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CUMULATIVE IMPACTS TO WETLANDS

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Abstract: "Cumulative impact," the incremental effect of an impact added to other past, present, and reasonably foreseeable future impacts, was reviewed as it pertains to southern forested wetlands. In the U.S., the largest losses of forested wetlands between the 1970s and 1980s occurred in southeastern states that had the most bottomland hardwood to begin with: Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, and South Carolina. These losses were due primarily to forestry and agriculture. Other sources of cumulative impact include decrease in average area of individual wetlands, shift in proportion of wetland types, change in spatial configuration of wetlands, and loss of cumulative wetland function at the landscape scale. For two wetland-related functions, flood flow and loading of suspended solids, watersheds that contained less than 10% wetlands were more sensitive to incremental loss of wetland area than were watersheds with more than 10% wetlands. The relative position of wetlands within a drainage network also influenced their cumulative function. Geographic Information Systems (GIS) are becoming an important tool for evaluating cumulative impacts and their effects.

Key Words: cumulative impacts, forested wetlands, geographic information systems

INTRODUCTION

"Cumulative impact," the incremental effect of an impact added to other past, present, and reasonably foreseeable future impacts, has been an area of increasing concern because piece-meal loss and degradation of wetlands over time has seriously depleted wetland resources. The concept of cumulative impact is not a new one; in the United States, the legal mandate for cumulative impact assessment has existed since the Council on Environmental Quality issued its recommendations for implementing the procedural provisions of the National Environmental Policy Act in 1978. However, ideas that have strong intuitive appeal may not affect decisionmaking if the conceptual and methodological tools for their implementation are lacking (Preston and Bedford 1988).

Impacts can accumulate over time or over space and be direct or indirect. An indirect impact occurs at a location remote from the wetland it affects, such as the discharge of pollutants into a river at a point upstream of a wetland system. While cumulative impacts can occur within individual wetlands (e.g., repetitive spraying of a pesticide within a wetland, multiple non-point-source pollution inputs to a wetland), the concept of cumulative impacts is generally used when there are many impacts to multiple wetlands.

Cumulative impacts occur to all wetland systems, not just southern forested wetlands. However, forested wetlands historically occupied long floodplain corridors that traversed the southeastern coastal plain, and those that remain are still intricately tied to the hydrology of the river systems that connect them, despite fragmentation by other land uses. Therefore, the techniques of cumulative impact analysis are indispensable for southern forested wetlands (Gosselink and Lee 1989). The purpose of this paper is to review the literature pertaining to cumulative wetland impacts, particularly as it applies to southern forested wetlands, and make recommendations for new approaches to cumulative impact analysis.

CUMULATIVE EFFECTS

Cumulative impacts are the human influences that cause ecological stress, and cumulative effects are the resultant changes. There are several ways in which effects accumulate and differ from the simple case (Beanlands et al. 1986):

1) time-crowded perturbations, in which disturbances occur so close in time that the system cannot recover in the time between;
2) space-crowded perturbations, in which disturbances are so closely spaced that their effects are not dissipated in the distance between;
3) synergisms, the interaction of disturbances to produce effects qualitatively and quantitatively different from the individual disturbances;

