LANDSCAPE-LEVEL PROCESSES AND WETLAND CONSERVATION IN THE SOUTHERN APPALACHIAN MOUNTAINS

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Abstract. The function of wetland ecosystems is not independent of the landscapes in which they are embedded. They have strong physical and biotic linkages to the surrounding landscape. Therefore, incorporating a broad-scale perspective in our study of wetland ecology will promote our understanding of these habitats in the Southern Appalachians. Changes in the surrounding landscape will likely affect wetlands. Broad-scale changes that are likely to affect wetlands include: 1) climate change, 2) land use and land cover change, 3) water and air-borne pollution, 4) a shift in disturbance/recovery regimes, and 5) habitat loss and fragmentation. Changes in climate and land cover can affect the hydrology of the landscape and, therefore, the water balance of wetlands. Excessive nutrients and toxin transported by air and water to wetlands can disrupt natural patterns of nutrient cycling. Periodic disturbances, like flooding in riparian zones, is required to maintain some wetlands. A change in disturbance regimes, such as an increase in fire frequency, could alter species composition and nutrient cycles in certain wetlands. Many plant and animal species that found in small, isolated wetlands have populations that are dependent on complementary habitats found in the surrounding landscape. Loss or fragmentation of these complementary habitats could result in the collapse of wetland populations.

1. Introduction

Wetland habitats harbor some of the most unique and endangered plant and animal communities in the Southern Appalachian Mountains. To date, conservation efforts in this region aimed at protecting these rare and highly dispersed habitats have mainly focused on regulating wetland destruction through permits, acquiring wetlands outright, or contracting with landowners for wetland protection. While these measures prevent the immediate destruction of wetlands, they may not provide for the long term persistence of these unique communities.

The existence of wetland habitats in any landscape, including the Southern Appalachians, depends on the presence of a combination of conditions created and maintained by the broad scale conditions. These conditions include climate, which ultimately determines the availability of water, and landscape-level patterns of land covers, which affects hydrology and population dynamics of wetland species. Landscape characteristics such as topography and land cover determine water retention, discharge, and spatial patterns of flow (Gosselink and Turner, 1978). The combination of sufficient water and appropriate hydrology results in places where soils remain submerged or saturated on a regular and/or extended basis. These conditions favor the development of hydric soils suitable for the development of plant and animal communities adapted to wet conditions. Climate and land cover are broad scale characteristics that are affected by processes operating at regional and landscape levels. Thus, in order to understand and preserve wetland habitats, understanding the effects of broad scale characteristics on wetland ecology is necessary.

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This paper will briefly describe the relationship between climate and landscape-level pattern on wetland hydrology, nutrient cycling, and population persistence. This paper will discuss the effect of changing climate on hydrology and disturbance, and its implication for Southern Appalachian wetlands. It will also discuss the influence of landscape-level patterning of habitats on hydrology and wetland populations.

Relationships between wetland ecology and broad-scale processes are illustrated in Figure 1. This figure is not an exhaustive list of all process and influences affecting wetlands, but it is useful for organizing this discussion. The three boxes denoting hydrology/water balance, nutrient cycling, and populations represent characteristics of wetlands. For example, wetlands are characterized by wet soils, populations of species adapted to wet conditions, and patterns of nutrient cycling (such as the formation of peat) that differ from more mesic and xeric habitats. Hydrology, nutrient cycling, and species composition interact by means of processes such as soil chemistry, evapotranspiration, and primary productivity within the wetland ecosystem. Climate and the landscape-level pattern of surrounding habitats are broad scale characteristics that may affect wetland ecology. The potential mechanisms of these broad scale effects will be explained below.

