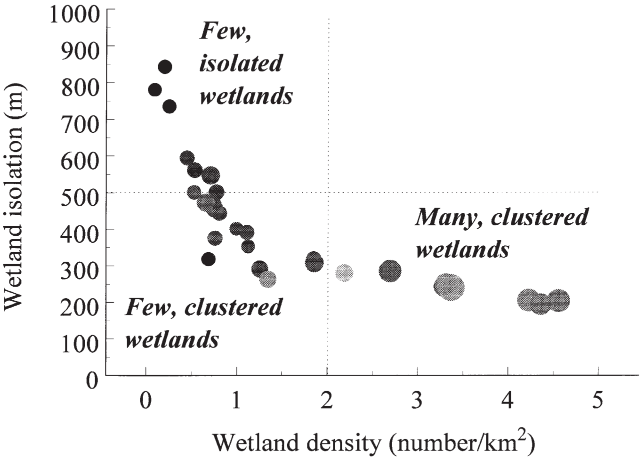

Figure 1. Wetland density and isolation in 30 landscapes distributed along an urban-to-rural gradient in the New York City region. Data points represent estimates for wetland mosaics in each landscape sampled. Human population density is indicated by the intensity of symbol shading (from light gray, 20 humans/km, to black, 20,000 humans/km). Aggregate wetland area (percentage of landscape in wetland) is indicated by symbol size (smallest, 0.1%; largest, 10%). Human density ($\log_{10}$-transformed) is highly correlated with wetland metrics in these landscapes (wetland density: $r = -0.682$, $p < 0.001$; *wetland isolation:* $r = 0.779$, $p < 0.001$; *aggregate wetland area:* $r = -0.685$, $p < 0.001$*). Dotted lines delineate domains of suitability of the wetland mosaic for persistence of populations of wetland organisms: the threshold of 0.5 km dispersal distance characteristic of many wetland taxa and the threshold for the occurrence of multiple (>2) wetlands within the spatial scale (1 km^2) at which population processes in most wetland organisms operate.*

My analysis of size-structured wetland loss in undisturbed landscapes in Maine produced several insights (Fig. 2). First, wetlands in the undisturbed landscapes were separated by distances averaging about 300 m that were within the dispersal abilities of most wetland animals (Gibbs 1995; Semlitsch 1998). Wetlands in the undisturbed landscape also occurred at a fairly high density (2.17/km^2), representing the occurrence of multiple local populations within the spatial scale (1 km^2) at which population processes in most wetland organisms operate (e.g., Gill 1978; Gibbons 1986; Berven & Grudzien 1990).

Second, various size thresholds for wetland protection have substantially different implications for the resulting structure of the wetland mosaic. For example, activities within wetlands <10 acres currently do not require oversight under nationwide wetlands permitting. Loss of all such wetlands would severely compromise wetland mosaics by eventually generating wetland mosaics with only one wetland per 4 km^2 of upland that are on average 1 km from other wetlands.

Third, relative gains in wetland protection were not constant but rather increased markedly as protection thresholds included smaller size classes of wetlands. Specifically, relative gains were comparable as protection thresholds changed from 10 acres (4.0 ha) to 4 acres (1.6 ha), from 4 acres to 1 acre (0.4 ha), and from 1 acre to complete protection (Fig. 2). Accordingly, short of complete protection, under this analysis only a 1-acre protection threshold would preserve a wetland mosaic with minimally sufficient attributes (i.e., ≥1 wetland/km^2 and ≤500 m from other wetlands) to retain, over the long term, metapopulations of most wetland organisms.

Conclusions

In evaluating my results, the known limitations of the NWI database must be considered. Validation studies of

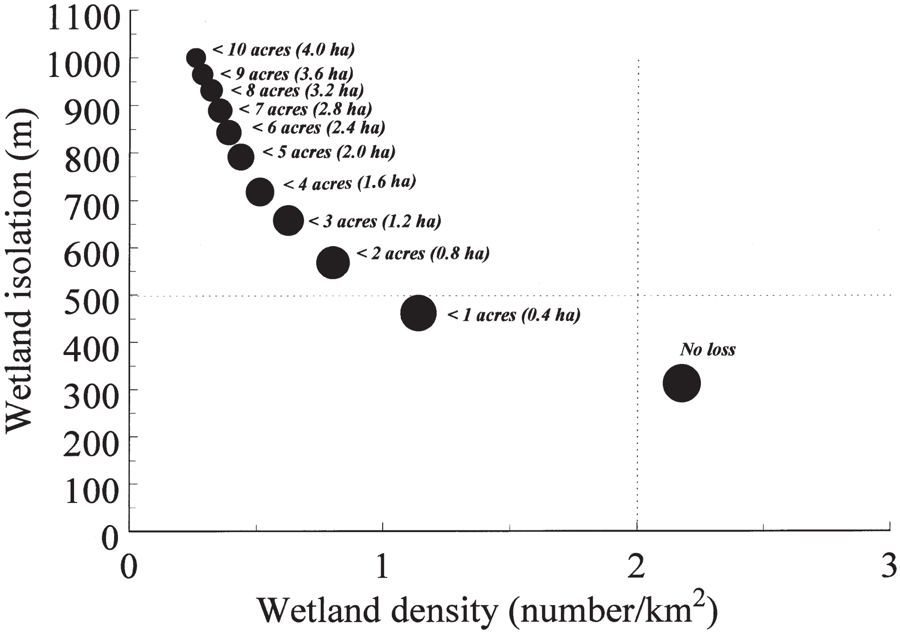

*Figure 2. Changes in wetland density and isolation in relation to simulated, size-structured loss of wetlands in undisturbed landscapes in Maine. Points represent the metrics of wetland mosaics averaged across all landscapes sampled (*n = 25*), with sequentially larger size classes of wetlands removed (≤1, ≤2, ≤3, . . . ≤10 acres). Aggregate wetland area (percentage of landscape in wetland) is indicated by symbol size (smallest, 6%; largest, 7.5%).*

NWI data reveal that substantial numbers of wetlands were overlooked by the interpreters of the aerial photographs used to delineate and map wetland mosaics (Stolt & Baker 1995). The problem is acute for small, forested wetlands, whereas larger and nonforested wetlands were detected reliably. Correction for this mapping bias, however, would likely accentuate rather diminish the differences observed between the scenario of complete wetland protection versus predicted losses of smaller wetlands (Fig. 2), whereas the remainder of the patterns detected would remain largely unchanged. Thus, the spatial analysis of wetland distributions I report indicates that wetland mosaics can absorb only modest losses and still retain wetland densities minimally sufficient to sustain the wetland biota. If conservation of wetland biodiversity is a goal of wetland protection programs, regulations used in nationwide wetlands permitting should be redesigned accordingly.

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