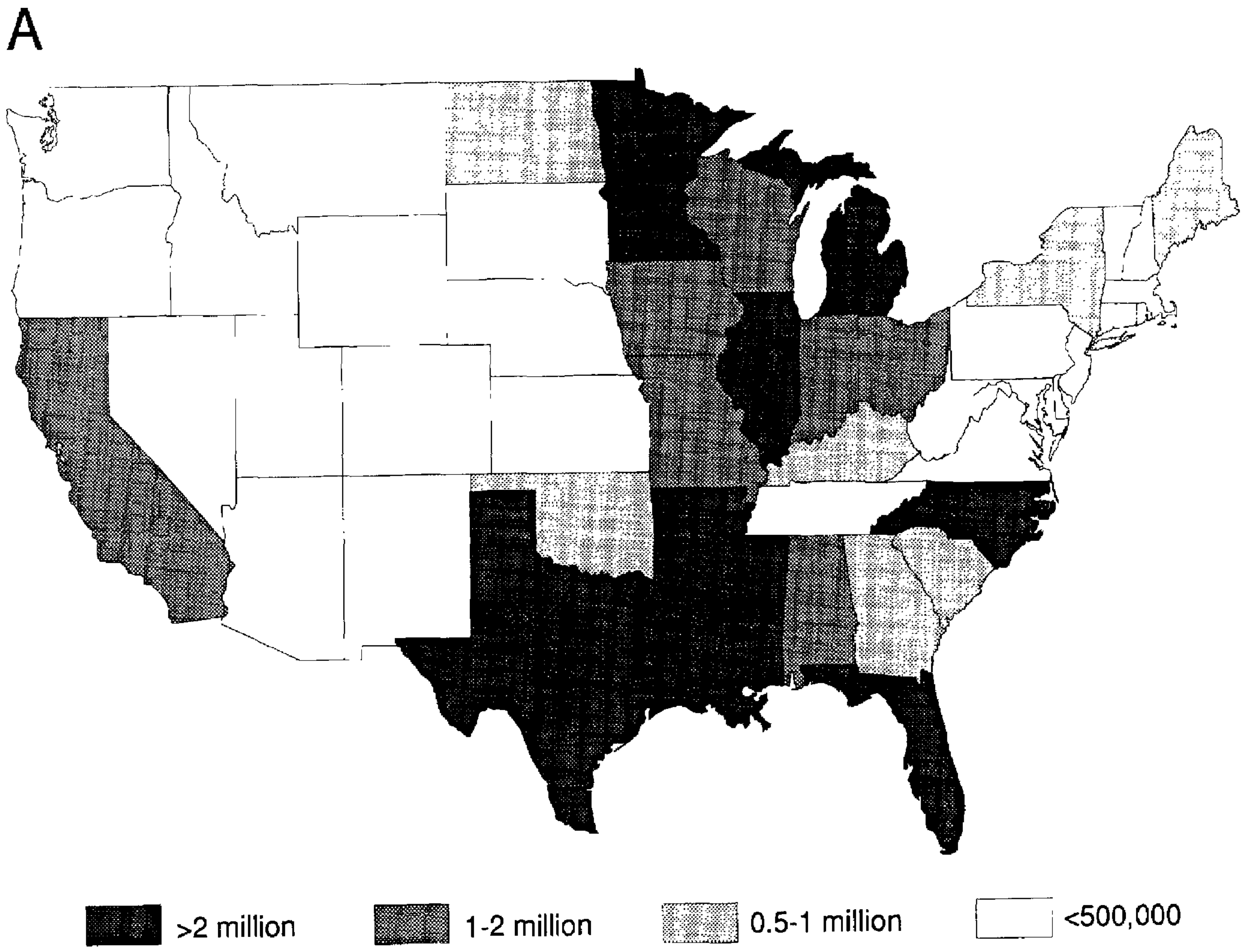


Figure 1. Wetland losses in the conterminous 48 states, 1780s to 1980s (data source: Dahl 1990). A) Loss of wetland area by state, ha.