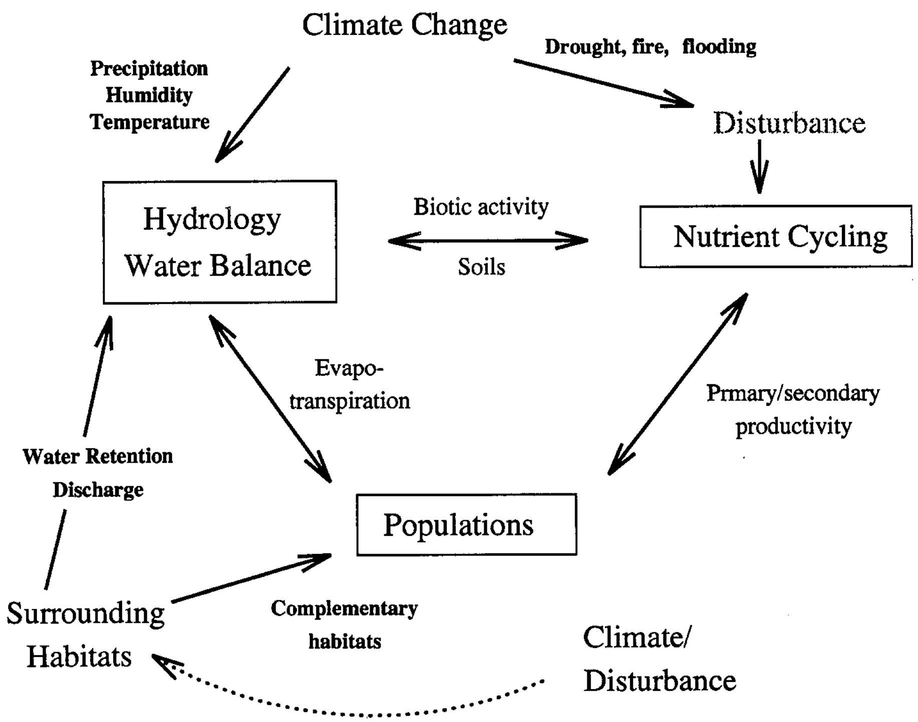

Figure 1. Conceptual relationships between wetland ecosystems and broad scale patterns of climate and the surrounding landscape. Boxes represent ecological processes operating within wetland habitats. Outside influences such as climate and landscape pattern of habitats may affect wetland hydrology, nutrient cycling, and population dynamics.

2. Climate and Hydrology

The hydrology of landscapes and wetland habitats is strongly related to climate. Precipitation provides the input of water for surface runoff and charging of ground water tables. Water loss occurs through surface and subsurface flows as well as through evapotranspiration. The resulting balance between water input and loss determines the location and seasonal wetness of potential wetland sites.

Evapotranspiration (ET) is a basic ecological phenomena related to primary productivity (Rosenzweig, 1968). For bogs (ombrotrophic wetlands), precipitation provides most or all of the water input. ET is the most important source of water loss. ET is also important for rheotrophic wetlands like fens and riparian zones because the stream flows and the amount of water available for subsurface flows can be reduced by high ET.

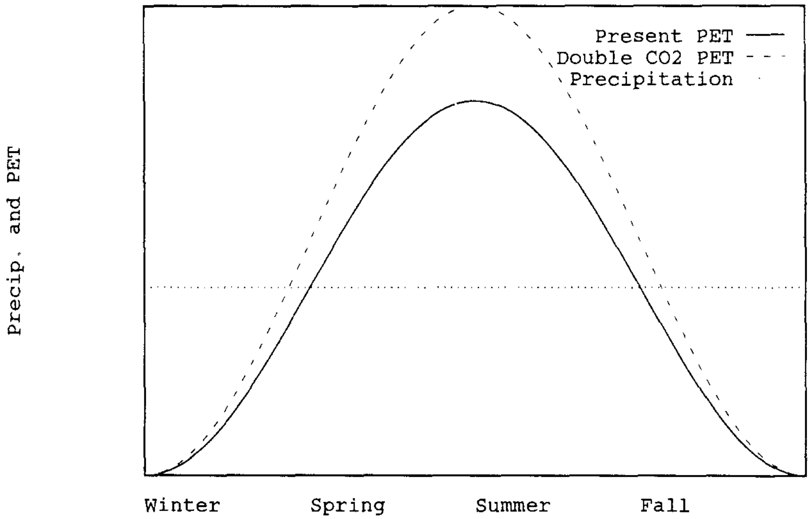

Figure 2. Annual patterns of precipitation and potential evapotranspiration (PET) in the Southern Appalachians. PET is less than precipitation but exceeds precipitation during the growing season. Warmer temperatures predicted to occur with increased atmospheric CO_2 would expand the growing season and increase PET.

Rates of ET depend on most strongly on the climatic variables of precipitation and temperature. Monthly precipitation totals are similar throughout the year in the Southern Appalachians. Though there is variation in the temporal pattern of rainfall from year to year, there are no regularly wet or dry seasons (NOAA, 1983; Swift *et al.*, 1988). The winters are characterized by high streamflows and wetter soils because precipitation (water input) exceeds water loss due to ET (Figure 2). ET is low during winter because of plant dormancy (reduced transpiration) and low temperatures (reduced evaporation).

During the growing season, soils begin to dry and streamflows drop as potential ET (PET) exceeds precipitation, resulting in a water deficit (Figure 2).

Global climate change models predict that, with double the current levels of CO2 in the atmosphere, the southeastern US could experience little change in precipitation but increased seasonal temperatures (Neilson *et al.*, 1989). The result would be greatly increased ET during the warm growing season months. The period to time where PET exceeds precipitation will increase, likely resulting in higher rates of water loss from ET (Figure 2). This could effect the water balance of both bogs and fens. Reduced periods of wetness could lead to local extinctions of species dependent on some minimal amount of submersion. Longer and more frequent droughts could promote the invasion of dryland species into wetland habitats.

3. Climate and Disturbance

Climate also effects the frequency and intensity of natural disturbances. Disturbance is an important factor for the maintenance of a diversity of plant communities in landscape (Pickett and White, 1985). These disturbances include flooding, drought, and fire.

Southern Appalachian forests are characterized by relatively small, highly scattered disturbances. Tree falls are the most common natural disturbance in this region, affecting approximately 1% of the deciduous-forested landscape annually (Trimble and Tryon, 1966; Runkle 1981, 1982). Recovery (canopy closure) from these small isolated disturbances is relatively quick. Periodic disturbances may also slow the transition of bogs into forest.

Both flooding and drought depend on seasonal pattern of water input to landscapes and water loss. Flooding is important for maintaining riparian wetlands like bottomland forest which depend on seasonal periods when soils are wet and anaerobic (Taylor *et al.*, 1990). A change in climate could change the seasonal patterns of streams flows. An increase in the severity of flood events could lead to the destruction of some alluvial habitats due to scouring by abnormally high stream flows. An increase in the frequency and length of droughts could result in the loss of long-lived species like trees that are intolerant to frequent drought stress. The most likely change due to climate for the Southern Appalachians would be a reduction in growing season stream flows due to higher ET driven by increased temperatures.

Fire depends indirectly on climate. Natural fire is a relatively rare source of disturbance for Southern Appalachian forests compared to forests in other regions of North America. In the past, fires have occurred most frequently on drier, south-facing slopes and lower elevation ridge tops (Barden and Woods, 1976; Harmon, 1982).

Southern Appalachian forests contain high biomass because of the great primary productivity of this region. However, the fire potential of these forests is seldom realized because of high rates of decomposition and prolonged periods when fuels are too wet to burn. At present, wetlands are seldom affected by natural fire. Wetter habitats such as forests on north-facing slopes and sheltered ravines burn infrequently (Harmon, 1982). Fires are common only during dry periods. If climate scenarios, such as those predicted by the climate change models, are realized, then periods of dryness will become much more common (Neilson *et al.*, 1990) raising the probability that wetter habitats will burn. As a result, the role of fire as source of disturbance will also increase.