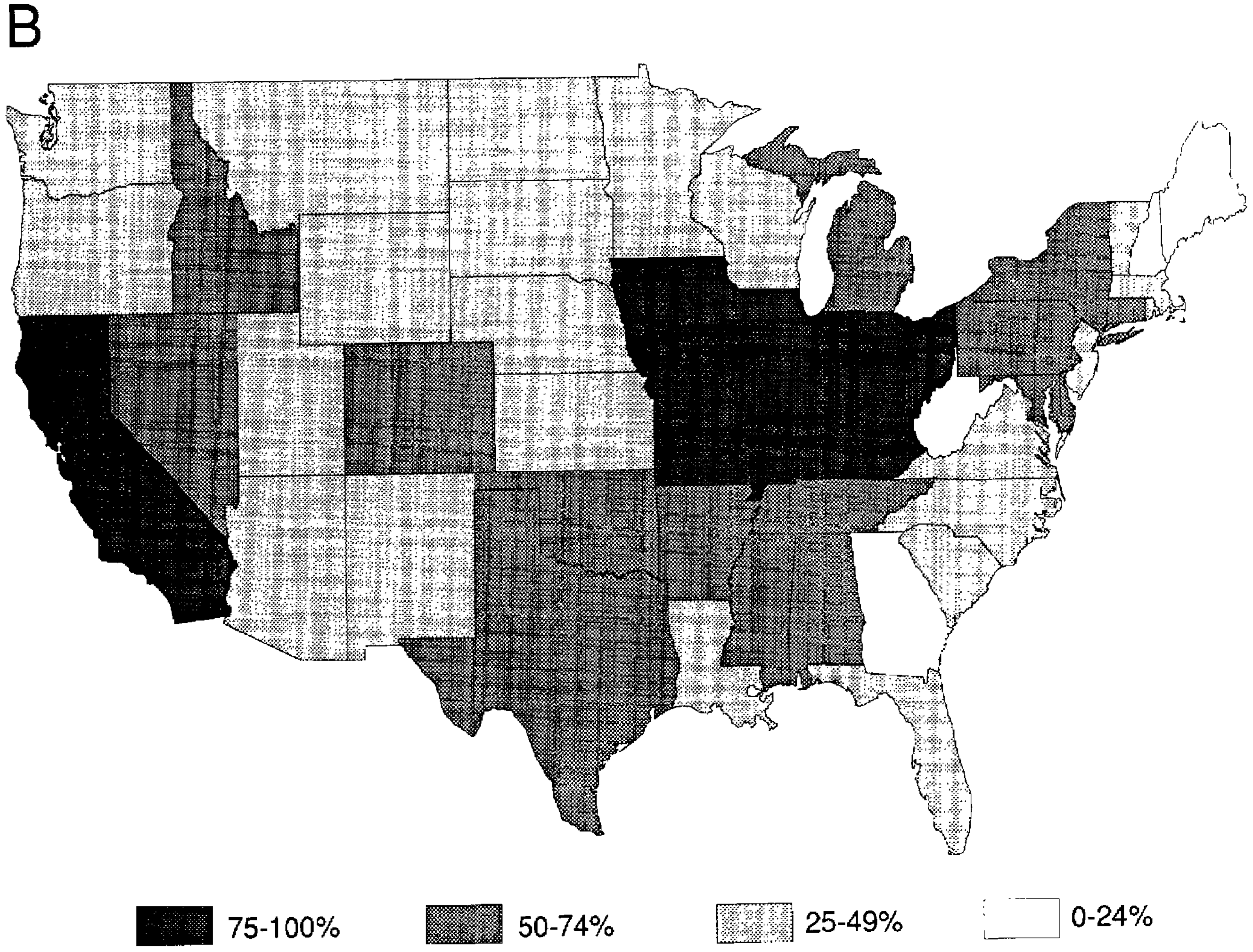
4) nibbling, disturbances that produce effects by small incremental changes; and
5) indirect effects, in which disturbances produce effects remote in time or space from the original disturbance.

Since records of actual impacts may be nonexistent or unavailable, the cumulative effects of past impacts can often be used as a measure of their influence. Measures of cumulative effect include wetland losses over time, loss of wetland function, and changes in the spatial configuration of wetlands.

Wetland Loss

One of the most commonly measured cumulative effects is loss of wetland area. As of the 1780s, wetland area in the conterminous 48 states totaled 221 million acres (89 million ha), and wetlands constituted 5% or more of the land area in 34 states (Dahl 1990). By the 1980s, however, wetland area had decreased 53% to 104 million acres (42 million ha), and only 19 states had 5% or more wetland. Losses of wetland area were greatest in the south, the midwest, and California (Figure 1a). Only four states (Maine, New Hampshire, West Virginia, Georgia) retained 75% or more of their original wetland area, while seven states *lost* more than 75% of their wetlands (Figure 1b). Such cumulative losses can be measured by comparing sources of historical data for wetland area (maps, air photos, statistical inventories) with comparable current data.