In wetland systems, more frequent fires will effect nutrient cycling by affecting community composition of wetlands. That is, fire intolerant species may be reduce or extirpated. Also, fire has been attributed as the cause of reduced levels of N, S, and K in some wetland systems (Moore, 1990). The most important effect of fire on wetlands may be its ability to change the frequency and spatial configuration of habitats in the surrounding landscape.

4. Surrounding habitats and hydrology

Currently used strategies for protecting wetlands include regulating the outright destruction of wetlands within boundaries delineated around hydric habitats. Such a strategy could result in "protected" wetlands remaining as islands in a sea of highly impacted habitats (Figure 3). A highly altered landscape will surely differ significantly in its hydrology and its connectivity between wetlands and other habitats suitable for wetland populations.

While climate has an overriding and long term effect on the water balance of wetlands, the surrounding landscape also affects water balance. Vegetative cover affects water retention and discharge in landscapes (Swank *et al.*, 1988, see Richardson this volume). Studies such as those conducted at Coweeta Hydrological Lab demonstrate that changes in forest cover in Southern Appalachian watersheds affect patterns of stream flow (Swank and Crossley, 1988). Changes in stream flow consequently affect alluvial wetlands. Murdock (this volume) provides an example of how changes in plant cover surrounding a streamside wetland altered streamflow and channel morphology that resulted in a lowered water table.

Water retention and discharge is also important for rheotrophic mires like fens that receive water from the surrounding landscape. Land cover changes that divert more precipitation in runoff rather than to the ground water will impose a cycle of inundation and drought on a fen instead of a slower more constant release from ground water sources. Fens are also sensitive inputs of pollutants carried in water. The most common effect is that of eutrophication from leached fertilizers, particularly nitrates, from agricultural operations (Moore, 1990).

5. Surrounding habitats and wetland populations

Wetlands are often delineated by their characteristic plant and animal species. In the Southern Appalachians, wetlands tend to be small in areal extent and relatively rare in landscapes. These qualities imply that wetland populations are small and may not persist independent of populations in the surrounding landscape. While some of these species are confined solely to wetland habitats, others may be found in other less hydric habitats albeit at reduced densities. The "facultative" plant species listed in delineation guides belong to this group.

Small wetlands have small populations that are prone to stochastic extinction without an influx of individuals and genes from the outside. Indeed, small, isolated bogs have been found to have a larger component of plants with light, wind-dispersed seeds than larger, well-connected wetlands (Moore, 1990). This pattern implies that more vagile species are better able to recolonize small isolated wetlands after disturbance or stochastic

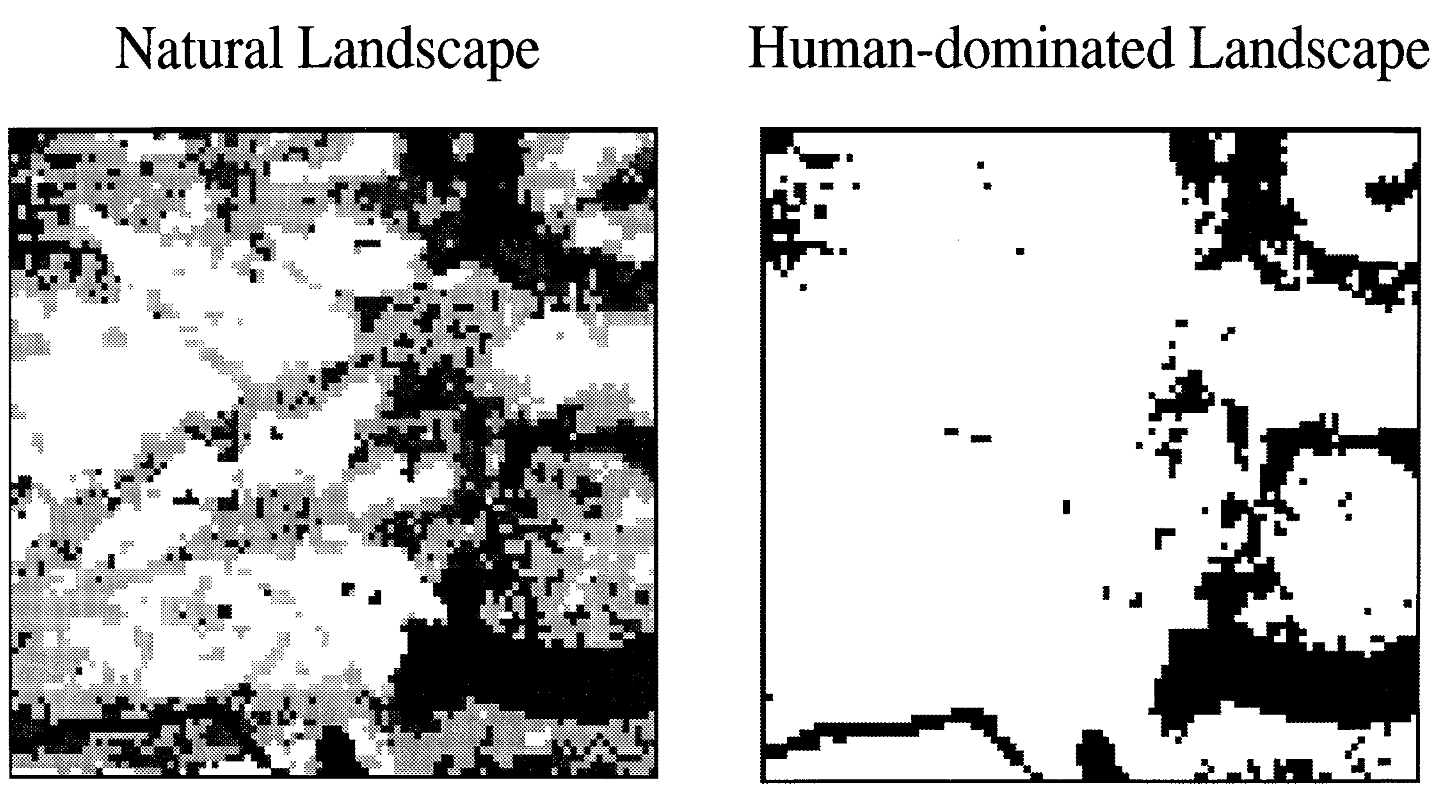

Figure 3. In natural landscapes, wetlands (black) may be surrounded by marginal habitats (shades of gray) that are suitable for dispersal and limited reproduction by wetland species and unsuitable habitats (white) that provide no resources for wetland species. If only wetlands are protected, a human-dominated landscape might develop where connectivity and additional resources provided by marginal habitats were lost through conversion to unsuitable habitat types.

extinctions (Figure 4). Therefore, populations in wetlands, particularly small ones, may not exist independent of populations inhabiting other wetlands and other habitats in the landscape.