In addition to being one of the best documented type of cumulative effects, wetland loss statistics have served as the justification for permit denials. In a 1985 case in Louisiana, for example, EPA vetoed a proposal that would have drastically altered the hydrology of 3,000 acres (1,200 ha) of bottomland hardwood, giving the following reason (USEPA 1985):



B) Loss as percent of initial (1780s) wetland area.

> "... in the last 80 years, over 800,000 acres of land in Louisiana have been lost.... Recent losses of forested wetlands in the State are on the order of 87,200 acres annually.... These losses affect not only biological, water quality, recreational, and flood protection benefits but also economic values of the wetlands because of the significance to Louisiana's coastal fishery."

The sources of impact that cause cumulative wetland losses are diverse, and their relative magnitude has changed over the past 30 years. In studies of wetland trends, the U.S. Fish and Wildlife Service (Tiner 1984, Dahl and Johnson 1991) summarized losses of wetland area by four major types of impact: agricultural development, urban development, conversion of wetlands to deep water habitats, and "other" types of wetland conversion, such as bottomland hardwoods that have been clear-cut and drained but not converted to agriculture or urban land (Figure 2). This analysis indicated a change in the predominant impact; agriculture was by far the major cause of palustrine wetland loss in the 1950s to 1970s, while "other" losses predominated in the 1970s to 1980s even though they were negligible in the 1950s to 1970s. This trend implies that the clearing of forested wetlands for nonagricultural purposes has escalated over the last decade. In the North Carolina coastal plain, wetland alteration between the 1950s to 1980s was due primarily to forestry (52.8% of total area altered), followed by agriculture (42.2%) and other types of development (5%) (Cashin et al. 1992).

While the total loss of wetland area is significant in itself, cumulative impacts may affect some types of wetlands more than others. The preferential loss of certain wetland types can be seen in the trend statistics derived by the Fish and Wildlife Service (Dahl and Johnson 1991). While forested wetlands constituted

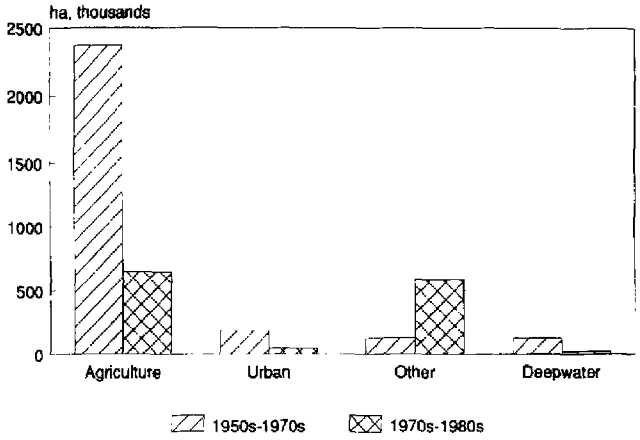


Figure 2. Wetland losses in the conterminous 48 states, by source of loss (ha/decade). Data sources: Tiner 1984, Dahl and Johnson 1991.

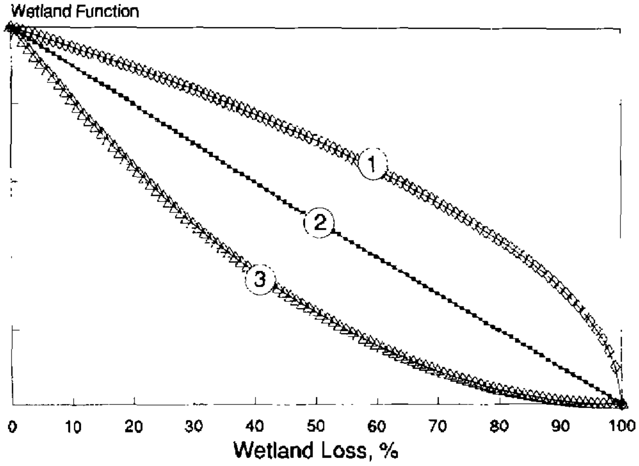


Figure 3. Possible relationships between loss of wetland area and loss of wetland function (after Gosselink and Lee 1987).