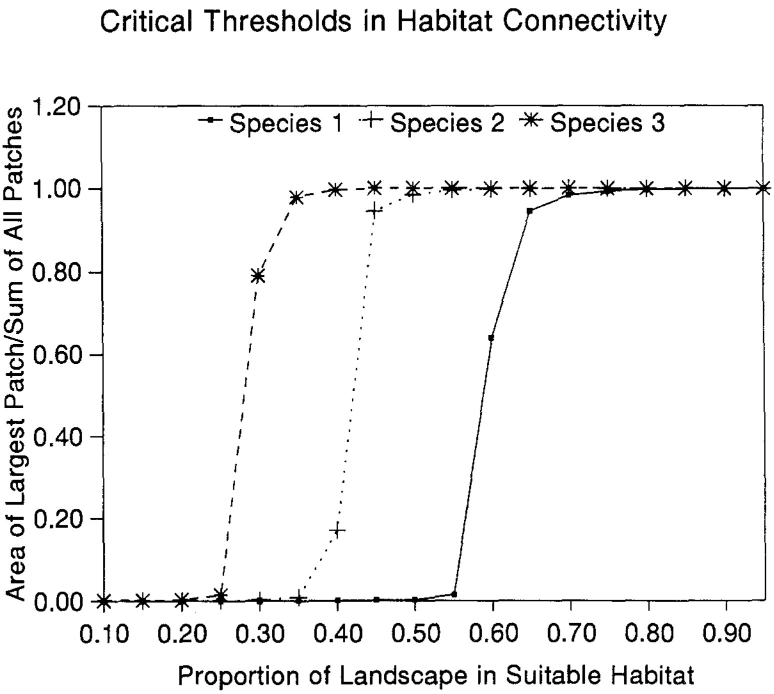

Figure 4. The ratio of the area of largest cluster (patch) of habitat to total area of habitat available (y-axis) provides an index of connectivity among the suitable habitat. Habitat is highly connected when this index is near 1 and highly fragmented when the index is near 0. This index is calculated for a simulated landscape where habitat is being lost in a random pattern. Species 1, 2, and 3 represent organism with low, medium, and high movement abilities, respectively. The index increases as the proportion of the landscape covered by suitable habitat increases. A rapid decline in index values associated with a small proportion of habitat loss indicates the presence of a critical threshold. These thresholds vary with movement ability of organisms. See Pearson *et al.*, (In press) for details of this analysis.

Less hydric habitats may contribute supplementary or complementary resources for wetland populations. Supplementary habitats may used by species in lieu of wetlands. These habitats provide a reservoir of dispersers for recolonization of wetlands after disturbance and of genetic diversity for wetland populations. Complementary habitats fulfill resource needs of a species that wetlands cannot. For example, wood frogs may spend most of the year foraging in surrounding forest but depend on the wetlands for breeding pools. Or, wetland plants may rely on pollinators that inhabit other habitats. Therefore, destruction of supplementary and complementary habitats in the surrounding landscape will have adverse consequences for populations in wetlands. Unfortunately, these linkages between wetlands and other habitats are not well known.

Populations in a particular wetlands may also be affected by connectivity or fragmentation in the surrounding landscape. Overall, the Southern Appalachians remain a forested landscape. Most of the intensive human land use in this region has occurred in the valley and lowland regions (Flamm and Turner, submitted). Unfortunately, a major portion of our wetlands are also located in these low-lying areas.

The impact of any land use on native ecosystems, including wetlands, depends on 1) the degree of habitat modification and 2) the spatial extent and pattern of modification.

The degree of habitat modification is the extent to which a modified land unit differs from the set of seral stages likely for that land unit under a natural disturbance regime (Pearson in press). For example, a paved parking lot in a valley does not resemble any of the set of possible land covers (seral stages) expected for that site. Moreover, heavily modified habitats show a high degree of contrast (sensu Kotliar and Wiens, 1990) to native habitats. The suitability of these modified habitats for wetland species is roughly related to the habitats' contrast to naturally occurring habitats. In nature, there are also sub-optimal habitat types used by many species. Land use by humans often does not totally destroy a patch of habitat. A particular land use may make the habitat only less than optimal for a period of time. Therefore, the contrast between impacted habitats and wetlands is important (Figure 3)

The spatial extent and spatial pattern of land use can affect the connectivity or fragmentation of landscapes. The loss of connectivity between native habitats will inhibit the ability of some ecological processes to move across the landscape. Connectivity can exert strong influences on ecological processes such as the movement and dispersal of organisms (Gardner *et al.*, 1989; Gardner *et al.*, 1991), the utilization of resources by animals (O'Neill *et al.*, 1988, Pearson *et al.*, in press), gene flow (Gilpin and Soule 1986), and the spread of disturbance (Turner *et al.*, 1991). Changing the patterns of connectivity can disrupt ecological processes that depend on movement within the landscape. For example, the persistence of a metapopulation of small mammals may depend on the ability of dispersing young to reach other populations. If the overall connectivity of the landscape is altered by the creation of habitats that act as barriers to dispersing young, the isolated populations of this small mammal could become extinct due to their own demographic instability (Brown and Kodric-Brown, 1977; Beuchner, 1989) or competitive interactions (Nee and May, 1992).

The spatial extent (area) of habitat loss reduces the total amount of habitat available. If habitat destruction is scattered about the landscape, habitat loss will affect the connectivity of remaining habitat. While suitable habitats are still common, scattered areas of habitat loss have little effect on connectivity. However, as more habitat is lost, landscapes can be transformed from well connected to highly fragmented very quickly (Figure 4). Crossing one of these critical thresholds of fragmentation can occur with only a small additional percentage of habitat lost. Moreover, the critical amount of habitat differs among species. Species with the ability to move or disperse over patches of unsuitable habitat are more tolerant of fragmentation than species with limited movement capabilities (Pearson *et al.*, in press).

The spatial pattern of habitat loss is also important. The spatial arrangement of habitats, within ecological constraints, is often determined by economics and social values in human-dominated landscape. As human populations increase, the amount of land converted to human use will increase, resulting in more habitat loss for many native species. Landscape connectivity can be maintained by organizing the spatial pattern of habitat loss and by protecting corridors for movement between wetlands.

The spatial pattern of habitat loss can be controlled by aggregating intensive land uses into one or a few locations. Aggregating habitat loss will protect the connectivity of the landscape even though the same spatial extent (amount of area) of the landscape is impacted (Figure 5). For example, if the same amount of acreage were to be allocated to each of a fixed number of homesites, aggregating the homesites into one or a few subdivisions would impact landscape connectivity less than scattering the homesites at low density across the landscape (e.g., Pearson *et al.*, in press).

Protecting corridors is another way of organizing habitat loss to protect landscape connectivity. Alluvial wetlands and riparian zones naturally serve as corridors because they provide connectivity between small bogs and fens. For wetland species that can also use more mesic habitats, the connectivity of non-wetland habitats in landscapes could affect the long term persistence of their populations. Protected corridors are intended to facilitate movement (dispersal and gene flow) between patches of suitable habitat (Diamond, 1975; Hudson, 1991). While satisfactory corridors permit animals to move between patches, they must be able to sustain plant populations if the distance between patch requires more than one generation to traverse. Corridors that satisfy the dispersal needs of the entire community must be short, wide, and free of environmental gradients that act as a barrier to wetland species. Corridors may not be effective for all species. Therefore, the best way to maintain connectivity is to limit the spatial extent of high intensity impacts keeping landscapes above the critical thresholds described above.

6. Conclusion

Wetlands of the Southern Appalachians cannot be preserved without considering the global and regional landscapes in which they are embedded. The hydrology of wetlands is affected by changes in climate and vegetative cover of these landscapes. The species that are characteristic of wetlands and give them value for conservation depend on the availability and spatial arrangement of suitable habitats in the landscape.

Climate and landscape patterns are being influenced by humans. Climatic patterns can be changed by carbon dioxide emissions and by changing global and regional vegetation. Using the land for food and fiber production alters disturbance regimes. Surface and ground water flows are affected by flood control, irrigation, municipal water uses, and hydroelectric power generation. New disturbances such as exotic species and fire are associated with human activities. The pattern of habitats on human-dominated landscapes is determined by social and economic values and ultimately on the numbers of humans using the land. Therefore, the ultimate fate of wetlands in the Southern Appalachians will depend on the stewardship of landscapes, not on the conservation of selected fragments of rare habitats. Long term, landscape-level processes must be considered to guarantee the long-term protection of these wetlands.