54% of the wetlands lost between the 1950s and 1970s, they accounted for 95% of all wetland losses in the mid-1970s to 1980s. Not surprisingly, the states with the largest losses of forested wetlands (>40,000 ha) during the latter time period were the southeastern states that had the most bottomland hardwood to begin with: Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, and South Carolina.

If wetland types that are preferentially impacted serve a key wetland function, their loss may have a far greater effect than would predicted by loss of area alone. Harris (1988) gives the example of Bachman's warbler, which throughout the 19th century nested in gaps in the pristine forest of the Southeastern Coastal Plain called "canebreaks." The introduction of cattle grazing and overly protective fire exclusion programs led to the demise of the canebreaks, resulting in a concurrent demise of Bachman's warbler, which is now presumed extinct.

Table 1. Examples of area-sensitive wetland bird species (after Leibowitz et al. 1992). Numbers represent patch size at which probability occurrence is 50% of the maximum probability of occurrence, determined from a series of habitat patch inventories. * = area includes adjoining undeveloped forest.

Species	Patch Size (ha)	Reference
Northern parula	*520	Robbins et al. 1989
Louisiana waterthrush	*300	Robbins et al. 1989
Red-shouldered hawk	*225	Robbins et al. 1989
Northern waterthrush	*200	Robbins et al. 1989
Pileated woodpecker	*165	Robbins et al. 1989
Black tern	20	Brown and Dinsmore 1986
Veery	*20	Robbins et al. 1989
Kentucky warbler	17	Robbins et al. 1989
Acadian flycatcher	*15	Robbins et al. 1989
Canada goose	11	Brown and Dinsmore 1986
Ruddy duck	11	Brown and Dinsmore 1986
Pie-billed grebe	5	Brown and Dinsmore 1986
Redhead	5	Brown and Dinsmore 1986
Blue-winged teal	1–5	Brown and Dinsmore 1986
Mallard	1–5	Brown and Dinsmore 1986

A cumulative effect of "nibbling" impacts is the decrease in size of individual wetlands, even though the number of wetlands may remain constant. Wetland size is an important determinant of habitat suitability for wildlife. Relatively common waterfowl species such as mallards and blue-winged teal will nest in very small wetland patches, but area-sensitive species such as the northern parula and the Louisiana waterthrush require much larger wetlands in order to nest successfully (Table 1). Many wetland-associated mammals also have minimum home range requirements that limit the sizes of wetlands they can successfully inhabit. Therefore, a decrease in average area of individual wetlands is as important to consider as cumulative area lost.

Loss of Cumulative Function

The loss of wetlands can result in a corresponding loss of cumulative wetland function at the landscape scale. Jones et al. (1976) evaluated the effect of wetlands in 34 Iowa watersheds on nutrient concentrations in streams draining those watersheds. They found that wetland area as a proportion of total watershed area was significantly correlated with nitrate concentrations in the streams ($r = -0.525$, $P < 0.01$), such that there was a 0.26 ± 0.07 mg l^{-1} increase for each percentage point decrease in wetland.

The cumulative loss of wetland function at the landscape scale may or may not be linearly proportional to area lost (Figure 3). If the relationship is linear (curve 2), each additional unit area of wetland lost has the same relative effect as every other unit lost, as illustrated by the Iowa watershed study (Jones et al. 1976). If the relationship between function and loss resembles curve 3 (Figure 3), initial wetland losses have the largest effect on function, after which additional losses of wetlands have less of an effect. For example, the first 20% of wetland loss in the relationship shown by curve 3 results in a 35% loss in cumulative wetland function, while the last 20% of wetland loss (i.e., 80–100%) results in only a 4% loss of function. If the relationship between function and loss resembles curve 1 (Figure 3), initial wetland losses have a small effect on functional value, but later losses have large effects. Nonlinear relationships can be used to define natural thresholds for regulatory purposes, beyond which additional wetland losses would cause unacceptable loss of cumulative function.

While real data substantiating these hypothetical relationships are rare, several studies of cumulative wetland function have derived relationships similar to curve 1. Empirical equations for predicting streamflow developed by the U.S. Geological Survey in Wisconsin and Minnesota indicate that flood flows are proportional to the negative exponent of the proportion of watershed area in wetlands and lakes (Conger 1971, Jacques and Lorenz 1988). This means that relative floodflow is decreased greatly by having some wetlands in a watershed, but a watershed with a large proportion of wetlands doesn't reduce floodflow much more than a watershed with an intermediate proportion of wetlands. For example, predicted floodflow was 50% lower in Wisconsin watersheds with 5% lakes or wetlands than it was in watersheds with no lakes or wetlands, but increasing the proportion of lakes and wetlands to 40% decreased relative floodflow by only an additional 30% (Novitzki 1979). Johnston and colleagues (1990) applied these equations to watersheds in central Minnesota and found that a watershed with 1.6% lakes and wetlands had a flow per unit watershed area that was ten times the flow predicted for a watershed with 10% lakes and wetlands, while watersheds with 10–50% wetlands and lakes had about the same flood flow per unit area. The incremental loss of wetland area would therefore have a small effect on floodflow from watersheds with 10–50% wetlands but a large effect on floodflow from watersheds with less than 10% wetlands.

The same 10% threshold was identified by Oberts (1981) for suspended solids, a measure of water quality function. Streamwater draining watersheds having 10 to 20% wetlands had about the same loading of suspended solids, so the contribution of suspended solids was relatively constant per unit area of watershed. However, watersheds with less than 10% wetlands had loading rates per unit area that were as much as 100 times greater than the loading rates from watersheds with more than 10% wetlands. Hindall (1976) found a similar relationship but with a threshold level at about 3% instead of 10%. It is important to understand functional relationships such as this in order to predict the incremental effect of an additional wetland losses.

While the previous examples have dealt with the effects of wetland loss, less drastic cumulative impacts to wetlands can still result in substantial degradation and loss of function. For example, work by Conner and Day (1982) has shown that the net primary productivity of southeastern bottomland forests decreases as the surface water in the wetlands becomes more stagnant. Therefore, a cumulative impact that indirectly influences the flooding regime of bottomland forests can have the cumulative effect of reducing their productivity.

Spatial Configuration of Wetlands in the Landscape

The spatial configuration of wetlands in the landscape may also be affected by cumulative impacts. Wetland density, the number of wetlands per unit area of landscape, is inversely proportional to the distance between wetlands. Therefore, the length of pathways between wetlands increases as wetland density decreases. This type of cumulative effect could be detrimental to animals that traverse over non-wetland areas to use the resources of several wetlands, the increased travel length putting them at greater risk to predation by humans and other animals.

Wetlands may be physically or hydrologically connected with each other in ways that affect their cumulative function. This connectivity was a distinguishing feature of southern bottomland hardwoods, which historically were long expanses of wetlands that filled riverbottoms for hundreds of km. Such interconnectedness provided wildlife, as well as early human settlers, with important travel corridors. However, over time, these vast expanses have been chopped into fragmented segments and isolated from each other by intervening urban and agricultural areas. The loss of connectivity greatly diminishes the function of southern bottomland hardwoods as conduits for wildlife movement.

The location of wetlands within a watershed can also affect their cumulative function with regard to water quality. Johnston and colleagues (1990) developed an index of wetland location for a landscape-level study of urban and rural stream watersheds in central Minnesota, calculated as:

$$RWP = \frac{\sum_{i=1}^{j} (j - i)Ai}{\sum_{i=1}^{j} Ai}$$

where

RWP = relative wetland position

j = stream order (Horton 1945) of water quality sampling station,

i = stream order of wetland, and

Ai = area of ith order wetlands.