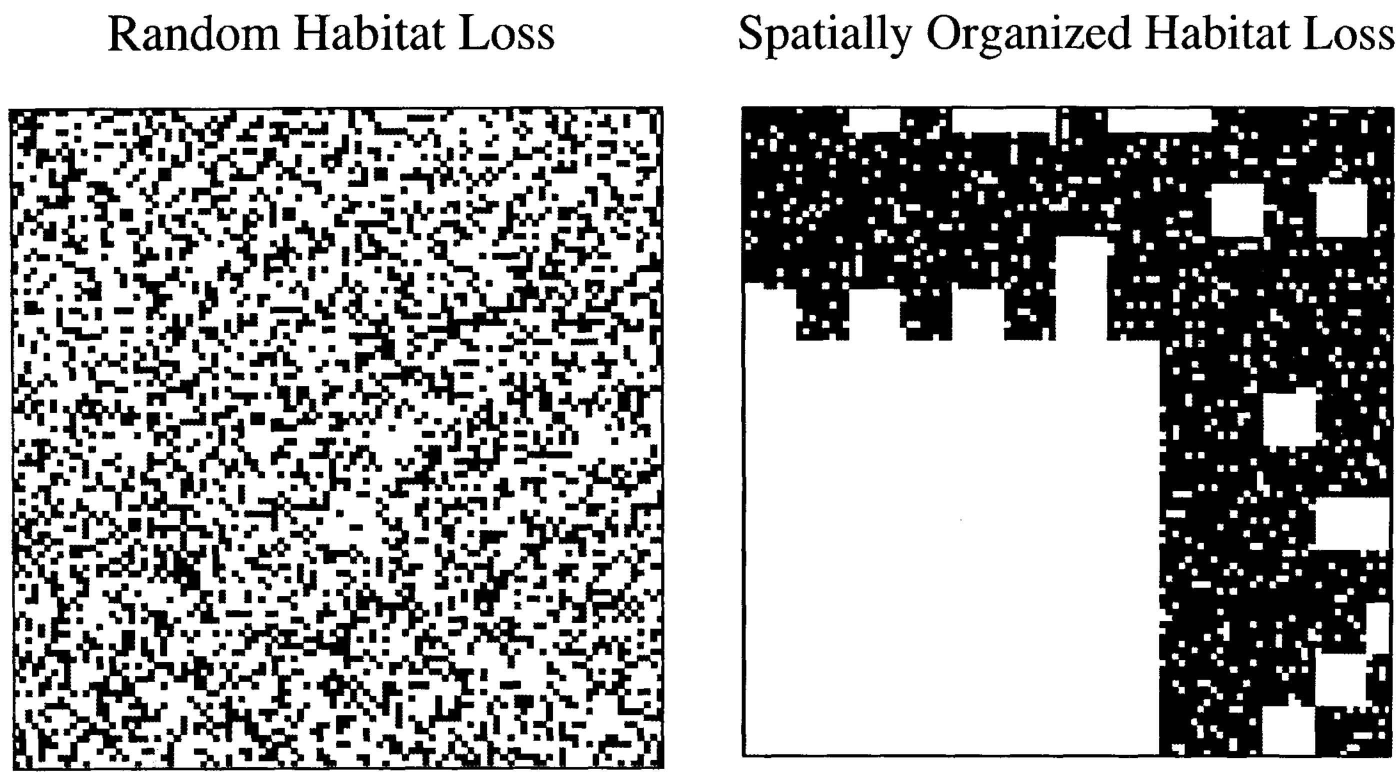

Figure 5. The spatial arrangement of habitat loss (open) can affect the connectivity of the remaining habitat (shaded). Both of these maps are 100 x 100 cells in extent and have 3280 cells (approximately 33%) of habitat remaining. Habitat loss that is random in space can result in a highly fragmented landscape consisting of many, small habitat patches. When habitat loss is spatially organized (aggregated), the remaining habitat is highly connected. (After Pearson *et al.*, in press).

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