Calculated values for the index ranged from 0 (i.e., all wetlands were on streams of the same order as that of the sampling station) to 2.6 (i.e., average wetland position was 2.6 stream orders upstream of the sampling station). Watersheds with wetlands located close to the sampling station had significantly better water quality (i.e., lower concentrations of inorganic suspended solids, fecal coliform, and nitrate; lower flow-weighted concentrations of ammonium and total phosphorus) than watersheds with wetlands located far from the sampling station. These findings do not necessarily mean that wetlands farther upstream from a sampling station are less important to water quality than are downstream wetlands, just that their effects on nutrients are not detectable very far downstream or are offset by intervening pollutant inputs.

Ogawa and Male (1986) investigated the influence of wetland position on flood mitigation potential using a simulation model approach. For upstream wetlands (i.e., stream orders 1–3), the encroachment of floodplain wetlands caused a local increase in peak floodflow, but that effect dissipated within a few km downstream because the large channel and floodplain storage capacities were able to accommodate the increased flow. The encroachment of downstream floodplain wetlands, however, caused increased flows that did not decrease with distance downstream. Therefore, the location of wetland impacts has important ramifications to cumulative effects at the landscape scale.

Relative wetland position and stream order are locational indices that are simple to use, yet powerful predictors of landscape-level wetland function. Future studies may yield more indices of this type that quantify wetland location relative to watersheds, streams, ground water, other wetlands, other habitats, and movement corridors.

GEOGRAPHIC INFORMATION SYSTEMS FOR CUMULATIVE IMPACT ANALYSIS

Cumulative impact assessment requires new tools capable of analyzing multiple wetlands and multiple perturbations spread over large distances and long time periods. Geographic Information Systems (GIS) provide these capabilities and are becoming increasingly important for analyzing direct and indirect cumulative impacts (Walker et al. 1986, Johnston et al. 1988a). GISs can depict cumulative impacts that affect wetlands both directly (e.g., the location of logged areas within wetlands) and indirectly (e.g., upstream sources of water pollution).

Information on cumulative impacts can sometimes be generated as a by-product of updating GIS data layers. For example, by using a GIS to record the location of permits issued for wetland drainage or filling, the Wisconsin Department of Natural Resources is generating information about the rate and location of wetland losses in the state (Johnston et al. 1988b). This kind of GIS record keeping can provide an institutional "memory" useful in monitoring the cumulative impact of permit issuance.

A GIS can also be used to analyze the cumulative effects of impacts. For example, a GIS can be used to quantify wetland alteration by comparing wetland maps representing two different points in time and measuring rates of wetland change. Transition probabilities derived from such analyses can be used to develop predictive models of future wetland trends (Pastor and Johnston 1992).

Finally, a GIS can be used to evaluate how wetlands function as landscape components, something that is difficult to assess in any other manner. A variety of quantitative measures are easily calculated with a GIS in combination with a suitable wetland map: loss of wetland area, decrease in number of wetlands, decrease in density of wetlands, decrease in connectivity, loss of wetland types, loss of wetland function, etc. Empirical studies such as the one done by Johnston et al. (1990) can relate these quantitative measures to their cumulative effects on wetland function. GISs linked to watershed models also hold promise for analyzing the landscape-level role of wetlands because they can simulate the direction and magnitude of fluxes between pollutant sources (e.g., nonpoint-source runoff from farm fields) and sinks (e.g., wetlands).

CONCLUSIONS

Wetlands are not isolated from each other nor from the landscapes in which they occur. Wetlands interact with each other by way of the waters and organisms that connect them, so that impacts to one wetland can indirectly affect others. Wetland impacts that seem minor on an individual basis may become major when considered collectively over time and space. Impacts that occur at one point along the continuum of cumulative wetland function may have a much greater effect than a comparable impact at a different point on that continuum.

Because wetlands are not isolated, assessments that evaluate wetland impacts as isolated occurrences only provide a partial picture. We need to think about wetlands as part of a bigger picture, as components of larger landscapes that include upland, surface water, and ground water. Finally, we need to put ourselves in that bigger picture, not only as sources of impact, but also as the potential solution to those cumulative impacts we have created.

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